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DESIGN CRITERIA FOR THE NUCLEAR DATA LINK COMMUNICATION SUBSYSTEM

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ABSTRACT

The Nuclear Data Link (NDL) is a proposed Nuclear Regulatory Commission (NRC) system that would acquire a limited set of data from each operating nuclear power reactor in the United States and transmit the formatted data to an operations center in the Washington, D.C., area. During an incident at a nuclear power reactor, teams of trained personnel would review and assess proposed actions during emergency situations and disseminate information to people requiring knowledge of the status of the current event. The NDL is functionally composed of three systems: (1) a data acquisition system, (2) a communication subsystem, and (3) an operations center. This report primarily addresses the criteria for the specification of a communication subsystem. The results of this study indicate that leased, dedicated telephone lines offer the most cost-effective approach for meeting NDL requirements.

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DESIGN CRITERIA FOR THE NUCLEAR DATA LINK COMMUNICATION SUBSYSTEM

1. INTRODUCTION

The Nuclear Data Link (NDL) is a system that would collect a limited set of data from each operating commercial light water reactor (LWR) in the U.S.A. and transmit the formatted data to the Nuclear Regulatory Commission (NRC) operations center in the Washington, D.C., area. During an incident at a nuclear power reactor, teams of trained personnel would review and assess proposed actions during emergency situations and disseminate information to people requiring knowledge of the status of the event.

Several incidents at commercial LWRs, including Three Mile Island (TMI) and Crystal River, have highlighted the need for a system fulfilling the functional intent of the NDL. Such incidents have shown that the NRC's response to incidents was slow and that information relating to the incident was at times conflicting and erroneous. These shortcomings were due largely to the lack of proper and timely information on the current status of the LWR. Difficulties in mobilizing reliable communications also contributed to the failure to gather experts capable of evaluating the situation and determining the proper solution to the incident.

After TMI, dedicated voice lines were installed at all commercial LWRs in an attempt to improve the accuracy and timeliness of plant status information during an incident. The Crystal River incident, however, showed that only a limited amount of data can be transmitted by voice and that this data is subject to interpretation errors between communicators. Thus, it became apparent that the human factor should be minimized in the information gathering, transmission, and display process.

With correct and timely information, the NRC, during an incident, would be able to review and assess the corrective actions of the licensee, independently assess the overall plant status, and provide assistance to the licensee. The NRC would also have accurate information about the incident to interface properly with Federal, State, and local officials.

It was initially determined that approximately 100 data parameters from each reactor would be necessary. This set of data would be transmitted once per minute to the NRC operations center and displayed as necessary for the analysts. The initial design was to be capable of monitoring 80 light water reactors.

To collect this data, a computer-based data acquisition system must receive information from selected plant sensors, a computer network or communication system must transmit the data to the operations center, and the operations center must store the data for retrieval, either through CRT displays or hardcopy output. These tasks are organized according to the functional diagram shown in Figure 1-1.

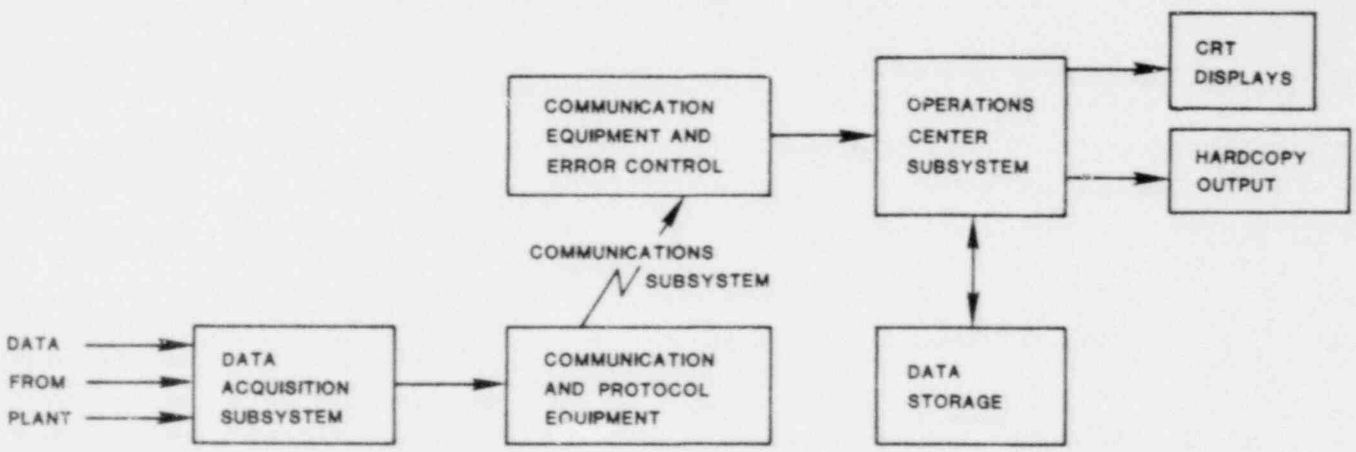


Figure 1-1. NDL Concept Overview

The system should be reliable in terms of assuring that accurate data from a plant reaches the operations center for analysis. Thus, the system should use proven, relatively simple techniques for gathering, transmitting and displaying the data, and at the same time, the methods should be sophisticated enough to allow for possible system expansion. At the time the study was done in April 1980, the assumption was that the system could expand to as many as 500 data points and 200 reactors.

The communications subsystem receives data from the data acquisition subsystem in a specified format and transmits the data to the operations center. This subsystem is composed of a transmission link and signal processing equipment at each end of the link to perform the communication tasks such as data transmission error and flow control, communication link diagnostics, and statistical compilations relating to the communication link performance.

This report analyzes the various methods which are available today for transmitting the NDL data. Communication link aspects, along with the computer techniques used for this task, will be discussed. An additional purpose is to illustrate, as simply as possible, the computer techniques used for data transmission.

A complete overview of the communications subsystem of the Nuclear Data Link is discussed in Section 2. Analyses of the network geography, the type of data being transmitted, traffic flow estimates, and reliability considerations are presented. On the basis of the analyses, a specification is given for the network architecture and the recommendation is made that leased lines and modems be utilized as the primary communications medium. (Alternative network implementations based on satellite or digital radio relay networks are also discussed in the appendices.)

Section 3 specifies the network terminations and the interfaces between the network and the terminations. The two generic terminations consisting of the site transmission unit and the operations center equipment are described. Special attention is devoted to the difference between the two types of terminations and the requirements for a front-end processor and a network management center.

Section 4 addresses the question of how to utilize the technical resources of the national laboratories, in case of an accident, by ad-hoc cooperation between these laboratories and the NRC operations center. Justification for a trial implementation of a wideband data channel is presented.

Conclusions and recommendations for the communications network are summarized in Section 5. This section is followed by nine appendices. Four appendices are tutorials on binary communication modulation, radio wave propagation, and computer communications. Four appendices deal with alternate network concepts and the rationale for their rejection. The feasibility of data exchange with the national laboratories, alluded to in Section 5, is discussed in more detail in Appendix G.

2. COMMUNICATION NETWORK DESIGN

2.1 APPLICATION ANALYSIS

Factors which must be considered in the design of a computer communication network, before a system configuration can be established, include the identification and location of the users, the quantity of data to be sent, the frequency of transmission, the reliability of the system, and requirements for system expansion. The relationship of each of these factors is discussed in this section.

2.1.1 Network Geography

Currently, there are approximately 73 operating commercial LWRs licensed to operate in the U.S.A. The number of LWRs is expected to reach approximately 180 by the year 1995 (Figure 2-1). Thus, the NDL design should be expandable to perhaps as many as 200 reactors. This represents a large number of computer systems that must interface with the communication network in order for the NDL to function properly. There should be system hardware commonality to provide data flow control, error detection and correction, and communication link diagnostic capability. A standard interface into a nonstandard site computer system must be provided. A proven method for providing a standard interface and communications network commonality is discussed in Section 3.2.

Figure 2-2 shows the January, 1978 locations of operating LWRs as well as those with construction permits and vendor orders. The clustering of reactor facilities near heavy population areas is obvious. Most of the reactors are located in the northeast, southeast, and midwest; thus, the major portion of the NDL network will initially reside in the eastern half of the United States, with only 14 or so plants in the west.

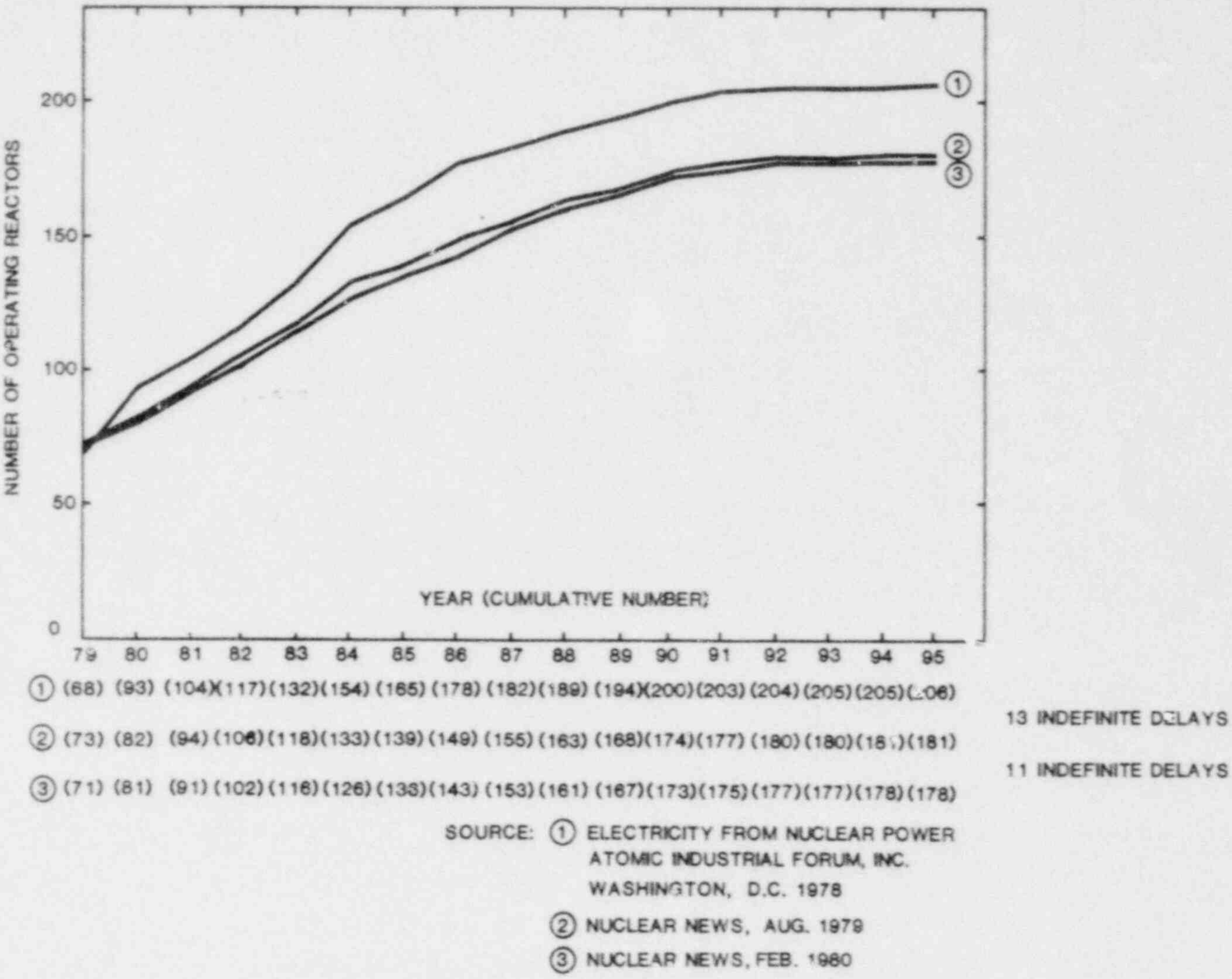
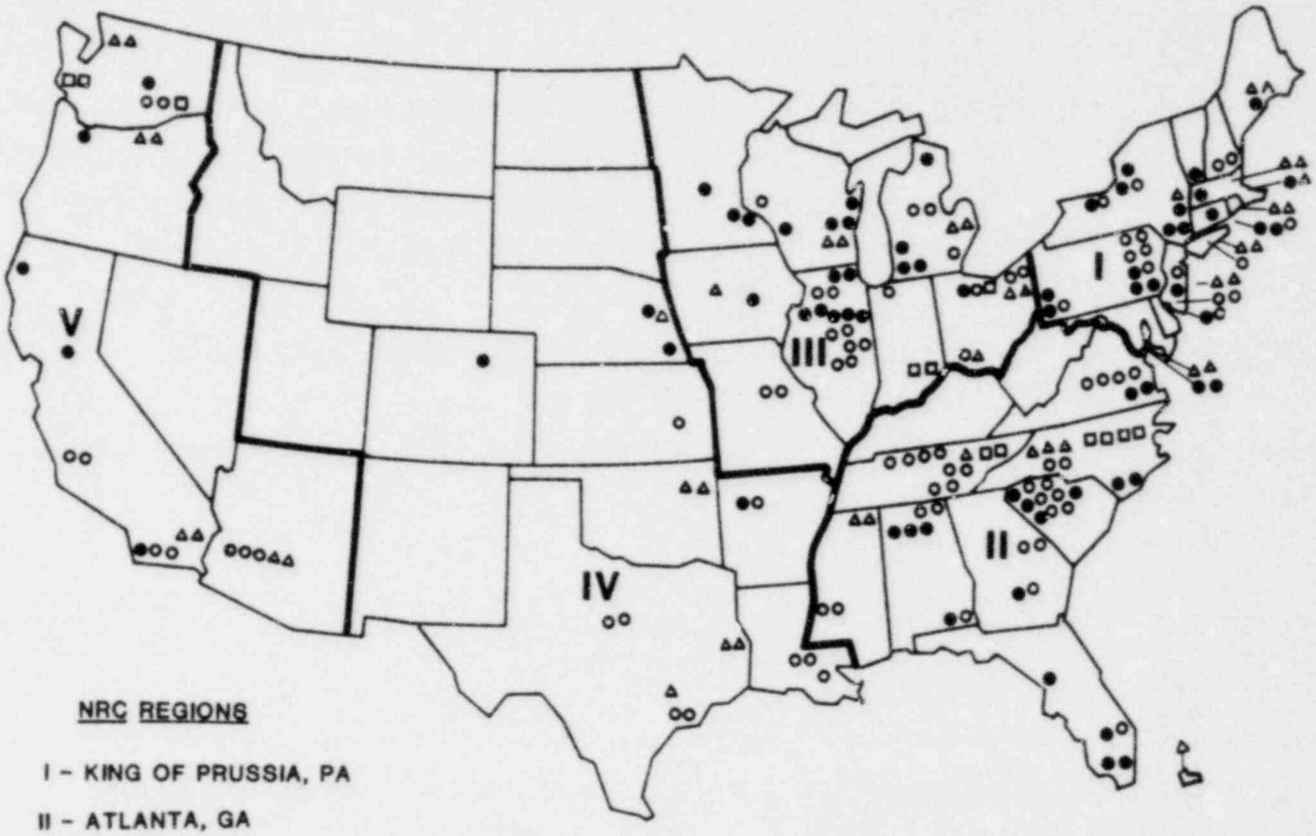


Figure 2-1. Projected Number of Operating LWRs in the United States

2.1.2 Reactor Data Requirements

Data from the reactors, as currently envisioned, consist of approximately 100 parameters (depending upon the reactor design), each of which falls into one of the following categories:

1. Reactivity control (5 parameters)
2. Core heat removal (55 parameters)
3. Reactor coolant system integrity (4 parameters)
4. Containment integrity (6 parameters)
5. Radiological conditions (29 parameters)
6. Meteorological conditions (4 parameters).



NRC REGIONS

I - KING OF PRUSSIA, PA

II - ATLANTA, GA

III - GLEN ELLYN, IL

IV - ARLINGTON, TX

V - WALNUT CREEK, CA

KEY

- ● WITH OPERATING LICENSES
- o WITH CONSTRUCTION PERMITS
- ▫ LIMITED WORK AUTHORIZATIONS
- ▵ ON ORDER
- ^ LETTERS OF INTENT/OPTIONS

68	REACTORS WITH OPERATING LICENSES	48,618 MWe
81	REACTORS WITH CONSTRUCTION PERMITS	87,504 MWe
13	REACTORS WITH LIMITED WORK AUTHORIZATIONS	13,840 MWe
50	REACTORS ON ORDER (INCLUDING 8 UNITS NOT SITED ON MAP)	57,217 MWe
1	LETTERS OF INTENT/OPTIONS	1,150 MWe
213	TOTAL	208,329 MWe

JANUARY 1, 1978

Figure 2-2. LWRs Currently Operating, under Construction, or Planned

These data must be converted to engineering units, time tagged, identified, and enclosed within a communication protocol for transmission to the operations center in the Washington, D.C., area. Error control must also be included with the transmission process.

Data compression techniques are being considered whereby information will be transmitted only if a parameter shows a significant change since the last reading. This can significantly reduce the traffic on the communication line, even during an actual event.

In this study, the possibility that the data list could conceivably increase to 500 parameters was considered. The communication link design features which will accommodate these requirements have been identified.

The operation center is currently envisioned to monitor one event or reactor accident at a time while storing data for up to four other simultaneous events. The number of simultaneous events to be monitored does not affect the point-to-point lines of the communication subsystem but will, however, affect the data concentration and storage requirements at the operations center. Note that if a multidrop leased-line configuration were used and multiple events occurred on the same circuit, the communication link could become saturated, resulting in lost data. This possibility was considered in determining the topology for the NDL.

2.1.3 Traffic Flow Estimates

The traffic flow requirements for the NDL were determined so that the communication channel will have the capacity to carry all of the traffic, both now and in the future.

It is currently estimated that 30,000 bits will be required for one set of parameter data (100 data points) from each site. This assumes that ASCII data is transmitted and that each parameter has an individual ID and time tag. The 30,000 bits could conceivably be reduced using data compression or ASCII to binary conversion. Since the final design and actual data format is not firmly established, this estimated upper limit must be considered at this time to assure that the communication link is sized large enough to handle the worst-case traffic load situation. It is also desirable to be aware of the high costs that can be encountered when large amounts of data are transmitted over communication facilities that charge for the amount of traffic being carried over the link, rather than for the mileage between the users' facilities. The number of characters is determined by considering the computer word lengths required to represent data to the desired accuracy and includes parameter identification and individual acquisition time information. The communication protocol overhead is also included. The link must be capable of handling the worst-case traffic situation, i.e., all 100 data points transmitted to the operations center every minute.* For 74 reactors, the traffic load would be

$$\text{Monthly bit load per site} = 30{,}000\ \frac{\text{bits}}{\text{min}} \times 1440\ \frac{\text{min}}{\text{day}} \times 30\ \frac{\text{days}}{\text{mo}}$$

$$= 1.296\text{x}10^{9}\ \frac{\text{bits}}{\text{mo-site}}$$

$$\text{Total monthly bit load for 74 sites} = 1.296\text{x}10^{9}\ \frac{\text{bits}}{\text{mo-site}} \times 74\ \text{sites}$$

$$= 9.59\text{x}10^{10}\ \frac{\text{bits}}{\text{mo}}\ \text{(all sites)}$$

$$\text{Total traffic load per month} = 9.59\text{x}10^{10}\ \frac{\text{bits}}{\text{mo}} \times \frac{1\ \text{char}}{8\ \text{bits}}$$

$$= 1.2\text{x}10^{10}\ \frac{\text{char}}{\text{mo}}$$

(This number is needed in estimating monthly charges for VAN service, which is discussed in Appendix C.)

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*At the time of this writing, continual data transmission once per minute was desired, with pre-event data being stored at the operations center.

Because of the geographic distribution of the network and the desired high reliability, remote diagnostic capabilities will also present additional traffic over the link.

Based on 30,000 bits, the data transmission time per site for various transmission speeds, in bits per second (b/s), is summarized in Table 2-1.

Table 2-1

Transmission Time versus Transmission Speed

Transmission speed (b/s)	Transmission time (seconds)	
	100 data points	500 data points
300	100.000	500.000
1200	25.000	125.000
2400	12.500	62.500
4800	6.250	31.250
9600	3.125	15.625

It is clear from these data that transmission speeds less than 1200 b/s would not be sufficient to transmit 100 data points every minute nor would transmission speeds less than 4800 b/s be sufficient for 500 data points every minute. Thus, based on the current data requirements and future expansion considerations, a maximum data rate of 4800 b/s has been used as a conservative upper limit.

2.1.4 Reliability

Irrespective of the communication network configuration adopted for the NDL, occasional failure of a portion of the network for extended periods of time is inevitable. However, estimates can be made of the probability or frequency of failure and the duration of the failure. On the basis of these estimates, decisions can be made on the necessity of providing redundant circuit routing to mitigate failures. Degradation resulting from short-lived (of the order of 10^{-3} second) failures can be reduced by signal processing techniques.

If the data transfer is conducted in an asynchronous polling mode, line failures can be a nuisance but not a disaster. At the first indication of failure of a dedicated line, the site transmission unit (STU) (see Section 3.2) could be accessed by an ad-hoc dial-up link. If the polling is synchronous and reports from one or more reactors are aborted for several polling periods, there may be trouble with the subsequent location and retrieval of the missing data. However, a higher-level communication protocol can handle this problem.

The duration of dedicated line failures may range from a few milliseconds to several days. Failures of several days are generally rare, and the longer the duration of the failure, the less likely it is to occur. Failures lasting a few seconds are not uncommon. In general, short duration failures will not seriously impact operation of the NDL. Routine requests for retransmission of one data frame can be handled by an automatic repeat request similar to the procedure described in Section 2.4.2.1.

In subsequent sections, the outage rates of some data links are quoted in terms of their availability. The availability parameter, a, measured over the period of time when transmission is required, is defined as

$$a = \frac{\text{total time that link is transmitting}}{\text{total time that transmission is required}}$$

The term unavailability will also be used, where

$$\text{unavailability} = 1 - \text{availability}$$

The reliability of any segment of the NDL can be expressed in terms of reliability functions. An approximation for estimating the NDL reliability as a function of time is given by the exponential function

$$R(t) = \exp(-t/MTTF) ,$$

where MTTF (mean-time-to-failure) is the average time before a failure of the link occurs. If the communication link fails, an attempt will be made to restore service. In this case, a figure of merit for the link can be given in terms of the mean-time-between-failures (MTBF). For the single parameter exponential distribution, MTBF is equal to the MTTF. Because the failure rate is constant over time, any failure is a "random failure" rather than a wearout failure.

Figure 2-3 shows typical plots of MTBF versus failure duration based on statistics for voice-grade communication lines in North America.[2] The lines oriented 45° to the axis are lines of constant unavailabilty for various classes of service. In an NDL data circuit, several components will be in series; e.g.. a microwave link with

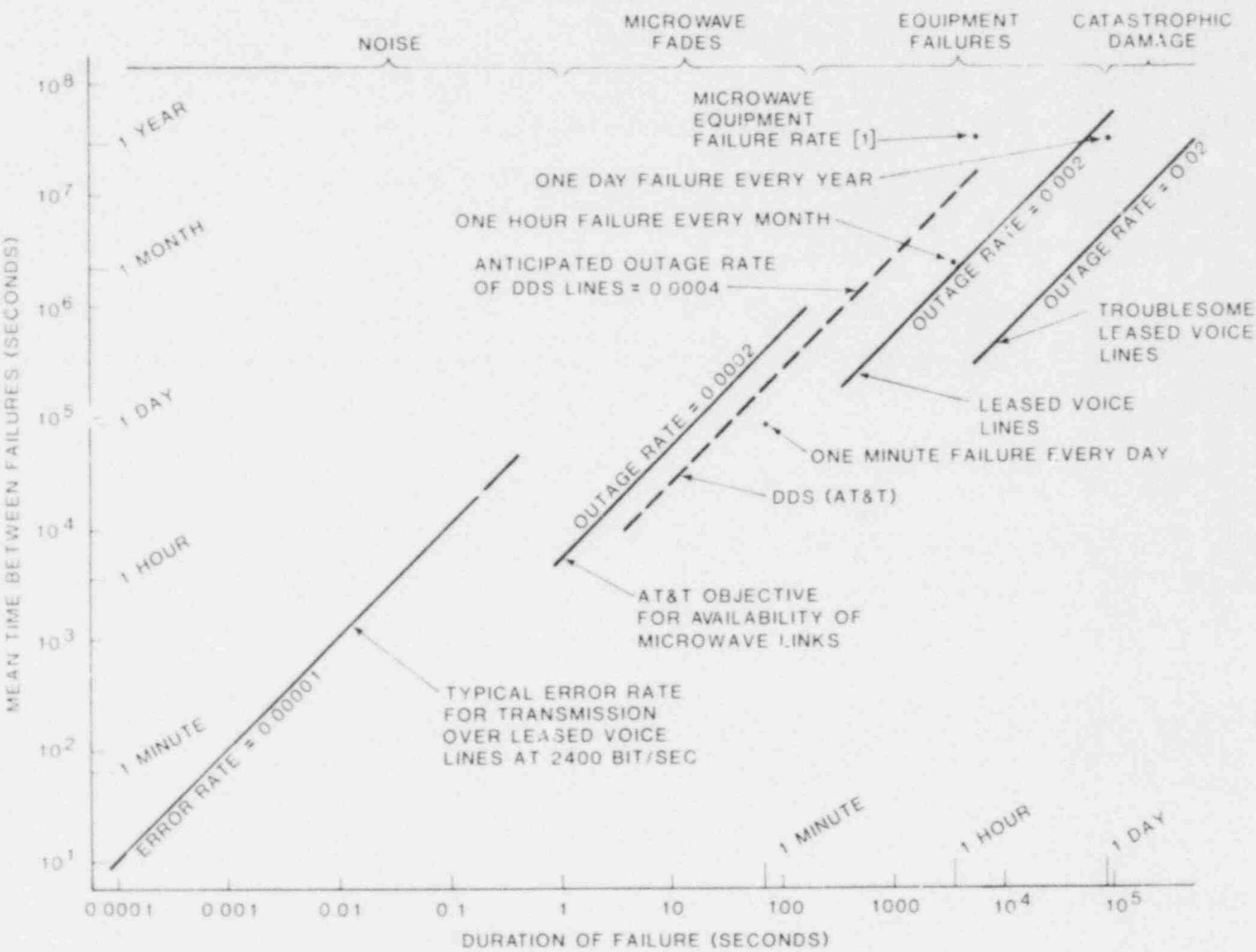

Figure 2-3. MTBF versus Failure Based on Statistics for Voice-Grade Communication Lines in North America (Adapted from Martin[2])

availability a_m will be in series with voice-grade transmission lines with availability a_v. The overall availability of this circuit is the product $a_m \cdot a_v$. From Figure 2-3 it is clear that outages on those portions of the NDL circuit which use leased voice lines are most significant in determining the unavailability of a particular NDL circuit.

