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ARPANET Host to Host Access and Disengagement Measurements

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GLOSSARY AND ACRONYMS

ARPA	Advanced Research Projects Agency
Avg	Average of hourly data
BSC	Binary synchronous line control protocol
CR	Carriage return
DEC	Digital Equipment Corporation
DOCB	Department of Commerce Boulder
Elf	Name of PDP-11 operating system software
EXEC	Executive software system
FTSC	Federal Telecommunications Standards Committee
Host	Computer center
IMP	Interface message processor
MHR	Minimal hop route
modem	Modulator and demodulator
NCC	Network control center
NCP	Network control program
NTIA/ITS	National Telecommunications and Information Administration/ Institute for Telecommunication Sciences
protocol	In communications, a set of rules governing the exchange of information
Telnet	Telnet software system
TIP	Terminal interface processor
VDH	Very distant Host

ARPANET HOST TO HOST ACCESS AND DISENGAGEMENT MEASUREMENTS

Judd A. Payne*

A set of telecommunications performance parameters have been developed for proposed Federal Standard 1033. The measurement of five of these parameters, access time, incorrect access time, access denial probability, disengagement time and disengagement failure probability are the subject of this report. The telnet protocol of the ARPANET is employed to measure the access and disengagement parameters from a Host to Host connection.

Key words: access, ARPANET, disengagement, Elf operating system, Host, IMP (interface message processor), NCP (network control program), performance parameter, protocol, Telnet, TIP (terminal interface processor)

1. INTRODUCTION

The National Telecommunications and Information Administration, Institute for Telecommunication Sciences (NTIA/ITS) is engaged in the development of proposed Federal Standard 1033. This proposed Standard was published in the Federal Register (1977). The development of the standard was authorized by the Federal Telecommunication Standards Committee (FTSC). The purpose of the Standard is to develop digital communication performance parameters for telecommunication systems from a user-oriented approach. As revealed by McManamon et al. (1975), a sampling of commercial and Federal standards generated a list of 132 engineering-oriented performance parameters for telecommunication systems. The purpose of proposed Standard 1033 is to standardize the description of the performance of telecommunication systems, and to present a set of considerably fewer performance parameters which would enable a user to better understand the performance of a telecommunication system.

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In order to demonstrate the usefulness of the proposed parameters in Federal Standard (FS) 1033 an ARPANET measurement program was established at ITS. Along with the measurement program, theoretical studies in support of the proposed standard have been reported (in papers scheduled for future publication) by Seitz and McManamon and Kimmett and Seitz.

This report is a sequel to two previous memorandums by Payne entitled "Access Time Measurements of the ARPA Network" (OT Tech. Memo. 76-229, 1976) and "Host to Host Disengagement Time on the ARPANET" (OT Tech. Memo 77-237 (1977). (These reports are available from U.S. Dept. of Commerce, Boulder, CO 80303.) These previous reports were concerned with the measurements of access time and disengagement time which are two of the proposed performance parameters in Standard 1033. This report concerns further measures of access time, disengagement time and initial measures for incorrect access time, access denial probability and disengagement failure probability.

The measurement of each of the proposed parameters required designing the experiment, developing the needed hardware and software, conducting tests and analyzing the results.

The contents of the following sections include an ARPANET description, a description of the NTIA/ITS Host[1], a definition of measurement parameters, a description of the design and method of making the ARPANET measurements, tables of measurement data, and a discussion of the results of the measurement data. This report concludes with an assessment of the utility of the proposed performance parameters as applied to the ARPANET and some recommendations for further study.

2. ARPANET DESCRIPTION

The ARPANET has been described and studied by many persons (e.g., Schwartz, 1977; Kleinrock, 1976; Davies and Barber, 1973).

[1]The designation "NTIA/ITS Host" is new. The organization name change to NTIA is recent and all previous literature refers to the same Host as the "OT/ITS Host."

Because of the ARPANET's overall success, many computer networks now or in the future plan to emulate the ARPANET (e.g., TELENET, AUTODIN II).

This description of the ARPANET will briefly review only those details necessary for the reader to understand the design of the experiments discussed in the main body of this report.

The word "ARPANET" refers to the Advanced Research Projects Agency (ARPA) computer network, which is operated by the U.S. Defense Communications Agency. In textbooks, the ARPANET's topology is described as a packet-switched, fully distributed computer network. The ARPANET was proposed by L.G. Roberts (1967).

Figure 1 illustrates the ARPANET geographic map as it existed in June 1977 (ARPANET Directory, 1977). This map shows the interconnected nodes of the ARPANET. The circles represent an enlarged version of those areas of the U.S. where many nodes are concentrated in some small geographic area. These nodes contain mini-computers which, along with their interconnecting links, form the communications "backbone" of the ARPANET. This communications backbone or subnet is described as a "packet-switched" subnet. A packet-switched network is designed to carry data in the form of packets. A channel is occupied only for the duration of the packet transmission.

In addition to the subnet, the ARPANET includes a number of independent computer systems called "Hosts". Each Host is connected to just one node. The Hosts may vary from a large computer center to a small (mini-computer) system. Examples of large systems attached to the networks are Control Data Corporation's model 6600 and 7600 systems[2], IBM's large scale model 360 and 370 systems, Digital Equipment Corporation's PDP-10 and many others. Among the mini-computer Host systems, the PDP-11 is employed most often because of its available communications

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[2]Certain commercial equipment, instruments, or materials are identified in this paper to adequately specify the experimental procedure. In no case does such identification imply recommendation or endorsement by NTIA, nor does it imply that the material or equipment identified is necessarily the best available for the purpose.

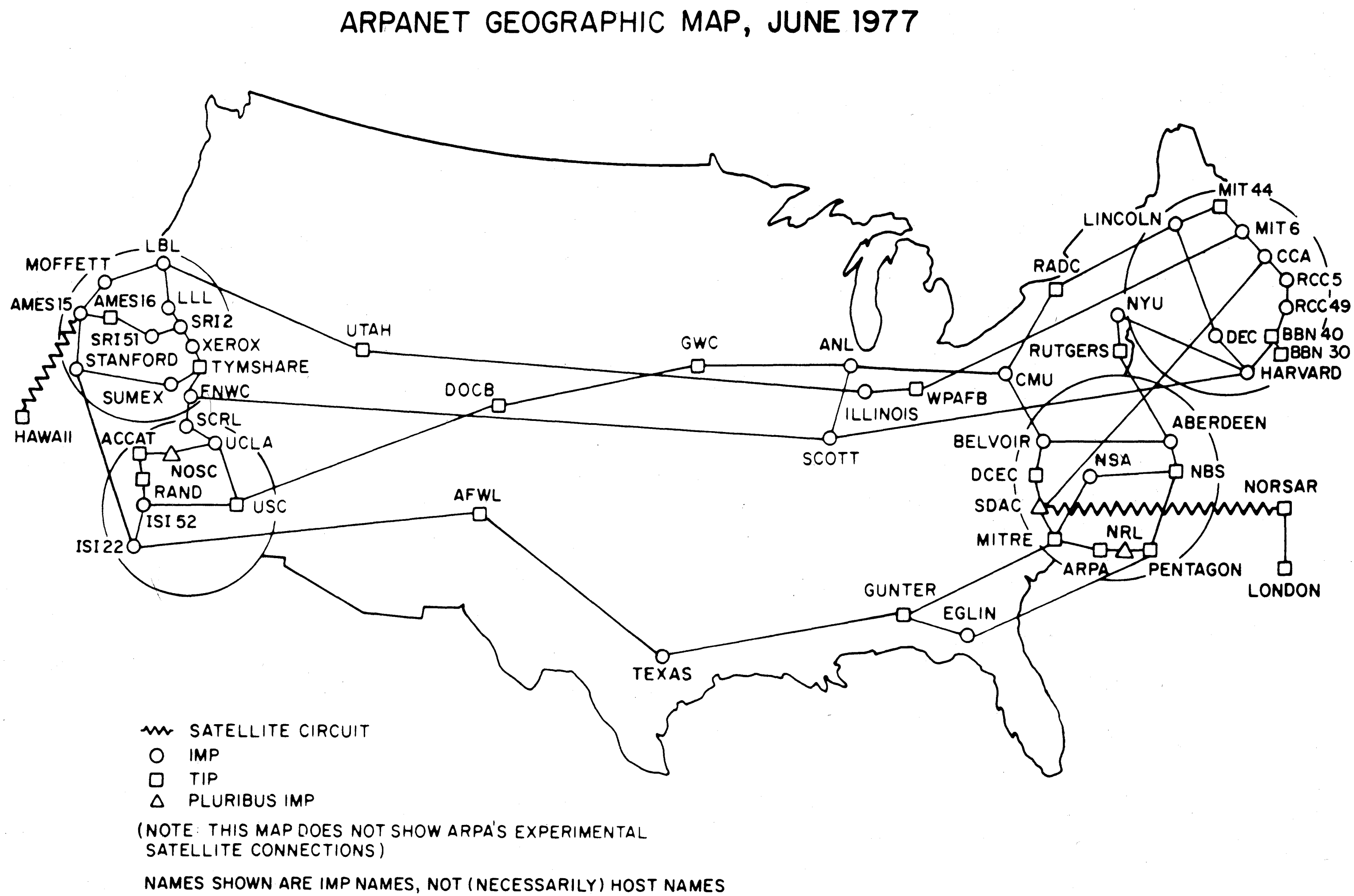

Figure 1. ARPANET geographic map from the ARPANET 1977 directory.

software and hardware interface devices. As of June 1977 the ARPANET network was composed of 57 nodes and 113 Host systems. Figure 2 is the ARPANET logical map as shown in the ARPANET 1977 Directory. This map identifies all the Host computers on the ARPANET and their nodal connections.

The network logical map of Figure 2 is called a logical map because the message paths between the Hosts are not physical connections, such as a telephone connection between calling parties. Physical connections exist between nodes (IMPs and TIPs) and between the nodes and attached Hosts. But a connection between two Hosts is called a logical connection and it is established by a message sequence protocol. After a connection has been opened between two Hosts, data messages between the two Hosts flow through the subnet by packet-switched, store-and-forward techniques.

The communication subnet, composed of nodes, provides the packet-switch capability for the ARPANET. The nodes are Honeywell mini-computers and they are interconnected by 50 kilobit per second (kb/s), full-duplex lines. These lines connect each node to one or more adjacent nodes so the network is considered to be fully distributed. The nodes are called Interface Message Processors (IMPs), pluribus IMPs, or Terminal Interface (Message) Processors (TIPs) depending on their function. As many as four Host computers can be attached to each IMP, and more than four can be attached to a pluribus IMP. The primary function of the IMP is to accept messages from the attached Hosts, to separate the message into 1000 bit packets, and to route these messages through the subnet backbone until the messages reach their destination Hosts. TIPs perform the same function as IMPs but also permit terminal devices such as teletypes and CRTs to be attached directly to the TIP. All messages flow through the subnet in the form of packets of data that are switched from node to node.

As of June 1977, 54 of the 113 Host systems were designated as server Hosts, which means that these particular Hosts will accept and respond to messages from any other Host on the network (i.e., some Hosts provide limited service). The remaining 59

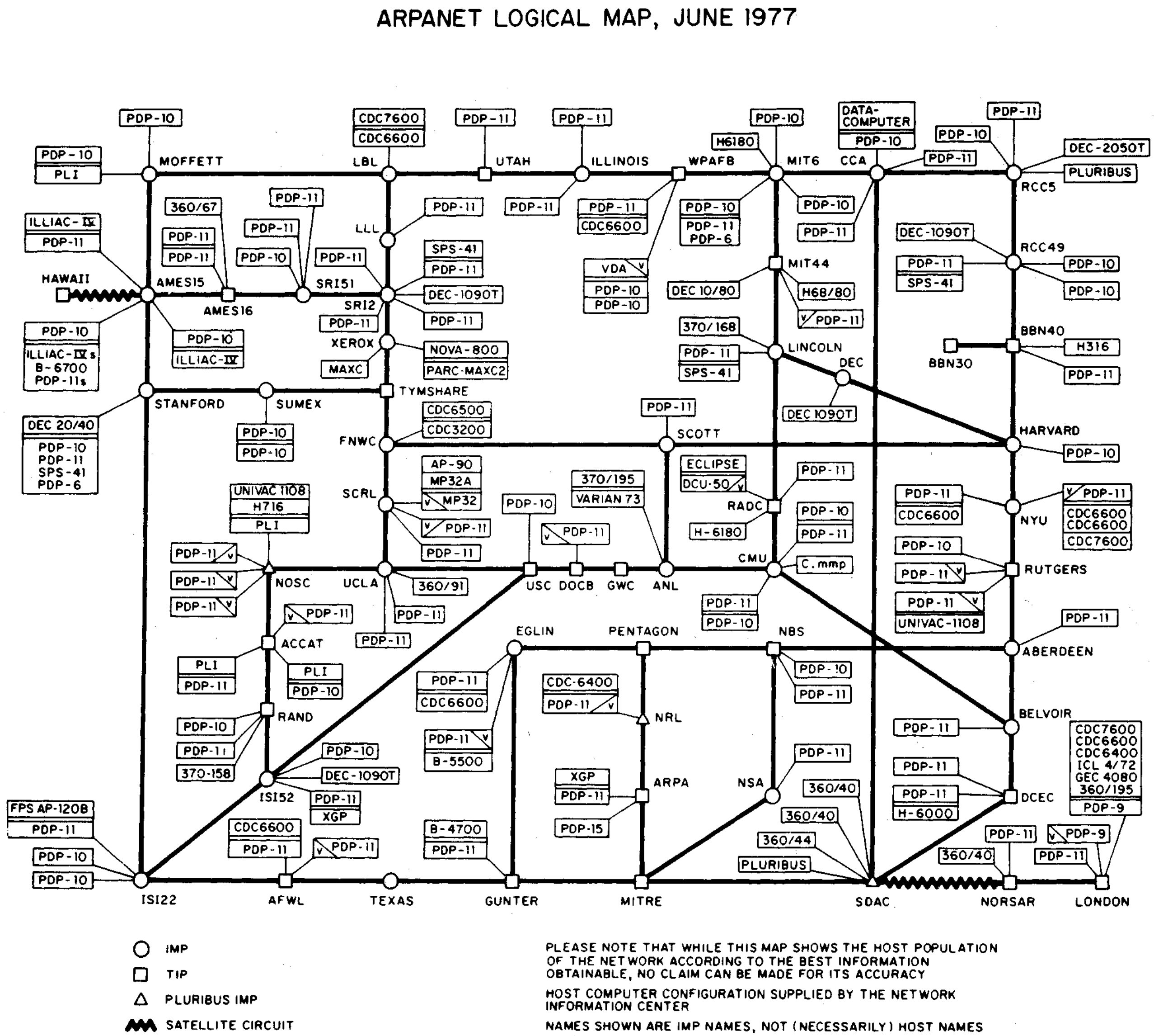

Figure 2. ARPANET logical map from the ARPANET 1977 directory.

