the new industrial revolution: packet radio and local area networking

"I see no reason why intelligence may not be transmitted instantaneously by electricity."

— Samuel Morse, 1832

Because the traditional methods of point-to-point communications — CW and RTTY — relied on relatively low data rates, conventional systems have been slow to take advantage of available technologies and the bandwidths they offer. Yet the widespread use of digital computers has created an urgent demand for faster data transfer (burst communication) requiring large bandwidths giving a totally new meaning to Morse's words.

Now that personal computers have taken the place of comparatively "dumb" terminals, used to access large central computers (CPUs) via low-speed telephone lines, communication between and coordination of individual computers has presented a new and difficult challenge to system planners. Because there are differences between various computers, they have difficulty "talking" to each other, and problems are created whenever they are combined in a common network. In order to solve this problem, a new science, called LAN or *L*ocal *A*rea *N*etworking, was created, which employs packet-like communications to transmit data on dedicated wire (pairs), coaxial cables, fiber optics or "through the air" (see **fig. 1**).

The need for wideband communications has also affected traditional analog modulation schemes, which are now being replaced by digital ones. The search is on for techniques that will enable diverse types of electrical information — including voice and video signals — to be combined and transmitted. At the same time new higher speed analog-to-digital converters are replacing conventional processing techniques not only in RF processors but in large distributed networks and private branch exchanges (PBX). In addition, compressed full-motion digital television signals, including digital voice and computer information, can be distributed over networks for videoconferencing.

This phenomenon is not a science fiction fantasy, but rather a reality of the new industrial revolution, in which information is managed through automatic communications between and among "intelligent" machines.

As an example, consider a corporation with several manufacturing facilities in widely separated locations. Each factory acts as an independent unit with its own offices and production facilities. To operate effectively and maintain the competitive edge, each unit needs to have, at hand, easy access to the latest technology and techniques of information processing and communications. The answer to this need is a series of interconnected local area networks deisgned to instantly respond *electronically* rather than on paper.

communication path determines technique used

Most data communications over paths shorter than one hundred meters employ (hard-wired) parallel busses (see **figs. 2** and **3**.) Although this relatively fast method of data transfer is fully compatible with computer I/O's, use of busses over greater distances becomes impractical. Consequently, local area networks use serial digital packet formats at rates in the 50 Mbit/s range.* In communications this is referred to

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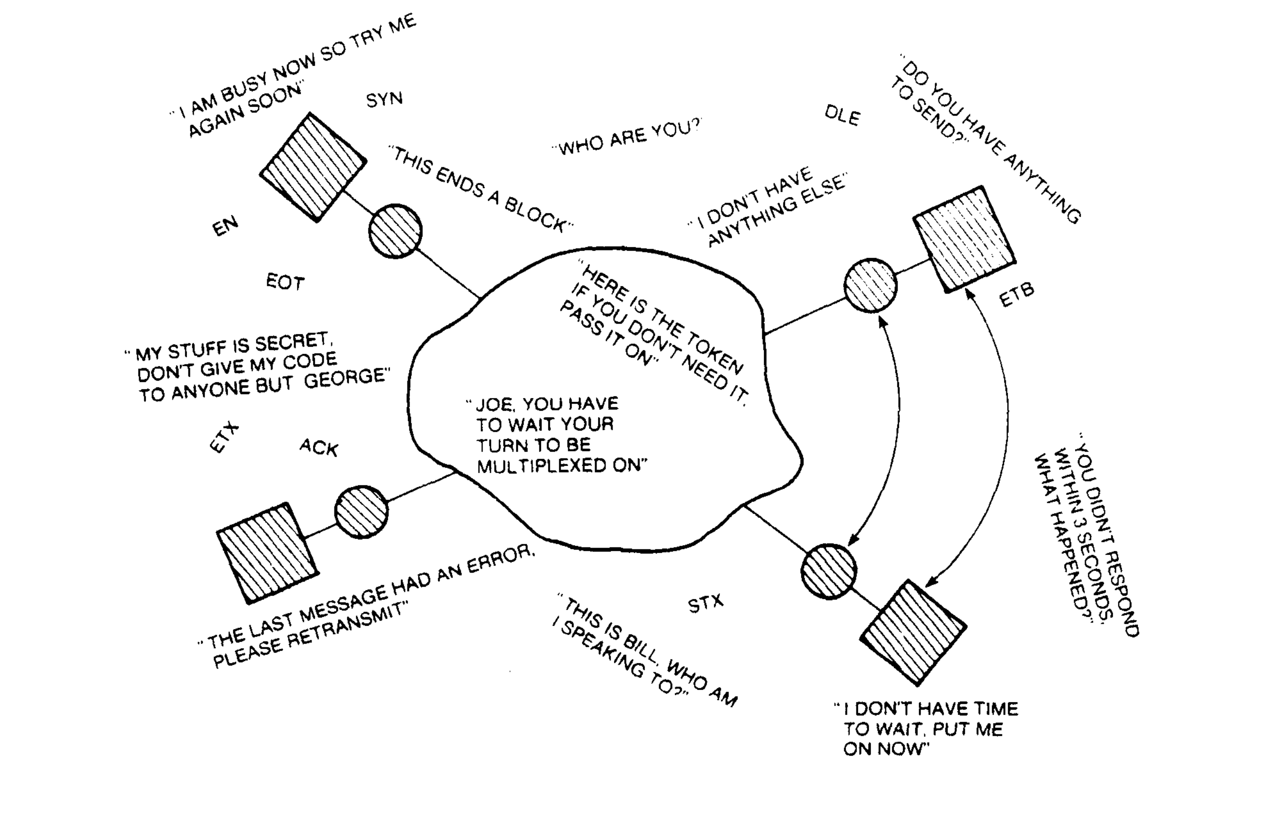


fig. 1. Some protocol requirements for local area networks.

