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NETWORK SWITCHING

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1. INTRODUCTION

In order to interconnect millions of telephones worldwide, a definite pattern of switching network hierarchy has been designed to handle mostly voice traffic in each country. These traditional analog networks are now rapidly changing due to: a) introduction of digital switching, and b) increasing data traffic resulting from computer communication. Several other major factors, such as governmental regulations, component technology, satellite communication, and office automation influence the manner in which switching networks are evolving to meet the future informational needs of society. This emphasis on information as an end product will change the fabric of the existing network and bring our society closer to the information age.

Digital switching, in which the conventional analog voice information is sampled, quantized, and converted by coding to a digital signal for time-division multiplexed switching, is being rapidly introduced in the existing telecom switching networks. It is only a matter of time before the largely analog telephone network becomes all digital [1]. The era of sending information by digital means is accelerating because it offers two advantages: lower cost and better performance. Devices like codec, microprocessors, memory, and other logic elements are no longer expensive. They are highly reliable, compact, and consume less power. As a result, digital switching networks implemented with these devices are cost effective, use fewer components, require less floor space, provide high reliability, consume less power, and are easier to install and maintain. The performance in the digital network is better because digital repeaters allow the digital signal to be regenerated at a predetermined location, to provide an overall transmission quality independent of distance. The performance is also enhanced due to the fact that information from a variety of sources (audio, video, facsimile, data, etc.) can be multiplexed and transmitted over telephone cable, coax, microwave, radio, fiber optics, and other media. This versatile source multiplexing capability will allow future networks to integrate voice and data information. information.

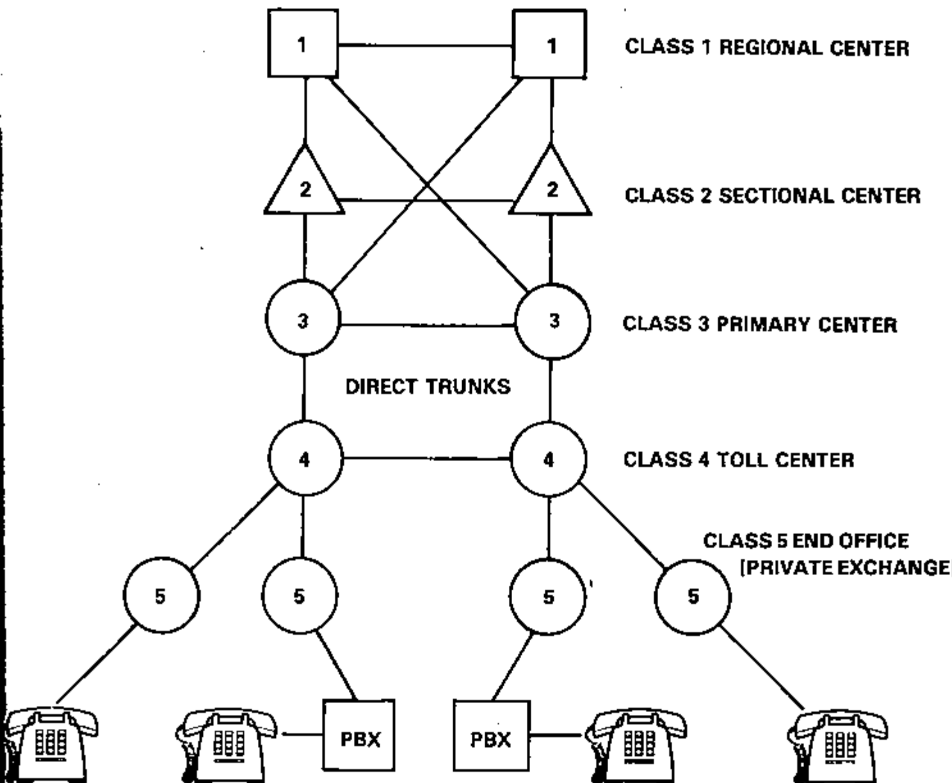
After a brief introduction to switching network hierarchy and switching technology, this chapter discusses the evolution of digital networks from the viewpoint of major influencing factors resulting in common carrier type public networks and corporate type private networks. The issues related to service integration in digital networks are also explored. Based on the trends in evolving digital networks, it is apparent that the networks of the future will enhance integration, not only of transmission and switching, but also of voice and data service capabilities.

2. SWITCHING NETWORK HIERARCHY

In order to interconnect millions of telephones worldwide, a definite pattern of switching hierarchy has been designed so that the hierarchical structure and associated priorities given to each switching node determine the routing pattern for the overall network traffic. As a result, the telecom network interconnects, almost instantly, over 90% of the approximately 400 million telephones in the world through this hierarchical structure, through clusters of equipment that the telephone user rarely sees. This switching system equipment has two basic functions: 1) signaling — to detect service requests (dialing, ringing, etc.) and 2) connection — to set up communication paths.

