ELECTRONIC COMMUNICATIONS SYSTEMS

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ELECTRONIC COMMUNICATIONS SYSTEMS

I would like to dedicate this volume to my brother-in-law,
Glen A. Smith (Bell Telephone Company),
and to
James Burnett (Bell Laboratories)
in appreciation for all the time and assistance they willingly gave to me.

PREFACE

The emergence of high-speed, large-capacity data transmission facilities should make it possible to provide large quantities of useful information on a fast response basis to a broad spectrum of users. Feedback and flexibility features inherent in currently developing telecommunications systems promise to increase organizational capabilities for more complete and faster response to societal needs in such areas as transportation, health care, education, crime control, mail service, and funds transfer. As computer and communication costs continue to decline, at-home terminals should gradually become more popular and affordable. In addition, telecommunications can be used by business, industrial, and government organizations to reduce the costs of necessary administrative functions.

Key developments in data transmission include digital transmission facilities, packet switching, and satellite transmission services. Digital transmission channels are replacing conventional analog voice grade lines in many cases for increased lower cost operations. Packet switching collects batches of slow-speed data into packets for high-speed transmission to achieve more efficient circuit usage, increased accuracy, and smoother data and code conversions than possible with other switching systems. Satellite transmission allows faster transmission of larger volumes of data than previously possible with existing facilities as well as expansion of voice, video, graphic, and data services. However, costs of ground stations must drop further before widespread distribution of data services becomes feasible.

Dedicated or dial-up (switched) services are available, depending upon data volumes, number and dispersion of sending and receiving locations, and response time requirements. Computerized switching and routing of messages, including integration of several functions, can increase system efficiency and reduce operating costs. Mechanization of existing telephone systems with new switchboards, keyboard systems, and other automatic features can also improve system efficiency and effectiveness.

Communications technology has progressed from a high overhead, high cost, slow response vehicle to a more modular, flexible form which can be characterized as a means of increasing corporate profits. By utilizing computing/communications capabilities in this manner, the development of communications technology is closely paralleling the stages of growth in data processing. More timely and higher quality information can be provided by today's computer communications systems than was possible with standalone computer facilities of earlier years. Satellites, fiber optics, and coaxial cables will significantly increase the speed and capacity of transmission channels. Adding computer processing units and computing functions to communication networks will result in such enhancements as electronic switching, smart terminals, and intelligent switchboards with special program functions. However, problems involving conversion of digital data to analog form and the incompatibility of much communications and data processing equipment must be overcome before communications systems reach their full potential.

Substantial reductions in the size, cost, and power requirements for microprocessors have made practical the distribution of computing power and information control to users at local sites in many instances. Centralized systems still permit economies of scale in the use of hardware, software, and personnel resources and centralized control over data processing operations. The degree of need for data access, local processing control, and minimization of communication costs are key factors in the choice between centralized and decentralized data processing. The growth of distributed networks has been facilitated by declines in communications costs and the need for more efficient use of personnel.

Distributed data processing permits distribution of storage and processing capabilities to areas where use is greatest, ease of expansion when data volumes increase and allows CPU mainframes to be relieved of local data processing requirements so they can perform other functions. In addition, distributed data processing systems are not vulnerable to single CPU failure and total system shutdown as is the case when centralized systems are used. Distributed word processing can also be implemented when miniprocessors, storage devices and communication capabilities are added to conventional word processing equipment. Distributed word processing will become even more practical as additional user options, convenience features, and software packages become available.

An increase in the cost and volume of information moved between offices, organizations, and administrative activities has spurred the search for streamlining paper work flows and improving office efficiency. With labor costs increasing 6% to 8% per year and automated technology costs decreasing 10% to 20% per year, many organizations are utilizing word processing equipment to perform typing, text editing, document storage/retrieval, and other administrative functions to reduce clerical costs and expand the capabilities of existing administrative staffs. Current word processing equipment uses CRT editing displays and random access disk storage in a manner similar to minicomputers which process data.

