NBSIR 80-2187

Local Area Network Feasibility Study for the Naval Sea Systems Command

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Charles B. Silio, Jr.

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U.S. DEPARTMENT OF COMMERCE

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U.S. DEPARTMENT OF COMMERCE, Philip M. Klutznick, *Secretary*
Jordan J. Baruch, *Assistant Secretary for Productivity, Technology, and Innovation*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

ABSTRACT

The Naval Sea Systems Command (NAVSEA) has tasked the Institute for Computer Sciences and Technology of the National Bureau of Standards (NBS) to perform a feasibility study of a Local Area Networking (LAN) capability to enhance NAVSEA's computing facilities. This report documents that feasibility study. In this report, NAVSEA's environment is established. This includes the physical and the computing environment. After establishing the environment, a representative set of application programs is used to determine NAVSEA's LAN requirements. Then a discussion of LAN topologies is presented, and those applicable to NAVSEA are indicated. Implementations of these applicable topologies are discussed along with the technologies involved and their advantages and disadvantages.

KEY WORDS: Carrier sense multiple access; environmental analysis; feasibility study; local area networks; requirements analysis.

DISCLAIMER

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EXECUTIVE SUMMARY

The Naval Sea Systems Command (NAVSEA) has tasked the Institute for Computer Sciences and Technology (ICST) of the National Bureau of Standards to perform a feasibility study of a Local Area Networking (LAN) capability to enhance NAVSEA's computing facilities. NAVSEA's computing equipment and physical environment have been determined to be stable and not expected to change prior to 1985. Due to increasing workload and diminishing staff NAVSEA has placed increasing emphasis on computer aided design to more efficiently utilize valuable staff time.

In order to provide efficient as well as convenient access to the local computing facilities, NAVSEA requires a LAN capability which can provide communications between the computing facilities and each terminal at rates of 9600 bits per second (bps). These terminals need to be dispersed throughout the engineering design areas of NAVSEA. This is NAVSEA's primary requirement, high speed dispersed terminal to computer communications. This implies the need for a flexible communication facility to handle terminal mobility and different terminal types. In addition, NAVSEA should consider soft-copy (CRT) terminals since hard-copy of most sessions is not required and CRTs can operate at higher communication rates. These terminals should be capable of displaying text and vector (line drawing) information, and should allow the user to point to information being displayed on the screen.

After reviewing the technologies available to provide NAVSEA with a LAN capability, two feasible LAN implementations are presented. One feasible implementation is to install a bus LAN. This requires the installation of a coaxial cable throughout the NAVSEA complex, and bus interface units between the cable and each device, terminal or computer. The other feasible implementation is to run individual point-to-point lines, using modems where necessary, between each terminal and a concentrator located in each building, and then run high speed lines from all the concentrators to a port contender in the central facility which will act as an intelligent front-end switch.

The bus LAN implementation has a number of potential advantages over the other alternative depending on the LAN signalling technology (baseband or RF). An advantage both technologies offer is inherent flexibility. Flexibility includes such things as arbitrary locations for network connections (i.e., additions or moves), consistent network protocols, and personalization for different device (terminals or computers) connections. Another advantage both bus signalling technologies offer is ease of media maintenance, since only a single (or two) cable(s) is

involved. In addition, RF signalling technology offers a potentially large bandwidth that may be divided into channels. Different priorities and speed ranges may be associated with different channels.

The primary disadvantages of a bus LAN are the current lack of complete high level communication protocols, the utilization of a new technology, and the current limited availability of bus interface units. The latter two disadvantages will phase themselves out during the next two years. Asynchronous terminal to computer communication does require some level of virtual terminal protocols, and most facilities do at least offer this minimum required level. Intelligent interface units are just beginning to be offered by commercial vendors. It is expected that over a dozen vendors will have commercial units available by the time NAVSEA is ready to procure them in 1982. Currently, the estimating rule-of-thumb for these intelligent interface units is approximately $1K, although LSI implementation and mass production may reduce this by as much as 70 percent.

The individual point-to-point lines implementation possesses two advantages. The first advantage is that all necessary components are currently available from a number of commercial vendors. The second advantage is the point-to-point lines implementation is currently less expensive than a Bus LAN, approximately $100K vs. $140K. The point-to-point lines implementation suffers from a lack of flexibility and more difficult media maintenance. This lack of flexibility is felt to be a serious disadvantage.

1.0 INTRODUCTION

The Naval Sea Systems Command (NAVSEA) has tasked the Institute for Computer Sciences and Technology (ICST) of the National Bureau of Standards (NBS) to perform a feasibility study of a Local Area Networking (LAN) capability to enhance NAVSEA's computing facilities. This report documents that feasibility study. In this report, NAVSEA's environment will first be established. This includes the physical and the computing environment. After establishing the environment, a representative set of application programs will be used to determine NAVSEA's LAN requirements.

Once the environment and requirements are established, a discussion of LAN topologies is presented. Those LAN topologies applicable to NAVSEA are indicated. Implementations of these applicable topologies are discussed along with the technologies involved and their advantages and disadvantages. The report concludes with a brief summary emphasizing NAVSEA's LAN requirements and two feasible implementation alternatives, along with their advantages and disadvantages. A brief review is included on Carrier Sensed Multiple Access (CSMA) bus LANs, since this is a relatively new and emerging concept. In addition, an overview of the International Organization for Standardization (ISO) Communication protocol reference model is provided, since this has become a standard framework for discussing communications.

2.0 ENVIRONMENT

2.1 Physical

NAVSEA is physically distributed primarily among 3 adjacent buildings at the southern end of the Crystal City complex. These buildings are all located on a single block and, therefore, no public thoroughfares need be crossed when going from one building to another. In addition, these buildings are physically interconnected both on ground level by malls and passageways, and below ground level by a multi-level parking facility.

Personnel and equipment face a rather dense working environment. Heating, ventilation, and air conditioning (HVA/C) in the normal working areas are generally poor. This is due to the Federal restrictions on temperature and also to the inconsistency/variability of the building's HVA/C system in maintaining a uniformly specified environment. The centrally located computer complex has its own HVA/C system which adequately maintains temperature and humidity requirements. Other intelligent devices distributed among the working areas do not enjoy this stable environment and, therefore, during the hot summer months are known to malfunction.

NAVSEA is committed to remain in these three buildings for at least the next five years. This does not mean that the current physical arrangements will remain unchanged during this time. Internal movement of personnel and equipment is expected to occur due to organizational changes and improved space allocations. This implies that any internal communication facility must have the flexibility to contend with the movements of personnel and equipment.

The Crystal City complex is privately owned and leased by the Navy via GSA. This causes serious problems, since any modifications to the building must go through a long and complicated chain of approval (namely, Navy chain of command, GSA, building management, contractor/craftsmen). Therefore, to string wire or cable (which might be done relatively inexpensively by Computer Operations personnel) requires a request with justification, followed by a long approval chain, then negotiations with an authorized contractor, and finally the work performed by designated craftsmen. In addition, NAVSEA feels even to access an existing cable above the false ceiling may require this chain of events. NAVSEA is trying to work out some agreement to expedite this process by having risers (a vertical cableway) installed in each building to use as needed for communication wires or cables. In addition, NAVSEA is trying to negotiate some level of Navy direct handling of the cable once installed without going through the request/approval/negotiation chain each time.

2.2 Equipment

NAVSEA's primary computation facility has been a centralized set of large mainframe computers, and secondary facilities have been a dispersed set of various large mainframe machines from another manufacturer. None of these machines are owned by NAVSEA, and all are remotely located. The primary facilities are located at DTNSRDC in Carderock Md, and are accessed both in an interactive (300 bits per second (bps) dial-up) mode and a batch (RJE) mode. Batch access is on a 50K baud leased line via a minicomputer acting as a local RJE station with a line printer, card reader, card punch, and an interactive graphics workstation. The secondary facilities are accessed in a similar manner, i.e., interactively via 300 bps dial-up lines, and for batch on a 4800 bps leased line via a minicomputer acting as a local RJE station.

NAVSEA has recently awarded a procurement to install a local processing facility consisting of 4 identical minicomputer systems. Two of these minicomputer systems will replace the current local RJE facilities, while the other two will provide highly responsive interactive graphics. All of these systems will, as a secondary function, provide local interactive and batch processing. The configuration of this system is as follows (see Figures 1a and 1b):

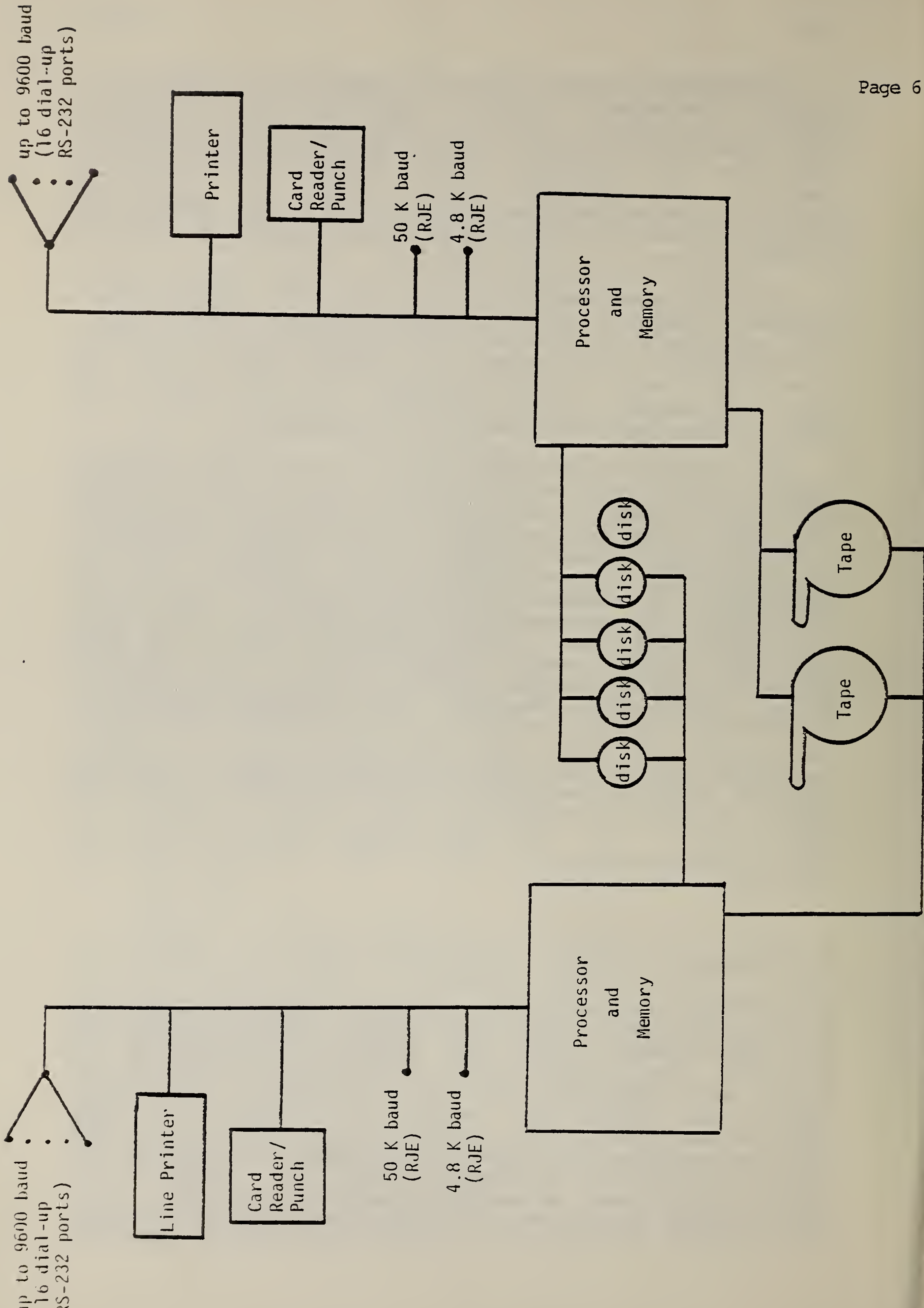
The two processors replacing both RJE systems share secondary memory (disk). These systems will each have a card reader and line printer, and will share a card punch, a printer/plotter, and a set of 2 magnetic tape units. The primary function of these processors will be to handle all RJE requirements; their secondary function will be to support local batch and interactive processing.