Figure 2-3 also shows short-time failures caused by the presence of noise which corrupts the information transmitted. Two approaches can be used to reduce errors resulting from noise. One approach is to increase the signal power so that it overrides the noise. The other approach is to include sufficient redundant information so that errors can be corrected. Either approach can be used to make the bit error rate (BER) arbitrarily small. However, providing adequate signal strength is the responsibility of the common carrier, while provision for error control must be included in the design of the data format.

The signal-to-noise ratio required to obtain the BERs of 10^{-5} or less required for NDL purposes can be obtained using those modulation techniques generally used for binary communications; namely, frequency-shift keying (FSK) or phase-shift keying (PSK). However, the current state of communication technology permits spectral efficiencies as high as 4 b/s/Hz. For a specific BER, some systems require a carrier-to-noise ratio only 1 or 2 dB above that required for the double-sided theoretical minimum Nyquist bandwidth.[3] These systems involve hybrid amplitude-phase modulation schemes that are both complex and costly and therefore should be avoided in any NDL implementation. Either FSK or PSK, together with error control, is recommended instead. A discussion of these modulation schemes and their associated spectral efficiencies is given in Appendix A.

Error-control procedures designed to handle the spectrum of errors that occurs on a communication line increase the probability of receiving correct data. Two types of error control can be used: (1) forward error control, where redundant information is included with the information transmitted to allow the receiver to detect an error and infer the correct message; and (2) feedback error control, where some redundancy is provided for error detection, but correction is made by retransmission. The latter method is most often used in data transmission systems and is preferable for NDL purposes, as discussed in Section F.3.4 of Appendix F.

2.1.5 Expansion Considerations

As noted in Section 2.1.2, when this report was prepared, it was believed that the NDL data list could expand from 100 to 500 data parameters, and thus a communication link should be capable of handling the increased traffic load from each reactor. This expansion capability can be provided by a 4800 b/s link. Current thinking may call for less expansion capability, but 500 data parameters is still a reasonable upper limit for sizing the link.

The equipment in the operations center, namely the front-end processor and the central computer, should be able to handle the increase from 100 to 500 data points and also service new reactors as they come on line. Table 2-2 shows an estimate of the increase in characters per month over the next 10 years for 100 and 500 data points.

Table 2-2

Estimated NDL Traffic Increases Over the Next Decade

Year	No. of Reactors	Traffic in char/mo	
		100 data points	500 data points
1980	74	1.2×10^{10}	6.0×10^{10}
1985	136	2.2×10^{10}	11.0×10^{10}
1990	173	2.8×10^{10}	14.0×10^{10}

Thus, the NDL could experience a tenfold increase in traffic over a 10-year period if the number of data points increases from 100 to 500. Data compression at the site would significantly reduce this traffic burden at the operation center and hence should be given careful consideration.

2.2 NETWORK ARCHITECTURES

2.2.1 Point-to-Point and Star Networks

A data communication network can be a simple collection of terminals, lines, and computers or it can be a complex system with hundreds of terminals and many computers connected across thousands of miles.

The terminals* of the NDL only have to transmit data to the operations center. There is currently no requirement for one reactor site to communicate with other reactor sites; hence only a point-to-point (star) or multipoint (multidrop) network is required. Other network topologies introduce degrees of complexity that can reduce the reliability of the NDL. For the sake of completeness, these alternative network topologies are described in Appendix B.

A point-to-point line is a communication line that connects two terminals. The line can be one-way, half-duplex, or full duplex, and it can operate synchronously or asynchronously. The most common network configuration is the star (Figure 2-4) in which each terminal has a point-to-point relationship with the central site.

In designing a point-to-point network, one basic question is whether the line should operate in half-duplex-mode, which uses two wires and allows transmission in both directions, but in only one direction at a time; or full-duplex mode, which uses four wires and allows transmission in both directions simultaneously. The throughput efficiency and circuitry costs must be examined to answer this question.

By examining a typical data block transmission, the total transmission time can be computed. For example, the total time for a data

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*The word "terminal" is henceforth used in its generic sense to mean anything from a basic teleprinter-style terminal to a computer.

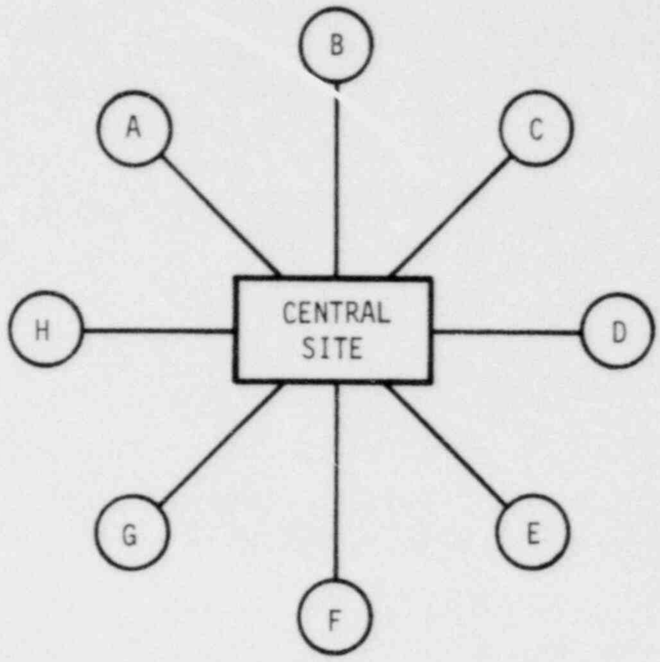


Figure 2-4. Star Network. This is an expanded point-to-point network.

block to be sent and acknowledged for a half-duplex line, if that data block takes 1 second to transmit over a distance of 500 miles with a modem turnaround time of 250 ms, is shown in Table 2-3.

Table 2-3

Half-Duplex Transmission Time

	Milliseconds
Modem turnaround time	250
Block transmission time	1000
Modem delay	10
Propagation delay (@1.5 ms/100 mi)	7.5
Receiving terminal reaction time	2
Modem turnaround time	250
ACK transmission time	50
Modem delay	10
Propagation delay	7.5
Transmitting terminal reaction time	2
Total	1589 ms

The throughput efficiency is calculated by comparing the time spent transmitting data to the total time required to send a block and receive its acknowledgment. Thus,

$$\text{Efficiency (throughput)} = \frac{1000}{1589} \times 100\% = 62.9\% \text{ (half duplex)}$$

This percentage ignores transmission errors, which generally are small and thus have little effect on the calculation.

It is clear that modem turnaround time can have a significant effect on data throughput and system response time. A four-wire, full-duplex communication line can minimize these effects by providing simultaneous transmission and reception.

To compare the efficiency of full-duplex transmission over half-duplex, the time required to transmit a block and receive an acknowledgment is computed in Table 2-4.

Table 2-4

Full Duplex Transmission Time

	Milliseconds
Block transmission time	1000
Modem delay	10
Propagation delay	7.5
Receiving terminal reaction time	2
ACK transmission time	50
Modem delay	10
Propagation delay	7.5
Transmitting terminal reaction time	2
Total	1089 ms

$$\text{Efficiency (throughput)} = \frac{1000}{1089} \times 100\% = 91.8\%$$

This is a significant increase in performance over the half-duplex line because the modem turnaround time of 500 ms is eliminated.

Long-haul telephone lines come out of the network as four-wire lines. Because the telephone company charges for the circuit based on mileage and not on the number of wires in the circuit, full-duplex lines cost the same as half-duplex lines. Also, full duplex modem charges are the same as half-duplex modem charges. Therefore, based on the throughput considerations and cost criteria, the NDL should use full-duplex lines for data transmission.

2.3 CARRIERS AND SERVICES

2.3.1 AT&T Leased Lines

The telephone network covers virtually every section of the country and thus offers a convenient way to connect to every reactor site. The telephone exchanges themselves range from step-by-step uniselector exchanges, through the crossbar exchange, to the modern electronic switching system (ESS), which is completely computer controlled.

Telephone exchanges are connected by various forms of communication media. The first level of connection is the low-speed twisted pair from the local telephone to the local telephone switching office. The frequency response of such a commercial telephone circuit is shown in Figure 2-5. The figure illustrates that frequencies between 300 Hz and 3400 Hz may be transmitted on the line, for a bandwidth of 3100 Hz.

From the local switching office, a broadband communication link, such as a coaxial or fiber optic cable, connects the local switching office to the main central office. This link is usually a digital communication link such as the T-1 carrier specified in Table 2-5 (see Figure 2-6, example of a private line telephone link).

T-1 is the maximum data rate for copper wire. T-3 is currently used by the telephone company for their fiber optic communication links. T-4 is difficult to implement today; however, Bell Laboratories has had a T-4 system under test using quaternary phase-shift keying (QPSK) in the 17.7 to 20.2 GHz band which allows 8 channels per

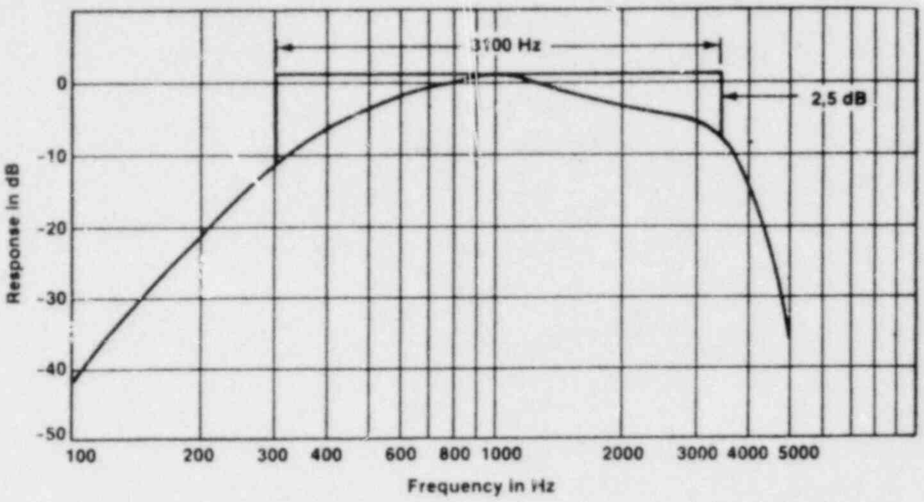


Figure 2-5. Commercial Telephone Circuit Psophometer Weighting (After Cuccia, p 27 -- see Bibliography)

Table 2-5

American Digital Transmission Hierarchies

North American T-Carrier	Voice Channel Capacity	Data Rate (Mb/s)	Equivalent Number of T-1's
---	1	0.064	---
T-1	24	1.544	1
T-1C	49	3.152	2
T-2	96	6.312	4
T-3	672	44.736	28
T-4	4032	274.176	168

polarization and 16 channels total. (QPSK encodes each two bits into one of four possible carrier phases, spaced 90° apart.) A repeater installation which has a total route capacity of 28,224 voice circuits was built in Massachusetts to study this system.

From the main central office, a microwave link transmits the data across the country. The microwave system is a broadband facility that provides line-of-sight radio communications. Because of the curvature

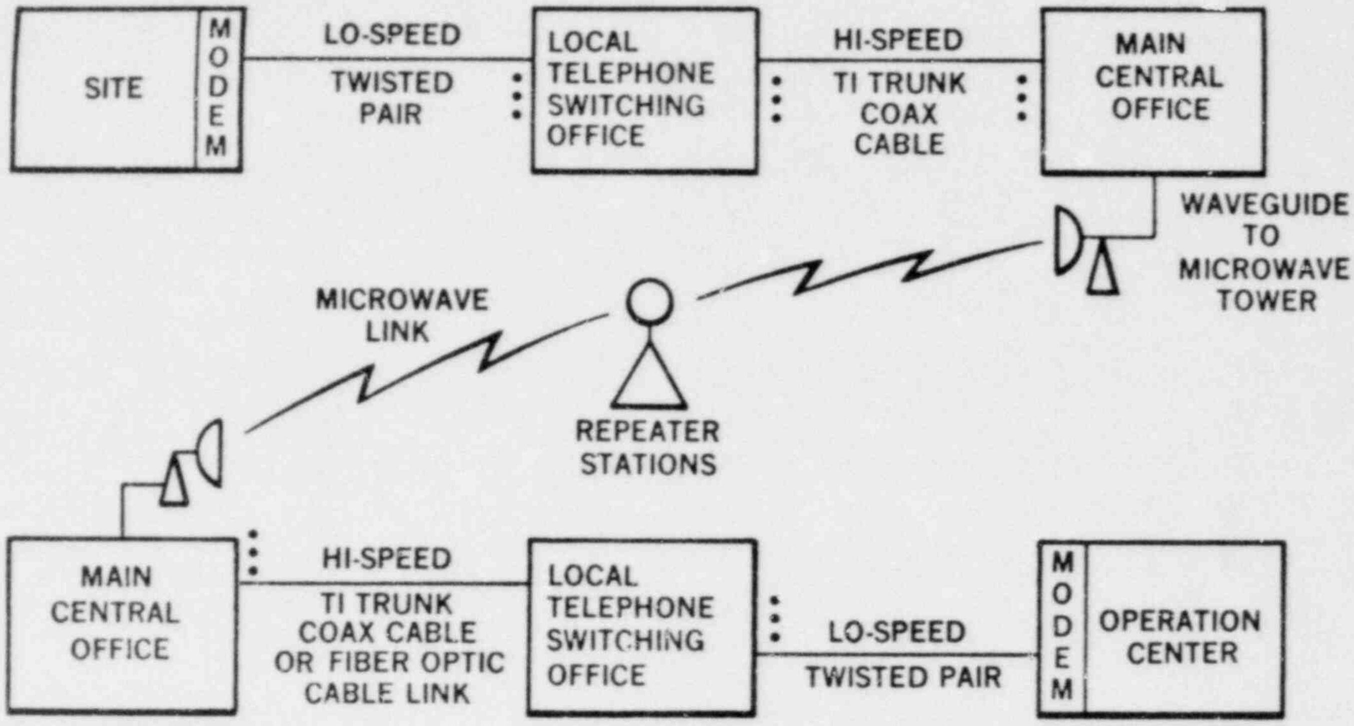


Figure 2-6. Example of a Private Line Telephone Link

of the earth, line-of-site communications is limited, and repeater stations are installed approximately every 40 km (25 miles) along the route. The microwave signal is received by the main central office at the other end of the link, where the process is reversed to the local switching office and the customer at the receiving end.

When a line is leased from the communication carrier, the carrier bypasses the switching equipment in the telephone exchanges, which gives a better quality circuit. This is because a substantial amount of the noise that is induced onto the telephone lines is caused by switching noises within the telephone exchanges.

Current telephone line modem technology uses adaptive equalizing to compensate for certain transmission characteristics on the line, thus allowing up to 4800 b/s transmission over the switched network and 9600 b/s transmission over a conditioned leased line which bypasses the switching equipment.

When a line is leased from a carrier, a four-wire line is used because the trunk portion of the telephone network, and thus the long-haul circuits, consist of four-wire lines. Thus, as noted earlier, a four-wire full-duplex circuit costs no more than a two-wire, half-duplex circuit.

It should be noted, however, that ordering two circuits from the telephone company does not provide a truly redundant circuit because both circuits will probably be in the same cable and on the same microwave link. True alternate cable routing would have to be ordered from the common carrier. This is very expensive and not warranted because dial backup can be provided at a lesser cost.

It must be emphasized that the modem and leased lines only provide the path for the data to flow. They do not control the flow of data nor provide any data error-recovery procedures. The NDL computer network must provide the error-control functions. It should be noted that the site transmission unit (STU), discussed in Section 3.2, is an integral part of the computer network and communications subsystem and impacts the flow of data within the NDL. Therefore, the STU must be specified by the system integrator in order for the system to be complete and operational. In addition to controlling the flow of data within the NDL, the STU could also provide communication link diagnostic capabilities. Thus, the primary function of the STU is to provide the data flow control, error control, and link diagnostic capabilities within the communication subsystem. With current technology, additional functions may be performed by the STU, but the communication functions must not be compromised.

The charge for leasing a line is currently based strictly on mileage between two points. Any amount of data can be transmitted with no increase in fees, the bandwidth of the line and modem speeds being the limiting factors.

The current charges for two-point line service from Bethesda, Maryland, to 48 sites with 74 reactors is given in Table 2-6. Note that the modem/service-terminal charges include charges for two modems

Table 2-6

Two-Point Private-Line Service Charges

	Modem/Service Terminals		Monthly	No. of	No. of
	Installation	Monthly	Mileage	Sites	Reactors
Region I (King of Prussia, PA)	$8,335	$6,936	$2,155	16	25
Region II (Atlanta, GA)	6,482	5,032	3,101	11	21
Region III (Glen Ellyn, IL)	6,022	5,372	4,736	13	19
Region IV (Arlington, TX)	1,584	1,558	2,379	4	5
Region V (Walnut Creek, CA)	1,083	1,383	5,105	4	4
	$23,506	$20,281*	$17,476	48	74

*The charge for two service terminals for each site is $86.60/month. Thus, $4157 of this amount is for Telpak service terminals, and $16,124 is for modem lease charges.

for each circuit plus the service terminals required for Telpak* line termination. The charges quoted are for 4800 b/s full-duplex service to each reactor. Different modem charges are shown in Appendix F, Table F-6. The average charge for line and 4800-b/s modem leasing is $510 per reactor per month.

Summarizing Table 2-6, mileage charges account for 46.3% of the total service charge, modem charges account for 42.7%, and service terminal charges account for 11.0%. The total charge per year for the leased lines and modems is $453,000.

2.4 ALTERNATIVE NETWORK IMPLEMENTATION

Satellites are one alternative to AT&T private lines; value-added networks (VANs) and digital radio relay networks are other alternatives and are discussed in Appendices C and H, respectively. For present purposes, it is sufficient to state that the VANs do provide the communication networking capability for transferring data between nodes of the network; however, they have significant drawbacks from the standpoint of the NDL. VANs do not provide for site data storage and do not have remote diagnostic capability nor the design

*Telpak is AT&T's Series 5000 interstate point-to-point or multipoint private line service.

flexibility possible with the STU and the end-to-end protocol recommended for the NDL. VANs are thus not recommended. With AT&T private lines, however, the communication networking capability must be furnished by the user. There are network packages available from commercial vendors that could provide this service at less cost than VAN service, and the user would have more control over his network architecture and operations. Satellite options are discussed in the following sections and in Appendix I.

2.4.1 Leased Satellite Channels

A leased-line communications network suitable for dedicated data transmission between the reactor sites and the operations center was described in Section 2.3.1. Cost of the service, provided by AT&T and other associated common carriers, is determined by the mileage between terminals which are linked by a microwave network of terrestrial-based repeater stations. Essentially the same performance can be obtained by replacing the terrestrial-based repeater with a satellite-borne transponder. However, as will be shown in this section, little savings in cost would result because of the rate structure for the service.

Western Union and American Satellite Corporation (ASC) provide a variety of leased satellite services typical of those available. Both carriers use Western Union's three geostationary satellites, Westar I, II, and III, for satellite transmissions. However, the two carriers use different ground-station configurations. With Western Union's service, reactor sites and the operations center could access the satellite ground stations through extension channels which would be leased lines provided by AT&T. American Satellite uses onsite satellite transmission facilities and is discussed in Section 2.4.2.

Western Union's Satellite Transmission Service is available only between specific city pairs served by ground stations near Atlanta, Chicago, Dallas, Los Angeles, San Francisco, Seattle, and New York.

City pairs are combined to form zones which form the base of the rate structure[4] given in Table 2-7. In each case the rates are for a leased channel between Washington, D.C., and 11 other locations. The basic leased channels are analog and support transmission speeds of up to 9600 b/s on one voice-grade channel.

Table 2-7

Western Union Satellite Transmission Costs

Zone 1, City Pairs; D.C. to:	
Los Angeles	
San Francisco	
Seattle	$1100/month
Zone 2, City Pairs; D.C. to:	
Dallas	
Houston	$ 820/month
Zone 3, City Pairs; D.C. to:	
Atlanta	
Chicago	
Indianapolis	
Milwaukee	
Minneapolis	
St. Louis	$ 550/month

Figure 2-7 shows the location of Western Union's satellite termination city pairs with respect to the central station nuclear power plants in the United States. Seven Region III reactors are located in the vicinity of Chicago. The average charge for one satellite relay channel between Bethesda and Chicago is $550.00 per month; dedicated leased line extensions from Chicago to the reactors would result in additional charges. The cost advantage of dedicated leased line service over satellite relay service is even more pronounced for reactors in Regions I, II, and IV.

Costs of leased line and satellite channels are comparable for links between the operations center and the reactors of Region V. The average charge for leased-line service direct to Region V reactors is

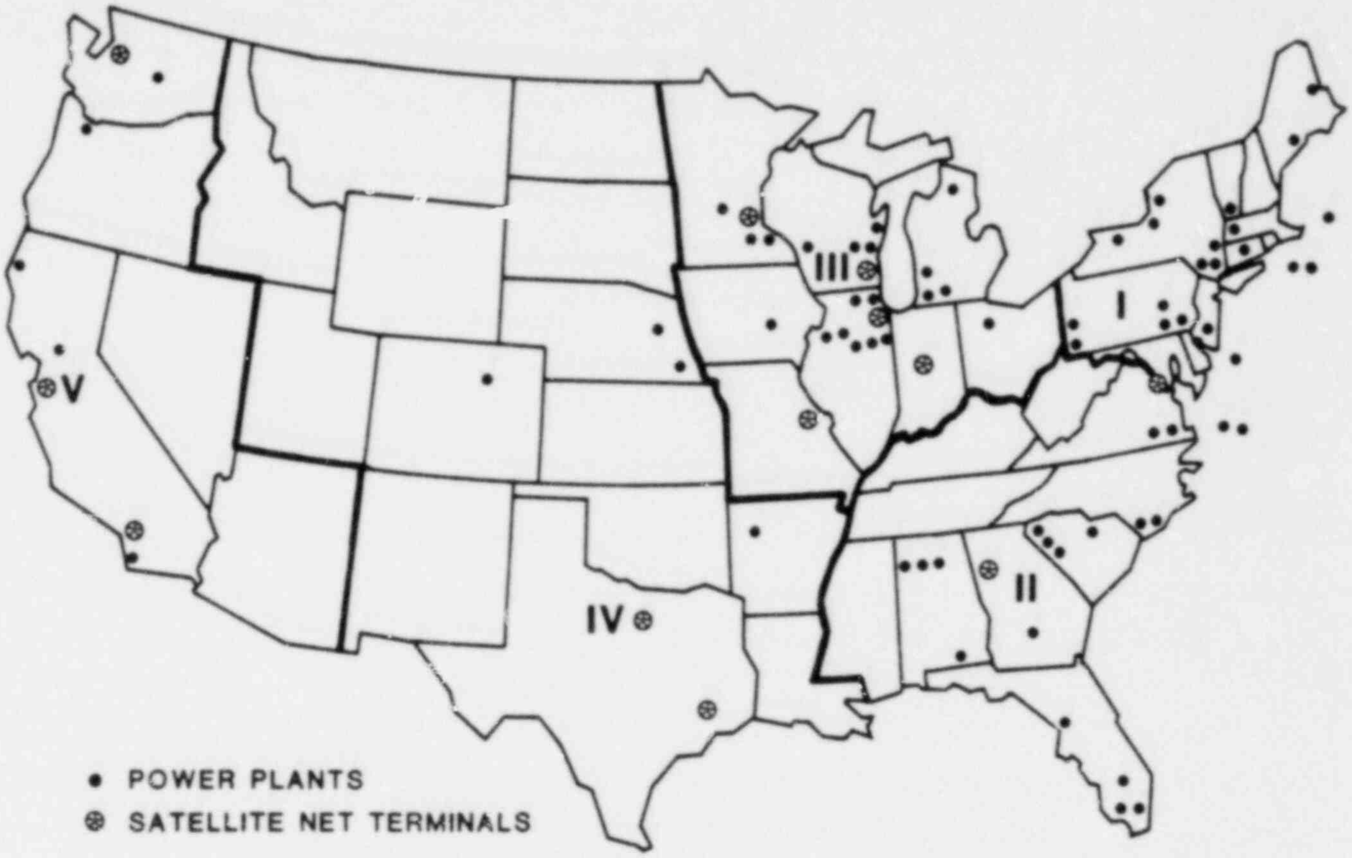


Figure 2-7. Western [illegible] City Pairs with Respect to Central Station Nuclear Power Plants

$1276.00, compared to $1100.00 for a satellite channel. Costs of local extensions would make the two services equally expensive.