Hosts are known as user Hosts, and normally they can only communicate with other server Hosts although there are some exceptions.

2.1. Protocols

The process which enables incompatible or different types of Host computers to exchange messages involves a number of layers or levels of communication protocol (ARPANET Protocol Handbook, 1978).

These layers of protocol are separated into three levels by Kleinrock et al. (1976):

(1) Level-0, the protocol which controls the transmission of packets between adjacent nodes (IMPs and TIPs)[3].

(2) Level-1, the protocol which controls the transmission of messages between source node and destination node.

(3) Level-2, the protocol which controls the transmission of messages between source Host and destination Host.

In addition to these three basic levels of protocol, there are higher levels of protocol which are intended for user applications of the ARPANET. All higher level protocols use the above three protocols. Examples of higher level protocols are:

(1) Telnet - primarily used to allow a human user at some Host site to establish a logical connection with another server Host system and to operate the server Host in a time-sharing mode.

(2) File Transfer Protocol - allows a user to transfer files of data between two Host systems.

(3) Remote Job Entry - allows a user at some Host system to run a batch job on some other server Host system.

The process which allows a specific program in some Host to communicate with a specific program in another Host is the Network Control Program (NCP) which is the level-2 protocol. The NCP software is resident in each Host and provides the means of communication between programs. For example, if a program or

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[3] Although Kleinrock does not distinguish it, there is a Host-IMP/IMP-Host protocol, Bolt Beranek and Newman (1976).

process in the NTIA/ITS Host desires to communicate with another process in a foreign or distant Host, it does so by calling the NCP in the NTIA/ITS Host and this NCP then communicates with the NCP in the foreign Host to establish a logical connection between the two processes. The NCP acts as the manager for a network user in arranging and maintaining connections to other Hosts in the network.

2.2. Architecture

Figure 3, which was obtained from the ARPANET Transition Plan (1975) and slightly modified, is a conceptual diagram of the architecture of the ARPANET. This diagram illustrates at least one approach to defining the architecture of this network. In this diagram the network is subdivided into three parts: the communications subnet, the Host computer subnet and the user subnet. These three subnets are identified in Figure 3 by a solid line, a dashed line, and a user symbol, respectively.

The communications subnet is composed of the nodes (IMPs and TIPs) of the network, the Network Control Center (NCC) and the 50 kb/s lines (solid lines) connecting the nodes and the NCC to each other. The Host subnet consists of the Host computer system and the communication line connecting the Host to the node. The user subnet consists of a person, the terminal and the line connecting the terminal device to the Host computer. In this figure the user is understood to be a person sending commands to the Host via a terminal device. The function of the user subnet is to initiate hardware and software components in the Host subnet which actually cause the communication subnet to transmit the data across the network. This three-part separation of the ARPANET into communications, Hosts, and users subnets is based on hardware boundaries or physical objects that can be easily identified. The boundary separating the communications subnet from the Host subnet is a special IMP/HOST interface attached to the IMP, which connects the line from the Host to the IMP. The boundary between the user subnet and the Host subnet is usually a

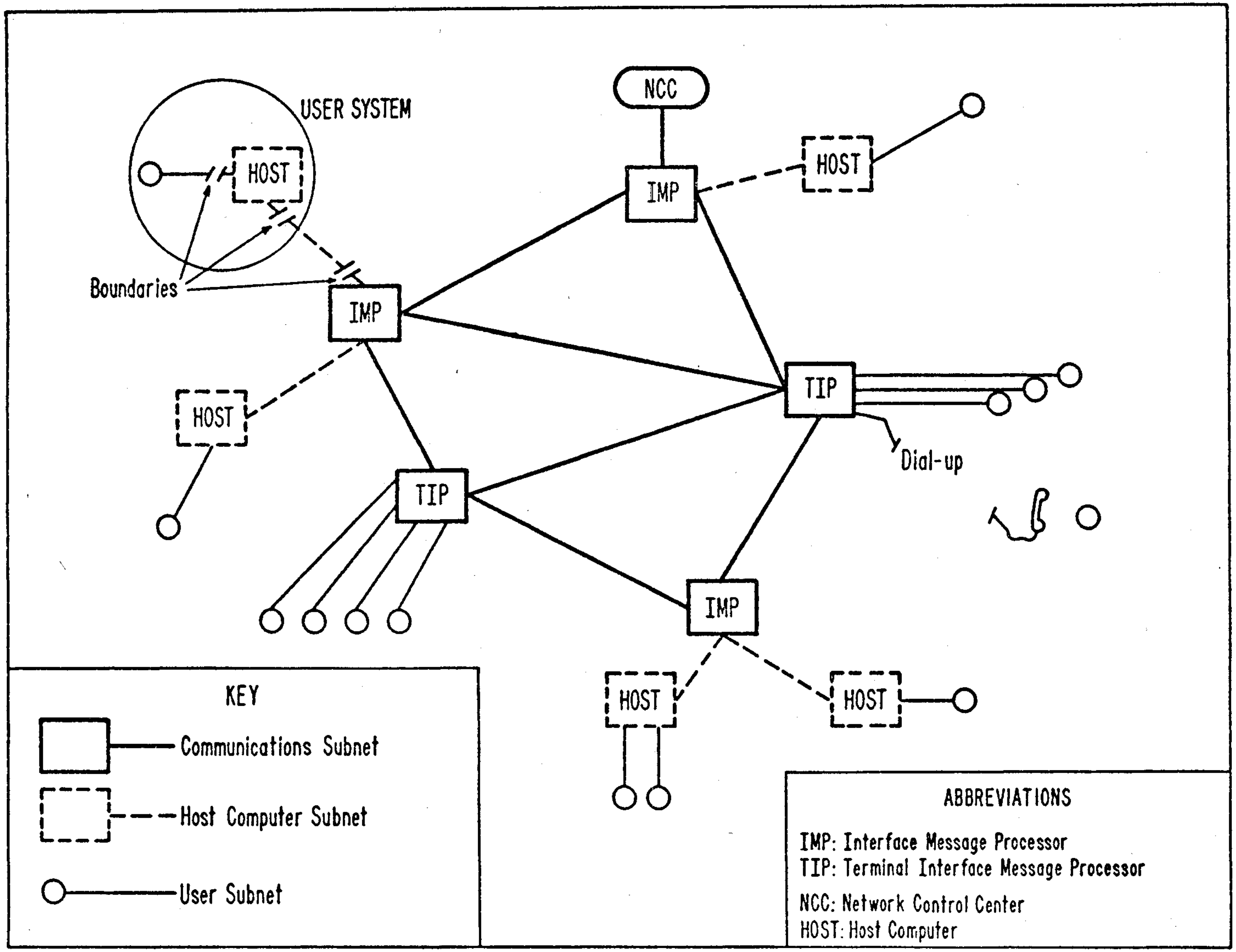

Figure 3. Conceptual design of the ARPANET.

serial line interface connecting the line from the terminal to the Host computer system.

Another approach to defining the network architecture of the ARPANET is to divide the network into just two parts, a user system and a communication system. This concept of a user system is based on the idea that the Host computer subnet and the user subnet combine actually to perform the task of using the communication subnet. The process of using the communication system implies that the user system contains the necessary hardware and software components to activate the communication system which sends data across the network to another user system. The boundary between the user system and the communication system could be the same as the three-part architecture boundary between Host and communication subnets. Or the boundary might be one of the three breaks as shown near the user system circle in Figure 3, depending on the particular hardware and software configuration of the user system.

The boundary of interface separating the user system from the communication system is defined by the PDP-11 operating system known as Elf. A PDP-11 operating system is defined in the DEC software manual as a collection of programs that organize a set of hardware devices into a working unit such that people can utilize the computer system.

Elf provides the means for the terminal user to establish connections and to send messages over the ARPANET. Elf is described by Retz et al. (1976) as composed of the following software modules:

(1) kernel,

(2) executive,

(3) network control program (NCP).

The Elf kernel software acts as the primary interface between system hardware and a program running on the PDP-11. The Elf executive software acts as the primary interface between system hardware and persons who operate the system. The NCP software in each Host serves as the interface between two programs or two processes in separate Hosts. The Telnet software (see Protocol 2.1) serves as a high-level protocol utilizing software which can establish a connection between two Host systems. Telnet employs the NCP software via system calls during Host-to-Host communications.

In general, PDP-11 operating systems are separated into just two components: monitor and utility programs. The functions performed by a PDP-11 monitor could include all the functions performed by the Elf kernel and executive. The NCP could be considered a utility program in that its main function is to establish and maintain a logical connection between programs or processes in separate Hosts. In this report the NCP is considered the functional interface or boundary between the user system and communication system while opening and closing connections between Hosts under Telnet control.

3. NTIA/ITS HOST DESCRIPTION

The NTIA/ITS PDP-11 Host mini-computer system (OT Host) was installed on the ARPANET in March 1975. This Host site is located in Boulder, Colorado, and is attached to the DOCB (Department of Commerce Boulder) TIP. The DOCB TIP is shown in Figure 2, near the center of the figure interconnecting the University of Southern California (USC) TIP and the Global Weather Central (GWC) TIP. The NTIA Host is shown attached to the DOCB TIP.

Figure 4 is a sketch of the NTIA Host connection to the DOCB TIP. All the necessary hardware and software components required by the system were obtained from known sources of these components. A PDP-11 computer was chosen because an ARPANET operating system had previously been developed for the PDP-11. This operating system (OS), known as the Elf OS was developed with ARPA funds. (Currently, Elf is being replaced by the Unix operating system.) In Figure 4 the connection between the PDP-11 and TIP is called a VDH (very distant Host) connection. The VDH connection is one of three standard connections used on the

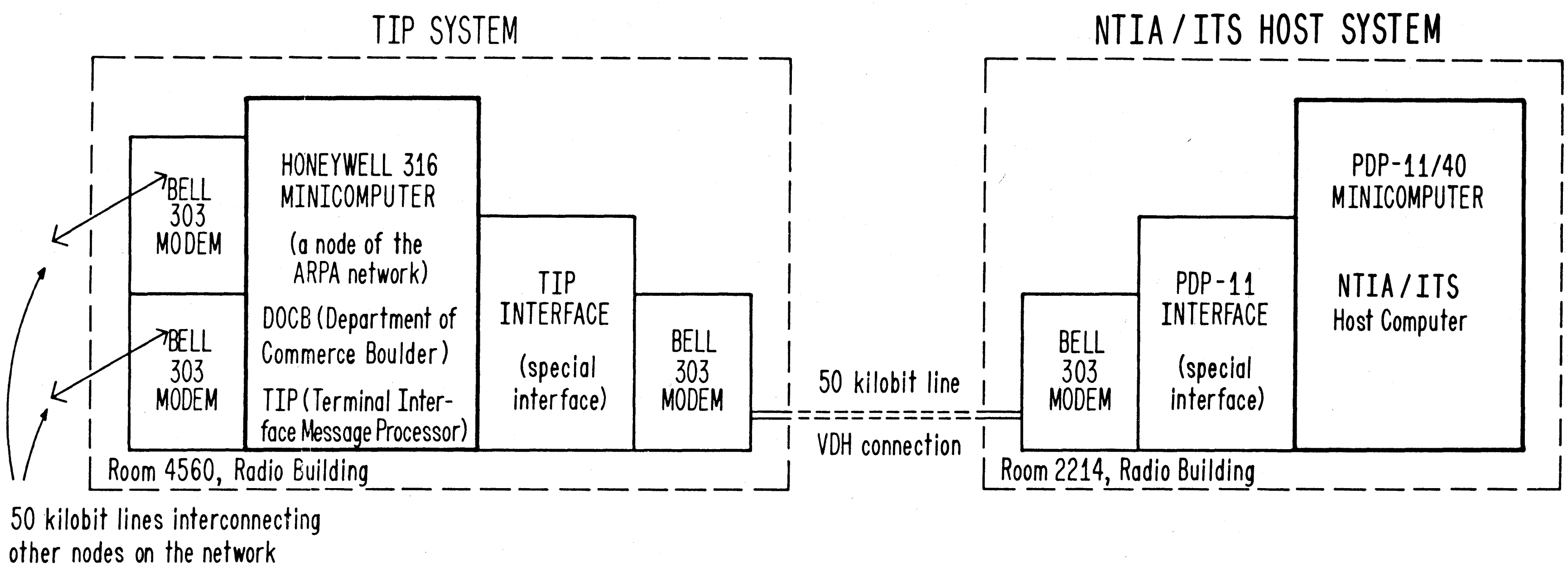

Figure 4. Sketch of the NTIA/ITS Host connection to the DOCB TIP.

network between an IMP or TIP and a Host. The VDH connection provides error detection and retransmission between the Host and TIP. A VDH connection is implemented by means of the following components:

(1) a special interface at each end of the connection;

(2) a special software package in the TIP and Host; and

(3) a 50 kb/s full duplex line connecting the two special interfaces.

The two special interfaces are attached directly to the TIP mini-computer and the PDP-11 mini-computer, and these interfaces provide the hardware which generates the synchronization and control characters for the binary synchronous line control (BSC) protocol. In each mini-computer a special software package is resident to implement the error detection and retransmission process for the VDH connection. Each interface plugs directly into a Bell 303 modem at each end of the connection. The Bell 303 modems are connected by means of two twisted pairs of shielded cable. The cable extends a distance of almost 1800 feet, within the Radio Building at DOCB.

The 50 kb/s lines which connect the DOCB TIP with adjacent nodes of the subnet are shown in Figure 4, located on the left side of the TIP system.