The other two processors will also share secondary memory (disk), as well as sharing a line printer, card reader, card punch, printer/plotter, and a set of 2 magnetic tape units. In addition these processors will each support a dynamic interactive graphics work station which is microprocessor driven. The primary function of these processors is to support interactive graphics, both static and dynamic. The interactive graphics workstation equipment will support the dynamic graphics applications. Lower cost graphics devices will support the static graphics applications. The current low cost graphics equipment is mostly storage tube devices. The secondary function of these processors is to provide local interactive processing.

Based on 1) the newly procured NAVSEA computing facility, 2) the time required to procure additional or new systems of the same complexity, and 3) NAVSEA's current long range plans, it is not expected that NAVSEA will significantly modify or replace this computing facility within the next 5 years.

2.3 Workload

NAVSEA's in-house staff has been steadily declining due to lower personnel ceiling constraints. Simultaneously with this diminishing staff, the workload has significantly increased mainly due to the increasing complexity of the various ship subsystems and their subsequent integration. This is especially evident in combat systems, communications, and other electronic subsystem areas. The overflow workload is being contracted out, putting an increasing burden on the in-house staff to monitor these efforts in addition to accomplishing their own tasks. As a result, NAVSEA has placed an increased emphasis on computer aided design processes to improve the productivity of its


up to 9600 baud
(16 dial-up
RS-232 ports)
Printer
Card
Reader/
Punch
50 K baud
(RJE)
4.8 K baud
(RJE)
Processor
and
Memory
disk
disk
disk
disk
disk
Tape
Tape
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and
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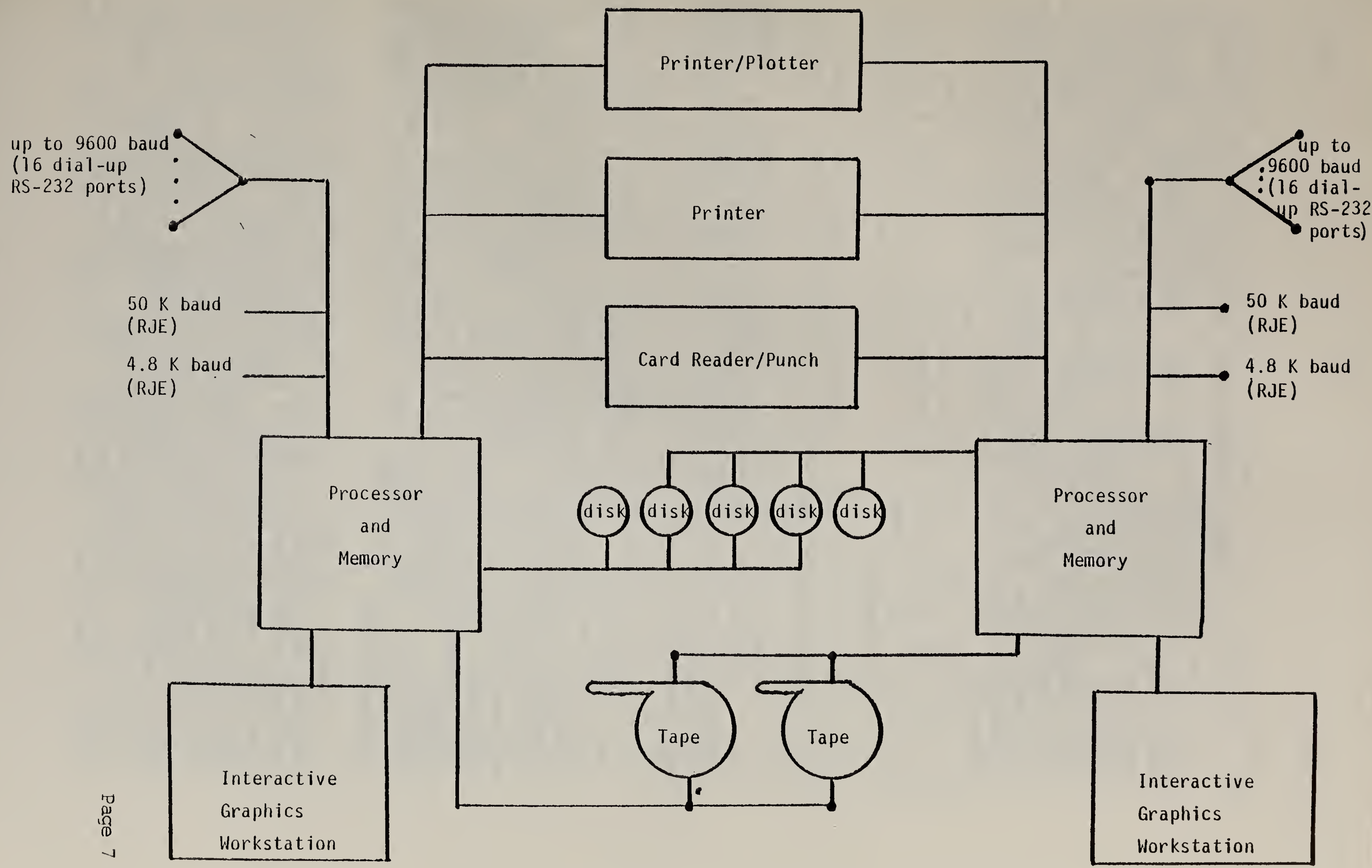

Figure 1b. Graphics Processors I and II.

staff.

NAVSEA has made a commitment to upgrade the computing facilities to support the ship design process. This requires responsive, flexible, and highly available computing facilities. As a first step, a local computing facility was procured (see section 2.2) to provide the required local processing capability. As a second step, a means of providing the design engineers convenient access to this computing facility, from their working areas, is required. This can be accomplished by providing computer terminals capable of displaying textual as well as graphical information sent from the computer at high communication rates.

3.0 REQUIREMENTS

3.1 Application Areas

In addition to on going sowtware development, NAVSEA has processing requirements in three major areas: interactive graphic applications, data base query and report applications, and scientific (engineering design) applications.

Interactive graphics applications can be divided into two categories: dynamic and static. Dynamic interactive graphics usually involves 3 dimensional objects which are displayed in perspective views. These objects are frequently manipulated, updated, translated and rotated. This requires tight coupling with a processor. In today's market this dynamic interactive graphics is generally expensive and can not be generously supplied throughout the engineering work areas. This type of facility is usually supplied in limited quantities, and shared by the user community. For NAVSEA this represents a small, but important, percentage of its interactive graphics applications.

Static interactive graphics applications form the majority of NAVSEA's graphics workload. These typically are 2 dimensional drawings, such as engineering block and wiring diagrams, and 3 dimensional arrangement and layout diagrams. These applications are designed to interact with the user through CRTs that display vector information as well as text and that permit the user to "point" to objects that are being displayed. Currently, these applications are implemented on storage tube terminals and the more complex interactive graphics workstation. Commercially available raster scan devices [COMP 80a, COMP 80b] may provide a less costly functional replacement. A lower cost for this class of device allows a greater number to be acquired and distributed in the engineering design areas.

Data base query and report applications form a large portion of NAVSEA's workload. Many programs produce output consisting of report type information, such as equipment lists, ship schedules, parts or connection lists, etc. Currently these reports are always output on the line printer in multiple copies and distributed for reference. This type of output could be kept on-line and viewed on a CRT terminal by either sequentially listing it or selectively viewing it through the use of an interactive editor. The authors' experience has shown that each individual has a threshold limit to the amount of information he/she will review on-line. This threshold is usually a function of the amount of information that can be displayed at one time and the speed with which the information can be accessed.

Data base applications require additional maintenance overhead. Program and database administrators spend a large portion of their time reviewing, adding, and changing verified information within the databases. Currently the portions of these procedures that are on-line require a more complex interaction than would be necessary if CRT terminals and appropriate software were available. Instead of viewing a field of information at one time, the entire record or a large portion of it could be displayed at one time. In this environment a more comfortable and efficient modification procedure could also be established.

Scientific application programs encompass a large range of input/output (I/O) interactions from a few data items of input to a complex and lengthy input data structure; similarly, the output may range from a few numbers to extensive tables or reporting formats. Some of the scientific programs are more conducive to graphical I/O. Currently, textual input files representing graphical information are prepared by the user and are output by the program. The output files are then sent to either the line printer or a hard copy plotter, whichever is appropriate.

As in the case of reports, the I/O may be accomplished in a more efficient manner interactively on a CRT terminal operating at high data rates. If convenient means existed to graphically specify input and view output, this would provide a more compatible user interface. By using CRT terminals capable of displaying vector information (e.g., line drawings), the graphical output data could easily be displayed without the need and time delay of obtaining hard copy. Entering information graphically is more complicated and may require special front-end programs.

The actual I/O to these scientific programs would still be textual files representing graphical information. The user would interact with the front-end program providing it graphical information. The front-end program would check this information and then translate it into the textual form required by the application. The output textual files would be translated, as before, into their vector representation and displayed on the CRT terminal rather than drawn on paper.

3.2 Representative Applications

In this section we discuss a representative set of application programs which encompass the various application areas discussed above. These programs are mainly electronics applications (vs. HVA/C, Hull, or Machinery applications), but are considered functionally representative.

EDS

EDS is a static interactive graphics, as well as a database, application program. The purpose of this program is to allow users to construct multi-level block and wiring diagrams. A diagram is constructed from a number of layered libraries. The lowest library layer is a template library which defines the basic geometric shapes that the user desires. The highest library layer is the diagram layer, which consists of a number of multi-level diagrams. Multi-level means that a diagram may exist at different complexity levels; from the simplest (highest) level which obscures detailed information, to the most complex (lowest) level which presents every detail. The primary function of EDS is to allow design engineers to extract "baseline" systems, and interconnect and modify them for specific designs. Each "baseline" system is represented by a number of geometric shapes (e.g. a rectangle), each corresponding to a component of that system. The components are interconnected by a set of lines, which are the system intraconnections. These connections may represent anything from a logical connection (highest level) to individual electrical connections (lowest level). Along with each connection is associated a textual label and attribute information, which defines the connection function. The user interacts with the program via a CRT terminal with vector drawing and "pointing" capabilities.

There are two basic user interaction modes: constructing and viewing. In the construction mode, the user constructs a diagram. In the viewing mode, the user views (displays) one or more diagrams. A diagram usually contains more information than the CRT screen is capable of clearly displaying at one time. Therefore, only a portion of a diagram is displayed at one time. Mechanisms are provided through which the user can traverse to different parts of a diagram. Due to the large amount of information comprising a single display screen, a communication speed of 300 bps is unacceptable in the viewing mode since the time delay is intolerable At 9600 bps the delay observed by the user becomes negligible.