Implementation of a satellite/leased-line network over a straight leased-line network would be recommended only if the wideband data capacity inherent in a satellite channel could be used to advantage in the NDL. Some of the advantages of a wideband transmission system are considered in Section 2.4.2, and the implications of these advantages with respect to an enhanced NDL are considered in Section 4.2. If, on the other hand, no advantage accrues from wideband data transmission capability, use of mixed common carrier services should be avoided.

2.4.2 Onsite Satellite Service

American Satellite's Satellite Data Exchange (SDX) Service is a high resolution, all-digital transmission service that would provide private, direct, location-to-location communication between reactor sites and the NRC operations center. Service would be implemented by means of ASC-designed and installed earth stations supplemented by various types of data communications equipment. No additional land-based carrier connection would be required. Onsite installations would include the antenna assembly, a weatherproof electronics shelter, transmit/receive equipment, and some additional equipment required for such optional features as encryption and/or voice channels. Additional details regarding SDX service are given in Appendix I.

The minimum bandwidth of an SDX channel is 56 kb/s. The bandwidth can be increased in 56 kb/s increments to a maximum of 1.544 Mb/s (for a 3- or 5-metre antenna).

Clearly, the data handling capacity of a dedicated satellite terminal greatly exceeds the NDL traffic requirements described in Section 2.1.3. An enhancement to the NDL in which the excess bandwidth can be utilized is described in Section 4.2.

ACS has a one-time installation charge in addition to a monthly service charge for equipment maintenance, depending on the options selected. Separate monthly charges would also be made for the satellite transponder channels leased by ASC from Western Union.

One-time installation charges for a 5-metre antenna at a reactor site would be $10,000 for the antenna and $8000 for deicing if required. Installation charge for a 10-metre antenna at the operations center is $15,000, and deicing would again be $8000, making the total antenna installation $23,000. Additional one-time installation charges might include CryptoLine at $200 and voice channels at $100 per channel.

The monthly service charge for an SDX 56 kb/s channel is $10,000. The cost is for each ground station, regardless of whether a common 56 kb/s satellite channel is shared or individual channels assigned. Voice service can be provided for $250 per month, and encryption can be provided for $375 per month per location. (Since decryption, at

$375 per month, will also be required, the net encryption/decryption cost increases to $750 per channel per month.) Bandwidth of a channel can be increased in 56 kb/s increments at a cost of $2500 per month per increment.

From the above schedule it is clear that the cost of SDX service is determined by the bandwidth (channel capacity) required and by any auxiliary processing services. Figure 2-8, a plot of charges versus distance between terminals, is a comparison of the cost of a typical SDX channel and an equivalent AT&T terrestrial-based data link with the same 56 kb/s bandwidth. Four different AT&T configurations using Series 8000 lines or Digital Dataphone Service in combination with Series 8000 extensions are shown. For distances less than 700 miles and bandwidths of 56 kb/s, it is less expensive to use AT&T leased lines. However, as the bandwidth increases, there is a distinct cost advantage in using SDX. The two-channel rate is obtained by multiplying the value of the ordinate (thousands of dollars) by two. For cost comparison purposes, the 4800 b/s Telepak service discussed in Section 2.3.1 is also illustrated in Figure 2-8.

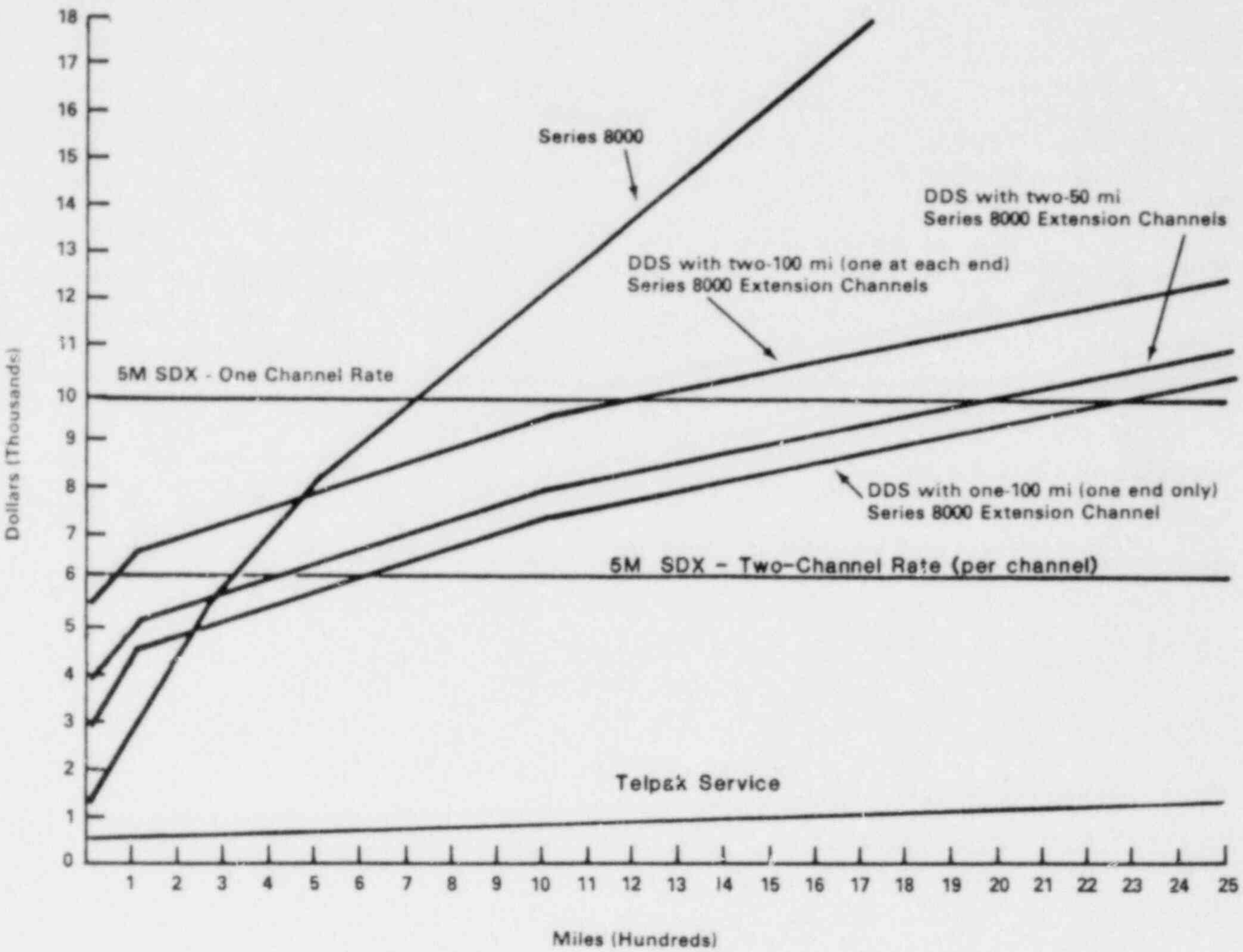


Figure 2-8. Typical SDX Channels versus AT&T 56 kb/s Digital Dataphone Service with Series 8000 Extension Channels or Series 8000. The AT&T Series 8000 is a wideband transmission service for data and facsimile transmission at speeds up to 56 kb/s.

3. NDL COMMUNICATION EQUIPMENT

3.1 MODEMS

The current charges for two-point private line service from Bethesda, Maryland, to 48 sites with 74 reactors was given in Table 2-2. As stated in Section 2.3.1, the average charge for line and modem leasing is $510 per reactor per month. A summary of Bell modems and modulation techniques is presented in Appendix F.

Rather than lease Bell-system modems, the NRC could purchase and maintain their own modems and communication test equipment. Several companies manufacture Bell-type modems for this purpose. As a costing example, Universal Data Systems manufactures a 4800-b/s, 208-type modem, the UDS-208A. Table 3-1 shows the current costs for the present system consisting of 74 reactors with private line service.

Table 3-1

Modem Purchasing Costs

	Unit Price	Totals
Site Equipment:		
74 UDS-208A stand-alone modems	2100	155,400
Operator Equipment:		
10 RM8 (houses 8 modems each)	1350	13,500
74 RM8-208A (4800-b/s modem cards)	1800	133,200
Spare Equipment (15%):		
1 Rack power supply, PS-8	500	500
12 UDS-208A stand-alone modems	2100	25,200
12 RM8-208A (4800-b/s modem cards)	1800	21,600
		$349,400

With the AT&T monthly lease charge of $16,124, the break-even point will be 22 months. An additional $4000 should be added to the above figure for communication line diagnostic and test equipment, taking the break-even point to 24 months. A minimum of six technicians would also be required to operate, test, and maintain the Network Management Center, and their salaries would also have to be considered. Two technicians would be at the operations center, and four would have to travel as required to replace faulty equipment at sites. This personnel requirement would increase if 24-hour service were required.

Unless the NRC is staffed with qualified technical personnel to operate and maintain the modem equipment for the NDL, it should lease the AT&T modems. The NRC will still need a qualified individual to determine the cause of communication problems and whether AT&T modems or lines are at fault. By leasing modems, any changes in data rate requirements will be more easily accomplished by changing to different modems. If modems are purchased, changing to a different data rate could be very costly.

3.2 THE SITE TRANSMISSION UNIT (STU)

The requirements for the STU are discussed in Reference 1 and Section F.3.1 of Appendix F. The type of equipment that can be used to perform the STU functions is discussed in this section.

Modern microelectronic technology has progressed to a point where the STU functions can be performed using a small microprocessor system. The unit would be about 14 cm high by 48 cm wide by 41 cm deep (5.5 by 19 by 16 inches). The unit could be placed anywhere where normal environmental conditions exist, such as in an office area or control room. There are no special air conditioning requirements or excessive power considerations. The microprocessor should be provided with battery backup capability.

As an example, a microprocessor system with 128,000 (128K) words of memory, input/output cards, chassis and power supply, 100K words of file-structured bubble memory storage, a terminal, and software license would cost less than $15,000. Quantity purchases of such systems result in substantial discounts.

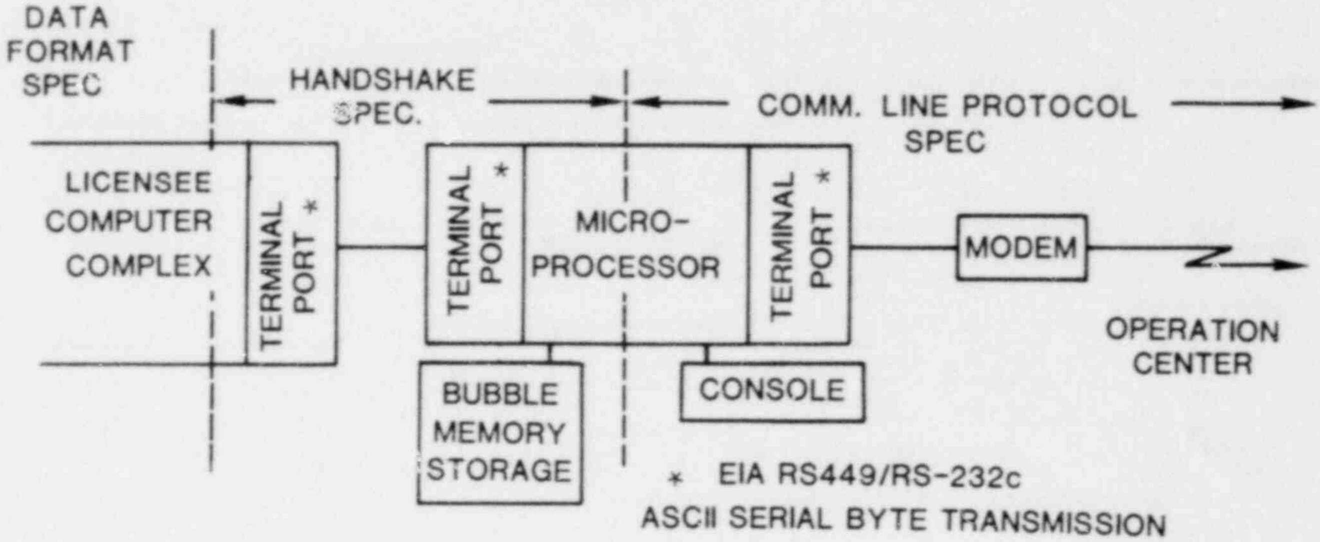
The STU would provide the common interface between different site computers and the protocol standardization necessary for a functional modern computer network. Figure 3-1 illustrates the microprocessor interface to the site computers and the categories of specification.

The data format specification would be implemented within the user's machine and would convert the data to engineering units. The specification would also require time tagging and identification of the parameter so that it could be properly interpreted by the operations center when it is received.

The handshake specification would be a terminal-to-terminal controller (available in all modern operating systems) using the terminal protocol provided by the RS449/RS232C interface specification. An additional application program (see Section F.1.6 in Appendix F) would be necessary in the licensee computer to establish and maintain communications with the STU and the NDL.

The communication line protocol for the NDL would be provided by the STU (which the NRC purchases and controls), thus relieving the site computer of any concern about the communication protocol implementation and maintenance.

If necessary or desirable, additional ports could be provided by the STU for data links to the utilities' corporate offices, the powerplant vendor, or the technical support center. It must be emphasized, however, that the primary purpose of STU is to provide the communications commonality for the NDL and that any additional services that the STU provides must not interfere with its primary functions, including communication link error control, as discussed in Section F.3.4 in Appendix F.



THE SPECIFICATIONS FOR THE SYSTEM ARE BROKEN DOWN INTO THE FOLLOWING CATEGORIES :

1. DATA FORMAT SPECIFICATION
2. TERMINAL TO TERMINAL HANDSHAKE SPEC.
3. TERMINAL TO TERMINAL INTERFACE SPEC *
4. COMMUNICATION LINE PROTOCOL

ADDITIONAL PORTS COULD BE PROVIDED FOR INFORMATION FLOW TO:

1. UTILITIES CORPORATE OFFICE
2. POWER PLANT VENDER
3. SITE TECHNICAL SUPPORT CENTER

THE CONSOLE WOULD BE USED FOR:

1. MANUAL DATA ENTRY
2. SYSTEM INQUIRY AND CONTROL

THE BUBBLE MEMORY COULD PROVIDE AS MUCH AS 600K BYTES OF NON-VOLATILE, FILE STRUCTURED STORAGE.

Figure 3-1. Example of a Microprocessor/Site-Computer Interface and Categories of Specification

The console connected to the STU is optional and could be provided as necessary for manual data entry and system inquiry and control. It could provide remote system testing that could not be provided by the operations center computer.

A bubble memory storage system could be included within the STU if it proved necessary to buffer large amounts of data at the site, either because of data compression algorithms or communication link buffering.

Regarding the maintenance of the STU, current microprocessor technology has proven to be quite reliable; thus a field STU could be expected to remain functional for several years under normal environmental conditions. Spare units should be kept in operating condition to completely replace failed units. The small cost of the STU allows for this type of maintenance procedure. The faulty unit would be returned to an actual "repair" facility for diagnostics and repairs. The repair procedure would involve isolating the faulty printed circuit board, replacing it with a functioning printed circuit board, and sending the faulty board back to the manufacturer for repair and credit. Thus the NRC would not have to be concerned about setting up and staffing an elaborate electronic equipment repair facility. This method of equipment maintenance has proven to be very practical and could easily be performed under contract by a service organization.

3.3 OPERATIONS CENTER EQUIPMENT

3.3.1 The Front-End Processor

A front-end processor is a computer-based device that often has some form of mass storage attached. The front-end processor is similar to a multiplexer in that it combines the data from a number of terminals onto a single high-speed line for transmission to the operations center computer. It is a more sophisticated device, however, because it can alter the form of the data streams prior to merging them onto a high-speed line.

By handling the communication network requirements, the front-end processor can take some load from the operations center computer. Communications is not a computationally demanding task; however, it is time consuming due to the error-checking sequences, data buffering, and queueing that take place.

For performing the front-end processes, a fast cycle time is more critical than a high-powered instruction set, and thus an inexpensive minicomputer can handle the communications as well as an expensive data-processing computer. By putting the communication handling outside the operations center computer in a front-end processor, the operations center computer is relieved of a lot of the load and can then be made available for data-processing purposes. The front-end processor may also be required to interface a large number of slow-speed lines into the operations center computer because, even though the operations center computer may support a small number of high-speed lines, it may not support a large number of slow-speed lines.

The front-end processor can serve as a store-and-forward device in that it can assemble complete messages or blocks of messages from the STU, store them in its memory, and then forward them to the operations center computer. Most mainframe manufacturers supply communications-handling software that enables networks to be put together fairly simply if the terminal and computers come from the same manufacturer. There also are "plug compatible" third-party terminal manufacturers that can be directly interfaced to the host as though they were supplied by the host manufacturer.

The front-end processor can improve utilization of communication lines by statistically averaging the traffic from the network onto the high-speed lines. The front-end processor can queue traffic for the communication line, which means that a one-to-one relationship between high-speed line time and the terminal time is not necessary. If a particular terminal is not transmitting, no high-speed line time is assigned to that terminal, and thus the time saved can be used by some other terminal. The result is that more terminals can be supported on one high-speed line because the line only needs to be able to handle slightly more than the average amount of traffic generated by the network, rather than the total amount of traffic that can be generated by the network.

The front-end processor may be able to increase network reliability if it is used as a data collection center that collects data from a network and later forwards entire blocks of messages to the operations center computer. If the operations center computer or the high-speed line fails, the front-end processor can still continue to assemble data without interfering with the operation of the network. When the operations center computer or the line comes up again, the blocks of data can then be transmitted to the operations center computer. In the opposite direction, the operations center computer can transmit an entire file of data to the front-end processor, which can keep it on mass storage. The front-end processor can then deliver the messages to the terminals when they are ready for them; thus a terminal that is out of action for any reason does not hold up the production process in the operations center computer. The NDL could use this feature for system messages to the site and for down-line loading operating systems and application software to the STU.

The front-end processor would be installed at the same location as the operations center computer. Remote data concentration in the front-end processor is not desirable because of the need for high-speed lines to the operations center and remote maintenance problems with the front-end processors. The link between the operations center computer and the front-end processor is usually a point-to-point line and can be either a high-speed serial data line or a parallel computer-to-computer interface (assuming that the communication protocol can support such a link). With auxiliary storage, the front-end processor could collect messages and data and hold them until the operations center computer is ready to process a batch of data.

3.3.2 The Network Management Center

A communication control center, called the Network Management Center (See Figure 3-2), will be a necessary part of the operations

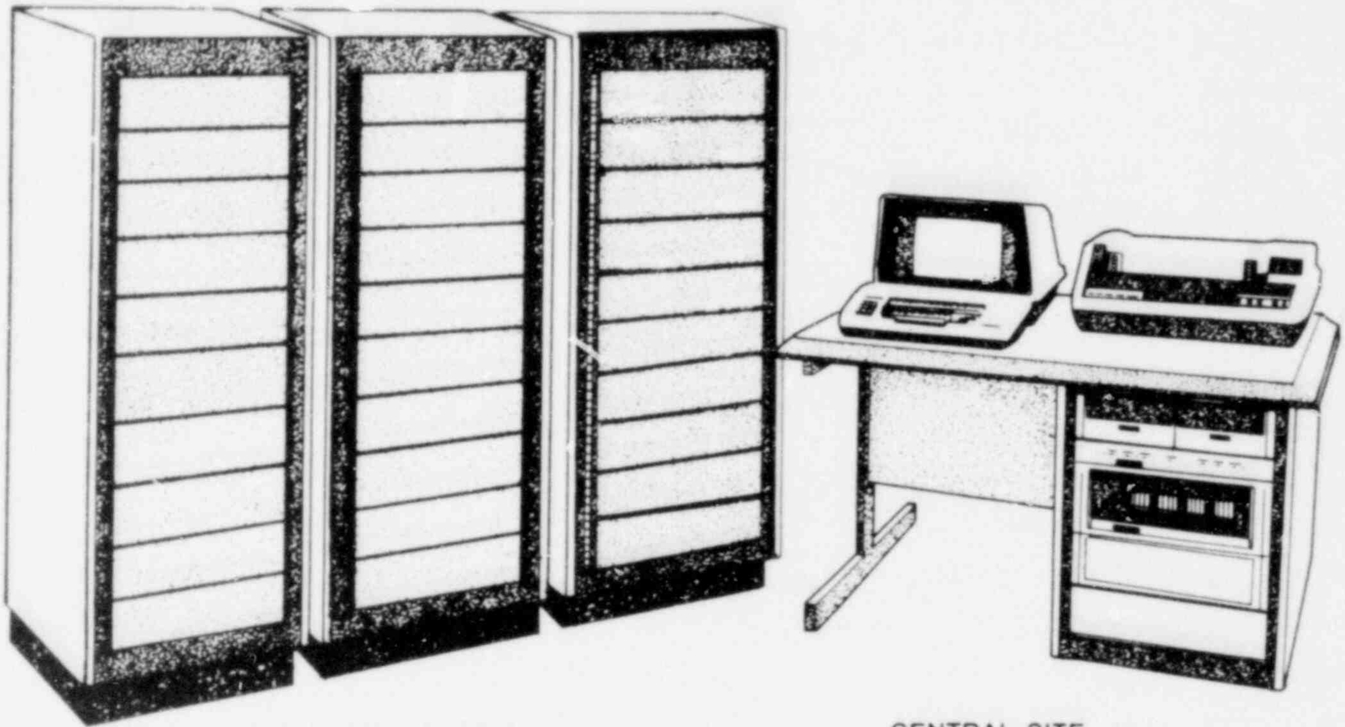


Figure 3-2. Network Management Center, Minimum Physical Requirements

center. All of the transmission and diagnostic equipment associated with the communication link will be located here for centralized communication diagnostic capability. As seen in Figure 3-2, the network management center will consist of at least three equipment racks for housing modems and test equipment, and a table which contains a small, computer-controlled diagnostic system including a floppy disk, line printer, and console terminal.

Because the cable length limit on the RS232C link is 50 feet due to the specified load capacitance limit of 2500 picofarads (see Section 3.1 of EIA RS232C), the Network Management Center must be located adjacent to or in the room housing the central NDL computer system in the operation center building. The room must be at least 3 by 7.6 metres (10 by 25 feet) for modem service to 100 reactor sites. This excludes the wire rack space for the telephone line junctions. Additional space must be allocated if the telephone wire racks are in the same room. The operations center computer space and air conditioning requirements must be added to the Network Management Center requirements.

Network management is accomplished without disturbing transmission of NDL data through an independent secondary channel as shown in Figure 3-3. This channel is frequency-division multiplexed with the main data channel and provides the communications path for command, control, and monitoring information. This enables control of the network from the operations center.