The Elf operating system permits several persons at terminal devices connected to the NTIA Host to use the network simultaneously. The network control program (NCP) within Elf will support simultaneously a number of independent connections or conversations, each involving a program in the NTIA-Host and another program in any Host on the network.

4. ACCESS AND DISENGAGEMENT PARAMETERS FROM PROPOSED STANDARD 1033

This section presents the definitions for the access and disengagement parameters from proposed Federal Standard 1033.

Access time is the average value of elapsed time between the start of an access attempt and successful access. Unsuccessful access attempts are not included in the average. The access phase is the interval of time over which access time is measured. Successful access or the end of access phase is accomplished when the first byte (8 bits) of user information is moved by the user system into the communication system toward some destination Host, after a connection has been established. In Section 2, the NCP was identified as the interface between the user system and the communication system. The access phase is completed when the first byte of user information passes through the Elf's NCP (i.e., point B in Fig. 5).

Related to access time are the two parameters incorrect access probability and access denial probability. Incorrect access probability is defined as the ratio of access attempts which result in incorrect access (i.e., a connection to the wrong destination Host on the ARPANET), to total access attempts counted during a measurement period. Access denial probability is defined as the ratio of access attempts which result in access denial (system blocking) to total access attempts counted during a measurement period.

Disengagement time is defined in proposed Federal Standard 1033 as the average value of elapsed time between the start of a disengagement attempt and successful disengagement. Unsuccessful disengagement attempts are not included in the average. Disengagement time measures the time span of the disengagement phase. Disengagement failure probability is defined as the ratio of disengagement attempts which result in disengagement failure to total disengagement attempts counted during the measurement period. The application of these parameters to the ARPANET will be discussed in Section 5.

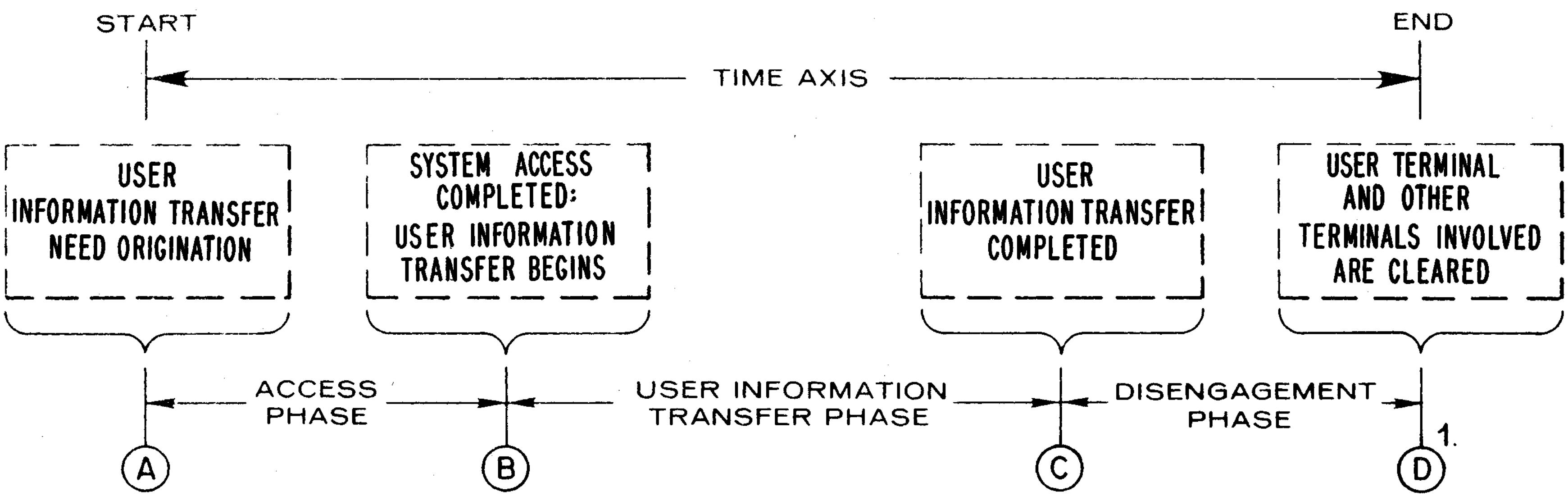

Figure 5. Illustration of access and disengagement phases which are measured by the parameters, access, and disengagement time (after McManamon and Seitz, 1976).

5. EXPERIMENT DESIGN FOR ACCESS AND DISENGAGEMENT PARAMETERS

The ARPANET computer network is both experimental and operational. The ARPANET provides a test bed for experiments such as the measurements related to proposed Federal Standard 1033. The five proposed performance parameters, access time, disengagement time, incorrect access time, access denial probability and disengagement failure probability are suited to measurement on the ARPANET.

Proposed Standard 1033 was developed for users of Federal telecommunication systems, where performance between end users of systems is the measurement objective. For any telecommunication system, one must determine how to apply these performance parameters to the given system. In the ARPANET case, the Telnet protocol was selected as a convenient means to demonstrate the application of the proposed performance parameters. Telnet was chosen because most persons who use the ARPANET employ the Telnet protocol to establish and close connections between Hosts.

Figure 5 delimits the three phases that users of telecommunication systems perceive. Access phase is the interval of time over which access time is measured. Since the Standard defines access time to include all of the access phase, one must initiate a data transfer of user information as the last event to end access phase. Point B of Figure 5 identifies the end of access phase as the beginning of user information transfer. User information is defined as non-overhead information provided by a user or user system that is transferred into the communication system. User information excludes all overhead information generated by both high and low levels of ARPANET protocols. The disengagement phase is the interval of time over which disengagement time is measured.

5.1. Network Events

As previously mentioned (Sec. 2) the ARPANET is a packet-switched, fully distributed computer network. Access time and disengagement time are measures of the message transmission delays that are built into the network. Access and disengagement are accomplished by the sending and receiving of messages between two Hosts on the ARPANET.

Some of the factors or events affecting access and disengagement time encompass the following ARPANET packet-switching delays (Heart et al., 1970):

(1) Propagation time, the electrical propagation time in the Bell system is estimated to be 30 ms for a coast-to-coast connection.

(2) Modem transmission delay, the rate at which bits enter and leave the modem (50 kb/s).

(3) Queueing delay, the time spent waiting in the IMP's packet queue while the IMP processes other packets.

(4) IMP processing delay, the time required for the IMP to process a single packet, estimated at 0.35 ms.

(5) Variable Traffic density, the amount of traffic in the subnet affects queueing delays and routing.

(6) Variable routes, the routing algorithm resident in each IMP or TIP can change routes between Hosts.

Flow control delays which affect message delay include:

(1) Flow control procedures between the Host and IMP (or TIP) which reside in the communications subnet.

(2) The maximum number of messages which a Host is permitted to have in transit on any connection is eight.

(3) IMPs which serve source and destination Hosts must exchange control messages which allocate a limited table space in memory for new connections between Hosts. See Bolt Beranek and Newman (1976).

Finally, the Telnet server Hosts on the ARPANET are usually serving local users and simultaneously responding to ARPANET message traffic. This also introduces variable delay in Host-to-Host message response.

5.2. Telnet Protocol

The ARPANET Telnet protocol was chosen as the user application level protocol for measurement of the performance parameters. The Telnet protocol within the Elf operating system is used to support user access to the ARPANET. Telnet allows a person at a terminal connected to some ARPANET Host to access (using a Telnet connect command) some other foreign Host as though his terminal were attached to the foreign Host. After the terminal user has completed his work on the foreign Host he then issues a disengagement command, a Telnet close command.

Figure 6 is a simplified sketch of how the Elf operating system software modules interface under the Telnet protocol. Figure 6 shows the interaction between the NCP's Telnet user and server processes and other processes. Access between two ARPANET Hosts under Telnet requires that the Telnet user process in some Host call (via the NCP) a Telnet server process in another Host and eventually establish with messages a full duplex connection between the two Telnet processes. A socket is used to couple the NCP to another process within the same Host, such as a Telnet process. Disengagement between two ARPANET Hosts under Telnet requires that a user process hang-up (close) the previously established connection to the server process. Sometimes the server closes the connection for reasons of its own choosing.

The NTIA/ITS Host Telnet software was modified to measure both access time and disengagement time. Elf system macros (segments of code) were inserted in the Telnet "connect and close" subroutine code to perform the time interval measurements for access and disengagement.

5.3. Design of Access Time Measurements

For the ARPANET, access time can be measured as a performance variable. The access phase (Fig. 5) is the interval of time over which access time is measured.

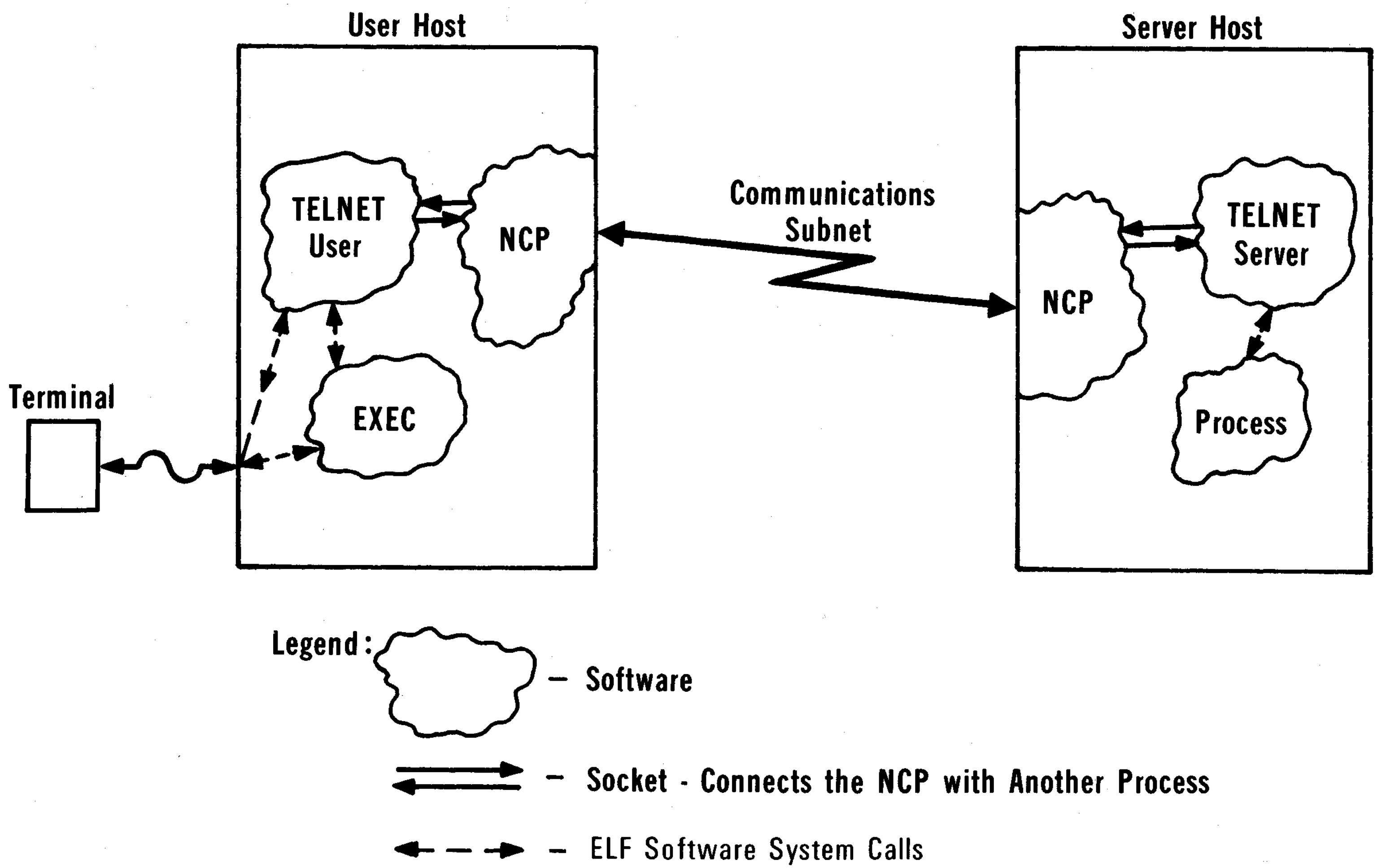

Figure 6. Host-to-Host connection via telnet protocol.

Successful access as illustrated in Figure 5, occurs when the first bit or byte of user information is moved by the user system into the communication system. In Section 2.2, the NCP was identified as the interface between the user system and communication system. For this experiment the access phase was completed when the first byte of user information passed through the Elf's NCP.

Start of access attempt was chosen as when the CONNECT TO ABC (CR) command was issued by the operator to Telnet (i.e., when the first character c is typed from the terminal keyboard, see Fig. 7). The time intervals to call the Telnet program and to type the CONNECT TO command were measured and recorded manually. The Elf telnet program was modified to measure the time period from the carriage return (CR) following HOST's name to the passage of the first byte of user information through the Elf's NCP. This time period is identified by variable time interval in Figure 7. The program computed this time interval by time stamping the above events using the time clock located in the VDH interface. The time is then printed on the terminal printer in milliseconds. All events within the variable time interval of Figure 7 occurred under control of software procedures of the Telnet user process. The Telnet connection process involves sending and acknowledging several control messages between Hosts ICP (initial connection protocol) (Postel, 1971).

