NBS TECHNICAL NOTE 804

Review of
Computer
Networking Technology

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[2] Part of the Center for Radiation Research.
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Review of Computer Networking Technology

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FOREWORD

This report is one of a series of publications produced
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This grant supports a broad program of investigation into
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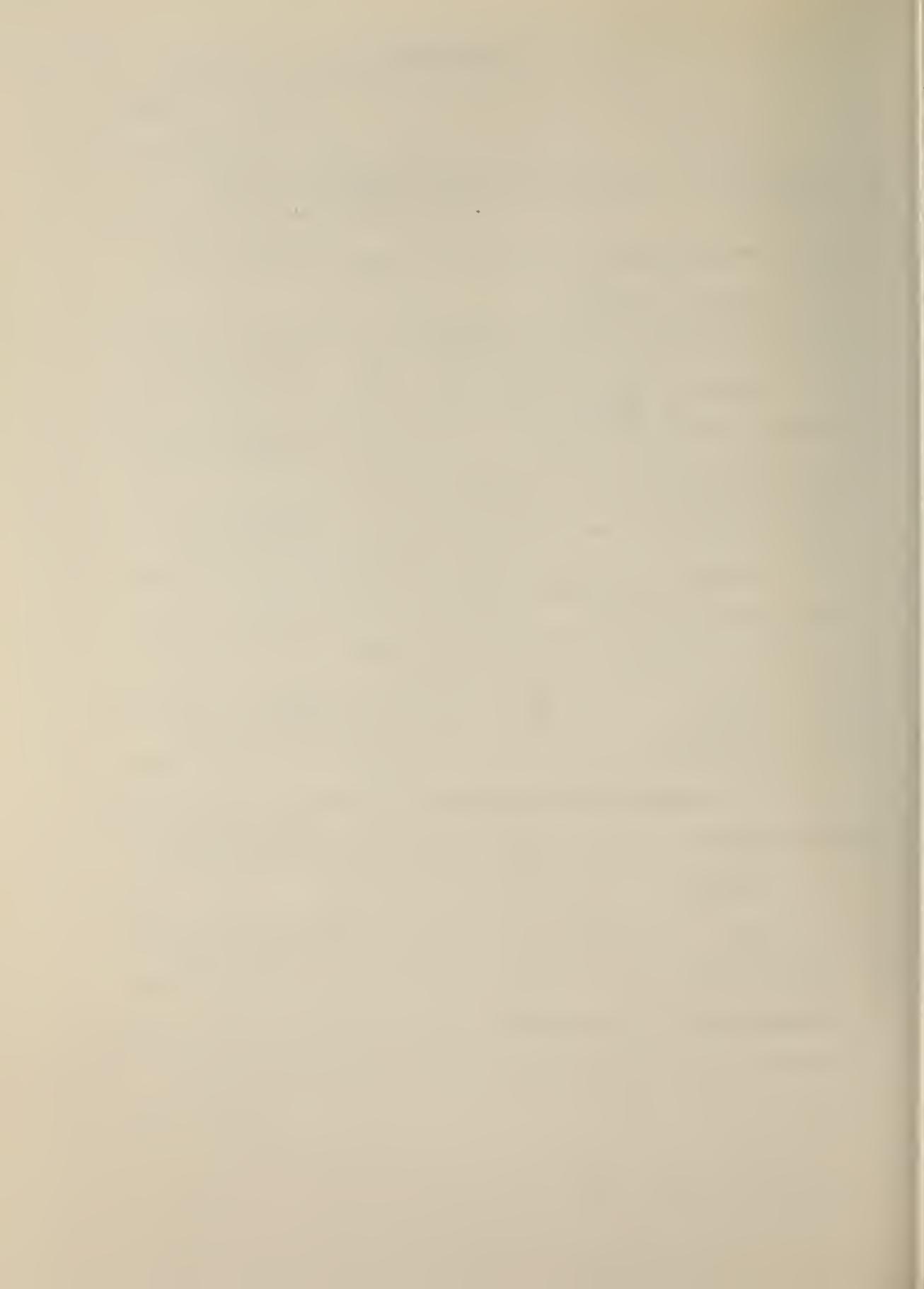
A listing of completed and planned publications produced
by the Institute under this grant follows:

1. Primary Issues in User Needs
   D. W. Fife
   Chapter 10 in Networks for Research and Education:
     Sharing of Computer and Information Resources
     Nationwide
   MIT Press, Cambridge, Mass.
   Expected Publication January 1973

2. Some Technical Considerations for Improved Service
     to Computer Users
   T. N. Pyke, Jr.
   COMPCON, 1973
   Seventh Annual IEEE Computer Society International
     Conference

3. Computer Networking Technology - A State of the
     Art Review
   T. N. Pyke, Jr. and R. P. Blanc
   COMPUTER Magazine
   Computer Society of the IEEE
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4. Review of Network Management Problems and Issues
   A. J. Neumann
   NBS Technical Note 795, October 1973

CONTENTS

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Robert P. Blanc

This report gives a descriptive summary of the technical
characteristics of existing computer networks, including data
communication technology and configuration related to support
of resource sharing services for a computer network. Included
are discussions of terminal support capabilities for the com-
munications network and a development of relevant network
terminology. The report concludes with a comparative evalu-
ation of existing technological approaches to networking.

Key words: Computer networks; computer-to-computer transfers;
interactive terminals; minicomputer-based systems; network con-
figuration; remote job entry; resource sharing.

1. INTRODUCTION

A review of the technical characteristics of existing

approaches to computer networking is presented for the pur-

pose of comparative evaluation in relation to their potential

for supporting resource sharing for the Networking for

Science Program of the National Science Foundation [1]. For

the purpose of this review, a computer network is considered

to be any interconnection of an assembly of computer systems

and/or terminals together with communications facilities [2].

Resource sharing in a computer network refers to the sharing

among network participants of computer resources, including

hardware, software, and data files. The purpose is to make

available, nationally, special computer resources which are

not locally accessible, such as processors unique in speed

or storage capabilities, specialized programs of interest to

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a distributed clientele, and large data files too expensive to reproduce. The coverage in this review is of sufficient depth but general in scope so that it should be useful to those planning, implementing, evaluating, and using other resource sharing computer networks. It is impractical to examine each technical detail of a network and relate it directly to resource sharing, since such a one-to-one correspondence is probably non-existent. But the features of a network will be described and, in whole, related to a set of network support requirements which are themselves prerequisites for sharing computer network resources. The categorization of the requirements will be by terminal or communications support, not by the end service provided, such as program preparation or information retrieval. The purpose in discussing these communications support functions is to identify techniques for making the user interface to existing networks more flexible and effective and to provide services that do not presently exist.

These support functions, which will be discussed in the first part of the paper, are the capabilities of supporting various classes of computer-based service, including interactive or conversational, remote job entry, where input and output are performed with card readers and line printers respectively, the support of minicomputer based systems such as automated labs, and computer-to-computer communications. Some of these capabilities are considered more essential

than others and this will be clarified in the text.

The next section is devoted to the description of the technical characteristics which can be used to classify a network. These attributes will be described, and alternatives in implementation, compared. Advantages and disadvantages for application in the Networking for Science Program are presented where possible. Of course, in most cases, it will not be clear whether a particular feature by itself is advantageous. Rather, it is the combination of technical attributes in the implementation of a network that can be evaluated. A byproduct of these discussions is the development of a working terminology for the technological aspects in computer networks.

The various technological approaches to networking in several selected existing networks are then examined. Completeness has not been achieved, but a substantial number of networks will be considered as representative of the available approaches to network technology. These networks include: TYMNET, the commercial timesharing network of Tymshare, Inc.; CYBERNET, the Control Data Corporation commercial network; GE Information Systems, the General Electric Corporation commercial network; MERIT, the Michigan Universitys' network; ARPANET, the experimental network of the Department of Defense Advanced Research Projects Agency; and TSS, an experimental network of IBM 360/67 Time-Sharing System computers. This report is confined to existing

approaches, and while suggested improvements in those approaches may be indicated, there will be no attempt to specify a new, but non-existent approach to network technology. A discussion of a network technology employing only off-the-shelf concentrators and multiplexers may be important for cost comparison, but is not addressed by itself in this report. The technical aspects of such an approach are well-understood and in addition, its application to a network of distributed heterogeneous computers is inconvenient at best. Concentrators and multiplexers will, however, be considered as specific network components, and at least one network making extensive use of concentrators, along with more sophisticated switching computers, will be discussed at length.

Each technological approach will be discussed in terms of technological characteristics and their ability to support the functional requirements. In addition, each of the networks possesses a number of salient features which will also be identified. The information presented in this section was obtained through personal contact with principals of the networks and/or through extensive investigation of the literature including that referenced in the annotated bibliography on resource sharing computer networks [3].

The last section evaluates the alternative approaches indicating the desirable features and issues related to the requirements of the Networking for Science Program. Although

it is difficult to separate technical and economic concerns, this review concentrates on technical factors - desirable technical characteristics and constraints of the technology because of various mixes of performance requirements.

It is important to note that, although specific networks are identified, there is not intent to favor or criticize those particular networks. Rather these networks have been chosen as well-known representations of important approaches to networking technology and it is the review of those technologies that is the purpose of this report.

NOTE: The identification of certain commercial equipment and networks in this report is done in order to adequately identify the network components and technologies discussed herein, and in no sense does it imply recommendation or endorsement by the National Bureau of Standards.

2. FUNCTIONAL CAPABILITIES OF THE COMMUNICATIONS NETWORK

Alternative technologies should be evaluated in terms of their responsiveness to user needs. One approach is to identify those needs and, subsequently select a communications technology to satisfy them. This approach is iterative in nature; that is, the best available data concerning user needs is employed in evaluating different alternatives, and as the data improves, so will the evaluation. At this point in time, a number of basic requirements can be identified in terms of particular types of usage that the communications network should be capable of supporting. These types of usage to be considered are interactive, remote job entry, communications with minicomputer based systems, and computer-to-computer transfers.

2.1 Interactive

Interactive uses depend upon the use of teletypewriter or equivalent terminals to communicate with a remote computer system. Computer terminals are the mechanisms by which information stored in computer data banks becomes translated into action by way of human beings. Of importance in evaluating a communications network are the habits of the terminal users, the characteristics of the terminals themselves, and the constraints placed on the communications network by these terminals.

Code, speed, and mode of operation are important characteristics of terminals directly related to the communications

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facility. There does exist a standard code for information interchange, ASCII, as specified in Federal Information Processing Standards (FIPS) Nos. 1 and 15, and this code should be supported by the network. For systems to be a part of a Federal installation, this support is in fact a requirement. In general a network must impose a series of constraints to operate effectively, and in the case of terminal to computer communications, the standard code is a constraint which is beneficial in that it diminishes the time and money spent on interfacing terminals, a cost ultimately borne by the user. Later when we examine the ARPANET we will see that its terminal interface is capable of supporting non-standard devices. This may at first appear desirable, but consider the scarce resource, main memory, that must be devoted to the variety of non-standard devices. In the ARPANET example, over one-thousand (1000) words of memory of the twenty-eight thousand (28,000) word minicomputer terminal interface are dedicated to software and tables to interpret the code of the non-ASCII devices [2]. It has been suggested that users of non-standard terminals pay an additional charge for the added resources that they consume, and this would appear to be one reasonable alternative.

Speed of terminals can range from 110 baud for a simple teletype to 9600 baud and greater for a C.R.T. Terminal with vector capability. Many communications networks are restricted to speeds considerably lower than that maximum

on the high capacity outgoing channel (that connecting the remote concentrator to the computer or computer front end) and are even more restricted on the slow speed input channel (that connecting the terminal to the concentrator or multiplexor) and are therefore incapable of supporting the higher speed devices.

Speed recognition, the automatic identification of terminal speed by the network, although not a basic requirement, is another capability worth considering in evaluating technologies to support interactive usage. When the terminal interface servicing dialup ports is capable of supporting a mix of speeds without devoting particular ports to particular speed devices, it will statistically provide better service in terms of the probability of obtaining a free port for attaching a device to the interface. That is, it can be shown that the probability of obtaining a free port is greater if all ports are accessible to any speed device than if subsets of the ports are devoted to particular speed devices. The physical realities of the two situations are: in the first case a user can dial a single number regardless of the speed of his device to obtain access to any port (ports are on a rotary) which will adapt to his device speed through automatic speed recognition; or for the latter situation, the user will dial, for example, three different numbers for three different devices to obtain access to any of a subset of ports (the subset is also on a rotary).

The modes of operation of a terminal, which for many terminals is switchable, can be full-duplex or half-duplex transmission depending on the terminal itself, and the computer system on the network with which the terminal is communicating. Half-duplex refers to the case where the user's keyboard is connected to the printer at the terminal, and to the convention that when the computer is producing output it does not respond to input from the user (except perhaps for a special "break" signal). When the computer is not typing it is in a mode to accept input from the user [4]. Full-duplex refers to the case where the user's keyboard is locally disconnected from the printer mechanism. When characters are received at the computer, they are returned to the user. The returned character or characters may not be identical to the received character; for example, some systems will return a control character as an up-arrow followed by the character ("ETX" is sometimes returned as "↑c"). The process of sending the received characters, exactly or modified, is often referred to as the echo-plex mode of operation. Full-duplex, however, also implies the separation of input and output to the point where a user at a terminal can be typing input while the computer is sending him output. In this case "echoing" will be delayed until the output has been completed. It is not unusual, nor particularly distasteful, to hear the terms full-duplex and echo-plex used interchangeably although it

is preferable to think of echo-plex as a subset of full-duplex (that subset related to the actual echoing of characters).

The communications network must be capable of fielding these alternatives. For example, if echoing is desired in the full-duplex mode, then in the network it must be determined which communications component is to perform the echoing and when. Some networks allow the interactive user to set and alter the mode as desired, while others are far less flexible. As will be seen in later discussions, the proper control of echoing is important to the efficient use of a network.

Line utilization generated by interactive usage is another consideration relevant to communications technology. Models together with actual data, for example, that derived by Jackson, Stubbs, and Fuchs of Bell Telephone Laboratories, can be used to predict communication facility utilization as a function of the number of interactive users, their application, and the speed of their terminals [5,6].

The "data stream" model derived is used to study the characteristics of holding time, defined as the time from connect to disconnect between a terminal and a computer system. However, the model has general applicability in the analysis of communication facility utilization and the tailoring of a communications system to the characteristics of interactive users and computer systems. Using the "data stream"

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model it was found that system load can greatly effect holding times, that user delay or think time is a significant component of holding time , that user send time is insignificant, and that computer transmit time is the smallest component of holding time. So the model provides a tool for determining the percentage of holding time during which useful work is performed and a means of studying ways to adapt communications systems to terminal traffic characteristics.

Statistics are also available from several networks in terms of the average number of characters generated per second by interactive usages at specific data rates and the number of interactive users that can be supported on a communications link of a specified capacity. Specifically, it was learned that on the TYMNET network using interactive users in the speed range of 110 to 300 baud, the average traffic generated by a user including both sending and receiving is 5.5 characters per second; and it is possible to support forty-six (46) interactive users over a 2400 baud communications circuit. Similar figures for the GE network indicate terminal duty factors based primarily on terminal output statistics to be 7 characters per second for 110 baud terminals [7].

