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A FIBER-OPTIC LOCAL AREA COMMUNICATIONS NETWORK

A fiber-optic-based, intelligent communications support system for interconnecting diverse computers and devices is described. The networking system, called Duplex Bus Communications Service, is being developed to support local area communications networking. A wide range of applications is planned, including integration of computers and computer devices at the University of California, San Francisco Hospitals and Clinics. The service facilitates system integration through the use of a new bus topology and microprocessor-based intelligent interface units.

INTRODUCTION

Several efforts are under way to design communication networks that connect computers and computer devices manufactured by different companies and serve different communities of users. When these devices are localized within a geographic area of a few square kilometers, such a communications support is referred to as a local area communications network.[1] The expected benefits resulting from cooperative use of computer resources by a collection of user communities are substantial. They include reduction of human work load and improved access to and utilization of computing resources.

A network based on an inexpensive approach to local area communications network technology, aimed at providing extensive communications service, is under development at APL. This network is called Duplex Bus Communications Service (DBCS).[2] It uses fiber-optics as the communications medium to provide high-capacity data communications while permitting ease of installation, physical expansion, and reconfiguration of devices. Through the use of microprocessors and comprehensive software support at each network connection, DBCS provides a range of communications services extending from simple message exchange to management of temporary integration of processes in different computers. The physical architecture of the network is reliable with respect to overcoming localized component failures (e.g., link or node failures). The software provides assured and secure data communications. In addition, the DBCS is an "open" system in the sense that new members may easily be added without modification to existing members.

The DBCS networking technology will be capable of supporting a wide range of applications, including:

- Information, data processing, and sensor systems integration[3,4]
- Office automation
- Electronic mail memorandum routing and retrieval
- Remote access to computer graphics, word processing, and other special resources or software packages
- Distributed database development
- Distributed data processing research

The development of local area communication technology has been planned in several stages. The first stage, nearing completion, involves demonstration and evaluation of an operational multiterminal, multicomputer network using off-the-shelf components. Subsequent stages will realize planned performance and service enhancements based on design improvements and operational experience.

NETWORK ARCHITECTURE

The DBCS architecture consists of three types of components: (a) network interface units that permit connection of computers, terminals, or other devices to the network; (b) dual strand fiber-optic cable links; and (c) junction boxes that direct all incoming data on a given fiber (encoded as light pulses) to all other outbound fibers. The fiber-optic links and junction boxes, operating at the same optical frequency, comprise a common communications channel.

Figure 1 illustrates a possible network configuration. Computers or other devices such as terminals or printers are connected to the network by means of the programmable network interface units (NIU's). These units are interconnected by means of junction boxes and the fiber-optic cables.

An NIU transmits data from its host(s) to the receiver of its junction box. The junction box retransmits the data to all the other outgoing fibers but *not* back to the originating source. Since all other junction boxes follow the same rule, data are transmitted to all nodes on the network except back to the sender of the data. Data are passed on the network in discrete packets containing source and destination addresses. Only packets addressed to a given NIU are read by that NIU.

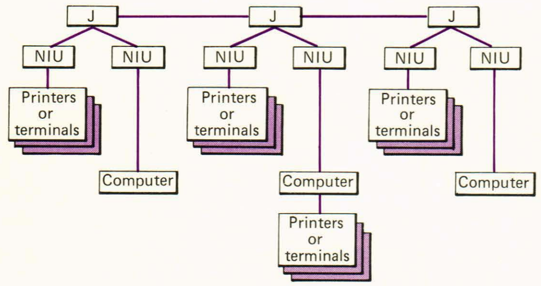

Fig. 1—A typical communications network configuration. Data and control signals are exchanged among heterogeneous host computers and user terminals under control of microprocessor-based NIU's via pathways consisting of fiber-optic cables and junction boxes (J). Data, encoded as light signals entering a junction box, are redirected to all other outbound cables. Data originating from a given NIU are heard by all other NIU's but not by the originator.

Each NIU competes with all others for use of the common communications channel. By listening on the channel until no signal is detected, an NIU can determine when to begin transmitting data. Another NIU may also attempt to transmit at approximately the same time. This may result in the superposition of two or more messages on the common channel. Such an event, called a "collision," is detected by the NIU's, which issue a network abort. This abort is achieved by flooding the network with a pulse of light that directs all receiving NIU's to disregard the packet. Each sending NIU then awaits a randomly determined interval before attempting retransmission, in order to avoid recurrence of the collision.

Two data packets may exist simultaneously without causing a collision. This situation will occur when two NIU's are sending messages to each other. In this case, their receive lines do not contain superposed data; however, the receive lines of all other NIU's do contain the superposition of the data sent by the two correspondent NIU's. This scheme permits simultaneous exchange, or full-duplex, within the DBCS architecture.

In the scheme presented above, each NIU contends with all others for access to the shared communications channel. Thus, DBCS uses a contention bus topology. The combination of listen-while-talk for access and collision detection logic is known as Carrier Sense Multiple Access with Collision Detection (CSMA/CD). The basic CSMA/CD algorithm has been modified in DBCS to permit full-duplex communications. This has been done to improve data transfer efficiency, to permit close coupling between two computers when necessary, and to support real-time applications such as feedback control and sensor-processor coupling.

Data communication in DBCS will be reliable in two different ways. First, the integrity of bits, bytes, packets, and complete messages transferred across the network will be ensured. This is accomplished with software embedded in each NIU to perform error detection, correction, and reporting. Second, the basic network is not vulnerable to single-point catastrophic failures, since NIU's on either side of a failed junction box can continue to communicate with all NIU's linked by operative junction boxes. Communications control is distributed among NIU's to avoid or minimize effects of NIU or junction box failures on network members.