The time interval to call the Telnet program is denoted by TEL CR and a curved arrow in Figure 7. This time interval was not included in the access time interval because once the Telnet program is installed, a series of connections could be conducted by the operator without calling Telnet again. One might question why the connect command (CONNECT TO ABC) time interval is included in access time, since this is not a function carried out by the communication system. The answer is that this operator action is part of the required Telnet connection process. Access time is variable between any two Hosts because

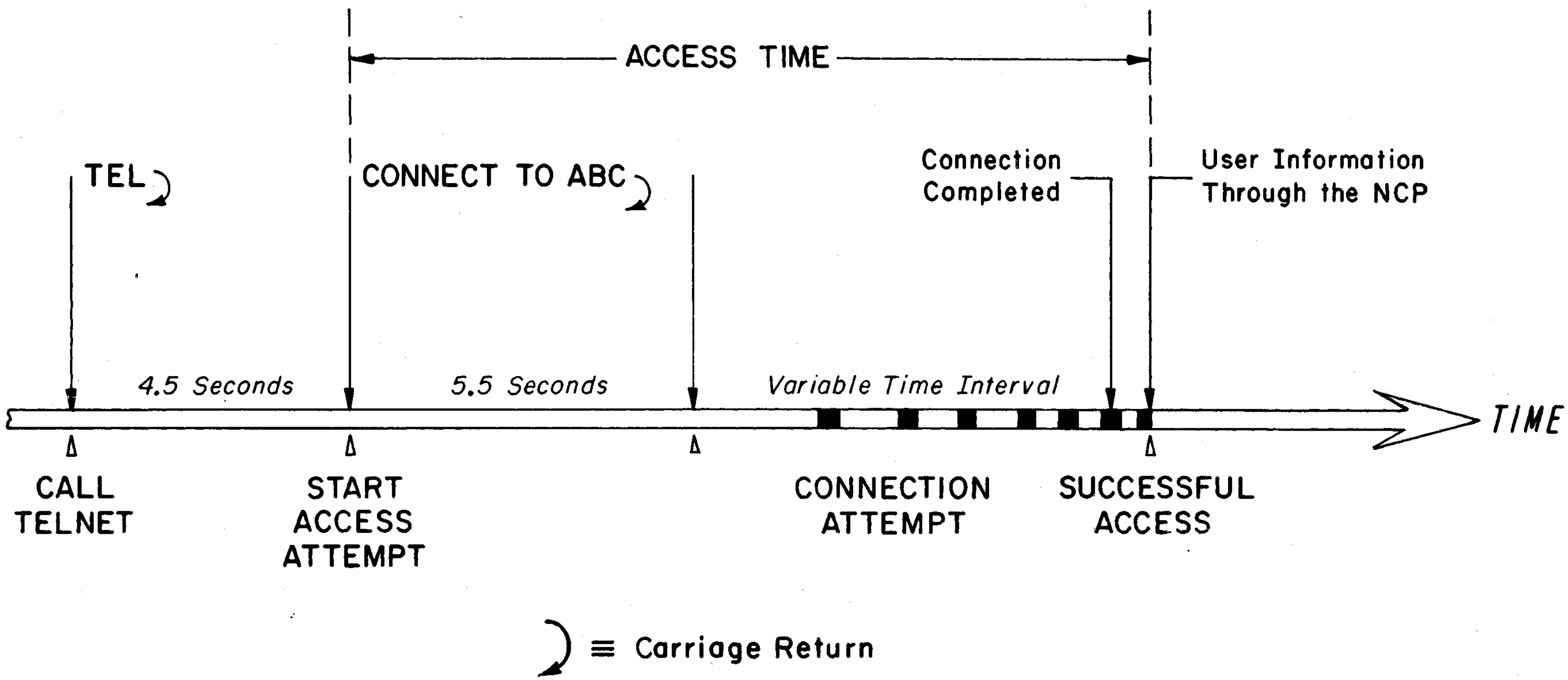

Figure 7. Flow diagram for measuring Host-to-Host access time via telnet protocol.

of the variable traffic load conditions, variable distances or routes between Hosts, and variable program load at Host sites (see Sec. 5.1).

The time interval printed on the PDP-11 terminal includes both the connection process time, which ends at the point labeled "connection completed" in Figure 7, and the time segment required to transfer a byte of user information from memory through the Elf NCP, which begins as soon as the connection is completed. These two time segments are referred to as connect time and transfer time. Connect time is a variable and transfer time may also be a variable when the local NTIA/ITS Host has more than one user logged on the system because Elf is a multi-user system. However, all measurements were conducted in the single user, single process mode, and transfer time required about 2 ms.

Assuming that the Telnet process is functioning, the steps performed to measure access time are as follows:

1. Operator types "CONNECT TO ABC (CR)", where ABC represents some Host name,
2. Connection attempt begins; if successful, the connect time plus transfer time are printed on terminal printer.

In the tables of Appendix and later sections of this report, the combination of connect time plus transfer time is referred to as connection-attempt time.

The variable time interval in Figure 7 represents the time required by the local Telnet software to open successfully a Host-to-Host connection (connect time) and transfer user information through NCP (transfer time). During this time interval (connection-attempt time), the NTIA/ITS Host Elf Telnet process also performs required software housekeeping arrangements.

In Figure 7, the 5.5 seconds needed to type the connect command represents the operator's typing speed and is not necessarily a typical value.

5.4. Design of Disengagement Time Measurements

For the ARPANET, disengagement time can be measured as a performance variable. The NTIA/ITS Host Telnet software was modified to measure disengagement time. Disengagement time measures the time span of the disengagement phase, Figure 5. This time span as applied to the Telnet protocol is illustrated in Figure 8.

After a terminal operator using Telnet has opened a connection to some distant ARPANET Host and has finished his interactions with programs in the server Host, then he must close or disengage the Host-to-Host connection. The operator disengages from the connection as follows:

1. He issues a CTRL (control) Y. This starts the disengagement attempt shown in Figure 8 which alerts the Telnet user process in the user Host. The Elf Telnet software immediately sends a "prompt" character to the operator's terminal. This event is not shown in Figure 8. The operator's terminal is now connected to the Telnet user process in the user Host.
2. The operator then types the letters CLO and carriage return (CR). In Figure 8, the time to complete these events is called command time. The average command time was 3.3 seconds. The 3.3 seconds represents the operator's typing speed and should not necessarily be considered a typical value.
3. The user Telnet program then begins the process of telling the Elf NCP to begin the closing process. This is called "close-attempt time" in Figure 8.
4. After the connection has been successfully closed, a "successful-disengagement" message is sent to the terminal informing the operator that the connection is closed; see Figure 8.

At this point disengagement is completed. The operator is now free to open a connection to some other Host on the ARPANET, or

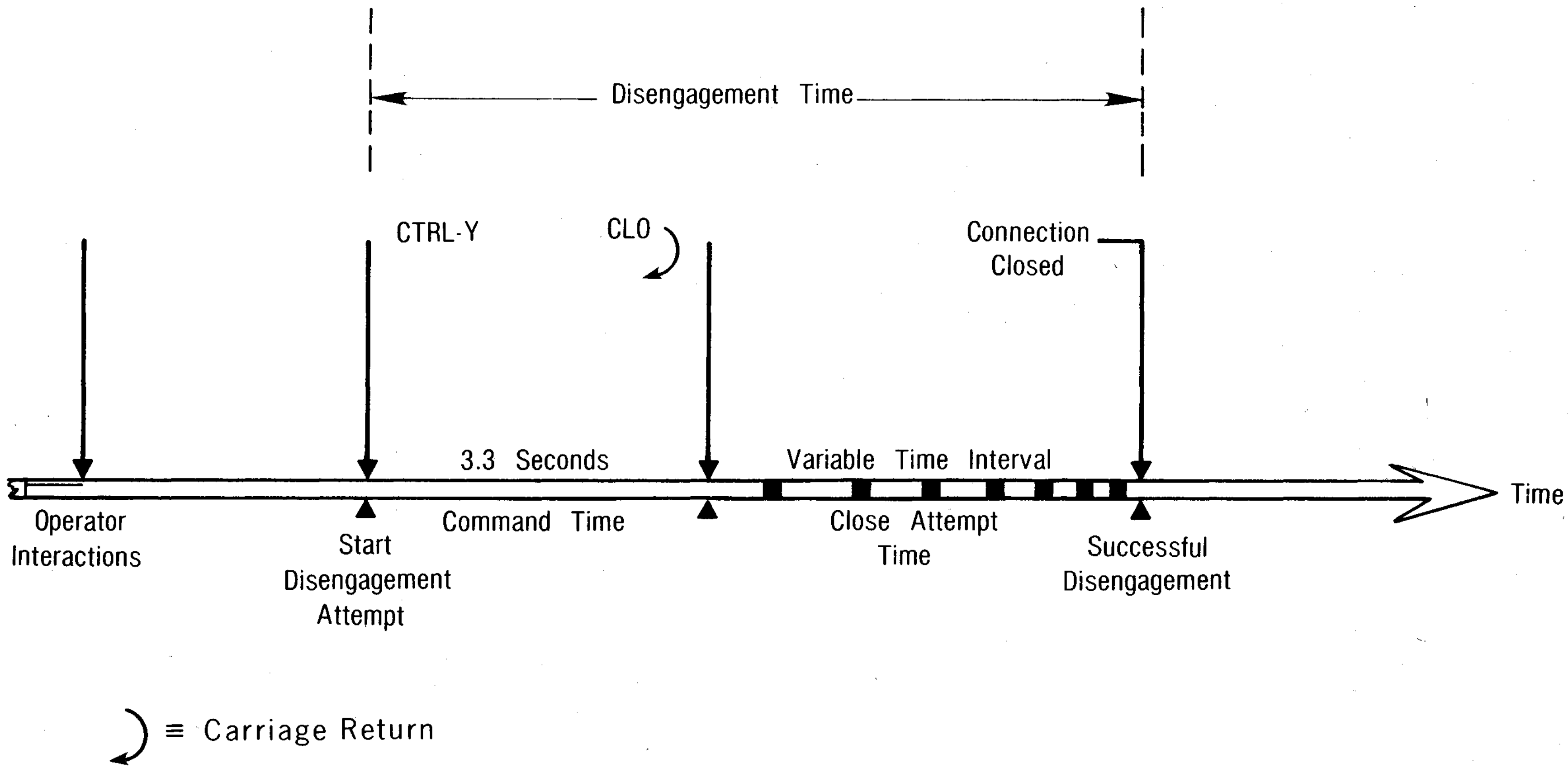

Figure 8. Flow diagram for measuring Host-to-Host disengagement time via telnet protocol.

to call up some process within the user Host or to terminate his use of the local system.

The variable time interval (close-attempt time) shown in Figure 8 represents the time required by the user Telnet software and the server Telnet software to complete the closing of a full duplex connection between these two software modules. During this time interval the user Host NCP and server Host NCP exchange acknowledged close (CLS) commands through the network, and their respective Telnet software performs housekeeping arrangements, including a "connection closed" message to the terminal operator. This variable time interval was measured by modifying the NTIA/ITS Telnet software so that it time-stamped the beginning and end of "close-attempt time". The difference between the beginning and end times was calculated and printed on the operator's terminal. Close-attempt time includes various housekeeping functions that the Elf Telnet is required to perform and the exchange of two acknowledged close commands through the network. This time interval is variable because of the events defined previously in Section 5.1.

5.5. Sample Size

In Section 4 the definitions of access and disengagement time specify that these parameters are averages.

From Section 5.1, one observes the various delays present in the ARPANET which cause these parameters to vary in a random fashion. The following network events occur during each access and disengagement attempt: propagation time delay, modem transmission delay, IMP or TIP processing delay for each packet, variable traffic density in the subnet, variable routes for each packet assigned by the routing algorithm resident in each IMP or TIP, and flow-control delays and variable response times by Host computers in message handling or processing. Most of these network events are independent of each other and this introduces randomness or variability into access and disengagement times.

In addition, each successful access and disengagement attempt implies that the above network events were repeated several times, because successful access and disengagement requires the exchange of several messages between source and destination Hosts. Access attempts employ the ICP (initial connection protocol) which involves four or more messages and their acknowledgments (Acks). Disengagement attempts employ two messages and their Acks. Therefore, one would expect that measurements of access and disengagement times would be variable and that these times should be described with probability relations and statistical averages rather than with deterministic methods or mathematical equations.

The histogram in Figure 9 was plotted to study to what extent the above events introduce randomness in measures of access and disengagement time. The histogram includes the measurement results of 200 successful access attempts distributed over an 8-hour interval (8 a.m. to 4 p.m. MDT on June 5, 1976) from the NTIA/ITS Host to Rutgers-10 Host. These 200 sample values were placed in ascending order and grouped in 16 equal class intervals of 65 milliseconds each. All measurement values were rounded off to the nearest millisecond by the measurement software. The Y axis displays the frequency count for each class interval and the X axis displays the equal class intervals of 65 milliseconds. The sample values ranged from 6.479 seconds to 7.513 seconds, with one value in the 27th class interval at 8.229 seconds. The frequency count for each class interval was plotted in Figure 9. The first class interval represents the time interval from 6.450 to 6.515 seconds. The peak and the shape of the histogram suggests normal or Gaussian distribution properties.

From the above discussion concerning the sum of independent, variable delay events (Central Limit Theorem), one can assume that access and disengagement times are normally distributed.