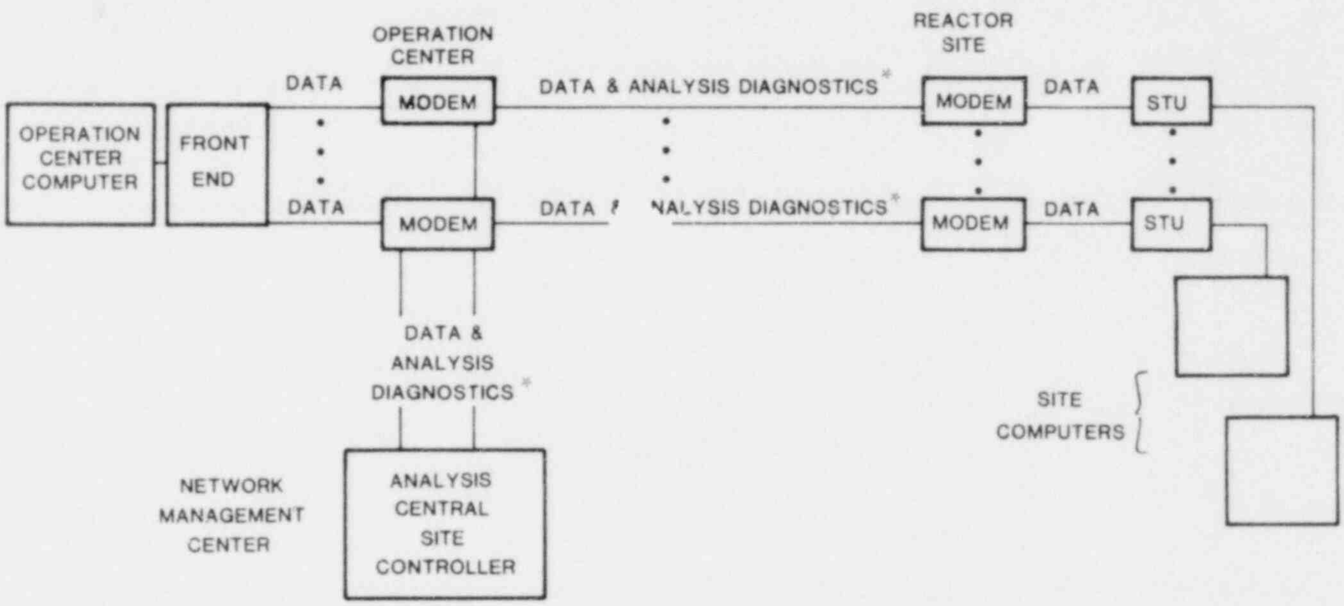


Figure 3-3. Network Management Center Functional Diagram

This network mangement technology is often mistaken for tech control, which is a trouble-isolation and repair approach requiring skilled technicians and sophisticated testing equipment to investigate line and modem problems. Tech control testing often involves personnel at remote locations. This would be impractical for the NDL because of the large number of remote sites and the distances between them and the operations center. Also, tech control testing can interrupt service, resulting in lengthly and costly downtime in large and geographically dispersed communication networks.

Network management eliminates the need for remote site personnel by providing central site operators with all pertinent network performance information. The network management center informs the communications operators at all times if and where network problems are happening. It automatically and continuously looks for status changes in lines, modems, and terminals, reporting these immediately to the central site. This technique eliminates the crisis-and-response method of network management. If service becomes necessary, the proper vendor can then be called.

When a line or primary modem fails, a network operator can transfer data traffic to the dial network or to a spare modem without interrupting data communications. Trends in line degradation can be identified and corrected before a failure occurs. The test results can be provided routinely without operator intervention.

Several vendors offer this capability, including AT&T with their Dataphone II service. For such a system, the modems and test equipment must be compatible and therefore from the same manufacturer since the modulation and diagnostic techniques vary among the different vendors.

4. EXTENDED NDL COMMUNICATION NETWORK

4.1 DATA EXCHANGE WITH THE NATIONAL LABORATORIES

In the current NDL configuration, data from the reactors flows through the network to the operations center, where they are processed by a computer that is at least in the "superminí" class. At the time of this study, neither the nature nor the extent of the data processing operations had been determined. However, it was clear that a limited staff of analysts and a modest-sized computing facility could be overloaded in the event of an emergency. Under these circumstances, it would be advantageous to send data to one or more of the large computing facilities maintained by the national laboratories.

During the Three Mile Island accident, a large amount of data had to be analyzed. Much of the analysis required the use of a large computer, such as a CDC 7600. This computational power, the computer codes to analyze the data, and analysts were provided to the NRC by the national laboratories.

For example, a series of calculations was performed at the request of NRC/PAS to assist in the evaluation of the Three Mile Island accident.[5] Commencing on 31 March 1979, the SANDIA-ORIGEN computer code was used to predict the radionuclide inventory of the reactor core and the accompanying decay heat generation rates. The SANDIA-ORIGEN code was originally developed for analyzing and characterizing a light water reactor (LWR) spent-fuel reprocessing facility and has since been used for a variety of fuel-cycle problems. The ease of input preparation and code operation allowed fast turnaround; the initial results were telephoned to PAS within a few hours after the request was made. Subsequent code runs were performed as requested for varying conditions, and the output listings were flown to

Washington, D.C. The development of the SANDIA-ORIGEN code and LWR fuel-cycle models allowed rapid response to NRC's request for detailed calculations related to the Three Mile Island accident.

It is unnecessary for the operations center to develop this computational power since it is already available within the national laboratory complex and could be used effectively if prior arrangements were made. Thus the large staff required to service the expensive large-scale computer would not be required in the operations center and indeed would not be desirable because of the infrequent use of this large computational power.

An elaboration on and a discussion of the feasibility of providing this capability with a minimum of expense is described in Appendix G.

4.2 WIDEBAND DATA CHANNEL

As indicated in Section 2.4.2, the data-handling capacity of a dedicated satellite channel greatly exceeds the anticipated traffic for the NDL described in Section 2.1.3. In fact, none of the wideband communication capabilities described in this report could be effectively utilized. However, if the NDL traffic could be augmented by routine housekeeping or even emergency traffic between the NRC and the reactor sites, a wideband channel might be cost effective. This enhancement is described in this section.

4.2.1 Channel Function

One consequence of Three Mile Island was the establishment of dedicated voice (telephone) service between the control rooms at all reactors and the operations center in Bethesda. This service, the Emergency Notification System (ENS), uses communication channel routes that parallel the routes required by the NDL. Substantial savings, particularly for long-haul traffic, might be realized by using the same communication channel for both NDL and ENS traffic. Joint utilization would justify one of the wideband data services, for example, American Satellite Corporation's SDX. It should be noted that maintenance charges are significant for any communication channel. In the option under consideration here, there would be only one maintenance charge for both functions.

Figure 4-1 shows one possible terminal configuration providing joint service to both the NDL and ENS. The left side depicts the site terminal; the right side depicts the operations center. On the top left is the STU. On the top right is the host computer at the operations center. The telephones indicated on both sides are for ENS traffic. Also shown on each side are one high-speed facsimile, business or industrial TV, slow-scan video, and a teletype terminal. Either a manual or automatic change-of-service mix could be arranged to meet requirements of the ENS.

In the event of an incident, the industrial TV and slow-scan video could be used, for example, to transmit pictures of the interior of the containment building. Although the feature would require some adjustments on the part of the participants, video teleconferencing between key plant personnel or onsite NRC personnel and response team members also would be feasible.

Although Figure 4-1 implies a common location for the NDL operations center and other emergency response facilities, the two functions could be separated geographically by use of local phone line extensions. Similarly, NDL functions and ENS functions could be separated at the reactor sites. The high-speed facsimile could be used for routine housekeeping traffic-written reports, etc.

4.2.2 Trial Implementation

Trial implementation of one broadband satellite communication channel could be carried out in parallel with the implementation phase of the NDL. It is suggested that two voice-grade, 9600 b/s satellite channels be bootstrapped to provide one 19200 b/s broadband circuit. Such a circuit could provide one 9600 b/s voice-grade circuit, and one 4800 b/s data channel, and the remaining bandwidth, 4800 b/s, would be

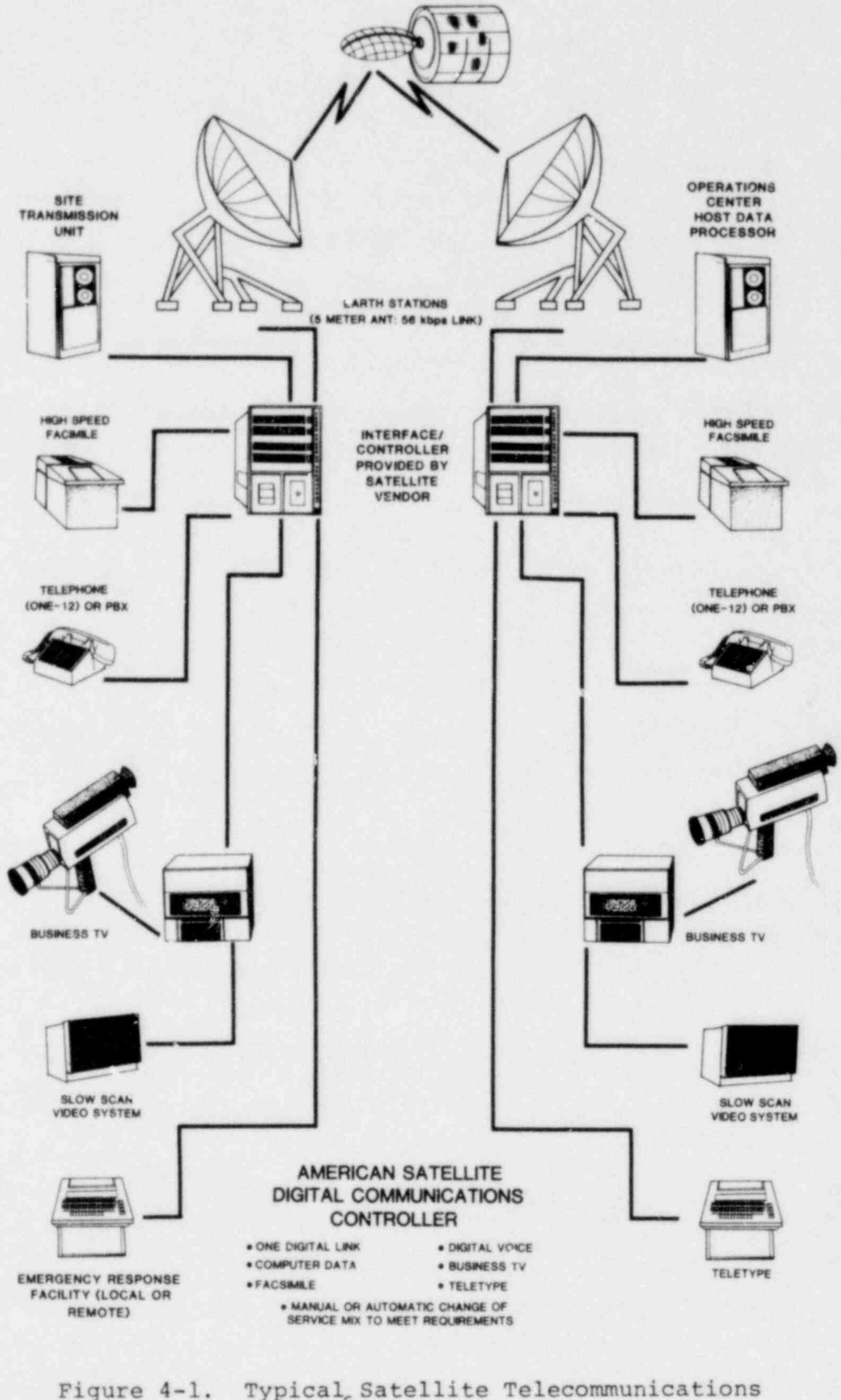


Figure 4-1. Typical Satellite Telecommunications Channel[6]

available for a mix of teletype, high-speed facsimile or slow-scan video.

Because the use of satellite channels is most cost effective for coast-to-coast services, one of the five Region V reactor sites would be a suitable candidate for a trial broadband implementation. Exact costs for one 19,200 b/s ASC satellite channel with ground-leased extensions between Bethesda and five Region V reactor sites could be determined when system requirements and features are established.

5. CONCLUSIONS AND RECOMMENDATIONS

This report addressed the criteria for specification of a communication subsystem for the NDL. The results of this study dictate that initially the physical link should be leased dedicated phone lines. Value-added networks, regardless of cost, do not provide the design flexibility required for the NDL. Also, because of their billing structure, VANs are not presently cost effective. Satellites would be cost effective only for cross-country links at multiple-unit sites or if the scope of the NDL is expanded to include voice, facsimile, and/or video transmissions.

A comparison of the relative advantages of leased line (LL), satellite relay (SR), and radio relay (RR) network is summarized in Table 5-1 (3 = most desirable, 1 = least desirable):

Table 5-1

Transmission Facility Comparisions

	LL	SR	RR
Communication channel reliability	3	3	1
Data handling capacity	2	3	1
Simplicity of operation	3	3	1
Cost of installation	3	2	1
Cost of operation	3	2	1
Ease of maintenance	3	3	1
Transmission security (encryption)	3	3	1
Expandability	3	2	1
Time to implement	3	2	1

Note, however, that a radio relay network cannot provide adequate communication services for the NDL.

The actual costs of leased lines, VANs, and satellites for the estimated amount of transmitted data is summarized in Table 5-2. As the table shows, for the NDL's estimated traffic volume, VANs and satellites are considerably more expensive than the leased-line approach. (Detailed discussion of the cost of VANs is given in Appendix C.)

Table 5-2

Communication Cost Summary
(74 Reactor Sites)

		Basic Monthly Charge ($ x 1000)
AT&T leased lines/modems[a b]		38
VANS	GTE Telenet[c]	78
	Tymnet[c]	345
Satellites, ASC[b]		400

[a]Must furnish own communication protocol functions.
[b]Fixed monthly charge regardless of amount of traffic volume.
[c]Charge based on traffic volume of 30,000 bits/site/minute.

A point-to-point network topology would provide the least complex and most cost-effective configuration for the NDL. This easy-to-implement configuration is suitable for the NDL because of the NDL's moderate data rate requirements and because reactor facilities do not need to communicate with each other.

The maintenance services for the communications network, including the modems, should be provided by the common carrier. This will relieve the NRC of the responsibility of analyzing line and modem failures themselves or of contracting for these services with a separate maintenance firm. The number of individual vendors and suppliers of services should be kept to a minimum throughout the system.

The leased-line facilities do not provide the communication protocol for data error detection and flow control. This necessary function must be provided by the STU, which is controlled by the NRC.

No other custom-designed equipment should be used within the NDL because equipment is already available to do the job. With custom equipment, maintenance and upgrading support may not be available in the future and, if available, could prove to be increasingly expensive as time goes on. This includes the computer networking capability, both hardware and software, and the STU.

Data encryption adds expense to the system, decreases system reliability, and is of questionable utility. Thus, data encryption should not be used for the initial implementation of the NDL. This feature can be added at a later date if it proves to be necessary.

Assigning a few knowledgeable NRC staff members to oversee the NDL and contracting the routine maintenance procedures to an outside firm would appear to be more cost effective in the long run. The Network Management Center staff should include people who can test the leased lines and modems on a regular basis. Line degradation can then be observed and documented, and link failures can be anticipated. A more reliable communications link can thus be maintained.

For practical reasons, telecommunication facilities should not be shared with any other government agency or system such as ARPA, DOE, or SECOM. The Federal Telecommunications System should also be avoided for dial backup facilities because prior approval for data communications is required, and the facilities as a rule are more noisy and experience more dropouts than the commercial telephone system. As a result, the actual data throughput may not be much faster than 300 b/s.

One possible enhancement of computational capabilities available to the NRC during emergencies, namely a wideband data link from the operations center computer to the national laboratories, has also been explored. This concept appears feasible but further study based on a more specific definition of the desired capabilities is required before good communications-system cost estimates can be formulated.

APPENDIX A

Conventional Modulation Schemes for Binary Communications

CONVENTIONAL MODULATION SCHEMES FOR BINARY COMMUNICATIONS

Two forms of frequency-shift keying (FSK) modulation are of interest for NDL binary communications: coherent and noncoherent. In noncoherent FSK, detection is accomplished by the use of a pair of bandpass filters. One filter is tuned to "peak" on marks, the other tuned to spaces. The two filter outputs are envelope-detected and sampled once per information pulse, and the mark/space decision is made according to whichever detected output is the larger. In coherent detection, it is assumed that an exact replica of the possible arriving signal, exact even to the timing of RF phase, is available in the receiver. The receiver, in effect, cross-correlates this replica against the sum of the received signal and additive noise.

Just as FSK can be regarded as frequency modulation in discrete steps, phase-shift keying (PSK) can be considered as a representation of a signal whose phase is changing in discrete steps. The performance of a PSK receiver is the same for coherent and incoherent detection, and coherent detection is usually used. As in the case of FSK, a reference waveform accurate in frequency and phase is assumed to be available at the receiver. The coherent detector is a synchronous detector whose output is proportional to the input envelopes and to the cosine of the phase difference. The binary decision is based on the algebraic sign of the detector output.

A fourth modulation technique of interest for NDL communications is differentially coherent PSK (DPSK). Using this technique, it is assumed that there is enough stability in the equipment and the transmission that there will be negligible change in phase from one information pulse to the next. Information is encoded by differentially encoding the information in terms of the phase change between successive pulses. Coherent detection is accomplished simply by comparing the phase of the "current" pulse with the previous pulse suitably delayed.

Irrespective of the type of modulation, the capacity of a channel is given by Shannon's theorem:[7]

> The capacity of a channel of band W perturbed by white thermal noise of power N when the average power is limited to P is given by
>
> $$C = W \log_2 \frac{P+N}{N}$$

This means that by sufficiently involved encoding systems, binary digits can be transmitted at the rate $W \log_2(1 + \gamma)$ bits per second, where γ is the signal-to-noise frequency ratio (P/N), with an arbitrarily small frequency of errors. It is not possible to transmit at a higher rate by any encoding system without a definite positive frequency of errors.

Figure A-1 shows a comparison of the theoretical error rates for the four modulation schemes versus the signal-to-noise ratio. As indicated on the figure, the curves were plotted using error probabilities given as exponential or complementary error functions whose arguments are elementary functions of the signal-to-noise ratio.

Table A-1 is a comparison of the actual performance achieved in three physically realized modulation schemes.[8]

Table A-1

Actual Modulation Scheme Performance

Modulation Scheme	Speed (b/s per Hz)	γ(dB)
FSK--noncoherent	0.8	11.8
PSK--coherent	0.8	9.4
DPSK	1.9	9.9

In each case the BER is 10^{-4}. Thus, the performance measurements verify the theoretical calculations.

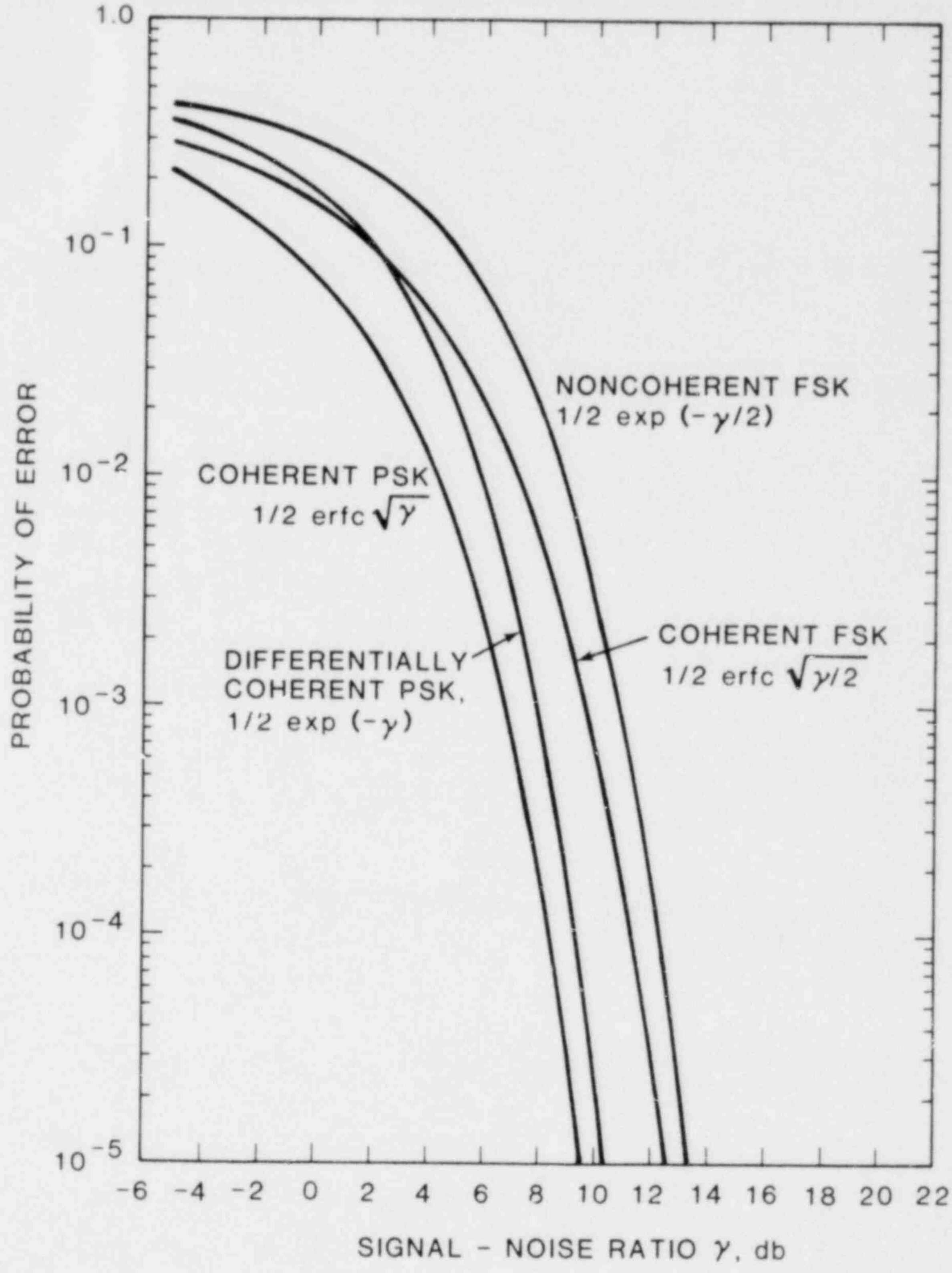


Figure A-1. Error Rates versus Signal-to-Noise Ratio for Four Binary Systems [following Schwartz, Bennet, and Stein[9]]

APPENDIX B

Alternative Network Topologies

B.1 MULTIDROP LINES

A multidrop (or multipoint) line, Figure B-1, is a line with two or more terminals connected to one communication line. Usually buffered terminals are used on a relatively high-speed line because buffered terminals make efficient use of the capacity of the communication line during transmission and do not use any line capacity while messages are being entered by the operator. Thus, the capacity of the line is shared among a number of terminals. A set of line-control procedures controls the flow of data within the network so that data to or from one terminal do not interfere with another terminal.

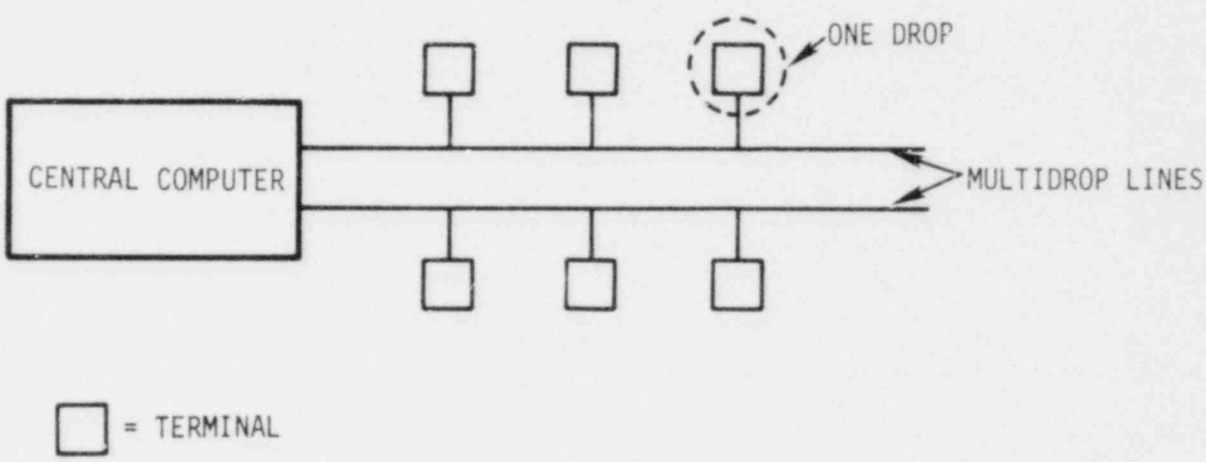


Figure B-1. Multidrop Lines

Multidrop lines are more efficient than point-to-point lines when each terminal transmits intermittently. However, the multidrop system is less desirable because a cluster of terminals, rather than only one terminal, is disconnected if one line fails. Because system reliability has high priority for the NDL, this aspect of the multidrop system is undesirable. Also, if the multiple events occur on the same multidrop, the line could become saturated due to multiple terminals attempting to dump data on the same line to the operations center, possibly resulting in delayed or lost data at the operations center.

B.2 STAR, RING, MESH, AND HIERARCHICAL NETWORKS

There are four basic network configurations: star, ring, mesh, and hierarchical (tree). The star network, discussed in Section 2.2.1, is very dependent on the integrity of the central site. If the central site is performing a critical function, it may be necessary to duplicate some of the equipment there in order to maintain service in the event of a central site equipment failure.

A ring network, illustrated in Figure B-2, consists of a number of computers connected together in a ring or loop. There are two paths that can be established between any two computers in the network; if one path fails, the other route can be used as a backup.