In this network of switching systems, a complete end-to-end circuit connection is established for each pair of voice users and dedicated for the full duration of use. A subscriber enters the switch node and originates a call by going off-hook and then directly dialing the number of the terminating party. The switch then sets up a dedicated connection between the originating and terminating subscribers, which consists of a series of patched together circuits paired together by switches at the junctions between them in the network. This connection is established by a signaling message that passes through the network. A return signal tells the source that transmission can begin. The connection exists for the two parties until they terminate the conversation. These switching networks, in which the connection is used exclusively during the conversation, are called circuit switching networks. Although some time-division multiplexing can take place in a portion of the transmission and/or switching system, the parties will not notice it. All traditional telephone public networks are of the circuit switching variety.

The standard switching network hierarchy classification and homing arrangements in the North American system are shown in Figure 1. In general, the telephone loops are terminated for the purpose of connection to each other and to the network at a Class 5 exchange. These exchanges are also called "end offices," "central offices," or "public exchanges." The switching exchanges which provide the



SWITCHING NETWORK HIERARCHY

FIGURE 1.

first stage of concentration for network traffic originating at end offices are called toll centers or tandem offices. Certain switching systems, in addition to connecting a group of end offices to each other and to the network, are selected to serve high ranking switching functions on the basis of overall network economies and controls. These levels are primary centers, (designated Class 3), sectional centers (designated Class 2), and regional centers (designated Class 1). Each of these high ranking switching systems performs functions and services of the low ranking systems. Since all the telephone loops are terminated at the central office, anything below the Class 5 level is considered a Class 6 office. For example, private automatic branch exchanges primarily used by business, hotel/motels, etc. are connected to the central office (below Class 5) for access to the switching network hierarchy.

3. SWITCHING TECHNOLOGY

For several years after the invention of the telephone, switching was performed manually. The introduction of electromechanical switching equipment (such as the step-by-step switch), during the early 1900s, revolutionized switching by opening the door to automation. During the 1940s, crossbar switching was introduced, followed by electronic switching in the 1960s. These two concepts further automated telephone switching by establishing common control.

Modern switching systems consist of two fundamental building blocks: control and switching matrix. Control, which provides all data necessary to establish a connection, can be implemented through electromechanical hardware or through a sophisticated stored-program digital computer system. As shown in Table 1, the control technology has improved from the electromechanical-type of direct progressive control in the 1920s to digital stored-program control using microprocessors in multiprocessor configurations in the 1980s [2].

The switching matrix, which is the heart of any switching system, provides physical transmission paths between any two or more telephones. The network technology of switching matrices has long been based on crossbar switches and relays. These are known as analog matrices because they process the voice represented by analog signals. On the other hand, in digital switching matrices, information is processed and converted to discrete binary signals. This binary information is then switched through semiconductor logic gates and/or memories.

TABLE 1
Control Developments

Time	Technology	Concepts	Components	Remarks
1920s	electro-mechanical	direct progressive control type	step-by-step	a part of the network needs periodic maintenance
1960s	electronics	wired logic	diode, transistor, etc.	concept not flexible in providing features
1970s	digital	stored program (monoprocessor)	electronic logic gates and core memories	expensive for small sizes, more flexible but complicated due to the type of components used (mainly core memories and monoprocessor)
1980s		stored program (microprocessor)	microprocessor and semiconductor memories	cost effective, flexible, simple to implement for small system sizes

As shown in Table 2, the switching matrix developments have progressed from the traditional electromechanical techniques of the 1920s and 30s to the electronic technology of the 60s and now to digital switching in the 80s. Similarly, the component technology required to implement the switching matrices has changed from relays and crossbar switches in the 1920s to logic gates and memories in the 80s.

TABLE 2
Switching Matrix Developments

Time	Technology	Concepts	Components	Remarks
1920s	electro-mechanical	analog (SD)	relay crossbar Strowger	bulky, requires periodic maintenance (contact cleaning, etc.)
1960s	electronics	analog PAM (TDM)	PNPN diodes transistors	lack performance and compatibility with outside telephone plant
1980s	digital	PCM DM DPCM	digital logic gates and memories	smaller, reliable, and cost-effective

4. DIGITAL SWITCHING

The most common method of digital information processing is called pulse code modulation (PCM). PCM, invented by A.H. Reeves in the 1930s, did not become a commercial reality until the 1960s when the Bell System introduced it for point-to-point digital transmission in metropolitan networks. PCM was found to have applications in switching only after the necessary semiconductor technology was developed.

PCM provides two main advantages over analog methods: performance and versatility. Since a signal is presented in a digital form, it can be regenerated. As a result, the noise, stability, and accuracy problems of analog transmission are eliminated. Because of PCM"s digital nature, information from a variety of sources (such as voice, video, facsimile, and data) can be multiplexed.

Over the last twenty years, two commercial PCM transmission formats have evolved: the North American 24-channel and European 32-channel. The North American format was introduced first. It involves multiplexing 24 analog voice channels, which are sampled at a frequency of 8 kHz and encoded into an 8-bit non-linear digital signal to form a 1.544 Mbit/sec stream. Similarly, the European format involves multiplexing 32 channels, of which 30 channels are used for voice and two are used for signaling. The European format results in a transmission rate of 2.048Mbits/sec.