With this assumption of normality, the Student t (Bendat and Piersal, 1966) distribution was used to establish confidence

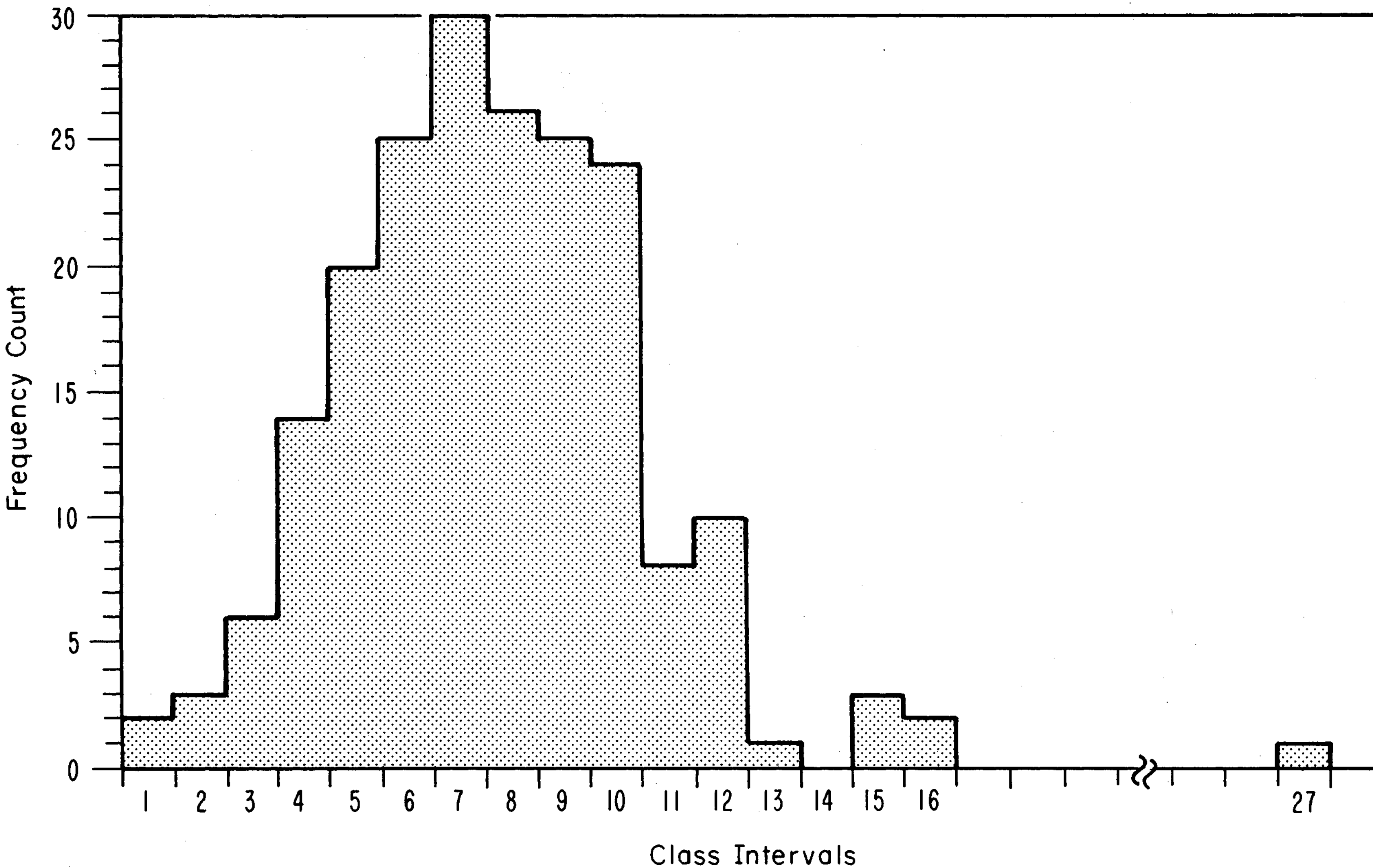

Figure 9. Frequency histogram for access time between NTIA/ITS Host and the Rutgers Host; each class interval represents 65 milliseconds of time.

intervals which relate to sample size for access and disengagement time measurements.

The arithmetic mean was chosen as the estimator for the true mean value of these parameters. The arithmetic mean $\bar{x}$ for sample size N from a random variable x(i) is $\bar{x} = \sum_{i=1}^{N} x(i)/N$. For a given sample of access or disengagement times between two ARPANET Hosts, the problem is to determine the sample size N within some confidence interval.

For the case of a normally distributed random variable with unknown true mean μ_x and unknown true variance σ_x^2, the Student t random variable is

$$t_n = \sqrt{N}(\bar{x}-\mu_x)/s, \ n=N-1, \tag{1}$$

$\bar{x}$ is the sample mean and s^2 is the sample variance. Here t_n has a Student t distribution with n=N-1 degrees of freedom. To obtain a confidence interval from the Student t distribution, the following probability statement applies

$$\text{Prob}\left[t_{n;1-\alpha/2} < (\bar{x}-\mu_x)\sqrt{N}/s \leq t_{n;\alpha/2}\right] = 1-\alpha, \tag{2}$$

where $t_{n;\alpha}$ is the value of t at some percentage α of the Student t distribution. A confidence interval can be established for the true mean value μ_x from equation (2).

$$\left[\bar{x} - (st_{n;\alpha/2}) / \sqrt{N} \leq \mu_x < \bar{x} + (st_{n;\alpha/2}) / \sqrt{N}\right] \tag{3}$$

This equation uses the fact $t_{n;1-\alpha/2}=-t_{n;\alpha/2}$. Equation (3) utilizes the Student t distribution to obtain a relationship between the sample size N and a confidence interval about μ_x based upon some value of α. The confidence coefficient associated with the above interval is $1-\alpha$.

For example, actual measurement data in milliseconds for connection-attempt time (Fig. 7) recorded at 0900 at DoCB from August 24, 1977 to September 17, 1977 between NTIA/ITS Host and the CMU-10A (Carnegie-Mellon University) Host are 1998, 2288, 2146, 1954, 2518, 1857, 2123, 2211, 2244, 2092,

$$\bar{x} = 21431/10 \simeq 2143.$$

The sample variance of this set of data is

$$s^2 = 1/(N-1) \sum_{i=1}^{N} (X_i-\bar{x})^2$$

and $s \simeq 182$ ms.

From the Student t distribution for $\alpha=0.05$ and N=10, $t_{n;\alpha/2}$ becomes $t_{9:0.025}=2.26$. Substituting in equation (3)

$$[2143 - (182x2.26)/3.16 \leq \mu_x < 2143 + (182x2.26)/3.16]$$

$$\text{becomes } [2013 \leq \mu_x < 2273]. \qquad (4)$$

Equation (4) says that the true mean value μ_x falls within the interval of 2013-2273 milliseconds or 260 milliseconds with a confidence coefficient of $(1-\alpha)$x100 or 95%. The confidence coefficient is the degree of trust associated with the confidence statement of equation (4).

At this point one can only say that for a sample size N=10, one gets a 95% confidence interval of 260 milliseconds about the true mean μ_x, assuming normally distributed data. A similar set of measurement data from the NTIA/ITS Host to CMU-10A Host for close-attempt times in milliseconds included in disengagement time, are: 1773, 1623, 1536, 1800, 1676, 1717, 1636, 1512, 1498, 1633.

$$\bar{x} \simeq 1641 \text{ milliseconds (ms)},$$

s=314 milliseconds and from equations (3) and (4) with $\alpha=0.05$ and N=10, μ_x falls within the interval of 1416-1866 ms with a confidence interval of 450 ms long. These two tests do not include the values for command time since these values are constants the confidence intervals are not affected for either access or disengagement times. Similar confidence intervals were measured for sample size N=10 and $\alpha=0.05$ for data recorded between NTIA/ITS and Harv-10 (Harvard University). The measurements were conducted at the same time and dates as the CMU-10A measurements. Connection-attempt time yielded an interval of $2316 \leq \mu_x < 3258$ in ms, or 942 ms, 95% confidence interval. Disengagement time yielded an interval of $1643 \leq \mu_x < 2047$ ms or 404 ms, 95% confidence interval.

In summary, the values of these four 95% confidence intervals (260 ms access, 450 ms close, 404 ms close, and 942 ms access) are not unreasonable when one considers the magnitude of the raw data, the small sample size (N=10) and the value of α. The author intends to use N=10 as a suitable sample size for measurements of access and disengagement times.

6. MEASUREMENT RESULTS

The sample value measurements are given in the Appendix. The overall measurement results are shown in Tables 1 and 2. Column one of each table is the name of the Host computer system accessed by the NTIA/ITS Host. A list of geographical locations for the selected Hosts is as follows:

Host Name	Location
USC-ISIB	Marina Del Rey, CA
UCLA-CCN	Los Angeles, CA
USC-ISI	Marina Del Rey, CA
CMU-10A	Pittsburgh, PA
CMU-10B	Pittsburgh, PA
HARV-10	Cambridge, MA
SU-AI	Stanford, CA
SUMEX-AIM	Stanford, CA
NBS-10	Gaithersburg, MD
RUTGERS-10	New Brunswick, NJ
BB&N	Cambridge, MA
BB&N-B	Cambridge, MA
CCA	Cambridge, MA
SRI-KA	Menlo Park, CA
SRI-KL	Menlo Park, CA
MIT-DMS	Cambridge, MA
MIT-AJ	Cambridge, MA
LONDON	London, England

Table 1. Measurement Values for Connection-Attempt Time and Close-Attempt Time in Milliseconds Averaged from Tables A.1 Through A.10

Host	MHR*	0900 Connect Close	1000 Connect Close	1100 Connect Close	0200 Connect Close	0300 Connect Close	0400 Connect Close	0500 Connect Close	Avg Connect Close
USC-ISIB	2	2820	3152	3074	3066	3000	2932	3303	3049
		1665	1701	1816	1679	2861	1698	1695	1874
UCLA-CCN	2	1895	1950	1977	1895	2350	1982	2286	2049
		1707	1779	2090	1758	1837	1789	2409	1910
USC-ISI	3	3787	3413	3539	3357	4518	3816	3592	3715
		1819	1691	1781	1727	1719	1657	1734	1723
CMU-10A	3	2207	2086	2290	2350	2194	2249	2278	2236
		1608	1646	1678	1646	1691	1657	1636	1652
CMU-10B	3	2084	2114	2177	2139	2176	2174	2199	2152
		1636	1648	1678	1661	1663	1614	1634	1648
HARV-10	4	2621	2612	2626	2789	2831	2633	2753	2695
		1809	1883	1881	1825	1867	1888	1954	1872
SU-AI	4	3128	2799	2591	3552	3369	4117	3748	3329
		1605	1749	1656	1742	1666	1692	1741	1693
SUMEX-AIM	5	3719	4091	3781	4387	4046	4544	4168	4105
		1897	2027	2124	1938	2046	2366	2581	2140
NBS-10	6	2988	2832	3105	2919	2809	2761	2844	2859
		1943	1949	1926	1951	1910	1913	1986	1940
AMES-67	6	3828	4722	4033	4166	5444	4431	5179	4543
		2631	2940	2406	2842	2823	2474	2696	2687
RUTGERS	6	3126	2767	2991	2895	3279	2985	2705	2964
		2012	2002	2007	1974	2070	1987	1928	1997
BB&N	6	6107	5331	5341	5423	5206	5055	5394	5408
		2313	2094	2050	3708	2329	1883	2144	2360
BBN&N-B	6	6440	9563	5793	5786	5918	5127	5013	6234
		2045	2069	1975	2192	2396	2116	2075	2124
CCA	7	4813	4846	4728	4551	4781	5001	4710	4776
		2215	2114	2098	1948	2156	1976	2384	2127
SRI-KL	7	4266	4858	4915	5730	5178	4683	5221	4174
		2095	3688	2158	1994	2142	2069	2565	2387
MIT-DMS	7	4424	4152	4206	4010	3942	4003	3878	4089
		2092	1992	1970	1969	1940	2042	2156	2023
MIT-AI	7	4516	4377	4205	4461	3676	4057	3758	4150
		2005	2043	2075	2070	1741	2961	1999	2128
LONDON	8	8146	2020	7681	7844	8235	7633	7635	7885
		4112	4060	3738	4685	4090	3816	4284	4112

*MHR - Minimal Hop Route

**Each Host shown in the table above has two lines associated with it. The top line shows the connection-attempt time and the bottom line shows the close-attempt time for every hour of the day when measurements were made. These measurement values are averaged for each Host in the far-right column "Avg".

Table 2. Measurement Values for Access Time and Disengagement Time Values (in seconds) Derived from Table 1

Host	MHR*	0900 Access Dengage	1000 Access Dengage	1100 Access Dengage	0200 Access Dengage	0300 Access Dengage	0400 Access Dengage	0500 Access Dengage	Avg Access Dengage
USC-ISIB	2	8.3	8.7	8.6	8.6	8.5	8.4	8.8	8.5
		5.0	5.0	5.1	5.0	8.4	5.0	5.0	5.2
UCLA-CCN	2	7.4	7.5	7.5	7.4	7.9	7.5	7.8	7.5
		5.0	5.1	5.4	5.1	5.1	5.1	5.7	5.2
USC-ISI	3	9.3	8.9	9.0	8.9	10.0	9.3	10.1	9.2
		5.1	5.0	5.1	5.0	5.0	5.0	5.0	5.0
CMU-10A	3	7.7	7.6	7.8	7.9	7.7	7.7	7.8	7.7
		4.9	4.9	5.0	4.9	5.0	5.0	4.9	5.0
CMU-10B	3	7.5	7.6	7.7	7.6	7.7	7.7	7.8	7.7
		4.9	4.9	5.0	5.0	5.0	4.9	4.9	4.9
HARV-10	4	8.9	8.1	8.1	8.3	8.3	8.1	8.1	8.2
		5.1	5.2	5.2	5.1	5.2	5.2	5.3	5.2
SU-AI	4	8.6	8.3	8.1	9.1	8.9	9.6	9.2	8.8
		4.9	5.0	5.0	5.0	5.0	5.0	5.0	5.0
SUMEX-AIM	5	9.2	9.6	9.3	9.9	9.5	9.9	9.6	9.6
		5.2	5.3	5.3	5.2	5.3	5.6	5.9	5.4
NBS-10	6	8.3	8.3	8.6	8.4	8.3	8.3	8.3	8.4
		5.2	5.2	5.2	5.3	5.2	5.2	5.3	5.2
AMES-67	6	9.3	10.2	9.5	9.6	10.9	9.9	10.6	10.5
		5.9	6.3	5.7	6.1	6.1	5.8	6.0	6.0
RUTGERS	6	8.6	7.8	8.5	8.4	8.8	8.5	8.2	8.4
		5.3	5.3	5.3	5.3	5.4	5.3	5.2	5.3
BB&N	6	11.6	10.8	10.8	10.9	10.7	10.6	10.9	10.9
		5.6	5.4	5.4	7.0	5.6	5.2	5.4	5.6
BB&N-B	6	11.9	15.1	11.3	11.3	11.4	10.6	10.5	11.7
		5.3	5.4	5.3	5.5	5.7	5.4	5.4	5.4
CCA	7	10.3	10.3	10.2	10.1	10.3	10.5	10.2	10.3
		5.5	5.3	5.3	5.2	5.3	5.3	5.7	5.4
SRI-KA	7	10.1	10.3	10.5	11.6	10.8	10.2	10.2	10.5
		5.3	5.4	6.9	5.0	5.8	5.4	5.0	5.6
SRI-KL	7	9.8	9.8	9.7	9.5	9.4	9.5	9.4	9.6
		5.4	5.3	5.3	5.3	5.3	5.3	5.4	5.3
MIT-DMS	7	9.9	9.6	9.7	9.5	9.5	9.5	9.4	9.6
		5.3	5.3	5.3	5.3	5.3	5.3	5.5	5.3
MIT-AI	7	10.0	9.9	9.7	9.9	9.2	9.6	9.1	9.7
		5.3	5.3	5.4	5.4	5.0	5.3	5.3	5.4
LONDON	8	13.6	13.5	13.2	13.3	13.7	13.1	13.1	13.4
		7.4	7.3	7.0	8.0	7.4	7.1	7.5	7.4

*MHR - Minimal Hop Route

**Each Host shown in the table above has two lines associated with it. The top line shows the access time (in seconds) and the bottom line shows the disengagement time (in seconds) for every hour of the day when measurements were made. These measurements values are averaged for each Host in the far-right column "Avg".