as base-band information because it is the basic format that every device will eventually generate and accept for communications. Base-band can be used directly in point-to-point communications between data devices such as universal asynchronous receiver/transmitters (UART). However, without complex protocols and equipment, only two devices can communicate over the given medium at a given moment. For communication among more than two devices (e.g., computers), other methods must be used.

One method of communicating between several digital base-band devices over the same pair of wires is by multiplexing them synchronously at both ends. Known as time division multiplexing (TDM), this represents an early form of local area networks, as shown in **fig. 4**. TDM uses permanently dedicated time slots that can sometimes be "empty" of information; *statistical* time-division multiplexers (STATDM) eliminates this problem by dynamically allocating the time slots according to the activity on the channels.

- ***Computer Bus:***
  1-10 cm to 100 meters.
- ***Local Area Nets:***
  Several meters to several kilometers.
- ***Local Distribution Nets:***
  A few kilometers to approximately 100 kilometers.
- ***Long Haul Nets:***
  Hundreds of kilometers to thousands of kilometers.

fig. 2. Categorization of networks by geography.

*Packet is a block of data handled by a network in a well-defined format including a header (opening ID) and having a maximum size and data field. Consequently, a message may have to be carried as several packets.

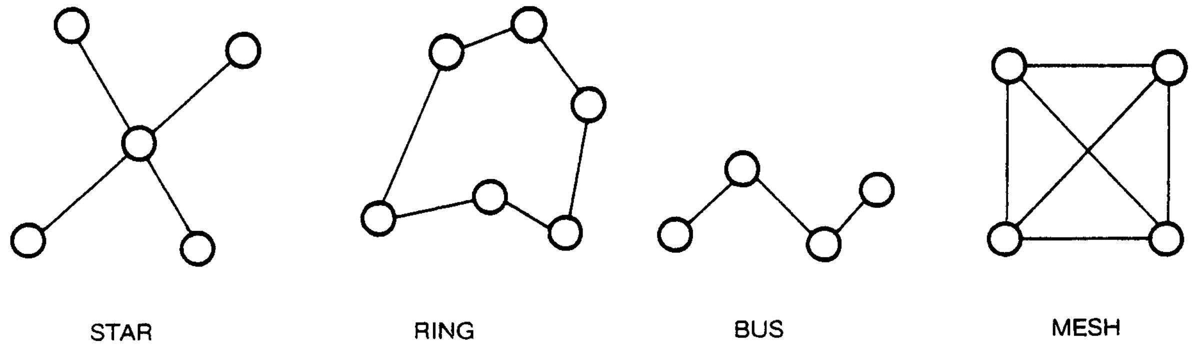


fig. 3. Types of local area networks.

