Foreword
Introduction and Issue Overview

I. Introduction

SINCE the late 1960's and early 1970's there has been a great deal of research in long haul packet switching networks (e.g., [1]), typically using 9.6 and 56 kbits/s transmission links. Today these systems have matured into operational services and are no longer looked upon as novelties. Local area communication networks constitute a comparatively more recent field, which started in the mid 1970's [2] and which is still gathering momentum through the present. The term *local* refers to packet switching communication on the users' premises, e.g., within a building or throughout a cluster of buildings, typically at rates in the range of 1–10 Mbits/s. Currently, much research and development work is being pursued in this field, in industry, at government laboratories, and in universities.

II. Motivation and Driving Forces

The driving force kindling interest in local area networks is the demand for greater economic productivity. Computers help people work more productively, in offices and factories. The widespread growth in the number of terminals and computers reflects this: local area networks are intended to allow for easy access from any terminal to any computer. At the same time, the relative cost of labor associated with installing and changing wiring associated with local networks is increasing. A variety of technologies (VLSI semiconductor technology, hardware packaging, and software) are currently being investigated to see what best meets productivity demands at acceptable costs. Local area networks are among these technologies and appear to be a necessary component for meeting these needs. Each of the following sections expands on these points.

A. Economics

Economic market forces for communication and information processing services in offices and factories are generating widespread interest in local area networks. As one example, office staff costs in the United States in 1960 exceeded $800 billion and will grow to well over $1.4 trillion by the end of the decade [3]. Office expenses today comprise approximately 25 percent of a company's cost of doing business and are likely to account for 45 percent by the end of the decade because of rising unit labor costs [4, p. 74].

American Telephone and Telegraph [5] estimates that 70 percent of the time spent by professionals in the U.S. on daily office activities is in communication with someone else. This breaks down into 15–20 percent on the voice telephone, 40–45 percent in face-to-face meetings, and 1–5 percent in document creation (writing documents for internal or external distribution). When not communicating, professionals spend 25 percent of their time distributing and filing documents, and retrieving them as needed. Only 5–8 percent of professional activity is related to thinking, planning, and analyzing, during normal business hours. Anything that can be done to increase the fraction of time a professional is doing useful work should reduce costs and increase profitability. In summary, this and other studies (e.g., [6], [7]) suggest that productivity gains in the office and factory approaching a factor of 2 may not be unreasonable, provided the customer costs are acceptable. Local networks are thought to be a key element to help achieve these goals.

B. The Demand for Communication Networks

The table below shows the installed base of communication devices in the U.S. as of 1981 and an estimate for 1986.

Installed Communication Devices [8]

Device	1981	1986E
Residential Telephone	130M	145M
Business Telephone	55M	70M
Noncable Television	60M	50M
Cable Television	20M	40M
Data Terminal	6.9M	17.0M
Personal Computer	1.2M	14.6M
Word Processor	1.0M	5.2M
Minicomputer	0.6M	1.7M
Mainframe Computer	61K	82K

Some forecast that the density of terminals and workstations will be approaching one per workplace by the end of the 1980's [9]. Based on this evidence, the impetus for establishing local networks to interconnect these devices appears to be inexorable.

Workstations and personal computers already have, and will continue to have, substantial processing capabilities due to powerful microprocessors. This has the potential for achieving productivity gains, provided the systems are easy to use [9], [10].

Current trends are toward sharing of data among these workstations because current technology for printers and secondary disk storage makes them relatively expensive components of data processing systems. This suggests a need for (local) networking of workstations with peripherals, to allow the workstations to share the expensive components [10].

C. Wiring

Current wiring technology has led to serious crowding of cable ducts and raceways in buildings with large numbers of terminals and computers. Local area networks, hopefully, will be more cost effective for initial wiring of new buildings and for managing changes of wiring in existing buildings [9], [10].

D. Technology

Advances in many different technologies are in part responsible for the advent and success of local area networks. First, unlike in long haul packet switching computer communication networks, transmission lines in local networks are a relatively inexpensive commodity. Local area network transmission systems can be based on twisted pairs, coaxial cable, and optical fibers [10], [11]. Data transmission rates on these media are advancing with little or no increase in manufacturing costs; currently, rates in the range of 1–10 Mbits/s throughout an office complex or factory can be provided in a cost effective manner.

Second, there is very large scale integration (VLSI) semiconductor device technology [12]. It allows intelligent adapters to local area networks to be manufactured at acceptable costs. (In 1981 local area network adapters cost upwards of several thousand dollars, while today the same adapter can be manufactured for hundreds of dollars [13].)

It also allows for personal computers and workstations, as mentioned earlier, to cost thousands of dollars today, unlike the hundreds of thousands of dollars in the mid 1970's.

III. Major System Approaches

Computer controlled private branch exchanges (CBX) implemented in digital technology and providing 64 kbit/s PCM channels are one approach to local area communications [14]. CBX switching systems employ centralized switching with central control. The switching technology is circuit switching. The topology of a CBX is a star. With a suitably configured CBX, both local data switching and transmission needs of a variety of terminals and computers can be satisfied.