In the construction mode, the user is incrementally building portions of the diagram. One may argue that this incremental addition of information can be acceptably performed at 300 bps. Due to the complexity of these diagrams one must often "traverse" from one place to another on the diagram, mainly to affect connections and accomplish esthetic rearrangement of components. This traversal requires a completely new screen of information to be displayed. Therefore, as is the case in the viewing mode, 300 bps is unacceptable and 9600 bps is required.

The prototype of this application program is targeted for implementation on the interactive graphics workstations (dynamic graphics). These workstations are located in the central computing complex. It is generally inconvenient and inefficient for the design engineer to reserve time in advance and then carry all his reference and working materials with him to these workstations. If static interactive graphic devices, communicating at 9600 bps were available in the design engineer's working area, the utility of this application program would be amplified. The design engineer might then efficiently and conveniently use the CRT to construct, modify, and view diagrams, rather than obtain hard copy (plotted) output. The engineers use the plotted output in an attempt to maintain their own local collection of diagrams, "pen-and-inked" to reflect the current status of "minor" changes.

ELXLST

ELXLST is a set of data base oriented application programs. Its purpose is to maintain a consistent repository of information on all electronic equipment that may be used in the combat system design of a ship. The data base information consists of equipment attributes such as space, weight, power, cooling, technical and administrative cognizance, etc., as well as the hierarchical structure of the equipment (i.e. its components, the subcomponents comprising each component, etc.).

The maintenance of the data base is carried out by a single data base administrator, after a well defined data verification process. The data base administrator uses both interactive and batch processing to maintain the data base. Interactive processing is used mainly for scanning or modifying a few individual data fields, and is currently performed at a data rate of 300 bps. Batch processing is used for major modifications or additions to the data base, and is performed via punched card input prepared from worksheets. To view one or more complete data base records currently requires a line printer listing.

Individual users create their own "Ship File", which is a subset of the data base, representing an electronics equipment list of the combat system for a specific ship design. Once a Ship File has been created the user may then "customize" the structure and quantity of equipments to fit the specific design. Only certain information may be customized, while the remaining, predominantly attribute oriented data, may not; and this non-customizable data must always be extracted from the data base for consistency. Each user may have as many Ship Files as desired, usually for different designs or trade-off studies. From these Ship Files the user may generate a number of predefined reports. These reports are used for reference information during the various ship design phases and are periodically distributed to other design engineers. Currently, the design engineers prepare their input data to this set of applications programs on worksheets, which they fill out by hand. These worksheets are then transcribed to punched cards, and all results are output on the line printer.

It would be more convenient for the users to prepare their input data and view the resultant output on-line. Preparing the input data at 300 bps may be acceptable based on a typing speed argument. But entering information at this rate does not allow for an efficient or convenient user interaction process that could be achieved at 9600 bps. Viewing the various outputs would not be acceptable at 300 bps, whereas at 9600 bps on a CRT it would be.

The Database Administrator does portions of the maintenance process interactively at 300 bps. Currently the bulk operations are more efficiently done by transcribing the information onto worksheets and keypunching it onto cards. At 9600 bps a more efficient user interaction procedure could be developed and the Database Administrator could do all the maintenance interactively.

RADHAZ

RadHaz is an interactive scientific oriented application program. Its purpose is to compute the on-axis power density of microwave antennas. The results are used to determine the hazardous areas onboard a ship caused by microwave radiation being emitted from these antennas. The design engineer enters about six numbers and a line or two of descriptive text. The output is a table, consisting mainly of radiation density values vs. on-axis distance from the antenna.

Currently, entering the input data at 300 bps is acceptable, although at higher speed more efficient interaction procedures could be considered. The resultant tabular output can get rather lengthy. At 300 bps it is not unusual to take five or ten minutes to list the output on a local terminal. It would be much more efficient to view this tabular output at 9600 bps, thereby, reducing this time.

3.3 Application Requirements

A large portion of NAVSEA's workload on the primary mainframe machines is RJE/punch card oriented. An attempt to encourage design engineers to use interactive terminals (300 bps dial-up) in the working areas, rather than punching cards, is slowly becoming successful. The main problems are poor response time and system unavailability, in addition to breaking traditional usage habits.

A large portion of NAVSEA's computing output is transient, and no permanent listing or printout is needed or desired. Therefore, soft-copy terminals (CRTs) are preferred to hard-copy terminals. When hard-copy is desired, it can be sent to the local line printer. If, however, there is an immediate need for hard-copy a printing device can be attached to the CRT (this is expected to be a rather rare situation). Currently, most terminals at NAVSEA are low speed hard-copy terminals, which means purchase of a number of soft-copy terminals should be considered. These terminals should be capable of displaying text and vector (line drawing) information, and should allow the user to point to information being displayed on the screen, depending on particular user needs.

For a large portion of the data base and scientific applications interactive access via 300 bps dial-up is barely acceptable. Working at these speeds has forced a mode of operation in which the design engineer minimizes the amount of information being displayed and, therefore, limits the ways in which he/she may interact with this design tool (the computer). It is clear that 9600 bps would be much more desirable. This speed allows the design engineer to quickly view and edit a screen full of data without becoming bored or impatient while waiting for the desired information to be displayed. In addition, more effective interaction methods would become available, thereby, increasing the capabilities and productivity of the design process.

Static interactive graphic applications form the majority of NAVSEA's interactive graphics workload. These typically are 2D drawings, engineering block and wiring diagrams, and 3D arrangement and layout diagrams. These applications require a large amount of information to be displayed at one time. As with the other applications, providing a low communication speed, such as 300 bps, causes a restrictive mode of operation and impatience on the part of the design engineer. To be more responsive to the design engineer a communication speed of 9600 bps is required. At this data rate reasonably complex drawings can be displayed in a short time allowing the design engineers to interact with the design tool on a continuous basis and in a convenient manner. Therefore, the design engineer is using the design tool in a more compatible and synergistic manner rather than the design tool dictating to the design engineer, thus resulting in a less productive environment because of user frustration.

This results in a primary requirement for a communication network that can connect a dispersed set of terminals to the local processing facility. Such a network must be capable of supporting communication rates of 9600 bps to each user. In addition, such a communication network must be flexible. Flexibility includes such things as arbitrary locations for network connections (i.e., additions or moves), consistent network protocols, and personalization for different device (terminals or computers) type connections.

Arbitrary locations for network connections are necessary due to potential relocation of existing terminals and acquisition of new terminals. Internal movement of personnel and equipment is expected to occur due to organizational changes and improved space allocations. Changing workload and other factors may cause acquisition of additional terminals. Different terminal types already exist within NAVSEA. As more terminals are acquired it is reasonable to expect that additional terminal types will appear due to technological advances and application requirements. The characteristics of each terminal must be accounted for. This may be accomplished by either the processor, the network, or both; and is sometimes referred to as a Virtual Terminal Protocol, although at a minimal level.

In addition to NAVSEA's current requirements, discussed above, there are two long range organizational goals which will emphasize and add to these requirements. The first goal is the introduction of Office Information Systems (OIS) processing capabilities. This would emphasize the current requirements for high speed communications, responsive processing, and high availability, while adding the requirement for a sophisticated screen (2 dimensional) editor. This editor would also provide program developers and design engineers a more efficient and convenient interface to the computer. The second goal is to provide access to Autodin II and other military networks. These goals add inter-processor communication for dispersed processors to the flexibility requirement. This implies the need for consistent high level protocols well beyond the minimun virtual terminal protocol, such as a file transfer protocol.

NAVSEA desires to foster interactive processing by providing interactive terminals (CRT based) distributed throughout the engineering work areas. To successfully accomplish this, it is necessary to provide each user with a communication speed of 9600 bps. This communication speed will provide adequate response to the engineering community for interactive static graphics as well as the other applications. Since NAVSEA is currently acquiring a completely new processing system, it is anticipated that this will comprise the processing environment over the next 5 years. Communications facilities and terminals are expected to be the only additions. In view of this situation and NAVSEA's commitment to interactive processing, the primary requirement is adequate terminal to computer communications. A general term for such a local communications facility is a local area network (LAN).

As a result of the above requirements the following questions concerning LANs need to be answered. What type of LAN is feasible to provide these communications? Are these or will these LANs be available in the near future on a commercial basis? Will these LANs provide the services necessary in a cost effective manner? The remainder of this report is concerned with the LAN alternatives available to NAVSEA can provide these communications facilities. The architectures and technologies of each alternative are discussed, along with their advantages, disadvantages, and availability (over the next two years).

4.0 LOCAL AREA NETWORKS

4.1 Scope

In this section we define LANs and their essential elements. In order to segment the universe of possible networks we use a taxonomy based on topology. Each topological classification is briefly described, followed by a discussion on the suitability/applicability of each of these topologies to NAVSEA's requirements.

A local area network is a data communication network limited in geographic scope. This limited geographic scope is generally referred to as a campus. LANs are distinguished from long haul networks in several ways. First, LAN nodes (host computers or terminal devices paired with communication interface units) within the campus are seldom separated by more than a few thousand meters. This encompasses the distance required to span a computer room, an office building or a complex of buildings (e.g. National Center buildings 2, 3, and 4). Second, LANs are owned and operated by a single organization. In addition to being cost effective, ownership allows the organization control and flexibility in the design and operation of the LAN. The discussion of LANs includes point to point communications circuits (both physical and virtual) that are configured in a star or multidrop topology, in addition to packet switched networks of varying topologies. Arbitrary network topologies are possible, but the star, ring, and bus forms are the most prevalent.

Local area networks are composed of four essential elements. The first component is a transmission medium, often twisted-wire pair, coaxial cable, or fiber optics. The second component is an access mechanism for controlling transmission on the medium, such as, various forms of polling, control token passing, or contention for determining which node may transmit at a given time. The third component is an interface that connects the host computers or other devices to the network. The fourth component is a layered family of protocols associated with the network for transporting information successfully from one node to another via the components of the network.

4.2 Topologies

The topology of a network dictates the range of possible routings (source to destination paths) between two communicating nodes within the network. Seven topologies commonly occur in discussions of computer network structures. Each of these topologies may be represented by a graph (see figure 2). The vertices of the graph represent the network nodes (host computers or devices paired with communication interface units). The edges of the graph represent the communication channels (links), which may be unidirectional or bidirectional. The seven topologies are as follows:

1. Mesh -- characterized by a set of nodes, in which each node may not have a direct link to every other node, although communication can be established between any two nodes. A node usually has a direct link to two or more "adjacent" nodes. Each link is usually bidirectional and control of the network is usually distributed. To communicate with a non-adjacent node requires the cooperation between intervening adjacent nodes along the communications route to pass on the information. In general, the route between source and destination nodes is not pre-determined and alternate routes exist. Upon receipt of the information, each node dynamically decides the next segment of the route (i.e. which adjacent node to pass the information to), based on its current knowledge of the state of the network.

2. Star -- characterized by the presence of a central node through which, and to which, all other nodes are connected. A communication between two nodes must pass through the central node. Each link is usually bidirectional and control of the network is usually handled by the central node.

3. Hierarchical -- characterized by a tree structured graph in which communication between two nodes not sharing the same path from the root node must establish a communication path through a common ancestor node located at a higher level in the tree. Each link is usually bidirectional and control of the network is usually handled by the root of the subtree involved in the specific communication, or may be fully distributed.

