CE & TECHNOLOGY:

COMPUTER NETWORK INTERCONNECTION: PROBLEMS AND PROSPECTS

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U.S. DEPARTMENT OF COMMERCE
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COMPUTER SCIENCE & TECHNOLOGY:

Computer Network Interconnection: Problems and Prospects

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COMPUTER NETWORK INTERCONNECTION: PROBLEMS AND PROSPECTS

Ira W. Cotton

ABSTRACT

This report examines the current situation regarding the interconnection of computer networks, especially packet switched networks (PSNs). The emphasis is on identifying the barriers to interconnection and on surveying approaches to a solution, rather than recommending any single course of action.

Sufficient organizational and technical background is presented to permit an understanding and appreciation of the problem. Four major types of interconnections are then surveyed:

1. Circuit Switched Network to PSN
2. Star Network to PSN
3. Simple Terminal to PSN
4. PSN to PSN

The major barriers to interconnection are then outlined. The report concludes with some comments on the prospects for overcoming these barriers.

An extensive bibliography, glossary with list of abbreviations, and listing of existing data communications standards relevant to interconnection are also included.

Key Words: Communications networks; computer networks; data communications; interconnection; networks; packet switching; standards.

1.0 INTRODUCTION

The data communications world has begun to undergo a major change in recent years, from an ad hoc array of "home brew" systems that worked more in spite of, than due to, publicly available facilities, to a more planned and integrated set of facilities designed both for the communications of data and for public use. At the same time, the data communications needs of users have been growing, measured in terms of sophistication, volume and geographic coverage. In an age of transcontinental and multinational business, users require access to a full range of services and coverage. Thus, the same user demands that lead to the development of high capability public data networks will inevitably also lead to the interconnection of these data networks.

Although it is clear that data networks, particularly public data networks, will be interconnected, the way in which this will occur is less clear. There are a variety of factors that will affect the way in which interconnection is accomplished, including technical issues, political and regulatory issues, and market power. This report will focus primarily on the technical issues involved in interconnection, though some of these other issues, particularly the regulatory issues, will also be touched upon. The intent, however, is to clarify the problem and illustrate the alternatives, not to presume to solve the problem nor to choose any alternative. The search for an optimum solution is currently an active pursuit of many organizations.

1.1 Environment

The current data communications networking environment is characterized by unprecedented innovation and growth. New technologies are moving from the laboratory to commercial application in record time, and a variety of new service offerings are being presented to customers. The result is both widened opportunities for users to avail themselves of these new services and confusion on the part of carriers and customers alike as to the service effectiveness and economic viability of all the new offerings.

The environment, in the U. S. at least, is also one of increased competition in the data communications marketplace. Barriers to entry have been lowered in many formerly monopolistic service areas. Consequently, many new firms are entering these markets. On the other hand, it is at least questionable whether all of these firms will succeed financially, and it is worth noting that legislation has been introduced in the Congress to reverse the pro-competitive policies of the FCC.

1.2 The Problem

The basic problem is to devise a strategy for the interconnection of computer communications networks that is workable and acceptable to users, carriers and regulatory authorities. Users seek solutions that are technically efficient, easy to use, and which enable them to take full advantages of all facilities on any of the networks that are so interconnected. Carriers also seek solutions that are efficient, though they are loathe to alter the internal operation of their systems. Any system for interconnection must also permit them to protect the integrity of their own network as well as to account for and charge for all services supplied. Regulatory authorities seek methods that are understandable, controllable, and for which tariffs can be devised.

Not all of these goals are congruent. Obviously, compromises may need to be made along the way. However, it is not clear that all the various groups are presently willing to compromise. Indeed, it has been suggested that the opposite is true:

> "We are again witnessing the saga of the large manufacturers attempting to dominate the customer community through standards of their own design while the users try to formulate less constraining industry-wide standards." [SA76]

Others looking at the data communications environment see a "jungle" [MCC74] or a "snarl" [PO75c]. Hyperbole considered, the data communications area is certainly a most "turbulent" [DO74] one at present.

1.3 Organizations

A variety of different groups are involved with network interconnection. In this section, we seek to identify the more significant of these groups, and to indicate their particular role and/or views.

1.3.1 Communications Carriers -

Carriers are organizations that actually provide "basic" data communications services, including telephone and telegraph, voice and data services, switched and point to point services, etc. Carrier organizations include both government agencies and recognized private operating agencies (RPOAs).

In most of the world, data communications is a state monopoly, run by a Postal Telephone and Telegraph (PTT) ministry or authority. Only in a relatively few countries do private companies provide domestic communications services, and in those countries they do so under government regulation. The United States and Canada are examples of such countries where communications have been provided by regulated monopolies, with only limited (but growing) competition between carriers.

International communications services are provided by private organizations that have been chartered to provide these services by a series of bilateral agreements between the national authorities of the countries they interconnect. The international carriers only provide service between the national carriers of the respective countries.

1.3.1.1 Common Carriers -

The common carriers are the government agencies (PTTs) and authorized private companies that provide the local loop and the bulk of the backbone, long haul telecommunications services. In most of the world there is one common carrier per country, the PTT. In the U. S. and Canada there are many (far fewer in Canada than in the U. S.), providing either or both local distribution and long haul services. In this country, AT&T is a common carrier, as are each of the regional operating companies. In addition, there are many smaller independent telephone companies in various parts of the U.S.

Common carriers generally have a monopoly position in many, if not all, of their markets. Their pricing policies are based on long term depreciation of extensive (and expensive) plant and equipment, and may also be influenced by internally or externally (say from a regulatory agency) generated policies regarding cross subsidization among the various markets served. The carriers, while dedicated to providing high quality service to the public, are motivated to maintain their monopoly positions and to pace the introduction of new service offerings so as not to unduly disrupt their long term financial positions.

1.3.1.2 Specialized Common Carriers -

Specialized common carriers are those American companies authorized by the Federal Communications Commission to provide limited telecommunications services of particular types or in particular markets, on a competitive basis. The first such specialized carrier was Microwave Communications, Inc. (MCI), which was authorized in 1971, after a long inquiry, to construct transmission facilities and operate data communications services between St. Louis and Chicago. Additional companies have since entered various regional markets on a competitive basis.

The specialized common carriers are accused by the established common carriers of "cream skimming," i. e., selecting only the high volume or most profitable markets to enter and ignoring the low volume markets where the established common carriers are required to provide service, often for revenues set at less than full costs. It is certainly true that specialized common carriers do have this flexibility to select their markets. However, this selectivity permits them to introduce new technologies and facilities more rapidly than the established common carriers would be wont to do.

1.3.1.3 International Record Carriers -

The International Record Carriers are those companies authorized by bilateral international agreements to provide data communications services between countries. Generally, they do not provide any service <u>within</u> each of the countries concerned, but simply provide a connection between two or more intra-national carriers. Also, in most cases the physical facilities and the revenue for international service is shared by a consortium of companies from each of the two countries.

The major U. S. based international record carriers are the International Telephone and Telegraph Company, RCA Global Communications, and Western Union International. The foreign partner sharing the facilities and the revenue in most cases is the PTT of the country concerned.

1.3.1.4 Value-Added Carriers -

Value-added network carriers are a type of carrier peculiar to the United States. These are private companies who have received formal approval from the Federal Communications Commission to lease basic communications services from common and specialized common carriers, to augment these basic services through the use of additional physical facilities (such as intelligent switching processors), and to resell the "higher value" service to the public. Currently, only two value-added carriers are in operation, Telenet Communications Corporation and Graphnet Systems, Inc., but other companies, including the International Telephone and Telegraph Corporation (ITT) and Tymshare, have filed with the FCC for similar authority. The first company to obtain authority to offer value-added services, Packet Communications, Inc. (PCI), was unable to secure sufficient financing to implement its planned system, and is now essentially defunct.

In countries where communications is a state monopoly, the organization of a value-added carrier does not exist. The same services may be offered to the public by the national carrier organization itself without the necessity for purchase and resale of the basic services.

1.3.2 Regulatory Organizations -

For most kinds of service, telecommunications has been felt to be a natural monopoly by governments worldwide. Free competition, it has been feared, could lead either to wasteful duplication of facilities or monopoly exploitation of the public. Furthermore, governments have sometimes felt that control over their national communications systems was a prerequisite to internal security. Consequently, telecommunications have traditionally been highly regulated or kept as a state monopoly.

1.3.2.1 Postal Telephone & Telegraph Administrations -

In most countries outside the U. S. and Canada, telecommunications is a state monopoly operated by a Postal Telephone & Telegraph Administration (PTT). These Administrations intrinisically perform the regulatory function, since they determine what facilities are to be constructed, what services are to be offered, and what tariffs are to be set.

1.3.2.2 Federal Communications Commission (FCC) -

The Federal Communications Commission was created by Congress through the Communications Act of 1934 to regulate interstate and international communications by wire and radio in the public interest. Through the years, the FCC has in large part determined the structure of the U.S. telecommunications industry.

No area has proved more perplexing to the FCC than that of data communications. Data processing and data communications are becoming increasingly interrelated; the FCC faces the increasingly difficult task of formulating regulatory policy for communications that leaves the data processing portion unaffected. FCC rulings have extraordinary impact on the data communications marketplace. Two fledgling industries owe their very existence to the FCC: specialized carriers and value-added carriers.

Martin [MA76] has reviewed the relevant actions related to data communications taken by the FCC in recent years, along with major issues currently facing it (with the exception of the recent <u>reopening</u> of the Computer Inquiry [BU76b] subsequent to the publication of his article). We cannot discuss all of these here, except to note that recent rulings have evidenced the Commission's desire to encourage somewhat greater competition in providing communications services, especially of new types and to large volume customers.

1.3.2.3 State Public Utility Commissions -

For telecommunications systems whose extent is purely intrastate, the particular state Public Utility Commission (or equivalent) has jurisdiction, rather than the FCC. In California, for example, a packet switched system is currently being constructed for the state university system by Pacific Bell. Since this is to be a purely intrastate system, no FCC application was required or was filed.

On the other hand, the FCC has been aggressive in defining the limits of exclusive state authority. Martin describes a case in which the FCC rejected the telephone companies' contention that interconnection to the local telephone exchanges was within the control of state utility commissions [MA76]. The FCC reasoned that such facilities, though located entirely within one state, are nevertheless used as links in interstate communications.

1.3.3 Standards Organizations -

A number of different organizations, including professional societies, trade associations, government agencies at both the state and Federal levels, and national and international standards bodies, are involved in the development of standards related to data communications and computer networking. An appreciation of the different roles of these various organizations is helpful in understanding the various cross currents in standards development, particularly as they affect strategies for the interconnection of networks. Additional detail on the standards organizations discussed here may be found in [SC74, HA75] or be obtained from the organizations themselves. Standards related to data communications and network interconnection produced by these organizations are listed in the Appendix.

1.3.3.1 International Standards Organization (ISO) -

The International Standards Organization is the primary international organization for the development of voluntary standards. Within ISO, Technical Committee (TC) 97, Subcommittee (SC) 6 is concerned with digital data transmission. Membership in this committee, as in all ISO activities, is provided by the national standards organizations of the participating countries. The U. S. member is ANSI X3S3 (see section 1.3.3.3).

Over the years, the ISO has been involved in a wide range of data communications standards activities, primarily directed at codifying existing practices. In contrast, one of the most significant ISO activities in data communications over the past few years has been the development of a draft international standard for a bit-oriented High Level Data Link Control Procedure (HDLC) where no common industry practice exists.