System proposals not based on CBX technology but also using centralized switches employ packet switching technology instead of circuit switching and, therefore, have the capability to handle bursty traffic. The alternative to centralized switching and control is a distributed control structure to regulate access to the transmission system. Topologies which inherently provide broadcasting, such as buses and rings, readily lend themselves to implement distributed access control. The access control functions are provided in adapters through which stations are attached to the network. All adapters are peer partners: there is no master adapter or master station controlling access of the other stations.

Within the bus and ring categories we can distinguish according to the media access control method. Basically, access can be either controlled, in which case no collisions occur, or random, which implies that collisions of transmission attempts may happen. Controlled access typically offers better traffic handling characteristics under heavy load than uncontrolled access. This suggests hybrid techniques that under light load allow immediate access and under heavy load behave like a controlled access method [15]–[17].

A final consideration is the choice of the medium: one or more twisted pairs of wires, a coaxial cable, or an optical fiber. Different modulation techniques can be used with different media: either *baseband* modulation where bits are transmitted as electrical signals without prior modulation by a sinusoidal carrier, or *broad-band* modulation where there is modulation of the electrical signals by a sinusoidal carrier into different frequency bands. A description of some of the best known systems to date follows.

A. Token Ring

In a token ring, a data structure which basically consists of a delimiter signal and a free indicator, called the token, circulates continuously when no traffic is offered for transmission. If a station requests to send, its adapter will wait for the delimiter signal and check whether the token is free. If this is not the case, then the transmission attempt will have to be deferred. Otherwise, the station sets the token to busy and data transmission commences. The variable length frame passes all adapters. The destination recognizes its address as part of the frame and copies the information into its receive buffer. When the frame returns to the sending station, it is erased from the ring. The sending station adapter also has the responsibility of issuing a new free token and passing it along the ring.

B. Slotted Ring

In a slotted ring, a constant number of fixed-length slots circulates continuously around the ring. A full/empty indicator within the slot header is used to signal the state of a slot. Any station ready to transmit occupies the first empty slot by setting the full/empty indicator to *full* and places its information in the slot. When the sender receives back the busy slot, it changes the full/empty indicator to *empty*.

C. Buffer Insertion Ring

In a buffer insertion ring, the contention between the traffic to be transmitted by a station and the data stream already flowing on the ring is resolved by dynamically inserting sufficient buffer space into the ring at each ring adapter. In contrast to the token ring where the sender is responsible for removal of the frame it transmitted, this function is performed by the receiver.

D. *Carrier-Sense Multiple-Access Collision-Detection Bus*

The best known random access scheme for bus systems is carrier-sense multiple access with collision detection (CSMA/CD). Under a CSMA protocol, every station ready to send listens (*senses carrier*) before transmitting an information frame in order to detect transmission attempts already in progress. If another transmission attempt is already in progress, the station will defer its sending until the end of the current transmission. Due to the nonzero propagation delay of energy on the bus, two or more stations can attempt to transmit but all the signals will interfere with each other (a so called *collision* detected by all stations). When a collision is detected, the transmission attempt is aborted and the station reschedules its packet by determining a (random) retransmission interval.

E. *Token-Passing Bus*

Token access on a bus means that the station ready to transmit and which received the free token can send an information frame. At the end of the transmission, the sender frees the token and passes an addressed token to the next station which should have an opportunity to transmit. It is important to note that in contrast to a token-ring system, the token has to be addressed since a bus system does not provide sequential ordering of the attached stations.

IV. Standards

A variety of groups are actively involved in developing standards for local area networks. Here we single out ECMA (European Computer Manufacturers Association) and the IEEE Computer Society Project 802. Project 802 started the standardization effort by working towards a standard for bus systems with CSMA/CD based on work done by Xerox, Digital Equipment, and Intel [18]. This effort was broadened by additionally considering both the token ring and the token bus [19]. Local area network standardization activities in ECMA began in 1981. In the meantime, ECMA adopted three media access control mechanisms as standards, CSMA/CD in 1982 [20], and token-ring and token-bus systems in 1983 [21], respectively.

V. Market Status

Currently, there are some 250 vendors of local area networks and network components covering all system approaches mentioned above. From a users point of view, it is interesting to observe that some vendors offer open systems, allowing interconnection of products from more than one vendor, whereas others decided to provide closed system solutions which make it difficult to network together equipment from other manufacturers.

Today there is scant information on how different local area network products perform on user premises. It will be such experience rather than engineering analysis which will eventually resolve the contention for one or a few predominant local area network technologies.

VI. Outline of the Issue

The issue is broken down into three areas, network technologies, software systems engineering, and media access and their performance.

A. *Network Technologies*

The papers in this section are concerned with design issues, engineering tradeoffs, and case studies for the various network technologies.