In digital switching, the analog information that has been converted to a commercial PCM format (24 or 32 channels) is switched through electronic digital devices, such as logic gates and/or semiconductor memories. Digital switching provides initial cost savings due to shorter prove-in distances for digital carriers, fewer trunk requirements resulting from non-blocking possibilities, and elimination of conventional load balancing problems. Digital switching systems implemented with microprocessor memories and per channel codec elements are cost effective, use fewer components, require less floor space, provide high reliability, consume less power, and are easier to install and maintain.

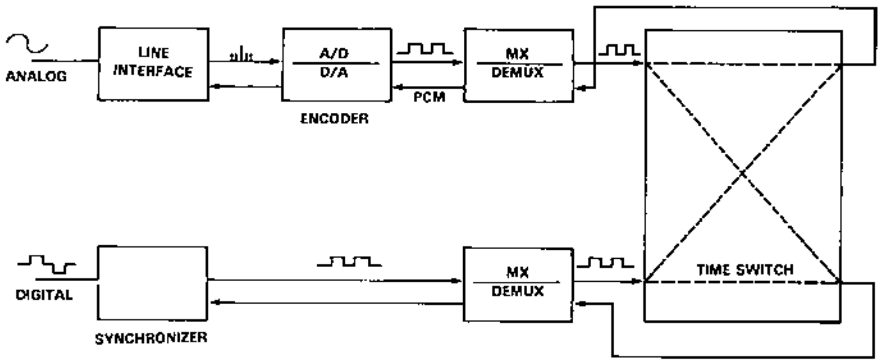
As shown in Figure 2, the input to any digital switching system may be analog or digital. Digital conversion of analog input demands that line interface circuits sample analog information. An A/D converter then sends the digital signal to a multiplexer for time division multiplexing and transmission. This arrangement is repeated, in reverse order, at the receiving end of the transmission.

TABLE 3

Comparison Between Analog and PCM Digital Networks

Analog	PCM Digital
switches analog waveform and requires analog components and crosspoints, such as PNPN, transistor relay, etc.	switches digital waveform and requires logic gate or memory as crosspoint element.
crosspoints are expensive and bulky (low packaging density)	crosspoints are miniature and inexpensive with hundreds or thousands per device (high packaging density)
line interfaces are simple	line interfaces are complex due to A/D conversion
line circuit costs are low	line circuit costs are high
network costs are high	network costs are low
non-blocking configurations are economically impossible	non-blocking configurations are natural
the network components are not consistent with the control components and future trends	network and control components are alike, consistent with future component trends
non-bandwidth limited	bandwidth limited
cannot be integrated with major carrier concepts	provides foundation for the integration of transmission switching
requires substantial space	less space required
difficult to install due to multistage configurations	large expansions can be configured easily
requires periodic maintenance of electronic crosspoint	periodic crosspoint maintenance is not required

Direct digital input does not need code conversion hardware and is fed directly into a synchronizer to derive accurate timing arrangements. As shown here, PCM digital switching is inherently a 4-wire process. In order to switch channels between two separate digital multiplexed buses, switching in space (between buses) and switching in time (between channels separated in time) is required.



DIGITAL SWITCHING PROCESS

FIGURE 2.

Since PCM transmission was first introduced in a predominantly analog switching network, digital-to-analog and analog-to-digital conversion was required at every switch node. Such conversion is necessary to interface with analog switching. This conversion is not only expensive, but also introduces quantizing noise at each analog switching node.

The phenomenal rate at which PCM transmission systems have been used worldwide has created a need for digital switching applications where transmission and switching are both handled in digital format. The expensive "conversion" is not required if digital switching is used in a digital PCM transmission environment. This integration of transmission and switching is highly desirable to improve overall network performance and cost.

Although the world's telecom networks are going digital, the changeover from analog is occurring gradually through careful planning in order to avoid any major service downtime. Almost all of the advanced countries in the world are now implementing digital switching networks to integrate transmission and switching in their national switching hierarchy.

5. FACTORS AFFECTING SWITCHING NETWORKS

The evolution of switching networks in North America is affected by the following major factors:

- government regulations
- component technology
- satellite communication
- data communication
- office automation

5.1 Governmental Regulations

Since the original Federal Communications Commission (FCC) decrees in the late 1960s, the private switching market, traditionally operated by telcos, has been open to competition. This has given birth to a new industry called "interconnect." This industry is designed to meet corporate communication needs and has grown considerably in the last five years in the PBX and key system markets. Along with the interconnect, a general trend toward deregulation and a political climate which favors competition in the U.S. has opened opportunities for new ventures by communication carriers other than the giant Bell System. As a result, the specialized common carrier industry has emerged to provide special business and residential service through specialized networks implemented through lines leased from the telephone company.