1.3.3.2 Consultative Committee For International - Telegraph & Telephone (CCITT)

The Consultative Committee on International Telegraph and Telephone is a major operating unit of the International Telecommunications Union (ITU) an intergovernmental organization concerned with establishing agreements, treaties and standards with respect to telecommunications. The CCITT was established within the ITU to examine and make recommendations on technical, operational and tariff matters relating to telegraphy, facsimile and telephony. The United States is officially represented on CCITT by the Department of State, with domestic common carriers, the FCC and the Federal Office of Telecommunications Policy serving as its principal technical consulting agents.

Three groups within the CCITT program of work are of prime interest to the computer networking community:

* Special Study Group A, Data Transmission, is the principal point for the data processing community's contacts with CCITT. The work program of this group includes all matters relevant to data transmission, including interfaces, modems and maintenance procedures.

* Joint Working Party ALP, Alphabet, is responsible for work on alphabets, codes and related matters pertaining to character transmission structure and keyboards.

* Study Group VII, New Data Networks, is responsible for working on the new types of data networks that are being introduced, with the emphasis on digital data networks.

It seems obvious that there is overlap between the interests of the CCITT and ISO committees just identified. This is true, but, as Vaughn explains [VA75], duplication of effort has been avoided through cooperation of the two groups. A CCITT administrative recommendation, A20, lays down the basis for this cooperation and the division of responsibilities between CCITT and ISO. Briefly, ISO is responsible for standards relating to customer-provided equipment such as computers and terminals (DTE) which connect to telecommunications facilities, while CCITT is responsible for standards for the telecommunications network interfaces and for the telecommunications networks themselves, including transmission channels, switching, signaling, etc. Naturally, in the current changing environment for data communications, the refinement of the division of responsibilities is a continuing process.

1.3.3.3 American National Standards Institute (ANSI) -

The American National Standards Institute is the primary organization in the United States through which voluntary national standards are promulgated and through which American positions on international standards and recommendations are expressed. Within ANSI, under Sectional Committee X3 on Computers and Information Processing, Technical Committee X3S3 on Data Transmission is responsible for defining the characteristics of digital data generating and receiving systems that function with communications systems and for developing and recommending standards for data communications. The Committee is organized into a number of task groups with specific responsibilities within this general program:

X3S31, Planning, is responsible for planning and coordinating the activities of the other task groups.

X3S32, Glossary, is responsible for developing a common vocabulary for use by all the task groups.

X3S33, Data Communications Headings and Formats, is responsible for defining formats (for data communications) of bits within characters and of characters within a hierarchy of groups, and for outlining functional control requirements and procedures for data systems other than those required for control of a data link.

X3S34, Data Communications Control Procedures, has been engaged in the development of a bit-oriented Advanced Data Communications Control Procedure (ADCCP).

X3S35, System Performance, is responsible for standardizing data communication system performance determination techniques and criteria.

X3S36, Digital Data Transmission Rates, is responsible for establishing standard signaling speeds for use at the interface between data terminal and data communication equipments.

X3S37, Public Data Networks, is focusing its activities on the development of standards for digital interfaces to public data networks, including those operating in the circuit switched and packet switched modes.

1.3.3.4 Electronic Industries Association (EIA) -

The Electronic Industries Association is a non-profit organization representing over three hundred manufacturers of electronic products. The organization has been involved in the promulgation of voluntary industry standards through its technical engineering committees. The responsibility for data communications standards in the United States is shared by the technical committees of EIA and ANSI.

Two primary committees in EIA relate to data communications standards [HIL72]:

TR30, Data Transmission Systems and Equipment, is responsible for developing and maintaining standards for the interface between data communication and data terminal equipment, including work on the interface between digital data terminal equipment and signal converters, data sets and modems. TR30 is the advisory body to ANSI X3S3 for these standards areas, both for domestic and internatinal activity.

TR37, Communications Interfaces, is responsible for developing and maintaining standards for the interface between common carrier-provided communications equipment and systems. This includes work on data, graphic and voice communication systems.

1.3.3.5 Federal Government Standards Organizations -

As the world's largest single user of computers and communications, the Federal Government is understandably concerned with the development of standards as a means of reducing long term costs and improving the effectiveness of operations. Consequently, a number of programs have been set up in Government to formally address the issue of standards. Efforts relating to interconnection have been addressed by programs administered by two principal organizations: the National Bureau of Standards and the Office of the Manager, National Communications System.

1.3.3.5.1 National Bureau Of Standards -

Through a combination of Congressional action (PL 89-306) and Executive Orders, the major responsibility for ADP standards in the Federal Government rests with the National Bureau of Standards. As outlined in [US74], the NBS role in ADP standards includes:

Providing guidance and leadership in the requirements determination, development and testing of ADP standards;

Participating in national and international voluntary standards activities;

Monitoring and coordinating all Federal participation in these voluntary activities;

Preparing recommendations for standards to be adopted for Federal implementation;

Monitoring the implementation of Federal standards and assessing their impact on computer services; and

Carrying out the necessary research and analysis in support of the development, implementation and management of ADP standards.

The Federal Information Processing Standards Publications (FIPS PUB) Series is the official publication medium for information relating to standards developed under these programs.

1.3.3.5.2 National Communications System -

The National Communications System has the responsibility, delegated by the General Services Administration, to administer the Federal Telecommunications Standards Program. The objectives of this program are:

To develop, coordinate and promulgate the technical and procedural standards required to achieve interoperability among functionally similar telecommunication networks of the National Communications System;

In concert with the National Bureau of Standards, to develop and coordinate technical and procedural standards for data transmission and the computer-telecommunications interface; and

Increase cohesiveness and effectiveness of the Federal telecommunication community's participation in national/international standards programs and on the Federal Information Processing Standards Program.

An agreement between the National Bureau of Standards and the National Communications System identified areas of exclusive and of joint responsibility. As outlined in [US74], NBS is exclusively responsible for standards in the area of teleprocessing, NCS is exclusively responsible for standards in the area of data transmission, and the two agencies share the responsibility for interface standards.

1.3.4 Hardware Manufacturers -

The major computer manufacturers are still the principal source of supply for data communications software for their systems. As such, they have both a strong interest in and a strong influence on the design of commercial telecommunications systems. However, what is in the best interests of the computer hardware manufacturers may not always be most effective for the telecommunications system. At least one industry critic suggests that the popularity of IBM proprietary link control procedures is primarily due to "IBM's ability to significantly influence a major segment of the data processing community, rather than by operational advantages" [BU76a].

With IBM moving to enter the data communications area more aggressively, such as through its Satellite Business Systems venture, its impact on telecommunications systems design can only be expected to increase. Though not so far reaching as IBM's, the influence of the other major mainframe manufacturers will also be felt, particularly within their user communities. Both Digital Equipment Corporation and Burroughs, for example, have announced proprietary approaches to network systems and are proceeding with implementation.

1.3.5 User Groups -

Users are presumably the ones most affected by decisions on telecommunications facilities, services and standards. However, users have not had any significant role in recent decisions regarding any of these issues and have been "conspicuously absent" from major meetings [FE75]. This may be due to the lack of a suitable mechanism through which user views may be expressed.

It is almost a cliche to say that user views are ultimately expressed in the marketplace. What is not always recognized is that this presupposes a freely competitive marketplace, which is not quite the case in telecommunications. Users can only express their preferences by selecting from among the available goods and services, or by refraining from consumption altogether. It would seem preferable to be able to influence in advance the selection of goods and services to be offered.

Telecommunications users lack any organized forum for expressing their preferences. Unlike the major computer hardware manufacturers, telecommunications companies have not fostered the development of user groups as a means of communicating with their customers. Only quite recently has a fledgling Data Communications Users' Group sought to attract such users under a common umbrella; it remains to be seen how successful such a group will be.

The only notable success users have experienced in the data communications area have been the joint user networks which have been developed in such specialized areas as air traffic information interchange [HIR74] and the over-the-counter stock exchange [MI72]. In these areas, private networks have been designed and implemented by a consortium of users. Because the systems were designed by users themselves, they reflected user needs rather than carrier or manufacturer convenience. Also, compared to the strength of an individual user, the influence of the joint group on carriers and manufacturers could be significant. This common approach to data communications needs in specialized industries may become more popular in the future.

2.0 TECHNOLOGICAL BACKGROUND

A clear understanding of basic networking concepts is necessary to appreciate the issues in network interconnection. In this chapter we present some of these basic concepts, including a review of the types of public data networks, an unraveling of the components of an interface, and a discussion of the various levels of protocol. Additional information of a tutorial nature may be found in [PY73, DA73] and elsewhere.

2.1 New Data Networks

The continuous and rapid decline in the cost of computer hardware has been called "the most dominant force over the past twenty years in both computer and communications architecture" [ROB74]. This continued decline in the cost of computation relative to the cost of communications has led to the introduction of intelligent computing components into communications systems in an effort to economize on communications bandwidth. This trend, which began with message switching systems and concentrator networks, has led most recently to the development and successful operation of packet switched networks, which employ computers as integral components of the communications system itself.

In the following sections we briefly review the various switching techniques employed in most computer networks.

2.1.1 Circuit Switching -

Circuit switching, as illustrated by the voice telephone network, is a system whereby a complete physical path is established from sender to receiver that remains in effect for the duration of the conversation. In most telephone exchanges, this route is actually established by mechanical means (such as relays), though the selection of the route may be made electronically. The process of selecting a route, or call establishment, may take on the order of seconds for a complex network. Once the route is established, however, data transfer is continuous through the network in the sense that there are no delays added to data by the switches. End to end transmission time through the network is limited only by the propagation times of the various circuit media employed (e.g., cable, microwave, satellite).

Circuit switched service customarily has been engineered for analog transmission, such as for voice telephony. The use of such systems for data necessitated the use of modems to convert the digital signals to analog form. Recently, with the growth in demand for data transmission service, both point-to-point and switched digital communications services have been designed and implemented. Such services are expected to become more widely available in the future.

2.1.2 Virtual Circuit Switching -

Virtual circuit switching as implemented in Tymnet [TY71] is the logical analog of physical circuit switching. The network consists of some number of point-to-point circuits connected by switching computers at the nodes. During the call establishment phase a complete path through the network is established from sender to receiver. This path is not changed for the duration of the call. In contrast to physical circuit switching, the definition of this path is accomplished by routing tables in each of the node computers. These tables in aggregate define all the virtual or logical circuits through the network. Actual data transfer is accomplished by forwarding the data from node to node towards the destination. The data are forwarded in blocks, and is stored briefly at each node while it is forwarded to the next node. Thus, virtual circuit switching employs a "store and forward" procedure to accomplish data transfer through the network and does introduce a finite delay at each node.

2.1.3 Message Switching -

Message switched networks also contain a number of circuits with switching computers at the nodes. Message switching is similar to virtual circuit switching in that data are transmitted through the network in blocks on a store and forward basis from node to node. Message switching differs from virtual circuit switching in that there is no fixed route followed by all the data blocks. Instead, each block contains a destination address which is examined by each node through which the block passes. The switch at each node determines the best output line on which to forward the block based on the destination address and the status of the network at the time of processing. Because each block is handled individually, there is no call establishment phase so far as the communications system is concerned.