4. Ring -- characterized by each node being connected to exactly two adjacent nodes in a circular arrangement. The transfer of information is unidirectional, through active interfaces, from predecessor node to current node to successor node. As a result, the transfer of information from a given node to its immediate predecessor in the circular ordering must pass through the interfaces associated with each of this node's successors (that is, each and every node interface) on the ring. Control of access to the ring is usually distributed among the

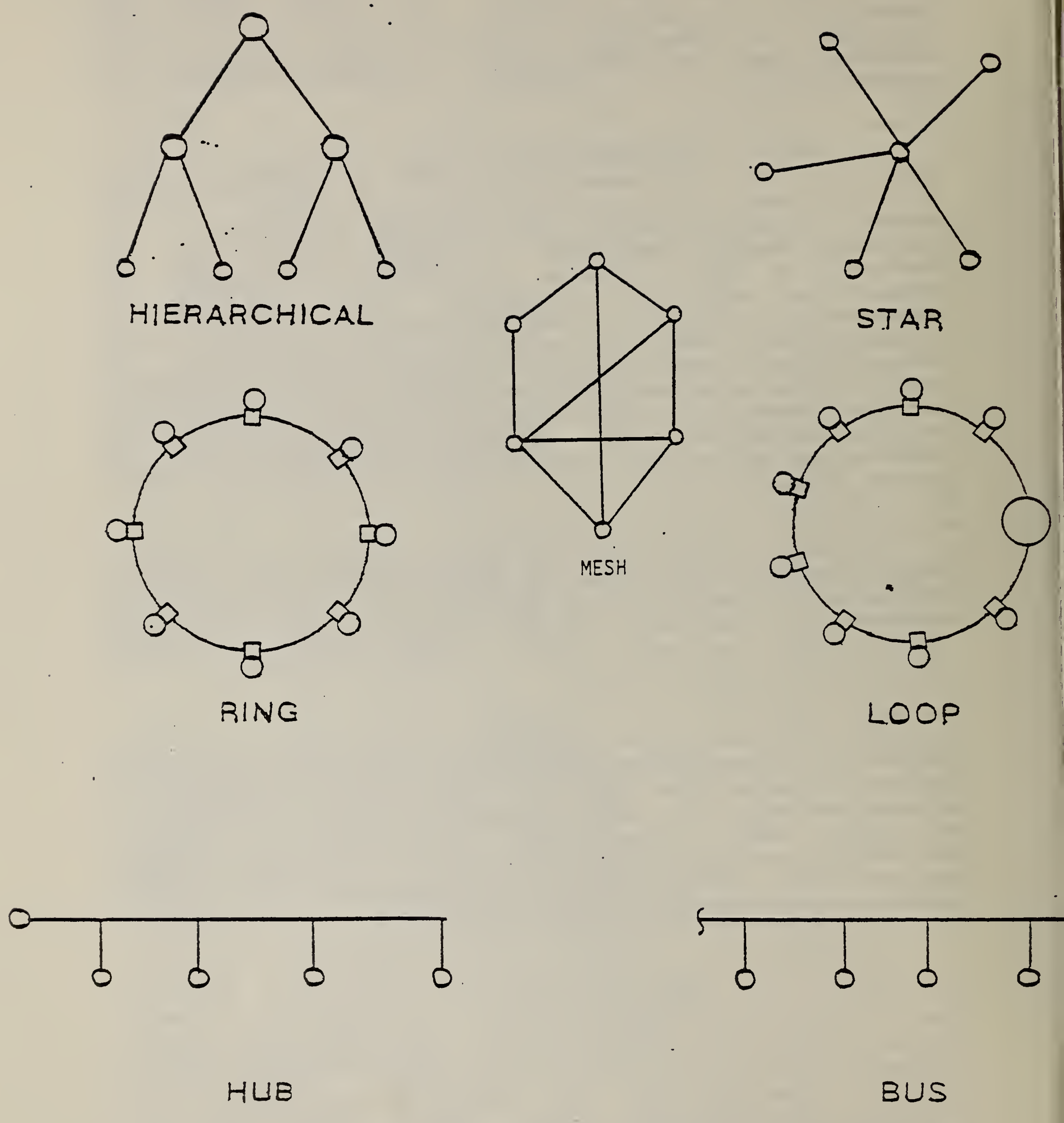

Figure 2. Graph representations of network topologies.

connected nodes. A second ring in which data travels in the opposite direction is sometimes added for reliability.

5. Loop -- characterized by the same structure as a ring except one master control node exists on the loop. This master control node supervises and synchronizes the passing of information on the loop.

6. Bus -- characterized by a straight line segment to which all the nodes are passively attached. A bus is a shared broadcast multiaccess communications medium used by pairs of communicating elements to transfer data according to some predefined and mutually agreed to protocol. As in any communications network, all parties sharing use of the bus employ the same protocol for gaining control of the communications medium, for identifying (addressing) the element to be spoken to, for establishing the point-to-point connection, and for releasing control of the communications medium. Once the temporary connection between talker and listener is established all other parties passively listen to the ensuing transmission, which is part of an overall conversation. A conversation may consist of many transmissions, each of which independently acquires and releases control of the bus. The conversation itself may have meaning only to the conversing parties. While communication actually takes place over a physical medium (or physical circuit), the nondedicated and timeshared use of the physical medium causes one to view point to point transfers of information as taking place over a virtual circuit. To manage these virtual connections requires appropriate buffering and necessary intelligence. This is provided in the bus interface units which connect each node to the medium.

7. Hub -- characterized by a multidrop line much like a bus in which a master node controls the flow of information. This topology implements a local circuit switched network in which a channel is established on a time shared basis whenever two entities connected to it need to communicate. In this configuration nodes are operated in polling mode under control of a master node. Several control disciplines are possible, although two are most common. One is roll call polling, where the master node successively invites each node to transmit in some pre-determined order. The other is hub-go-ahead polling where each node that has nothing to send passes the poll along to the next node in turn.

4.3 Suitability/Applicability Of Topologies

In this section we discuss briefly the relationship of each of the above topologies to NAVSEA's requirements.

1. Mesh -- this topology is best suited for long haul networks where switching computers (or simply, switches) are used at the nodes for forwarding messages, transactions, and data, and is not considered suitable for satisfying NAVSEA's requirements. While not suitable for the terminal to computer requirements, this configuration may be a suitable topology for maximal interconnection of the four processors located in the NAVSEA central site.

2. Star -- this configuration could satisfy the terminal to host computer communications requirements typical of NAVSEA. The central node can be viewed as a complex of four computers, each accessed through specific port addresses. Point to point connections between the terminals and the central site must be provided. Therefore, communications channels must radiate out from this central location to provide computer access for the remote terminals. This can be accomplished by running a point to point dedicated (nonswitched) line from each terminal to the central site, using switched line dial-up facilities provided by the telephone company, or by an inhouse private branch exchange (PBX) for both data and voice. It is not expected that all terminals will be in use simultaneously because the number of terminals greatly exceeds the number of available computer ports. Therefore, a means for serving terminal user demands on some first-come first-served contention basis must be provided. Various devices are available that can be used individually or in tandem for mapping n requesting lines into m available connections where n is greater than m. Basically these devices are a) dial-up rotary switches and b) port selectors or intelligent patch panels. These devices are discussed further under networking options.

3. Hierarchical -- in the NAVSEA environment configurations based on this topology, using multiplexers and concentrators, actually implement only a minor variant of the star topology. Therefore, this topology is not considered separately, but is included in the star topology. One could view remote multiplexers, or concentrators, on a one per floor or on a one per building basis (or both) as a hierarchically structured network. Multiplexers and concentrators can be used to share the bandwidth of a single wire among numerous terminals, resulting in less overall wire and fewer wires emanating from the central site. This bandwidth sharing is possible because the communication

requirements of remote demand terminals are bursty in nature. Even at peak burst rate, a single terminal does not exhaust the channel capacity of a communications medium such as twisted wire pair.

4. Ring -- this topology is attractive because it reduces the numbers of cables required for point to point connections, but in general it is not well suited for a large number of nodes. The ring topology is not considered suitable for meeting NAVSEA's requirements, because it poses potential problems. The primary problem is commercial availability in the U.S. Currenty, the majority of operational rings are experimental. No known commercial rings are planned for the near future. A potential problem is related to connectivity and delay due to the sequential topology. To implement a ring requires the use of an active interface at each node, which incorporates a failsafe switch. Active interfaces generally cause a delay in the flow of information around the ring. They may remove information, examine it, and then place it back on the next ring segment. Depending on the duration of this delay the overall accumulated delay may be significant. Adding nodes to the ring requires splicing the new node into an existing ring segment, while the ring is disabled. This may be a problem depending on the location of the new node relative to the nearest existing ring segment. Each node on the ring may increase communication delays because of its active interface as well as introducing additional traffic. An other potential problem is related to maintenance and reliability due to active interfaces. Failsafe switches have been designed so that data and control information will bypass an interface in the event of most failures and continue along the ring. Failures that can disable the entire ring are still possible (as in all other systems).

5. Loop -- although enjoying the same cost advantages of ring networks because of the reduced numbers of communications lines and reasonably simple interface logic, this structure has the same problems associated with rings. Therefore, it is considered no more suitable than the ring for NAVSEA's requirements.

6. Bus -- The ease of interfacing to and expansion of a coaxial cable bus strung throughout a campus make it a particularly attractive alternative for satisfying NAVSEA's requirements. The principal characteristic of a bus is an intelligent microprocessor controlled interface unit typically used at each bus connection. As a result, direct virtual circuit communication is possible between any pair of nodes. Control of access to the bus is usually distributed among all bus interface units on some asynchronous contention basis, although synchronous time

division multiplexed schemes can also be used. The main component of this topology is the intelligent interface unit, which is now becoming commercially available. This unit allows existing terminals to readily access the network.

7. Hub -- the variants of this topology are not considered applicable to NAVSEA's requirements. This decision is based primarily on the network interface requirements and partially on the communications overhead incurred. Control of the network is accomplished through the use of polling. This requires each terminal to possess the capability of recognizing its own address, participating in the polling protocols, and buffering information between polls. The current NAVSEA terminals (mostly asynchronous) do not possess these capabilities, which are normally associated with synchronous terminals. An alternative to requiring the terminals to possess these capabilities, is to use an intelligent interface unit (similar to that of the bus topology). Currently no known appropriate interface unit is commercially available. Considerable time is wasted in polling nodes that have nothing to transmit, and at any given time a large number of silent nodes is expected among the set of asynchronous demand terminals. Contention is likely to provide better response times for the nodes on a high bandwidth bus than would the use of centralized control.

5.0 NETWORKING OPTIONS

Only two of the seven topologies discussed in the previous section were considered suitable for satisfying NAVSEA's requirements, namely, the star and the bus topology. Means for implementing these two topologies are considered in this section. To maintain a consistent discussion, all implementations assume 100 terminals, uniformly distributed throughout the 3 buildings, connecting to the central complex of 4 processors, each having 16 ports operating at 9600 bps.