First, the focus is on transmission and interface design considerations. The initial paper, by R. V. Schmidt, E. G. Rawson, R. E. Norton, Jr., S. B. Jackson, and M. D. Bailey, is concerned with an optical fiber CSMA/CD bus. E. S. Lee and P. I. P. Boulton complement the previous paper with a case study of an optical fiber local area network called *Hubnet*. H. Keller, H. Meyr, and H. R. Mueller present transmission design considerations and tradeoffs for a synchronous token-passing ring, in contrast to the earlier papers dealing with buses. D. Taylor, D. Oster, and L. Green, study and compare interface design tradeoffs using currently available VLSI components for an *Ethernet* interface. In contrast, R. C. S. Morling, G. D. Cain, G. Neri, M. Longh-Gelati, and P. Natali describe tradeoffs for a discrete component implementation of a high performance interface. The final paper in the design issues category, by S. R. Ahuja, discusses a different high performance bus interface design.

Attention turns next to broader system engineering issues. Three different types of ring communication systems are compared. The first is a token-passing ring: a series of design tradeoffs are discussed by W. Bux, F. Closs, K. Kuemmerle, H. Keller, and H. R. Mueller encompassing media and modulation techniques, protocol fault tolerance, and traffic. The second, by D. E. Huber, W. Steinlin, and P. J. Wild, discusses buffer insertion ring design tradeoffs. The third, by A. Hopper and R. C. Williamson, discusses what functions are candidates for software and what functions are candidates for hardware, both VLSI circuitry and discrete integrated circuits, for a slotted ring.

The focus shifts next to token-passing busses. T. L. Phinney and G. D. Jelatis describe error handling for the IEEE 802 token-passing bus; this is an overview of what a token-passing bus *should and should not* do. S. K. Rahimi and G. D. Jelatis complement this paper with a discussion of a simulation study that systematically verified the assertions of the token-bus protocol and provided insight into design tradeoffs for error handling and for quantifying traffic handling characteristics.

Next, we turn to *central* control rather than *distributed* control of local area networks. First, A. G. Fraser is concerned with developing a universal data transport system, and argues that a hierarchy of centrally controlled switching systems is appropriate, as well as presenting a case study in system design for a virtual circuit packet switch for streams of bytes. The second paper by T. P. McGarty and G. J. Clancy deals with design tradeoffs for cable television technology (CATV) based local area networks for such a hierarchically administered system.

B. Software Systems Engineering

This section deals with software design considerations for controlling local area networks. The first paper by G. Ennis and P. Filice is a detailed case study in local area network protocols. A highly structured data communications network architecture implementation is described, built on top of a broad-band CSMA/CD bus network.

For computer workstations, two views or design choices are presented. The first, by G. Ellis, S. Dillon, S. Stritter, and J. Whitnell, focuses on personal computer local area networking design considerations where the emphasis on manufacturing cost and timeliness for meeting market needs is paramount. The second, by P. J. Leach, P. H. Levine, B. P. Douros, J. A. Hamilton, and D. L. Nelson, describes a token-ring local area network for highly intelligent processor nodes. Different aspects of hardware and software design tradeoffs are described in detail.

C. Media Access Methods and Performance Analysis

Papers in this section are concerned with media access methods and their performance.

The first two papers address variations of CSMA/CD which help improve its performance especially as the load increases and contention becomes severe. The initial paper by W. M. Kiesel and P. J. Kuehn uses the idea of staggered scheduling delays which help provide dynamic priorities in addition to low collision probability. This is to be contrasted with the paper by A. Takagi, S. Yamada, and S. Sugawara in which collisions are resolved by means of reservations so that the previously colliding packets are then transmitted conflict-free.

The third paper, by M. Ajmone Marsan and D. Roffinella, deals with multiple channel local area network protocols. It extends single channel access methods (CSMA and CSMA/CD) to multiple channels and shows that significant performance gains are possible.

The fourth paper, by F. A. Tobagi, F. Borgonovo, and L. Fratta, proposes a broadcast bus local area network called *Expressnet* based on unidirectional transmission. The access scheme for Expressnet is a conflict-free round robin, which permits efficient operation even when the bandwidth is high, the packet size is small, and/or the distance is long. The sixth paper, by J. O. Limb and L. E. Flamm, presents a simulation study for multiplexing voice and data over Fasnet, a unidirectional network meeting the same objectives as Expressnet.

The seventh paper, by I. Rubin and L. F. DeMoraes, provides a systematic analysis of polling and token-passing schemes.

E. Arthurs, G. L. Chesson, and B. W. Stuck close this section with an analysis of theoretical traffic handling limitations of a sliding window flow control protocol over a single virtual circuit: allowing the receiver to buffer two packets achieves virtually all the performance gains of infinite buffering, at less storage cost.

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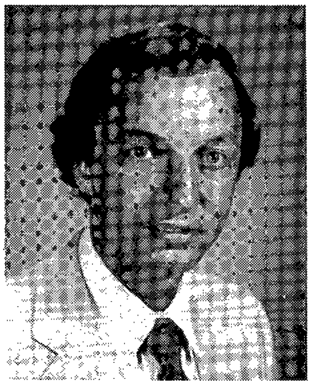

Barton W. Stuck (S'67–M'72) was born in Detroit, MI, on October 25, 1946. He received the S.B. and S.M. degrees in 1969, and the Sc.D. degree in 1972, all in electrical engineering, from the Massachusetts Institute of Technology, Cambridge, MA.

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