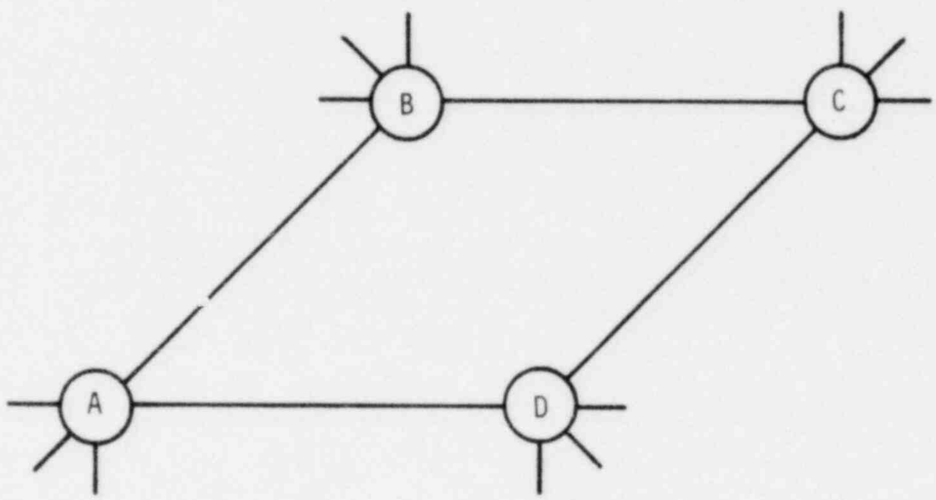


Figure B-2. Ring Network

The failure of one node on the ring causes only the terminals on that node to be disconnected from the network, while the remaining nodes can communicate by using other parts of the ring.

The mesh network, shown in Figure B-3, is an extension of the ring network. This topology is used if there is a need to handle large volumes of traffic from many terminals in many cities.

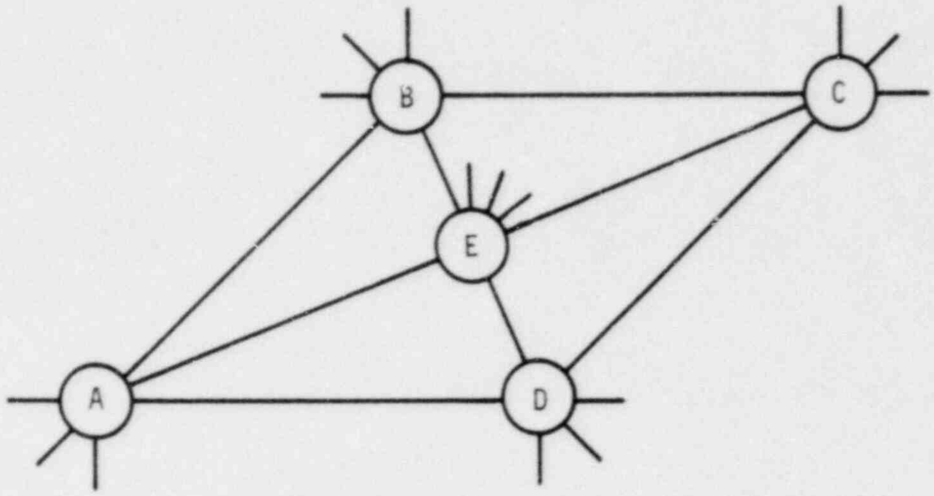


Figure B-3. Mesh Network

The hierarchical (or tree) network is shown in Figure B-4. Various levels of computers converge as in a corporate organization chart. The communication lines farther up the "tree" are generally higher-speed lines since the data is concentrated from the slower-speed lines below.

The star, ring, and mesh networks involve different lengths of communication lines, and they provide different degrees of reliability. In designing a network, trade-offs are made between reliability, efficiency, and costs, and a system may contain different types of networks -- one section based on the star configuration, for example, and other sections based on the ring or mesh.

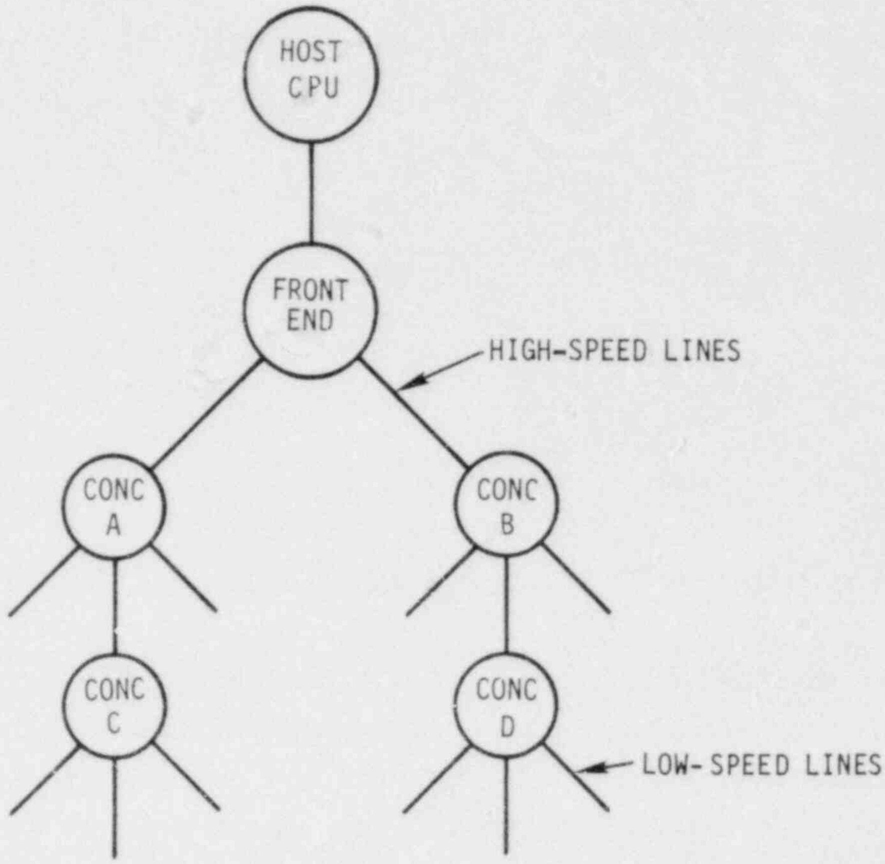


Figure B-4. Hierarchical Network

APPENDIX C

Value-Added Network Options

VALUE-ADDED NETWORK OPTIONS

Value-added networks (VANs) are an alternative to AT&T dedicated leased lines. VANs charge by traffic volume rather than mileage. The VANs supply the necessary communication protocol for data transmission either furnished as a software package installed in the user's machine or as a microprocessor-based, onsite network interface processor which connects to the user's system. Access points into these networks are limited relative to nuclear reactor locations, and in many cases the closest access point only allows 1200 b/s transmission speeds (see Figures C-1 and C-2). The VAN access points can be reached via dial-in ports (using local telephone exchanges), private lines, and TWX lines.

Onsite microprocessor-based data communication processors enable communication between the network and the user's computers and terminals without requiring changes in the site installation's hardware or software. The microprocessor provides the necessary communications protocol control that handles the data flow through the VAN.

Two typical VANs are GTE's Telenet, illustrated in Figure C-1 and described in Table C-1, and Tymnet, illustrated in Figure C-2 and described in Table C-2. Telenet is a packet-switching network, whereas Tymnet is a store-and-forward message-switching network, as illustrated in Figure C-3.

A packet-switching network consists of a number of computer-based switching centers interconnected by high-speed communication lines using analog or digital transmission. Messages are split into packets that are individually passed through the network. Each packet contains destination address and error control information. With large volumes of data in the network, packets belonging to different users share the resources in the switching nodes and the interconnecting lines.

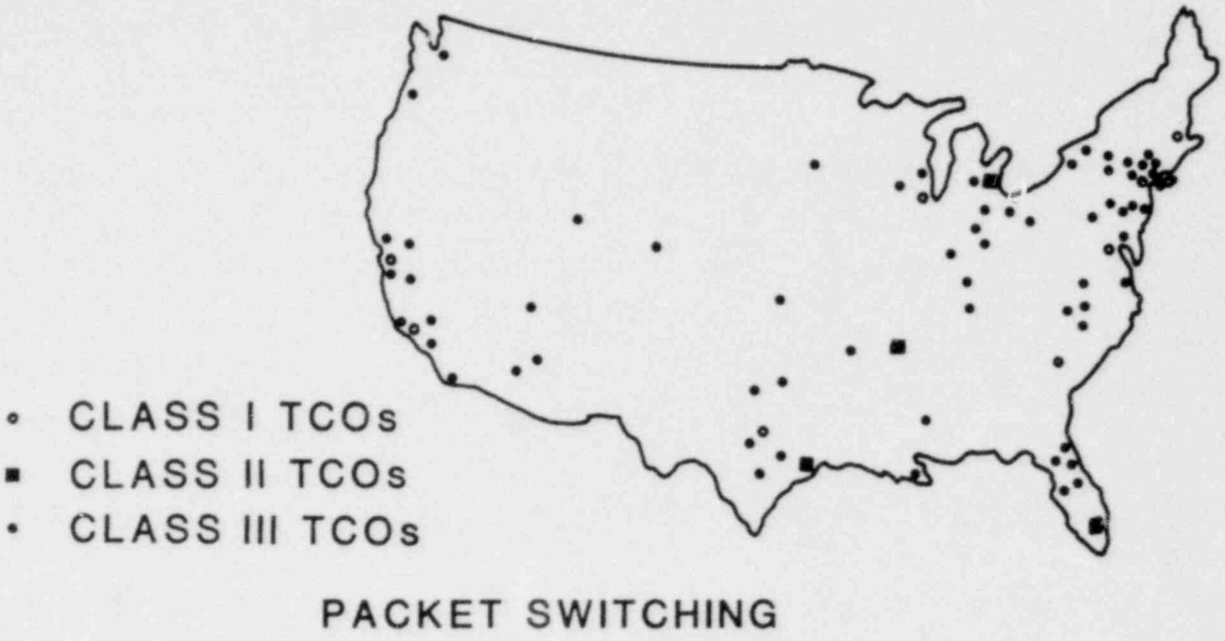


Figure C-1. GTE Telenet [after Taylor and Williams[4]]

Table C-1

Telenet Access Points and Costs

Class I TCOs (56 kb/s access)

San Francisco, Boston, Newark, Washington, D.C., Atlanta, Chicago, New York, Dallas, Los Angeles

Class II TCOs (9.6 kb/s access)

Detroit, Houston, St. Louis, Miami

Class III TCOs (1.2 kb/s access)

Ohio: Cincinnati, Akron, Cleveland, Columbus, Dayton, Toledo, Youngstown
N.Y.: Albany, White Plains, Buffalo, Hempstead, Rochester, Syracuse
Pa.: Philadelphia, Allentown, Pittsburgh
Tex.: Austin, Ft. Worth, San Antonio
Calif.: Colton, Glendale, Sacramento, Marina Del Rey, San Carlos, San Diego, San Jose, San Pedro, Santa Ana, Ventura
N.C.: Charlotte, Winston-Salem, Raleigh/Durham
Conn.: Hartford, New Haven, Stamford
Mass.: Springfield
Fla.: Ft. Lauderdale, Tampa, Orlando, St. Petersburg, Jacksonville
Mich.: Ann Arbor

Class III TCOs (cont.)

Nev.: Las Vegas
Ky.: Louisville
Wis.: Madison, Milwaukee
Tenn.: Memphis, Nashville
Minn.: Minneapolis
La.: New Orleans
Va.: Norfolk, Richmond
Okla.: Oklahoma City, Tulsa
N.J.: Paterson, Trenton
Neb.: Omaha
Ariz: Phoenix, Tucson
Oreg.: Portland
Utah: Salt Lake City
Wash.: Seattle
Del.: Wilmington
Mo.: Kansas City
Ind.: Indianapolis
Colo.: Denver
Ala.: Birmingham
Md.: Baltimore

Public Dial-In Ports

Standard (to 1.2 kb/s).............$3.25/h
WATS.............................. 15.00/h

Private Dial-In Ports

110-4.8 kb/s.......................$160-450/mo

TWX ports.......................... 210/mo

Dedicated Access Facilities

50-1.8 kb/s.......................$300-380/mo
2.4-9.6 kb/s...................... 1,100/mo
56 kb/s........................... 2,100/mo

Charge per Thousand Packets........$0.50

Private Packet Exchange

Controller.........................$800/mo
Ports (110-56Kb/s)................60-200/mo

Telenet Processors

TP 1000 (to 300 b/s)..............$240-600/mo
TP 2200 (with no ports)...........550/mo
Per asynchronous port...........120-200/mo
Per asynchronous port...........175/mo
TP 4000 (with no ports)...........850/mo
Per asynchronous port...........120-200/mo
Per synchronous port............175/mo

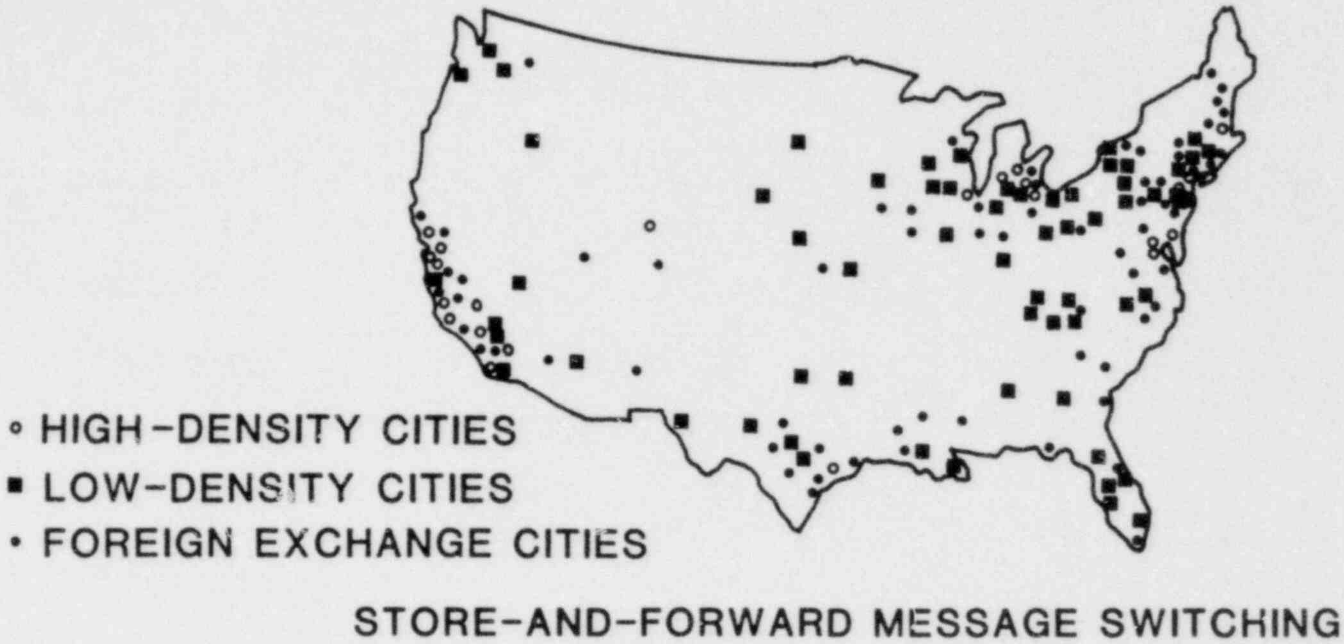


Figure C-2. Tymnet [after Taylor and Williams[4]]

Table C-2

Tymnet Access Points and Costs

Tymnet Access Points

<u>High-Density Access Cities</u>

Calif.: El Segundo, Los Angeles, Mountain View, Newport Beach, Oakland, Palo Alto, Riverside/Colton, San Francisco, San Jose/Cupertino, Ventura/Oxnard
Colo.: Denver
Washington, D.C.
Ill.: Chicago
Mass.: Boston/Cambridge
Md.: Baltimore
Mich.: Ann Arbor, Detroit, Plymouth, Southfield
N.J.: Englewood Cliffs, Lyndhurst, Wayne, Newark/Union, Pis⁻ıtaway
N.Y.: New York
Pa.: Philadelphia
Tex.: Houston
Va.: Arlington

<u>Low-Density Access Cities</u>

Ala.: Birmingham
Ariz.: Phoenix, Tucson
Calif.: Hayward, Sacramento, San Diego, Santa Rosa
Conn.: Darien, Hartford
Ga.: Atlanta
Fla.: Jacksonville, Miami, Orlando, Tampa, St. Petersburg
Iowa: I.s Moines, Iowa City

<u>Low-Density Access Cities (cont.)</u>

Idaho: Boise
Ill.: Freeport, Rockford, Springfield
Mass.: Springfield
Ind.: Indianapolis, South Bend
Minn.: Minneapolis
Kan.: Wichita, Shawnee Mission
Mich.: Jackson, Kalamazoo
Mo.: Kansas City, St. Louis
La.: Baton Rouge, New Orleans
Neb.: Omaha
N.C.: Durham/Raleigh, Winston-Salem
N.J.: Princeton
Nev.: Reno/Carson City
Okla.: Oklahoma City, Tulsa
N.Y.: Buffalo, Corning, Rochester, Syracuse, White Plains
Ohio Akron, Cincinnati, Cleveland, Columbus, Dayton
Pa.: Erie, Pittsburgh, Valley Forge
Oreg.: Portland
Tenn.: Chattanooga, Memphis, Nashville
Tex.: Austin, Dallas, El Paso, M.dland, San Antonio
Utah: Salt Lake City
Wash.: Richland, Seattle
Wis.: Madison, Milwaukee

Tymnet Costs

<u>Asynchronous Interfaces (to 1.2 kb/s)</u>

Single user..........................$100/mo
Up to 8 users........................ 1,000-1,250/mo
Up to 16 users....................... 1,500-1,750/mo
Up to 62 users....................... 2,150-2,750/mo

<u>Synchronous Interfaces (to 4.8 kb/s)</u>

Up to 64 users....................... 1,400/mo
Up to 256 users...................... 2,150/mo

<u>Connect Time</u>

High-density (to 4.8 kb/s)..........$1-5/h
Low-density (to 4.8 kb/s)........... 4-8/h
Foreign exchange (to 1.2 kb/s)..... 5-6/h
WATS (to 1.2 kb/s).................. 14-15/h

<u>Dedicated Ports (to 300 kb/s)</u>

Each, for first 15 ports............$475-650/mo
Each, for over 15................... 300-400/mo

<u>Usage Charges (110-300 b/s)</u>

First 40 million characters.........$0.10/thousand
From 40-80 million characters...... 0.08/thousand
Over 80 million characters.......... 0.01/thousand

Usage Charges (1.2-4.8 kb/s).......$0.03/thousand chars

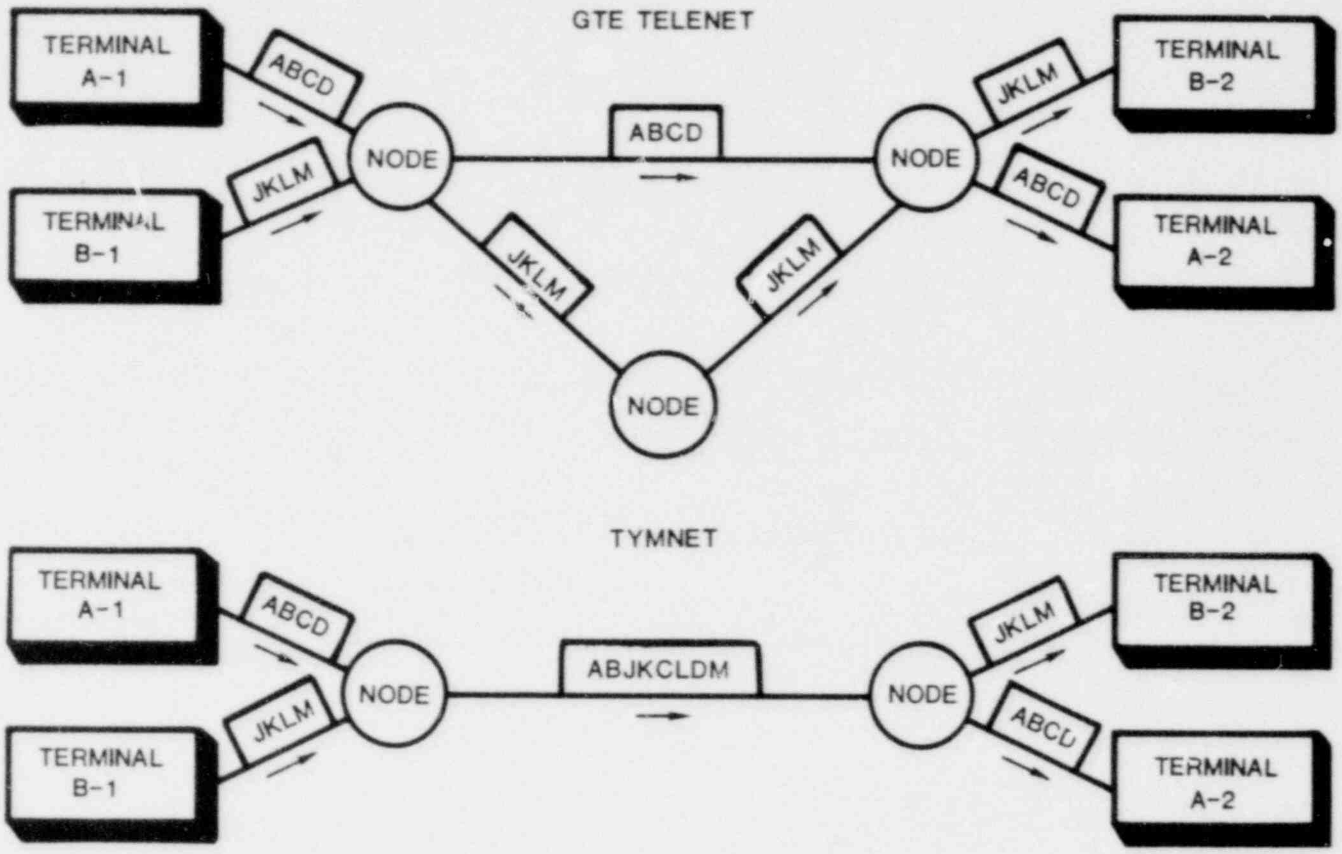


Figure C-3. Packet-Switching Network versus Store-and-Forward Message-Switching Network

A store-and-forward message-switching system stores the entire message on a mass storage device and holds it until the receiving node is ready to accept the entire message. If the receiving terminal is busy, other terminals can still send messages to the node: these messages are queued on the mass storage and are output when the called terminal is ready. The computers in the network allow communication between incompatible terminals through code conversions, message formatting, and transmission mode selection.

Telenet supports transmission speeds up to 56 kb/s, whereas Tymnet supports speeds to 4800 b/s. Their cost structures are different, as the following example illustrates.

The calculations that follow are based on the NDL traffic flow estimates presented in Section 2.1.3 and on the current rate structures for Telenet and Tymnet. As mentioned previously, VAN charges are based on traffic volume rather than mileage. As will be seen, if large volumes of data are to be transmitted through the NDL, the lease-line option is more cost effective.

For GTE Telenet,[4] the lowest packet charge, utilizing full packets (an unlikely occurrence) with a maximum of 128 characters per packet and assuming 100% efficiency, is \$45,000 per month, as shown below in the following equations (assuming a monthly traffic flow of 1.2×10^{10} char/mo, as estimated in Section 2.1.3).

$$1.15\text{x}10^{10}\ \frac{\text{char}}{\text{mo}} \times \frac{1\ \text{packet}}{128\ \text{char}} = 9\text{x}10^{7}\ \frac{\text{packets}}{\text{mo}}$$

$$9\text{x}10^{7}\ \frac{\text{packets}}{\text{mo}} \times \frac{\$0.50}{1000\ \text{packets}} = \$45{,}000/\text{mo (Packet Charge)}$$

Telenet processor charges would have to be added to this figure as follows.

A 4800 b/s private dial-in port to Telenet costs \$450 per month; for 74 sites, this would be \$33,000 per month. Thus, the total monthly charge for GTE Telenet service would be

$$\$45{,}000 + \$33{,}000 = \$78{,}300/\text{mo}$$

Note that this is only for one-way data transmission. The packet charges would increase proportionally for traffic flowing from the operations center back to the site. Finally, GTE Telenet charges are based on how efficiently the packets are used. In reality, the monthly costs could be substantially higher since it is unlikely that 100% packet utilization would be realized.

For Tymnet, the maximum supported data transmission rate is 4800 b/s. Tymnet charges are based strictly on character volume, the charge for 4800 b/s being $0.03/1000 char. With the NDL traffic volume of 1.15×10^{10} char/mo, the Tymnet monthly usage charge would be

$$1.15 \times 10^{10} \ \frac{\text{char}}{\text{mo}} \times \frac{\$0.03}{1000 \text{ char}} = \$345{,}000$$

Connect time and interface charges would also have to be added to this figure.

APPENDIX D

Ionospheric and Tropospheric Radio Wave Propagation Mechanisms

IONOSPHERIC AND TROPOSPHERIC RADIO WAVE PROPAGATION MECHANISMS

Ionospheric Wave Propagation

The ionosphere is that region of the earth's atmosphere in which the constituent gases are ionized chiefly by solar radiation. This region extends from about 50 km above the earth to several earth radii, with the bulk of the ionization located at altitudes between 90 km and 1000 km. Within the ionized region, the actual electron density distribution undergoes important diurnal variations as well as important pathological effects ("magnetic storms" and "sudden ionospheric disturbances") related to solar flares and sunspots. The distribution is also affected by the latitudes of the terminations of the link, the season of the year and a long-term variation in solar activity.