Using the model of Jackson and Stubbs, the figures from GE and TYMNET and the preliminary data of a Network Measurement Machine [4] developed at the National Bureau of Standards, the following tabulation has been generated:

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Average Characters Per Second (Half Duplex)

	Max	User	System	Combined
Network Measurement Machine (applied to scientific users)	10	2.3	7.5	4.5
TYMNET	10	0.5	5.0	
GE	10		7	
	30		21	
Jackson, Stubbs (moderately loaded scientific)	10	0.48	8.8	3.6
(heavily load scientific)	10	0.27	2.1	1.5
(moderately loaded business)	15	0.8	8.3	4.0

In the above the maximum utilization "max", refers to the channel capacity. The channel is composed of modems, circuits, interfaces, and terminals, and its capacity is determined by the most limiting component. In the preceding, the terminal speed of 110 baud determines the channel capacity; because the commonly used modems, 103 A's or equivalent, are capable of 300 baud and voice grade circuits are capable of operating at even higher speeds. The column labeled "user" indicates the average number of characters generated per second when the user has the channel. Typically this will be during the period of user think time combined with user transmit time. The column labeled "system" refers to the average number of characters per second generated during the time at which the system has the channel. This time will be the sum of response time and transmit time. The "combined" column is the average weighted by time.

This kind of data is essential for the analysis of the relationship in terms of loading between the communications network and the interactive user. In many networks, a concentrator is used to interface interactive terminals on its low speed side to the network on its high speed side. Assuming that the bandwidth of the minicomputer used as a concentrator in terms of speed and buffer space will not be the limiting factor, then knowing the average traffic gener- ated by a given speed terminal, and knowing the efficiency of the communications discipline, the number of terminals that can be serviced on a given high speed channel can be calculated.

Average traffic statistics are somewhat useful since concentrators employ asynchronous multiplexing; that is, bandwidth under-utilized by some terminals will be utilized by those requiring it rather than devoting fixed time slots to terminals regardless of utilization as is the case with synchronous multiplexing [8]. The averages though can be somewhat misleading in that averaging holds only for large numbers of terminals and the peaking effects are somewhat unpredictable. So the averages are more meaningful for concentrators that support large numbers of terminals. The efficiency of the communications discipline indicates the amount of actual data that can be transmitted in a message block allowing the overhead. These factors all taken together might give an accurate projection of compatibility between a high speed communications channel and a number of

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interactive terminals for a particular concentrator, but the analysis in fact is somewhat more complex. Most communication facilities are symmetric; that is, input bandwidth equals output bandwidth, while user interactions with a system are typically asymmetric heavily favoring output or traffic from the system to the interactive terminal. Therefore, total average traffic or average number of characters transmitted is not as significant as the average number received by a terminal from a system since traffic in this direction will correspond to the greatest line utilization and is the traffic that the line capacity must match. Furthermore, these averages taken over a total network with a large number of users and different kinds of terminals and systems are not nearly as useful as burst characteristics relative to particular kinds of uses, known terminal characteristics, and given systems.

A Network Measurement Machine has been developed at the National Bureau of Standards for measuring the activity of interactive users, communications facility utilization, and the performance of a network as seen by its users [4]. This device interfaces at some point between users and systems and, operating in transparency to both system and user, records the entire dialogue, time tagging and identifying as to source each character received. This makes it possible to select networks, systems, mixes of terminals, and types of users described by discipline or application and vary

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whatever parameters are appropriate to arrive at the desired results on traffic characteristics. For a system designer this type of measurement makes it possible to tailor a communications facility to a specific class of users or to vary the mix of users to accommodate an existing communications facility. From the users standpoint, application of the Network Measurement Machine allows a network subscriber to specify performance requirements for a communications network, and to then monitor the network performance to see that the requirements are consistently met. For example, if response time is the criterion it is possible to measure the communication network plus system performance (computer system with which the terminal is interacting) or to measure only the effect of the communications network. This can be done by comparing data collected when the terminal is connected through the network with that obtained when the terminal is connected directly to the computer system bypassing the network. This latter type of measurement should be particularly useful to users of a communications network.

2.2   Remote Job Entry

Remote job entry is a computer usage mode employing card readers, line printers, and possibly card punches located remotely to submit jobs and receive output from a computer system. Communication with a remote job entry device will typically require a higher data rate than communication with interactive terminals and synchronous instead of asynchronous

transmission as in the case of interactive terminals. With asynchronous transmission, each character is initialized by a start bit and terminated by a stop bit adding two bits of overhead to each character transmitted. Synchronous transmission is continuous with regular timing, the bits of one character immediately followed by those of another with no start and stop bits and no pauses, thus giving the most efficient line utilization. Besides being inherently faster because of the elimination of start and stop bits, synchronous transmission uses higher speed modulation techniques than asynchronous transmission; specifically multilevel signaling can be used. Also, synchronous transmission can tolerate a higher degree of distortion on high speed circuits than can asynchronous transmission. In addition to the speed advantage, there is also an advantage in the integrity of the data transmitted. The stream of characters is normally divided into blocks for synchronous transmission. At the end of each block an error-checking pattern is transmitted based on the contents of the block. The receiving system must generate the same pattern or an error is realized. Acknowledgement of good data and timeouts and/or negative acknowledgements for bad are used to control retransmission when necessary. The specifications of the block size, the method of error detection and correction, and the formatting and interpretation of the data transmitted determine a protocol.

The synchronous communication requires the development
of a synchronous protocol to establish the proper two-way
exchange of information between the remote job entry device
and the communications network. This protocol may vary
among devices and therefore requires flexibility in the
network to recognize and adjust to different devices, or
restrictions as to which devices are allowed on the network.
ANSI Standard X3.28-1971 specifies procedures for the use of
communications control characters of American National Stan-
dard Code for Information Interchange (ASCII) in specified
data communication links.

Many existing networks provide adequate support for
interactive terminals, but make no provisions for remote
job entry devices in their communications network. This
raises an interesting question. Should remote job entry be
supported on the same communications facility as interactive
terminals? Remote job entry and interactive uses can entail
different traffic patterns and quantities, different communi-
cations protocols, different buffering requirements in the
communications network, different interfaces, and different
response requirements. It may be true that the network that
most effectively and economically supports interactive terminals
is not efficient for remote job entry. On the other hand,
the potential "economies of integration" of providing a
single facility to handle both kinds of application cannot be
ignored, nor can the convenience to the user requiring both

of finding them on the same network. Therefore both courses should be considered in the evaluation of alternatives.

As will be examined in more detail later, existing networks have taken different approaches to handle this mix of needs. TYMNET is tailored for interactive traffic, and for the moment, ignores remote job entry [9]. CYBERNET supports remote job entry traffic on its wideband links [10]. GE was developed for interactive use with background batch systems accessible through the interactive network [11]. ARPANET will handle both with the same communications network, but it is not clear what the effect on response time is of mixing interactive and remote job entry traffic under conditions of heavy loading [12]. It should be realized that the differences in the device characteristics are customarily resolved at the interface and then transmission is synchronous over the high speed circuits of the communication network. The distinctions to the communications network are those of the different kinds of traffic generated and the different response times required. Interactive users will generate small messages (block size may be constant but the actual data within the block is small in amount) and require rapid, consistent response times of less than two seconds. Remote job entry users may transmit large messages or multi-block messages being interested more in total throughput than in response time to any particular message. There has been a proposal to divide a communications link into two logical channels, one being a demand channel

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for short messages and quick responses, the other being a reservation channel for long messages [13]. The reservation for that channel could be made over the demand channel. This is meant to be particularly applicable to satellite links and presents an interesting concept for continued research.

2.3 Minicomputer-based Systems

Minicomputers can communicate with large computer systems for the purpose of providing support to the large systems in the form of front end processing or device control, for example, or the minicomputer can be the receiver of support from the large system where the system provides a service more economically than can be performed in the minicomputer, such as cross-compilation (advantages in speed and editing capability), large computations, and large file storage. In the former, minicomputers can be an integral part of a network, acting as an interface between the user at his terminal or remote job entry device and the network of computers. This supporting role of the minicomputer is very important when discussing network functions in relation to components, but it is the latter interaction - the network supporting the minicomputer - that is relevant to the discussion of network capabilities and customer needs.

Minicomputers can relate to a network in a hierarchy of three levels. At the lowest level there is the minicomputer or intelligent terminal which will be the user of the network analogous to a human user at a terminal. At the second

level is the interface to the network which quite probably
will also be a minicomputer. The interface is analogous to
the terminal interface (often a concentrator) in the case of
the human user. This interface for the minicomputer-based
system (hopefully a single interface can control many mini-
computers) can do as little as provide access to the network
or can be quite sophisticated both in the services it provides
as an interface and the services it can provide locally which
will eliminate the need to access the network in some cases.
For example, a sophisticated interface could recognize and
resolve differences between the minicomputer based systems
and it could realize protocols for performing simple tasks with
remote systems on the network such as logging in. Further-
more, it could provide simple compilers and file storage to
the mini-based systems so that they could perform those
tasks without the necessity of even using the network. In
both cases the support can occur in varying degrees depending
upon the intentions of the designer. At the third level is
the network itself with its variety of host computers.
Such a hierarchy is presently being implemented at the Insti-
tute for Computer Research at the University of Chicago [14].

The minicomputer, which might be monitoring or control-
ling a laboratory experiment or controlling a number of
other minicomputers which are themselves controlling experi-
ments, needs certain services from a larger computer or
computers on the network. For example, the minicomputer

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could store its large files on the disk system at a larger remote computer. A larger computer might have a cross-compiler which has the capability of producing code which will run on the minicomputer. Due to the relatively high cost of minicomputer peripherals [15], a number of minicomputers could share a set of peripherals located somewhere on the network. The minicomputer could be sending data to a larger system for the purpose of obtaining large scale computations.

These services are obtained by the minicomputer through interacting with the processes on a larger system much the same way as a human user would. Difficulties arise, however, in that the outputs from these processes are somewhat unpredictable and require responses from the observer. Since the observer is a minicomputer, it must anticipate all system responses, which as stated can be unpredictable. The introduction of a network of computer systems with which the mini can interact to receive services compounds the problem as the proliferation of heterogeneous systems makes responses even less uniform. This indicates that a set of protocols should exist on the network to standardize the interaction between network computer systems and minicomputer based systems that they serve.

A recent paper presents three (3) potential solutions to the problem including : (a) special controlled protocol channels in which a clean, well-behaved channel all the way to the applications program is provided to the automation

user; (b) special filters at some point between the user and the applications program to assure the automation user a uniform-looking network; (c) a very smart terminal node that can take into account and react to a wide variety of messages and initialization sequences [16].

The important consideration in evaluating an existing network relative to minicomputer based systems is that it be flexible enough to accommodate the communication needs of the minicomputer and the development of the necessary protocols. For example, sufficient bandwidth in the links of the network connecting the minicomputer to the target computer system must be available to facilitate the traffic, anticipated to be more intense than that of interactive human users. A file transfer capability would be useful, for example in the application of cross-compilation where source code and object modules are exchanged. Synchronous communications between nodes is certainly important for handling the volume of traffic generated at a satisfactory speed. Therefore, although there may presently exist few networks which satisfactorily support minicomputer based systems, there do exist more networks commensurate with the requirements for development of this support.

2.4 Computer-to-Computer

Computer-to-computer communication is comprised of inter-process transfers, where the processes are software processes or programs running on different, separate host computers.

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There are a number of kinds of applications for which
this kind of communications may be useful including: data
sharing, program sharing, load sharing, and multiprocess
solution to a problem. Data sharing is a mode of network
operation in which programs or data requests are sent from
various computers on the network to utilize a data base
resident at a particular node. This is particularly useful
when the data base is large and costly to transport or repro-
duce and the programs are relatively small. When the opposite
is true, large programs and relatively small amounts of data,
then program sharing may be appropriate. This is a mode of
operation in which data is sent to use a program resident
at a particular node. Load sharing is a mode of network
operation in which a workload is distributed among the
service computers on the network to achieve a balanced com-
pute load at each site.

Multi-process computing is a mode of network operation
generating true process-to-process communications in which
an application requires the execution of programs concurrently
on several processors. One of the few examples of this type
of operation is the McRoss experiment which simulates an air
traffic control system through execution on distributed
PDP-10 TENEX systems on the ARPANET [17]. These kinds of
applications are certainly intriguing to the software
engineer but at this time are a limited utility to the
discipline-oriented customer interested in using a network

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to support research, not as the object of research. To allow for the possible incorporation of this form of communication at a future time, if it becomes stabilized and non-cumbersome to use, requires a communications network consisting of links of considerable bandwidth to avoid propagation delays and provide rapid interprocess communication between computers, compatible to that internal to a computer. Sophisticated protocols will also have to be developed to facilitate comfortable interaction between computers.

Special capabilities must be implemented to provide for any kind of convenient computer-to-computer communication. For a user to transfer a program from one computer to use a data base at another, for example, there should exist a standard, easy to understand and easy to use calling sequence to trigger the interaction regardless of the systems in use. Where such network control languages have been developed, then computer-to-computer communications is an intriguing possibility for the applications user. Solving a problem with programs running on distributed processes is certainly more sophisticated than data or program sharing and at this point in time does not constitute a mandatory capability for the present considerations. In any case, for computer-to-computer communications to be effective a substantial degree of reliability among participating systems is necessary when processes are dependent upon all of those systems.

When evaluating existing networks, it becomes clear that some are more capable of accommodating computer-to computer communications than others. It must further be determined if this capability has been developed at an expense considerably greater than that required to satisfy the other capabilities and if its usage results in the deterioration of service for those other functions.

3. TECHNOLOGICAL FEATURES

In order to characterize the technology employed in an existing computer network, it is necessary to consider the features which are the components of the technology. There are those features which can be used to describe the componential structure of the network and the interrelationships of those components, and these will be described under the category of communications. Other characterizations, take a more global view of the network, and these will be described in the discussion on network configurations. Whenever practical it will be shown how a particular feature and the manifestations of that feature relate to the functional capabilities previously discussed. Particular features, when considered in isolation, are not necessarily conducive to analysis of their advantageous employment in a computer network, but rather it is the combined effect with other attributes that allows evaluation. Nevertheless, in some cases it will be possible to make generalizations about the effectiveness of the usage of alternative components. The primary purpose of this section, however, is to identify technological features and clarify the terminology for use in the next section, where existing networks are described and characterized.

3.1 Communications Circuits

In a computer network there are those circuits that interconnect the nodes of the network, circuits that connect ter-

minals with the network, and those circuits, logical or physical, which provide the end-to-end path between communicating processes. Consider first the circuits that physically connect the nodes in a network. The transmission media here can be voice grade lines or wideband and they can be owned, leased from a common carrier, or dialup. Voice grade circuits can be modulated to operate in the range of 110 baud to 9600 baud. Wideband lines operate from 19,000 baud to 250,000 baud and some economies of scale exist if there is in fact a need for that kind of bandwidth. For a more complete discussion, see Reference 2. The functional requirements discussed earlier could potentially be satisfied by voice grade lines, although a lot depends on the topology and traffic patterns of the network, as it might, for example, be more economical to provide a single very high speed link than to provide multiple lower speed lines to accommodate known network traffic [18]. The decision of whether to lease (or purchase) lines or to rely on dialup facilities depends on utilization. First, dialup lines are at present restricted to 4800 baud or less (2000 baud with common carrier provided modems). This could cause an unsatisfactory level of service to those functions performed marginally at that speed, for example, remote job entry utilizing some of the faster and more sophisticated devices. In addition, if holding times are significant then the dialup facility will be uneconomical where toll calls are involved.