2.1.4 Packet Switching -

Packet switching is a special type of message switching distinguished by a number of different characteristics, each of which may not seem too critically different, but which in aggregate serve to define a quite different type of communications system [COT75]. First of all, packet switched systems employ transmission blocks of a maximum length which is generally significantly smaller than most message switched systems. Next, packet switched systems make no attempt to store blocks for any prolonged period of time while attempting delivery. Rather, transmission blocks, or packets as they are called, are discarded if difficulties are encountered in their delivery, in which case they must be retransmitted by the sender. Packet switched systems are designed to rapidly forward the packets towards their destinations with minimal delay in the node. Finally, packet switched systems will refuse to accept input when necessary to prevent saturation.

With this basic internal network capability, a number of different types of services may be offered to customers. Two principal (and different) types that have been identified are designated as datagram and virtual circuit service.

2.1.4.1 Datagram Service -

Datagram service is the most fundamental service that could be offered by a packet switched network. Under this service, individual packets are accepted by the network from source terminals and are delivered independently to the destination terminals, with the order of delivery bearing no fixed relationship to the order of entry into the network. Any sequencing of packets that is required in order to transmit a stream of meaningful information must be done by the receiving terminal. All packets must be fully addressed when they are entered into the network.

2.1.4.2 Virtual Circuit Service -

Virtual circuit service undertakes to provide a communications service more nearly resembling an actual physical circuit. A call establishment phase is required, during which sending and receiving terminals are prepared to exchange information and during which network resources may be reserved for the data transfer. Data accepted by the network as a stream of packets will be delivered in the order entered without further customer responsibility. Since the destination of a stream of information is known to the network after the call establishment phase, a highly abbreviated addressing scheme, identifying the virtual circuit rather than the receiving terminal, may be employed with data packets. A single channel terminal would not even have to provide this much identification with data packets, since there could be no ambiguity as to the destination of the data. A "permanent virtual circuit" service could also be provided wherein a single access terminal determines at subscription time the destination to which all data from the subscribing terminal would be sent. This would even eliminate the need for call establishment.

2.1.5 Value-Added Networks -

As identified in section 1.3.1.4, value-added networks are a special type of new data network that are independent of the switching system with which they are implemented. A value-added carrier obtains basic communications services on a point to point basis from established common carriers, provides special equipment such as switching computers at the nodes to improve or "add value" to the service, and sells the new service to end users.

2.1.5.1 Additions To Basic Communications -

Value-added networks improve the quality of the basic communications service in a number of ways. Through adaptive multiplexing, high speed lines can be shared by large numbers of users and more efficient use can be made of the available bandwidth. Alternate routing permits the network to maintain continuity of operations in the event of selective internal component failures. Powerful error detection techniques combined with mechanisms for the network to automatically retransmit data in which errors are detected provides an end to end error rate to users that is many orders of magnitude better than basic communications services could provide.

2.1.5.2 New Services -

The intelligent components in a value-added network can be employed to provide new services to customers not provided by other types of communications services. Among these services are speed recognition and conversion, code conversion, and the imposition of a set of standard protocols network wide. Speed and code conversion permit a wide variety of different terminals to communicate with each other. Standard protocols provide a means for user processes on different systems to do likewise.

2.1.5.3 Non-Technical Benefits -

Value-added networks also offer a number of non-technical benefits. Among these are the total management of a multi-vendor communications system and the ability to obtain service on a metered basis. Many users would welcome the opportunity to obtain an end to end service rather than operating their own private networks. The ability to obtain service in continuously varying volume is of great value to organizations whose demands are not constant.

2.2 Interface Components

An interface, simply enough, is something between two systems, devices or components that serves to connect them. The interface may be a system, device or component itself, or a set of specifications to which the connected things adhere.

Computer communications interfaces are generally composed of both devices or components and specifications. There are many different aspects or ways of describing a computer communications interface. One possible breakdown, and the one chosen here, is to distinguish between different levels of function, viz., physical, electrical, logical and procedural. These different functions or levels of an interface are outlined following. A more detailed overview of computer-communications interfaces may be found in [NE74b].

2.2.1 Physical -

The physical portion of the interface specifies the way in which the two devices are actually connected mechanically. This includes the number of wires and the dimensions of the physical connectors (generally a male and female connector are specified) in which the wires terminate. For example, a 25-pin connector is currently in widespread use for computer-communications interfaces; new 15 and 37-pin connectors will be standardized for use with the new interfaces now under development.

2.2.2 Electrical -

The electrical portion of the interface specifies the voltage levels and duration (or for some interface specifications, the current flow) to be used for signaling on the various leads. The basic capability provided by adherence to the standards at this level is the transfer of data bits across the interface. These bits may be identifiable as parts of characters and/or be used for higher level signaling functions within the interface.

2.2.3 Logical -

The logical portion of the interface specifies how the data bits and/or characters are grouped into fields for the purposes of signaling and data transfer. The use of certain characters for communications control functions such as synchronization (SYN) and start of header (SOH) is also specified at this level. In a sense, the logical specification of a computer-communications interface provides a language that may be employed for controlling and effecting data exchange across the interface. Standards at this level are sometimes called "elements of procedure."

2.2.4 Procedural -

If the logical level of the interface is viewed as specifying the syntax of the data flow across the interface, then the procedural specifications should be viewed as providing the semantics. Specifications at this level determine the legal sequences of communications control characters, or the legal contents of various fields, or the valid commands and responses in controlling data flow. The same basic set of control characters or fields may be used in a variety of different ways according to the procedural specifications. Standards for these different ways are sometimes called "classes of procedure."

2.3 Protocol

The term "protocol" is generally used to refer to the logical and procedural aspects of an interface. Thus, a protocol specification includes both syntax and semantics. Semantics also include relative timing information -- not just the legal commands, but who can issue them and when.

A complex interface may contain several levels of protocol. An appreciation of this aspect of protocols is quite important in designing and evaluating network interconnections.

It has been suggested* that the term "protocol" be used to designate communications conventions between entities at

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* Louis Pouzin, private communication.

the same level while "interface" be used to designate conventions between entities at adjacent levels. This is an attractive suggestion, and some confusion may be eliminated if the use of these terms in this way becomes widespread.

2.3.1 Link Control -

Although they could be implemented in software and therefore be considered as a type of process to process protocol, in most cases link control disciplines or protocols are at least capable of or intended to be implemented in hardware and should therefore be discussed separately. The link control protocol is simply part of the transport mechanism to get data reliably and in a controlled fashion from one end of a link to the other.

Link control protocols are either bit-oriented or character-oriented. In both cases, there is a way to frame discrete units of information, a set of commands and a way to convey them, and an error detection mechanism. Some examples of link control procedures are American National Standard (ANS) X3.28 (character-oriented) and the ISO High-Level Data Link Control Procedures (bit-oriented).

2.3.2 Process To Process -

In computer communications systems, most protocols are for the exchange of information between processes, where a process may loosely be viewed as a program. (Multiple use of a re-entrant program is viewed as multiple processes). In the case of a simple terminal, the actions of the human operator are considered to constitute the process.

Many different processes may reside in the same physical device. For example, a host computer may have a communications handler process, various operating system processes, and many user (application level) processes. Messages entering the host through the same physical interface may be intended for any of these processes. In most cases, there is a hierarchy of control for delivering messages to the proper recipient. The communications handler must examine all messages; the operating system must examine all messages intended for user processes. Thus, the basic structure for all messages must have some mechanism for identifying the level and identity of the proper recipient. Frequently, information for recipients at multiple levels may be conveyed in the same physical message.

For example, the various levels of communication in a packet switched network have been identified, and a mechanism recommended to distinguish between them [OH74]. The method is simply to nest messages within messages, according to relative position in the hierarchy. Each recipient then "peels off" the part intended for it and passes the remainder to the next level recipient. This approach works quite well, and is implemented in most packet networks (e.g., [CA70]).

2.4 Control Requirements

There are a variety of control-related functions that must be performed by <u>all</u> computer networks. When networks are interconnected, these functions must be addressed in some way by the interface.

2.4.1 Addressing -

In a communications system, some means of addressing is required whenever sender and receiver are not directly connected. With a multi-channel terminal such as a host computer, which also contains different levels of addresses (such as operating system level, user program level), the question of addressing the proper recipient is non-trivial.

2.4.2 Signaling -

Signaling refers to the means by which control information is exchanged between the network and its users. The two primary classes of signaling techniques are in-band and out-of-band signaling. In the former, control information is exchanged in the same way that data are exchanged, with some special identification marking it as control; in the latter, some other means is provided for exchanging control information, separately from data. Where nested protocols are concerned, control information sent at a different level of protocol may be considered as out-of-band signaling, even though all the data at all levels of protocol are transported by the same physical means.

2.4.3 Flow Control -

Flow control refers to mechanisms for throttling the rate of data exchange between any two points in order to prevent overload. With probabilistic message generation and fixed capacity in network components (such as buffers), overload would be inevitable without such mechanisms to temporarily stop or slow down the rate of message arrivals.

Sequencing and acknowledgments of messages can be considered as part of flow control or can be treated separately. The question of sequencing is generally considered as part of the service to be offered (e.g., datagram or virtual circuit) and not as a mechanism that can be implemented in a variety of ways. Message acknowledgement, on the other hand, can be accomplished in a number of ways, and is frequently integrated with flow control mechanisms.

Just as message exchange can occur between parties at various levels in a hierarchy, so too can flow control be implemented for any of these levels. Of course, the actions of a flow control mechanism at lower levels in the hierarchy (at the communications handler, for example) would also be effective for all higher levels. Pouzin [PO75d] discusses some objectives of flow control and some alternative implementations.

2.4.4 Error Control -

While lower levels of an interface may adequately address the question of error detection and possibly even retransmission, somewhat higher levels may have to become involved with the detection of duplicate data occuring due to retransmissions after timeouts and reinitialization in the event of catastrophic failure. Message acknowledgement may also be implemented as part of an error control scheme, and in fact, error and flow control can be based on the same mechanisms.

3.0 CIRCUIT SWITCHED NETWORK TO PSN INTERCONNECTION

Packet switched networks commonly use the switched telephone network for local distribution to terminals. Switched connections are less frequently used between the nodes of a packet net. Integrated data networks designed for both message-oriented and continuous stream data may eliminate the need for interconnection.

3.1 Access

Circuit switched networks are commonly used today as a means of local access to packet switched networks. A local dial connection can readily be made between both simple terminals and packet-mode terminals (terminals that are capable of dealing in packets, including host computers) and the access node of the packet network. Modems at the terminal and the packet node permit the dial network to be used in this way.

The connection may be initiated by either the terminal or the packet node. Connection establishment from simple terminals is generally manual (the terminal operator dials the call). Connection establishment from a host computer may be manual or automatic (the computer itself can dial the call if equipped with an automatic calling unit). Connection establishment from a packet node would normally be automatic, as there is not generally an operator for such nodes.

3.2 Inter-node Links

The communications links between nodes in a packet switched network are generally provided by dedicated (point-to-point, unswitched) circuits. However, the switched network could be used as a means of providing backup or extra capacity, and could even be used instead of dedicated facilities. At least one network, MERIT, has taken this approach [BEC72], although even they concluded after some experience that point to point facilities would be more suitable. Use of the circuit-switched facility is accomplished through automatic calling units, the software for which "has proven to be much more complex than originally envisioned" [AU73].

3.3 Integrated Data Networks

This section on the interconnection of circuit switched networks and packet switched networks has been based on the premise that separate backbone networks of each type will exist due to the inherent suitability of each for a particular type of traffic. At the present time this appears to be true; however, attention is beginning to be directed to the design of "integrated" or hybrid data networks capable of efficiently transporting both voice (or real time data) and message traffic [COV75, DE76]. Discussion of the details and tradeoffs in the design of integrated data networks is beyond the scope of this Technical Note. However, it does seem evident that such networks will be built in the not too distant future. Obviously, providing a single network for both types of traffic would eliminate the necessity to interconnect two separate networks of different type.