COMMUNICATIONS PROTOCOLS

Communications functions are performed according to rules known as "protocols." These functions range from managing the physical transfer of bit streams at the low level through managing high-level functions such as control of integrated and structured data exchanges among cooperating programs in different computers.[5] These protocol functions are accomplished by the hardware and software within each NIU. Distributed network control is achieved through use of a common network protocol system design within each NIU.

The design decision to perform most protocol functions within the NIU's rather than within each host computer provides significant advantages, including simplification of development and maintenance activities. Instead of having to develop protocols within each computer host for every other host with which it may need to communicate, only one interface—to the network—is needed. Future changes may include protocol revision, changes of computers in various user areas, or changes in the applications designs supported by the network. Rather than implementing new software in each computer on the network to accommodate the new environment, only changes to DBCS software will be required because the protocols are within the NIU's. These changes can be made in a uniform, controlled manner since they will be the responsibility of a network manager, rather than the responsibility of several distinct user groups needing to cooperate.

The protocols are designed to provide various communications services. Simple message exchange without receipt acknowledgment (like a letter dropped in a mailbox) is known as "datagram service." The next level of service is called "virtual circuit service" in which message sequencing and delivery are assured. Finally, to link two computing devices across the network, the content and time reference of messages as well as their associated virtual circuit must be monitored. The administration of such an event-oriented circuit is called "session management."

Typically, session management is achieved for a given pair of computers by maintaining separate cooperating programs in each participating computer. The DBCS has been designed to provide session management services via a negotiation process between the initiating computer (or person at a terminal) and its NIU. This NIU then assumes responsibility for establishing and maintaining the required virtual circuits with other NIU's.

Major protocol program modules are depicted in Fig. 2 in their relative functional location within an NIU. Briefly, communications protocol functions are performed asynchronously by two separate microcomputer modules. Higher level management protocols, such as control of processing sessions between two network hosts and input/output of complete, sequenced messages, are implemented by the host/terminal interface module. Through use of a shared memory for buffering of messages, the network interface module partitions complete messages into smaller, more efficient packets and includes destination and source addresses. When the network is quiet, these packets are then sent (and resent as necessary) to their destination until error-free delivery is acknowledged by a return message.

The following is an example of NIU protocol operation involving a user at a terminal and a remote computer. Following conversion from the terminal's data code to a single network code, a connection and processing session between the user and the computer is negotiated across the network using the process-to-process and session-control protocol modules in the terminal and computer NIU's. Following this establishment phase, data between the terminal and computer are exchanged interactively under the control of the lower-level protocol modules. The transport control modules ensure end-to-end accuracy and correct sequencing of messages within a process session. Routing and data link modules ensure that data are properly addressed and accurately delivered to destination NIU's. The contention/collision control modules regulate both the access to the network and the retransmission of packets that collide on the network. Data bit errors occurring during packet transfer between two NIU's are detected by continuous packet collision detection and a standard error detection algorithm. Retransmission of aborted packets is attempted a preset number of times, and correction of data packet errors is achieved with a retransmission algorithm.

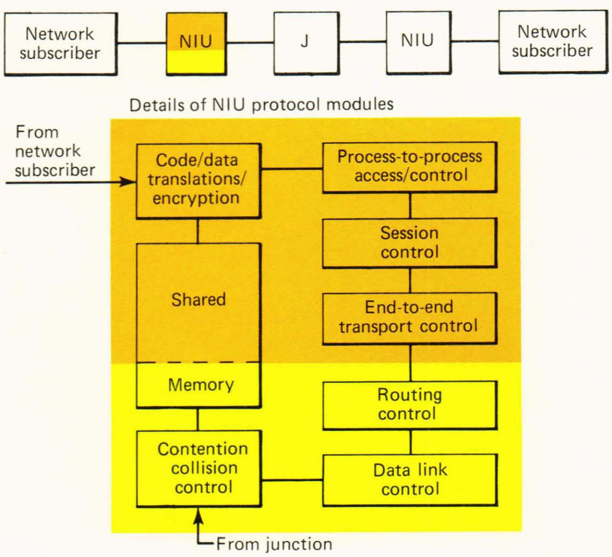

Fig. 2—Network Interface Unit protocol modules. Two microcomputers execute program modules to control data transfers. The upper microcomputer handles data translations, program access control, session management, and end-to-end message sequencing. Data messages from and to the attached subscribers are stored in a shared buffer area. The lower microcomputer in the NIU works independently to address, deliver, and acknowledge delivery of data exchanged between NIU's.

SUMMARY

A local area communications network technology has been developed in order to support a wide range of potential applications and to provide a test bed for continuing distributed data processing research. The components of an initial network, based on the DBCS architecture described above, have been designed, fabricated, and tested. The overall system is designed to provide several new features including (a) a new fiber-optic-based branching contention bus; (b) the embedding of high-level communications protocols within the network to provide extensive subscriber services and to simplify development and maintenance activities; (c) duplex communications capabilities; (d) implementation of open system concepts; and (e) secure, reliable data communications among computers and computer devices of various kinds.

Two distinct applications are planned for 1981. The first will integrate two minicomputers and clusters of terminals into an operational network. The second will support integration of four different minicomputer systems, each servicing distinct functional areas of a hospital. The latter application will be a major step toward implementing a distributed, composite information system at a large university hospital. These applications will provide a basis for continuing research in distributed processing and local networking in diverse environments.

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