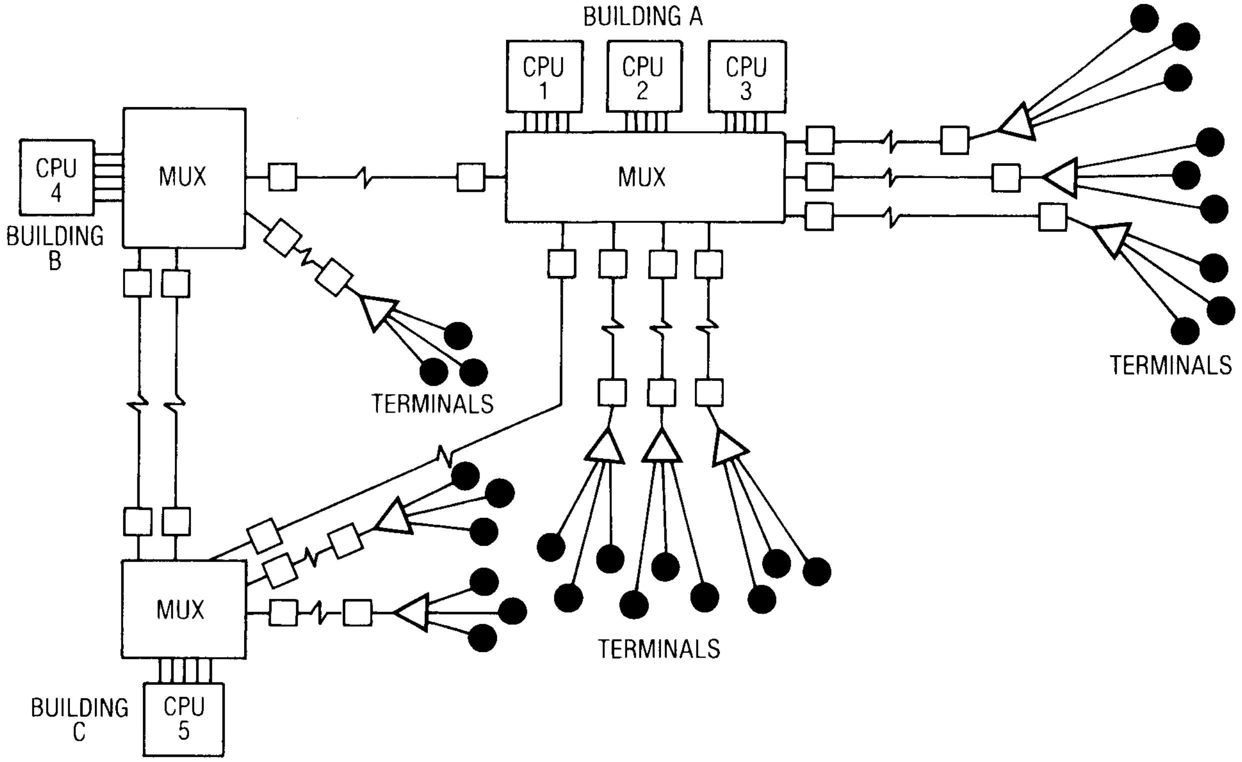


fig. 4. Block diagram of a campus local area network using multiplexers.

Other simple local area networks use an intelligent central switching facility in a star configuration that resembles conventional telephone PBX technology. By using base-band directly on wires and without multiplexing or central switching, we occupy 100 percent of that medium's bandwidth. (Also known as the percentage bandwidth factor.)

When base-band signals are translated to radio or optical frequencies, it becomes possible to pack more base-band channels into one single frequency, as shown in **fig. 5**. The higher the frequency, the more base-band channels can be transmitted.

Frequency division multiplexing, designated as the broadband approach to local area networks, can be further subdivided according to some interesting protocols, as shown in **fig. 6**.

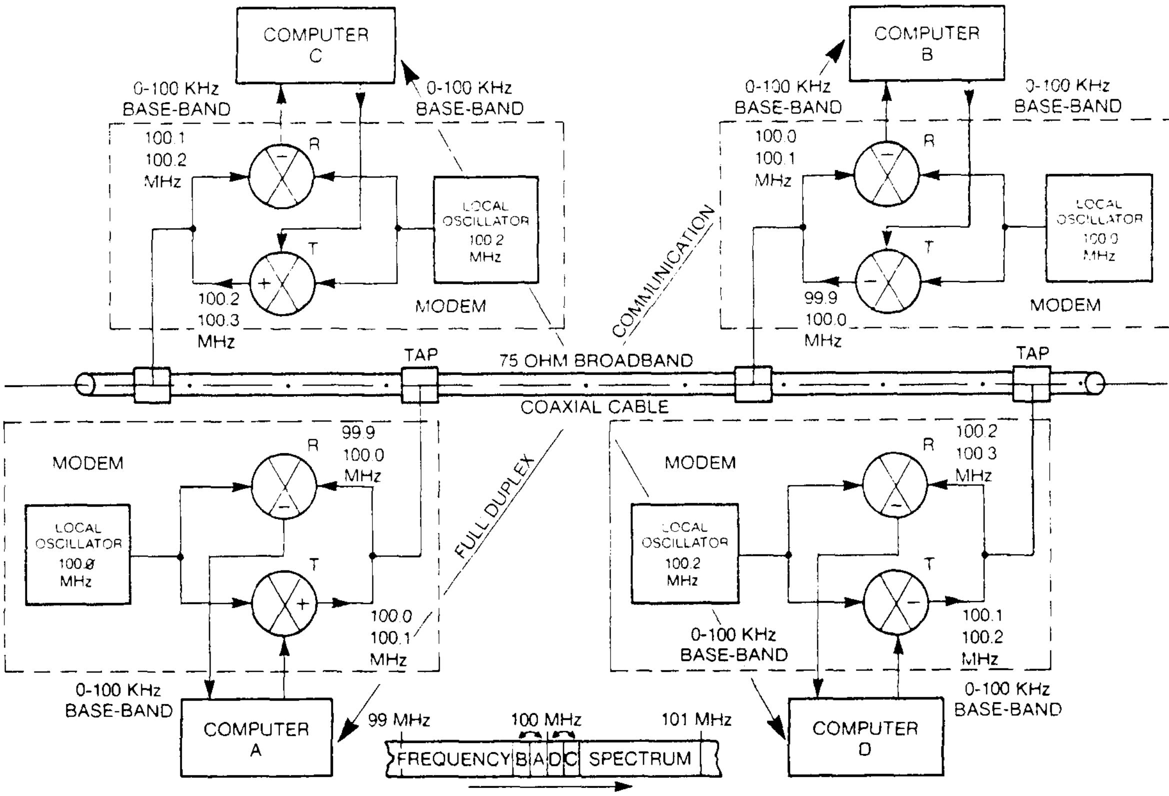


fig. 5. The concept of percentage bandwidth shows that the best medium utilization occurs when many base-bands are modulated on top of much higher frequencies as in frequency division multiplexing (FDM) techniques using radio-like processing.

listen while talking

In an effort to find better ways of utilizing the spectrum *without* switching and/or multiplexing new packet techniques using radio and coaxial cable networks have recently been developed and implemented. By borrowing ideas from real-life situations, designers have applied the characteristics of human interaction to communications between machines.