4.0 STAR NET TO PSN INTERCONNECTION

A star network is one in which the computing resources are centralized at a single node. The canonical model is a timesharing system with a large number of user terminals connected through a possibly quite complex communications system. However complex the communications system, all terminals effectively have direct access to the central facility.

The existence of this central point of access for all users greatly facilitates the interconnection of such a network with distributed packet switching systems. The entire star network can be modelled as a multi-channel data terminal equipment (DTE) capable, with suitable interfaces, of operating in the packet mode. Thus, a star network can be interconnected with a packet switched network in the same way that an ordinary host computer is interfaced to the PSN.

There are a variety of ways to interface host computers to packet switched networks. One alternative is for the network itself to undertake to simulate some (array of) device(s) that the host already supports. Thus, some networks interface to hosts through multiple asynchronous low speed lines or through a single multiplexed synchronous line into the host's normal front end or communications controller.

The other alternative is to specify a new interface to which the host must conform and whose procedures the host must support. This was the approach taken in the ARPA network [HE70]. Based on experiences with this and other experimental systems, considerable work has been done towards standardizing the interface between multi-channel (sometimes called "multiaccess") user terminals and packet switched networks.

4.1 Emulating Known Devices

Perhaps the easiest approach to interfacing from the host point of view is for the network to undertake to emulate devices that the host (or host front end) already supports. There are two main categories under this approach:

1. The PSN can appear to the host as an array of low speed asynchronous terminals and interface through a number of terminal ports on the host or the host front end.

2. The PSN can appear to the host as a terminal network and interface through a multiplexed port on the host or the host front end (according to some protocol or multiplexing discipline that is already supported).

Essentially, the difference between these two categories is the difference between space division multiplexing (by separate ports) and time division multiplexing (through a single port).

Each of these categories has been implemented in Tymnet [TY71, BER72]. This is not surprising, since a commercial network would be expected to seek to minimize the implementation effort required on the part of (potential) customers. The primary advantage of this approach is precisely that it does not impose any new requirements on the host. By emulating known devices, the network can be employed interchangeably (or simultaneously) with those devices, and cutover is greatly facilitated.

The disadvantages of this approach is that only those facilities which were supported by the old interface will be usable with the new network. This may force the utilization of the PSN in an inefficient manner. For example, single asynchronous terminal access lines, and even protocols for multiplexed access lines, generally lack any provision for flow control. This might force the line to be used at a lower rate than possible, or alternately introduce the possibility of data loss. Another disadvantage is that a network supporting many different hosts with multiplexed interfaces might need to implement many different protocols for the various hosts. Unfortunately, the standardization of communications disciplines has not progressed to the point where all hosts can be supported with a single discipline. Even for interfaces employing multiple asynchronous ports, two different families of terminals (ASCII and EBCDIC) might need to be emulated for different hosts.

4.2 Special Host Interfaces

If changes to the host hardware and/or software are permitted, then more efficient interfaces can be devised which take full advantage of all network capabilities and services. The problem of designing an efficient host interface is not unlike that of designing an access method. Looking towards the network, the interface must provide for reliable data communications with the network device and must support a multiplexed link. Looking into the host, the interface must have the ability to accept and deliver messages from individual processes, either through appropriate operating system service routines or by its own.

In terms of the required control functions discussed earlier, we have just identified the error control and addressing function. In consequence of the finite capacity of both the host and (especially) the switch, the interface must also provide some form of flow control. In the absence of flow control, data would likely be lost at times due to overflow, or the data transfer rate across the interface would have to be limited to some low value. Even then there would be some finite probability for data loss.

4.3 Standard Host Interface -- X.25

At the beginning of the current four year CCITT study period, a Special Rapporteur was appointed within Study Group VII to deal with issues relating to packet switching and to prepare draft Recommendations in this area, if possible. The Rapporteur convened a number of international meetings over the past few years, and, with the active assistance of interested PTTs and RPOAs as well as national standards organizations from various countries, succeeded in producing a draft Recommendation X.25 which was adopted by the CCITT Plenary Assembly in the fall of 1976. This section will outline the details of the draft Recommendation. More detailed summaries may be found in [RY76, HO76].

4.3.1 Overview -

CCITT Recommendation X.25 is an international standard for the "interface between data terminal equipment and data circuit-termination equipment for terminals operating in the packet mode on public data networks." Simply stated, this interface is intended for use by host computers and other types of customer terminals which are intelligent enough to format data in the ways specified by the interface specification and to respond in the proper ways to the complex control signaling requirements of the interface. The interface is designed for multi-channel use; that is, it provides for communications with multiple independent user processes within a single user terminal (computer). It is expected that a simpler interface specification will be developed for single channel terminals (e.g., remote batch terminals or single user intelligent terminals).

The X.25 Recommendation is structured into three independent parts as follows:

Level 1 - the physical, electrical, functional, and procedural characteristics to establish, maintain and disconnect the physical link between the DTE and the DCE.

Level 2 - the link access procedure for data interchange across the link between the DTE and the DCE.

Level 3 - the packet format and control procedures for the exchange of packets containing control information and user data between the DTE and the DCE.

For Level 1, the X.25 Recommendation specifies the use of CCITT Recommendation X.21, a new general-purpose interface for synchronous operation on public data networks. For an interim period, the use of Recommendation X.21bis (essentially the same as EIA RS-232) is approved.

For Level 2, the X.25 Recommendation uses the principles and terminology of the High Level Data Link Control Procedure (HDLC) specified by the International Standards Organization (ISO). This is a bit-oriented line discipline suitable for use in a variety of environments. (It is expected that this level will be totally specified by reference to ISO standards once they are completed for HDLC).

For Level 3, the X.25 Recommendation specifies a set of packet formats and elements of procedure developed for this use by the various carrier organizations planning to offer public packet switching services. The type of service supported by the current X.25 Recommendation is the so-called "virtual circuit" service (as described in section 2.1.4.2), though other services such as "datagrams" (described in section 2.1.4.1) are identified as areas for future study.

4.3.1.1 Packet Size -

The current X.25 interface recommendation specifies that all user data shall be passed to the network in packets with a maximum data field length of 128 octets. Thus, no packet assembly/disassembly capability is assumed by the interface. (Networks supporting the X.25 recommendation are free to disassemble the 128 octet data fields into still smaller packets for internal switching, if this is required). The X.25 recommendation also permits Administrations to offer additional maximum data field lengths from the following list: 16, 32, 64, 256, 512, and 1024 octets, or exceptionally 255 octets. The maximum data field length applying to a given DTE is fixed at subscription time.

4.3.1.2 Addressing -

The current X.25 Recommendation specifies a multiplexed interface between the packet terminal and the network. Up to 4095 "logical channels" can be in operation simultaneously between the terminal and the network. Each of these channels identifies an independent data connection between a user process in the packet terminal and a user process or single access terminal elsewhere in the network.

Call Request packets are used during the call establishment phase to set up a virtual circuit between the originating and destination stations. The originating station selects the logical channel number that it will use to identify the virtual circuit and indicates the network address of the called DTE. Network addresses can be of variable length up to a maximum of eight octets. There are no standards in the X.25 Recommendation for network addresses; however, work is proceeding in other CCITT groups on a standard network numbering scheme.

Data packets sent during the data transfer phase will only be identified by the logical channel number. The network will associate the logical channel numbers at each end with the appropriate virtual circuit until Clear packets are exchanged to terminate the circuit.

4.3.1.3 Flow Control -

The flow control specified by the current X.25 Recommendation at the packet level applies during the data transfer phase for data and reset packets on each logical channel used for a switched or permanent virtual circuit. Transmission is controlled separately for each direction of each logical circuit and is based on authorizations from the receiver. Packets are numbered modulo 8 (or optionally modulo 128 when extended) for the purpose of flow control and positive/negative acknowledgements.

Three commands are provided for the purposes of flow control. A receive ready (RR) packet acknowledges sequenced packets up to some given number (modulo the appropriate base) and approves the sending of the next one in sequence. A receive not ready (RNR) packet temporarily disallows the transmission of further packets on a given logical channel. An acknowledgement for packets previously received can also be conveyed by the RNR packet. Finally, a reject (REJ) packet may be sent to request transmission or retransmission of sequenced data packets beginning from a given number. Note that all these commands are exchanged between the host and the packet network, and not end to end between subscribers. The ultimate effect of a command from the host to the network, however, might be to cause the network to issue a similar command to the source customer station.

4.3.2 Criticisms Of X.25 -

The X.25 Recommendation has been criticized on the basis that it is too complex, fails to support datagrams, and duplicates functions at several levels [PO76a,PO76b].

It is indeed true that the X.25 Recommendation is a complex specification, intended for implementation in a host computer or intelligent front end. For simpler, single access terminals (such as remote job entry terminals), a simpler interface, perhaps a subset of X.25 would be more appropriate. This subject has been raised in the appropriate standards bodies, and is expected to be addressed in the next study period.

It is also true that X.25 only supports virtual circuit service. Datagrams were left for further study by the designers of the Recommendation. Acceptance of the X.25 Recommendation does not rule out its extension or the development of an additional Recommendation to cater for datagrams. It is understood that the subject of Datagrams will also be addressed during the next study period.

The question of duplication of function is perhaps the most intriguing one. It may well be that in the zeal to identify independent levels that could be standardized separately, some duplication of function has been kept in the total Recommendation. If this is the case, experience with implementation and use of the interface should reveal the necessity for change. The Recommendation is recognized as likely to evolve somewhat during its early years of use.

4.3.3 Future Developments -

The area of packet network interface standards is still a very dynamic one, and Recommendation X.25 should not be viewed as the final word in the matter. In fact, a variety of developments can be foreseen in this area:

1. Adoption by ANSI - It is likely that ANSI will adopt the Recommendation as an American National Standard now that it has been adopted by CCITT. It is possible that modifications would be made prior to such adoption, but it does not now seem likely that significant modifications will be made.

2. Modification to X.25 - The details of X.25 will undoubtedly continue to be analyzed during the next four year CCITT study period, and modifications to the Recommendation will likely be proposed based on experience with its implementation and use.

3. Additions to X.25 - As distinct from "modifications" to the current version of the Recommendation, a number of study points are identified, for example, datagram service and access by character-mode terminals. It can be expected that these points will be addressed during the next study period, and that the Recommendation may be expanded or new Recommendations developed to address these points.

4. "Simplification" of X.25 - A simplified version of X.25, intended for use by single-access DTEs (e.g., RJE terminals with limited intelligence), can be expected to be developed within ANSI, if not within CCITT.

5.0 SIMPLE TERMINAL TO PSN INTERCONNECTION

"Simple" terminals are defined as those character-mode user terminals which do not contain the logic to format information into packets before transmission. Rather, information is transmitted asynchronously as it is entered. The canonical model of a simple terminal is a teletypwriter.

As Davies and Barber recognize [DA73], the problems relating to the connection of simple terminals fall into three main areas: 1) the basic physical connection, 2) the procedural interface for controlling the terminal, and 3) the interfaces between the user and remote computing services as well as with other users. The physical connection problem involves the hardware interface between the terminal and the network; the procedural interface covers the special signals and control information that has to be interchanged between the terminal and the network; the user interface involves network command languages, service command languages, user languages, and a variety of man-machine interaction considerations.