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The second kind of circuit in a network is that connecting a customer device - timesharing terminal, remote job entry station, minicomputer based system, etc. - with the network interface, possibly a multiplexer or concentrator. This circuit, part of the low speed channel side of the multiplexer or concentrator, can operate at a maximum speed equal to that of the circuit connecting nodes, but is usually sharing that high speed circuit with a number of other low speed circuits and thus operates at a considerably lesser baud rate. Voice grade facilities are sufficient for most applications. The speed achieved through wideband service can not normally be utilized except, possibly, in a computer-to-computer transfer where one computer is entering the network as a terminal port to interact with a remote computer doing likewise. Holding times with interactive terminals are usually short enough to justify the use of dialup facilities, although leased lines are sometimes employed in the more critical applications to guarantee access. All of these physical circuits can be used as either full-duplex, allowing for two-way simultaneous transmission, or half-duplex, facilitating two-way transmission but in only one direction at a time. This is dependent upon the number of physical wires (2 or 4 wire), or upon the modulation techniques used (2 wire can be used in full-duplex mode).

Also the circuit can be synchronous or asynchronous, the synchronous interface typically offering higher speeds and

better error checking at a higher cost. Ideally the network

should be capable of supporting both types of circuits for

terminal connections.

The third kind of circuit in a computer network can utilize

the other circuits in its establishment. This is the end-to-

end circuit which connects two processes, for example a pro-

gram in a computer with a user at a terminal or two programs

in two different computers. In contrast, those circuits dis-

cussed previously connected two or more physical devices and

will be used in part to form this circuit, a physical or

logical connection between processes. If the circuit is

physical, then switching hardware will establish the circuit

making the proper connections at each switching point. If the

circuit is logical, than no direct physical connection exists

at any of the switching points, necessarily computers in this

type of communication between the input and output lines, but

instead, the connection is established in tables of the com-

munications software of the computers establishing the con-

nection, and is executed by other computers at each switching

point. In any case, whether the circuit if physical or log-

ical, it remains in existence for the duration of the inter-

process communication. When the circuit is physical, then

line or circuit switching is the terminology used to describe

the communications protocol. When the circuit is logical,

existing terminology does not adequately describe the con-

dition, but the term "message switching" has been employed.
Message switching, however, properly refers to communication
without the establishment of a circuit, or perhaps it would
be more accurate to say that the circuit is established only
for the duration of a single message.

For discussions in this report, and to remain compatible
with similar discussions found in the literature, we will
make the following distinctions: line switching establishes
a physical circuit path, physically connecting the input path
to the appropriate output path at each switching point, and
exists for the duration of interaction between processes;
virtual circuits are circuits that are established in the
tables of the switching computers logically connecting an
input port to an output port for the duration of interaction
between processes; message switching refers to the absence
of a circuit, logical or physical, relying instead on des-
tination addresses found in the message itself so that the
switching computers can determine the appropriate path or
ports to use for the message to arrive at the known destination
For additional clarification line switching is commonly applied
to the public switched network accessed through dialing, the
virtual circuit concept is used in describing TYMNET [20],
and message switching occurs between switching computers in the
GE network [11]. In the ARPANET, a special variety of message
switching, called packet switching [19], occurs. In this case,
messages from a host computer are further divided, by the net-

work interface message processor, into packets for transmission in the network.

It is not clear which kind of circuit technology is best suited to a generalized network. Arguments exist favoring the logical circuit and message switching concepts for making better use of carrier facilities to increase effective throughput on a given speed circuit and for allowing greater flexibility in interprocess communication as to which process can interact with what other processes over which circuit. This is because many logical circuits can be established or many messages switched with different sources and destinations over a given physical circuit. Although this increased capability employs a more sophisticated technology than line switching and a proportionate degree of complexity in its development and its subsequent use, its importance is gaining increasing acceptance [11, 19, 20].

3.2 Communications Hardware

Communications hardware encompasses devices for transmission, switching, and termination of communications signals, such as data terminals, modems, acoustic couplers, PBX equipment, store-and-forward message switching computers, etc. Many of these, such as modems and acoustic couplers, are not germane to the discussion of existing networks. What is important to the discussion of networks are the interfaces between the host computers and the communications network, the interfaces between the users terminal devices and the communications net-

work, and the message switching computer. Communications
network refers to the network exclusive of the user terminals
and host computers, or to paraphrase, those components of the
total network connecting the user terminals to the host com-
puters. In ARPANET terminology, the host computer nodes and
the communication network are the "resource sharing computer
network", while the communications network is the "communi-
cations subnet" [19]. Selection of one type of network com-
munications component over another is difficult to evaluate
without entertaining an economic argument, but where distinct
technical advantages exist relative to functional capabilities
they will be presented.

The interface between the host computer and the network
can occur in three different ways corresponding to three
different hardware considerations. First, the host computer
can be an integral part of the communications network, pos-
sibly performing a message switching function for the network
(where messages will be directed to itself or other nodes on
the network), and thus requiring no special interface computer.
The IBM research network, Network 440 was configured this
way with a central computer acting as a host and a message
switcher [21]. Second, the host computer can be connected to
the network through the message switching computer, again
requiring no additional hardware other than the transmission
medium, as is the case with the ARPANET [19]. Last, the com-
puter may be connected to a front-end computer which acts as

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an interface to the message switching computer and therefore the network, intercepting and controlling all input and output between the network and the host computer. The ARPA Network Terminal System (ANTS) could be applied as a front-end computer in this manner [22].

The use of front-end computers has a lot of appeal in networking. It can perform the functions of network interprocess communications control controlling the flow of messages between processes in the host computer and processes elsewhere on the network, and it can be responsible for making and breaking the connections between processes. These functions can be performed in the host computer itself, but with three distinct disadvantages:

(1) extensive revisions and additions to the host system may be required;

(2) substantial overhead in the host computer may be required to perform these functions;

(3) transportability is minimal or non-existant except to computers with identical operating systems.

Furthermore, a front-end computer in addition to acting as a host computer interface can also function as a terminal controller and possibly a peripheral controller. There are however two disadvantages to using the front-end technique:

(1) two controllers may be required--the standard host controller plus the front-end computer;

(2) the host computer's network interaction is limited
     to that supported by existing host communications
     hardware and software.

The interface between the terminal devices and the communications network is usually a multiplexer or concentrator. A multiplexer is a non-programmable device with predetermined speed selections and a concentrator is a programmable computer. Concentrators offer a number of advantages over multiplexers. Multiplexers employ fixed time slots on the high speed link to transmit data from the terminals and/or other devices being multiplexed and cannot take advantage of under utilization of some devices to accommodate increased utilization on others. Concentrators, on the other hand, with their buffering capability and programmed logic can use the high speed link to the optimal advantage of all devices [8]. Since concentrators are programmable they can perform automatic speed recognition to accommodate automatically different speed devices, whereas multiplexers are limited to a single speed or predetermined set of speeds. Concentration need not be performed on a computer devoted to that application but may be merely a function of a general purpose minicomputer which is also acting as one of the switching computers in a network such as is done in the TYMNET [20] and ARPANET [23]. One seemingly practical approach is to use concentrators as network nodes and use multiplexers to access the concentrator ports when terminal locations warrant it practical as is done on the GE

network [11].

The least attractive possibility for a network interface is the use of the host computer itself. This situation occurs when no special terminal interface has been developed for the network so that terminals can access the network only by connecting to their host computers as is presently the case with MERIT [24] and TSS [25]. This implies that to communicate with a remote system, processing must be done by both the remote system and the users host system, driving up overhead and costs.

Message switching computers are also relevant to the discussion of communications hardware. In order for a user to establish a connection with a particular computer, he can dial a unique number to make that connection, the number being different for each computer to which he wishes to connect (the number can also be given to a computer which will dial it by using an automatic calling unit). If a user, however, is to dial only one number, or be connected to one leased line regardless of which computer or computers with which he wishes to communicate, then a switching computer must be employed in the network architecture. The switching computer performs the store-and-forward function, that is, a message is received enroute, stored only until the proper outgoing line is available, and then retransmitted. In the ARPANET, for instance, the design end-to-end delay through several store-and-forward nodes is less than 0.5 seconds [26].

Each message contains an identification of the sending device
and an address for the receiving process allowing the switching
computer to route messages from any source to any destination.
The switching function can also be performed by mapping the
input ports of the switching computer to the appropriate
output ports [20]. Besides the inherent flexibility in soft-
ware switching, the store-and-forward technology allows for
optimal line utilization, since interprocess messages can be
mixed with interprocess messages involving different host
computers and terminal devices on the network. Also, the
switching computer can perform other functions such as con-
centrating terminals and interfacing to service computers.

3.3 Communications Software

Communications software can best be discussed in relation
to the control it exhibits over a network. The ARPANET uses
a well-structured layered approach [27] and the terminology
describing this structure is useful in discussing network com-
munications software. At the lowest level is the synchronous
communications protocol governing the exchange of information
between switching computers [19]. Next, the so-called first
level protocols control the exchange of information between
a host computer and its interface. Using these two protocols
in its implementation is the level two protocol controlling
the exchange of information between host computers [28].
Finally, there are the level three protocols which control the
information exchange between actual processes where a process

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may be a computer program or a user terminal [27]. At this level are the protocols which are very relevant to the user in relation to the utility of the network. In the case of ARPANET third level protocols exist to allow for initial connection to a remote process, to control communication between a terminal process and a computer process, to transfer data and files between processes, and to define remote job entry communications.

For a network to truly be a utility, there should exist in the hierarchy, a network control language which is concerned with human considerations related to the use of the diversity of systems that can exist on a network. In the network control language there should be a set of standard commands to perform common simple and intermediate system control functions regardless of the system being used on the network. For example there is a set of simple functions such as logging in, listing files and directories, etc., which should certainly be standardized in addition to some of the intermediate functions such as running common compilers and executing jobs.

The control functions from the lowest level on up can be distributed to various network components. It is useful to consider different possibilities to aid in understanding some of the concepts applied and the relationship of alternatives to networking considerations. If switching computers are involved some network component must be responsible for establish-

ing an initial connection between two processes desiring to communicate (a customer terminal and a host computer program for example). This type of control can be centralized in the network (even though topologically the network is distributed), such that every process desiring to communicate with another process on the network will do so by initially connecting to the same computer which will establish the desired connection [20]. Since a single computer is establishing all initial connections it may be more convenient to approach standardization in the connection mechanism relieving the user of the burden of learning a variety of protocols for the different systems on a distributed network. There is, however, enormous dependency on that single computer, and it is essential that backup systems be incorporated into the architecture. Another possiblity is to allow the interfaces to the network of the involved processes to be responsible for establishing the initial connection, thus distributing that function to all nodes on the network [23]. This removes the dependencies of those connections from any one computer implying that failures will cause only local disturbances.

The control of traffic flow through the network is another software function. The traffic flow between the various communications components will be typically controlled by ordinary line control procedures [29]. The flow control between processes can involve special software in the computers on which those processes are running. This is the

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situation with the ARPANET where interprocess flow control is host resident [28]. An alternative is to use the regular software controller of a particular computer to control inter-process communication. This can be done if all of the computers and systems are similar [25] or if a front-end device performs a mapping function between the network and the software con-troller [24]. Another alternative is to have a central com-puter be responsible for flow control accepting inputs from all processes in remote computers desiring to communicate [21]. The separation of communicating processes and the computer or computers which regulates the traffic flow between them can lead to the capability of sending information to a process on a computer which is not at the time available.

When a message can transverse more than one path in a network from a source to a destination, then the communication software must perform a routing function. If the network is circuit switched, then a physical connection is established at each switching point, and remains so established for the duration of the connection [25]. The software involvement is minimal, in this case, and can, for example control an automatic calling unit. If a logical or virtual circuit is established, then communications software residing in some network component or components must select the optimal path for the establishment of that circuit [20]. This can be done by comparing the conditions of the possible circuits to select that with some combination of least traffic and least errors.

In a message switching network, each individual message, is routed dynamically, or as in the case of ARPANET, messages are divided into packets, each of which is dynamically routed. Considerable attention has been given to the development of routing strategies for a packet switched network such that circuits are efficiently utilized and high throughput can be obtained [19, 30].

Another facet of network control is the measurement of network performance. It is possible to generate statistics to monitor the internal performance of the communications network, for example, queue lengths, message sizes, routing, etc., to aid in tuning the system and providing fault detection and correction [31, 32]. Another set can be recorded to provide more of an external measurement on network usage [4]. Recordings of traffic flow between nodes can be analyzed to determine proper distribution of facilities including placement and number of service computers, switching computers, and device interfaces, and bandwidth and topology of communication circuits. In addition usage statistics can be kept of the different processes available at the service sites and of the generic types of services available such as timeshared, batch, or graphics. Both the internal and external measurements will aid in determining the effectiveness of the computer network and the appropriate distribution of services.

3.4 Configuration

The preceding discussions have described network parameters which identify the network technology at a local level in terms of its components. To get a more global representation of a network technology, it is helpful to examine networks in terms of configuration and configuration alternatives. Alternatives will be considered relating to network topology, composition, size, and distribution.

Network topology can be centralized or distributed. Centralized networks, also called star networks, are those in which all nodes connect to a single node. This is a description of topology, only, and implies nothing about location of computing power, network control, or user distribution. The alternative topology is distributed where, in the limit, each node is connected to every other node, although the terminology is commonly applied to topologies approaching this full connectivity. There exists a third alternative which more accurately describes a certain condition of a distributed network. This is the ring configuration commonly used in describing the Distributed Computer System [33]. Observing the topology a ring can be seen connecting the nodes of the network. In the case of TYMNET a number of such rings are then themselves interconnected forming a multiring structure [20]. This is a special case of a distributed network.

For a network of distributed computers, a distributed topology would seem more practical for connecting existing computer

centers, in addition to the reliability factors that favor a distributed network. If it were the intention in building a network of constructing one large and reliable computing facility to which all customers could connect, then a centralized (or some modification of a centralized) topology might be in order [34]. If the intent is to connect to existing distributed centers, and not radically disturb the balance of computing power, a distributing topology is implied. There exists a potential arrangement using advanced communications technology where a network can be a centralized network while the computing power remains distributed. Consider using satellite communications to replace existing earth-bound long-line circuits. Transmission from any user (human or computer) to any process can travel to a satellite and, using the satellite's broadcasting ability, to the target [13]. This topologically, is a centralized network that allows for distributed computing power, and worth mentioning because a potentially powerful transmission medium is considered. To avoid ambiguities it is probably helpful to qualify statements of centralization or distribution with references to topology, computing power, switching, and network control. In the satellite example distributed computing power with central switching is the desired description.

As the terms composition, size, and distribution are fairly descriptive, little development is necessary other than the definition of alternatives. Network composition can be homo-

geneous or heterogeneous referring to the host computers on the network. If the network is homogeneous then all host computers are the same and if heterogeneous, all are not the same. The term heterogeneous is sometimes applied to networks having computers which are different models from the same manufacturer [21]. For this report, the most meritorious are those that are capable of connecting to the majority of existing large scale computing systems and not just different models of a computer. One of the details included in the survey in chapter 4 of existing networks will be a list of the actual computers connected.

The size of the network in terms of the number of nodes and distribution or actual location of those nodes is also important. For purposes of this report, it should be evident that a network can support on the order of thirty (30) to fifty (50) nodes with a national, and possibly, international distribution.

A number of technical factors have been identified to describe a network communications technology and characteristics of configuration have been discussed, and at the same time, a working terminology has evolved. Whenever possible, technological factors were considered independent of the other factors comprising a network technology, and evaluated using generalities as to their effective application in the Networking for Science Program. It is now possible to investigate existing networks and discuss the technology applied using the

aforementioned terminology subsequent to the comparison of
those varied approaches and the technology or technologies
that they represent.

4. EXISTING NETWORKS

It was not considered practical to attempt to review every existing network. The networks chosen are considered a fair representation of the various current approaches to network technology for networks of computers having potentially national scope. It is important to distinguish between a technology, which is the primary concern of this paper, and implementations based on that technology. This distinction is necessary because networks not included in this report may be reasonable alternative implementations employing the technologies represented by those chosen.