5.2 Component Technology

Semiconductor component technology today offers considerably more performance by providing more components on a "chip" at lower cost. This is having far-reaching implications on terminal, transmission, and switching equipment. Electronic telephones with multibutton feature capabilities are bringing new dimensions to telephone networks. The per channel codec and filters are making digital switching cost effective and compact. With the advances in semiconductor technology, bubble memory, fiber optics, and other components, information management, storage and transmission are becoming a reality through telephone networks.

5.3 Satellite Communication

In the 16 years since its introduction, satellite communications has changed the way we think about overseas communication. U.S. - developed satellites now carry more voice, data, and facsimile and, during an average day, handle about 2/3 of all overseas telephone traffic. Domestic use of satellites is also increasing. The U.S. has developed domestic satellite systems to provide high quality telephone traffic, high speed data, and mobile communication facilities.

5.4 Data Communication

The boom in data communication that started in the 1960s is beginning to find wide acceptance through new service offerings. Low speed data in the 300 - 2400 baud range, and below, is easily handled through normal telephone networks. However, high speed data require improved facilities with line conditioning capabilities. Because of its inherent digital nature, a 64 kbit (8 kHz sampling multiplied by 8 bits per channel) data switching capability is provided for all voice channels in the PCM digital network.

The heavy emphasis on data to enhance communication with computers will require data transmission and switching along with digital voice.

5.5 Office Automation

The introduction of word/text processing in the mid 1970s, coupled with the rapid introduction of digital switching and data transmission, has greatly accelerated the drive toward a fully automated "office of the future." The aim of the office of the future is to increase productivity of the white collar office worker through efficient communication and information management facilities. This would require step-by-step integration of routine office functions (like electronic mail, filing, and text editing) into an office which has efficient interface with intercompany and intracompany data bases through novel hardware and software products.

6. EVOLVING DIGITAL NETWORKS

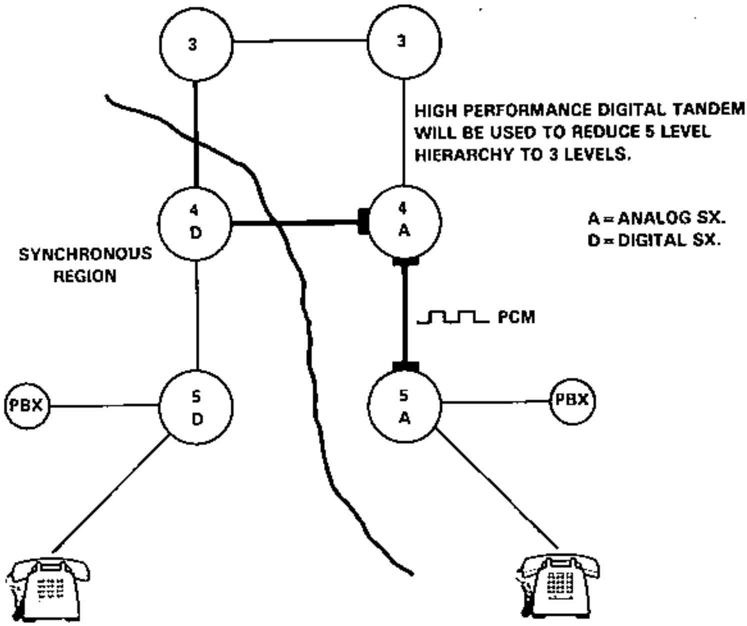
Based on the developments affecting switching networks, four major types of digital switching networks are evolving in the United States:

A. Telco
B. Specialized Common Carrier (SCC)
C. Corporate
D. Data

6.1 Telco Networks

The U.S. telco network, considered the best in the world and operated mainly by the Bell System, is an incredibly complex mesh of millions of circuit miles of transmission facility and thousands of switching modes. It handles approximately 150 million telephones with over 10,000 switching systems, over 100,000 telephone operators, and 150,000 test and maintenance personnel. This network handles approximately 200 billion local calls, over 20 billion toll calls, and approximately 100 million overseas messages per year.

This complex telco network is evolving from analog to digital systems with minimum service interruptions. As shown in Figure 3, transmission facilities were the first part of the network to successfully use digital PCM techniques. Here the savings were that of copper wire versus digital repeaters and channel bank hardware for interface with the analog switching plant. The PCM carrier is also used for interoffice trunks and intertandem trunks along with subscriber line carrier for pair gain devices.



TELCO NETWORKS

FIGURE 3.