Despite these variations in the electron density distribution within the ionized region, there is always sufficient ionization that the reflective properties of the ionosphere can be used for communication at some frequency in the HF band. Antenna radiation obliquely incident upon the ionosphere is 'reflected' down to earth at a distant point, enabling long-distance point-to-point radio communication. At the high end of the HF band and the lower end of the VHF band, the wavelength is sufficiently short that the ionization density changes only slightly in the course of a wavelength. As the wave penetrates into regions of greater electron density, the refractive index decreases, and the angle of refraction increases correspondingly. The variation in refractive index causes a turning of the wave back toward the surface of the earth.

At the low end of the HF band, the ionized region may be considered to consist of several thin but discrete layers, each having a constant ionization density that differs from that of the adjacent layer. In this case the incident wave will be partially refracted by the first layer. The refracted wave penetrates to the second layer, where it is partially reflected and partially refracted and similarly for subsequent layers. Reflections from various parts of the ionized region sum to form a resultant reflected wave.

Scatter Propagation Involving Ionization Phenomena

The feasibility of communication systems based on scatter propagation of naturally occurring ionization in the atmosphere has been demonstrated. For example, radio scattering at VHF is possible from ionization associated with auroral disturbances or long trails of ionization produced by bursts of meteorites. Meteor-burst communications at modest power levels have occurred using duplex digital techniques in the the 30 to 40 MHz region of the radio spectrum, over distances of 600 to 1300 km. Although some practical applications using meteor-burst propagation have been suggested for intermittent data transmission from remote sensors, the propagation channel is open only for brief intervals because the ionized particles forming the meteor trails are rapidly neutralized. Moreover, the trail must be properly oriented with respect to both the transmitter and the receiver. Similarly, auroral scattering can occur only during solar storms. Therefore, these techniques cannot be used to provide communications with sufficient reliability for NDL purposes.

Tropospheric Wave Propagation

The troposphere is that portion of the earth's atmosphere extending from the surface to an altitude of about 10 km. Wave propagation within the troposhere beyond the line-of-sight can result from several mechanisms classified as diffraction, normal refraction, abnormal reflection and refraction, and tropospheric scatter. Diffraction occurs if the curved surface of the earth acts like the edge of an obstructing screen for points below the radio horizon line of a transmitting antenna.[10]

Normal refraction of a radio wave occurs if, as is usually the case, the dielectric constant of the atmosphere is greater than unity near the earth's surface, but decreases to unity at great heights where the air density approaches zero. The change in dielectric constant, and therefore the refractive index, causes the radio rays to undergo a downward bending as the refractive index decreases. The bending may be accounted for by using straight raypaths and assigning to the earth an "effective" radius 4/3 times the actual radius.

Abrupt changes in the refractive index or its gradient can cause abnormal refraction and reflection. These abrupt changes are the result of such nonstandard atmospheric conditions as temperature inversions and deviations from the moist standard atmosphere which has a water-vapor pressure of 1000 pascals at sea level, decreasing with altitude at the rate of 100 pascals per 305 metres, up to 3.1 km. Under nonstandard conditions, the waves become trapped and tend to propagate along a duct conforming to the earth's curvature. Ducting generally occurs at ultra-high frequencies (UHF) but does not occur more than 25% of the time over land areas.

Consistent and reliable beyond-the-horizon signals for distances up to 640 km have often characterized tropospheric forward-scatter communication channels. Forward scatter propagation is possible by virtue of inhomogeneities in the refractive index of the atmosphere within the common volume of the troposphere occupied by the transmitting and receiving beams. The received signal is generally ascribed to scattering from eddies or "blobs" in the troposphere due to turbulence or perhaps even uncorrelated reflections from many layers of limited extent and arbitrary aspect.[11] A useful rule of thumb for tropospheric forward-scatter propagation has been given[12] as follows: at 160-km range, the median field strength is approximately 57 dB below the free-space value, and a further loss of about 0.08 dB per km occurs at greater distances. In order to compensate for seasonal variations, an allowance of from 8 to 16 dB should be made for slow fading, and a further allowance of 3 to 8 dB should be made for fast and random fading which is Rayleigh distributed.

Propagation in any of these five tropospheric wave propagation modes would not be sufficiently reliable for NDL purposes.

APPENDIX E

The SECOM II Network

THE SECOM II NETWORK

The Security Communications II (SECOM II) system is a frequency-diversity system providing a high degree of reliability for duplex digital communications. It was designed to provide nationwide communications via a repeater network between a central controller and a fleet of vehicles.[13] Figure E-1 is a schematic diagram of the SECOM II network configurations. The propagation modes have been discussed in Appendix D under ionospheric wave propagation.

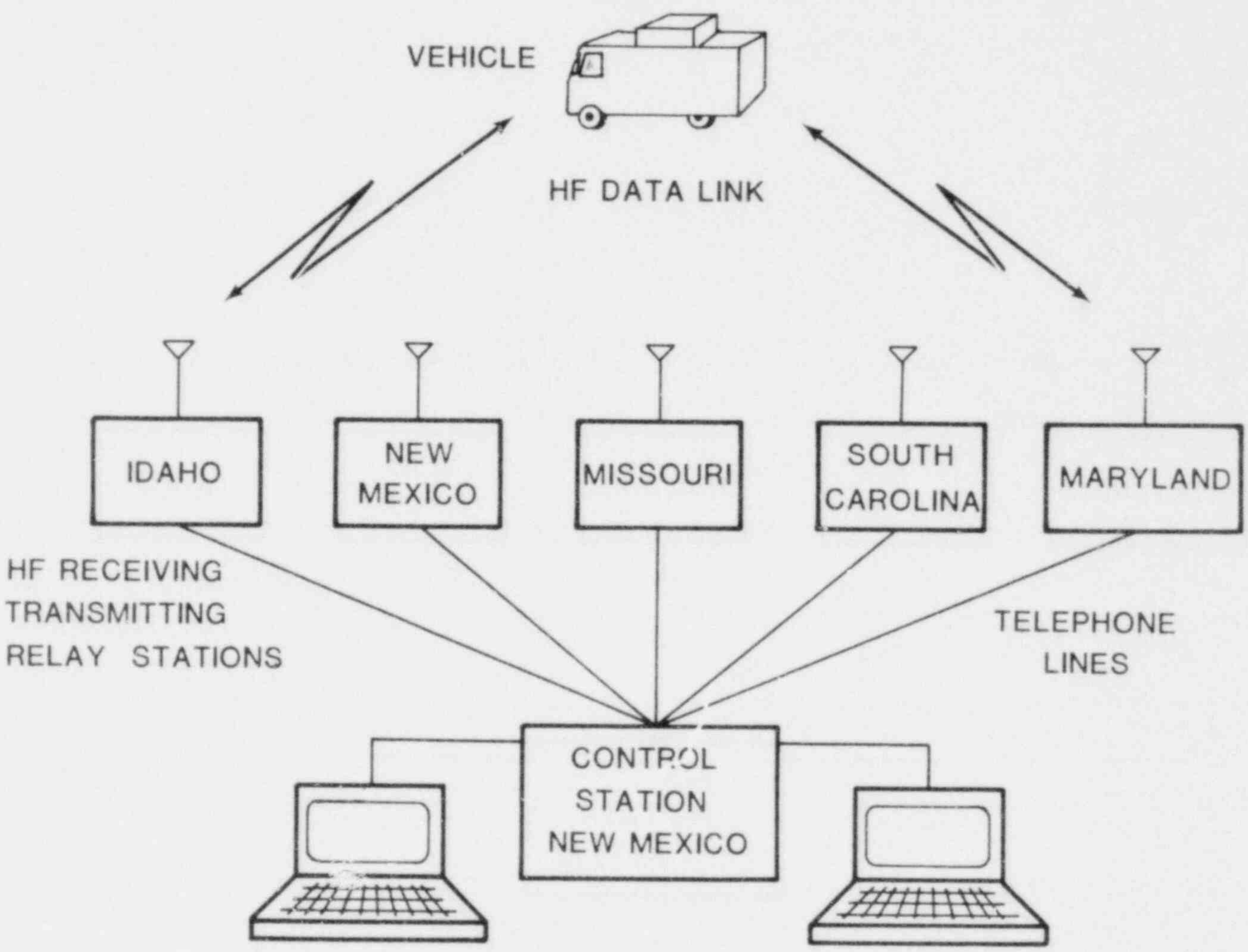


Figure E-1. SECOM II System

Each relay station consists of an equipment building or trailer and four or five antennas oriented for optimum coverage. Attached to each antenna is a fixed-tuned receiver for each of the four frequencies used in the system. Control of the network is exercised from the SECOM Control Center (SCC) in DOE Albuquerque Operations Office Headquarters in Albuquerque.

The SECOM relay stations

- Process bit-by-bit majority logic of all received messages
- Initiate an error-detecting code check of the majority message
- Attach received message count data to the majority message
- Generate a new error-detecting code
- Transmit the message three consecutive times at 1200 b/s over phone lines to SCC.

The SECOM control center

- Receives messages from up to five stations
- Performs majority logic and CRC code checks
- Determines the best station, antenna, and channel for response
- Generates and transmits auto-acknowledge through selected relay stations
- Sends messages to CRT, printer, and disk file.

The diversity technique used in SECOM II is to transmit sequentially, within a short time interval, the same digital data stream at four frequencies in the HF band. A microcomputer at each relay station which receives a transmission is used to determine which message is of highest quality, check for errors, append a figure of merit, and transmit the message to the SCC via dedicated phone line. At the operations center, the "best channel" for response is easily determined by simply observing the number of incoming messages on each channel. In a similar manner, the "best relay station" and the "best antenna" is determined. Then the response is sent via the channel, station and antenna determined to be "best" by evaluation of incoming message counts.

Each SECOM II digital message is 100 bits in length. Of these, 20 bits serve as a preamble and 16 bits provide an error-detecting, cyclic, redundancy code. Each message is transmitted twice on each of the four channels in biphase at 300 b/s utilizing 1300 and 2100 Hz tones. The reliability of the system is guaranteed by redundant transmissions; each message is transmitted eight times. If receipt of the message is not acknowledged over the duplex channel, the message is transmitted another eight times, and so on until five attempts have been made.

It should be noted that the 300 b/s transmission rate used in SECOM II is very close to the maximum transmission rate realizable in an HF relay network. Moreover, because of the high redundancy, the data throughput is very low. Even if reliability were traded off for higher data transmission rates, the capacity of the system would be insufficient for NDL purposes.

APPENDIX F

Computer Communications

COMPUTER COMMUNICATIONS

F.1 COMMUNICATIONS SOFTWARE

The aim of communication is to transfer information from one point to another. In data communications sytems, this information is called data or a message. In order to send data from one point to another, three system components must be present. A source is needed to generate a message and place it on a transmission medium, which carries the message to the third element, which is the receiver. These elements are the minimum requirements for any communication process, and if one of them is absent, communication cannot take place.

These fundamental elements and the interactive processes between them can be present in many different forms depending on the particular communication system. These give each communication system its own characteristics, but there are a number of properties that are common to all modern computer communication systems.

The following sections explain the functions of some of these properties for the benefit of the non-specialist, so that he may become more familiar with the techniques and procedures used to transmit information between computers.

F.1.1 Polling

When many terminals are connected to a computer, a technique called polling can be used to ensure an orderly flow of data to the computer. Polling is the process of inviting a terminal to transmit data. This can be done sequentially, or if one terminal has higher priority, that terminal could be polled more frequently.

When a terminal is polled, it is then allowed to send data if it has any. Each terminal in a polled system has a unique address. A poll transmitted from the computer is seen by all terminals, but only the terminal whose address is in the poll recognizes it; thus if a terminal does not see its own address, it ignores the data. Polling is generally done at a much faster rate than that at which messages or data are generated.

There is a polling delay resulting from the amount of time required to transmit a message, transmission delays, and equipment response times. This delay can be quite significant for large numbers of terminals connected to a network. To accurately determine this delay, the actual time required to poll a terminal should be measured since this time will vary from location to location even if the distances are equal. The delay is estimated in the following example.

For a terminal 750 km (466 miles) from the computer facility, the theoretical propagation delay of light is 3.34 μs/km. In practice, the delay is longer, due to amplifier delays, switching circuits, etc. A realistic estimate is to assume a propagation delay of 10 μs/km. This equals 7.5 ms over the 750-km line.

The modem also introduces a delay called the modem turnaround time. This is equal to the time required for the modem to switch from the receiving to the transmitting mode.

On a multidrop line, line splitters are used to split off local drops from the main line. These introduce about a 2.25-ms delay.

For a line operating at 4800 b/s, the raw data throughput is 600 ASCII characters per second. The modem turnaround time is typically 50 ms. The modems themselves introduce a delay of 10 ms when a signal passes through them.

A polling message consisting of 14 characters would require $14 \div 600 = 23.5$ ms to transmit, and the no-traffic responses (NTR) of typically 5 characters in length would require $5 \div 600 = 8.3$ ms to transmit.

A terminal and computer reaction time of 7 ms yields a total time for an unsuccessful poll of 128.3 ms (see Table F-1). This figure by itself does not seem significant, but if 80 reactor sites are polled sequentially, this becomes 10.3 seconds. This large delay can be reduced if "group polling" is used, where all terminals in a particular cluster are polled at once with a common group address. If more than one terminal responds, however, this could cause a contention problem which must be resolved by the cluster controller.

If a terminal has a message to transmit back, the polling time can increase by a factor of three, as shown in Table F-2. For 100 characters, including control and error-detecting characters, the transmission time would be 100 ÷ 600 = 167 ms. Message acknowledgements and other delays can increase the overall transmission time approximately 360.5 ms. While these calculations are only approximations, they illustrate that significant delays can be produced using polling techniques over long distances when large numbers of terminals are involved.

Table F-1

Calculation of Time Required for an Unsuccessful Poll

Poll transmission time		23.5 ms
Propagation delay	Transmission Delays	7.5 ms
Modem delay		10 ms
Line splitter delay		2.25 ms
Terminal reaction time		2 ms
Modem turnaround time		50 ms
NTR transmission time		8.3 ms
Transmission delays		19.75 ms
Computer reaction time		5.0 ms
Total		128.3 ms

Table F-2

Calculation of Time to Receive an Input Message

Poll transmission time	23.5 ms
Transmission delays	19.75 ms
Terminal reaction time	2 ms
Modem turnaround time	50 ms
Message transmission time (100 characters)	167 ms
Transmission delays	19.75 ms
Computer reaction time	5 ms
ACK transmission time	17 ms
Transmission delays	19.75 ms
Terminal reaction time	2 ms
EOT transmission time	10 ms
Transmission delays	19.75 ms
Computer reaction time	5 ms
Total	360.5 ms

F.1.2 Message/Data Buffering and Queueing

F.1.2.1 Buffering

When messages and data flow through a network they must be stored at the transmitting end until acknowledgment (ACK) of the message received correctly is received by the transmitter. This is true whether packet-switching or store-and-forward technology is used. When the message is acknowledged as being correctly received, it is deleted from system storage. If the message is not acknowledged, the message is retransmitted and not deleted until acknowledged.

This buffering of messages until ACK must be accomplished at some point within the communication subsystem. To burden the site computer with this function is unreasonable because it requires that the site data acquisition system use a higher-level protocol which is difficult to implement and impossible to verify completely. This function is best accomplished by a computer under network control, namely the STU (discussed in detail in Section 3.2 and Section F.3.1 of this appendix). Without the STU, the network will not be able to buffer messages, determine the completion of message transaction, nor control the flow of data from the remote site to the central facility.

F.1.2.2 Queueing

A queue is a store or buffer for messages or packets arranged in sequence; the two ends are known as the head and tail. New messages or packets are added to the tail and removed at the head. This is the "first in-first out" method. A queue can be stored as a list or in a circular buffer.

Queues are used in a computer network to (1) hold transmitted data at a node until the correct receipt of the data at an adjacent node is acknowledged, and (2) hold data until a link is available to transmit the data to an adjacent node.

There is usually a queue for each outgoing link; these queues are generally short in length, but a mechanism must be set up for handling queues of any length.

There are several methods for organizing a queue, two of which are the "free list" and "circular buffer." The storage region used for packets is divided up, usually into equal-sized areas ready for allocation.

With the free list concept, each packet storage area has space for the packet and for a store heading, which contains additional data needed in handling the packet. The concept is illustrated in Figure F-1.

When packet stores are not in use, they are held in a "pool" ready for allocation. This is organized in the structure shown in the figure, which is a list of free spaces called the "free list." A fixed location contains the starting address, S, and at address S the first packet store begins. In the first word, the address of the next

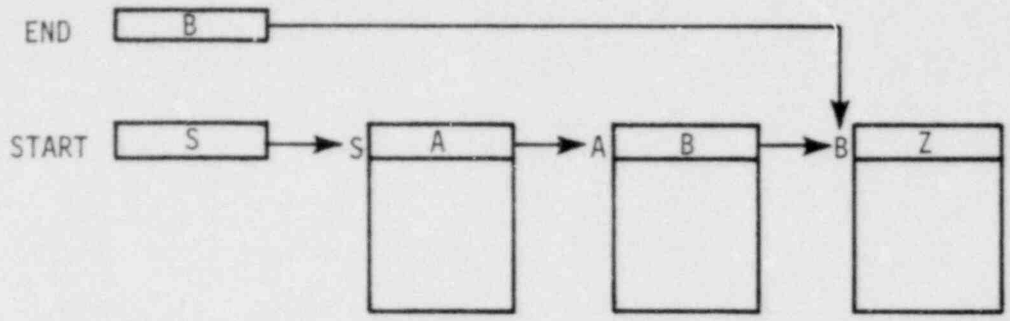


Figure F-1. List of Free Packet Stores

packet store is held, and so on. Thus, each envelope contains in its first word a "pointer" to the next envelope in the list. The final packet store, B, contains a special heading indicating that it is the last packet store. There can also be provided an "end" pointer giving the address, B, of the last envelope, though this feature is not always needed.

Figure F-1 is misleading because it gives the impression that the members of the list are linked together in the sequence that they occupy in the store. Even if this were true at the start, after many envelopes have been allocated for use by packets and returned to the list, their linkage connections would go quite randomly over all packet stores. The normal condition has free envelopes linked in an arbitrary sequence.

The queue for output packets on a network link must hold transmitted packets until their receipt has been acknowledged by the receiving end. To deal with this, three pointers to the queue can be held: one for the tail at which queue pointers are attached, one for the point at which output occurs, and one for the true head of the queue where the packet will be discarded.

One method for accomplishing this is by using a "circular buffer," illustrated in Figure F-2.

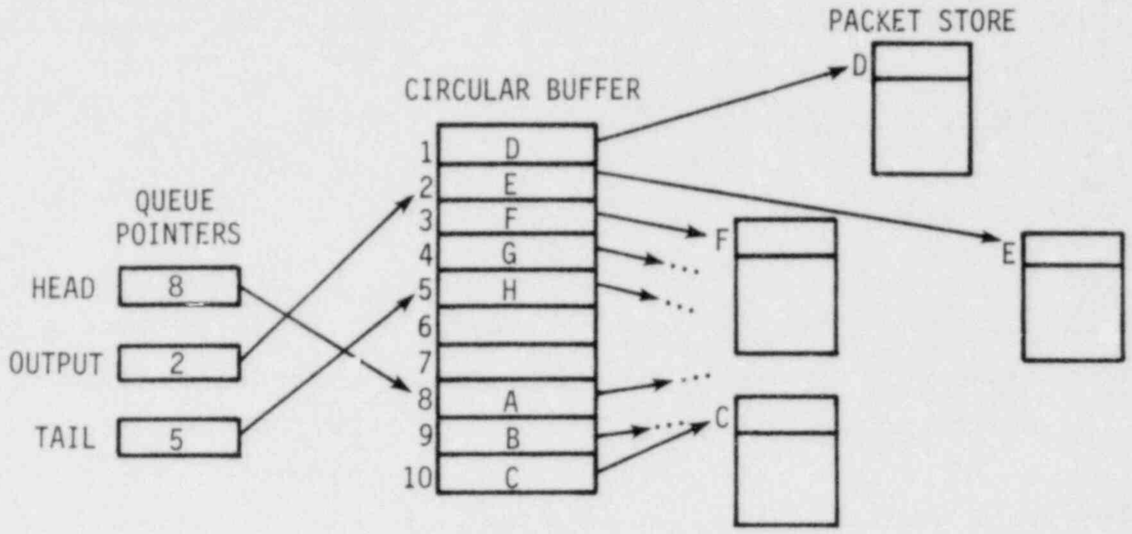


Figure F-2. Output Queue Employing a Circular Buffer

The packets in the queue in the figure are labeled A, B, C,... H and are referenced by the words held in the circular buffer. The head, output, and tail positions of the queue are indicated by three pointers to certain items in the buffer.

To add a new packet to the queue, the tail pointer is incremented by one, and the new value, 6, indicates the word of the circular buffer in which the pointer to the packet must be put. To discard a packet, the head pointer is referred to. In Figure F-2, it points to word 8 which contains A. The store envelope at A is returned to the free list, after which the head pointer is incremented by one. These operations are simpler than processing the queue as a list. The size of the queue is easily calculated from the queue pointers. The buffer is referred to as "circular" because word 1 is regarded as following after the last word 10. Incrementing a value by 10 in any of the queue pointers produces the value 1. A queue organized by a circular buffer has a finite size, which can be a difficulty or an advantage. Little space is wasted because the packet store uses only the space necessary for the actual size of the queue. The available packet stores are dynamically allocated to the various queues being used.

These two forms of queue illustrate that a data structure and its representation in a computer store are two different things. The software design must use a representation that is not only correct in its structure but also efficient to use.

F.1.3 Restart/Recovery

The communication protocol must be able to recover from a system failure. If a computer or part of the network fails, there must be a reliable method of getting back into normal operations afterwards. When the failed portion recovers, a command is required to indicate that outstanding data or messages have been corrupted and should be abandoned. A reply to this command is required to indicate that it has been received, that all calls have been disconnected, and that the other network control programs are again ready to cooperate with the recovery portion of the network.

An alternative restart method can be adopted if the network contains an acceptably coherent clock. Each process can have a time-out covering a reasonable delay in the response to any of its messages. If this delay is exceeded, the associated network control program assumes that the remote network-control program has gone out of action and sends an interrogation signal to the remote program at regular intervals. Only when one of these interrogations is answered does the central control program assume that the other network control program has recovered.

These features must be tested in new protocol implementations because a new protocol usually exhibits some problems when it is put into real operation.

F.1.4 Statistics Gathering

Utility programs should be included in the network to aid in monitoring system activity and to maintain network integrity. These programs can be written by the user or supplied by a vendor as an integrated package along with other data communication software. Some of the functions to be performed are

- Network status, including connected nodes and their current state
- Remote diagnostic tests
- The number of blocks received in error
- The number of node initializations
- The number of retransmission errors
- Timeout occurrences
- Missed message acknowledgments
- File transfer aborts
- File routing information
- The occurrence of requeueing events
- Down-line system loading to remote nodes
- Total system traffic count.

Statistics on network performance are useful for network diagnostics and maintenance as well as for determining trends in traffic load patterns.

F.1.5 ASCII Code for NDL Data

Data transmitted between the data acquisition system and the STU will be represented in American Standard Code for Information Interchange (ASCII) or a subset of the code, because ASCII is currently the most widely used code for representing data between different computers and terminals. The data being transmitted will be converted to engineering units with an associated identification label and time tag.

The ASCII code consists of eight bits: seven bits for information and one bit for parity checking (see Figure F-3).

The 7 information bits can be arranged in 128 combinations. This allows a full upper- and lower-case alphanumeric character set with additional graphic and control characters. When writing ASCII combinations in binary, it is conventional to number the bits from one through seven and to place the least significant bit on the right.

Bits b_7	b_6	b_5				0	0	0	0	1	1	1	1
						0	0	1	1	0	0	1	1
						0	1	0	1	0	1	0	1
b_4	b_3	b_2	b_1	Row	Column	0	1	2	3	4	5	6	7
0	0	0	0	0		NUL	(TC_7)DLE	SP	0	@	P	`	p
0	0	0	1	1		(TC_1)SOH	DC_1	!	1	A	Q	a	q
0	0	1	0	2		(TC_2)STX	DC_2	"	2	B	R	b	r
0	0	1	1	3		(TC_3)ETX	DC_3	#	3	C	S	c	s
0	1	0	0	4		(TC_4)EOT	DC_4	$	4	D	T	d	t
0	1	0	1	5		(TC_5)ENQ	(TC_8)NAK	%	5	E	U	e	u
0	1	1	0	6		(TC_6)ACK	(TC_9)SYN	&	6	F	V	f	v
0	1	1	1	7		BEL	(TC_{10})ETB	'	7	G	W	g	w
1	0	0	0	8		FE_0(BS)	CAN	(	8	H	X	h	x
1	0	0	1	9		FE_1(HT)	EM	)	9	I	Y	i	y
1	0	1	0	10		FE_2(LF)	SUB	*	:	J	Z	j	z
1	0	1	1	11		FE_3(VT)	ESC	+	;	K	[	k	{
1	1	0	0	12		FE_4(FF)	IS_4(FS)	,	<	L	\	l	¦
1	1	0	1	13		FE_5(CR)	IS_3(GS)	–	=	M	]	m	}
1	1	1	0	14		SO	IS_2(RS)	.	>	N	^	n	~
1	1	1	1	15		SI	IS_1(GS)	/	?	O	_	o	DEL

Figure F-3. The ASCII Code

Figure F-3 illustrates that the two large center columns contain control characters. These can be used to control

- Transmission of data
- Data format
- The logical relationship of data
- Physical functions in terminals.