5.1 Requirements

Simple terminals lack any internal processing capability to format or disassemble packets, or to respond to any but the lowest level of communications control. In modern networks that are designed for process to process communications, a terminal handler must be provided somewhere as a surrogate process for the terminal. So far as the network is concerned, the terminal handler process, also referred to as "packet assembly/disassembly" (PAD), communicates in the same way as all other processes in the network (in conformance with whatever network protocols have been established). So far as the terminal is concerned, the terminal handler communicates with it in the character asynchronous mode.

5.1.1 Buffering -

The buffering function in support of simple terminals is primarily to provide for the conversion (in both directions) between character asynchronous and synchronous data. From the terminal to the network, the accumulation of input characters in a buffer permits packets to be assembled which contain more than a single character of data, thus greatly improving the efficiency of line utilization within the PSN (and probably lowering the customer's charges as well). From the network to the terminal, multicharacter packets must be held in a buffer while they are disassembled and delivered to the terminal one character at a time.

5.1.2 Flow Control -

As discussed previously, flow control includes mechanisms for throttling input so as to prevent the receiving device from overflowing and losing data. This is not a support function that customarily has been provided for simple terminals. (Sequencing has customarily been provided for such terminals). Flow control is, however, more critical in a networking environment, where device capacities are designed with average needs in mind, yet in which the peak to average ratios for resource demands may be quite high.

The flow control problem arises on input from simple terminals and on output to simple terminals where the data source is operating at a higher rate than the receiving terminal. In the latter case, the data source is normally a computer, so previously discussed flow control mechanisms can be applied. The problem, then, is principally one of throttling input <u>from</u> simple terminals.

The EBCDIC family of terminals is probably superior to the ASCII family in the ease of implementing flow control, since most EBCDIC terminals are built to respond to keyboard lock/unlock control sequences. Thus, on approaching overload, it is a relatively simple task for the terminal support device to temporarily lock the keyboard. Most terminal operators are sufficiently attuned to the characteristics of their keyboard to recognize at once what has been done.

ASCII family terminals, however, lack the lock/unlock facility. The most common approach for such terminals has been to ring the terminal's audible alarm (which is provided on most ASCII terminals) to indicate overflow. This has the disadvantage of occurring only <u>after</u> an overflow has occurred, and frequently leaves the operator confused as to which characters have been accepted and which not.

5.1.3 Signaling -

Signaling refers to the exchange between the terminal and the network of a variety of different control information necessary to establish, maintain and terminate calls. With intelligent devices, much of this control information is passed at lower levels in the interface, but the nature of simple terminals requires that it be conveyed at the highest level when they are used. In general, all signaling functions between simple terminals and the network have to be accomplished, with the operator's cooperation, by means of what characters are keyboarded and what characters are printed (or displayed).

Conventions need to be established for signaling service requests, such as the address of a destination station, or a request to disconnect. All this signaling normally occurs "in-band", when the terminal is recognized as authorized to transmit. One exception is the "break" key, provided on most simple terminals, which can interrupt network output to the terminal. Use of the audible alarm or "wiggling" the keyboard by successively locking and unlocking it could, in a sense, be considered as out-of-band signaling to the operator.

5.2 Additional Services

Additional services can be provided in support of simple terminals where logic in the supporting device is used to advantage. These services may be viewed as "value-added" services as discussed previously. When they are provided, they may be viewed as integral to the interface.

5.2.1 Speed Recognition -

A useful function for the terminal support or PAD device to provide is speed recognition for a variety of speeds on the same access line. Algorithms for speed recognition upon the input of a known initial character are well understood and have been in use for years. The advantage to users is that a single access line can be used by all terminals within the range of recognition. (This feature is most commonly used to identify terminals which may be operating at burst speeds of 10, 15 or 30 characters per second.)

Adequate buffering and flow control facilities in the PSN make it possible for terminals operating at different speeds to communicate directly with each other.

5.2.2 Code Conversion -

The code employed by a terminal may be viewed as one of the parameters describing that particular terminal; however, the significance of this parameter relative to all the others warrants individual discussion.

Unfortunately, not all terminals employ the same character set, even for the basic alphabetic and numeric characters, thus necessitating some translation capability in the terminal support device if a wide variety of terminals are to be supported. Fortunately, the great majority of simple terminals do fall into one of two main classes according to the character set employed: ASCII and EBCDIC. Thus, only one translator is generally required, since one of the two codes is generally "built into" the software of the terminal handler.

The particular code used by a terminal can be detected as in 5.2.1 to provide for automatic code conversion.

5.2.3 Special Terminal Parameters -

Even among terminals within the same character set family there may be individual differences that would interfere with interworking if not handled properly. Some examples of such differences are requirements for different timing delays and/or different requirements for the transmission of padding characters after such functions as carriage return or line feed. The wide variety of requirements in such areas among different terminals may require that tables be kept of the characteristics of various terminals or that each terminal user have the capability to change parameters from the initial set.

5.3 Alternatives

Given the above requirements for simple terminal support, there are two primary ways that a network can undertake to provide it. The network can finesse the problem by requiring all terminals to access through host computers which provide the support. If the network does provide support for direct access, it can be through a separate device specifically for this function, or by adding capability to the network switch. Each approach naturally has its own advantages and disadvantages.

5.3.1 Host Computer -

The simplest approach to terminal support on a network is not to provide any at all. Terminal users can be required to connect to a local host which provides all terminal support functions and access to the network. So far as the communications subnet is concerned, terminal traffic is no different from the intercomputer traffic it is designed to carry. This approach has been implemented in the MERIT network [BEC72].

The advantage of this approach is that it greatly simplifies design of the subnet. The primary disadvantage is that communications functions are forced on host computers that may be ill suited to perform them. Such functions as buffering characters from asynchronous terminals and performing speed and code conversion are better performed by specially designed communications processors rather than general purpose hosts. In addition, two computers must be employed (and paid for) whenever a terminal wishes to access a remote computer through the network. Even if terminal support at the local computer is provided by a front end processor, there is some reduction in the capacity of the local system that could be avoided if the terminals could be provided access directly to the network.

5.3.2 Intelligent Concentrator -

An alternative to the use of a general purpose host to provide terminal support and access to a network is to install a separate device exclusively for that function. Such a device could be called an intelligent concentrator, since it is generally based on a stored-program minicomputer and since its function is to concentrate the traffic from many individual terminals. As mentioned previously, this function has also been referred to as "packet assembly/disassembly", since the concentrator will generally communicate with the packet network according to the standard packet level interface (such as X.25, for example). Rosenthal [ROS76] has reviewed some advanced uses of minicomputer-based systems for the interconnection of terminals and networks.

5.3.3 Expanded Switch -

A final alternative configuration for providing terminal support and network access is to integrate the functions of an intelligent concentrator with a network switch. This is the approach that was taken in the development of the ARPA network TIP [OR72, MI73]. A TIP is an IMP (Interface Message Processor) expanded with the addition of a terminal multiplexer and code to support it. The code includes the minimal set of functions of a small host computer, since all communications in the ARPANET are between processes in host computers.

This integrated approach has the advantage of eliminating the need for separate devices just for terminal support. On the other hand, it greatly complicates the design of the switching node and results in a situation in which failure of the terminal support hardware or software may adversely impact the capability of the node to perform its switching function, and thus adversely impact the network as a whole.

5.4 Standards

A small number of sets of standards exist at the physical, electrical and logical level for the connection of simple terminals to packet switched networks. (Folts [FO76] reviews recent and planned developments in this area.)

At the procedural level, however, no widely accepted standard exists. The ARPA network developed one standard for use network wide which has been in use for over five years now [OR72, MI73]. Telenet, as the commercial sequel to the ARPA network, learned from that experience and developed a new standard for use within its network [TE75]. The CCITT is now planning to consider developing recommendations for the procedural level of the interface between simple terminals and packet switched networks. One proposal has already been developed by the CEPT group [CEP76].

6.0 PSN TO PSN INTERCONNECTION

The packet switched networks that have already been built or that are currently under construction all differ quite considerably in the internal details of their implementation. Consequently, it does not appear possible, even if it were desirable, to effect interconnection through standardization of internal operation. However, as with the attachment of multi-channel DTEs to PSNs (discussed in Chapter 4), interconnection can be effected through standardization of a common interface. For network to network interconnection, such an interface is called a gateway.

6.1 Gateway Functions

The primary function of a gateway is to resolve differences between the two interconnected networks in such a way as to permit meaningful communications between users on each of the networks. For packet networks, Cerf and Kahn [CER74a] have identified the major differences between networks that must be resolved:

1. Each network may have distinct ways of addressing the receiver of a message.

2. Each network may accept data and employ internal transmission blocks of different maximum size.

3. The success or failure of a transmission and its performance in each network is governed by different time delays in accepting, delivering and transporting the data.

4. Recovery procedures for lost or altered data may differ between networks.

5. Status information, routing, fault detection and isolation are typically different in each network.

6.1.1 Packet Size -

Differences in packet size is one of the first obstacles with which a global strategy for network interconnection must deal. The problem is basically one of coping with the fragmentation that must inevitably occur when the two interconnected networks employ different internal maximum packet sizes.

Maximum packet sizes are selected by different networks for maximum internal operating efficiency in consideration of the implementational details of the particular network. Such factors as propagation delay and anticipated frequency and distribution of errors go into the analysis. The optimal values for different networks may differ widely, especially between systems which use terrestrial links exclusively and those which use satellite links.

Some systems also require user terminals to enter all data in terms of packets, while other systems can accept data in longer blocks and provide packet disassembly/assembly functions.* An interconnection strategy must make minimal demands on the design of the internal operation of the networks.

6.1.2 Addressing -

Addressing across network boundaries requires either a standard network numbering scheme or a means of address translation in the gateway. For public networks, a standard numbering scheme seems likely, given the success of this approach in the public circuit-switched (telephone) network. Such a project is currently underway in CCITT.

6.1.3 Flow Control -

Flow control is necessary across network boundaries even more strongly than between host computer and a network. The interface between two networks is ultimately between their switching nodes, each of which has limited capacity. Flow control also provides each network with a mechanism for protecting itself from disorderly operation on the part of the other. If not performed by the error control mechanisms between the networks, means must be provided for the detection of duplicate and missing packets. Flow control may be accomplished in ways similar to that employed for host to network interfaces.

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* Note that there is a dual use of the term "packet" in many references. The same term is frequently used to refer to the block of user data entered into the network as is used for the transmission block sent between nodes within the network. The two need not be the same.

6.2 Gateway Alternatives

There are a variety of different ways in which the gateway between two packet switched networks may be implemented. In the following sections, we review the major alternatives.

6.2.1 Common Host -

One of the simplest and most straight forward approaches to interconnecting two networks is to do it through a host that is attached to each network. Under this approach, the individual subnetworks do not even have to be aware that they are interconnected. All messages which need to be sent from one network to the other are simply transmitted to a special process in the gateway host which then retransmits them into the other network. The host is responsible for any reformatting and signaling conversion that may be necessary between networks.

Because of the relative ease of implementing this approach (especially if the host were already connected to each network, and it is only the interconnection procedure that needs to be developed), it has been a quite popular way of interconnecting networks. As the most intelligent component in the network, hosts are certainly capable of performing whatever translations are necessary. However, this does involve the host in communications processing, with its high overhead, and so may not be a suitable long term solution to the problem. General purpose computers are generally not the most cost-effective means of accomplishing communications processing, and few hosts could justify performing this function except in experimental or limited volume situations.