Imagine a business meeting in which several dynamic men and women exchange information and make decisions in one room. The process is rapid and contains several important elements common to all the speakers:

- A leading address to one or more participants preceeds any conveyed message.
- A message is conveyed.
- An end remark is usually followed by an invitation to answer.

If two persons begin to speak simultaneously their messages "collide," and one or both stops talking and tries again later. (In earlier packet radio, neither party would have "known" that a collision had occurred until they noticed that an acknowledgement had not been received at the end of the transmission.)

This relatively simple concept is the basis for a type of local area networking known as *Ethernet*. Ethernet allows the transmitting station to listen in on the "ether" while transmitting a packet, in a method known as "listen while talking." This method is similar to the situation that occurred in the hypothetical business meeting described above. It allows for any

collisions caused by another station that had decided to transmit to be immediately detected, which in turn causes the transmitter to cease transmission and restart at a later time. Ethernet can be used either at base-band over wire pairs and/or coaxial cables, or over channelized broad-band busses in CATV-like networks equipped with special modems as shown in **fig. 7**.

The concept was developed as a consequence of problems with simpler packet radio techniques that do not necessarily allow for the collision detection characteristic of Ethernet. These technologies evolved from the well-known ALOHA network. Developed at the University of Hawaii in 1970, the ALOHA system was essentially the first practical packet radio network, and covered the Hawaiian Islands, as shown in **fig. 8**.

The purpose of the ALOHANET was to provide inexpensive, statewide user-to-central computer communication for several hundred terminal users who were experiencing poor telephone modem connections at the time. Unlike previous networks, which used node-to-node communications, ALOHA network communication was accomplished in a radio broadcast mode, in which each station was heard and addressed by the central packet station known as the "Menehune", located in Honolulu, via two 100-kHz random-access channels at 407.35 MHz and 413.475 MHz. Although the system did not allow for direct user-to-user communications, information was nevertheless transmitted by transferring data to the central packet station and then forwarding it, after processing, to the destination user.

The packet transmission data rate was 9600 baud, with packets consisting of a 32-bit header, a 16-bit header parity check field, and up to 80 bytes of data followed by a 16-bit data parity check field. The maximum size packets were, therefore, 704 bits in length. Each took about 73 milliseconds to transmit; the entire network's propagation delay time was therefore, negligible in comparison to other systems. The random-access user-to-computer (407.350 MHz) channel allowed for packet headers containing user addresses to be identified by the Menehune central station. One natural consequence of the random nature of transmission was the probability of packet overlapping and collision. However, frequency division multiplexing was not considered necessary because of the burst nature of the computer traffic and the lack of additional radio channels. The collided packets were rejected by the Menehune station, and that fact was made known to the respective transmitting terminal by the absence of an acknowledgement signal on the computer-to-user return channel (413.475 MHz). This channel presented no random collision problem, since only the central processor's transmitter was broadcasting to all the other stations.

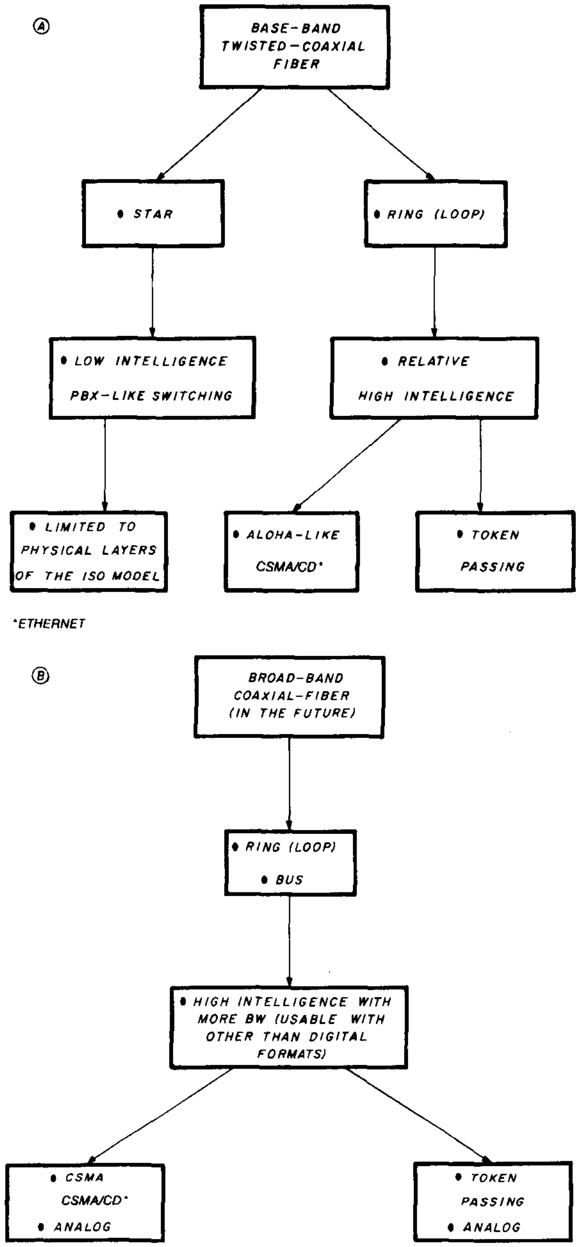


fig. 6. Characterization of networks by frequency domain and protocols; (A) using coaxial cables, (B) using fiber optic cables.