These control functions apply to display and formatting of data on a terminal. They may be used to turn a recorder on and off, for example, or to cause the contents of a screen to be printed on an auxiliary printer. Also, they can be used as information separators to make records easier to handle by a computer.

The use of any of these features is entirely optional. Note that these control characters control terminal and data functions only, not communication functions. The control features can be used between the site computer and the STU, which is a local short distance link. However, from the STU to the operation center, a higher-level communications protocol must be used for data flow and error control. The ASCII control characters do not supply these features.

The parity bit can be used for error detection between the site computer and the STU to detect single bit errors, as shown in Figure F-4. This method is not acceptable on a long-distance communication line for two reasons. First, the parity bit imposes a 12.5% communication overhead on the data (one out of eight bits) which is substantial and unnecessary when more advanced error detection techniques are used (Section F.3.4). Secondly, the parity bit will not detect two dropped bits since the parity would remain the same for two dropped bits. On a noisy leased line, errors tend to occur in bursts of noise, and usually two or more bits are affected. A cyclic redundancy check (CRC) error detection method is more effective for this type of error and is discussed in Section F.3.4.

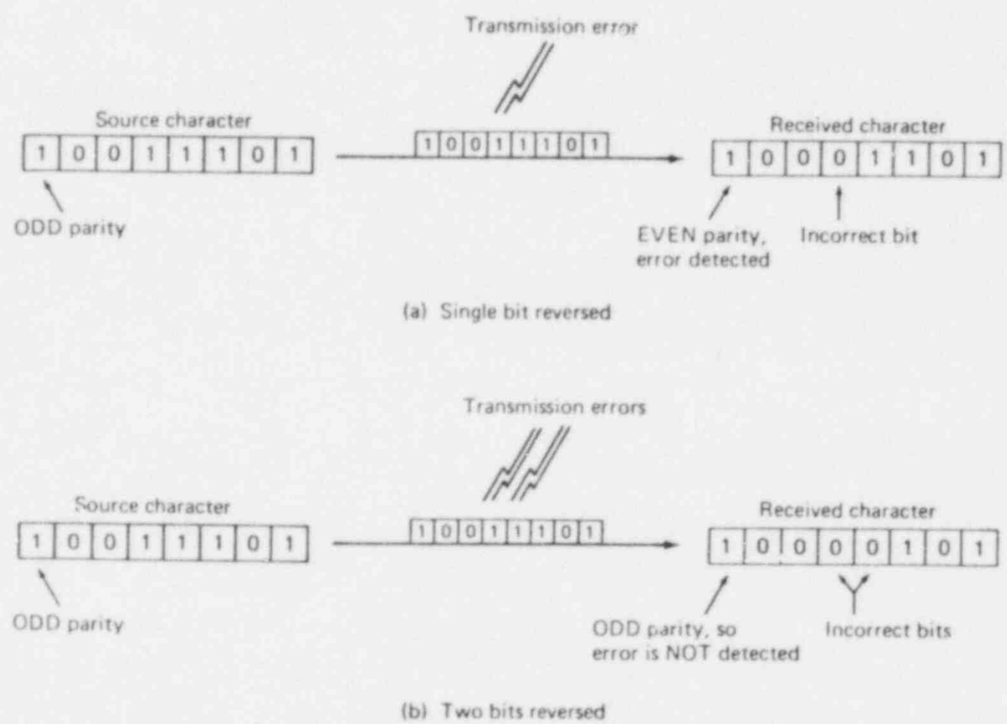


Figure F-4. Bit Error Detection Using the Parity Bit:
(a) Error Detected,
(b) Error Not Detected

Some terminals and computers use a 96-character subset of ASCII, which means they do not handle the lower-case characters. In these cases, if a code combination corresponding to one of the lower-case characters is transmitted, it may (but not necessarily) be interpreted as its upper-case counterpart.

F.1.6 Network Access Program

A network access program to communicate with the STU and the NDL network must be developed as part of the NDL communication package. The program will provide the terminal handshake requirements, network access control, and diagnostic capability between the STU and the licensee data acquisition system.

The program will be installed in the licensee data acquisition system separately from the data acquisition and formatting software routines. As part of the communication package, it must be developed and controlled by the system developer specifically for the NDL needs.

The program will be developed in a structured, self-documenting manner using a high-level language, such as FORTRAN, commonly available on all computers. Merely writing a specification for this task is not sufficient to assure a workable system. A real, workable program must be developed and proven operational for the system during the prototype development phase. The program will be supplied to the licensee for direct application within his data aquisition system or may be modified or rewritten to suit his individual requirements using the furnished, workable program as a specification and model.

The licensee cannot be expected to develop this program on his own because to do so would result in many different versions throughout the NDL that consequently would require a very difficult and costly verification process during the installation of the NDL system. Providing a proven program to the licensee will result in a more reliable and less costly system implementation.

F.2. INTERFACE STANDARDS

F.2.1 Network Interface Specifications

A standard network interface must be used throughout the NDL to provide for ease and uniformity of system implementation. The physical link interface will be the RS232C/RS449 specification* because it is currently the most widely adapted standard today and is supported by virtually every manufacture of computer equipment. The new RS449 specification will eventually replace the RS232C, but equipment using RS232C will not become obsolete because it is a subset of RS449. RS449 will support a higher data rate of up to 2 Mb/s and increased interface cable distances from 60 to 1200 metres (200 to 4000 feet) (versus the 20,000 b/s and 15 metre (50 feet) limit of RS232C). Detailed information on these recommeded standards can be obtained from the Electronic Industries Association, 2001 Eye St. NW, Washington, D.C. 20006.

The Electronic Industries Association (EIA) has developed its recommended standards in close coordination and cooperation with the international standards activities of the International Telephone and Telegraph Consultative Committee (CCITT) and the International Standardization Organization (ISO), and thus the EIA's recommendations are compatible with CCITT's. The CCITT work applicable to data communications is published as the V-series and X-series standards.

The V-series is related to data transmission over the telephone network; many standards in the series deal with modems. The best known is V.24 (RS449/RS232C), which lists the interchange circuits between a modem and its data terminal equipment.

The X-series relates to public data networks. Examples are X.20 for start/stop (asynchronous) terminals, X.21 for synchronous terminals, and X.25 for packet-mode terminals.

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*RS stands for recommended standard.

Table F-3 summarizes standards counterparts, and Table F-4 summarizes X-series recommendations.

Table F-3

Standards Correlation

EIA	CCITT Recommendations (electrical/functional)
RS423A	V.10(X.26)
RS422A	V.11(X.27)
RS449	V.24/V.10/V.11
RS232C	V.24/V.28

Table F-4

X-Series Recommendations

Number	Title
X.3	Packet assembly/disassembly facility (PAD) in a public data network
X.20	Interface between data terminal equipment (DTE) and data circuit-terminating equipment (DCE) for start/stop transmission services on public data networks
X.21	General purpose interface between DTE and DCE for synchronous operation on public data networks
X.24	List of definitions of interchange circuits between DTE and DCE on public data networks
X.25	Interface between DTE and DCE for terminals operating in the packet mode on public networks
X.26 (V.10/RS423)	Electrical characterization for unbalanced double current interchange circuits for general use with integrated circuits equipment in the field of data communication
X.27 (V.11/RS422)	Electrical characterization for balanced double-current interchange circuits for general use with integrated circuit equipment in the field of data communications
X.28	DTE/DCE interface for a start-stop mode DTE accessing the PAD on a public data network situated in the same country
X.29	Procedures for exchange of control information of user data between a packet mode DTE and a PAD

The RS449 serves as the basic interface document, referring to the electrical characteristic of RS422A and RS423A. The RS422A specifies electrically balanced receivers and generators that tolerate more and produce less noise to provide increased performance up to 10 Mb/s and to meet more demanding requirements in the future. RS423A (X.26) stipulates unbalanced operation with a transmission capability up t 100 kb/s. The inherent flexibility designed into RS423 (X.26) facilitates the orderly transition from RS232C (V.28) to the future use of RS422 (X.27).

F.2.2 Asynchronous and Synchronous Transmission

There are two primary modes of communication: asynchronous and synchronous transmission. In asynchronous transmission, the time interval between transmitted characters may be of unequal length. Transmission is controlled by start and stop bits at the beginning and end of each character. The transmitter always reverts to a mark condition (logical 1) for at least one interval at the end of each byte (8 bits) and always goes to a space condition (logical 0) for one interval before starting to send the next byte. This enables the receiver to synchronize with the transmitter at the beginning of each byte and start its sampling at the correct instant.

Synchronous transmission sends data characters and bits at a fixed rate, with the transmitter and receiver synchronized by a common clock, thus eliminating the overhead associated with start/stop bits. Synchronous transmission usually involves block message formats. Byte synchronization is achieved by preceding the data stream with two or more SYNC bytes having a predetermined bit pattern which the receiving terminal can recognize and use to identify the start of the first data byte.

Asynchronous serial data transmission has the following advantages:

- It can be generated easily by electromechanical equipment such as a teletype keyboard.
- It can easily be used to drive mechanical equipment such as a teletype printer.

- Characters can be sent randomly because each character has its own synchronizing information.
- Asynchronous interface cards for minicomputers are inexpensive relative to synchronous interface cards.

The disadvantages are

- Separate timing is required for both transmitter and receiver.
- The method is distortion-sensitive because the receiver depends upon incoming signal sequences to become synchronized. Any distortion in the sequences will affect the reliability with which the character is assembled.
- Speed is limited because a reasonable amount of margin must be built in to accommodate distortion.
- It is not efficient because at least 10 bit times are required to send 8 data bits.

The advantages of synchronous serial data transmission are

- A common timing source can be used for both transmitter and receiver.
- The receiver does not require the clock-synchronizing logic as the asynchronous technique does.
- It is more efficient because there are no bit times wasted with the use of start/stop bits. All bits on the line are data, with the exception of the synchronizing pattern at the beginning of the bit stream.
- The method has low distortion sensitivity because the timing is provided along with the data.
- Higher speeds are achievable because of the low distortion sensitivity.

The disadvantages are

- Characters must be sent synchronously, not asynchronously, as they become available (which is desirable for most real-time and mechanical applications).
- One bit time added to or missing from the data bit stream can cause the entire message to be faulty.
- The equipment to accommodate this mode of operation is more expensive than the equipment required for asychronous modes of operation.
- Synchronous interface cards for minicomputers are expensive relative to asynchronous interface cards.
- Mechanical equipment cannot transmit or receive this format directly.

F.2.3 Bits versus Bauds

Baud is defined as a unit of signaling speed as measured by the number of signal events per second. The bits per second (bps or b/s) unit measures the number of information bits transmitted in 1 second. Since a signal event can represent more than one bit, baud rate does not equal b/s, except in the case where one signal event represents one bit and all signal pulses are information pulses.

When information is transmitted down a telephone line, the data is modulated onto a sine-wave-like carrier. The limit to the frequency of a sine wave that can be successfully transmitted is approximately 3000 Hz, as discussed in Section 2.3.1. Early modems modulated one bit per cycle of the fundamental carrier frequency. Thus a 1200 b/s modem used a 1200 Hz carrier. As better modulation techniques were developed, it became possible to modulate more than one bit per cycle of the carrier. Thus 2400 b/s modems use a 1200 Hz carrier by modulating 2 bits per cycle of the carrier, 4800 b/s modems modulate 3 bits per cycle on a 1600 Hz carrier, and 9600 b/s modems use a 2400 Hz carrier with 4 bits per cycle.

The baud rate refers to the carrier frequency. Thus, the previously mentioned 9600 b/s modem really uses a 2400 baud carrier. However, computer and manufacturer literature sometimes describes the modem as a 9600 baud modem. As a simple analogy, bauds are containers traveling along a communication channel, and they may or may not carry bits of information. The term b/s is more meaningful and thus is used exclusively in this report.

F.3. COMMUNICATION PROTOCOLS

F.3.1 Introduction

The word protocol is used to describe the orderly exchange of information between computing equipment. A protocol is necessary for communications between two computing elements over a communications path. The three fundamental reasons why a protocol is necessary are

1. To establish a standard data element
2. To establish necessary conventions
3. To establish a standard communications path.

The standard data element that a protocol establishes creates a virtual data element, such as a stream of characters, messages, records, or files, to exchange between nodes. It is essential to have conventions between two communications nodes. The conventions to be considered include the nature of the data representation itself, the format and speed of the data representation over the communication path, and any sequence of control messages that are sent. The protocol conventions range from character definitions to the definition of control messages for starting and stopping traffic.

The establishment of a standard communication path by a protocol is necessary to create a virtual communications medium with certain desirable characteristics. For example, the addressing structure over the communications path may allow communication with one entity or with several others. Communication may proceed at one level of priority or at several, and messages may either be sequenced or not. Errors occurring in the data stream may be detected, and the control of traffic flow may be simple or complex. The conventions for initiating and terminating communications may also vary.

Most computer manufacturers have their own set of network protocols incorporated into some form of network architecture. One of the aims of these network architectures is to give users the tools for setting up a network and for performing flow control, error control, and other related functions without involving the applications programs.

The use of a standard protocol provides a flexibility that can drastically reduce system development time and maintenance efforts and allows adaptation and evolution as requirements change. The only way to ensure that the protocol in use is indeed standard and uniformly implemented throughout the computer network is to have the protocol under the control of the network. If this is not done, the network won't work.

The purpose of the STU is to establish the standard, uniformly implemented communication protocol throughout the entire NDL. This microprocessor-based device is absolutely necessary in that it provides a standard interface for communication between dissimilar site computers and the NDL as well as providing for uniform protocol implementation. (Section 3.2 discusses the type of equipment necessary to perform the STU functions.)

There are many protocols in use today, each having advantages and disadvantages. The decision of which one to use for the NDL cannot be made until the merits of each one are evaluated based on the system requirements for the NDL. The following section, however, does compare three basic types of protocols and clarifies those characteristics that need to be evaluated before a protocol selection is made.

F.3.2 Basic Protocol Comparisons

To understand how protocols differ and to make judgments about the advantages of each requires a basic understanding of the function that protocols perform. The functions that protocols perform include

- Controlling data transfers (formatting, control information, and handshaking procedures)
- Error checking and recovery (refer to Section F.3.4)
- Information transparency (binary, ASCII)
- Line utilization (protocol overhead, acknowledgments)
- Synchronization (sender/receiver)
- Communications facility transparency (serial async/sync, parallel)
- Bootstrapping (remote software loading).

One of the older protocols in the industry is IBM's Binary Synchronous Communication protocol (BSC or BISYNC). This protocol uses an optional header which, if used, starts with Start of Header and ends with Start of Text. The contents of the header is defined by the user. The text portion of the field is variable in length and may contain transparent data. BISYNC employs a rigorous set of rules for establishing, maintaining, and terminating a communications sequence.

To detect and correct transmission errors, BISYNC uses either vertical, longitudinal, or cyclic redundancy checking (VRC, LRC, or CRC; see Section F.3.4) depending upon the information code. If the code is ASCII, a VRC is performed on each character and an LRC on the whole message. If the code is EBCDIC, a CRC is performed. BISYNC calls for the retransmission of the block when an error occurs and will retry several times before it assumes the line is in an unrecoverable state.

BISYNC supports several information codes, reserving certain bit patterns in each set for control characters. In the transparent data mode, BISYNC uses "character stuffing" to distinguish the data from a control character (ASCII control character DLE). If a DLE bit pattern is sent as data, BISYNC stuffs an extra DLE pattern in the data stream to distinguish it from the DLE control character. The extra DLE is removed by the receiver.

BISYNC transmission is half duplex. The line must be turned around twice between each data block. BISYNC was designed for serial synchronous lines, but because it is a character-oriented protocol, it can be implemented on asynchronous and parallel channels. IBM, however, does not offer BISYNC for these facilities. BISYNC does not include bootstrapping as part of its line control procedure.

Digital Equipment Corporation's link protocol, Digital Data Communications Message Protocol (DDCMP), is designed to operate over synchronous or asynchronous channels, full or half duplex, over dial-up or leased lines, as well as over serial or parallel transmission facilities. DDCMP is in the public domain and can be implemented on many operating systems.

The only control character used is the first character in the message; the remainder of the message is transparent. The control character is used to distinguish between data, control, and bootstrap messages. The header contains 8 bytes, followed by the message field of variable length -- up to 16,383 bytes.

DDCMP uses CRC-16 for detecting transmission errors. The response field of the header specifies the number of the last good message received. Hence when operating in the full-duplex mode, the line does not have to be turned around for acknowledgment, and a sequence of correctly received messages can be acknowledged by only one ACK message (up to 255 messages in one acknowledgment). DDCMP achieves transparency by using a count field in the header.

DDCMP has a bootstrap message as part of the protocol. It begins with the control character DLE. The information field contains the load programs and is totally transparent.

IBM's Synchronous Data Link Control (SDLC) was announced in 1973. Unlike BISYNC and DDCMP, it is bit-oriented rather than character-oriented. It is designed for synchronous operations, both full and half duplex. The only control character has the bit pattern 01111110. There is a fixed length 24-bit header, a variable length information field, and a fixed length 24-bit trailer.

Like DDCMP, SDLC uses an efficient procedure for data exchange. SDLC uses CRC-CCITT to detect transmission errors. It handles CRC with an inversion technique that differs from methods used by character-oriented protocols, thus slightly improving the range of detected errors in the domain of possibilities.

SDLC is a bit-oriented protocol and only has to be sure that a flag-character bit pattern anywhere between frames does not arrive at the receiver.

SDLC achieves transparency with "bit stuffing." If the flag sequence 01111110 appears anywhere in the message, a zero bit is inserted whenever five "1" bits appear in a row. Thus, a 01111110 bit pattern that is meant to be data would appear in the data stream as 011111010), or as 9 bits. The receiver also counts bits, and if it detects five 1's in a row followed by a zero bit, it removes the zero bit. If the sixth bit is 1, it is a legitimate flag, and the end of the message has been received.

Because of the bit-stuffing requirement of SDLC, it cannot be used for serial asynchronous or parallel facilities. Asynchronous characters are fixed length, and bit stuffing would destroy them. On parallel connections, a separate wire would be needed for the stuff bit. SDLC is designed for efficient use of high-speed, serial, synchronous, full-duplex facilities.

SDLC does not provide for bootstrapping as part of its protocol.

The X.25 standard consists of three distinct protocol levels:

1. The physical/electrical level (RS232)
2. The link control level (HDLC)
3. The packet level.

All three levels of the interface are independent of each other, and the first two of these could be replaced by any other protocol that performs the same function. The third level is the one that actually gives the X.25 interface its identity, and replacing it will result in a different interface.

The first level of the interface incorporates X.21-V.24/RS232 (see Section F.2.1) for connection to the telephone network using modems. It specifies the electrical and procedural characteristics for the operation of the data transmission circuit.

The second level of the interface is an HDLC link level procedure to ensure the correct exchange of data between terminals and data networks (i.e., error control). An HDLC data frame carries a single packet across the X.25 interface.

The third level is the packet level, which gives X.25 its character of a virtual circuit interface to a packet-switched network. It provides the ability to establish calls using virtual circuits and to send and receive data. A window mechanism associated with each virtual circuit performs flow control. Reset and restart facilities allow recovery from errors at the interface. Calls can be closed down and virtual circuits freed so that they can be used for other calls.

A number of national and international standards organizations has been cooperating over the past years to produce standard data-communication protocols. These organizations include the American National Standards Institute (ANSI) and the ISO. The cooperative efforts of these organizations have resulted in the development of a variety of standard data-communication control procedures and codes. Two of these protocols are the Advanced Data Communication Control Procedures (ADCCP) developed by ANSI and the High-Level Data Link Control (HDLC) developed by ISO. These protocols differ slightly from SDLC.

Relevant characteristics of the five protocols discussed are summarized in Table F-5.

F.3.3 Flow Control

Flow Control means the control of data flow within the network to prevent overspill of queues or buffers or loss of data because the intended receiver is unable to accept it. A link protocol usually attempts to deliver data as fast as it can, but there may be some restriction imposed by the rate at which the receiving device can accept data. A terminal may be double buffered so that it can be receiving one block of data while it is printing another block. If the communication line can deliver data faster than the terminal can print it, the system could become flooded unless some control is built in. Also, part of the network could become "congested," i.e. the queues into which packets should be accepted are always full, and it becomes impossible for packets to move. An extreme form of congestion is

Table F-5

Communication Protocols

Feature	Protocol				
	DDCMP	BISYNC	SDLC	ADCCP	HDLC (X.25)
Full Duplex	yes	no	yes	yes	yes
Half Duplex	yes	yes	yes	yes	yes
Serial	yes	yes	yes	yes	yes
Parallel	yes	no	no	no	no
Data Transparency	count	char. stuff	bit stuff	bit stuff	bit stuff
Asynchronous	yes	no	no	no	no
Synchronous	yes	yes	yes	yes	yes
Point-to-Point	yes	yes	yes	yes	yes
Multipoint	yes	yes	yes	yes	yes
Error Detection (CRC)	CRC-16	CRC-16	CRC-CCITT	CRC-CCITT	CRC-CCITT
Retransmit Error Recovery	yes	yes	yes	yes	yes
Bootstrapping Capability	yes	no	no	no	no

"lock-up," a situation in which certain flows have stopped indefinitely, possibly because of a logical error in protocol or network design.

An important feature of a link protocol is to maintain proper flow control; that is, a link protocol regulates flows during normal operation and is principally a method for transmitting flow restrictions back to the place where the flows can be controlled.

Avoiding congestion prevents network overloading from spreading and causing more loss of performance than is really necessary. Flow control and congestion avoidance are related because the policies needed for congestion avoidance are enforced by the flow-control mechanism.

A simple terminal-to-terminal character interchange procedure does not provide the mechanisms necessary for network flow control. A link protocol is necessary to provide this feature.

F.3.4 Error Control

In a modern computer network, error control is handled by the network. An important function of a line protocol is to assure the correct reception of data. Therefore, the network must have end-to-end control of the protocol.

Communication facilities are subject to errors due to noisy lines and switching facilities, among other things. To compensate for this, line control procedures include the generation, transmission, and testing of check bits. These check bits, called block check characters (BCC), make up the trailer field of the transmission block. They are generated by a checking algorithm which is usually applied only to the information field of a block.

As mentioned in Section F.1.5, the parity bit method of error detection is unacceptable for a communication link because of the 12.5% overhead that it imposes and because of its inability to detect even numbers of errors. The transmission errors on a communciation line usually occur in bursts where two or more bits are affected as a group. There are error detection schemes that can detect burst-type errors.

When an error is detected, the affected block is retransmitted. Retransmission is the only practical method of error correction on terrestrial links because forward error correction in the true sense requires a very large communication overhead. Satellite links that use forward error correction have an overhead of 60% or more. However, they have a very large bandwidth and hence can afford the overhead penalty. Because of the distances involved, satellites experience significant delays in transmitting data, so the overhead penalties associated with forward error transmission are justified.

Each block of data transmitted is error-checked at the receiving station in one of several ways: with vertical redundancy checking (VRC), which is parity checking by character as the data is received; and either longitudinal redundancy checking (LRC) or cyclic redundancy checking (CRC), which check the entire block after it is received. After each transmission, the receiving station either acknowledges correct reception of the block and requests the next block, or does not acknowledge, in which case the previous block is retransmitted. Until the block is accepted, the data buffer cannot be released by the transmitting system.

VRC is an odd-or-even parity check performed on a per-character basis, and it requires a parity-check bit position in each character. For an eight-level code (such as ASCII), seven bits represent data, and the eighth bit is reserved for checking purposes (hence the 12.5% overhead). The presence or absence of the eighth bit provides the inherent checking feature. For example, in an even parity check, the parity bit is used to make the total number of "1" bits in the character even. Parity (VRC) can only detect an odd number of errors.

LRC is a technique for checking an entire block of data. An exclusive "OR" logic is used for the the bits in the message, and the resulting character (BCC) is transmitted as the last character in the block. The receiving device independently performs the same counting procedure and generates a BCC. It then compares its own BCC with the one received. If they are not identical, an error condition exists, and the sending device is notified of the error. LRC is frequently used in conjunction with VRC to increase the error detection capability within a system.

CRC is a more sophisticated method of block checking than LRC. This type of error checking involves a polynomial division of the data stream by a CRC polynomial. The 1's and 0's of the data become the coefficients of the dividend polynomial, while the CRC polynomial is preset. The division uses subtraction modulo 2 (no carries), and the remainder serves as the CRC. The CRC (16 bits in length) is transmitted as the last 2 characters in the block; thus for large data blocks, the CRC overhead is very low. As with the LRC, the receiving station compares the transmitted remainder with its own computed remainder, and an equal condition indicates that no error has occurred.