In this section selected networks are classified in terms of the technology or technologies that they represent. For each network, following a brief overview accompanied by graphical representations of the network, the communications enployed will be identified in relation to communications circuits, communications hardware and communications software using terminology developed in the previous section. Following this is a description of the network configuration, again relying on the aforementioned terminology. Then, if a network possesses any salient features related to the technology employed and in the author's opinion, particularly noteworthy they will be itemized. Finally, the network technology will be related to the previously discussed desirable support capabilities for a computer network.

4.1 TYMNET

TYMNET is a distributed network of heterogeneous computers (see Figure 1). It exists primarily to connect the users of the time-sharing service of Tymshare, Inc., to the computers of Tymshare. However, because of the wide distribution of communications facilities and the flexibility in host and terminal interfaces the network lends itself nicely to the connections of non-Tymshare host systems and their users nationally distributed. This is different from the kind of service that can presently be obtained from common carriers in that value is added to the carrier circuits because of the front-end, store-and-forward, error detection and retransmission, and concentration processing capabilities of the mini-computers which are an integral part of the network.

Overview

The network consists of approximately ninety (90) minicomputers, Varian 620's, interconnected by common carrier voice grade facilities. The Varian 620, when employed in TYMNET, is called a Tymsat and serves in two separate capacities, as a base Tymsat and as a remote Tymsat. The base Tymsat is responsible for acting both as a message switching computer in the communications network and as an interface to the network for host or service computers. When the host computer is one of those generally supported by Tymshare, such as an XDS 940,

DEC PDP-10, or IBM 370, the Tymsat has been programmed as a communications controller replacing the standard components for that function. Computers of a kind not employed by Tymshare have thus far been interfaced to the net through the Tymsat where the Tymsat sends and receives input and output appearing as a rotary of asynchronous modems to the standard communications controller for that machine, e.g., an IBM 270X or 3705 for an IBM 360 or 370. Presently under development is a Tymsat to replace the IBM communications controller. This will eliminate the need for the IBM 270X or 370X and allow for greater flexibility in terminal support. The base Tymsats are each connected to a host computer in either a one-to-one or one-to-two fashion (connecting approximately forty host computers throughout the country) and to one another either directly or through an intermediate base Tymsat in a multiple ring or distributed manner. The circuits used are from 2400 to 9600 baud synchronous, full-duplex, private leased lines.

Terminal Interface

The remote Tymsats act as store-and-forward computers and as concentrators for user terminals. Each is capable of supporting up to thirty-one (31) asynchronous full-duplex modems allowing for terminal speeds in the 110 to 300 baud range. In addition, some remote Tymsats with added hardware and software can support hardwired terminals in the 600 to 1200 baud range. The remote Tymsat can identify a terminal

by the first character typed as to its baud rate and carriage return delay time. It is possible to allow a terminal to connect with two different baud rates, one for input and one output. In addition, conversion to and from ASCII with the accompanying overhead is provided for EBCDIC or Correspondence coded terminals. The remote Tymsat also performs echoing when a user terminal is operating in echo-plex mode. The remote Tymsats are connected to the base Tymsats, and thus the host computers, in what is best described as a multiple ring configuration. A circuit passes through a number of remote Tymsats and one base Tymsat using store-and-forward techniques to exchange information between any remote Tymsat and any base Tymsat. The high speed links to the remote Tymsats (versus the low speed links which connect the terminals) are again 2400 to 9600 baud synchronous, full-duplex, private leased lines. Data is blocked and buffered and the usual error checking and retransmission, as necessary, is incorporated allowing for virtually error-free transmission between Tymsats. Error detection between terminal and Tymsat is accomplished through character echoing.

Character Transmission

When transmitting interactive traffic in a network there are two related problems for which TYMNET has implemented an interesting solution. The first is concerned with transmitting characters in echo-plex mode, which is almost always the situation when interacting with full duplex systems. The

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problem is to echo a character without any uncomfortable delays to the user. An uncomfortable delay would result, for example, if a user typed two characters in succession before the first was echoed. To meet this "instantaneous" echo requirement it is necessary to transfer a character through the network to the service computer, assigning the character and its echo a high priority. Of course, transmitting a single character is quite costly in terms of overhead since each unit of transmission must contain the appropriate header and error checking information. This is to identify the data as to source and destination and to insure its integrity. The TYMNET implementation provides a solution by having the remote Tymsat (that to which the terminal is connected) perform all echoing requiring immediate response (i.e., type ahead does not require immediate response). The second problem is that of reducing the "overhead to data" ratio in message transmission. Remote echoing helps by making it possible to buffer, prior to transmission through the network, an entire line of input from a user; because it is the line and not each character in the line that requires a response. The TYMNET approach to the blocking of data goes further to ameliorate the overhead problem by collecting, at each Tymsat, the input from multiple sources destined for the same output port, to form a single block. The maximum block size is 66 characters and the attempt is to approach that maximum prior

to transmission thus increasing efficiency in terms of the
message overhead to data ratio. Of course there is com-
putational overhead at each node (Tymsat) since sending nodes
must assemble the characters of a block and receiving nodes
must disassemble them.

Virtual Circuits

Blocks are transmitted through the network over full-
duplex virtual circuits. These circuits are established at
log-in time and exist for the duration of the interaction
between terminal and processor. The circuits are not
physical but exist as table definitions in the software of
involved Tymsats associating an input channel with the
appropriate output channel at each switching point (Tymsat).
A circuit is established by the network supervisor (computer
program) in active mode (Sam). TYMNET provides multiple
paths for circuits in the event of line failure. When a
user connects to TYMNET he is originally communicating with
the Sam which after the appropriate exchange of information
will establish a circuit from that user's terminal to the
proper service computer by selecting the appropriate Tymsats
to complete the virtual circuit. The Sam is so named because
it is a function which can be overtaken by one of three
backup supervisors in the event of failure. A backup
supervisor will become active by detecting a failure, polling
the Tymsats to get network status information, and assuming
the active role. This is performed transparent to users

other than those who may have been connected to the pro-
cessor running the Sam that failed. It should be noted
that in the event that a processor fails, its base Tymsat
can still function in the role as a network store-and-forward
computer. Since virtual circuits are established and fixed
for the duration of processor interactions, recovery from
a physical line failure is not as clean. When a line fails,
users communicating through virtual circuits using that line
in their definition must reconnect.

At this time the TYMNET computer network can have 900
individual users simultaneously connected to the network.
The communications network exhibits a high degree of
reliability with a stated average 1.4 failures per node
per year. Presently, most usages are through interactive
terminals because the TYMNET does not support remote job
entry. However, high-speed printers exist in many field
offices to which large volume printing may be routed.

TYMSHARE, INC.
TYMNET
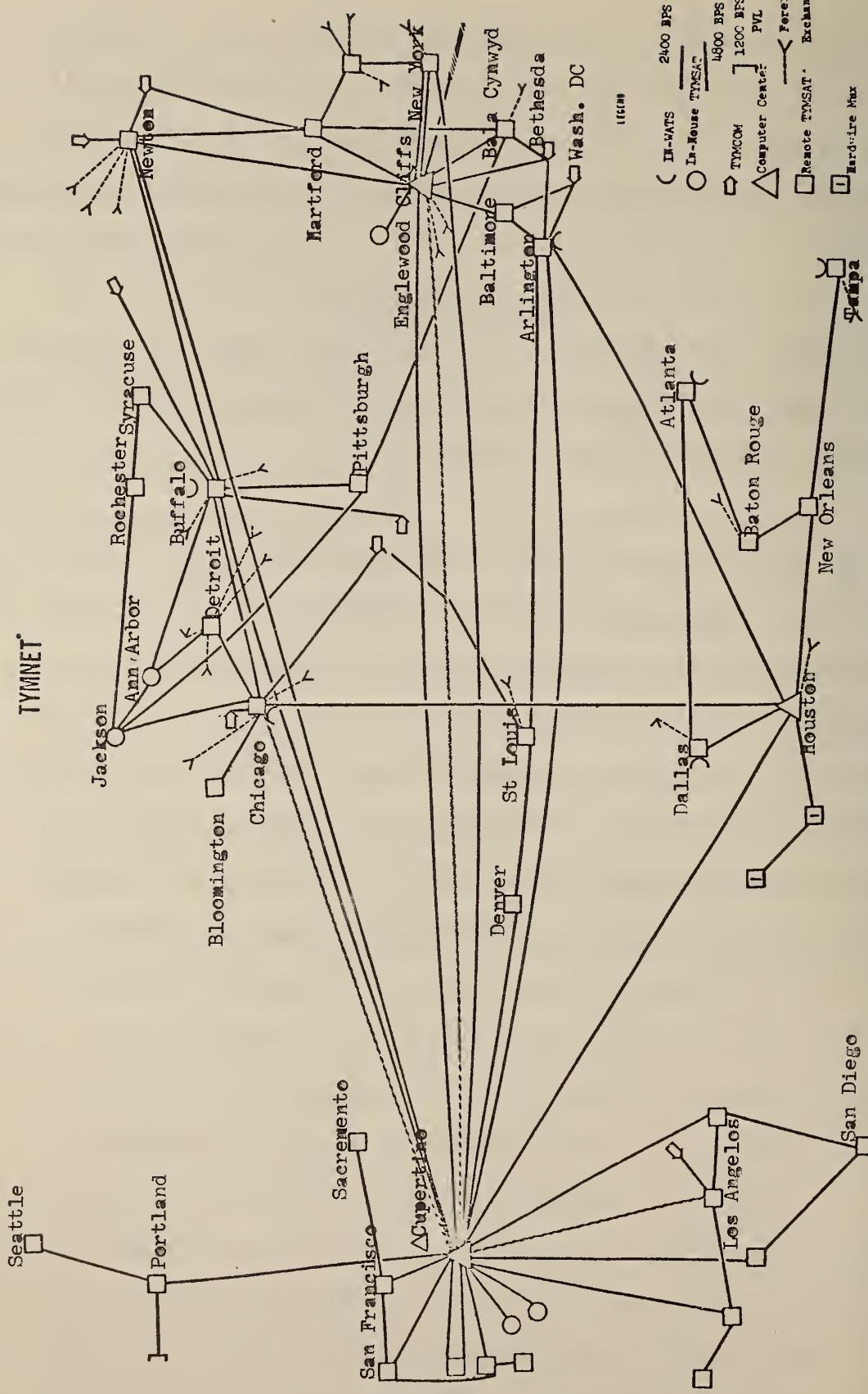
Figure 1

Communications

Communications Circuits

> Internode - circuits are voice grade, leased, synchronous operating at 2400, 4800, 7200, or 9600 baud.

> Terminal to network - circuits are full duplex dial-up or hardwired operating at 110 to 300 baud (dial-up), 600-1200 baud (dial-up in certain cities), and 600-1200 baud (hardwired).

> Interprocess - virtual circuit established at log-in time by the network supervisor in tables in the store-and-forward nodes.

Communications Hardware

> Single host interface - a Varian 620 (8K of 16 bit words, 1.8 μsec cycle time) called a base Tymsat, also acting as a store-and-forward node.

> Dual host interface - a Varian 620 L-100 (12K of 16 bit words, 1.0 μsec cycle time).

> Terminal interface - a Varian 620 called a remote Tymsat also acting as a store-and-forward node. Each remote Tymsat supports up to 31 asynchronous, full-duplex terminals and performs speed recognition, local editing, and character conversion.

Communications Software

Initial connection - all users initially connect to the
same processor, the supervisor in active
mode, (Sam), which will establish the
optimum communications circuit between the
user and the appropriate processor on the
network. Alternate routing occurs during
leased line outages. The Sam also acts as
a service computer on the network.

Protocols - computer processes communicate by looking
like terminals to one another.

Configuration

Topology

    Distributed - service computers, store-and-forward nodes,
          and user terminals are well distributed and
          interconnected in a multiple ring config-
          uration.

    Actual distribution - international connecting 53 cities
          throughout the nation in addition to a link
          to Paris, France.

Composition

    Heterogeneous - XDS 940

                  XDS Sigma 7

                  DEC PDP 10

                  DEC PDP 9

                  DEC PDP 15

                  IBM 370/155

                  IBM 370/158

                  IBM 360/40

                  IBM 360/50

                  IBM 360/65

                  IBM 360/67

                  Burroughs B6700

                  Honeywell G275

                  Univac 1108

                  CDC 6400

Size - approximately 40 host computers, over 90 communi-
cations nodes serving 900 individual users
simultaneously.

Salient Features

TYMNET is reliable with an average number of failures of 1.4 per year for a Tymsat and an error rate of less than one bit in 4×10^9 bits transmitted.

The communications facility is efficiently utilized supporting approximately 46 users operating at speeds of 110 to 300 baud on a 2400 baud circuit.

Terminal recognition is automatic with baud rate, character rate, and carriage return delay time detected and input and output speeds may be set independently.

The network supervisor in active mode which controls all connections can be transferred in the event of failure to another processor without effecting users. It maintains the current status of all network activities.

TYMSHARE will lease the communications service (TYMNET) exclusive of its host systems, allowing a customer to connect his own computer to the network to serve his own users. This service is charged for on the basis of value added to common carrier facilities and operates under FCC Tariff Number 260, Shared Facilities. The service is presently used by many organizations including the National Library of Medicine in Washington, D. C.

Terminal Support Capabilities

Interactive

    Code - network code is ASCII although terminals may
        operate in ASCII, EBCDIC, or Correspondence code.

    Speed - 110 to 300 baud dial-up and 600 to 1200 baud
        hardwired (requiring on-site Tymsat).

    Mode - full-duplex.

Remote Job Entry

    RJE support does not exist but is planned for future
implementation. A synchronous protocol may be developed
in a Tymsat-like device to support RJE devices of the
IBM 2780 variety.

Minicomputer-based Systems

    No minicomputers are on the network other than as an
integral part of the communications net (Tymsat). There
is no support for synchronous communications at the user
level and the bandwidth is presently limited to 9600
band on the high speed circuits.

Computer-to-Computer

    One computer can connect as a terminal to another and
vice versa allowing for interprocess communication.
Files can be transferred from one processor to another
in this manner.

4.2 CYBERNET

CYBERNET is a commercial network of large to super scale Control Data Corporation (CDC) computers and it operates as a division of CDC. These computers have been connected to a communications network (see Figure 2) to form a national computer network satisfying a number of important objectives. Reliability is increased by allowing a user to access an alternative computer in the event of a failure of his local computer. Workloads can be leveled among the participating systems by routing jobs from loaded systems to unloaded ones. Computers can be better utilized by specializing in applications to which they are best suited and the network allows for the routing of jobs requiring those applications to the proper computers. Large data bases can be kept at selected sites and need not be copied at each site to be accessible since the network will provide access as required. Also access to the super computer CDC 7600, when connected, will be more generally available with the national CYBERNET network. This presentaion is limited to the U.S. but CDC is evolving similar networks using the same technology in Europe and Australia, and on a smaller scale, in other countries

Overview

The technology employed by CYBERNET is difficult to characterize. It is heterogeneous in that it interconnects different models of Control Data computers including the

CDC 6600, CDC 3300, and CDC 6400, and plans exist to connect
a CDC 7600. The communications links interconnecting com-
puters are a combination of voice grade and wideband, and
even include a satellite link. The switching mechanism
employed is mostly line switching but a special use of mes-
sage switching exists. The topology, control, switching,
and computing facilities are all distributed. CYBERNET
appears to be an add-on network where new technologies are
incorporated as needed, void of commitments to particular
hardware, software, or communications facilities.