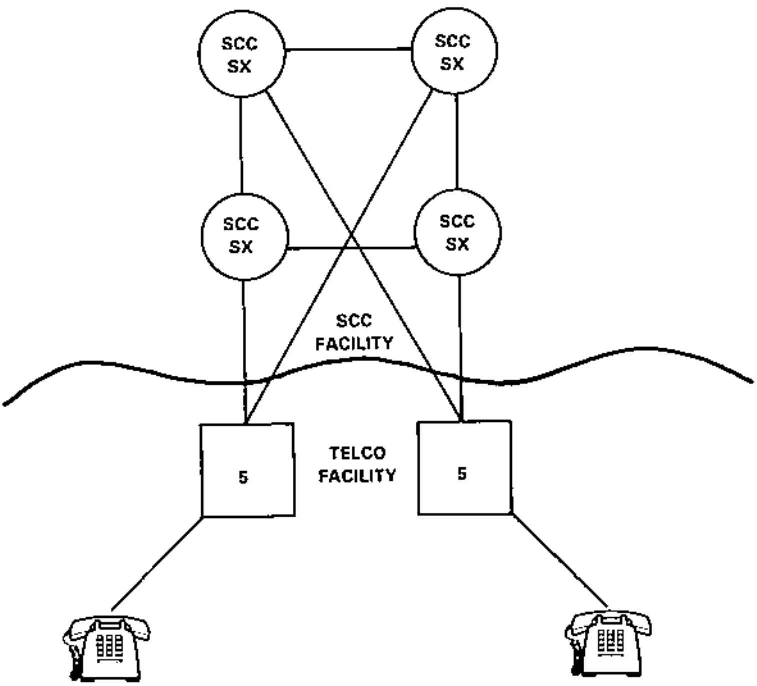
The next thrust of digital implementation in the telco network was tandem switching. In 1976, the Bell System put into service in Chicago the largest digital switching system in operation, called No. 4ESS. It has 107,000 terminals, capability for 1.7 million CCS traffic capacity, and 550,000 busy hour call attempts capability [3]. By now, it is estimated that about 40 No. 4ESS systems have been installed. The key to the evolving digital telco network is that, due to the high terminal and traffic handling capacity of the No. 4ESS, the 5 level switching hierarchy potentially could be reduced to three switching levels. (Figure 3).

The Bell System, due to its heavy revenue in the long distance telephone network, has concentrated on digital implementation for toll tandem applications. At the same time, independent telephone companies have installed digital central offices and digital PBX systems developed by independent U.S. equipment manufacturers. At present, it is estimated that several hundred thousand lines of digital central office equipment and probably an equal amount of digital PBX equipment is in operation in the telco network.

The telco based digital network is developed to provide synchronous and asynchronous operation. In general, it is believed that the higher ranking switching exchange in the hierarchy will provide a master clock mechanism to provide slave operation for the lower ranking exchanges. As a result, several synchronous exchange areas with high stability clocks will evolve in the network. The communication between these synchronous areas could be synchronous or asynchronous with an allowable slip objective (due to clock differences) of one slip or less every five hours on any end-to-end communication.

6.2 Specialized Common Carrier (SCC) Network

The specialized common carrier network shown in Figure 4 consists of leased lines from the telco, connected to specialized tandem switching network. In a specialized common carrier network, the subscriber dials a normal seven digit number to gain access to the specialized network. At this time, the subscriber gets a special tone and is ready to dial additional digits (10 or more, with or without account code identity) for the terminating party.



SPECIALIZED COMMON CARRIER NETWORK

FIGURE 4.

Since the landmark decision by the FCC in 1971, which opened the private line interstate communications market to competition, SCCs have been moving in the direction of more generalized, dial-up service that competes with the message toll services, which is the heart of Bell's offerings. Five major specialized common carrier networks are in existence:

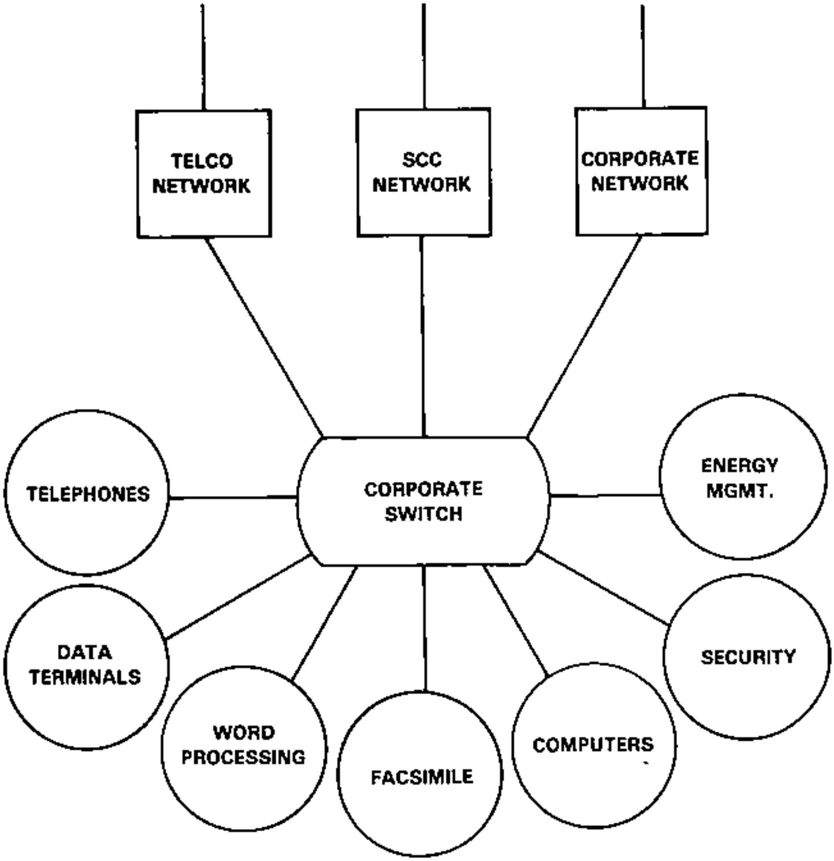
1. MCI (Microwave Communications, Inc.)
2. SPCC (Southern Pacific Communications Company)
3. USTS (United States Transmission Systems – ITT)
4. SBS (Satellite Business Systems)
5. Western Union