The basic types of word processing equipment include standalone, shared logic, distributed, and hybrid. Standalone systems are the simplest to operate, most common in use, and can be used as building blocks in larger systems. Shared logic systems provide large-capacity storage, sharing of peripherals (printers, facsimile, OCR readers, copiers, etc.), more sophisticated communication options, and lower costs per work station. They are limited by the fact that operators must frequently compete for processing time, text editing functions are complicated, and such systems are vulnerable to single CPU downtime. Hybrid systems permit the same terminal to perform both word processing and data processing functions. Existing networks can be expanded to link word processing, data processing, facsimile, OCR, and copying equipment in one integrated system.

Distributed word processing systems allow work stations to share a variety of resources, input-output peripherals, files, etc., and can be interconnected to distributed data processing networks. Integrations of word processing and distributed data processing systems would permit stored data files to be used for such word processing functions as text editing, automatic document generation and storage, and message transmission. Some word processor-produced reports and documents can be transmitted to computer systems, and current-day data base systems have the capability of selecting data elements and transmitting these to word processing systems for inclusion in word processor-prepared reports.

Communicating word processors with multifunctional, shared file capabilities incorporate some of the positive features of both standalone and shared logic systems. Unlike shared logic systems, communicating word processors can continue to operate even if the minicomputer which drives the network goes down. For best results, communicating word processors will need to be able to send and receive messages in multiple modes. Since word processors are more cost effective for text editing and document generation than minicomputers in most cases, word processing equipment should gradually become a more common user interface to the data processing system.

A wide variety of terminals are available for use with communication networks. Teletypewriters and cathode ray tubes with keyboards are the most common types, but optical character readers, touchtone telephones, facsimile units and computer output to microfilm units are seeing increased use. Terminals now available are becoming more flexible, modular, general-application oriented, and smarter. Intelligent terminal configurations can perform many logic functions independent of the central processing unit.

Many other peripherals are available for use with distributed word or data processing networks. Nonimpact printers (ten times faster than impact printers) can be adapted to shared logic word processing networks and some lower priced models could be used as copiers. Computer output to microfilm units, with a 4-to-1 cost advantage and 100-to-1 space advantage over magnetic tape, is ideal in many cases for storage of documents or data. OCR units can scan hard copy documents produced by OCR ball typewriters (which serve as data entry devices), transmit them to a word processor for editing and storage, with output retrieval being handled by a 50-character-per-second printer. Facsimile units when coupled to broad band channels in satellite systems are competitive with other media in terms of cost and speed for actual document transmission.

The choice between smart and dumb terminals is heavily influenced by computing and communications cost, volumes of data to be processed at local sites, and data input and editing requirements. Smart terminals reduce data entry errors, cut data entry time, and increase operational flexibility in load handling. Dumb terminals are less costly to acquire and operate, require less operator training, and are less complex to understand and use than smart terminals. As terminals decline in cost and multifunctional capabilities are added, integration of administrative systems will likely occur as users strive to reduce total costs and improve overall efficiency.

Expansion of data, voice, message, graphic, and facsimile services should permit using organizations to cut costs, add administrative capabilities impossible before, and integrate administrative functions in word/data processing systems for faster overall performance. Technological developments in hardware, software, and communications are expected to lower data communications costs and help expand service usage. Conventional methods of conducting business are likely to change rapidly as data is increasingly stored, processed, and transmitted by electronic means. One intriguing application is the substitution of computer conferencing for more costly travel, in many cases at a cost comparable to mail and telephone service costs. The availability of wider band transmission channels on satellite systems should open up substantial teleconferencing opportunities.

Electronic mail and messenger services with rapid delivery capabilities are becoming more feasible using facsimile, time-shared message switching services, or standalone word processors. Facsimile is versatile in handling a wide variety of media but is costly and inflexible in message editing, storage, and retrieval. Time-shared systems are best for small users, while standalone systems are more suitable for larger users in many cases. Communicating word processors send whole characters and don't require paper, while facsimile systems require documents for scanning and transmit hundreds of bits for each character. Facsimile seems best suited for convenience applications requiring transmission of entire documents, while communicating word processors are good for routine correspondence. Electronic mail services are likely to expand slowly until centralized and economical word processing/text editing and filing systems can be offered to both large and small users.