This scheme, known as pure ALOHA, presents some drawbacks as pointed out earlier; because the individual terminals have to wait until no acknowledgement is received, and then re-transmit the packet at random, with no guarantee that a collision will not occur again.

The relatively low throughput of pure ALOHA (see **fig. 9 A** and **B**) arises from the high practical probability of packet collision, which in turn is the result of

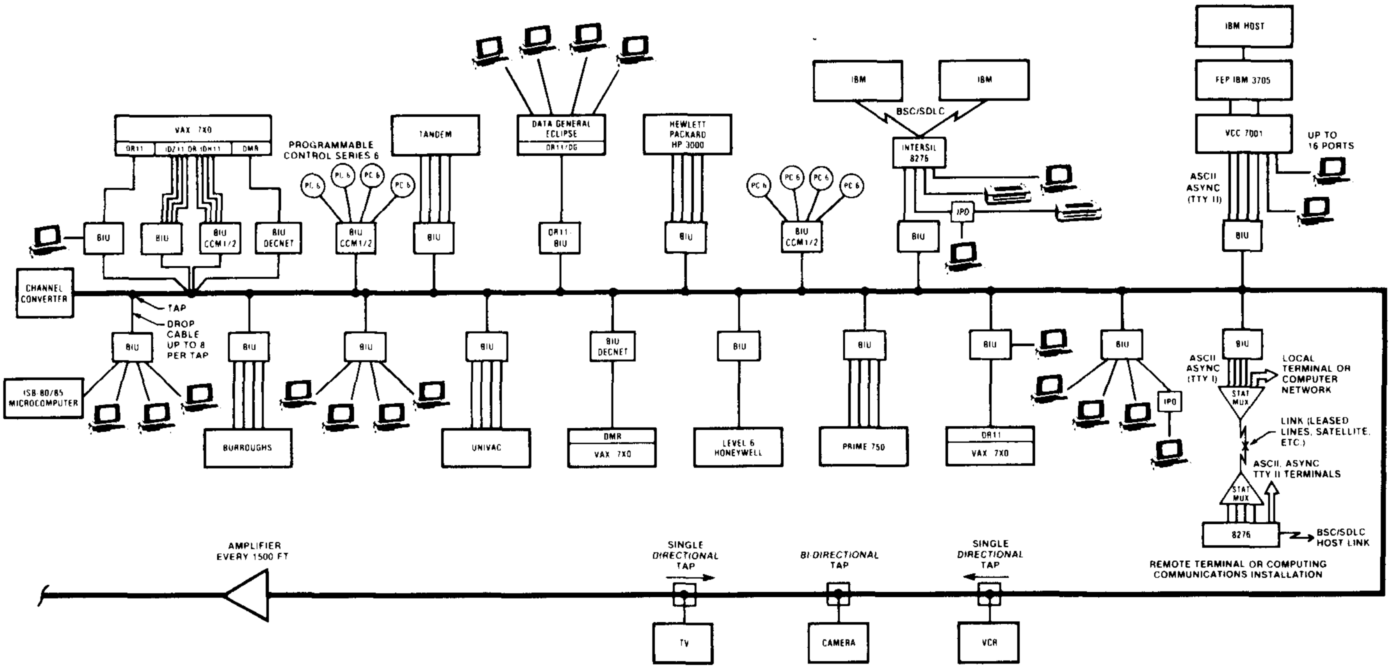


fig. 7. The GE-NET is an example of Ethernet implemented on a broad-band CATV-Network.

the total lack of discipline in transmissions from the terminals.

To correct the situation, various proposals were made to improve the bandwidth utilization. Among them were slotted ALOHA, which restricts and synchronizes terminal transmissions for better throughput and the various carrier sense multiple access (CSMA) techniques presently used.

The present AX.25 protocol used in Amateur packet-radio networks is superior to the ALOHA protocol because it listens before it transmits; however, the characteristic "listen while talk" feature of Ethernet is not available on these networks. The more advanced Ethernet concept was pioneered by the Xerox Corporation in November, 1978, as part of a proposed nationwide network known as the Xerox Telecommunications Network (XTEN).

