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Technology Trends in Telecommunications: An Overview

U.S. DEPARTMENT OF COMMERCE
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PREFACE

This article describes the technology trends for telecommunications and their impact on the services provided to the user. The impact of divestiture, together with the advancement of some enabling technologies, is leading to a rapid diversification of the telecommunication industry. This diversification is the subject of this study that summarizes trends in a historic perspective.

This report was developed by a team of telecommunication specialists within the Computer Systems Laboratory of the National Institute of Standards and Technology (NIST). Mention of certain vendors, commercial equipment, services, and instruments does not imply recommendation or endorsement by NIST.

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I. Introduction

A. Significance of Telecommunications Technology for:

1. Productivity

Today's business is driven by information. Two-thirds of U.S. businesses are based on manipulation of information. Effective access to information is therefore the key to productivity in a competitive marketplace. This need is felt by diverse markets including airlines, financial institutions, real estate, construction, small business, heavy industry, and emergency medical care. The users of this information are not only in fixed locations, but also mobile locations. In order for these users to be productive, they must have reliable access to their information, on demand. Because the information may be located far from its point-of-use and at multiple locations, a telecommunications infrastructure is critical to productivity.

Traditional Automated Data Processing (ADP) businesses (e.g., banking and airlines), have become geographically widely distributed businesses that depend heavily on the availability of telecommunications resources for communication within the organization or with the parties with which they do business. Telecommunications has made timely transactions and access to information possible from widely distributed sources. National and international organizations have centralized corporate data which must be accessed, in a timely fashion, by their agents located anywhere around the world. The growth of these organizations is highly dependent upon the ability to access advanced communications wherever they do business, nationally or internationally.

Telecommunications is also becoming increasingly important to manufacturing industries. It provides a direct link to suppliers, reducing the overhead of "middlemen" and greatly enhancing the effectiveness of "just-in-time" production techniques. Such real-time ordering techniques would not be possible without effective telecommunications. In addition, communications within the organization are enabling better coordination of the organization. For example, the engineering department can monitor production line activity in real-time, from remote locations. When problems arise, solutions can be developed remotely and sent to the production department for implementation.

The specific information required by users is becoming more and more sophisticated. Productivity has been enhanced by high performance personal computers that have enabled use of increasingly sophisticated applications by individuals. Since the information required is frequently located in a remote location from the user, efficient telecommunication, capable of meeting the requirements of sophisticated applications, is critical to bring the data to the user.

Advanced applications are currently available in the marketplace, prepared to bring information to users. These applications will be placing increasing demands on the telecommunications infrastructure as their use becomes widespread. The lack of availability of advanced telecommunications is currently one of the major factors that inhibits more widespread use of these technologies.

One such advanced application is personal videoconferencing. Videoconferencing has the potential for substantially reducing the time spent traveling to meetings. It also makes telecommuting a more viable option to the traditional office. It allows face-to-face meetings, without the overhead of travel. A videoconference, combined with desktop data conferencing, not only allows face-to-face interaction, but real-time, collaborative work, without travel, using any applications that may reside on the workstation. This could involve joint editing of documents, graphics editing, etc. More complex extensions of these applications involve concurrent engineering in a Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) environment, where the parties involved in the project may be in widely separated geographic locations. Advanced telecommunications preclude the need for travel to each other's location and provide timely access to each other's data, still retaining the potential for personal interaction similar to that in an on-site meeting.

Much time is still spent in business waiting for transfer of large paper documents. Many organizations are moving toward a realization of the "paperless office." Transfer of documents in electronic form greatly enhances the availability of information and reduces the possibility of damage or loss of paper documents. Many of the issues that have inhibited the paperless office, in the past, are now being resolved. At the heart of this concept is a telecommunications infrastructure.

Cellular telephones have made a significant impact on the availability of voice-based communications. This technology has made the ability to communicate with voice-grade service virtually ubiquitous. Data devices used with traditional telephones are now being used with cellular phones. If digital communications, comparable to those in the terrestrial-based service, become available in a wireless form, the same advanced applications that are used in the office could be used virtually anywhere. This will enable both the "portable office" and the Personal Digital Assistant (PDA). A portable office is a small, easily portable system that contains information and communication services that include a computer, facsimile machine, printer, and wireless telephone. Such systems are currently available from IBM[1], Apple[1], AT&T[1], and others.

Sophisticated applications typically demand and create new types of data. Voice and text are just a small subset of the types of information that needs to be communicated. Increasingly, users require image and video data to fulfill their needs efficiently. Video and image data place heavy requirements on telecommunications. High-speed communications are required for timely transmission of high resolution images and

[1]Mention of companies and/or products in this report does not imply endorsement by U.S. Government Agencies.

high-fidelity, full-motion video. This requirement becomes immediately apparent for remote medical diagnosis and large-group videoconferencing. The transmission of these types of data must result in high quality images being viewed by the user.