The implementation of electronic funds transfer systems could reduce mail volumes by one-third, handling many financial transactions which presently go through the mails. EFTS may improve customer service and system efficiency, but operating and acquisition costs could increase faster than expected and hinder implementation. Present experience indicates that large volumes of transactions are required to justify an EFTS installation. Although no major communication barriers to EFTS installation now exist, problems of privacy, error correction, job losses, and unfamiliar media must be overcome. Adding point-of-sale terminals to banking systems would facilitate check elimination and all electronic funds handling. High initial costs and lack of widespread customer acceptance indicate that only limited applications of POS-EFTS are feasible at this time.

CONTENTS

PART I

BASIC COMMUNICATION CONCEPTS, NETWORK FUNDAMENTALS, AND EMERGING SATELLITE AND PACKET NETWORKS

INTRODUCTION / Data communications systems permit remote data processing using terminals for data capture, channel facilities for data transmission, and computers for data processing. Modems are employed to translate digital signals into a form communication networks will accept, and front-end processors are used to free up central processing time at peak periods, to provide system growth capabilities, and to allow backup facilities in case the central system goes down. The wide variety of terminals, services, and networks available makes communications planning difficult and time consuming.

In terminal-based systems, coding, transmission mode, and speed vitally affect compatibility requirements, as Edwards points out. The common communication codes use six or seven bits and are more flexible and suitable for data processing than the five-bit Baudot code. The transmission mode can be serial (cheaper) or parallel (faster), half-duplex (one-way transmission) or full-duplex (two-way simultaneous transmission), and synchronous (faster, more complex, costly) or asynchronous (slower, simpler, cheaper).

MacMahon maintains that the key to data communications in the future is the development of a universal, shared, national/international, accessible, cheap, standardized, and efficient network. Such a network should be universal enough to handle diverse applications, shared to permit high utilization, national/international to facilitate multicountry data exchanges, accessible to many users, cheap in terms of low-cost connecting devices, efficient in network usage, and standardized to permit its utilization by many different users and devices. Since the communications industry has been characterized by compatible technology while the computer industry has not, arranging a marriage between the two will pose considerable interfacing difficulties.

Digital transmission, satellite transmission, and packet switching are key technological developments that will have an important impact upon the development of a universal communications network. Digital transmission is more accurate and economical than the older, more common analogue version. Packet switching helps ensure efficient network utilization, accurate transmission, and smooth code and speed conversions. Satellite transmission is expanding in usage with the addition of higher frequencies and more accessible locations. The addition of stored program digital switching to satellite, packet switching, and digital transmission facilities makes possible the development of more widespread, accessible, accurate, and economical communication networks than would otherwise be possible.

Farber and Baran* point out that the number of communication services offered and suppliers available is increasing rapidly as the cost of communications and computing declines. The growing use of digital computing within the communications industry plus the increasing interweaving of data processing and communication activities is blurring the once clear-cut distinction between data communications and data processing. As usage of computer-communications systems increases, many of our present institutions are likely to change radically. For example, automation of hotel and airline reservations, financial transactions, and mail services has already changed existing office operations and structures.

Technology is disintegrating the traditional boundary between communication and computer service suppliers, despite the inclination of regulatory bodies to treat them as separate functions. Although small microcomputers can perform many functions, there will always be a need to have large-scale networks that permit resource sharing, integration of related functional activities, and performance of functions not possible with smaller systems. Existing digital channels have proven to be suitable for transmission and switching of large data volumes, and analog voice channels are slowly evolving into an all-digital system. Future consumers of data services should have a larger voice in regulatory disputes between suppliers if their best interests are to be adequately safeguarded.

Quinlan discusses the advantages and disadvantages of current data transmission techniques with respect to cost minimization and resource utilization. Point-to-point systems can be dedicated or shared, using subvoice grade lines (low speed, low cost), voice grade lines (widely used, medium speed and cost), or wideband lines (high speed and cost, often used for computer-to-computer transmission). Dedicated point-to-point systems

*See David Farber and P. Baran, "The Convergence of Computing and Telecommunications Systems," *Science*, vol. 195, 18 March 1977, pp. 1166–1170, for a more complete discussion of these key developments.

are economical for high-volume applications. Multiplexers can reduce costs on point-to-point systems with many outlets but are vulnerable to line loss. Frequency division multiplexing permits larger volumes of data to be transmitted during a given time period than ordinary transmission. Time-division multiplexing is more expensive than frequency-division multiplexing but is economical for six or more channels, permits computer multiplexing and demultiplexing, and allows greater packing density per channel. TWX and Telex services are generally economical only for low-volume applications.