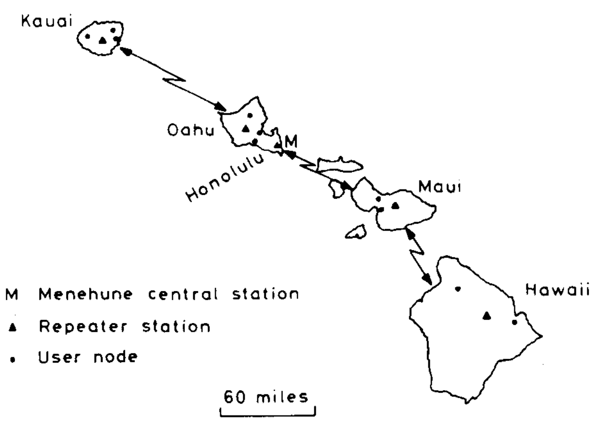


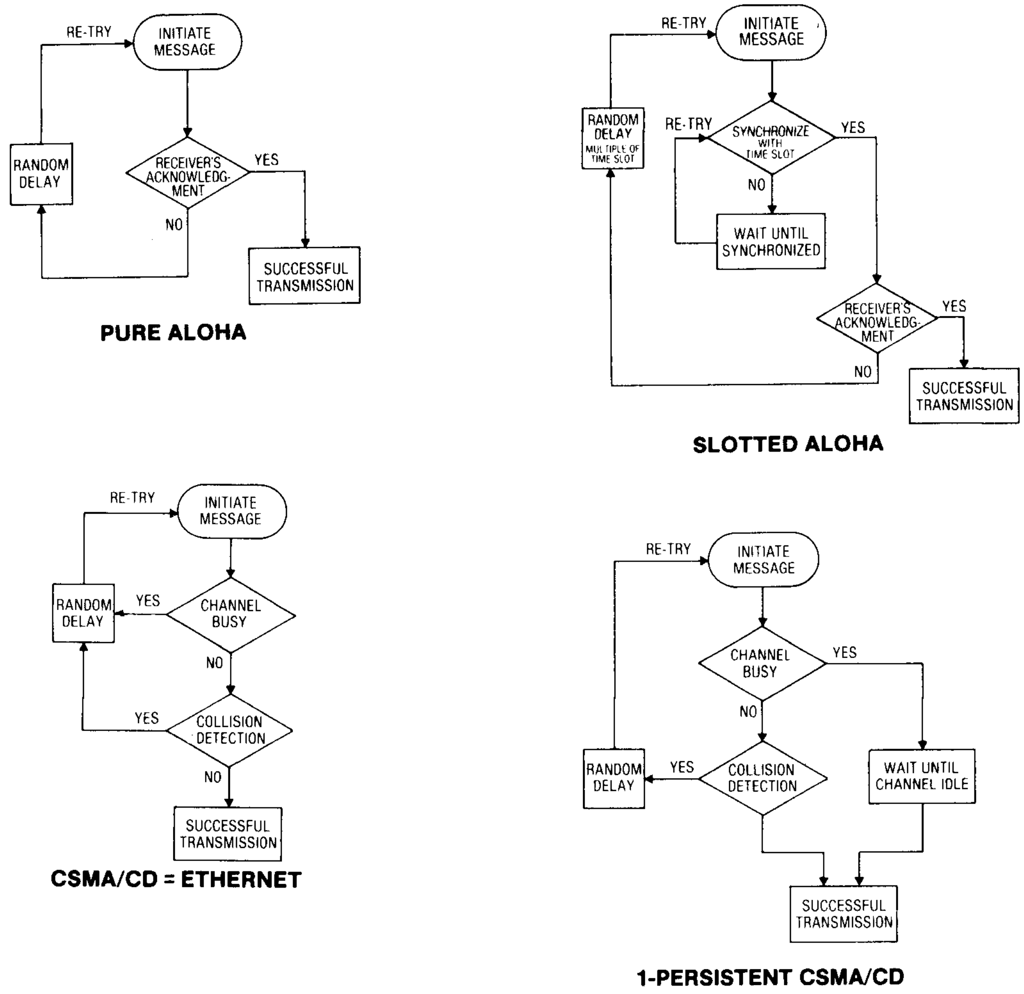
fig. 8. Map of the ALOHA network.

satellites would provide the link

The overall XTEN approach required satellite communications to link together through shared earth stations located in all the major cities around the country. Microwave radio, and/or infrared fiber links were envisioned to connect the local users to the earth stations, and finally, individual buildings and/or campuses were to be connected through a 3-Mbit/s packet network.

In its modern form, Ethernet is a base-band local area network allowing a theoretical rate of 10-Mbit/s over coaxial cable. It can connect as many as 1024 stations over a span of 7600 feet. Each station is designated by a 48-bit code and collision detection (CSMA/CD) is accomplished through the previously described techniques. In spite of the many improvements since the ALOHA days, the opponents of Ethernet still maintain that when network traffic is especially heavy, real-time applications such as those on aircraft or in automated factories could fail to be completed within the limits of their prescribed times, resulting in long collision recovery time, and even the risk of catastrophic failure.