6.2.2 Common Switching Node -

Another approach to interconnecting packet networks would be to have a switching node which is common to each of them. Kirstein and Lloyd [KI75] argue that this is the most complex method to implement, since it involves implementing in the same device all the switching capabilities of each network as well as the mappings from each low-level protocol to the other. If the networks are very different, these mappings could be quite difficult (and even more difficult than mapping at higher levels).

6.2.3 Internode Device -

The final possible approach, and also a very popular one up to the present, is to provide a separate device performing only gateway functions between each of the networks to be interconnected. This gateway is generally designed to appear as a special host to each of the networks (rather than seeking to perform the gateway functions at the subnet level). By interconnecting at the host level, the "sovereignty" of each of the networks involved is preserved [WA75]. Under this approach, the gateway will not seek to convert between the host-to-host protocols of the two networks (which Walden and Rettberg believe would be impossible), but will communicate with each network in the lowest form of host/network protocol supported by the network. Experiments with such a gateway are currently being performed [HIG75].

As Cerf and Kahn [CER74a] recognize, in practice a gateway between two networks may be composed of two halves, each associated with its own network. Each half-gateway would only be responsible for translating between the internal packet format of its own network and some common internetwork format. The internetwork format and signaling conventions for internetwork data exchange could be standardized in much the same way that the host to network interface is standardized.

6.3 Gateway Standards

While international recommendations have not yet been developed for completely specifying the means of interworking between public packet switching networks, the approach to be taken for interconnection is clear. The "two half-gateway" model will be followed, with each network free to deal with the required translations in whatever way it chooses. The international recommendations will specify the nature of the interface between the networks, without making any statements about functions performed in the nodes that are interconnected. It seems likely that the circuit will be specified to be high speed, full duplex, and that low level signaling will be according to X.21 and data transport will be according to a procedure from HDLC. A new set of internetwork packets will be defined for signaling and data exchange between networks, similar to those specified in X.25. Roberts [ROB76] also suggests a few optional features that would be desirable in X.25 for internetting (though he stresses that these features would also be desirable for the host interface):

1. Extended numbering at the link level, to permit a larger number of unacknowledged packets to be outstanding (particularly important for long delay channels such as satellite links);

2. Extended numbering at the packet level or variable packet size per call, addressing the same problem as #1, but at the packet level;

3. Accounting information on call setup and clearing packets, in order to permit international tariffs to be established.

Common host-to-host protocols are essential to do anything useful after networks are interconnected. While at least one candidate for a standard host-to-host protocol has been suggested [CER74a], the widespread adoption of any such standard does not appear imminent. On the other hand, there are a number of interconnection experiments currently in progress [GI75] that may lead to a better understanding of the way in which an acceptable standard should be structured.

7.0 BARRIERS TO INTERCONNECTION

There are a number of barriers that have to be overcome in order to interconnect two networks successfully. Technical problems must be overcome so that data exchange and control signaling can be performed efficiently and reliably between the two systems. Solving the technical problems may be sufficient for an experimental system. Interconnecting for commercial purposes raises additional problems of a legal and regulatory nature.

7.1 Technical Barriers

The primary technical barriers to network interconnection have been identified in the previous four chapters for each type of interconnection discussed. In the following sections, we summarize the situation and prospects for advances in the major technical areas. Before doing so, however, it is appropriate to comment on the role of standards in overcoming technical barriers.

7.1.1 Standards -

The development of any particular standard or group of standards in a particular area can assume one of two primary roles:

(1) Development of the standard can serve to codify existing practice; or

(2) The standard can pace innovation in the field by providing for compatibility in advance of implementation, or where implementations are not yet frozen.

The second role, that of standardizing in advance of implementation, is somewhat riskier, but the payoff is potentially much greater in terms of the benefits that may be gained. Such an approach is frequently criticized on the grounds that it may stifle, rather than simply pace, innovation. This argument can only be answered when the alternatives are well understood.

With respect to packet network interface standards, it has been argued that "any" standard will do. This may be an extreme position, but with logic so cheap and getting still cheaper, there is also some validity to this view. There are strong benefits to be gained from standards in this area, and the extra cost or effort to modify a suboptimal standard later may not be very significant.

7.1.2 Host Interface -

It has been suggested that the intense technical debates of the past few years has resulted in "a remarkable unanimity regarding the basic structure of a standard method for accessing data communication networks" (i.e., a standard host interface) [SA76]. An essential similarity, from the "logical structure point of view", is noted for IBM's system network architecture (SNA), the CCITT X.25 Recommendation, and protocols recently announced by Digital Equipment Corporation, Burroughs, Honeywell, and others. Based on this similarity, it is argued that there is "little technical justification for each of the manufacturers to support network access protocols which differ only in details."

Lack of technical justification notwithstanding, it is not clear when, and indeed if, the various proprietary access protocols will be abandoned in favor of a common standard. The lack of manufacturer support (in the real sense of software maintenance) for a common access protocol may be a serious barrier to network growth.

7.1.3 Application Level Protocols -

Application level protocols for use in a network environment have not been seriously addressed by any formal standards group. This appears likely to change as work is completed on lower level issues. However, the lack of suitable protocols at the application level will continue to be a barrier for the near future. For this reason, most network utilization will tend to be terminal-to-host or among private subgroups with homogeneous hosts.

7.1.3.1 User To User Protocols -

Standard end-to-end protocols have been nearly universally identified as a critical factor in accomplishing useful tasks in a computer networks [CER74a, CER74b, COT75, KI75, MCK74, PO75a, PO74]. Unfortunately, this is a problem that has plagued computing since the first few machines were built with different architectures. The gleam of hope in the networking environment is that networks may provide the means as well as the incentives for developing portable and/or standard software and means of representing data.

A great deal of knowledge has been gained from such experimental networks as the Arpanet about ways of standardizing information interchange between dissimilar systems [CR72]. It remains to build upon this basic knowledge to design commercially acceptable systems and standards for today's and tomorrow's public data networks.

Johnson, in a projection on the future roles for packet switching networks [JO76], suggests that "it is reasonable to hope that the 1980 session of the CCITT will be able to agree on standards for process-to-process communication between host computers using a network up to quite a high level." However, he feels that "even these standards will have to allow a great deal of choice and flexibility," and that "it is doubtful if process-to-process communications between differing systems will ever be a straightforward matter."

7.1.3.2 Simple-Terminal Access -

While host systems differ more widely than do simple terminals, it was possible to employ their built-in intelligence to conform to a given interface standard. This is not directly possible with unintelligent simple terminals. There are at least two major families of asynchronous terminals and a number of families of synchronous terminals all of which are unable to directly communicate across family boundaries. It appears that a major function of public networks will be to cater for these different terminals to allow them to intercommunicate. This will unfortunately necessitate the support of a number of different interfaces by the network switch or surrogate device for terminal handling.

At the highest procedural level of signaling according to what characters are typed, it does seem feasible to standardize. Work along this line has been identified and is continuing.

As the cost of logic continues to decline, it may become feasible at some point to devise a simple and inexpensive black box to convert lower level terminal interface functions to a standard. Present approaches of accomplishing this conversion in switch or terminal support software does not appear suitable for commercial use.

7.1.4 Gateways -

The lack of a recognized international standard for a gateway between public packet networks cannot presently be cited as a major obstacle to the interconnection of such networks, given the early stage of developments and small number of networks. However, if development of an international standard is prolonged beyond the point when the networks <u>are</u> ready to interconnect, then the prospect of the standard being completed might delay that interconnection. Administrations might be reluctant to interconnect according to bilateral standards knowing that international standards afterwards might obsolete their own design.

7.2 Non-Technical Barriers

It may well be that the most severe barriers to network interconnection are of a political/legal nature rather than of a technological nature. There are, as section 1.3 indicated, a number of quite different vested interests that are affected in various ways by the prospect and reality of interconnection. An extensive discussion of all the political/legal issues is beyond the scope of this technical note; we can do no more than illustrate some of the problems in order to impart an appreciation for this type of barrier.

7.2.1 National Barriers -

The prospects for the interconnection of U. S. domestic networks are influenced both by competitive considerations and the regulatory policies of the FCC. In the latter case, the policy has been to encourage, and in some cases require, networks to provide interconnections requested by other networks. This is most commonly the case when a specialized or packet-switched network wishes to use the telephone system for local delivery. In many cases AT&T has been quite reluctant to provide such inteconnection until required by the FCC.

The situation may be somewhat different for two value-added networks with roughly the same geographic coverage. These networks may both not wish to interconnect due to competitive considerations, though it may be in the public interest for such interconnection to be available for customer use. It remains to be seen how this question will be resolved.

7.2.2 International Barriers -

Interconnection of networks across national boundaries requires (minimally) bilateral agreements between the nations concerned. Such agreements are generally entered into quite cautiously, and the services to be offered are generally limited to those that are available intranationally in both countries. Multilateral agreements are even more difficult to obtain than bilateral agreements, though they may be necessary for effectively coordinating international networks.

7.3 Mixed Barriers

A number of barriers to interconnection cannot easily be classified as totally technical or totally non-technical. Such questions as internetwork accounting and the security provisions to be included in public networks might be classed as "mixed" barriers to interconnection. Kuo [KU74] identifies some of the major issues that must be addressed to overcome these barriers.

8.0 CONCLUSIONS

It is possible now to interconnect widely dispersed data processing systems and terminals through public networks. It will soon be possible to do this in a standardized way. Access to systems in Canada seems assured within the near future; access to systems in Europe and possibly Japan can also be expected. It has been forecast that by 1980, international and intercontinental links between networks will be routine, and most major computer users in industralized countries will have reasonably easy access to a worldwide communications utility [JO76].

8.1 Standards Development

The development of effective standards for data network interconnection may continue to be hampered by the large number of organizations participating. Coordination between all of these groups is not always as good as it might be, and the lines dividing areas of responsibility are not always clearly drawn. The dangers in such a situation are that so many non-standard and incompatible systems will be constructed that adoption of an eventual standard would be difficult and costly; or that a single-company standard would be imposed on the industry through market power rather than technical merit.

Fortunately, it appears that both of these dangers can be avoided for data network interconnection, since the pace of activity in the formal standards bodies is quickening. Consensus has been reached for the first stage of X.25, and work is in progress on extensions. The significance of this development is likely to be far reaching:

> "Before 1976 it was commonly assumed that each country's packet network would be significantly different from all others... However, now that CCITT

has agreed on a standard interface protocol, X.25, this potential nightmare is firmly behind us. Perhaps more than users realize, the adoption of a standard network access protocol constrains not only this interface, but also the entire range of network services... The result will undoubtedly (and fortunately) be a remarkable degree of similarity of both structure and services between the packet networks evolving throughout the world." [RO76]

8.2 Use Of Service

The availability of standardized service from public networks will obviate the need for many current private data networks. In the U.S. at least, the computer network environment promises to be a very competitive one. Some degree of competition already exists for providing the communications service nationally, and other companies have indicated their intention to enter that market. With respect to the data processing services offered through networks, a major effect of the network is to increase the scope of competition. Through networks, data processing service vendors can compete for clients nationally and internationally. The effect of network interconnection is to widen the scope of this competition even more.

The benefits to customers from widened competition are (1) an increased range of alternatives from which to choose in solving their problems, and (2) reduced price and/or improved service resulting from competition in either of these areas. On the other hand, the availability of additional alternatives may make the users' task of selection more difficult. Frisch [FR75] sees a "potential for disaster" when users try to configure the best network to meet requirements. Still, the problems arising from an abundance of alternatives seem preferable to problems arising from a paucity of them.