A variety of communication network services are available to meet diverse user needs. Direct distance dialing networks are economical and reliable for low- and medium-volume applications. Dataphone services with variable transmission speeds are available over the telephone network for data communications. WATS services are available for bulk data transmission inside or outside specific geographic areas, allowing ordinary voice transmission during the day and data transmission at night over the same network if desired. Either modems (digital to analog converters) or acoustical couplers (with telephone cradle) can be used to link terminals to transmission channels.

Multidrop lines (similar to party lines) help increase channel usage, cut transmission costs, but also increase transmission delays. Buffered terminals which collect data in batches before transmission are often used with multidrop lines to reduce traffic queues. Systems designers must also decide whether line switching or message switching (no direct terminal connection or real-time communication) will be used. With changing volumes and user needs, a mixture of services, channels, and equipment will likely be required in many organizations.

Duffy indicates that until very recently the only available communications services—Telex, private line point-to-point or multipoint facilities, and dial-up networks—had serious drawbacks. Telex, with its speed and cost limitations, is not fast or economical enough for larger users. Private line networks can be very expensive for small- to medium-size organizations. The costs of dial-up facilities (long distance or WATS) are controlled by distances between parties and length of the telephone call rather than by volume of message traffic generated. WATS services are billed at flat rates which make no allowance for drop-offs in traffic volume levels and are subject to limitations as to the number of users on the line.

The concept of packet networks emerged in the early 1960s as a network sharing counterpart to computer time sharing. One essential element is the use of a minicomputer to control routing and traffic flows. Two companies, Tymnet and Telenet, now furnish common carrier packet network services in the U.S. A wide variety of terminals, both CRT and hard copy, can be connected to this network. The cost of using Tymnet, for example, includes transmission costs (per 1,000 characters), cost per hour for connection to the network, and cost for connection to the host computer. Either WATS or private line service can be used, depending on the number of locations and traffic volumes involved. Packet switching is likely to become increasingly important as communication traffic volumes grow and conventional networks become overcrowded and uneconomical.

Sanders* points out that digital data networks have evolved from modem-connected analog telephone channels to a medium in which computers, terminals, and other devices are connected independently. Despite their popularity, packet networks are not always the most effective way to handle message traffic. Networks should permit alternative resource selection, shared use of redundant and nonredundant facilities, centralized network management, low error rates, and compatibility with dissimilar equipment.

Digital switching, one of the most important technological developments in communications, can take the form of message switching (entire message stored for later delivery), packet switching (divide messages into smaller blocks to minimize transmission delay), and time-division circuit switching (modified version of packet switching which uses smaller blocks of data). Message switching has proven useful for handling administrative messages in large organizations but involves too much delay for many interactive applications. Packet switching significantly shortens time delays in transmission, but time-division circuit switching can result in shorter network time delays, particularly for messages sent by low-speed terminals.

Concentration of incoming lines to a trunk line will not always result in lower cost operation. Costs of providing digital transmission services have been declining rapidly while local distribution costs have not changed appreciably, so local distribution costs will likely become more important than efficient use of long-haul trunks. Neither time-division circuit switching nor packet switching is clearly more efficient in all cases or easier to implement. Both types of switching techniques and combinatorial forms will all have a role to play in future networks.

Bruun draws a clear-cut distinction between message switching (store-forwarding of complete messages) and packet switching (block transmission of word-size segments with message assembly at the receiving end). Packet switching combined with wide band lines reduces errors and noise encounters as well as increases the transmission rate for large computer files. Minicomputers can be used to perform routing functions, bypassing normal channels if they are congested. Packet switching also facilitates man-machine interaction and real-time interaction between computers.

*See Ray W. Sanders, "Comparing Networking Technologies," *Datamation,* July 1978, pp. 88–93, for a more detailed discussion of these topics.