Consequently, new methods have been developed to provide more discipline in accessing networks. One



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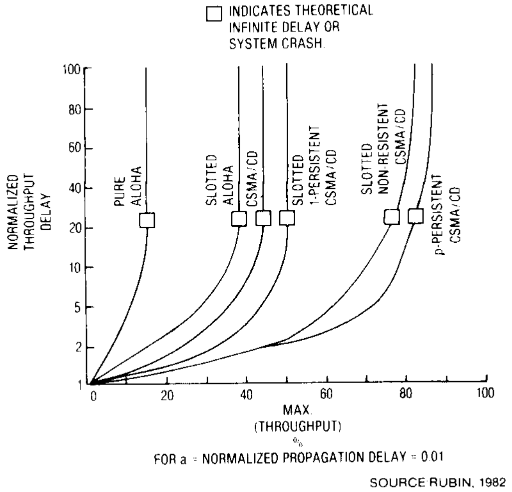

PROTOCOL	MAX. THROUGHPUT (%)
PURE ALOHA	18.4
SLOTTED ALOHA	36.8
CSMA/CD	40.0
1-PERSISTENT CMSA/CD	52.9
SLOTTED 1-p CSMA/CD	53.1
0.1-p CSMA/CD	79.1
NONPERSISTENT CSMA/CD	81.5
0.03-p CSMA/CD	82.7
SLOTTED NONPERSISTENT CSMA	85.7
IDEAL SCHEDULING	100

B

fig. 9. (A) Variations of the ALOHA concept, and their functional flow diagram, (B) system crash is indicated by the maximum throughput delay for the different methods shown.

such method is the newly introduced *token-passing* technique, which consists of passing an accessing token from terminal to terminal, which in turn provides a well-ordered method of accessing the network for the participating users. The relatively complicated error recovery algorithms of token-passing make this approach difficult to implement, however. (Most base-band, token-passing networks can also be implemented in broad-band.)

A compromise between the CSMA and *token-passing* is now being examined, with products to follow in the near future.

applying what we've learned

Shown in **fig. 10** is a radio transceiver with a built-in computer terminal; it could also be considered a computer terminal with a built-in radio transceiver. Behind its friendly look lies a packet radio network of unprecedented complexity.

Imagine a nationwide dispatching operation involving thousands of roving service or supply vans, with drivers. Obviously such an operation would require foolproof, effective communications and positive inventory control of all parts used in the field (with automatic reordering). A combination of radio paging, telephone dispatching, and paperwork would be necessary.

In such an application increased productivity and elimination of delays associated with the paperwork means improved communications. Equipped with this portable radio terminal, otherwise known as a PCX, a fleet can reliably access a distributed database network that keeps track of all inventories even as they are being continously modified from the field by all other portable radio terminals. This — and dispatching and ordering functions as well — happens in real time, in all locations, and without the inevitable delays associated with paperwork.

These developments are expected to open new doors in professional and Amateur packet radio activities, with products such as hand-held transceivers expressively made for data networking applications. Networks using satellite packet gateways will allow electronic mail to be carried from one side of the world to the other, and facilitate the handling of emergency traffic on a worldwide scale.

what we can expect

Today's personal computer is a small first step in the eventual connection of diverse communication technologies in terms of interactive thinking of machines. This new science has been named *telematique* or *telecybernetics*.

Theoretically, the ideal local area network should allow any computer or office/factory device to communicate with any other device within its geographical

fig. 10. The portable radio data terminal (PCX) can provide interactive data communications with large data bases geographically dispersed. Thousands of such devices can modify inventories in real time, while roving around cities as part of area-wide packet networks operating in the 800-MHz business band. The local networks are in turn connected with a nationwide data network which provides updating of information to all other PCXs located elsewhere on the network. (*Photo courtesy of Motorola Inc.*)

boundaries. However, current local networks are limited in that they perform only limited functions in specific settings. This approach may or may not survive the present technological revolution. Such is the case with some inexpensive base-band systems that can work with only certain brands of computers. *The problem is essentially one of standardization.* The age of the throwaway computer is here; the average life time of a design appears not to exceed two years. And although the new machines are increasingly powerful, with built-in LAN capabilities, combining them into networks remains one of the most challenging tasks ever encountered.

To help minimize these problems, the International Organization for Standardization (ISO) introduced the Open System Interconnection (OSI) model in 1978, a concept for developing communications between dissimilar devices. The model has since been adopted by the IEEE and is now reflected in the IEEE-802 standard, as shown in **fig. 11**. Upon completion, this standard is expected to ensure compatibility between local area networks with only a minimum amount of work required of the user.

conclusion

Today's local area networks cannot be expected to provide communications between dissimilar devices without additional customized hardware and software interfaces. At the same time, standardization is not expected to resolve the fundamental incompatibility of computers that use different operating systems, languages, and syntaxes. Technical experts seem in

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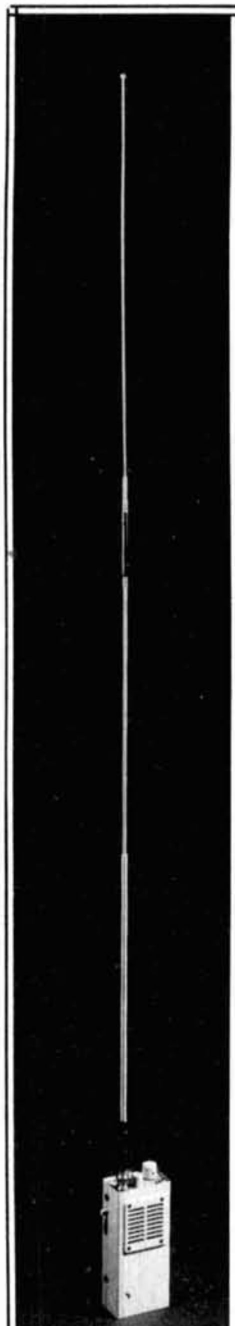