6.3 Corporate Network

The corporate private network is evolving as the backbone for high traffic-carrying office information systems with an integrated voice and data capability. Digital satellite communication with ground facilities on customer premises is expected to become the major medium for all long distance communication between corporate offices for the Fortune 1000 organizations in the next decade. These networks will change the way business is conducted. They will facilitate communication of voice, text, data, facsimile, Telex, video, and allow transfer of large distributed data bases.

The conventional electromechanical and/or electronic PBXs that have been designed to handle voice traffic for internal (line-to-line) and external (line-to-trunk) communication in businesses, hospitals, hotel/motels, and universities are now changing to stored program controlled digital systems which, along with hundreds of fancy call processing features for station users, attendants, trunks, etc., provide several major system features to monitor and control communication costs. These features include traffic measuring, detailed call recording, least cost routing and automatic trunk queueing. With the emphasis on improving the office productivity of white collar workers, the nature of information to be handled by PBXs is also changing rapidly. As a result, the digital stored programmed PBX is becoming a total corporate switching system which will interface with telephone, data terminals, word processing, facsimile, computers, security and control.

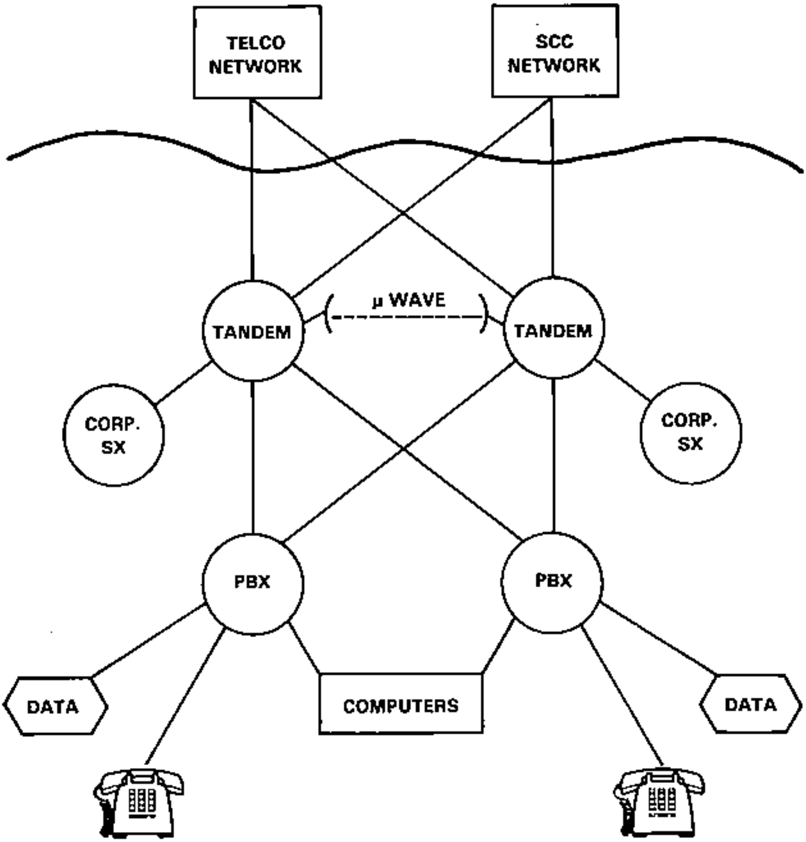
It is apparent that the corporate switch will form the crux of the overall data and voice communication activities of the future. In other words, along with the normal voice, the corporate switch will handle data from a variety of sources to implement and enhance new concepts aimed at office automation, like electronic mail, and



CORPORATE SWITCH
FIGURE 5.

message centers. It will also facilitate distributed data base transfer between computers and enhance control functions, such as security and energy management. As shown in Figure 5, the corporate switch will communicate with the outside world through telco, specialized common carrier, or private corporate owned transmission facilities.

In today's office environment, all of the corporate switch functions are provided through isolated building blocks. For example, today's telephone network is totally different in terms of cable plant from the corporate computer network, which in turn is different from the security system. Through a combination of voice and data switching



PRIVATE CORPORATE NETWORK

FIGURE 6.

capabilities the corporate switch will incorporate all of these facilities into one homogeneous monolithic node with integrated service potential.