Centroids

The bulk of the computing power for the network is
performed by the centroids. The centroids are all currently
CDC 6600's operating under SCOPE operating system, although
because of the SBC acquisition, plans call for connecting
IBM 370's. Access to the centroids is primarily via wide-
band batch terminals (see "Terminal Interface"). The
centroids are interconnected with full duplex 40,800 baud
wideband communication links. The switches employed are
multiway wideband switches. These switches connect to
each other in a distributed fashion, to the centroids, one
per switch, to the nodes, one or more per switch, and to
the wideband batch terminals. The CYBERNET concept of nodes
will be discussed later. The switches allow the terminals
to access the facilities of the network providing flexibility
in that the terminal can connect to any centroid, and provid-

ing down time back up and load leveling.

It should be pointed out that load leveling is not automatic, but involves a human decision to use, by dialing, one facility rather than another. Also down time back up for any job is entirely dependent upon that job not using permanent disk files, since the file systems are host dependent.

Nodes

The term node as used in CYBERNET refers to computers which act as processors and store-and-forward computers. The nodes are actually CDC 6400's using the KRONOS time-sharing operating system. Their main purpose is to provide time-sharing service to low-speed interactive terminal users. It is, however, possible to access the batch computers - CDC 6600's - from a low-speed terminal indirectly through the CDC 6400's. Jobs can be submitted via terminal to the CDC 6400 KRONOS time-sharing system destined for the CDC 6600 SCOPE batch system and KRONOS will forward the job to SCOPE using a wideband switch. One paper presents plans for the nodes to have a number of important capabilities for load balancing and resource sharing [10].

Terminal Interface
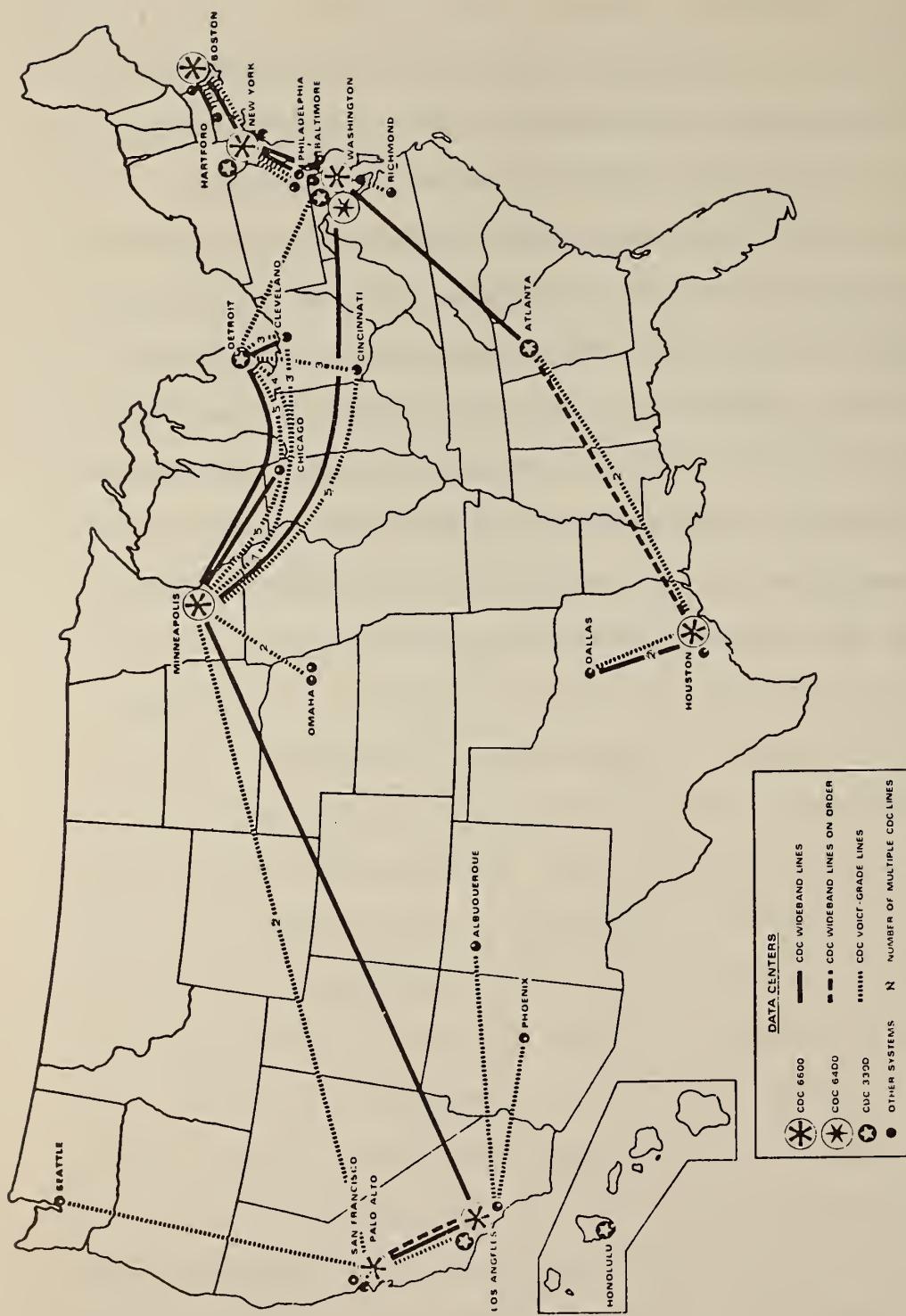
Terminal support on CYBERNET includes support for inter-active or conversational terminals, remote peripheral pro-cessors, satellite computers, and computers with terminal facilities. The interactive terminals are those of the 110

to 300 baud range and using ASCII. The remote peripheral processors are conventional computer peripherals driven at a remote site. The typical configuration is a card reader, a line printer, and a modem controller. Supported are low speed (2000-2400 baud), medium speed (2400-4800 baud), and high speed (40,800 baud) devices using 300 card per minute (CPM) and line per minute (LPM) readers and printers, 600 CPM and LPM readers and printers (planned), and 1000 CPM and LPM readers and printers respectively. The CDC 200 User Terminal is the standard CYBERNET device for low and medium speed remote peripheral processors. It is a hard-wired rather than programmable peripheral device. The satellite computers are programmable peripheral processors and appear to the network as the hardwired remote peripheral processor. They are distinguished by their ability to do off-net processing and, when on-net, can support the higher speed readers and printers. The satellite computers pres-ently used number over 25 including: Honeywell 200 series, Univac 9200's, and IBM 1130's. The last class of terminals are computers with terminal facilities which are computers which have been programmed to behave as terminals to the network. This is the manner in which the larger scale IBM 360's access the network. At this time nearly 800 remote peripheral processors, satellite computers and computers access CYBERNET. In addition the CDC 6400 KRONOS system and the CDC 6600 SCOPE are programmed to appear as terminals

to the net while simultaneously serving terminals connected
to them.

The look alike technique is important for computer-to-
computer communications on CYBERNET. The standard remote
peripheral processor for CYBERNET is the CDC 200 User
Terminal, but other devices have been programmed to look to
the network like the CDC 200 including: CDC 8090, CDC 160A,
IBM 1130, UNIVAC 9200, UCC's COPE, Honeywell 200, and IBM
360/30 and larger IBM 360's. The nodal computers can look
like wide band terminals to the centroids and to each other.
This is an uncomplicated method of performing computer-to-
computer commmunication and renders it less difficult for
incorporating new systems into the network.

The CYBERNET Network

Figure 2

Communications

Communications Circuits

    Internode - full-duplex 40,800 baud wideband facilities
between wideband switches. A plan calls for
switching nodes being developed which will
initially be connected by 2400 and 4800 baud
lines [10].

    Terminal to network - voice grade operating a 110 to
4800 bits per second and wideband facilities
at 40800 bits per second to connect terminals
which include interactive terminals, remote
peripheral processors, and satellite com-
puters.

    Interprocess - all interprocess communication, node to
centroid for example, is via a look alike
technique where one process appears as a
standard network terminal to another. These
communications are established by direct
connection or connection through a wideband
switch.

Communications Hardware

    Host interface - multiway wideband switch can interface
host or hosts to the network.

    Terminal interface - terminals connect (multiplexed or
individually) through the host computers,
the nodes, or the wideband switches. Ter-

minals can be computers.

Communications Software

    Initial connection - user selected through appropriate settings on wideband switch. Also done automatically by nodal computers.

    Protocols - computers communicate through look-alike techniques appearing as network standard terminals or peripherals to the network.

Configuration

Topology

    Distributed - nodes, centroids, and user terminals are
          distributed.

    Actual distribution - computer centers exist in at least
          12 cities around the country and links exist
          to over 45 cities including Honolulu and
          Anchorage, Alaska. KRONOS systems are in
          Washington (3), and Los Angeles and over 30
          metropolitan areas are covered with local
          phone service.

Composition

    Heterogeneous - CDC 6600
                  CDC 6400
                  CDC 3300

    Peripherals -   IBM 360
                  CDC 3150
                  CDC 8090
                  IBM 1130
                  UNIVAC 9200
                  Honeywell 200

    Size - at least 9 CDC 6600 SCOPE batch computers and 4
          CDC 6400 KRONOS time-sharing computers with
          a large number of users (approximately 600
          simultaneous users on KRONOS and 250 RJE
          stations on SCOPE).

Salient Features

Many companies add value and resell at a higher price via terminal the facilities of CYBERNET and do therefore not have to have their own computers to be in that business. Bulk discounts apply.

Several packages are offered through CYBERNET by independent companies on a royalty basis including a dynamic structure package, a time series analysis package, a 1970 Census Tape processing package, a data management system, and a crystallography package.

Super computer processing power is made available on a nationally accessible basis to the paying customers of CYBERNET.

Terminal Support Capabilities

Interactive

   The code is ASCII, speeds are in the 110-300 baud range
   although nothing in the design precludes higher speeds,
   and the mode is half-duplex.

Remote Job Entry

   Support is extensive centered around the CDC 200 User
   Terminal which is a non-programmable device supporting
   a card reader, a line printer, and a modem controller.
   Other devices can be programmed to look like this device.
   Card readers and line printers operate in the speed
   range of 300-1000 plus cards per minute and lines per
   minute.

Minicomputer-based Systems

   Minicomputers have been programmed to look like either
   remote peripheral processors or as so many terminals to
   the network.

Computer-to-Computer

   Computer communicate by look alike techniques to the
   network.

4.3 GE Information Services

The General Electric network is a commercial network
implemented to make available the computing services of
General Electric Information Services. The network encom-
passes over 300 cities in North America, Japan, and Europe,
making it international in scope. The communications net-
work allows a user to make a local phone call to connect to
the main computing facilities in Cleveland, Ohio, providing
services ranging from light computation to remote batch
processing. The network has the interesting capability of
connecting customer in-house computers to GE network service
computers for the purpose of exchanging files. This will
be discussed later.

Overview

The GE network is a centralized, hierarchical network.
Topologically, all communications paths lead to the central
facility. The central facility itself is composed of a
number of processors with varying capabilities, switching
computers which allow flexibility in the choice of user-
processor connections, and central concentrators which
establish initial connections and act as interfaces between
the processors and the network. There are presently two
switching computers and each central concentrator is con-
nected to both of them. They are able to switch messages
between central concentrators. Each central concentrator
acts as a network interface for from one(1) to six (6)

processors. Moving out from the central facility, each
central concentrator can connect to a maximum of eight (8)
remote concentrators. At the present, more than fifty (50)
remote concentrators are in service. The remote concentra-
tors typically have forty-eight (48) ports connected to
the public switched network using local loops, foreign
exchange, and frequency division multiplexers. The FDM
multiplexers can multiplex up to nine ports on a voice
grade circuit. Finally, there is the user at his terminal
who can dial a local number and through the hierarchy of
communication, establish a connection with the desired
processor.

Remote Concentrators

The remote concentrators are Honeywell 416 or GE Diginet
1600 minicomputers. They act as network interfaces for ter-
minals of speeds up to 300 baud. They are responsible for
recognizing terminal speed, code, and other characteristics.
All non-standard codes are converted to ASCII before trans-
mission onto the network. There is no echo'ing (characters
are printed by the terminal when a key is depressed) and
transmission is line at a time, that is, characters are
buffered until a line is completed before transmission on
the network. The remote concentrator can also perform line
and character deletion editing. In addition, it is able to
recognize whether a terminal is entering a command or data
(as in file building) and only interrupt the central system

when a command has been entered. Each remote concentrator

is connected to a central concentrator by a pair of 4800

baud voice grade lines. There also are being developed

remote high speed concentrators using Diginet 1600's [11].

These will support synchronous terminals up to 4800 baud.

Included in the set of synchronous terminals are computers,

and in particular, an OS teleprocessing package has been

developed to permit IBM 360 or IBM 370 computers to inter-

face through the high speed concentrator. The high speed

concentrators will initially connect to the central concen-

trators over dual lines at 9600 baud. At this time remote

job entry devices and IBM 360 or 370 computers connect to

the central facility via 2000 or 4800 baud dialup circuits.

Central Facilities

The central concentrators are Gepac-4020's. They store-

and-forward data to and from terminals in their role as

interfaces between the host and the network and also between

remote concentrators and the network. Host or central

computers are connected in a variety of ways depending on

the host involved including direct memory to memory inter-

facing and remote communications channels using synchronous

communications protocols. The central concentrator deter-

mines to which system the user is to be connected at log-

on time. If it is a system that is not connected directly

to the concentrator, then the concentrator will send all

messages from the user to a switching computer which will examine the destination address for each message and route it accordingly. The circuits are two-line links in the speed range of 4800 to 14400 baud. The switching centers which provide the connections between concentrators are Gepac-4020's or Diginet 1600's. There presently exist two switches which operate independently. The host or central processors themselves can be either G635's, G605's, G265's, or HISI 6000's.

Computing Services

The network and its central system offer different kinds of computer services depending on the host computer being used. The Mark I time-shared system offers BASIC, ALGOL, and a simplified version of FORTRAN. The Mark II time-shared service is an outgrowth of Mark I and offers extended capabilities including geographically distributed transaction oriented processing, and it runs on the Honeywell G635. The most interesting service is the Mark III which combines the Mark II time-sharing system and the GECOS III remote-batch system running on the larger Honeywell 6080. All on-line activities are handled by the Mark II (called Mark III foreground) which is optimized for that kind of work. Large batch tasks are done by GECOS (called Mark III background) likewise optimized for batch. A high-bandwidth interface allows background work to be submitted by Mark II across the interface to GECOS. Therefore, batch jobs originating from

low or high speed terminals connected to Mark II, can be run
on the background GECOS and the output sent back to a file
on Mark II where a user can print it on a high speed printer
or scan it with his terminal. The high bandwidth communi-
cation channel between Mark II and GECOS is actually a
shared disk device. This is not to imply that the two have
a common file system, on the contrary, the file systems are
independent and distinct.

Interprocessing

GE's facility known as Interprocessing is an exciting
concept. A customer is permitted to use his in-house
computer for production-type processing, then transfer his
files through the GE network to the central computers, to
make them available on-line throughout the international
network for customer interactive query and update. Period-
ically, the updated files are transferred back to the cus-
tomer's in-house computer. Pontiac Division of General
Motors uses the Interprocessing capability of the network
maintaining order and delivery information for its thousands
of automobile dealers [35].

For the future, there are indications that GE will expand
the Mark III foreground - background concept to include other
manufacturer's equipment for running the background jobs,
including IBM systems and possibly the Control Data 7600 [34].
Also considered is the possiblity of supporting remotely

located background systems such that a customer owned and
operated computer could be connected to the network as a
background system. This would allow a customer to couple
his machine and applications to the massive on-line capabil-
ity of the GE network.

Communications

Communications Circuits

Remote to central concentrator - dual 4800 baud voice
grade.

High speed remote to central concentrator - dual 9600
voice grade.