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ASYNCHRONOUS TRANSMISSION - Transmission in which time intervals between transmitted characters may be of unequal length. Transmission is controlled by start and stop elements at the beginning and end of each character.

BLOCK - A group of characters or digits transmitted as a unit, over which a coding procedure is usually applied for synchronization or error control purposes. Syn: FRAME, TRANSMISSION BLOCK. See also: PACKET.

CENTRALIZED (COMPUTER) NETWORK - A computer network configuration in which a central node provides computing power, control, or other services.

CHANNEL - (1) That part of a communications system that connects a message source to a message sink. (2) A means of one way transmission.

CIRCUIT - In communications, the complete electrical path providing one or two way communication between two points comprising associated send and receive channels.

CIRCUIT SWITCHING - A method of communications, where an electrical connection between calling and called stations is established on demand for the exclusive use of the circuit until the connection is released.

COMMON CARRIER - In telecommunications, a public utility company that is recognized by an appropriate regulatory agency as having the authority and responsibility to furnish communication services to the general public.

COMMUNICATIONS COMPUTER - A computer that acts as the interface between another computer or terminal and a network, or a computer controlling data flow in a network.

COMPUTER NETWORK - An interconnection of assemblies of computer systems, terminals and communications facilities.

CONTROL PROCEDURE - The means used to control the orderly communication of information between STATIONS on a DATA LINK. Syn: LINE DISCIPLINE. See also: PROTOCOL.

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* See also [NE74a].

DATA COMMUNICATION - The interchange of data messages from one point to another over communications channels.

DATA COMMUNICATION EQUIPMENT - The equipment that provides the functions required to establish, maintain and terminate a connection, the signal conversion, and coding required for communications between DATA TERMINAL EQUIPMENT and data CIRCUIT. The DCE may or may not be an integral part of the DTE or of a computer, e.g., a MODEM. Abbr: DCE.

DATA LINK - An assembly of terminal installations and the interconnecting circuits operating according to a particular method that permits information to be exchanged between terminal installations. Note: the method of operation is defined by particular transmission codes, transmission modes, direction and control.

DATA TERMINAL EQUIPMENT - (1) The equipment comprising the data source, the data sink, or both. (2) Equipment usually comprising the following functional units: control logic, buffer store, and one or more input or output devices or computers. It may also contain error control, synchronization, and station identification capability. Abbr: DTE.

DATA TRANSMISSION - The sending of data from one place for reception elsewhere.

DECENTRALIZED (COMPUTER) NETWORK - A computer network, where some of the network control functions are distributed over several network nodes.

DISTRIBUTED NETWORK - A network configuration in which all node pairs are connected either directly, or through redundant paths through intermediate nodes.

FULL DUPLEX OPERATION - Two way simultaneous operation.

GATEWAY - An interface device between two networks.

HALF DUPLEX OPERATION - Two way alternate operation.

HOST COMPUTER - A computer attached to a network providing primarily services such as computation, data base access or special programs and programming languages. Compare: COMMUNICATIONS COMPUTER.

IDENTIFICATION - (1) The process of providing personal, equipment or organizational characteristics or codes to gain access to computer programs, processes, files or data. (2) The process of determining personal, equipment, or organizational characteristics or codes to permit access to computer programs, processes, files or data.

INFORMATION PATH - The functional route by which information is transferred in a one-way direction from a single data source to a single data sink.

INFORMATION (TRANSFER) CHANNEL - (1) The functional connection between the source and the sink data terminal equipments. It includes the circuit and the associated data communications equipments. (2) The assembly of data communication equipment and circuits including a backward channel if it exists.

INTERFACE - (1) A shared boundary defined by common physical interconnection characteristics, signal characteristics, and meanings of interchanged signals. (2) A device or equipment making possible interoperation between two systems, e.g., a hardware component or common storage register. (3) A shared logical boundary between two software components.

LINK - The logical association of two or more data communications stations interconnected by the same data communications circuit for the purpose of transmitting and receiving data using prescribed data communication control procedures.

MESSAGE SWITCHING - A method of handling messages over communications networks. The entire message is transmitted to an intermediate point (i.e., a switching computer), stored for a period of time, and then transmitted again towards its destination. The destination of each message is indicated by an address integral to the message.

MODEM - Modulator-demodulator. A device that modulates and demodulates digital signals so that they may be transmitted over an analog transmission medium. Syn: Data Set.

NETWORK CONTROL PROGRAM - That module of an operating system in a host computer which establishes and breaks logical connections, communicating with the network on one side and with user processes within the host computer on the other. Abbr: NCP.

NODE - (1) An end point of any branch of a network, or a junction common to two or more branches of a network. (2) Any station, terminal, terminal installation, communications computer, or communications computer installation in a computer network.

ONE-WAY ONLY OPERATION - A mode of operation of a data link in which data are transmitted in a preassigned direction over one channel. Syn: Simplex Operation.

PACKET - A group of binary digits including data and control elements which is switched and transmitted as a composite whole. The data and control elements and possibly control information are arranged in a specified format.

PACKET SWITCHING - A data transmission process, utilizing addressed packets, whereby a channel is occupied only for the duration of transmission of the packet. Note: In certain data communication networks, the data may be formatted into a packet or divided and then formatted into a number of packets (either by the data terminal equipment or by equipment within the network) for transmission and multiplexing purposes.

PROCESS - (1) A systematic sequence of operations to produce a specified result. (2) A set of related procedures and data undergoing execution and manipulation by one or more computer processing units.

PROTOCOL - A formal set of conventions governing the format and relative timing of message exchange between two communicating processes.

SIMPLEX OPERATION - (1) Two way alternate operation. (2) One way only operation.

SINK - (1) The point of usage of data in a network. (2) A data terminal installation that receives and processes data from a connected channel.

SOURCE - (1) The point of entry of data into a network. (2) A data terminal installation that enters data into a connected channel.

STAR NETWORK - A computer network with peripheral nodes all connected to one or more computers at a centrally located facility.

STATION - That independently-controllable configuration of data terminal equipment from or to which messages are transmitted on a data link. It includes those elements which serve as sources or sinks for the messages, as well as those elements which control the message flow on the link by means of data communication control procedures.

STORE AND FORWARD - Pertaining to communications where a message is received, stored and forwarded (as in message and packet switching).

SYNCHRONOUS TRANSMISSION - A transmission process such that between any two significant instants there is always an integral number of unit intervals.

TARIFF - (1) A published rate for services provided by a regulated communications carrier. (2) The means by which regulatory agencies approve communications services. The tariff is part of the contract between customer and carrier.

TERMINAL - (1) A point in a communications network at which data can either enter or leave. (2) A device that permits data entry into or data exit from a computer system or computer network.

TERMINAL INSTALLATION - (1) The totality of equipment at a user's installation, including data terminal equipment, data communication equipment, and necessary support facilities. (2) A set composed of a data terminal, a signal converter, a possibly intermediate equipment; this set may be connected to a data processing machine or may be part of it.

TRANSPARENCY - A property of a communications medium to pass within specified limits a range of signals having one or more defined properties, e.g., a channel may be code transparent, or an equipment may be bit pattern transparent.

TWO WAY ALTERNATE OPERATION - A mode of operation of a data link in which data may be transmitted in both directions, one way at a time (but not simultaneously). Syn: Half-Duplex Operation.

TWO WAY SIMULTANEOUS OPERATION - A mode of operation of a data link in which data may be transmitted simultaneously in both directions over two channels. Note: one of the channels is equipped for transmission in one direction while the other is equipped for transmission in the opposite direction.

VALUE-ADDED SERVICE - A communications service utilizing communications common carrier networks for transmission and providing added data services with separate additional equipment. Such added service features may be store and forward message switching, terminal interfacing, and host interfacing.

LIST OF ABBREVIATIONS

ADCCP - Advanced Data Communications Control Procedure

ANSI - American National Standards Institute

ARPA - Advanced Research Projects Agency (U. S. Department of Defense)

ASCII - American Standard Code for Information Interchange

AT&T - American Telephone and Telegraph Company

CCITT - Consultative Committee on International Telegraph and Telephone

CEPT - European Conference of Postal and Telecommunications Administrations

DCE - Data Communications Equipment

DEC - Digital Equipment Corporation

DTE - Data Terminal Equipment

EBCDIC - Extended Binary Coded Decimal Interchange Code

EIA - Electronic Industries Association

FCC - Federal Communications Commission

HDLC - High-level Data Link Control [Procedure]

IBM - International Business Machines Corporation

IMP - Interface Message Processor

ISO - International Standards Organization

ITT - International Telephone and Telegraph Corporation

ITU - International Telecommunications Union

MCI - Microwave Communications, Inc.

MERIT - Michigan Educational Research Information Triad

NBS - National Bureau of Standards

NCS - National Communications System

NCP - Network Control Program

PAD - Packet Assembly/Disassembly

PCI - Packet Communications, Inc.

PSN - Packet Switched Network

PTT - Postal, Telephone and Telegraph [Authority]

RJE - Remote Job Entry

RPOA - Recognized Public Operating Agency

SDLC - Synchronous Data Link Control [Procedure]

SNA - Systems Network Architecture

TIP - Terminal Interface [Message] Processor

VAN - Value-Added Network

WUI - Western Union International

APPENDIX

EXISTING DATA COMMUNICATIONS STANDARDS AND RECOMMENDATIONS

International Standards (ISO)

International Recommendations (CCITT)

American National Standards (ANSI)

Electronic Industry Association Standards (EIA)

Federal Information Processing Standards (NBS)

Federal Telecommunications Standards (NCS)

ISO 646--1973	7-Bit Coded Character Set for Information Processing Interchange [cf. CCITT V.3, ANSI X3.4]
ISO 1155--1969	The use of Longitudinal Parity to Detect Errors in Information Messages
ISO 1177--1970	Character Structure for Start/Stop and Synchronous Transmission
ISO 1745--1975	Basic Mode Control Procedures for Data Communication Systems
ISO 2022--1973	Code Extension Techniques for Use With the ISO 7-Bit Coded Character Set
ISO 2110--1972	Data Communication-Data Terminal and Data Communication Equipment Interchange Circuits -- Assignment of Connector Pins
ISO 2111--1972	Data Communications-Basic Mode Control Procedures -- Code-Independent Information Transfer
ISO 2375--1974	Data Processing -- Procedure for Registration of Escape Sequences
ISO 2593--1973	Connector Pin Allocations for the High Speed Data Terminal EQuipment
ISO 2628--1973	Basic Mode Control Procedures--Complements
ISO 2629--1973	Basic Mode Control Procedures --Conversational Information Message Transfer
ISO 3309--1976	Data Communications -- High Level Data Link Control -- Frame Structure
ISO DP 4335	High Level Data Link Control Procedures (Proposed Draft International Standard) -- Elements of Procedure (Independent Numbering)

INTERNATIONAL RECOMMENDATIONS (CCITT)

Series V Recommendations

(Data Transmission Over Telephone or Telex Networks)

V.1	Equivalence between binary notation symbols and the significant conditions of a two-condition code.
V.2	Power levels for data transmission over telephone lines.
V.3	International alphabet number 5.
V.4	General structure of signals of International alphabet number 5.
V.10	Use of the telex network for data transmission at the modulation rate of 50 bauds.
V.11	Automatic calling and/or answering on the telex network.
V.13	Answer-back unit simulators.
V.15	Use of acoustic couplers for data transmission.
V.21	200-baud modem standardized for use in the general switched network.
V.22	Standardization of data-signaling rates for synchronous data transmission in the general switched telephone network.
V.22bis	Standardization of data signaling rates for synchronous data transmission on leased telephone circuits.
V.23	600/1200-baud modem standardized for use in the general switched telephone networks.
V.24	List of definitions for interchange circuits between data terminal equipment and data circuit terminating equipment.
V.25	Automatic calling and/or answering on the general switched telephone network including disabling of echo-suppresors on manually established calls.