As shown in Figure 6, the private corporate network would consist of several PBX and/or office switching systems handling data, telephones, and computers, connected to each other through digital tandem nodes. These tandem nodes could be implemented either on a shared basis as a part of the corporate switch with joint PBX/tandem capabilities, or on a stand-alone basis. The tandem nodes would communicate either through analog facilities or through digital T-1 lines using microwaves, radio, fiber optics, etc. The communication with off-net links would be through telco and/or specialized common carrier facilities.

Several major corporations are now moving to improve overall communications cost and performance through their own private networks. The private networks also provide the necessary control to manage internal corporate communication resources effectively. The private corporate network market for products such as PBX, tandem, microwave, satellite, terminals, and associated services is one of the fastest growing telecommunication markets in North America today.

6.4 Data Networks

The advances in computer communication require switching networks capable of handling a variety of data terminals at multiple bit rates. Data traffic rates range from low speed teleprinter terminals of 75 - 300 bits per second up to a few mega bits per second for facsimile, video, and interactive graphic terminals. As a result of these varying data speeds, it is desirable to develop packet switching networks to send data packets (typically 50 - 500 milliseconds per packet).

As opposed to traditional voice based circuit switching, the packet switching networks are fast and do not require end-to-end connection in space at all times. In other words, packet switching eliminates the need to dedicate an actual physical path for each call. In packet switching arrangements, a network of intelligent switching nodes is created by placing computers in selected locations and interconnecting them via leased telephone lines in such a way as to permit any node to communicate with any other node in the network. The packet switching data network consists of interconnected terminals and/or computers that communicate through message packets. These terminals allow interactive data communication and transfer between terminal users. Message switching is similar except that the intermessage time per message is typically much greater (from seconds to several minutes).

One of the problems with the packet switching data networks is achieving compatibility between various types of terminals and/or computers. This compatibility does not exist in the industry at this time. Based on the expected high growth in the data communication market, at least three large corporations are setting up ventures for nation-wide data transfer networks:

1. Advanced communication service and a scanning band satellite system service, both from AT&T.
2. Satellite Business Systems (SBS) — a three-way partnership formed by IBM, Comsat, and Aetna Life and Casualty Co.
3. Xerox telecom network by Xerox Corporation.

The value added networks have added features to existing networks leased from telcos or specialized common carriers. In practice, there are three leading value added networks which use packet switching techniques: TYMNET, TELENET, and GRAPHNET. The future digital voice networks need to coexist and provide proper interface with these data networks.

7. SERVICE INTEGRATION THROUGH DIGITAL NETWORKS

Service integration through digital networks will play an important role as new networks evolve from predominantly isolated voice switches to fully integrated voice and data networks. The main reason for this service integration is to reduce overall equipment costs by sharing hardware and software facilities, and increase performance by providing uniform operations, such as feature transparency, uniform numbering plan, centralized maintenance, and centralized operators.

Two types of services are being integrated in the digital networks: 1. traditional and 2. neoteric. The traditional service integration includes facilities like main satellite attendant service and remote access for maintenance and administration. Main satellite service is required to provide an expansion capability for a multi-location facility where uniform numbering plan and feature transparency are necessary. Centralized attendant service is essential to manage centralized attendant resources at a single location in applications such as catalog houses and department stores. The integration of these traditional services generates additional traffic on the tie trunks between these facilities and regional centers. The neoteric services, like electronic mail, message center, word processing, and telephone directory management are predominantly large data base oriented computer services that require appropriate interface with the switch controller. Most of these new services are data processing oriented and have very little impact on the overall switching network architecture. These services do require efficient data transmission through the switching matrix. Data transmission and switching in a predominant voice environment require special handling in the switching matrix and greater control due to different holding times and associated patterns.