Central concentrator to switching center - dual links in
the speed range of 4800-14400 baud.

Terminal to network - maximum for asynchronous terminals
is the 300 baud and 4800 baud for synchronous.
Low speed terminals connect to frequency
division multiplexors which connect to the
remote concentrators.

Interprocess - user terminals are connected through their
remote and central concentrators to the pro-
cessor or processors connected to that
central concentrator or, using message
switching, are connected to processors on
other central concentrators (concentrators
to which their remote concentrators are not
directly connected).

Communications Hardware

Host interface - hosts interface to the network through
the central concentrators which are GEPAC-
4020's. More than one processor (six max-
imum) can be connected to a central concen-

trator.

Terminal interface - asynchronous terminals, after
multiplexing, interface to the network
through the remote concentrators which are
Honeywell 416's or GE Diginet 1600's. Syn-
chronous terminals will in the future inter-
face through high-speed concentrators using
Diginet 1600's. At this time synchronous
terminals must dial the central concentrator
facilities.

Communications Software

Connection - central concentrators connect user terminals
to the appropriate processor using informa-
tion in the user number.

Traffic flow regulation - distributed between remote
and central concentrators.

Protocols - computers can connect to the network using
BTAM (Basic Terminal Access Method) operating
under OS. This facility is limited to IBM
360's and IBM 370's.

Configuration

Topology

    Centralized - all communications feed into a central system in Cleveland. Within that central system the compute power is distributed among a number of processors.

    Actual distribution - the network extends via local telephone to over 250 cities in the U.S., nine cities in Canada, Mexico City, San Juan, London, Birminghan, Manchester, Brussels, and Amsterdam. ·

Composition

    Heterogeneous - GE 635
                      GE 605
                      GE 265
                      HISI 6000

    (plans call for background systems employing IBM and CDC machines [34]).

    Size - Approximately 50 remote concentrators in 13 U.S. and European cities. Each concentrator can have 48 user ports. Maximum capacity is on the order of 2000 simultaneous users. The total customer base is 3000 firms with over 10,000 individual users [7].

Salient Features

A service called Interprocessing is offered in which files from a customers own computer may be transferred through the network to the GE system computers for on-line access by the customers terminals, possibly, distributed throughout the country. Updated files can be periodically sent back to the customers computer.

In addition to the time sharing services, background systems, interfaced to the network through the time sharing systems, run batch jobs submitted via terminal or remote job entry stations.

Plans call for the introduction of IBM and possibly CDC equipment into the network for running background jobs lessening incompatibility problems with customers facilities.

Terminal Support Capabilities

Interactive

   Code - ASCII, EBCD, Correspondence.

   Speed - 10, 14.8, 15, and 30 characters per second.

   Mode - half-duplex.

Remote Job Entry

   Synchronous support is provided for the IBM 2780 binary

   synchronous line discipline and compatible devices. The

   high speed code is EBCDIC. The connection is via 2000

   bit per second dialup to the central facility although

   high speed remote concentrators are being developed.

Minicomputer-based Systems

   Synchronous interfaces and sufficient bandwidth exists

   to support these systems although no such applications

   presently exist.

Computer-to-Computer

   With the appropriate communications adapter (IBM 2701,

   2703, or a 3705 emulating a 2701/2703) and a GE-provided

   software package, certain computers can connect to the

   high speed service as does a remote job entry device.

   These are all IBM 370's and IBM 360's models 22 and up

   using IBM OS-BTAM. The interconnection is used mainly

   for large file transfers.

4.4 MERIT

MERIT is a state network developed with funds provided by the National Science Foundation, the State of Michigan, and the three participating universities: Michigan State University, University of Michigan, and Wayne State University. It interconnects the computing facilities at these three universities, IBM 360/67's at two nodes and a CDC 6500 at the third (see Figure 3), and provides a working model to study the problems associated with the use of remote computing facilities, that is, the use of computing facilities at a university different from the university of the user. The several problems being analyzed, in addition to the technical development of the network, include the following: the provision of a mechanism for exhanging computer dollars among the universities; the inclusion of the smaller state universities into the network and finding a suitable mechanism for payment of the communication facilities; and the problem of informing potential users of services that are available on the network and the detailed procedures of using the network resources [36].

Communications Computer

The technology used in this network goes beyond the much simpler directly connected host-to-host network by employing communications switching computers which act as interfaces between the host computers and the network, and also as store-and-forward nodes. The Communications Computer

is a Digital Equipment Corporation PDP-11/20 with 16K of 16-bit memory. The primary purposes of the Communications Computers are the following: to multiplex logical connections over physical communications links communicating with other nodes using a binary synchronous communications protocol, to receive messages from their respective host computers for transmission on the network, and to receive messages from other nodes for delivery to their hosts or for forwarding to another host.

The interface between the Communications Computer and the host computer is a special hardware device. It allows for the transmission of software determined length data records to and from the memory of the Communications Computer (CC) performing whatever memory alignment operations are required for word lengths which differ from that of the CC. It also provides a multi-address capability which allows the host to treat the CC as many identical devices. This simplifies the task of programming the host computers since the CC does all the multiplexing functions.

Network Control

To interface a host to the network requires no changes in the operating system of that host computer. Instead the network features are extensions to the operating systems, requiring only that device support for connections, which appear similar to other peripheral devices, be added to the system. Therefore, when a connection is established be-

tween processes in independent host computers, the con-
nection behaves as an input/output device in each host. An
initial connection is established to prepare the "connection
device" for record traffic by a single user request. The CC
propagates this connection request through the network to the
remote process and then the connection is completed with the
allocation of a "connection device" to each process. Traffic
is exchanged through the read/write mechanisms of the host
computers under the control of a network master/slave
mechanism to regulate traffic flow. The master, the remote
end of the connection, can always initiate the sending of a
record to the slave. The slave is restricted to send one
record on each go-ahead from the master. The record traffic
regulation mechanism, as can be noted from the preceding, is
resident in the host computers.

Circuits

The original communications circuits interconnecting the
CC's were 2000 baud dial-up facilities. Each CC was inter-
faced to a maximum of eight (8) direct dial telephone lines.
To establish full duplex channels, two (2) dial up telephone
lines were used to form a single communications channel, thus
giving each CC a maximum of four (4) full duplex channels.
These channels could be evenly distributed among the three
(3) computers in the network, giving two links between each
pair of computers, or they could be distributed unevenly to
match the traffic requirements. A single automatic calling

unit was employed by each CC to automatically dial lines as
required. This single unit by a special multiplex arrange-
ment was shared among the direct dial telephone lines.

In the fall of 1973 the dial-up communication channels
will be replaced with point-to-point channels operating at
4800 baud. These full duplex channels require only one
line rather than the two lines previously used.

The number of logical connections between computers is
a function of facilities available to service those con-
nections themselves. These logical connections are multi-
plexed by the CC over the physical connections.

Command Language

A network command language exists for communicating with
remote hosts. Commands exist for logging into remote hosts,
copying files to and from remote hosts, transmitting and
receiving records with remote hosts and a number of other
useful activities. Since network access is only through a
local host computer, an overhead in terms of local proces-
sor time and money is associated with communicating with
remote hosts.
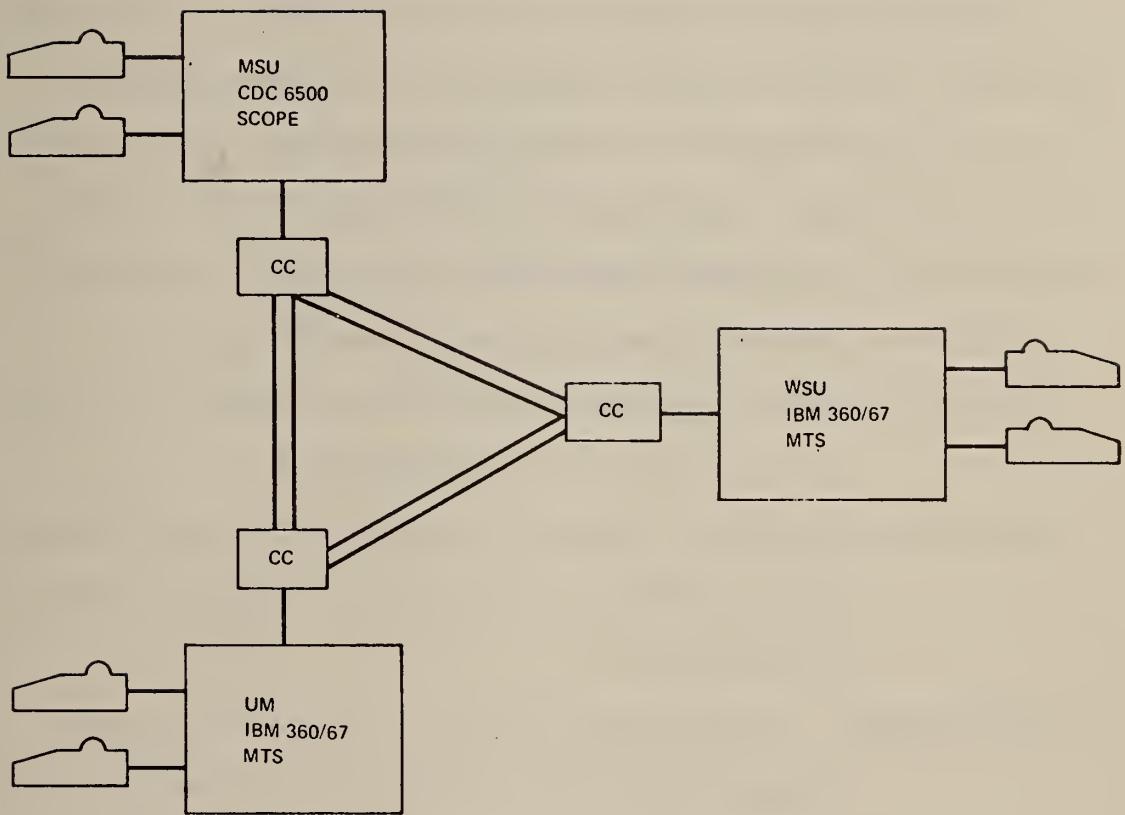
Figure 3

Communications

Communications Circuits

    Internode - circuits are voice grade, dial-up using
Bell Telephone 201A's to operate at 2000
baud. Full duplex is achieved by associating
two (2) dial-up lines with each channel.
Eight lines stem from each node for sending
and receiving, thus forming 4 full duplex
2000 baud channels. Upgrading to point-to-
point lines using Bell Telephone 208's
which operate at 4800 baud. Each full duplex
circuit will require one line.

    Terminal to network - access to network is only through
host computers. No special terminal inter-
face exists.

    Interprocess - connection between a pair of processes
appears as an I/O device in each host. Once
allocated to a process, a connection is
dedicated to that process.

Communications Hardware

    Host interface - interfaced through Communications
Computer (CC) (DEC PDP-11) which can also
act as a store-and-forward node. The CC
appears as a number of identical but separate
I/O devices to its host.

Terminal interface - only through host computer.

Communications Software

Initial connection - function is distributed and
accomplished by allocating a connection
device (host thinks its an I/O device).

Protocols - network interactive service allows users to
access resources on a remote host and to
control file transfers and process-to-
process computing. Network batch allows users
to submit batch jobs on their local host
for subsequent execution and/or printing
elsewhere.

Configuration

Topology

    Distributed - nodes exist in three universities, one
                node per university.

    Actual distribution - Michigan State University, Uni-
                versity of Michigan, and Wayne State Uni-
                versity, all in Michigan.

Composition

    Heterogeneous - IBM 360/67
                     CDC 6500

    Size - 3 nodes with one host computer at each.

Salient Features

A special multiplexing system was developed to allow an automatic calling unit to be shared by eight (8) dial-up lines.

A network command language exists for communicating with remote computers and provides some file and record transfer capability.

Communication interface units have been designed to permit the use of wideband facilities if desired at some future time.

Host software has been greatly simplified by allowing the host to treat the communications computer as several peripheral devices.

Terminal Support Capabilities

Interactive

    Code - no terminal interface but Communications Computers
translate local host character strings to ASCII.

    Speed - as determined by host through which terminals
interface.

    Mode - as determined by host.

Remote Job Entry

    Protocols - none.

    Device support - as supported by host. No separate RJE
network interface exists.

Minicomputer-based Systems

    Interface - no special interfaces or software support
other than what may be supported locally by a host com-
puter.

Computer-to-Computer

    Protocol - exists for host to host communications.

    Implementation - network connections appear as I/O
devices to a process.

4.5 ARPANET

ARPANET is a distributed network of heterogeneous computers employing store-and-forward packet-switching communications techniques. There has been interest shown in making ARPANET technology publicly available, possibly on a regulated basis. At this time there is a proposal by Packet Communications Inc., to offer a packet-switching service providing the host interfaces, network control programs, communications links, and terminal processors to compete for the data communications market [37]. This proposal stands as a formal application to the FCC along with an application by MCI Data Transmission Corporation (MDT) to offer a similar kind of service. Two other corporations, Telenet Communications Corporation and Telecommunications Network Inc., have also expressed an interest in this type of service.

Overview

The communications network or communications subnet is composed of interface message processors (IMP) and terminal IMPS (TIP) connected in a distributed fashion by 50,000 baud synchronous wide band circuits (see Figure 4). The IMPS are Honeywell DDP 516's with 16,000 words of memory which act as interfaces for host computer systems and as store-and-forward nodes in the network. A host is connected to an IMP and thus to the communications subnet by a channel, and if the host is very distant from the IMP, it can con-

nect via a synchronous communications line using block control procedures [38]. The latter method is appealing in that it eliminates the requirement of locating the IMP, a component of the communications subnet beside the host computer that wishes to connect to it. It is conceivable that the communications subnet could become physically independent and hosts would connect to the nearest IMP using the synchronous link. Presently each IMP can interface from one to four host computers to the network. The software interface between host and IMP is called the network control program (NCP). It is responsible for initiating connections, regulating traffic flow, and realizing network protocols between all communicating processes. The NCP resides wholly in the host computer thus making the host an integral part of the communications network for communications to and from the host. The NCP is closely related to the supervisor of the host system [39] and is difficult and time consuming to implement for even first rate systems personnel. Proposals have been presented to transfer some of the NCP functions to the interface processor and possibly diminish the developmental efforts of interfacing a new host [40]. In addition, some organizations are investigating the use of minicomputers as front end processors performing the NCP functions in addition to such functions as peripheral control. It is important to realize that tradeoffs do exist in the different approaches.

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Moving the NCP into a front end processor eliminates the
need to make extensive alterations in the host system
software and can reduce the overhead associated with run-
ning the NCP in the host computer. However, all communica-
tions to and from the host computer would be limited to the
capabilities of the host's standard software and hardware
controller.

Packet Switching

Host-to-host messages are passed from the sending host
to its IMP, where they are broken into packets (thus the
term "packet switching" used in describing the ARPANET) and
relayed to their destination by the network of IMP's using
store-and-forward techniques. Packet routing is adaptive to
the conditions of the network considering failures and load-
ing characteristics and, in general, the several packets of
a single message may follow different routes. The destina-
tion IMP will reassemble the message and deliver it to
proper host. The overhead of dynamic routing should be
compared to the advantages gained over techniques where a
route is chosen for communicating between two processes on
the basis of communication facilities loading and then not
dynamically altered for the duration of the connection.