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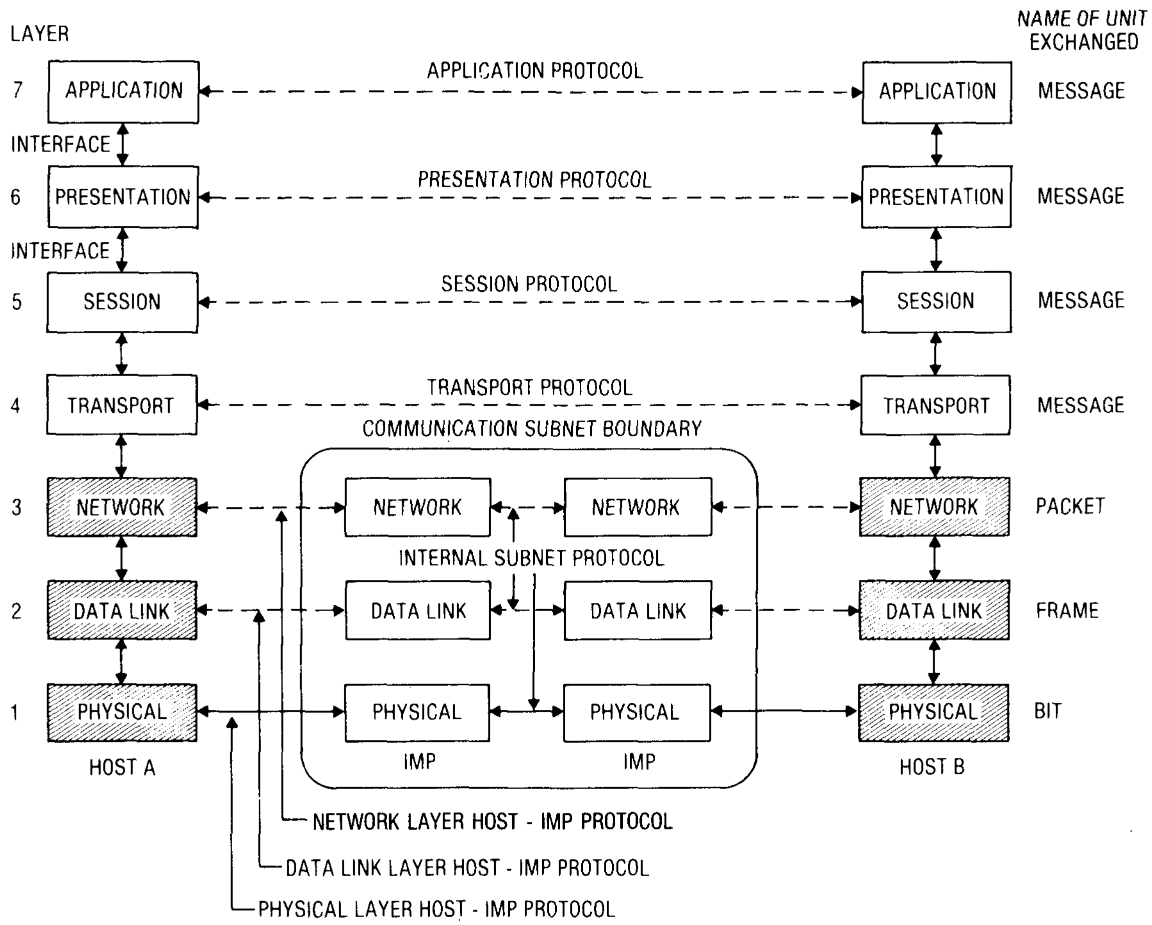

fig. 11. The seven-layer ISO OSI model has been adopted by IEEE's Project 802 Committee and a set of protocols is now available for the bottom layers.

doubt as to whether the processing imposed by the protocols will still permit real-time applications such as digitized voice or compressed video-conferencing — services that have been part of the promised land of LAN. The question still remains whether or not electronic mail belongs within the ISO OSI structure, outside of it as a separate service, or somewhere in between. It is well known that few true distributed database products are available today. Not to be confused with file sharing, these systems involve similar databases that are geographically dispersed. The intent is to provide each LAN containing such a database with updated information in real time. The problems associated with finding, updating, and verifying this information at several locations calls for traffic-intensive communications not yet compatible with the ISO OSI model because of the current lack of "intelligent" software.

The hardware-oriented issues with packet communications seem small when compared with the above issues; progress remains to be made in frequency division multiplexing technologies required for broad-band optical communications and in the design of fiber-optic power splitters (the optical equivalent of RF-power splitters). At light frequencies the process becomes impractical because of temperature instabilities. Consequently, achieving broad-band communications over fiber optics remains a laboratory experiment. Fibers are usually used in base-band modes; applications using Bragg technology are possible, however, in real time broadband-to-base-band converters (patent pending by the author and Honeywell, Inc.).

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