5.1 Implementing A Star

Rotary switches

Rotary switches are accessed through the telephone company's (telco) direct dial network or through a private branch exchange (PBX) network, thereby limiting the communications rate to that of either the public switched network or of the PBX. This limitation ranges from 1200 bps to 4800 bps depending on the quality of the intervening lines and switch gear. A telco modem or equivalent will provide 4800 bps communications over dial up lines. Recent introductions of rather expensive 9600 bps modems that work over the switched network have been made by modem manufacturers other than the telco. These sell for over $4000.00 each, and a pair of them is needed for each connection. In addition, modems built by different manufacturers are not guaranteed to interoperate at 9600 bps. The cost of a dial up rotary is approximately $17.00 per month per line. Held [HELD 77] cites a telco rotary cost of $1359 per month for a unit that handles 48 incoming lines for 300 bps terminals and connects them on a first come first served basis to 32 computer ports. The $1359 does not include the cost of the 80 modems that are also needed to implement this system.

A dial-up rotary allows a remote terminal user to call a single number and gain access to one of several auto answer modems. The rotary scans each telephone line that is connected to one of these modems for one that is not busy. If all lines are in use, it generates a busy signal, thereby forcing the terminal user to wait and try again later. At least one rotary switch is required for each distinct computer and/or each class of service, such as line speed, in order to connect to the correct speed modem. Additional dial-up rotaries are required for each computer and for each transmission speed that the user may specifically select.

This option could meet NAVSEA's requirements. However, it suffers from two major disadvantages which relates to its use of the existing switched dial-up telephone network. First, 9600 bps over dial-up facilities is not available from the telco directly. Second, the provision of 9600 bps service using the new microprocessor controlled digital signal processing modems is considered too expensive. The cost would be approximately $2800 per month for the rotaries plus approximately $656,000 for 164 modems (assuming they will actually work at 9600 bps in this configuration). This is not considered to be a viable or cost effective option for meeting NAVSEA's requirements.

Port contenders/intelligent patch panels

The use of patch panel equipment was an early approach to solving the inefficiency problem of each terminal user being assigned permanently to a computer port or of having multiple rotaries for user access to multiple computers. This both enabled a user to manually connect to multiple resources and, with additional cables and switches, provided a level of system monitoring and diagnostics. Since micro-computers can now function in add-on intelligence roles, a new approach is possible using a micro-based intelligent patch panel, also called a port contender. All terminal users contend equally for the available connection resources.

Although the range of options and facilities varies from vendor to vendor, intelligent patch panels provide a high level of feedback to the terminal user attempting to make a connection. This feedback eliminates the need for intervention by computer site personnel. For example, a port contender can generate status messages during excessive downtime, thus diminishing the flood of phone calls to the computer site. Typically, intelligent patch panels provide tutorial response messages such as "wrong speed," "busy," "wait?"(contention), and "unassigned", which helps minimize the extent of operator training. Where security is an important consideration, a response message, such as "unauthorized", not only tells the user that he is excluded from a particular resource but also flags the attempted intrusion for the site manager at the system console.

Additionally the port contender can serve as a control tool. It provides four methods of effectively managing computer and communications resources: universal access, contention and user feedback, statistics, and dynamic console control. (See [VONAR 80] for further discussion of advantages.)

Intelligent patch panels are currently available from a number of manufacturers [COMP 80c, EVANS 80, HELD 77, VONAR 80]. Prices range from under $10,000 for a small table-top unit with 50 interfaces to over $100,000 for a unit with full-redundancy, options, and several hundred interfaces. A unit capable of acommodating approximately 100 incoming (terminal) lines for switching into approximately 64 computer port access lines can be obtained for approximately $45,000. The intelligent patch panels are in effect private branch exchanges for digital data, but they only provide virtual circuit connections between two communicating entities.

Selection of service class, where a given class may consist of several ports operating at a particular speed on a single computer, is provided by both inband and out of band signalling. Examples of this type of signalling include escape command sequences, thumb wheel switches on the limited distance modems, or use of separate signalling wires. The intelligent patch panel essentially provides the services of a rotary for each class of service and, because of its low cost, represents an attractive means for meeting NAVSEA's requirements.

The drawback to this configuration is the inflexibility and expense of providing full duplex 9600 bps point to point connections for the remote terminals. There are two ways of stringing the necessary wires: renting the channels from the telco, or using in-house or contracted labor. The current telco tariff in Virginia for an 11000 series local area data channel for passing 9600 bps at a line length of less than three miles is approximately $6 per month. This applies to a four-wire full duplex channel entirely in the same building. That same channel running between buildings on the same campus costs approximately $18 per month; or, if it must be run through the local telco wire (local loop switching) center costs approximately $21 per month. In all three cases the installation charge per end is approximately $21 (there are two ends, unless the channel is used as a multidrop line for which there are more than two ends). The cost of leasing lines from telco, over a 5 year period, is estimated to be approximately $89,000. The cost of leasing lines (vs. installing your own) may increase significantly due to potential tariff changes [BROAD 80] incited by increased long distance competition (and lower prices) which will be offset by increased local communication prices.

Asynchronous limited distance modems capable of speeds up to and including 9600 bps are recommended on lines running between buildings. They can be leased from the telco for approximately $20 per month plus an installation charge of approximately $100 each. Similar limited distance modems can be purchased from other vendors for approximately $300 each for stand alone units used at remote terminal sites and approximately $175 each for multiple rack mounted units used at the intelligent patch panel frontend in the central site. Renting asynchronous limited distance modems, over a 5 year period is estimated to cost approximately $168,000. In comparison, the purchase cost of similar modems is estimated to be approximately $39,000, plus any maintenance that may be required.

This option could meet NAVSEA's requirements in a more cost effective manner than the previous option. In addition, this option provides extra services to the user and the site manager, as discussed above. Assuming purchase, rather than rental, of the modems, the concentrators, and the port contender result in an approximate cost of $100,000. Another advantage of this option is that all the hardware and most (if not all) of the software is currently available "off-the-shelf". To obtain a customized system to perfectly fit ones' requirements may require "cutting and pasting" between different vendors' products (i.e., a multi-vendor installation); although it is possible to obtain a "turn-key" installation from a single vendor. However, this option does have some disadvantages which relate to the flexibility and maintainability of the resultant implementation.

5.2 Implementing A Bus Network

The shared component of a bus LAN consists of a single (or a pair of) coaxial cable strung throughout a building. Individual nodes connect to the cable with the use of a CATV-style tap and a small transceiver. The transceiver is connected at the tap, with a cable running down to an interface located by the user's equipment. Coaxial cable and taps can be commercially purchased from a number of vendors. The flexible coaxial cable whose outer conductor is made of woven copper wire mesh sells for about 21 cents per foot, whereas the more rigid extruded aluminum shielded lowloss cable ("broadband" cable) sells for about 33 cents per foot [DINES 80c]. The cost of installing the coaxial cable is approximately $1.50 per foot [DINES 80c]. The use of a passive medium (coaxial cable) and the lack of active elements in the shared portion combine to help provide a reliable and flexible system. This approach also provides for easy reconfiguration of nodes. Nodes can be moved by disconnecting them at one point and reattaching them at another without affecting the operation of the network.

Stringing the "single" cable throughout NAVSEA will be less of a problem (cost and complexity) than stringing the many point to point lines required by the other options. In reality this would not be a single piece of cable, but might be a number of segments organized in a tree structure. One possible organization would use a cable segment as a main "spine" connecting all buildings. In each building a vertical "riser" cable segment, spanning all floors, would connect to the spine through a repeater. On each floor a cable segment, traversing that floor, would connect to the riser in that building through a repeater. An advantage of this organization is that any segment can be disconnected (i.e. for testing, etc.) without affecting the operation on the remaining connected segments.

Once this cable is in place devices may be easily connected to the LAN by tapping into the cable at any convenient location. The bulk of the cable installation cost is attributed to labor costs. Therefore, consideration should be given to installing a second cable at the same time for a marginal cost increase. This second cable could provide future expansion or possible backup facilities to the network.

The other component of a bus LAN is the intelligent communications interface unit (CIU). The CIU provides an interface between each device and the network. The CIU is responsible for handling the protocols associated with the network as well as those associated with the individual devices.

From the point of view of a device, the CIU should make the LAN appear transparent. Devices should not be aware of or concerned with the operation of the network. Devices should communicate with their intended destinations (e.g. a terminal communicating to a processor) through virtual connections as if they were directly connected at their normal or desired speed. This requires that the CIU buffer information between the device and the network. In addition, the CIU must be aware of the individual characteristics of the device (i.e. speed, control characters, device features and capabilities, etc.).

From the network point of view, the CIU is the communicating entity and the devices should be transparent to the network. This requires the CIU to participate in the network protocols. This encompasses the electrical interface, the type of signalling (baseband or RF), introducing and extracting information from the cable, recognizing its own address, formatting information, deciding when to transmit, and possibly providing error detection and retransmission.

Details of the individual bus LAN offerings must be reviewed as they become available. From these details it will be necessary to determine the impact on NAVSEA's installation. The following information will aid in these determinations.

1. "personalization" -- devices that are to be connected to the network require that their individual communications characteristics be accounted for. This function should be handled by the CIU. The process by which this is accomplished (i.e. who can do it, how is it done, etc.) and the limitations involved (i.e. which parameters can be changed, which can't, which are not considered, how often can parameters be changed, when may these parameters be set or changed, is special equipment necessary, etc.) are important to know, since they may be costly.

2. protocols -- protocols are handled by the CIU (i.e. signalling, sensing, data transmission, error detection, minimal virtual terminal protocols, etc.). These are generally sufficient for terminals. Inter-Processor communications can emulate terminals, but this is rather inefficient and inconvenient for many applications. Higher level protocols (i.e. file transport protocol, etc.) are better suited for these purposes. Most of these higher level protocols will be implemented in software and reside within the various processors. The interface between these protocols and the CIU protocols must be considered; this includes items such as error control, flow control, etc. If the vendor already offers, or intends to offer, these higher level protocols, their capabilities should be investigated (i.e. what can and can't be done). If the vendor doesn't offer these higher level protocols, the facilities by which they may be accomplished by the user should be investigated.

3. configuration -- depending on the particular vendor's product, many different configurations are possible. An intelligent choice can impact the cost of the LAN and the benefits to the organization. A CIU can handle a number of terminals. More terminals clustered about a CIU may result in lower cost per terminal connection. It is expected that vendors may offer a basic system along with options. These options should be investigated as to the benefits that the organization might derive from them. The selection between baseband and RF signalling can impact the additional applications (e.g. video, voice, and channelization) that may utilize the LAN.

4. Technical Control Center (TCC) -- although the medium is passive and reliable, failures will occur. A TCC provides the means to locate failures on the cable. This usually includes a time domain reflectometer. The facilities offered or recommended by the vendor to accomplish this trouble shooting function should be evaluated.

5. Measurement Control Center (MCC) -- monitors the network operation and provides measurement reports of the service being delivered to the user and the utilization of the network. This can help the organization determine heavy usage and poor utilization. As a result, expansion or reallocation of equipment can be initiated to alleviate these problems. In addition, malfunctions or other improper operations on the network may also be determined. The facilities

offered by the vendor to accomplish this function should be investigated.

NAVSEA's primary requirement is to provide flexible high speed (9600 bps) terminal to processor communications. A bus LAN provides this. It also provides additional flexibility and features. Processor to processor communication will also be possible, since all processors are connected to the cable. This can be accomplished at no extra harware cost, since any device connected to the cable can communicate with any other device on the cable. If the additional processor to processor traffic is expected to be heavy, a separate cable (baseband) or channel (RF) may be considered. A separate cable is feasible since all four processors are co-located within a central site. Therefore, the installation effort and amount of cable required are negligible.