All Hosts were selected arbitrarily from the ARPANET directory on the basis that they were listed as unlimited server Hosts. All tables are formatted into lines that contain two rows of numbers for each Host. The top-row number relates to access and the bottom-row number relates to disengagement. These sets of numbers are distributed in seven columns with a time of day as the heading.

Table 1 is derived from Tables A.1 through A.10 in the Appendix. The Appendix contains ten tables of sample data for connection-attempt time and close-attempt time. From Section 5.3, access time is the sum of connection-attempt time (a variable) and operator action time (a constant). From Section 5.4, disengagement time is the sum of close-attempt time (a variable) and operator action time (a constant).

Table 1 was constructed by averaging all values of connection-attempt and close-attempt times for each particular time slot. There are ten tables so that approximately ten sample values were used in each sample size as discussed in Section 5.5. The headings for columns 3 through 8 are the particular times of the day (Mountain Standard Time) and were chosen arbitrarily. The samples were measured on dates that ranged from August 23, 1977 to September 21, 1977 (see tables). The connection and close-attempt values were measured and rounded off to the nearest millisecond. Millisecond accuracy was obtained by using the VDH timer attached to the PDP-11. This timer or clock is a count-down register which counts at 8 μs (microsecond) intervals.

The sample values in Table 1 and the tables in Appendix A were recorded to the nearest millisecond because of their significance in Host-to-Host network performance. The tables in the Appendix also record three other events. The letter A denotes that the access attempt failed. This happened when the terminal operator issued the connect command and the Elf system Telnet failed to respond. The letter F denotes that the disengagement attempt failed. This happened when the terminal operator issued a close command, after a connection was established, and the Elf system Telnet failed to respond. The letter O denotes that the terminal operator issued a connect command to some distant Host and he received a message from the subnet saying that the particular Host was not operating on the network. It is not certain why some of the access and disengagement attempts failed, but one suspects that there were defects in Elf.

The far-right column headed by the letters "Avg", is the average for the other seven columns of data. These numbers represent the average of data in all ten tables in the Appendix for all hours for each Host.

Tables A.1 through A.10 also contain the data needed to measure the three remaining parameters: incorrect access probability, access denial probability and disengagement failure probability. These values are obtained from the A, O, and F designations explained in Section 7.1.

Table 2 contains the access and disengagement times. These values were computed from Table 1 with the addition of operator action times of 5.5 seconds for access and 3.3 seconds for disengagement. The values of Table 1 were rounded to the nearest tenth of a second and added to their respective operator action time to produce Table 2.

7. ANALYSIS OF RESULTS

This section examines the measurement results presented in Section 6 and in the Appendix.

7.1. Access and Disengagement

If one examines the measurement values beginning with the tables in the Appendix, one can make some performance assessments about the ARPANET. Section 5.1 discusses the packet switch and flow control delays that are present in the ARPANET. These delays along with the telnet connect and telnet close processes combine to produce the values in all tables. In all cases, the

NTIA/ITS Host was the source Host and the destination Hosts are listed in column 1 of all tables.

Column 2 of all tables contains a number for each Host. This number was derived from Figure 1 and represents the minimum number of subnet links or the minimum hop route (MHR) between the NTIA/ITS Host (source mode) and the destination Host (destination node) listed in column 1. Each access and disengagement attempt generates several messages between Hosts (Sec. 5.2). Each message (i.e., these are single packet messages) may travel a different route depending on the status of the subnet and the routing decisions by the subnet (Sec. 5.1). Therefore, the MHR is not necessarily the subnet route used during all measurements. However, the MHR does offer some insight to ARPANET Host-to-Host performance.

For example, if one observes the magnitude of the data in all tables, the magnitude seems to increase as the MHR increases. This is not true for all Hosts in column 1, but the trend is apparent. In Table A.1 the value at time 1000 for SKI-KL is 17200 ms for close-attempt time and in Table A.6 the value for BB&N at 0200 for close-attempt time is 14248 ms. These large values are assumed to be caused by temporary system blocking. The large values for London, England were attributed to the very great length of the satellite path, and to an MHR=8.

Another observation from the tables is that connection-attempt time is almost always larger than close-attempt time. The reason these times are larger can be attributed to the following:

(a) New connections between Hosts require the source and destination IMPs which serve the source and destination Hosts, to exchange special control messages (Sec. 5.1). This requirement causes additional delay for initial connection between Hosts.

(b) The Telnet connection process requires the exchange of more messages than the Telnet closing process. These extra exchanges cause additional delays.

(c) Another influencing factor could be the priority within the destination Host operating system for initial connections. If priority is low this can cause additional delay.

(d) The number of local jobs (i.e., the number of active terminals logged-on plus the number of active processes in effect) at some destination Host would also influence the initial connection process. If the destination Host is running near capacity, then more delay will occur.

In Table 1, one cannot separate the Host operating system delays from the subnet switching delays within the access and disengagement measure. The reason is that the processes for Telnet and NCP in each Host and the subnet processes overlap in time. One can measure part of the Telnet process: the message-typeout time on the terminal (which requires about 780 ms for both access and disengagement). All the remaining time for each measurement value is spent in computer execution and data communication systems activity.

Table 2 shows much the same information that Table 1 shows except that the rounding of Table 1 values tends to simplify the difference between destination Host access and disengagement time values.

Although access time and disengagement time values cannot be separated into Host operating system delays and subnet switching delays, one can make some assumptions about these functional delays and relate these assumptions to ARPANET system performance.

First, assume that the NTIA/ITS system performs its access or disengagement functions at the same speed each time. This assumption is valid because the NTIA/ITS system performed all measurements in single user mode, where all software and hardware systems performed the same operations for each access or disengagement attempt (i.e., same operation repeated under same source Host conditions).

Second, assume that when MHR values are equal the packet switching subnet performs its functions within a tenth of a second for each attempt. The one exception is the case where (a) above applies, i.e., where special control messages between source and destination IMPs (for new connections between Hosts) cause additional delays. A tenth of a second difference allows for the variable subnet events presented in Section 5.1. This becomes a reasonable assumption because IMPs can process a packet in 0.35 ms.

Third, assume that destination Host response times are variable for connection and closing attempts. The variability of destination Host response time could be attributed to a large or small number of local users, program jobs and active terminals attached to that destination Host. These factors in turn influence priorities of operating system processes on the destination Host. For example, Telnet server process priority could vary according to local user load level.

One applies these three assumptions to the last column of Table 2. This column, headed "Avg", is the average value for all access measurements (top value) and disengagement measurements (bottom value) over all days and hours for that particular destination Host.

First, the values for London, England are the largest, as one would expect, because of the satellite-link distances. Next, the access times for Rutgers and NBS-10 are two to three seconds smaller than other Hosts with the same MHR value. One could explain this difference in access times as a combination of reason (a) above and the fact that these two destination Hosts are more readily accessible since there are fewer users. Reason (a) refers to the fact that source and destination IMPs must exchange control messages. The control messages allocate a limited table space within the IMP for each new connection. Conceivably, the more Hosts there are attached to an IMP (four is maximum), the more ARPANET connections exist and the more likely

IMP table space could become a problem and cause delay. In the ARPANET directory, Rutgers is one of two Hosts attached to the Rutgers TIP and NBS-10 is one of two Hosts attached to the NBS TIP. Therefore it appears that Rutgers and NBS-10 are more readily accessible because they have fewer ARPANET users or connections and more IMP table space than other Hosts with the same MHR values. Another observation is that CMU-10A, CMU-10B and UCLA-CCN all have small MHR values and seem to offer the fastest access to the NTIA/ITS Host. These three Hosts provide the fastest access despite the fact that UCLA-CCN is attached to a 3-Host node (IMP) and both CMU-10A and CMU-10B are attached to a 4-Host node.

Finally, in the Avg column one notes the uniformity of the disengagement times compared to access times. With the exception of London (7.4 seconds) and AMES-67 (6.0 seconds), all Hosts are in the 5.0 to 5.6 second range for disengagement time. This implies that once the initial connection is established, ARPANET Hosts respond more uniformly to message exchange. Further, the uniformity of the disengagement times could offer users a convenient performance tool. Because if disengagement time is discovered to be outside the range of 5.0 to 5.6 seconds, then one could suspect abnormal operations somewhere in the system.

7.2. Associated Parameters

The three other parameters associated with access time and disengagement time are incorrect access probability, access denial probability and disengagement failure probability.

Incorrect access probability is defined in Section 4. For the ARPANET, this parameter is interpreted as a connection to the wrong destination Host during the access phase. During access attempt, the NTIA/ITS terminal operator receives a herald from the destination Host proclaiming the Host name and other information. The herald identifies the destination Host. In 1221 successful access attempts, the NTIA/ITS operator did not receive a herald from an incorrect Host. Thus, for incorrect access probability, the measurements yielded an answer of 0/1221=0. An upper bound probability P for the occurrence of an incorrect access event can be computed based on the binomial distribution, the 1221 independent trials and a confidence coefficient α=0.05.

$$(1-P)^{1221} = \alpha$$

$$P = 0.0025.$$

Access denial probability is defined in Section 4. Although access denial was probably due to Elf timing problems, the overall system was blocked and all "A" events were counted to determine access denial probability. The "O" events were not included because in these cases the system was not operational (the destination Host was not on the ARPANET). The total number of A events was 18 and there were 1239 access attempts. Access denial probability was 18/1239=0.015.

Disengagement failure probability is defined in Section 4. The "F" symbol in Tables A.1 through A.10 denotes this event. From these tables a total of 1221 disengagement attempts resulted in 40 failures. Disengagement failure probability was 40/1221=0.033. When disengagement failure occurred during a disengagement attempt, the Telnet close command timed out after 30 seconds and printed a "timed out" message to the terminal operator. When access failure occurred during access attempt, the Telnet connect command generated a loop in Elf and the system had to be halted and re-started.

8. SUMMARY AND CONCLUSIONS

NTIA/ITS is engaged in the development of proposed Federal Standard 1033. This standard contains several proposed performance parameters, five of which are measured over the ARPANET and discussed in this report. These five parameters (Sec. 4) are applied to the ARPANET as follows:

(1) Access time is defined as the average value of elapsed time between the start of an access attempt and successful access. For the ARPANET Access time is

the time required to complete a Host-to-Host Telnet connection and call local NTIA/ITS NCP.

(2) Incorrect access probability is defined as the ratio of access attempts which result in incorrect access to total access attempts counted during a measurement period. For the ARPANET Incorrect access probability is the ratio of access attempts resulting in a connection to the wrong ARPANET destination Host to the total access attempts to all destination Hosts during the measurement period.

(3) Access denial probability is defined as the ratio of access attempts which result in access denial to total access attempts counted during a measurement period. For the ARPANET Access denial probability is the ratio of access attempts to destination Hosts which resulted in access denial to the total access attempts to all destination Hosts during the measurement period.

(4) Disengagement time is defined as the average value of elapsed time between the start of a disengagement attempt and successful disengagement. For the ARPANET Disengagement time is the time required to close a Host-to-Host Telnet connection.

(5) Disengagement failure probability is defined as the ratio of disengagement attempts which result in disengagement failure to total disengagement attempts counted during the measurement period. For the ARPANET Disengagement failure probability is the ratio of disengagement attempts to a destination Host which resulted in disengagement failure to total disengagement attempts to all destination Hosts during the measurement period.

The Elf (operating system) telnet was modified to measure access time and disengagmeent time. These two time intervals include the sum of two sequential time intervals:

(1) An operator action time is needed to type a connect (5.5 seconds) or close (3.3 seconds) command to Telnet.

(2) A variable connection or closing time interval is required by the Telnet connect and close commands between two ARPANET Hosts, see Table 1.

Access and disengagement times were measured over ARPANET paths from the NTIA/ITS Host (source) to 19 destination Telnet server Hosts (see Sec. 6, Tables 1 and 2) selected arbitrarily from the ARPANET 1977 directory. Approximately ten sample values of access time and disengagement time were averaged for each destination Host for each of seven time slots and recorded in Table 2 (Sec. 6). The overall average for each destination Host is contained in the last column in Table 2 headed by Avg. The values in the column headed by Avg (Table 2) were averaged over all recorded measurement data (about 70 sample values). These data revealed that Host-to-Host access time is more variable than disengagement time. This variability is probably caused by greater delays during the initial connection process at the destination Host (see Sec. 7.2) and by the exchange of IMP-to-IMP control messages required for initial connections (see Sec. 5.1). The uniformity of disengagement times in Table 2 demonstrates that after initial Host-to-Host connections are established (access), Host-to-Host message exchanges function in a uniform manner.

From 1221 successful access attempts the incorrect access probability was determined to be zero for Host-to-Host Telnet connections. An incorrect access probability of zero in 1221 measurements (Hosts) can be interpreted as good Host-to-Host operational performance. Access denial probability was computed from Tables A.1 through A.10 (Appendix A). In 1239 access attempts, access denial probability was found to be 0.015. Disengagement failure probability was also computed from Tables A.1 through A.10 (from 1221 disengagement attempts) and found to be 0.033.

The primary conclusion is that the five proposed performance parameters selected for measurement here were applicable to the ARPANET and that these parameters were measurable.

9. RECOMMENDATIONS

The author recommends that measurement experiments be conducted which employ many Hosts simultaneously to provide data related to network performance. The network measurements could be used to test the proposed performance parameters for overall network performance.

The remaining performance parameters of proposed standard 1033 concerning accuracy, efficiency, and reliability need to be tested. The author recommends that these parameters be measured on the ARPANET.