Protocol Levels

Protocols in the network are constructed according to a
layered approach. The lowest level protocol is a synchronous
communications protocol governing traffic exchange between

the IMPs. Error checking is extensive and retransmission takes place as necessary. The so-called "first level" protocol governs the exchange of information and data between host and IMP. The "second level" protocol governs the logical exchange of information between Network Control Programs in communicating hosts. The "third level" of protocol refers to any communications occurring between processes in host machines. Such protocols include the initial connection protocol, which can be used by all processes to initially communicate, the file transfer protocol, the remote job entry protocol, and the telnet protocol. Some third level protocols make use of other third level protocols. For example, the remote job entry protocol as recently defined uses the telnet protocol which in turn uses the initial connection protocol, and it also uses the file transfer protocol. The hierarchy of protocols is such that all higher level protocols use the lower level protocols to function.

Terminal Interface

TELNET is a special third level protocol which defines a network virtual terminal and permits all terminals on the network to provide a similar interface to processes in any host. This allows for the use of any terminal supported by the network, and support is extensive, with any host system on the network even if a host could not support a particular terminal through its standard terminal controller. A special IMP which is augmented by the addition of 12K of memory and
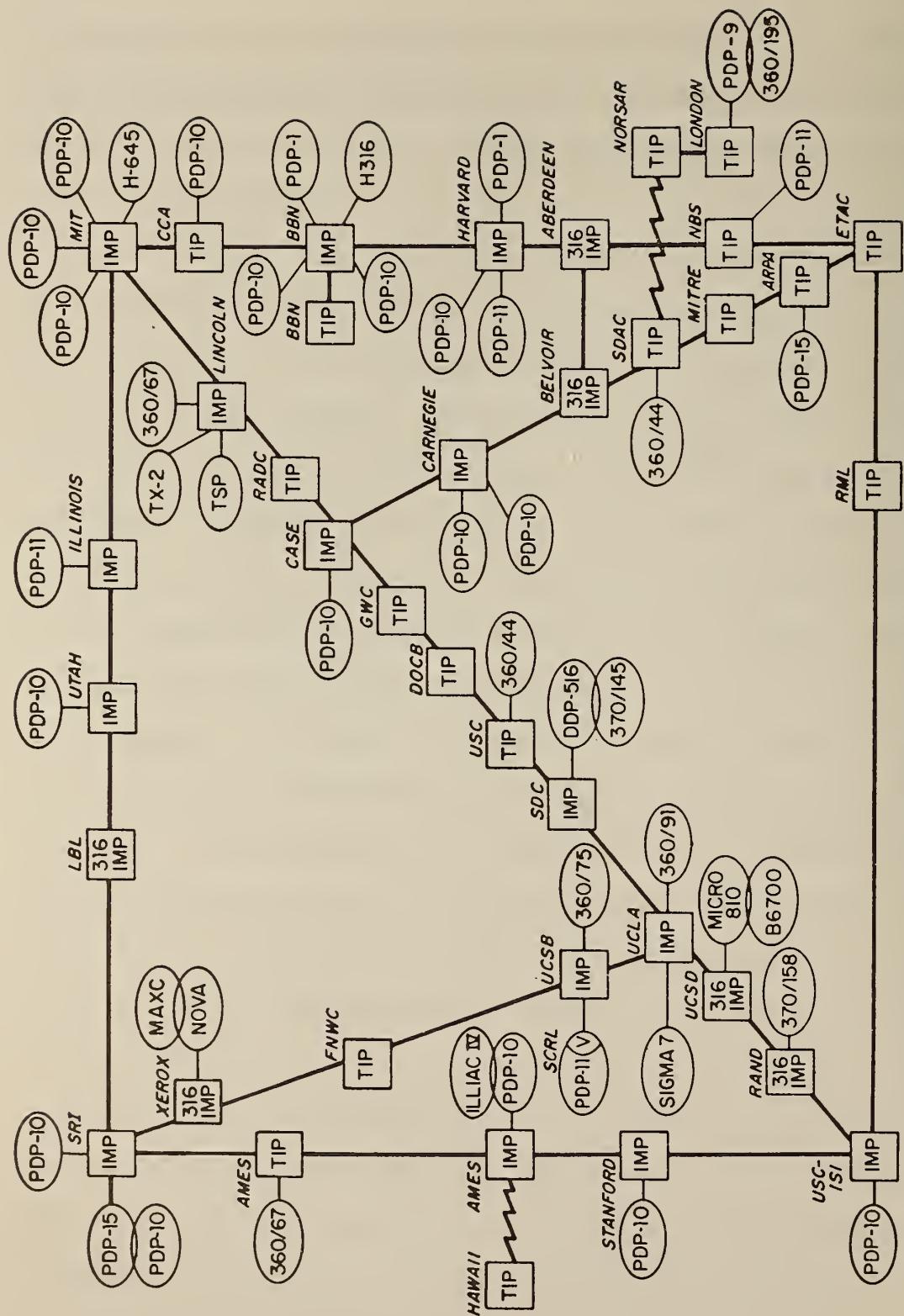
a multi-line controller can provide direct network access to
terminals (dial-ups, leased, and hardwired) without going
through any host by providing the TELNET function and NCP
itself [41]. This device is called the TIP. It has portal
access for 63 terminals but due to buffering restrictions
may be constrained to support a smaller total number when
some of the terminals are operating at higher speeds. Syn-
chronous interfaces are presently not provided. Input speed
can be as high as 2400 baud asynchronous and output speed
can be set up to 19200 baud under special conditions where
the terminal supplies clocking. A great deal of flexibility
exists to accommodate the peculiarities of different terminals.
A user can specify code, speed, when to transmit (on-line
feed for example), and how to echo and by which network
component echoing is to be performed. Some of this flex-
ibility is, however, accompanied by considerable cost in
overhead, particularly the ability to support the variety of
devices using non-standard codes. This overhead cost can
be measured by the large amount of main memory reserved to
facilitate these devices [2].

Character Transmission

In the servicing of interactive terminals on the ARPANET
there exists a potential problem area. This occurs when ter-
minals are interacting with a system in echo-plex mode. The
echoing is often not one-to-one, that is, a particular
character inputted from a terminal may require a different

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character or character string to be echoed. Also certain characters require an immediate host system reaction. Therefore the user will choose to have echoing performed by the host system rather than the TIP, which can only echo characters exactly as inputted at the terminal. This requires that packets be sent through the network containing only one character if the echoing process is to maintain pace with the input process. Since there are approximately 150 bits of overhead per transmission, then approximately 158 bits must be transmitted of which only 8 bits are data. Added to this are 158 bits of additional overhead for the echoed character transmitted from the host system. Even if characters are sent in larger blocks, six (6) at one time for example, the result will be very choppy echoing, in addition to an overwhelming overhead of approximately 700 percent. With moderately or heavily loaded network, this kind of overhead would certainly be intolerable. The solution involves putting additional sophistication in the TIP so it can echo characters as the host system would. Since the host systems are heterogeneous, there would have to be a mechanism for exchanging control information between a host and TIP to notify the TIP of idiosyncracies in echoing. Then with characters being echoed at the TIP to which a terminal is connected, it would be possible to buffer an

entire line to form a packet for transmission on the network. This problem and potential solutions are presently receiving attention in the ARPANET community.

FIGURE   ARPA NETWORK, LOGICAL MAP, SEPTEMBER 1973

Figure 4

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Communications

Communications Circuits

Internode - circuits are leased, full duplex, synchronous,
50,000 baud wideband. It is possible to use
other speeds and 230,000 and 9600 baud have
already been employed in two applications.

Terminal to network - leased or dialup, full or half
duplex, asynchronous. Speeds can be from
75 to 2400 baud on input and up to 19200
baud on output.

Interprocess - packet switched at communications network
level (IMP to IMP).

Communications Hardware

Host interface - host is connected through the interface
message processor (IMP) which also acts as a
message switcher. Four hosts can be inter-
faced through one IMP. The IMP is a Honey-
well DDP-516 or 316 with 16000 words of
memory.

Terminal interface - terminals are interfaced through
the terminal IMP (TIP) concentrator which
also acts as a message switching node. Up
to 63 terminals can be interfaced by one
TIP (this limit is theoretical as buffering
problems prevail before it is realized depend-
ing on terminals speeds). The TIP is a

Honeywell H-316 with 28,000 words of memory.

Communications Software

    Initial connection - this function is distributed and carried out by network control programs which are host resident.

    Protocols - four levels of protocol exist with the highest level controlling interprocess communication. At this level exist the initial connection protocol, data and file transfer protocols, remote job entry protocol, and telnet protocol (see text of this section).

Configuration

Topology

    Distributed - hosts, IMP's, and TIP's connected in a
           distributed fashion.

    Actual distribution - national coverage with 38 locations
           throughout the country, with connections to
           Hawaii, Norway, and England.

Composition

    Heterogeneous - IBM 360/44/65/67/75/91

                  IBM 370/145

                  DEC PDP 10

                  DEC PDP 11

                  Honeywell H645

                  XDS Sigma 7

                  Burroughs B6700

                  CDC 6600

    Size - approximately 40 host computers connected through
           21 IMPs and 18 user nodes or TIPs (terminal
           users can also access network through host
           computers).

Salient Features

A minihost system (ANTS) has been developed at the University of Illinois to run on a PDP-11 [22]. That minihost can be used to provide device support and user support not available through the TIP.

A telnet protocol exists which allows for the use of any terminal on any system by mapping the real terminal into the network virtual terminal.

A remote job entry protocol has recently been developed.

Dynamic routing techniques are used to route messages through the network.

New versions of IMP software are loaded from a control center passing from IMP to IMP without the necessity of manual intervention at each site.

Terminal Support Capabilities

Interactive

    Code - network code is ASCII.

        Non-standard terminals are mapped into ASCII at

        the interfaces for transmission on the network.

    Speed - 75 - 2400 baud.

    Mode - full-duplex with half-duplex support provided.

Remote Job Entry

    A Protocol exists requiring an operator using TELNET and

    a terminal to initiate the various phases. There exists

    no special RJE device support or synchronous interface.

Minicomputer-based Systems

    No synchronous interface to allow for useful employment,

    but an NCP has been written for a minicomputer (PDP-11)

    to allow it to act as a minihost.

Computer-to-Computer

    Protocols exist for host-to-host communication (see text

    of this section).

4.6 TSS

TSS is an experimental network of homogeneous computers, all presently IBM/360 model 67's, designed and implemented as a joint effort by Carnegie-Mellon University, Princeton University and IBM Research Division. The project was conceived to investigate the uses and advantages of computer networks while keeping modifications to existing hardware and software to implement that network at a minimum. The network is point-to-point, dialup, and involves no front end computers, message switching, or special interfaces for terminals (see Figure 5).

Operating System

All of the systems are IBM 360/67's operating under the time-sharing system TSS/360. Systems modifications to TSS were intentionally kept at a minimum. Only the following were necessary: (1) the basic system initialization routine was modified to permit the processor to accept incoming calls from other installations; (2) the task initialization routine was modified so a task can determine whether it is operating on a primary (local) or secondary (remote) processor; (3) the central terminal communication mechanism was modified to detect communication with another location and therefore make calls to the Computer Access Method (developed for networks), rather than the customary Terminal Access Method, which in essence allows a primary process to appear as a terminal to a secondary process, and thus facilities normally available

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to terminals are at the disposal of the primary process;
(4) the task termination routines and the task abnormal ter-
mination routines were modified to transfer control to the
communications logoff routine if processing is occurring on
a secondary processor.

Communications Controller

The hardware used is the standard communications con-
toller for IBM computers, the hardwired IBM 2701 Transmission
Control Unit. The unit must have a Synchronous Data Adapter
and communicates using the Binary Synchronous Communications
protocol. This allows for the half duplex mode of operating,
that is, two-way nonsimultaneous transmission. Data flow is
in one direction at a time, then the IBM 2701 control unit
must reverse the line direction at the end of each exchange.
The IBM 2701 controls a 2000 baud dialup modem for point-
to-point switched operation. The IBM 2703 Transmission
Control Unit can be substituted for the IBM 2701 in this
application because transmission speeds greater than 48000
baud are not used.

Computer Access Method

The communications software, residing in the IBM 360/67,
which was created for the network to access the hardwired
IBM 2701 or IBM 2703 Transmission Control Unit is called the
Computer Access Method (CAM). CAM has the TSS standard
access capabilities of open, read and write, error recovery,
check (to check the completion status of the previous I/O

operation), and close. When communication with another computer is taking place, I/O calls are made to CAM which effectively makes a processor appear as a terminal to the other processor so that processors communicate in their normal I/O stream having all the facilities normally available to a terminal at their disposal.

Network Commands

A number of network commands were developed to control communications with remote processes. One command establishes the initial communication with a remote processor. This is accomplished by dialing automatically the correct number to establish the communications link between the two independent processors. Another command can interrupt the communication with the network and temporarily return control to the TSS command interpreter. This command has a complementary command which can terminate the suspension and return control the network command interpreter to resume the previously interrupted interaction. The send data set and receive set commands are able to transfer entire files between remote processors. Finally a command exists to terminate communications with a remote processor.

Figure 5

Communications

Communications Circuits

    Internode - 2000 baud dialup lines operating in half-
           duplex.

    Terminal to network - no separate interface. Connection
           is through host computer only.

    Interprocess - line switched. A switched physical cir-
           cuit is devoted to each pair of communicating
           processes.

Communications Hardware

    Host interface - host is an integral part of the communi-
           cations network and connects through its
           standard controller (IBM 2701).

    Terminal interface - none other than through host computer.

Communications Software

    Connection - Computer Access Method (CAM) residing wholly
           in host system establishes physical connection
           by dialing for 2000 baud switched circuit,
           and uses it for the logical connection be-
           tween processes.

    Protocols - simple protocols to allow for initial con-
           nection to a specific node, initiation of
           computation process, disconnection from a node,
           test outstanding responses, and send and
           receive data sets.

Configuration

Topology

    Distributed - hosts are distributed and communicate
          through dialing.

    Actual distribution - Carnegie Mellon University, Prince-
          ton University, Rutgers University, IBM
          Research, Nasa Lewis, Nasa Ames, and Bell
          Telephone Labs.

Composition

    Homogeneous - IBM 360/67.

    Size - 7 host computers.

Salient Features

The design philosophy of using existing communications components and the terminal look alike techniques (a processor looks like a terminal to the processor with which it communicates) enable the processors to be easily interconnected for the purpose of experimenting with networks.

A simple network control language exists enabling a user to perform some unsophisticated but useful functions.

Terminal Support Capabilities

Interactive

    Code - no terminal interface other than host computer
        exists.

    Speed - as determined by terminal/host interface, usually
        10 or 15 characters per second.

    Mode - half-duplex when using standard terminal/host
        interface.

Remote Job Entry - no special support.

Minicomputer-based Systems - no special support.

Computer-to-Computer

    Using the Computer Access Method (CAM) one computer con-
    nects as a terminal to another and vice versa allowing
    for interprocess communication.

5.0 CONCLUSIONS

Various approaches to computer networking technology
have been realized in the six networks discussed. The rela-
tive merits of the different types of components and config-
urations were discussed in previous chapters. It is useful
now to consider briefly these network technologies relative
to their potential application in the Networking for Science
Program. Only the communications network, or in ARPANET
terminology the "communications sub-net," will be considered.
The communication network will, however, include considerations
relevant to the host interface and of course the terminal
interface. Furthermore, when discussing the alternatives, it
is important to distinguish between a network technology and
the implementation of that technology. For example, to imple-
ment a particular technology as it appears in an existing
network, it might be possible to build an identical or cus-
tomized version, connect to the network, or lease service from
the network. These implementation alternatives are not
addressed in this particular report.