RF signalling provides for many simultenaeous channels through the technique of frequency division multiplexing (FDM). Using RF signalling each device can be assigned individual frequency channels of different speeds. For example, each terminal could be assigned its own 9600 bps frequency channel and the processor to processor communications could be assigned separate 1 Mbps channels. This requires frequency scanning and selection capabilities by the CIU, which could be provided by a frequency agile modem. Other possible configurations may include designated frequency channels for OIS applications, voice or video information, or even a shared carrier sensed multiple access channel (e.g. MitreBus).

Another additional feature is the possibility to interface to other networks (e.g. AUTODIN II and other military networks). This interface requires a gateway. A gateway is a communications processor which translates the protocols of one network into another. Gateways generally handle protocol translation at or below layer 4 in the ISO model (see section 6.2). Therefore, they do not guarantee higher protocol layer compatibility. Gateways to other networks can easily be connected to the LAN. This would allow access to any of these gateways from any device on the LAN without additional processor assistance, as would be the case with the Star implementations.

In summary bus LANs are rapidly becoming commercially available [3COM 80]. Within the next six months many product announcements are expected. Currently, little is known regarding details of these potential offerings. After the products are announced, detailed information on their specifications and services will be available. From this it will be necessary to determine the impact on each customer's current or planned installation. The cost per terminal connection, exclusive of the main cable installation is expected to range from $600 to $4000, depending on configuration and vendor. The rule-of-thumb is currently $1000 per terminal connection, not including installation. This will most likely come down, with LSI implementations and mass production, by as much as 70%.

6.0 SUMMARY

Given NAVSEA's stable expected environment and their requirement to provide reliable and responsive computing power to the engineering design areas, NAVSEA should consider CRT based terminals distributed throughout NAVSEA's 3 adjacent buildings. These terminals must be capable of displaying vector drawings as well as text, and provide a convenient user pointing feature. A LAN communication facility to the central computing complex which can sustain rates of 9600 bps to each terminal is required to support these terminals. Options were reviewed in this report to provide this communications facility.

The first option centered around leasing point-to-point lines from the telephone company and interfacing to the computers via rotary switches (only if dial-up and modems are used) or port contenders. This option suffers the disadvantages of high cost and inflexibility of the configuration. Any time an additional terminal is required a new point-to-point wire has to be installed. If a modification in terminal location is desired, depending on the distance involved, this may also require a new wire to be installed. It is not a trivial problem to maintain and trouble-shoot this multitude of wire, especially at the central complex where hundreds of wires are bundled together. The cost of this option is estimated to exceed $300K.

The main disadvantage to the first option, leased lines, is the cost. Leasing by itself results in increased cost (which accumulatives) over time. In addition, future increases in the leasing rates are expected.

Another option is for NAVSEA to run and maintain its own lines. This second option requires a fixed initial cost plus whatever costs are incurred over the life of the lines for maintenance. To further minimize the problems of a large number of individual wires at the central complex and performance problems on the wires due to speed, distance, and variations in ground potentials between buildings, concentrators can be used. Wires from each building could be run to a concentrator located in that building and then a single high speed line could be run between buildings. This would somewhat increase the cost of this option, but it would be partially offset by the decrease in wire installation and maintenance costs. The maintenance of these concentrators would be somewhat more complex since they would not be located at the central complex. The lines from the concentrators would then interface to the processing complex through a port contender. The estimated cost of this option is $100K.

While this second option is the least cost option, it suffers the same inflexibility as the first option, for additions and modifications as well as potential expanded services.

The third option is the bus LAN. This option is feasible for four primary reasons. The first reason is it meets all of NAVSEA's requirements mentioned above, both current and future. The second reason is it has three potential advantages over the other alternatives. (1) Its inherent flexibility; devices (including intelligent workstations) can easily be added or moved, since "tapping" into the cable is possible anywhere. (2) Its relatively simple media maintenance; only a single passive cable. (3) Its potentially large bandwidth that may be channelized; different priorities and speed ranges may be associated with different channels. The third reason is that NAVSEA is planning for installation in the 1982 time frame when availability is expected to be sufficient. The fourth reason is that any user can communicate directly with a new server anywhere in the system.

The bus LAN option requires a single coaxial cable be strung throughout the 3 buildings. Therefore, only a single cable need be installed and maintained. The current estimated cost of a NAVSEA implementation is approximately $140K. The interface equipment is estimated by rule-of-thumb to cost $1000 per terminal connection; this may be reduced in the future by as much as 70% if LSI implementations and mass production are taken advantage of. The current cost of a NAVSEA inplementation is approximately $140K. This bus LAN may be either baseband (digital) or broadband (RF). The main advantage of baseband is a less complex interface (i.e. cheaper), while the main advantage of broadband is a significantly larger overall bandwidth that may be frequency division multiplexed into a number of channels. As mentioned earlier in this report a number of manufacturers are committed to commercially providing LAN facilities [3COM 80].

7.0 APPENDIX: REVIEW OF BUS LOCAL AREA NETWORKS

This section provides a general review of bus LANs. A discussion of the concepts involved is presented first. This is followed by a discussion of the ISO model for computer networking architecture. This model provides a general framework for communication protocols. The remainder of the section discusses two existing bus LANs; their architecture, environment, and operational experience.

7.1 Concepts Of Bus LANs

Messages to be passed over a bus are usually grouped into entities called packets, which may vary in length up to some maximum. If parallel channels are available, such as in a computer backplane bus, then a bus transaction may consist of the execution of a protocol to gain control of the medium during one or more time frames, the passing of a parallel address during the next time frame, the passing of parallel data for one or more additional time frames, followed by release of the bus. This sequence of time units for passing a packet of similar information holds also for a single channel bus over which information must be passed in a bit serial fashion.

When extending a bus outside a computer chassis, the cost of connectors and cableing can be minimized by using a single channel with a high enough bandwidth to support the resulting serialized data. Coaxial cable can support high bandwidth communications and provides excellent rejection of electromagnetic interference. One coaxial cable can provide a single baseband signalled channel or several RF frequency division multiplexed channels. This can be accomplished using off the shelf, inexpensive, and readily available community antenna television (CATV) cable and components. Connections can be placed in convenient locations along the cable to provide passive taps onto the communications medium. The cable is accessed through the taps by intelligent node interfaces (variously called bus interface units or modules, BIUs or BIMs, network interface units, NIUs, or communications interface units, CIUs). All components are passive, in that they do not remove or hinder the flow of information on the medium during examination or failure. The CIUs handle all the necessary protocols and buffering required. In this type of broadcast network all nodes share the medium and passively listen for information addressed to them.

The type of signalling generally distinguishes two variations of bus networks, those that use baseband signalling such as ETHERNET, NBSNET, HYPERCHANNEL, and Net/One, and those that use radio frequency (RF) modems in distinct frequency division multiplexed channels such as MITREbus and the General Motors Assembly Division system. The frequency division multiplexed systems are sometimes referred to as cable bus systems (and sometimes using the misnomer "broadband" systems). Cable bus systems are attractive because they provide the opportunity to support many different services (e.g., data, voice, and television traffic) on the same cable. This configuration may be optimal where there are both continuous high-bandwidth users (such as remote batch terminals and computer to computer transfers) and bursty low speed users (such as interactive terminals).

A single lowloss coaxial cable is capable of supporting a bandwidth of 300 MHz [DINES80a]. The actual transmission speed is usually limited by the choice of interface electronics and the degradation of signals on the cable itself. Typically, existing local area bus network implementations communicate in the 1 to 10 Mbps range. HYPERchannel transfers information at 50 Mbps [THORN 80], but it is intended for high speed computer/shared mass storage transfers where higher speed is important. The penalty paid for using this high speed transfer capability is in the cost of the CIUs which range from $26,000 to $40,000 each. In comparison, the cost of a microprocessor controlled CIU for lower speed (1-10 Mbps) communications is approximately $1000 per terminal or computer port connection (the range is approximately $500 to $4000). Usually, these CIUs are capable of handling several terminals or port connections simultaneously. They are configured as a cabinet with power supply and slots for a number of terminal or port interfaces. The actual cost of a given CIU depends on the power supply, the cabinetry overhead, and the number of terminals or computer ports connected.

A bus LAN also requires a decentralized control strategy be implemented by the CIUs. One very simple control strategy that has been used and shown to work for bus networks is contention. In a contention net, any node wishing to transmit simply does so. Since there is no control or priority, nothing prevents two or more nodes from attempting to transmit simultaneously, in which case a collision occurs. This results in the messages being garbled and received with errors, requiring retransmission at a later time.

Collisions are the primary limitation on the number of users and the amount of data that can be transmitted over the channel. The ALOHA system developed at the University of Hawaii (which uses radio communications rather than a physical bus, and is not a LAN by our definition) was the first to use this contention control strategy. This original strategy leads to relatively low channel utilization. If the CIUs follow certain additional protocols, significant improvements in channel utilization result. One rule is listen before talk (LBT) in which CIUs monitor the channel before transmitting. A CIU refrains from transmitting while any other CIU is transmitting, this is sometimes called deference. This LBT type of communication network is referred to as carrier sense multiple access (CSMA). The action taken by the CIU when the channel becomes free is referred to as persistence. The CIU is called non-persistent if it always reschedules the next transmission attempt for some later time. The CIU is called p-persistent if it waits for the medium to become free and immediately attempts to transmit with probability p; and, with probability (1-p) it reschedules the next transmission attempt for some later time, rather than waiting. For example, the CIU's of NBSNET have p=1 (i.e. always waits and immediately transmits), and thus are called 1-persistent.

Another improvement in channel utilization can be obtained by having the transmitting CIUs monitor the channel while they are transmitting. If a collision does occur (as might happen if two or more CIUs were waiting for the channel to become idle) each of the CIUs must wait or "backoff" a different period of time (typically random) to prevent repeated collisions. The average backoff is typically chosen as an increasing function of the number of retry attempts, thus providing a collision moderating mechanism when traffic is heavy. If the CIUs abort the transmission immediately after detecting a collision, this strategy is called "listen while talk" or simply collision detection (CD). Similar to the situation of two or more people starting to talk at the same time. With CD, colliding packets can be very rapidly truncated so as not to waste an entire packet time on the channel. Carrier sense multiple access with collision detection (CSMA-CD) was first used in the experimental Xerox Corporation implementation of ETHERNET, and is now used in most baseband signalled bus networks including NBSNET, and Net/One. Theoretical studies, confirmed by measured data on the ETHERNET, show that the CSMA-CD mechanism provides utilization in excess of 90% of channel capacity.

7.2 ISO Open System Reference Model

The previous section has provided a brief description of the structure and operation of CSMA bus LANs. The rules by which any communications system operates are also known as communication protocols. Several layers of communication protocols have been identified for communication over public packet mode networks. Standardization efforts are currently underway for these protocols at NBS [BLANC 80]. The following are excerpts from desJardins [DESJAR 80] which are intended to provide an overview of the current framework of communication protocols. This model was primarily constructed based on experience with and requirements for global networks. Questions have been raised as to the applicability of this model to LANs. Work in this area is currently being conducted and will investigate the layers and their associated functions as they apply to LANs [NBSIR 80].

"The International Organization for Standardization (ISO) in cooperation with other standardization bodies, have developed and adopted an architectural reference model for interconnecting "open" systems into distributed application networks. These are systems which are "open" to communication and cooperation with other systems by virtue of their mutual support of standardized procedures. The Reference Model of Open Systems Interconnection (RM/OSI) is intended to provide a common basis for the coordination of standards developments for each of the seven layers (see figure 3) into which it is divided. It also provides for the evaluation of existing standards and for improving these standards to meet the needs of future distributed systems and applications.