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APPENDIX. MEASUREMENT TABLES

This Appendix contains the raw sample values recorded during the measurement experiment. These sample values are listed in the 10 tables (A.1 through A.10). Each table denotes the name of the Host, the approximate time of day when data were recorded, the MHR (minimal hop route), a value for connection attempt time (top value) and a value for close attempt time (bottom value). The tables also show access attempt failures (A), disengagement attempt failures (F), and whether or not the destination Host was operational on the ARPANET (O). The MHR is the smallest number of links connecting the nodes separating the destination Host server from the NTIA/ITS Host's DOCB TIP located in Boulder, Colorado. The MHR data were determined from Figure 1.

Table A.1. Sample Values from Measurements on August 23, 1977 (Each Rectangle Space Contains (top) the Connection Attempt Time (ms) and (bottom) the Close Attempt Time (ms))

Host	MHR	0900 Connect Close	1000 Connect Close	1100 Connect Close	0200 Connect Close	0300 Connect Close	0400 Connect Close	0500 Connect Close
USC-ISIB	2	2504	4035	2628	3193	4289	3208	3239
		1753	1647	1556	1600	1805	F	1670
UCLA-CCN	2	2090	2016	1914	2318	1920	1992	1906
		1700	1993	4535	1898	1759	1864	1850
USC-ISI	3	3173	3643	3353	4881	3792	3762	3451
		1705	1783	2143	F	2012	1725	1565
CMU-10A	3	2244	2420	2130	2328	2182	2151	2166
		1512	1667	1689	1624	1773	1618	1602
CMU-10B	3	2529	2079	2293	2208	2850	2247	2091
		1734	1831	1590	1628	1973	1674	1596
HARV-10	4	2672	2444	2679	2659	2812	2622	2674
		1611	1882	1846	1819	1797	1932	1770
SU-AI	4	2424	3997	2369	3463	2789	2782	2442
		1600	1724	1664	1899	1618	1565	1682
SUMEX-AIM	5	4006	3784	5336	A	4648	5405	5708
		1912	2136	2268		2860	2618	8084
NBS-10	6	3474	3195	2708	3078	2726	2821	2898
		2002	F	1775	1993	1984	2053	1998
AMES-67	6	3318	4962	2850	3870	5412	4949	4453
		3128	3223	1913	5413	3511	2191	4226
RUTGERS	6	2993	3277	2825	2455	2984	2776	3261
		2016	2092	1998	2259	1911	1847	1874
BB&N	6	4876	4642	5853	5383	4492	4328	4534
		2180	2259	1905	1985	1917	1941	2380
BBN&N-B	6	6581	4748	5975	6058	4920	5018	3913
		1852	1998	1997	2345	2077	2037	1802
CCA	7	6135	4912	5092	5180	3515	5785	8717
		2255	2205	1964	2147	2033	1802	2134
SRI-KA	7	4295	4666	4239	3733	5472	4719	4055
		2341	2153	1987	2108	2279	2078	1678
SRI-KL	7	4133	5200	5484	5209	4328	5528	4537
		2278	17200	1903	1835	2263	2103	2152
MIT-DMS	7	4309	3908	4338	5353	3970	5385	3909
		2334	2254	2031	1902	2035	2177	2075
MIT-AJ	7	4468	4315	4614	5096	4093	4827	3964
		2335	2701	2076	2140	1941	2175	2305
LONDON	8	7733	8010	7981	7164	9397	7838	7936
		4273	3873	4084	3804	4089	3772	4672

A - Access Attempt Failed
F - Disengagement Attempt Failed
O - Destination Host Off-net
MHR - Minimal Hop Route

Table A.2. Sample Values from Measurements on August 29, 1977 (Each Rectangle Space Contains (top) the Connection Attempt Time (ms) and (bottom) the Close Attempt Time (ms))

Host	MHR	0900 Connect Close	1000 Connect Close	1100 Connect Close	0200 Connect Close	0300 Connect Close	0400 Connect Close	0500 Connect Close
USC-ISIB	2	2935	2494	2756	3104	2547	2620	3256
		1513	1737	1606	1475	1312	1511	1639
UCLA-CCN	2	2055	1813	1892	1978	1950	1890	2013
		1704	1782	F	1708	F	1875	1759
USC-ISI	3	3160	3363	3568	2919	4052	2742	2439
		1741	1916	1725	1668	1611	1701	1797
CMU-10A	3	2518	1777	2153	2157	1895	2052	1842
		F	1675	1610	F	1518	1574	1548
CMU-10B	3	1855	A	2372	2092	2341	1936	2331
		1613		1912	1571	1522	1525	1586
HARV-10	4	2511	2409	3017	2664	2822	2721	2688
		1834	1899	1996	1718	2035	1823	2024
SU-AI	4	2692	2476	1592	2205	2672	5882	2444
		1653	1651	1743	1737	1534	1677	1833
SUMEX-AIM	5	3697	3916	4424	4604	4696	5210	3485
		1805	2326	2035	2282	2042	2442	1775
NBS-10	6	0	2917	3034	2984	2773	2954	3058
			1879	1690	2044	1874	1798	1967
AMES-67	6	3010	0	0	6207	6058	7485	3560
		2613			3122	2088	2713	1864
RUTGERS	6	3157	3056	2937	2975	5132	2926	2880
		2052	2095	1993	2054	2149	1892	1886
BB&N	6	7448	3901	6185	4840	5539	3058	4453
		2317	1940	2035	1881	2098	1902	1933
BBN&N-B	6	4034	5000	4482	5112	5092	A	4103
		1979	2188	1893	2198	2128		1847
CCA	7	4061	6959	3882	A	4369	4268	3886
		2369	1923	1966		1962	1972	1973
SRI-KA	7	5247	5509	4542	5224	4207	4816	5076
		2166	2025	s080	1939	1873	2084	2241
SRI-KL	7	0	4056	4447	8839	4802	0	4350
			1937	2134	2032	1995		2100
MIT-DMS	7	4167	4324	4375	3531	3262	4198	3536
		1995	1940	1934	1912	1814	2372	1787
MIT-AJ	7	3864	4244	4025	4404	3615	2706	3774
		1991	1881	1796	1987	1849	10061	1916
LONDON	8	8078	8589	8442	8279	7504	8534	7954
		4003	3720	4454	4370	F	4285	4297

A - Access Attempt Failed
F - Disengagement Attempt Failed
O - Destination Host Off-net
MHR - Minimal Hop Route

Table A.3. Sample Values from Measurements on September 2, 1977 (Each Rectangle Space Contains (top) the Connection Attempt Time (ms) and (bottom) the Close Attempt Time (ms))

Host	MHR	0900 Connect Close	1000 Connect Close	1100 Connect Close	0200 Connect Close	0300 Connect Close	0400 Connect Close	0500 Connect Close
USC-ISIB	2	2648 1688	2896 1748	2688 1965	3130 1510	3008 14337	2629 1498	2914 1772
UCLA-CCN	2	1997 F	1764 1758	2149 1863	1993 1637	2231 2036	1850 1865	0
USC-ISI	3	5014 1849	3203 1644	4616 1645	2851 1550	3140 1673	3485 1585	5737 1885
CMU-10A	3	1824 1498	1664 1659	2185 1666	2094 1569	2092 F	1883 1633	2039 1599
CMU-10B	3	2232 1502	2575 1681	2166 1654	2002 1619	2001 1573	2175 1661	2224 1659
HARV-10	4	2562 1779	3097 1968	2423 1865	2840 1863	2729 1906	0	0
SU-AI	4	2366 1631	2793 1747	2607 1575	2349 1756	2727 1902	2283 1604	2710 1880
SUMEX-AIM	5	5373 1961	5653 2054	5082 1982	5606 1855	3874 1667	2601 1077	4240 F
NBS-10	6	2688 1840	3138 1762	0	0	0	0	0
AMES-67	6	5758 4092	4505 4234	5690 3952	2989 1918	0	0	9758 4213
RUTGERS	6	3100 1868	3241 2018	2448 2080	3148 1863	2905 1964	2650 1838	3211 1876
BB&N	6	0	0	0	0	0	0	0
BBN&N-B	6	14621 1944	5141 2202	A	5701 1986	5801 2080	5419 2157	6778 2027
CCA	7	4511 2017	4019 2114	5365 1948	4729 1892	6190 2345	4926 1927	3618 1889
SRI-KA	7	4660 2258	4950 2094	4998 2095	4134 1876	4346 1841	4166 2021	4431 2174
SRI-KL	7	3908 2451	4333 1772	4351 1916	4887 2002	5347 2030	4694 1905	5424 7019
MIT-DMS	7	3492 2152	A	4605 1996	4548 1875	4691 F	3216 1907	3783 2151
MIT-AJ	7	4542 2080	3963 1951	4491 2493	4362 1922	2825 2070	4351 2009	4330 2068
LONDON	8	7711 4052	6863 3813	7496 4037	7516 3658	9256 4497	7781 3857	7884 3707

A - Access Attempt Failed
F - Disengagement Attempt Failed
O - Destination Host Off-net
MHR - Minimal Hop Route

Table A.4. Sample Values from Measurements on September 6, 1977 (Each Rectangle Space Contains (top) the Connection Attempt Time (ms) and (bottom) the Close Attempt Time (ms))

Host	MHR	0900 Connect Close	1000 Connect Close	1100 Connect Close	0200 Connect Close	0300 Connect Close	0400 Connect Close	0500 Connect Close
USC-ISIB	2	2470 1786	5014 1714	5020 1672	3304 1786	2278 1692	2974 1856	3185 1649
UCLA-CCN	2	2070 1478	1972 1674	1955 1817	2308 1750	7139 1778	2140 1734	2146 1795
USC-ISI	3	2957 1666	A	3312 1744	3946 1638	3661 1607	0	4050 1731
CMU-10A	3	2469 F	2157 1817	1933 1588	2197 F	1899 1739	2120 1637	2086 1682
CMU-10B	3	2146 1621	2072 1601	0	2021 1711	2074 1548	2125 1698	2007 1524
HARV-10	4	2797 2097	2498 1897	2258 1852	2964 1824	2725 1814	2781 F	2936 1757
SU-AI	4	A	2585 1624	2577 1622	2742 1755	3255 1609	3082 1761	2824 1719
SUMEX-AIM	5	3261 F	3527 1731	6156 1969	5072 2069	3618 1842	5517 1973	4520 2068
NBS-10	6	0	0	0	0	0	0	0
AMES-67	6	2895 1899	4428 2025	3960 2033	4695 1997	8540 2579	5338 F	3690 2134
RUTGERS	6	2886 1992	2764 1831	2881 1884	3231 2035	2728 1950	3403 1922	2848 1718
BB&N	6	5358 2429	4242 1912	4461 1702	6049 2307	4542 2226	4914 1953	5580 2069
BBN&N-B	6	3961 1850	4711 1942	4476 1966	4955 2052	4947 2187	4421 2035	4539 2062
CCA	7	3792 2019	4292 1853	4345 1778	4415 2088	3673 1967	6341 2147	3617 1807
SRI-KA	7	3795 2110	4614 2108	4668 1973	4265 1977	5036 1996	3688 1872	3859 1934
SRI-KL	7	4424 1884	5031 F	4813 2012	0	5366 2172	5628 2186	5178 2126
MIT-DMS	7	4294 2166	3506 2191	3961 1751	3493 1942	3821 2093	3513 1918	3490 2453
MIT-AJ	7	4596 1945	5814 1880	3677 2140	3954 1933	4363 1938	4452 2224	3945 1775
LONDON	8	8836 4478	7560 4147	8435 4055	8669 F	8526 4223	6843 3655	7300 4860

A - Access Attempt Failed
F - Disengagement Attempt Failed
O - Destination Host Off-net
MHR - Minimal Hop Route

Table A.5. Sample Values from Measurements on September 7, 1977 (Each Rectangle Space Contains (top) the Connection Attempt Time (ms) and (bottom) the Close Attempt Time (ms))

Host	MHR	0900 Connect Close	1000 Connect Close	1100 Connect Close	0200 Connect Close	0300 Connect Close	0400 Connect Close	0500 Connect Close
USC-ISIB	2	3180	3047	3289	A	2657	A	5155
		1750	1612	1365		1819		1778
UCLA-CCN	2	1904	1897	2014	2035	2673	2064	2050
		1522	1682	1799	1675	2189	1782	1859
USC-ISI	3	4065	3762	3112	4293	3608	2590	2892
		1751	1730	1817	1800	1513	1679	1905
CMU-10A	3	2211	0	1896	2354	2146	2377	2207
		1636		1675	1715	1735	1762	1630
CMU-10B	3	2052	1850	2351	1917	2029	2410	2443
		1527	1599	1705	1620	1620	1396	2004
HARV-10	4	2652	2516	2238	2464	4251	2386	2907
		1865	1919	1825	1837	1833	1980	1689
SU-AI	4	2452	2584	2485	2502	2238	4279	6386
		1569	1923	1747	1631	1618	1694	1690
SUMEX-AIM	5	3292	3248	4102	3567	3976	6596	3611
		1725	2025	1900	1832	2167	2933	2104
NBS-10	6	3042	2683	3154	A	2953	2804	2825
		1941	2002	1952		2158	1903	1942
AMES-67	6	3751	3778	6199	A	7357	4616	3388
		1949	2189	3862		4884	2025	2737
RUTGERS	6	A	2821	3156	2918	3201	2867	A
			1999	1940	1939	3112	F	
BB&N	6	5672	7542	4555	4266	7842	A	5486
		2304	2167	2131	2481	3240		2014
BBN&N-B	6	4178	5048	8511	4799	10268	5480	4001
		1921	1913	1989	2098	3736	2027	2012
CCA	7	4586	4272	4359	3555	4382	5443	4828
		2061	2417	F	1690	1996	1960	2297
SRI-KA	7	4422	4671	5836	6387	7136	4965	4378
		1989	2024	1908	1883	1966	1728	1963
SRI-KL	7	4127	4839	4109	3929	5707	4642	4491
		2210	1925	2342	2093	1891	F	1875
MIT-DMS	7	4859	4878	4281	3131	4105	4044	4045
		1909	1938	1937	2100	1882	1786	2213
MIT-AJ	7	4769	4578	3994	4213	7164	4302	3708
		1812	2131	2089	2301	1975	1994	1933
LONDON	8	0	0	0	0	0	0	0

A - Access Attempt Failed
F - Disengagement Attempt Failed
O - Destination Host Off-net
MHR - Minimal Hop Route