There are many constants that may be used to perform the CRC division. Two versions are

- CRC-16, which uses a polynomial of the form $X^{16} + X^{15} + X^2 + 1$, meaning the following bit pattern: 11000000000000101. Note: The polynomial is a summation of decreasing powers of some dummy variable (by convention this variable is represented as X). This scheme allows mathematical treatment of the transmitted data. For example, the bit string 10011001 can be expressed as:

$$D(X) = (1)x^7 + (0)x^6 + (0)x^5 + (1)x^4 + (1)x^3 + (0)x^2 + (0)x^1 + (1)x^0$$

which reduces to:

$$D(X) = x^7 + x^4 + x^3 + 1$$

- CRC-CCITT, which uses a polynomial of the form $x^{16} + x^{12} + x^5 + 1$. Each CRC type generates a 16-bit BCC.

The CRC can detect:

- All odd numbers of errors (as can parity)
- Single-burst errors
- All errors which change two bits
- All occurrences of double-error bursts of two bits or less.

The CRC cannot detect the error pattern corresponding to the bit pattern of the generating polynomial. (The odds against this occurring are very high.)

F.3.5 Data Encryption

Although data encryption ensures nearly inviolate message privacy, the proposed transmission concepts are sufficiently sophisticated in themselves to discourage even the most dedicated interceptor. For example, it is possible that a microwave signal could be illictly received or altered by someone, but this would be prohibitively expensive and difficult for the following reasons:

1. The intercepting party would need to know the exact facility route information across the continent. This is extremely difficult because facilities can be cable and/or microwave, and routing is changed from time to time.

2. The exact frequency that the route is using in each facility span would have to be determined because the analog facilities are multiplexed many times into different frequency layers.

3. Expensive radio equipment is needed to demultiplex the signals after interception and to block the signal transmission.

4. A computer would be needed to interpret the data message, change the message content, restructure the protocol, and reconstruct the error check message.

5. The altered signal would have to be remultiplexed to the proper high frequency slot and inserted into the line-of-sight radio route without interrupting synchronization on the data stream. Any interruption would signal an erroneous message to the receiving computer.

The computer required for interception would have to be large and very costly, and the monitoring time involved to provide the necessary message patterns preparatory to service interruption would be extensive.

Therefore, data transmitted over any of the carriers of interest should be sufficiently coded for NDL data that encryption would not be necessary.

F.4 BELL MODEMS AND MODULATION TECHNIQUES

Table F-6 summarizes the leased line modems available from AT&T, along with their approximate monthly cost. Two basic types of modulation techniques are

1. FSK -- Frequency shift keying uses different frequencies at the transmit and receive ends to distinguish between the

Table F-6

Selected Properties of Bell System Voice-Grade Modems

Bell Designation	Line Facility	Approx. Monthly Cost ($)	Operating Mode	Synchronization	Modulation	Data Rate (b/s)	Comments
103, A3, E	Dial-up	35	FDX[a]	Asynchronous	FSK[b]	300	Originate[c]/answer[d]
103F	Leased 2-wire	35	FDX	Asynchronous	FSK	300	Originate/Answer
113A, B, C	Dial-up	20	FDX	Asynchronous	FSK	300	Originate only (A,C) Answer only (B)
201A	--	--	Obsolete	--	--	--	--
201B	Leased 2- or 4-wire	60	HDX[e]/FDX	Synchronous	4PM[f]	2400	Single channel
201C	Dial-up	70	HDX/FDX	Synchronous	4PM	2400	Single channel or up to 6, 12, or 30 channels
202C5, 9, 11	Dial-up	50	HDX	Asynchronous	FSK	1200	No reverse channel
202C6, 10, 12	Dial-up	50	HDX	Asynchronous	FSK	1200	5 b/s reverse channel
202S	Dial-up	40	HDX	Asynchronous	FSK	1200	Up to 8 channels in one housing
202D/R	Leased 2- or 4-wire	50	HDX/FDX	Asynchronous	FSK	1800	Single channel
202T	Leased 2- or 4-wire	40	HDX/FDX	Asynchronous	FSK	1800	Up to 8 channels in one housing
203	--	--	Obsolete	--	--	--	--
208A	Leased 4-wire	130	HDX/FDX	Synchronous	8PM[g]	4800	Single channel
208B	Dial-up	160	HDX	Synchronous	8PM	4800	Auto-answer
209A	Leased 4-wire; D-1 conditioning	240	FDX	Synchronous	QAM[h]	9600	D1 line conditioning required
212A	Dial-up	40	FDX	Asynchronous/ Synchronous	Dibit PM	300, 1200	Auto-answer

[a] FDX = Full-duplex

[b] FSK = Frequency-shift keying

[c] Originate refers to frequency assignments for 103/113 modems:

Transmit	Receive
1070-Hz space	2025-Hz space
1270-Hz mark	2225-Hz mark

[d] Answer refers to frequency assignments for 103/113 modems:

Transmit	Receive
2025-Hz space	1070-Hz space
2225-Hz mark	1270-Hz mark

[e] HDX = Half-duplex

[f] 4PM = Phase modulation with four states per signal element (baud)

[g] 8PM = Phase modulation with eight states per signal element (baud)

[h] QAM = Quadrature amplitude modulation

logical 0 (space) and the logical 1 (mark) states. For the Bell 103/113 system, the frequency assignments are as follows:

	Originating End	Answering End
Transmit	1070-Hz space 1270-Hz mark	2025-Hz space 2225-Hz mark
Receive	2025-Hz space 2225-Hz mark	1070-Hz space 1270-Hz mark

2. DPSK -- In differential-phase (dibit-phase) shift keying, the bit pattern is determined by measuring the phase shift on the phone line. For the Bell 201 B/C, the dibit phase shift pattern is defined as follows:

Dibit	201 B/C Phase Shift
00	45°
01	135°
11	225°
10	315°

Amplitude modulation (AM) requires twice the bandwidth of baseband and thus is inefficient in restricted bandwidth applications such as voiceband data transmission. Also, amplitude modulation is difficult to implement because level changes of many decibels can occur during transmission, requiring automatic power-gain control circuits along with the basic demodulation circuitry. For these reasons, AM is seldom used in data transmission.

APPENDIX G

Data Exchange with the National Laboratories

DATA EXCHANGE WITH THE NATIONAL LABORATORIES

In the event of an emergency, a computer of substantial capacity would be a definite asset to the NRC staff in assessing the gravity of the emergency. However, computational power alone would be insufficient. It may become necessary to rapidly marshall the skills of those analysts of the national laboratories or nuclear steam supply system vendors familiar with the execution of certain computer codes. Data transfer between analysts by mail would be unsatisfactory, and data transfer by voice telephone would be cumbersome if not impractical. Instead, data transfer could be automated using the same communication principles and design considerations described in this report.

One cost-effective computer architecture for the NDL would be a machine whose resources could be increased as the need arises. Routine reports on plant variables and status of safety systems could be processed by a machine of modest capacity. However, it could prove beneficial to increase computing resources at the onset of a reactor incident. This could be accomplished by making remote use of the computing facilities at the national laboratories. More computing power could be provided as needed by configuring the operations center computer as a remote job-entry terminal for the large computers.

Implementation of such a network to aid NRC analysts is envisioned as an ongoing process, perhaps requiring several years. Enumeration of the codes that are currently available and that fall into this category is beyond the scope of this report. It is sufficient to say that most analysis codes are currently available at the national laboratories. It is not necessary nor desirable to duplicate the codes, computer facilities, or technical expertise at the operations center since the required analysis can be accomplished at the labs, and the results can be transmitted via the network back to the operations center.

Figure G-1 shows one possible enhanced NDL network configuration. It should be noted that in this enhanced mode of operation, the computer at the operations center acts as a remote job-entry (RJE) terminal for submission of batcn jobs to computers at the laboratories shown. Even in the batch environment, timely assessments and supplementary data relevant to the reactor of interest could be made available as needed by the NRC analysts. The required interfaces are implemented with off-the-shelf software protocol emulators that make the operations center computer appear to be just another RJE terminal for the other computers. The specific emulators required are the CDC MUX 200 and the IBM 2780/3780 interface protocol emulators for CDC and IBM equipment, respectively. The costs would depend on the specific computing system selected for the operations center. However, for a typical total cost estimate, Digital Equipment Corporation will provide a CDC interface protocol emulator for $5100 and an IBM interface protocol emulator for $8100.

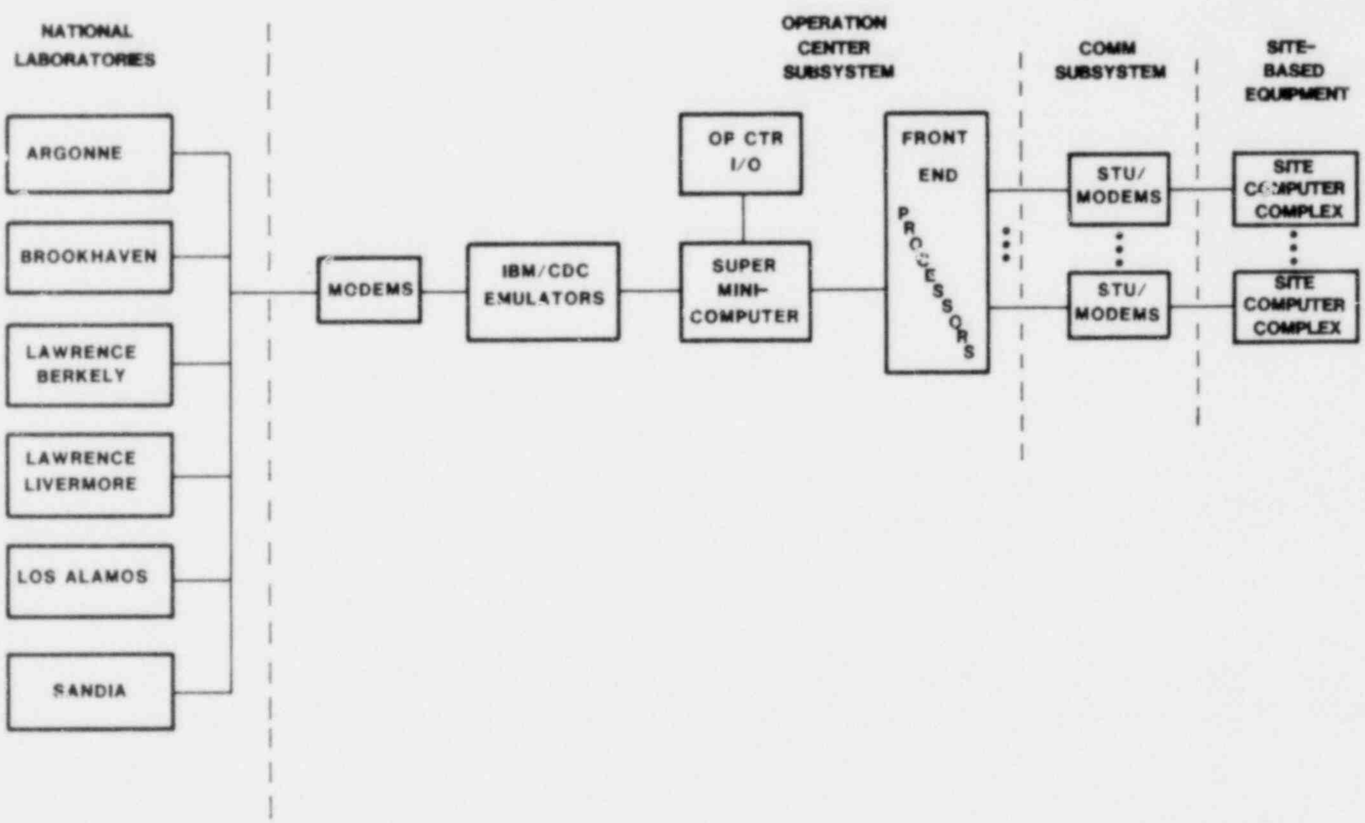

Figure G-1. Enhanced NDL Communication Network

Feasibility of the scheme described in this section has already been demonstrated.[14] A 4800 b/s synchronous communications link has been established between a VAX 11/780 computer at the Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, and a CRAY-1 computer at the National Center for Atmospheric Research, Boulder, Colorado. Programs, data, and intermediate graphics data are transmitted between the two systems. The implementation is justified on the length of complexity of the numerical calculations which are required to "time-step" a fluid dynamical model through many iterations. Models such as these would be required to predict the geographical distribution of the fission products in the event of a radiological release.

The particular computer network in Figure G-1 is shown only for illustrative purposes. Specific computers selected would be those computers at installations with technical resources of demonstrable utility to the NRC. Although only national laboratories are shown, computers at other governmental agencies and even at industrial installations, such as nuclear steam supply system vendors, could be included in the network.

The NDL would not be burdened by hardware and software maintenance for the large machines in the network. Ongoing cost could consist of either leased-line rental costs computed at the rates given in Section 2.3.1 or dial-up and computer connect time charges. Central processor unit charges would be based only on the time consumed in actually processing the data. However, compensating for the services of analysts competent in the execution of computer codes would have to be negotiated with the participating installations.

APPENDIX H

Digital Radio Relay Networks

DIGITAL RADIO RELAY NETWORKS

In this appendix, alternative radio relays to the microwave relay networks of Section 2.3 are considered. At microwave frequencies, the transmission paths are line-of-sight. Only the major carriers, for example, AT&T or GTE, can justify the enormous capital investment in repeater stations and the personnel required to provide various land-based telecommunication services. The number of repeater stations needed for a digital radio relay network can be reduced considerably by using the high frequency (HF), very high frequency (VHF), or ultra high frequency (UHF) bands where certain properties of the ionosphere or trophosphere can be exploited to provide transmission paths beyond the horizon (see Appendix D). The capital investment required for HF, VHF, or UHF relay is also reduced correspondingly. Unfortunately, the tradeoff is reduced reliability and reduced channel capacity. In fact, the channel capacity of a HF relay would be insufficient for NDL purposes (see Section 2.1.3).

By judicious choice of transmission frequencies for a given set of ionospheric conditions, in theory it would be possible to provide a one-hop HF link between any one reactor site in the contiguous United States and the operations center at Bethesda, Maryland. However, more than one propagation path is possible, leading to multipath effects in which signals transmitted simultaneously travel over different paths and therefore arrive at the receiver at different times. The several different signals may then add constructively or destructively, depending on the values of the relative phase shifts, resulting in performance degradation measured, perhaps, in tens of decibels. Experimental studies have shown that any attempt to transmit serial digital streams over long distances via the ionosphere at a rate exceeding 100 to 200 pulses per second will tend to result in a severe intersymbol (adjacent-symbol) interference problem.[9] Such undesirable effects may be minimized by using narrow bandwidths and by carefully selecting the operating frequency.

Special modulation and reception techniques have been developed which mitigate the degradation resulting from fading and multipath effects. Of these techniques, the most widely used are multiple-receiver combining techniques categorized as diversity. One such technique providing a high degree of reliability for duplex digital circuits is the DOE SECOM II system designed to provide HF communications between a central controller and a fleet of vehicles via a repeater network consisting of five relay stations.[13] This system is described in Appendix E. For present purposes, it is sufficient to state that the 300 b/s transmission rate used in SECOM II is close to the maximum transmission rate realizable in an HF relay network. Clearly, this channel capacity would be inadequate for the NDL traffic loads projected in Section 2.1.3.

Channel bandwidth and reliability adequate for the NDL traffic loads could be realized with a tropospheric VHF/UHF forward-scatter relay (see Appendix D). As in SECOM II, diversity combining techniques would be required. However, because its transmission range would be limited to about 320 km, as many as 50 relay stations might be needed for adequate coverage.

Estimates on costs and time required for implementation of a radio relay network are given because joint use of existing relay networks appear to be unfeasible. As discussed above, joint use of SECOM II is not practical because data rates are too low. Military communication networks also were considered but eliminated as a possible alternative for this application because these networks are designed and developed to fulfill specific missions and could not be effectively shared. Shared usage of military frequencies and communications networks by the civilian sector has been resisted in the past due to the potential interference with routine military operations and the desire not to establish the precedent of allowing civilian use of military facilities on a continuous basis.

A realistic cost estimate can be obtained by extrapolating the results of a 1975 cost estimate for duplication of the SECOM network.[15]

Excluding the cost of land, the five relay station networks could be duplicated in 1975 for $1,800,000. The same network could be duplicated in 1980 for roughly $3,000,000, assuming a uniform annual 10% inflation rate over the 5-year period. In order to obtain the bandwidth required for the NDL traffic estimates presented in Section 2.1.3, it would be necessary to implement a UHF tropospheric forward-scatter relay consisting of up to 50 stations and costing about $30,000,000. Costs required to acquire land and facilities for each of the 50 relay stations are difficult to estimate because there are several options available which include use of existing facilities or government-owned property. These costs could easily reach $20,000,000 bringing the total implementation costs to about $50,000,000.

If the diversity control scheme used in SECOM II were adopted, then dedicated phone links would be required between the 50 relay stations and the network control center. It should be remembered that a radio relay is considered here only as an alternative to a network of 80 dedicated phone lines. Implementaton of a radio relay network of sufficient channel capacity and reliability for NDL purposes would result in a reduction in the number of dedicated phone lines but require acquisition of a physical plant costing somewhere between $30,000,000 and $50,000,000. (Some dedicated phone lines are required for network control.)

In addition to the initial installation costs, annual costs for power and maintenance would be substantial. Maintenance for the SECOM II system, including the operation of three mobile depots to service the five relay stations, currently costs $150,000 per year. Again using a linear extrapolation, estimated maintenance costs for a 25- to 50-station UHF relay network would run from $750,000 to $1,500,000 per year. That is, the minimum projected annual maintenance fees for a dedicated radio relay would run three times the annual charges quoted in Section 2.3.1 for communication services purchased from a common carrier.

A minimum period of 60 months is estimated for implementation of a radio relay network. Considerable time would be required to negotiate leases or execute memoranda of understanding if the relay stations were to be sited on government land. Studies on the impact to the environment by the relay stations and their antennas would be required for many locations. Although this would be a straightforward procedure, considerable legal work might be involved. Finally, frequency allocations would have to be obtained. Because the network is for the convenience of the government, the cognizant agency for frequency allocations is the National Telecommunications and Information Administration of the Department of Commerce. Presumably space could be arranged in the 162 to 174 MHz band for a VHF link or the 406 to 420 MHz band for a UHF link. These bands have been set aside for government agencies.

APPENDIX I

ASC Satellite Communications

ASC SATELLITE COMMUNICATIONS

The technical feasibility of implementing a data communication network for the NDL using onsite, i.e., reactor-sited, ground stations has been demonstrated by the financial community. A significant advance in electronic fund transfer technologies was realized early in 1979 when Western Bancorporation, a major holding company with banks scattered throughout 11 western states, activated a network installed by ASC. Ultimately, the network will include 18 earth stations serving 4 regional data processing centers, 22 banks, and 800 branches.[16] In comparison with this network, development of a network linking all reactors licensed or planned in this century with the NRC operation center would seem a modest achievement.

Although the technical feasibility of such a network is established, its cost effectiveness compared to other alternatives must be proven. The cost of satellite services is not based on volume of traffic like some terrestrial services, but includes charges based on access equipment and bandwidth. Anticipated data traffic flow for the NDL would not effectively utilize the minimum available bandwidth of 56 kb/s.

The satellite-based transmission services provided by ASC here provide high-speed (over 56 kb/s) communications between sending and receiving stations. In the ASC communication option, data from a reactor site would be relayed to the NRC operations center in Bethesda, Maryland, by means of a dedicated satellite communication channel. Such a satellite network would be capable of accommodating many types of traffic, including a mixture of voice signals, high-speed facsimile, computer data, and even full-color "freeze-frame" television signals. According to carrier claims, performance levels of 1 error in 10^8 bits should be realizable. Satellite transmission services provided include provision for alternate data/voice traffic, private-line voice traffic, two-way point-to-point data traffic, wide-band data traffic, video transmission, and intercarrier transmission. As with AT&T leased lines, charges are made for the channels used, not for the volume of data sent.

The only significant difference between the installations at the reactor sites and the operations center is in the diameter of the antenna: 3 or 5 metres at reactor sites and 10 metres at the operations center. As the diameter of the antenna increases, the directive gain in a given direction, defined as the ratio of the radiation intensity in that direction to the average radiated power, also increases. The directivity of a large, uniformly illuminated circular aperture is proportional to the square of the diameter of the aperture in wavelengths.[17] The increased directivity at the operations center is required to reduce the average transmitter power and thereby decrease the probability of severely impacting the electromagnetic environment, a factor which would influence issuance of an FCC license. Because the communication traffic and, therefore, the channel bandwidth required at the operations center will be greater than that required at the reactor site, a larger effective radiated power will be required at the operations center. Instead of increasing transmitter power, it is preferable to increase the directivity of the antenna to achieve an increase in effective radiated power.

Each message sent to a geostationary satellite 22,300 miles above the earth travels essentially the same distance regardless of its point of initiation or destination. The time required for propagation of a signal from reactor site to operations center will be roughly 0.25 second. If provision is made to enhance the reliability of transmission, an error check is made on each frame. If the frame is incorrectly received, a request is made for retransmission of the frame. The propagation time, if uncompensated, would severely impact throughput. ASC has overcome this impediment by providing a microcomputer-controlled buffer/interface called the signal delay compensation unit which enables ASC to boost the throughput to 28% beyond that of terrestrial links.[18] The signal delay compensation unit is included in the equipment supplied by ASC at each terminal.

ASC can optionally provide data transmission and traffic flow security to protect against volume and pattern analysis. ASC calls the option CryptoLine. With CryptoLine, data is scrambled by an electronic variable key located in the unit. Once received, the scrambled data is taken from the receiver and unscrambled. All data scrambling and unscrambling uses the National Bureau of Standards Data Encryption Standard algorithm. Either the electronic code book mode or the cipher block chaining mode to encrypt and decrypt data is available. Delay variations associated with any given link are compensated by an elastic buffer which allows the data bit time to shift back and forth several bits with respect to the clock bit time. Cryptovariables are 64 bits, including 8 parity bits. Encryption and decryption use the control signals recommended by RS422, RS423, RS232 and CCITT V.35. (Section F.2.1 in Appendix F explains RS, V-, and X-series recommendations.)

Following are three examples of combinations of services that could be implemented for a service over a 112 kb/s SDX link.

1. Option with RS232C interface only. Up to 32 data channels: each channel, 19.2 kb/s or lower. The total cumulative data rate must be equal to or less than 110 kb/s.
2. Option with RS232C interface and voice digitizer. Two digitized voice channels, each using 32 kb/s bandwidth. An additional 28 channels are available, each operating at 19.2 kb/s or lower. The cumulative data rate for the 28 channels can add up to 46 kb/s.
3. Option with V.35, RS232C interfaces, and voice digitizers. One voice channel and one 56 kb/s wideband data channel. Additional 28 channels are available, each operating at 19.2 kb/s or lower. The cumulative data rate for the 28 channels can add up to 22 kb/s.

The ground station for a dedicated satellite channel would be customized to conform to NDL requirements. Ground station maintenance would be performed by ASC, which would retain ownership of the equipment. Contracts are generally negotiated for a 3-year service period. The installation cycle is about 8 months. Although the installation generally would not be difficult, environmental electromagnetic interference impact studies must be performed for each location and FCC approval obtained for antenna size.* In addition, an FCC license would be required for the transmitter.

Network availability is guaranteed at 99.9% on an annual basis. In order to achieve this availability, it will be necessary to provide deicing capability to keep the antenna free from ice at those locations subject to ice storms.

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*Increasing antenna diameter increases directivity, thereby decreasing potential interference of NDL equipment with other communicators.

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LIST OF ACRONYMS

ACK	Acknowledgment
ADCCP	Advanced Data Communication Control Procedures
ANSI	American National Standards Institute
ARQ	Automatic repeat request
ASC	American Satellite Corporation
ASCII	American Standard Code for Information Interchange
BCC	Block check characters
BER	Bit error rate
BISYNC	Binary Synchronous Communication
BNL	Brookhaven National Laboratory
CCITT	International Telephone and Telegraph Consultative Committee
CRC	Cyclic redundancy checking
DAS	Disturbance Analysis System
DCE	Data circuit-terminating equipment
DDCMP	Digital Data Communications Message Protocol
DOE	Department of Energy
DTE	Data terminal equipment
EBCDIC	Extended Binary Coded Decimal Interchange Code
EIA	Electronic Industries Association
ENS	Emergency Notification System
ESS	Electronic switching system
FEP	Front-end processor
FSK	Frequency-shift keying
HDLC	High-Level Data Link Controls
HF	High frequency
I/O	Input/output
IRC	Incident Response Center
ISO	International Standardization Organization

LL	Leased line
LRC	Longitudinal redundancy checking
LWR	Light water reactor
MTBF	Mean-time-between-failures
MTTF	Mean-time-to-failure
NDL	Nuclear Data Link
NIH	National Institutes of Health
NTR	No-traffic response
PAD	Packet assembly/disassembly facility
PSK	Phase-shift keying
QPSK	Quaternary phase-shift keying
RJE	Remote job entry
RR	Radio relay
SAFE	Safeguards Automated Facility Evaluation
SCC	SECOM control center
SDLC	Synchronous Data Link Control
SDX	Satellite data exchange
SECOM	Security Communications
SR	Satellite relay
STU	Site transmission unit
UHF	Ultra high frequency
VAN	Value-added network
VHF	Very high frequency
VRC	Vertical redundancy checking

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