"The RM/OSI is based on the concept of cooperating application activities called application-processes (AP). An AP can be one or a cluster of activities performing a defined set of functions according to the set of procedures established by an industrial engineer or software designer. In a computerized system, the APs would be hosted within an environment provided by a computer or computers and their associated terminals or peripherals. In such an environment, the procedures of the APs might be implemented by computer programs.

"The purpose of OSI is to enable an AP hosted on an "open" system which supports the OSI protocols to communicate with any other AP located on any other open system to which the first is interconnected by any means whatever. As a special case, the two APs may reside in the same open system, but they would normally have no knowledge of this fact. It is anticipated that most open systems will be interconnected by having acccess to the world-wide public data networks being developed by the International Telegraph and Telephone Consultative Committee (CCITT) member countries, either directly or through local area networks.

"Only the portion of the AP which participates in the open procedures -- the "application-entry" as it is known technically -- is considered to be within the scope of the

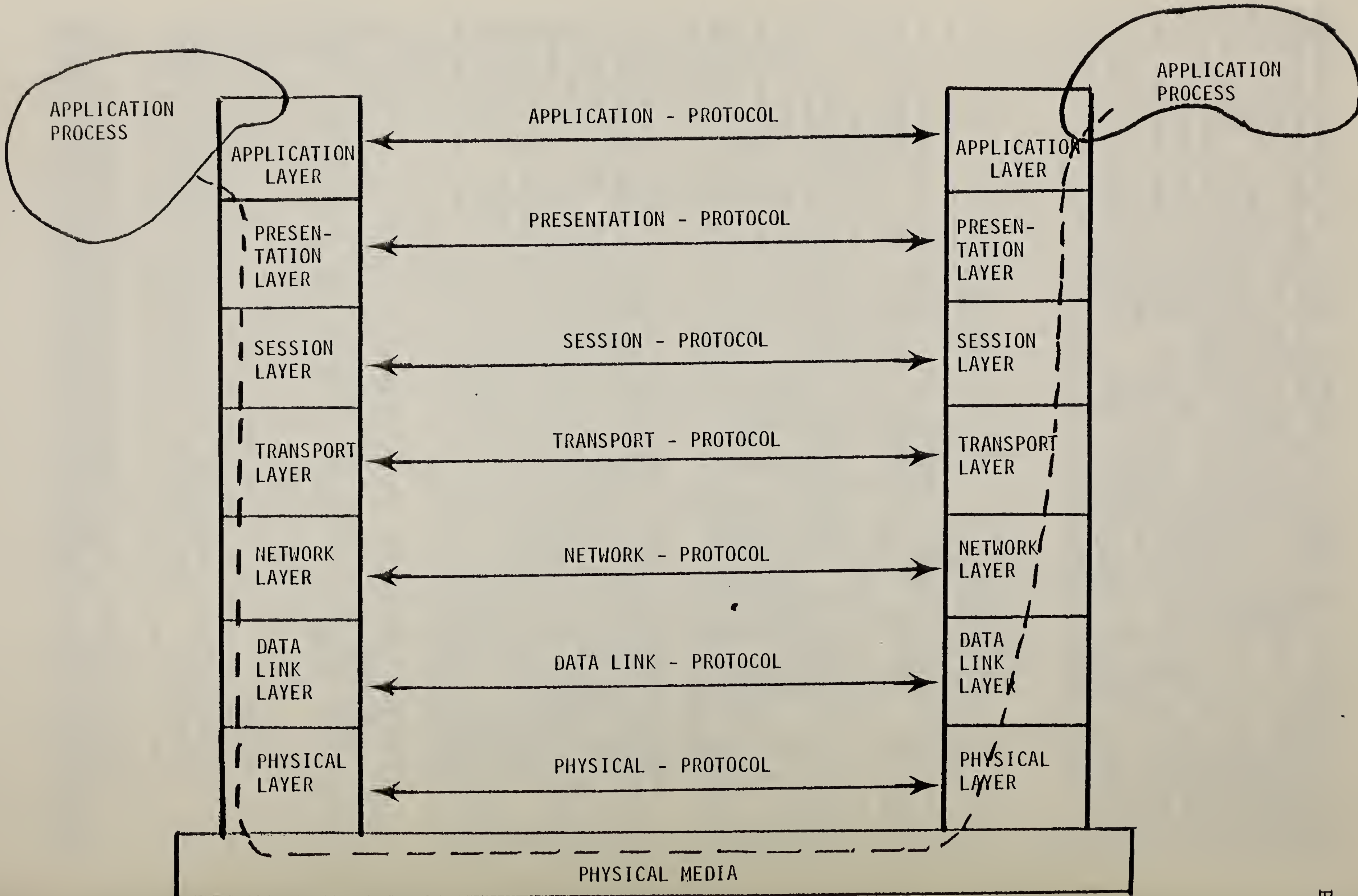

Figure 3. ISO Open Systems Reference Model.

open system. OSI is not intended to define either the functions or the implementations of the end-user APs, nor the implementations of the systems which host the APs and provide the open interconnection facilities. Rather, OSI is intended to provide a basis for compatible communication and cooperation among the APs to accomplish common objectives.

"When two APs in open systems need to communicate, a logical association called a "session-connection" between them is first established through intervening communications networks. The APs may then exchange messages according to established open systems interconnection protocols.

"The architecture adopted for the RM/OSI is based on the popular concept of layering. In this approach, a deep complex structure is partitioned into a number of independent functional layers.

"Each layer performs one well defined set of functions, using only a well defined set of services provided by the layer below. These functions implement a set of services that can be accessed only from the layer above. Communication among the functional entities which make up the layer is achieved by agreed protocols of the layer operating across connections provided as a service by the next lower layer.

"A decision which must be made prior to implementation of a computer network is concerned with the physical distribution of networking functions amongst various hardware components. To some extent this distribution will be constrained by the existing complement of hardware which is to be networked. There are, however, several degrees of freedom available to the network designer. The following paragraphs discuss each of the layers within the ISO model.

<u>Application Layer (Layer 7)</u> carries out the application oriented aspects of interprocess communication between APs in conjunction with the management functions which support APs. Application protcols include management protocols such as application rollback/recovery and remote job entry, and user protocols such as mail/message and order entry. To execute these protocols, application-entities must accomplish the exchange of meaningful information; this service is provided by the Presentation Layer.

<u>Presentation Layer (Layer 6)</u> manages the entry, exchange, display and control of structured data being communicated bewteen application-entities. Each presentation-entity provides a local "presentation-image" of the exchange data structure as a service to its application-entity. Presentation protocols such as

virtual terminal and virtual file accomplish the negotiation, management and exchange of parameters and data needed to ensure a consistent distributed data structure. To execute the presentation-protocols, presentation-entities need to communicate between themselves; the service of facilitating this communication is provided by the Session Layer.

<u>Session Layer (Layer 5)</u> provides services to establish and maintain a "session-connection" or cooperative communication channel between two presentation-entities, and to control their orderly data exchange interactions (e.g., control of turn to send). To implement the transfer of data, the session-connection is mapped onto and uses a transport-connection.

<u>Transport Layer (Layer 4)</u> provides reliable, cost-effective transfer of control information and user data between two session-entities. This includes cost-effective service selection, service quality monitoring and notification, multiplexing, and flow and error control. To accomplish the data transfer, transport-entities need to be able to move blocks of data from a source open system, across an entry network, several intermediate networks and an exit network, to a destination open system. This network data transfer must be provided at a known cost and quality of service, so that the transport entities can select from alternative avaliable network-connections those which enable the transport-entities to meet the session-entities quality of service requirements at least total cost.

<u>Network Layer (Layer 3)</u> provides network-connections at known cost and quality of service between any two open systems. This includes intranetwork routing and switching protocols for all open data communication networks, as well as internetworking protocols which are executed at gateways between networks. The "connections" may be implemented in a connection oriented network such as a CCITT X.25 or X.21 network, or may be "sublayered" on top of a "datagram" oriented network such as an Ethernet-type network, Alteratively, the connection oriented part of the Network Layer service -- e.g., sequentiality of message delivery, abbreviated addressing, low delay -- may be implemented or optional in some network-entities in order to provide a lower quality of service at an attractive lower cost.

<u>Data Link Layer (Layer 2)</u> provides for reliable exchange of a logical sequence of data blocks between equipments

connected by a single physical link. This includes protocols to address different logical link terminals on the same physical link, to identify sequences of data blocks, to detect and respond to errors, and to control the flow of data across the link.

Physical Layer (Layer 1) provides for the physical, mechanical, functional and procedural characteristics required to activate, maintain and deactivate the physical circuits between different equipment.

"Message exchanges between application-processes in different open systems normally communicate through all seven layers of the architecture (Figure 3). However, some systems will provide complete geographic "transparency" of OSI by providing OSI facilities within the system environment such that only the Transport Layer knows whether the partners are located in the same system or in different systems. And of course, two APs located in the same system may operate entirely outside of OSI protocols. Other uses of the architecture can be readily imagined, such as using OSI higher layer protocols to communicate between APs in a "closed" local network environment, or using "closed" application-protocols across an otherwise open systems interconnection environment."

7.3 ETHERNET

Ethernet is a bus LAN with distributed control based on carrier-sense multiple-access with collision detection (CSMA/CD). First described in [METCA76], this architecture has been the subject of considerable analysis and has inspired numerous variations. The prototype Ethernet system developed at the Xerox Palo Alto Research Center provides a data transfer rate of 2.94 Mbps. It connects up to 255 computers, and spans a linear distance of 1 kilometer. A piece of 75-ohm coaxial cable with terminators on each end constitutes the bus. Transceivers are located next to the cable and are attached to it by pressure taps. The transceiver provides ground isolation and a high-impedance connection to the cable for transmitting and receiving. Twisted pair cable brings signals and power to the transceiver from a controller in the computer.

The nodes consist mainly of "Alto" minicomputers and other personal computers capable of text editing, illustration, document preparation, interpersonal communication, etc. These machines appear in clusters, sometimes with over 100 Altos in one campus (building or group of adjoining buildings). Each campus is supported by various specialized servers providing remote access to shared resources such as large file systems, magnetic tapes, and high-quality printers. The campuses are interconnected by communication facilities consisting mostly of leased telephone circuits, but also including other networks such as the ARPANET and the ARPA Packet Radio network. The overall internetwork architecture in which the Ethernet system operates is called "Pup" [BOGGS 80].

The lowest level of internet protocol is a simple end-to-end datagram -- a standardized packet (called a "Pup") which is media independent but otherwise retains the common properties of the underlying packet networks. The communications network and interfaces are assumed to make a "best effort" to deliver a packet from a source process at one node to a destination process at another, possibly using the Pup internet transport mechanism en route. Packets may be lost, duplicated, or delivered out of order, after a great delay, and with hidden damage. For performance reasons the underlying networks are designed to make such events uncommon. In the Pup/Ethernet concept it is the responsibility of the communicating processes to provide the level of reliability they require through suitable end-to-end protocols. The Ethernet CIU for the Alto computer is implemented partially in hardware, partially in microcode, and partially in software. The hardware contains a small (16 word) buffer, parallel-serial and serial-parallel converters, CRC generator and checker, and Manchester phase encoder and decoder. The microcode performs address recognition, schedules retransmissions when collisions occur, and provides the interface seen by the software. The software is responsible for basic packet formatting, Pup encapsulation and decapsulation, and interfacing to the network-independent software. This software distributes and collects Pups (internetwork datagrams) to and from the communicating processes.