Table A.6. Sample Values from Measurements on September 9, 1977 (Each Rectangle Space Contains (top) the Connection Attempt Time (ms) and (bottom) the Close Attempt Time (ms))

Host	MHR	0900 Connect Close	1000 Connect Close	1100 Connect Close	0200 Connect Close	0300 Connect Close	0400 Connect Close	0500 Connect Close
USC-ISIB	2	3225 1624	2387 1685	2794 F	3438 1665	3620 1399	2802 1824	3038 1685
UCLA-CCN	2	1681 1993	2000 1841	1833 1681	2150 1571	1952 1708	1819 1674	1960 1797
USC-ISI	3	2865 1824	3470 1671	3967 1689	3799 1602	4938 1708	6335 1714	3612 1610
CMU-10A	3	2123 1717	2166 1518	2800 1670	2021 1673	2113 1615	1883 1562	2148 1684
CMU-10B	3	2143 1691	1745 1652	1856 1559	2151 1581	2015 1548	2086 1572	2344 1612
HARV-10	4	0	2590 1955	2444 1688	3156 1881	2447 1767	2411 1712	2477 2443
SU-AI	4	2430 1576	2535 1860	3098 1640	2533 1650	2472 1548	2456 1854	2537 1848
SUMEX-AIM	5	0	0	0	4341 2035	3609 1922	3059 2275	3956 1767
NBS-10	6	2717 F	2344 2032	2563 1730	2752 1899	2716 1939	2723 1861	2664 1940
AMES-67	6	5310 2942	5726 4356	4440 1850	0	6226 2603	3982 2475	10393 2772
RUTGERS	6	3234 1915	2939 1837	2740 2027	2339 2042	2917 1893	2973 F	2915 2055
BB&N	6	5840 2185	5530 1921	5239 2050	4783 14248	5458 2151	5691 2068	5512 2375
BBN&N-B	6	6720 1929	4295 1961	4508 2129	5521 1976	5316 2071	3393 1890	6051 2249
CCA	7	4691 2071	4203 1935	4596 1951	3962 1920	4390 2166	3406 1968	5002 2144
SRI-KA	7	4756 1893	4551 2254	5234 1979	6347 2067	6125 2103	3670 2215	4482 1915
SRI-KL	7	4200 1956	5429 2017	4378 2160	5544 1814	5253 2306	4407 2045	5445 2015
MIT-DMS	7	4647 1991	3581 1692	4128 2159	3769 1910	3833 2046	3412 1855	3325 2645
MIT-AJ	7	5049 2102	4012 1923	4754 2250	5102 1918	4034 2029	3677 2141	3508 1900
LONDON	8	9941 4214	10507 5287	8618 4786	0	0	0	0

A - Access Attempt Failed
F - Disengagement Attempt Failed
0 - Destination Host Off-net
MHR - Minimal Hop Route

Table A.7. Sample Values from Measurements on September 14, 1977 (Each Rectangle Space Contains (top) the Connection Attempt Time (ms) and (bottom) the Close Attempt Time (ms))

Host	MHR	0900 Connect Close	1000 Connect Close	1100 Connect Close	0200 Connect Close	0300 Connect Close	0400 Connect Close	0500 Connect Close
USC-ISIB	2	2352	3677	3129	2889	2494	3408	3361
		1592	1652	1820	1446	1672	2155	1716
UCLA-CCN	2	1757	2069	2092	1911	1790	2273	1861
		1702	F	1784	1732	1436	1697	1779
USC-ISI	3	2757	2964	3606	3097	3255	3780	3933
		1607	1727	1641	1827	1746	1447	1882
CMU-10A	3	2332	1529	1858	1686	1924	2085	2124
		1587	1446	1682	1585	1583	1560	1514
CMU-10B	3	2082	2315	2283	0	1861	2111	2008
		1865	1656	1685		1627	1677	1593
HARV-10	4	2534	2422	2477	2867	2615	2628	2858
		1670	1660	1794	1820	1707	2090	2022
SU-AI	4	2449	2986	2543	1878	6627	5075	6373
		1586	1668	1568	1753	1877	1763	1565
SUMEX-AIM	5	3042	3792	3091	4446	4099	4182	3695
		1746	1973	2551	1714	1847	1930	1735
NBS-10	6	3245	3210	3376	2551	2529	2762	2653
		2059	2208	2232	F	1860	1828	2094
AMES-67	6	3701	5820	2851	4144	A	2843	5587
		1688	3075	1845	3335		2319	2233
RUTGERS	6	2987	3011	3349	2910	3591	A	3029
		2124	2028	F	1781	1779		1878
BB&N	6	5015	4572	5891	5939	4767	5774	4760
		2267	2157	2281	2908	2834	2224	2130
BBN&N-B	6	5925	5391	4367	11626	4603	0	0
		2105	2133	1756	3343	2101		
CCA	7	4256	6084	5124	4927	4405	3640	3719
		2134	2335	2332	2024	2151	F	2092
SRI-KA	7	3453	4167	5678	11592	4675	4672	3927
		1852	1971	20289	1881	1922	1913	1810
SRI-KL	7	4407	5197	4705	A	4597	4281	4792
		1942	1972	1958		2023	2287	2127
MIT-DMS	7	0	4287	3626	4280	4019	4697	3665
			2208	F	2018	1700	1858	1908
MIT-AJ	7	4120	4562	3564	4030	3456	3780	3370
		1861	2008	1808	1931	2056	1891	1734
LONDON	8	0	7522	0	7849	0	0	0
			3933		4020			

A - Access Attempt Failed
F - Disengagement Attempt Failed
0 - Destination Host Off-net
MHR - Minimal Hop Route

Table A.8. Sample Values from Measurements on September 15, 1977 (Each Rectangle Space Contains (top) the Connection Attempt Time (ms) and (bottom) the Close Attempt Time (ms))

Host	MHR	0900 Connect Close	1000 Connect Close	1100 Connect Close	0200 Connect Close	0300 Connect Close	0400 Connect Close	0500 Connect Close
USC-ISIB	2	2940	2719	2594	2718	2683	3350	3442
		1814	1746	2830	1535	1299	1611	1696
UCLA-CCN	2	1840	2070	A	2088	1842	1951	1858
		1672	1725		1779	1862	1719	1828
USC-ISI	3	3118	3082	4269	4670	3664	3359	3268
		1933	1427	1861	1930	1635	1870	1742
CMU-10A	3	0	0	0	2097	1857	2052	2561
					1633	1678	1881	1856
CMU-10B	3	1848	2082	1993	2473	1838	2203	2119
		1591	1795	1653	1656	1582	1634	1602
HARV-10	4	0	2592	2717	2996	0	0	0
			1834	2248	1871			
SU-AI	4	2767	2432	2390	6487	4170	8474	5587
		1638	1793	1633	1743	1629	1634	1765
SUMEX-AIM	5	3515	5627	3291	3801	3168	5101	4244
		1731	2085	1829	1800	1734	1794	2022
NBS-10	6	2797	2699	3868	3297	2632	2691	3000
		1819	1885	2239	2103	1647	1695	1963
AMES-67	6	3076	4151	3481	3468	2802	3156	2306
		2984	2853	2034	1852	2160	2187	2472
RUTGERS	6	3136	3216	3172	3197	3097	2762	3218
		1861	2006	1847	1904	1994	2128	2200
BB&N	6	6578	5745	5041	6418	5355	5327	6423
		2007	2468	2070	2024	1938	2517	2366
BBN&N-B	6	5041	5336	5245	4676	8317	5884	4482
		1796	2026	2015	1976	3369	1808	2008
CCA	7	4972	4479	5393	5306	4727	5342	5138
		2089	2342	2179	1964	1912	1937	2055
SRI-KA	7	4529	4826	5528	7487	5030	6535	4873
		2029	2242	2208	2110	7668	2504	1978
SRI-KL	7	4319	4361	6087	0	4165	3572	4054
		1940	1837	2508		2662	1911	2175
MIT-DMS	7	4756	4243	4220	3915	3776	3978	4128
		2078	1941	1912	2085	1785	2078	2022
MIT-AJ	7	4402	4600	4673	4268	3282	4102	3668
		F	2063	2076	2280	1811	1936	2018
LONDON	8	7527	0	0	0	7347	7279	7323
		3758				3910	3450	4386

A - Access Attempt Failed
F - Disengagement Attempt Failed
0 - Destination Host Off-net
MHR - Minimal Hop Route

Table A.9. Sample Values from Measurements on September 20, 1977 (Each Rectangle Space Contains (top) the Connection Attempt Time (ms) and (bottom) the Close Attempt Time (ms))

Host	MHR	0900 Connect Close	1000 Connect Close	1100 Connect Close	0200 Connect Close	0300 Connect Close	0400 Connect Close	0500 Connect Close
USC-ISIB	2	3173 1625	2382 1799	2769 1712	2935 1513	2837 1615	2926 1568	2955 1799
UCLA-CCN	2	1717 1893	2061 1757	1965 1663	2097 2043	1896 1936	2151 2024	1913 1723
USC-ISI	3	4265 2267	3774 1647	2992 1531	3160 1741	3107 1968	4557 1707	2901 1700
CMU-10A	3	2146 1536	1954 1800	2092 1552	1990 1715	2021 1723	2241 1597	2030 1622
CMU-10B	3	1750 1630	0	0	2343 1857	2228 1759	2131 1545	2113 1500
HARV-10	4	0	2943 1930	3195 2014	2511 1834	2591 1871	2546 1808	2734 1977
SU-AI	4	7652 1558	0	3417 1684	0	0	0	0
SUMEX-AIM	5	3869 2253	0	3441 2574	3405 2085	4002 2204	4532 4825	4681 1849
NBS-10	6	2904 1856	2621 1951	3048 1952	2904 1881	3461 F	2581 1987	2559 2024
AMES-67	6	0	4889 2124	4357 2069	3632 3051	3495 1952	4090 2069	4609 2285
RUTGERS	6	3007 1954	2935 2142	3126 2245	3069 1943	3024 1876	2976 2135	3267 1958
BB&N	6	6240 2546	4871 2097	5727 2158	5232 2127	5470 2499	6705 2364	4443 1895
BBN&N-B	6	4885 2294	4988 2087	5147 1915	4034 1979	4172 2048	6721 3297	5106 2327
CCA	7	5390 2427	4705 2034	2741 2161	3944 2029	4587 2891	4243 1836	4263 2054
SRI-KA	7	5652 1857	5199 2433	5421 1678	5247 2166	6356 2432	5492 2052	7072 2217
SRI-KL	7	4746 2099	5405 2332	4684 2126	0	3307 2066	4709 2044	4671 2270
MIT-DMS	7	4045 2114	4042 1657	4306 2066	4166 1937	3667 2071	4326 2194	4467 2266
MIT-AJ	7	4832 1910	3611 1849	4056 1949	4723 2217	4283 F	4316 2215	3557 2339
LONDON	8	7673 4008	7510 3757	4904 4751	8078 4003	7791 3719	7730 3925	7239 4016

A - Access Attempt Failed
F - Disengagement Attempt Failed
O - Destination Host Off-net
MHR - Minimal Hop Route

Table A.10. Sample Values from Measurements on September 21, 1977 (Each Rectangle Space Contains (top) the Connection Attempt Time (ms) and (bottom) the Close Attempt Time (ms))

Host	MHR	0900 Connect Close	1000 Connect Close	1100 Connect Close	0200 Connect Close	0300 Connect Close	0400 Connect Close	0500 Connect Close
USC-ISIB	2	2768 1505	2872 1612	3075 F	2879 1511	3591 1661	3389 1564	2486 1546
UCLA-CCN	2	1839 1645	1837 1799	1976 1578	2109 1783	2141 1828	1987 1656	4871 7294
USC-ISI	3	6494 1848	3453 1677	2600 2014	3757 1787	11959 1715	3734 1489	3640 1526
CMU-10A	3	1998 1773	1794 1587	2342 1761	2027 1650	2199 1855	2038 1744	2288 1623
CMU-10B	3	2200 1583	2194 1369	2105 F	2048 1712	2468 1837	2312 1760	2310 1662
HARV-10	4	0	0	2799 1726	2772 1780	2490 2076	2971 1872	0
SU-AI	4	2917 1639	0	2828 1719	7811 1758	A	2745 1678	2435 1688
SUMEX-AIM	5	3423 2045	3180 1885	2887 2015	4641 1776	4773 2172	3239 1796	3544 1825
NBS-10	6	3040 2081	2683 1874	3095 1845	2869 1786	2646 F	2750 2194	3091 1966
AMES-67	6	3642 2387	3239 1987	2473 2098	4425 2044	3662 2809	3417 3810	4044 2028
RUTGERS	6	3637 2330	3311 1970	3273 2047	2718 1916	3212 F	3533 2148	2745 1913
BB&N	6	7941 2586	6941 1928	5125 2120	5904 F	6234 2061	4641 1978	7358 2133
BBN&N-B	6	8453 2782	5970 2241	9424 2118	5373 1962	5741 2158	4676 1675	6145 2341
CCA	7	5739 2711	4570 1986	6384 2605	4937 1780	7571 2137	6619 2235	4310 2391
SRI-KA	7	4432 1895	4372 1891	4110 1825	6596 1930	4768 2467	4295 2069	4739 1793
SRI-KL	7	4126 2093	4729 2002	6094 2520	5974 2190	4867 2015	0	9267 1791
MIT-DMS	7	4249 F	4599 2101	3847 1947	3910 2010	4278 2031	3258 2280	4435 2038
MIT-AJ	7	0	0	0	0	0	0	0
LONDON	8	7668 F	7600 3951	7889 4133	7351 8259	7827 4105	7432 3770	7808 4047

A - Access Attempt Failed
F - Disengagement Attempt Failed
0 - Destination Host Off-net
MHR - Minimal Hop Route

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

A set of telecommunications performance parameters have been developed for proposed Federal Standard 1033. The measurement of five of these parameters, access time, incorrect access time, access denial probability, disengagement time and disengagement failure probability are the subject of this report. The telnet protocol of the ARPANET is employed to measure the access and disengagement parameters from a Host to Host connection.

16. Key Words *(Alphabetical order, separated by semicolons)*

access; ARPANET; disengagement; Elf operating system; Host; IMP (interface message processor); NCP (network control program); performance parameter; protocol; Telnet; TIP (terminal interface processor)

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