V.26	2400 bits per second modem standardized for use on four-wire leased circuits.
V.26bis	2400/1200 bits per second modem standardized for use in the general switched telephone network.
V.27	4800 bits per second modem standardized for use on leased circuits.
V.28	Electrical characteristics for unbalanced double-current interchange circuits.
V.30	Parallel data transmission modems standardized for universal use in the general switched telephone network.
V.31	Electrical characteristics for single current interchange circuits controlled by contact closure.
V.35	Data transmission at 48 kilobit per second using 60 to 108 kHz group band circuits.
V.40	Error indication with electromechanical equipment.
V.41	Code-independent error control system.
V.50	Standard limits for transmission quality of data transmission.
V.51	Organization of the maintenance of international telephone-type circuits used for data transmission.
V.52	Characteristics of distortion and error rate measuring apparatus for data transmission.
V.53	Limits for the maintenance of telephone-type circuits used for data transmission.
V.56	Comparative tests of modems for use over telephone-type circuits.
V.57	Comprehensive data test set for high data signaling rates.

Series X Recommendations

(Data Transmission Over Public Data Networks)

Section 1: Services and Facilities

X.1 User classes of service for public data networks.

X.2 Recommended user facilities available in public data networks.

Section 2: Data Terminal Equipment and Interfaces

X.20 Interface between data terminal equipment and data circuit terminating equipment for start-stop services in user classes 1 and 2 on public data networks.

X.21 Interfaces between data terminal equipment and data circuit terminating for synchronous operation on public data networks.

X.24 List of definitions for interchange circuits between data terminal equipment and data circuit terminating equipment on public data networks.

X.25 Interface between data terminal equipment and data circuit terminating equipment for terminals operating in the packet mode on public data networks.

X.30 Standardization of basic model page-printing machine in accordance with International Alphabet No. 5.

X.31 Characteristics, from the transmission point of view, at the interchange point between data terminal equipment and data circuit terminating equipment when a 200-baud start-stop data terminal equipment with International Alphabet No. 5 is used.

X.32 Answer-back units for 200 bauds start-stop machines in accordance with International Alphabet No. 5.

X.33	Standardization of international text for the measurement of the margin of start-stop machines in accordance with International Alphabet No. 5.

Section 3: Transmission, Signaling and Switching

X.40	Standardization of frequency shift modulated transmission systems for the provision of telegraph and data channels by frequency division of a primary group.
X.50	Fundamental parameters of a multiplexing scheme for the international interface between synchronous data networks.
X.70	Terminal and transit control signaling system for start-stop services on international circuits between anisochronous data networks.

Section 4: Network Parameters

X.92	Hypothetical reference connection for packet switched data transmission services.
X.95	Network parameters in public data networks.
X.96	Call progress signals in public data networks. services on international circuits between anisochronous data networks.

Section 5: Charging Methods and Accounting

AMERICAN NATIONAL STANDARDS (ANSI)

X3.1--1969	Synchronous signaling rates for Data Transmission
X3.4--1968	American Standard Code for Information Interchange
X3.15--1966	Bit Sequencing of the American National Standard Code for Information Interchange in Serial-by-Bit Data Transmission
X3.16--1966	Character Structure and Character Parity Sense for Serial-by-Bit Data Communications in the American National Standard Code for Information Interchange
X3.24--1968	Signal Quality at Interface between Data Processing Equipment and Synchronous Data Communications Equipment for Serial Data Transmission (EIA RS-334)
X3.25--1968	Character Structure and Character Parity Sense for Parallel-by-Bit Data Communication in the American National Standard Code for Information Interchange
X3.28--1975	Procedures for the Use of the Communication Control Characters of the American National Standard Code for Information Interchange in Specified Data Communication Links
X3.32--1973	Graphics for the Control Codes of ASCII
X3.36--1975	High Speed Synchronous Data Signaling Rates
X3.41--1974	Code Extension Techniques for Use With ASCII
X3.44--1974	Determination of Performance of Data Communications Systems
X3.57--*	Message Heading Formats for Information Interchange Using the ASCII for Data Communication System Control
X3.__--*	General Purpose Interface Between Data Terminal Equipment and Data Circuit Terminating Equipment for Synchronous Operation on Public Data Networks

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* Currently out for ballot.

ELECTRONIC INDUSTRY ASSOCIATION STANDARDS (EIA)

RS232C	Interface between Data Terminal Equipment and Data Communications Equipment Employing Serial Binary Data Interchange
RS334	Signal Quality at Interface between Data Terminal Equipment and Synchronous Data Communications Equipment for Serial Data Transmission
RS366	Interface between Data Terminal Equipment and Automatic Calling Equipment for Data Communications
RS422	Electrical Characteristics of Balanced Voltage Digital Interface Circuits
RS423	Electrical Characteristics of Unbalanced Voltage Digital Interface Circuits

Under Development

RS-ABC	General Purpose Interface Between Data Terminal Equipment and Data Circuit Terminating Equipment for Operation on Analog Public Data Networks
RS-XYZ	Transitional Interface Between Data Terminal Eqiupment and Data Circuit Terminating Eqiupment for Operation on Analog Public Data Networks

FIPS PUB 1	Code for Information Interchange (ANSI X3.4, ISO 646)
FIPS PUB 16	Bit Sequencing of the Code for Information Interchange in Serial by Bit Data Transmission (ANSI X3.14)
FIPS PUB 17	Character Structure and Character Parity Sense for Serial-by-Bit Data Communication in the Code for Information Interchange (ANSI X3.16)
FIPS PUB 18	Character Structure and Character Parity Sense for Parallel-by-Bit Data Communications in the Code for Information Interchange (ANSI X3.25)
FIPS PUB 22	Synchronous Signaling Rates Between Data Terminal and Data Communication Equipment (ANSI X3.1)
FIPS PUB 35	Code Extension Techniques in 7 or 8 bits (ANSI X3.41)
FIPS PUB 36	Graphic Representation of the Control Characters of ASCII (ANSI X3.32)
FIPS PUB 37	Synchronous High Speed Data Signaling Rates Between Data Terminal Equipment and Data Communications Equipment (ANSI X3.36)

FEDERAL TELECOMMUNICATIONS STANDARDS (NCS)

Published Standards

1001 - Synchronous High Speed Signaling Rates Between DTE and DTE (June 1975)

1002 - Time and Frequency Reference Information in Telecommunication Systems (April 1974)

1020 - Electrical Characteristics of the Balanced Voltage Digital Interface (September 1975)

1030 - Electrical Characteristics of the Unbalanced Voltage Digital Interface (September 1975)

Proposed Standards

1003 - Data Link Control Procedures

1004 - Message Formats

1029 - General Purpose Interface Between Data Terminal Equipment and Data Circuit Terminating Equipment for Operation on Analog Telecommunication Networks

1031 - Functional and Mechanical Characteristics of Digital Interface Circuits

1032 - Signal Quality for Digital Interface Circuits

1033 - Standard Performance Criteria for Assessment of Telecommunication Systems Supporting Federal Information Processing Systems

1037 - Glossary of Essential Telecommunication Terms and Definitions

1040 - General Purpose Interface Between Data Terminal Equipment and Data Circuit Terminating Equipment for Synchronous Operation on Digital Telecommunication Networks

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

This report examines the current situation regarding the interconnection of computer networks, especially packet switched networks (PSNs). The emphasis is on identifying the barriers to interconnection and on surveying approaches to a solution, rather than recommending any single course of action.

Sufficient organizational and technical background is presented to permit an understanding and appreciation of the problem. Four major types of interconnections are then surveyed: (1) Circuit Switched Network to PSN, (2) Star Network to PSN, (3) Simple Terminal to PSN, and (4) PSN to PSN. The major barriers to interconnection, both political/legal and technical, are then outlined. The report concludes with some comments on the prospects for overcoming these barriers.

An extensive bibliography, glossary with list of abbreviations, and listing of existing data communications standards relevant to interconnection are also included.

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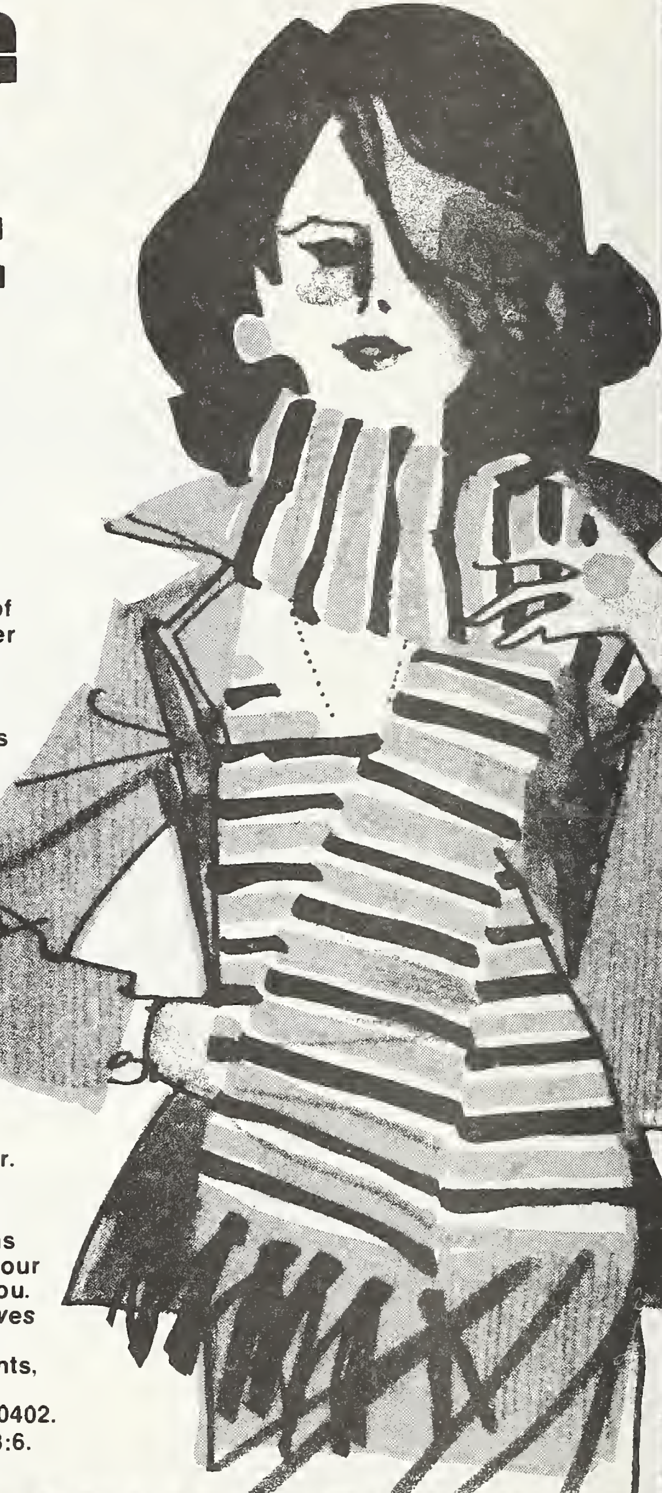

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