The prototype Ethernet system has served for several years as the dominant local network in a nationwide Pup internet used regularly within a number of Xerox research and development communities. The internet presently consists of about 25 Ethernet systems interconnected by 20 or so gateways and various long-haul transmission facilities. Over 1000 hosts (mostly Altos and other personal minicomputers) are connected to these networks.

Extensive measurements have been performed on one operational Ethernet system to which approximately 120 computers are connected. These machines include personal computers, servers, time-sharing systems, and gateways to other parts of the Pup internet. Users of these machines use the network regularly for file transfer, electronic mail, bootstrap or downline loading, software distribution, and many other purposes. In a typical 24-hour period, 2.2

million packets are carried in this network, totalling approximately 300 million bytes. For a 3-megabit per second channel, this amounts to only 0.9 percent utilization of the available bandwidth. But the utilization has high variance, and observed utilization has been as high as 3.6 percent for one hour, 17 percent for one minute, and 37 percent for one second. On the average, only 0.79 percent of all packets are delayed due to deference, and less than 0.03 percent are involved in collisions [SHOCH79]. The analytical model of CSMA/CD performance under heavy load and overload conditions, first presented in [METCA76] has now been verified experimentally. The network remains stable, its capacity is shared fairly among the contending hosts, and efficiency exceeds 97 per cent when traffic consists of relatively large packets (about 4000 bits).

Failures of an entire Ethernet system have been quite rare. For example, the 120 host network on which measurements have been taken has suffered outages only a few times per year, and only for a few minutes at a time while the problem was located and corrected. Failures affecting individual hosts or those that increase the packet error rate have been more frequent. The usual causes of catastrophic failure were incorrectly installed cable taps, shorted or malfunctioning transceivers, and broken CIUs that transmitted data indefinitely. The most serious failure occurred when lightning struck near a pair of buildings that had an Ethernet cable strung underground between them. The input transistors in a dozen or so transceivers became fused. Finding all the shorted transceivers took several hours. Partitioning the network made it apparent that there were problems in all sections. A time domain reflectometer was helpful in locating the damaged transceivers among the 100 or so units connected to that network. Damage such as this has been attributed to a difference in ground potential between the two buildings. An improved design for preventing such problems has been proposed that includes insulated tap blocks and connector housings as well as current-limiting resistors in the transceiver input circuits. Various other performance degrading malfunctions have been identified and techniques for eliminating or at least restricting their effects have also been proposed, and some have even been implemented.

7.4 NBSNET

NBSNET is a bus LAN designed and built at the National Bureau of Standards. It is a variant derivative of ETHERNET in that it employs a carrier sense multiple access, collision detection (CSMA-CD) protocol with a one megabit per second data rate and Manchester encoding on the coaxial distribution cable. It has been in routine use since October 1979 and now serves about 70 user devices in eight different buildings. The current user devices are primarily graphic and alphanumeric terminals, with a smaller number of mini and microcomputers connected. Both terminal access and file transfer protocols have been implemented. Most nodes keep traffic and error statistics during each connection and report the information to a central logging node when the connection terminates.

This network is intended to serve more than a thousand user devices at the NBS Gaithersburg, Maryland, and Boulder, Colorado, sites. The Gaithersburg system is operational and installation is proceeding at Boulder. The network user devices are dispersed among a number of buildings at the NBS Gaithersburg, Maryland, site. The network topology (although that of a bus) has a tree structure, with a main coaxial cable (actually in two segments) connecting all buildings. Each individual building is served internally by local cables connected to the main cable through a repeater. The repeater, used between network segments, is an active device that performs the functions of amplification and bit regeneration, delaying the signal by one bit period. It also contains circuitry to detect and enforce collisions on both segments to which it is attached and contains failure isolation circuitry to truncate transmissions greater than a maximum of two milliseconds.

NBSNET was designed to provide the following set of required network services:

1. Full connectivity between user devices such as terminals, microcomputers, minicomputers, and large host computers;

2. Ability to screen each node from most characteristics of the distant device with which it is communicating;

3. Speed conversion over the range of at least 110 to 9600 bps;

4. Flow control to/from user must be either in-band or out-of-band, to suit the user equipment with no restriction on the method used at the distant user device.

5. Ability to address over 1000 different user nodes (however, practical electrical and protocol considerations limit the network to a few hundred simultaneously active devices);

6. Cover a site 1.5 km long with 20 buildings;

7. Data encryption should be available as an option;

8. Most node failures should not affect the communication of other nodes.

The building block of the network is a microprocessor-based CIU called a Terminal Interface Equipment (TIE). The TIE connects the user device to the coaxial distribution cable. The TIE is partitioned into three active portions:

1. a user board (UB) that contains an MCS6512 microprocessor and all the memory serving a single user;

2. a network board (NB) containing the serial/parallel converters, the direct memory access controllers for the UB buffer memory, and the sequencer to contend for and transmit a packet onto the network using a CSMA-CD protocol; and

3. a TAP, which contains the line driver and receiver for the coaxial bus cable, the collision detector, and a failure-disconnect system to automatically remove "run-away" TIEs from the network.

A single NB/TAP combination can support eight UBs in the same card cage. The NB and UB circuit cards are approximately 24 cm on a side, and each cost approximately $400. The card cage costs about $500, the main power supply about $400, and the TAP about $140. Each UB contains 2K to 8K of read only memory which holds all the software needed to personalize the UB to the user device as well as to implement the network protocol. All signals to and from the TAP (located at the site of connection to the main bus cable) are optically isolated at the NB, and this section of the NB and the TAP are powered by a floating power supply. The signal leads between the NB and TAP are coaxial cables. The same TIE hardware design is used for both terminal and computer connections. Only the software in the TIE is changed to suit user characteristics. Operator commands can be used to vary almost all of the personality characteristics and to override others.

The cost of bringing the network to a user is composed of six components, the distribution cable (and repeaters) and its installation, the user's TIE and its installation, and the cable from the TIE to the user and the cable installation. The interbuilding distribution cables were installed throughout the NBS Gaithersburg site as a single project, which represented about one-tenth of the development cost. Cabinets were installed to contain the repeater amplifiers to serve each building. The repeaters are installed as required by service requests. In most cases the TIE cabinets are installed in closets off the corridors, and a TIE to TAP cable is run to the nearest shared bus cable. A TIE to user cable is then run over the corridor false ceiling and through the walls into the user's room. The RS-232 connector for the user terminal/connection is mounted on a cover plate similar to that used for electrical outlet box covers. The per-user cable and installation costs average $422 for present users with a range of $300 to $1750. The average TIE hardware cost is $670 per user, with four users per cabinet. This excludes main bus cable and repeater cabinet installation costs as well as all design and development costs.

Now that the network is successfully operational a measurement and control center is being built to measure network performance, identify marginal conditions, and assist in planning for enhancements. Performance data similar to that published for Ethernet will soon be available.

In eight months of operation there was only one complete failure of the network in which users system wide could not communicate successfully. This lasted for 1.5 hours, and before the exact source of failure could be located the problem corrected itself. Lightning caused one partial network failure in an outlying cable segment because of induced failure of a repeater line driver. This failure was repaired within a few hours, and the remainder of the system remained operational. Single TIE failures account for the vast majority of failures, and these were principally due to defective power supplies.

The TIE provides desirable network services. For example, "dumb" terminals can communicate with each other directly over the network without concern for bit rate incompatibility, provided that flow control signals are recognized by the sending terminal or manual typing speeds are used. The terminal user is given control over many parameters implemented in the node software so that they can be instantly modified to suit various terminals. A "rotary" is simulated in user board software so that multiple ports of a server computer can be automatically searched when a connection is being attempted.

8.0 GLOSSARY OF TERMS

Packet: A packet of information is a finite sequence of bits divided into a control header part and a data part. The header contains enough information for the packet to be routed to its destination. There are usually some checks on each such packet, so that any switch (or interface) through which the packet passes may exercise error control. Packets are generally associated with internal packet-network operation and are not necessarily visible to host computers attached to the network.

[ISO 78] A group of binary digits, including data and call control signals, switched as a composite whole. The data, all control signals, and possible error control information, are arranged in a specific format.

Datagram: A finite length packet of data together with destination host address information (and, usually, source address) which can be exchanged in its entirety between hosts, independent of all other datagrams sent through a packet switched network. Typically the maximum length of a datagram lies between 1000 and 8000 bits.

[NBS 77] A user facility in a packet network in which individual packets are accepted by the network from source terminals and are delivered independently to the destination identified in its address field. The order of delivery bears no fixed relationship to the order of entry into the network.

Gateway: The collection of hardware and software required to effect the interconnection of two or more data networks, enabling the passage of user data from one to another.

Host: The collection of hardware and software which utilizes the basic packet-switching service to support end-to-end interprocess communication and user services.

[MCNA 77] A computer attached to a network providing primarily services such as computation, data base access, or special programs, or programming languages.

Protocol: A set of communication conventions, including formats and procedures which allow two or more end points to communicate. The end points may be packet switches, hosts, terminals, people, file systems, etc.

[NBS 80] A defined procedure or set of rules for interactive behavior in a communications environment.

Protocol Translator: A collection of software, and possible hardware, required to convert the high level protocols used in one network to those used in another.

Terminal: A collection of hardware and possibly software which may be as simple as a character-mode teletype or as complex as a full scale computer system. As terminals increase in capability, the distinction between "host" and "terminal" may become a matter of nomenclature without technical substance.

[ANSI 77] A point in a system or communication network at which data can either enter or leave.

Virtual Circuit: A logical channel between source and destination packet switches in a packet-switched network. A virtual circuit requires some form of "setup" which may or may not be visible to the subscriber. Packets sent on a virtual circuit are delivered in the order sent, but with varying delay.

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NBS-114A (REV. 2-80)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET (See instructions)	1. PUBLICATION OR REPORT NO. NBSIR -80-2187	2. Performing Organ. Report No.	3. Publication Date

4. TITLE AND SUBTITLE

Local Area Network Feasibility Study for the Naval Sea Systems Command

5. AUTHOR(S)

Alan Mink and Charles B. Silio, Jr.

6. PERFORMING ORGANIZATION (*If joint or other than NBS, see instructions*)

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

7. Contract/Grant No.

8. Type of Report & Period Covered

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (*Street, City, State, ZIP*)

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

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

The Naval Sea Systems Command (NAVSEA) has tasked the Institute for Computer Sciences and Technology (ICST) of the National Bureau of Standards (NBS) to perform a feasibility study of a Local Area Networking (LAN) capability to enhance NAVSEA's computing facilities. This report documents that feasibility study. In this report, NAVSEA's environment will first be established. This includes the physical and the computing environment. After establishing the environment, a representative set of application programs will be used to determine NAVSEA's LAN requirements. Then a discussion of LAN topologies is presented, and those applicable to NAVSEA are indicated. Implementations of these applicable topologies are discussed along with the technologies involved and their advantages and disadvantages.

12. KEY WORDS (*Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons*)

Carrier sense multiple access; environmental analysis; feasibility study; local area networks; requirements analysis.

13. AVAILABILITY

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14. NO. OF PRINTED PAGES
52

15. Price
$8.00