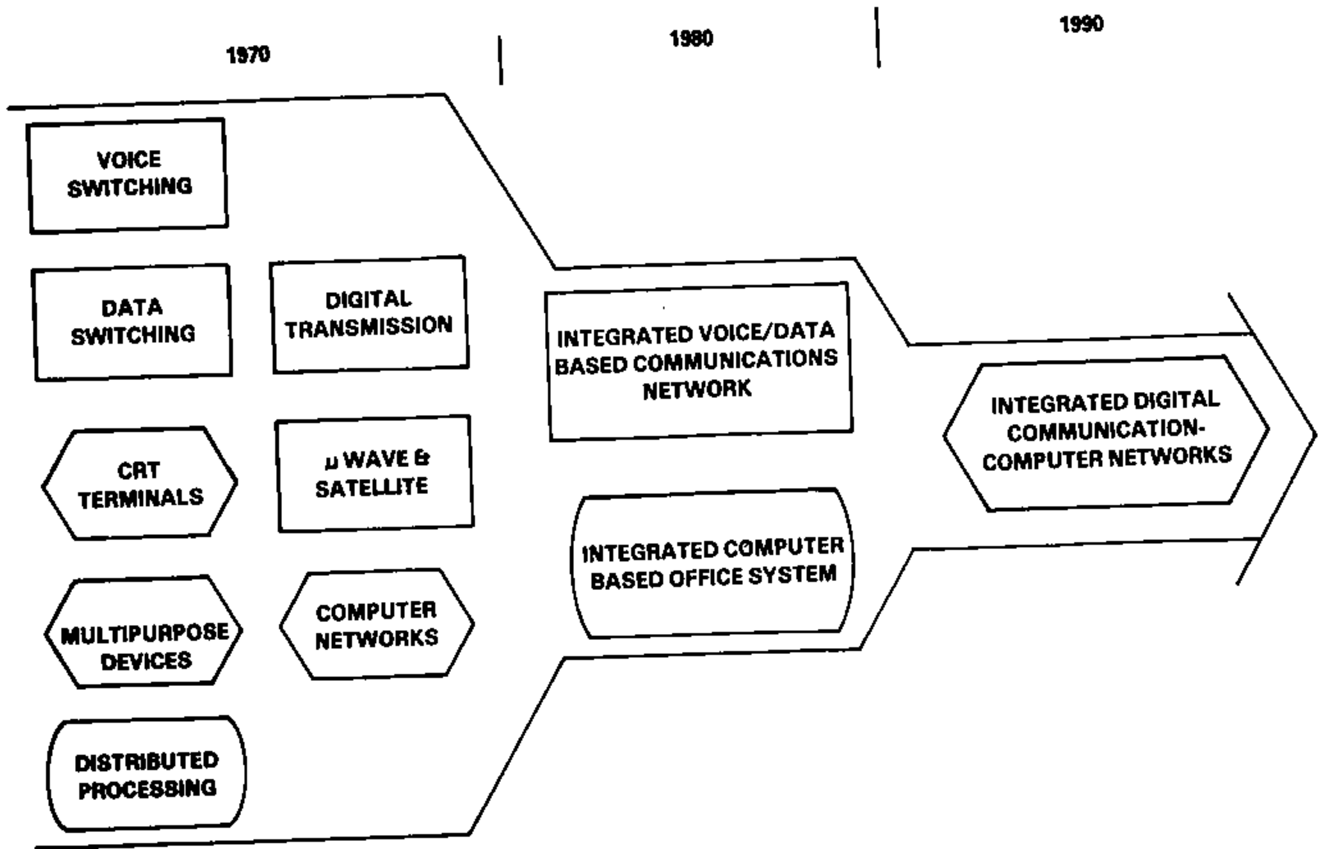
Almost all communication switching matrices have been designed to incorporate blocking, so that the number of subscribers terminated on a switching system are far greater than the number of network ports [4]. As a result, the number of simultaneous calls in a system is limited by the number of available network ports. This means that, if all the network ports are busy, there is no facility to set up additional communications and dial tone is delayed until a network port is available. Normally, blocking networks are based on careful traffic considerations in terms of holding times, number of origins, busy hour acceptance, etc., in order to guarantee a certain grade of service so that the probability per telephone subscriber of blocking does not exceed a certain percentage (.01 percent for example). All traditional analog, electromechanical, and electronic networks have built-in blocking characteristics. The PCM digital networks have only recently allowed non-blocking and full availability at significantly lower cost. However, due to the traditional telephone approach, even today, several digital switching products are designed to incorporate blocking.

Most of the present voice based switching networks are designed to handle shorter holding times in the order of 120 - 180 seconds per call. With the introduction of data traffic, these holding times are going to change considerably to as much as 30 or more minutes per call. As a result, traditional traffic calculations do not apply to an office switch where integrated voice and data is essential. These office switch products must provide completely non-blocking, full availability switching matrices, so that every inlet can carry the full 36 CCS (100 calls per second) traffic.

8. NETWORKS OF THE FUTURE

As shown in Figure 7, the switching networks of the 60s have been isolated in the form of a separate building block of predominantly analog equipment and facilities. The networks of the 70s started implementing digital technology with digital switching and stored program control to provide integration of transmission and switching. By the 70s, stored program control was well recognized for feature flexibility, automatic maintenance, and administration. However, the voice based switching and transmission facilities were still basically assigned. The isolation is evident in separate equipment, facilities and services.

The digital networks of the future are aimed at integration of data and voice through the same equipment and facilities. This shared concept would ultimately enhance service integration. The impact of this integration will be felt first by the North American and European corporate world. It will definitely change the manner in which



EVOLUTION OF FUTURE INTEGRATED DIGITAL NETWORKS

FIGURE 7.

business is conducted in the future. The successful implementation of future digital networks lies in our ability to provide a proper balance between digital technology-driven office automation facilities (such as electronic mail, electronic filing, word processing, executive work station, etc.) and the human desire to be constantly challenged with growing aspirations and creativity in the normal work environment. Only the future will provide the answer.

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