TSS

The last three networks outlined were the research networks
TSS, MERIT, ARPANET. TSS technology can be distinguished by
a number of important features. Looking at the configuration
it is distributed and homogeneous. The homogeneity certainly
impedes broadening the use of TSS, and is not easily overcome
as the network is composed of computers of the same model and

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same operating systems. The communications circuit and hard-
ware are also limiting factors. The circuits are circuit
switched rather than message switched which is not necessarily
detrimental but is somewhat less flexible. The host interface
is a non-programmable IBM 270X which eliminates the front end
processing possiblity and thereby restricts the kinds of com-
puters that can be interfaced. No separate terminal interface
exists. The fact that there is no multiplexing of communications
circuits further hinders usage. The general principle of the
TSS approach, that is, having computers dial one another and
communicate through their terminal handling facilities has
some merit as it allows for rapid, relatively inexpensive
startup. The concept would have to be modified in order to
include heterogeneous systems, line multiplexing, and separate
terminal interfaces.

MERIT

The MERIT network technology with its additional sophisti-
cation overcomes some of the drawbacks of the TSS approach.
It does in fact include heterogeneous computers. Two dif-
ferent kinds of computers and three different operating systems
are connected. The host interface is a Digital Equipment
Corporation PDP-11 minicomputer that provides some front-end
processing capability and an interface flexible enough to han-
dle more than one kind of computer. Better circuit utilization
is achieved through line multiplexing. However, there exists no
direct terminal interface which implies that the minimum connection

mechanism is through a host computer system. Furthermore, since the MERIT technology has been applied to interconnect only three computers, it has not been demonstrated that the technology could be applied unaltered to a large network of distributed computers and users.

ARPANET

The ARPANET technology appears to be the most sophisticated network technology presently in operation on a national basis. It connects heterogeneous computers of many different manufacturers in locations throughout the country. It is distributed in topology, switching, control, and computing power, making it extremely flexible for alternatives in each category. The communication circuits are message switched utilizing 50 kilobit per second wideband links. The host interface is a programmable minicomputer which as an interface is able to accommodate many different kinds of host computers including more than one simultaneously, and as a node in the network, has message-switching store-and-forward capabilities. In addition it has the ability to perform dynamic routing through the network. The terminal interface is also a minicomputer capable of supporting a large number of terminals, running in a wide range of speeds, operating in different modes, and using standard as well as non-standard character codes.

It is perhaps because of these extensive capabilities that there exists unanswered questions concerning the ARPANET technology. For instance the host interface through its

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sophistication and complexity is quite difficult to implement.
It requires a great deal of time (actual amount of time and
money is presently undocumented) for a systems programmer
familiar with both the interface and the host operating
system. This is because the network control program resides
in the host computer itself. There are presently efforts
underway on a limited basis, to move the network control
program out of the host into a front end computer [22], and
there are proposals which favor protocols for interprocess
communication with less host dependency [40]. It is impor-
tant to point out that a large number of NCP's have already
been implemented for a variety of computer systems which could
be used in newly attached identical systems. However, in the
present state of the ARPANET, the network control program and
its associated overhead of CPU time and core used must be
considered as directly related to the communications network.

The terminal interface processor (TIP), as noted, has
extensive capabilities to handle selected speeds, codes, and
modes of operation. Nevertheless, there do exist shortcomings
with the TIP. It can only support asynchronous terminals and
in order to connect with most remote job entry devices
synchronous support is needed. One way to implement syn-
chronous support is to contain it in the already overburdened
TIP. Another approach, one which has already come into
existence in one instance, is the use of a minicomputer as
a mini-host system on the net, providing the desired device

support. The Center for Advance Computation at the University of Illinois has developed such a system using a DEC PDP-11. The system is called the ARPANET Terminal System, or ANTS for short [22]. At any rate there needs to be a standard network-wide remote job entry device controller.

Network traffic in terms of quantities and characteristics is another potentially troublesome area. With peak loading of roughly ten percent capacity, it has never really been adequately demonstrated that the network will not deteriorate under conditions of maximum loading. Besides quantity, the characteristics of the traffic may result in poor network performance. To date most of the traffic has been that associated with terminal-to-computer interaction. It is an open question what will happen to response times when mixes of interactive (single packet) and file transfer or remote job entry (multiple packet) traffic occur. Analysis, however, has shown that success is highly probable with significantly different degrees of overhead for different traffic mixes [12].

Finally, there exists a very human problem that occurs when trying to use the network, and is likely to occur with any very heterogeneous network. With the proliferations of systems, it is cumbersome to learn the system command sequences necessary to perform even simple transactions, such as logging-in on each system. One possible solution would be to implement a higher level protocol (fourth level?) to standardize some of the basic interactions between a user and

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a system. This protocol could be realized in the hosts, TIPs,
or quite conceivably on mini-hosts systems such as that under
development for remote job entry devices.

CYBERNET

The commercial networks--GE, CYBERNET, TYMNET-- have
developed technologies which appear to have successfully
satisfied their own needs and in some cases could be useful
for applicability in the Networking for Science Program.
CYBERNET is a distributed network in all respects. It is
heterogeneous in that it connects different models of Con-
trol Data computers. Other manufacturers' computers can
connect as peripherals to the network by looking like a CDC
network standard device. The look-alike technique is used
quite extensively in the CYBERNET approach even for communi-
cations between host systems. The communications circuits
are varied using wideband, voice grade, and public switched,
but for the most part wideband circuits are used for inter-
connecting computers. Instead of using message-switching
and store-and-forward computers, wideband switches are
employed so that various interconnections are established by
dialing, or having dialed, the appropriate number. The host
interface to the network is the wideband switch. Apparently
batch terminals can also interface to the network through the
switches but normally interface directly through the host
systems. Interactive terminals interface through different
host systems--the CDC 6400's running the KRONOS time-sharing

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system--which can then themselves access the batch systems.
The technology does not at this time seem particularly suit-
able as the technology for the Networking for Science Program.
The use of wideband switches rather than message-switching
computers limits the interconnections that can occur. No
host interface other than the switch exists and no terminal
interface exclusive of a host system exists.

GE Information Services

The GE approach represents an entirely different kind of
network technology. It is a centralized network with all
host computers interconnected but located in a central loca-
tion. It is, however, possible to connect a customer com-
puter at the periphery of the network for the purpose of
exchanging files with one of the central systems. This inno-
vation has been put into practice to make customer's batch
created files available on-line to a national distribution
of the customer's own users [35]. The network is heterogeneous
with different models of Honeywell computers running different
operating systems. Plans call for connecting to the network
computers from other manufacturers [34]. Also the concept
of allowing customers to connect their own computers to
exchange files with the central system and utilize the vast
communications network is planned to be expanded.

The communications circuits are message-switched with
the apparent restriction that communications are with one of
the central systems. The host interface is a computer, but

only systems at the central site are integral to the network. As mentioned, however, certain customer computers can interface as remote job entry devices. Communications are directed to the central systems so that if many customer computers are connected to the network it is not clear that they could establish direct communications with one another using the GE communications network. Also terminals connected to the network through the terminal interfaces communicate with the central system and may not be able to communicate with customer computers. This centralization is the drawback to use of the technology per se in a distributed network although the extensive coverage and capabilities of the net may warrant further consideration.

It is useful to point out that the technology itself may be applicable to networks of distributed computers in two different ways. First, the central complex may be viewed as a large message switching center. All communications between computers connected to the remote concentrators at the periphery and customer's terminals could be routed through the central switch. Second, the technology used to interconnect the computers at the central complex could be applied to a network of distributed computers. Both of these are conjecture.

TYMNET

TYMNET has already entered the business of offering only the services of the communications network exclusive of the Tymshare host computers. In such cases customers interface their own

host computers and their users, their own terminals, and thereby utilize the TYMNET national data communications network. This reportedly is permitted under Federal Communications Commission Tariff 260 covering joint use agreements. The customers make a contractual arrangement with Tymshare for use of a certain percentage of the capacity of TYMNET for handling the communications traffic between the customer's terminals and customer's host system or systems. The Telephone Company then bills the customer for the specified percentage of the communications charges. In addition, Tymshare bills the customer for value added services. These include the utility of the host and terminal interfaces along with the store-and-forward capability of the communications computers. Also included is the involvement of the Tymshare host computer running the supervisor which establishes all initial connections.

The TYMNET technology has a number of characteristics that could make its usage a powerful convenience. It has been demonstrated that it can support a network, well distributed, with nodes, computers, and users all over the nation and in Europe with a clear possiblity of connecting new host systems and users wherever they may presently exist. The host computers themselves are heterogeneous being different models and from different manufacturers and it appears conceivable to connect computers of any of the primary manufacturers using their standard interface equipment. The communications

circuitry is voice grade connecting the switching nodes which are store-and-forward minicomputers. The voice grade circuits appear to be quite sufficient for the interactive traffic that exists on the network and some rather impressive figures exist to indicate a high usage of the facilities through efficiencies in line concentration. For example forty-six (46) interactive users are supported on a 2400 baud facility.

Switching is performed by establishing a virtual circuit through the nodes of the network. The systems supervisor, the system initially contacted by every user, sends information to the nodes to set up a virtual circuit from user process (terminal) to server process (computer). This virtual circuit concept would seem to decrease communications overhead once the circuit is established, although there is the disadvantage that dynamic re-routing cannot occur to accommodate circuit failures. Nevertheless, the virtual circuit reportedly results in nearly an 80 percent efficiency in line utilization rather than the 60 percent efficiency associated with true message switching [7]. This is due primarily to a reduction in overhead due to the use of only a single character to address a virtual channel. Furthermore, the central supervisor performing all connections presents an advantage: only the supervisor has global knowledge of the network so that the individual nodes can be handled independently relative to software changes and debugging. In the event of a failure at the supervisor node, a backup system will take

over, first polling the network to determine its status.

The host interface to the network is a minicomputer, which for the sake of convenience, can make the network appear as terminals to the host's regular terminal interface, although the interface is more sophisticated in the case of Tymshare host computers. Interfacing new computers in the past has not been particularly difficult. The terminal interface is also a minicomputer acting as a concentrator and a store-and-forward node. It can handle terminals of a variety of speeds and when communicating with some of the host sytems will perform local echoing.

The network technology appears quite capable of satisfying the communications needs of a network of computers distributed throughout the country, and large numbers of interactive users (presently 900 simultaneously). With a present average number of failures of 1.4 per year per node, reliability is another asset. One big drawback to the network is its lack of support of synchronous devices and remote job entry. This situation may not be permanent as plans call for the imple-mentation of synchronous device support to control certain types of remote job entry devices. Also batch processing is anticipated on the Digital Equipment Corporation PDP-10 com-puters which have become a part of the network. Also the incor-poration of large IBM computers into the system is underway for more remote job entry and batch processing.

Concluding Statement

In keeping with the purposes of this report, the discussion has been exclusive of economic considerations, concentrating on functional capabilities. All of the networks discussed have particularly worthy features. It is, therefore, worthwhile to suggest at this time that a single network technology need not be selected. It is entirely possible to use the best features of each network technology matching the task to the proper network.

Although the discussion of the usage of services provided by the host computers of the networks did not fit into the context of this report, it is important to the concept of multiple networks. Suffice it to say that if the services are readily available and compatible with the needs of user groups, than the most convenient access may be through the networks to which the hosts are already attached.

Two of the networks discussed--TYMNET and ARPANET--are presently offering a computer communications service to which a customer can connect computers acting as host systems, as well as terminals. Each has considerable experience in host computer and terminal interfacing and is representative of a computer communications network to which customers can connect their servers and users, nationally distributed, with a minimal effort in communications development. Both networks, resultant of both their present state of development and the inherent characteristics of their technologies, represent important

advantages and also possess serious limitations, the details

of which are described in the text of this report.

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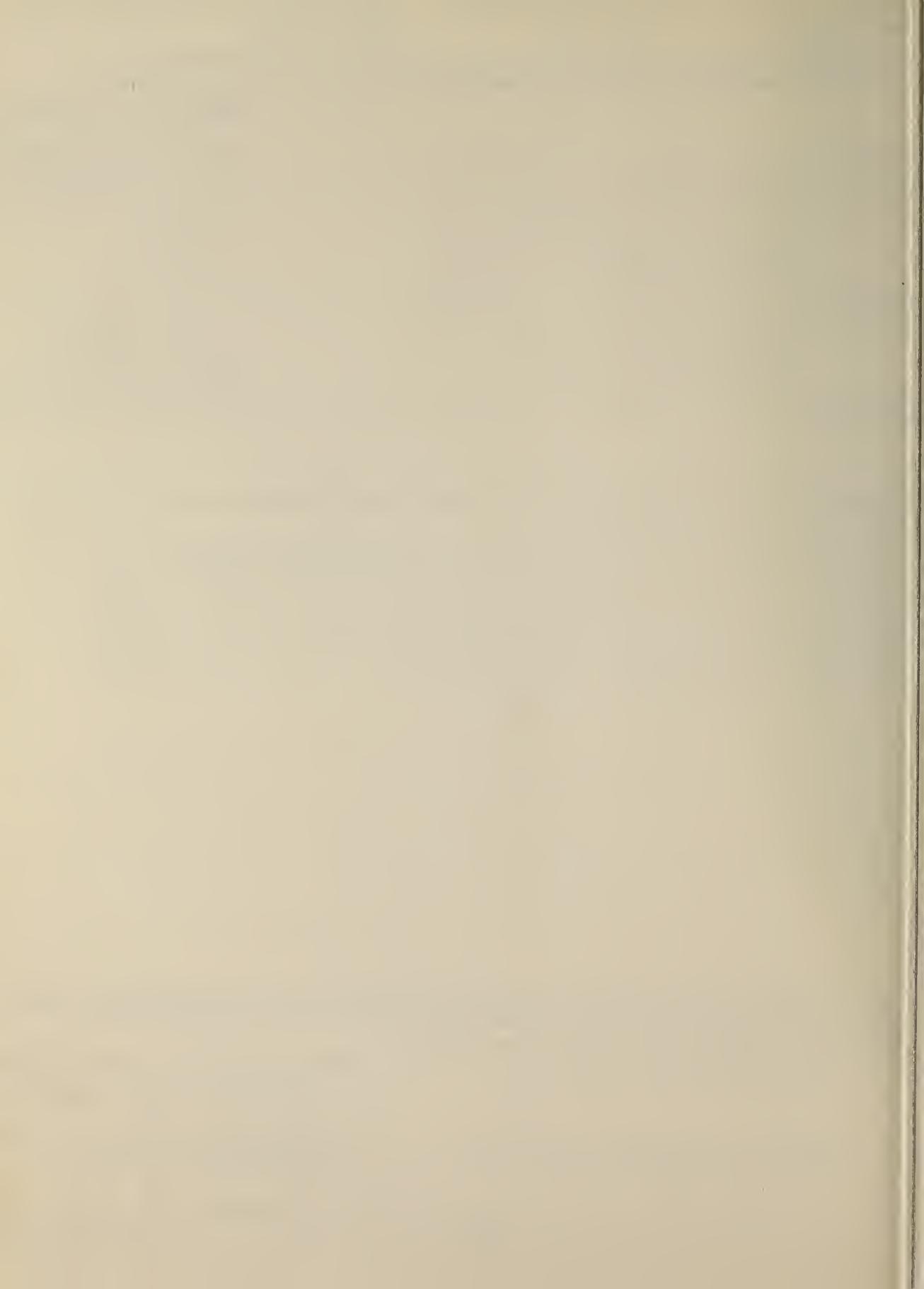
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15. SUPPLEMENTARY NOTES

16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

This report gives a descriptive summary of the technical characteristics of existing computer networks, including data communication technology and configuration related to support of resource sharing services for a computer network. Included are discussions of terminal support capabilities for the communications network and a development of relevant network terminology. The report concludes with a comparative evaluation of existing technological approaches to networking.

17. KEY WORDS (Alphabetical order, separated by semicolons) Computer networks; computer-to-computer transfers; interactive terminals; minicomputer-based systems; network configuration; remote job entry; resource sharing.

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