The rapid introduction of digital wireless networks is an important part of the emerging digital communications scene. The introduction of Digital Cellular, Low Earth Orbit (LEO) and Geosynchronous Earth Orbit (GEO) Satellites, and Personal Communications Services (PCS) poses both a challenge and an opportunity for the data user. On the one hand, wireless access will introduce significant new portable data services, such as personal notebooks, paging, E-mail, and fax, that will put the Information Age in the user's pocket. On the other hand, the challenge of creating a seamless and transparent environment for the user in multiple access environments and across multiple network connections is formidable.

Multimedia Wireless Data represents more than just a combination of the Radio, Network Switching and Data technologies of which it is composed. These disciplines have evolved largely in independent communities and their fusion is neither obvious nor direct. Each has been spawned with separate technologies and in separate markets. It is only recently that combinations of these disciplines have been merged.

Cellular telephones, for example, combine the Network Switching and Radio technologies for voice applications, while ISDN combines Network Switching and Data technologies. The integration of all three disciplines into Multimedia Wireless Data services combines the challenge of operating in the harsh radio environment with the sophisticated protocols required for data, and with the seamless services, switching, and transparency required of modern networks.

The fusion of these disciplines is particularly challenging in light of the variety of access mechanisms that are possible, such as Cellular, Satellite, and Wireless Local Area Networks (WLAN), each presenting separate sets of strategies, standards, and problems. The successful integration of these technologies has typically been viewed under the umbrella of Personal Communications Services (PCS) and Networks (PCN). While market forecasts for PCS are euphoric, the technical coordination and management problems facing PCS are formidable. Essential to real progress in addressing these problems are, first, a clear strategy for accomplishing these technical challenges, and second, much greater cooperation among the independent communities of interest. The potential for PCS applications appears unbounded. It offers the possibility for creating a new infrastructure for the Information Age with improved services, convenience, and productivity.

Mobile users demand additional capabilities from telecommunications. Rural locations are not likely to have advanced telecommunications available from the local telephone office. Non-land-based users will clearly require other sources of telecommunications. Occasional business, an emergency, or a special situation may require resources from alternative sources, such as satellite and other wireless forms of communication, to support these situations.

These alternative sources must also be integrated so that they interwork. Users of one telecommunications facility must be able to communicate with a resource located on a different facility. A mobile user, communicating via satellite, must be able to access information located on the terrestrial network. Examples of situations in which different facilities' interworking is necessary include large-scale disasters such as Hurricane Andrew. A fragmented communications infrastructure could make it impossible for operations to communicate with each other.

2. Global Competitiveness

The trend toward high-speed digital telecommunications is a global phenomenon. U.S. industry has been the leader in developing this technology. However, it has lagged behind Japan and Europe in deploying the Integrated Services Digital Network (ISDN) (Ref. [1]). The United States now has the necessity of catching up with parts of the rest of the industrialized world, in the deployment and use of advanced digital communications (Ref. [2]).

U.S. telecommunications standards play a key role in opening international markets. When North American telecommunications standards are accepted internationally, American companies can sell the same telecommunications equipment and services in other countries as they sell in the U.S. For example, an electrical appliance manufacturer must produce two different products to establish a market in the U.S. and in Europe, since electricity is not offered in the same forms on both sides of the Atlantic. Conversely, if ISDN standards are adhered to, an ISDN telephone manufacturer could sell the same phone in Germany, Britain, Japan, France, or the U.S.

Standards are a particular problem for U.S. competitiveness in wireless applications. While we are the world's leaders in wireless technology, we have fragmented the market with different technology, and as a result are losing the competition for international markets. North American carriers are, for example, balancing five different technologies for cellular service (AMPS, N-AMPS, TDMA, ETDMA, CDMA). U.S. companies have lost, by some estimates, $12 billion in international cellular sales because the European Global Systems Mobile (GSM) is viewed by comparison as a stable international standard, even though the technology is inferior to U.S. cellular products.

Adherence to standards also benefits non-telecommunications companies in the U.S. More markets are opened when telecommunications standards are in place, since electronic commerce can be carried across international lines via the telecommunications services. If U.S. telecommunications companies maintain an active role in global intercommunication, other U.S. industries benefit, by being able to maintain a more active role in global markets.

Promoting a market in which interoperable computer and telecommunications equipment exists, coupled with the utilization of high bandwidth network technology, can have a two-fold positive effect upon U.S. industry. The market for computer and telecommunications equipment will be further integrated, and market growth will be accelerated. However, a report released in 1990 (Ref. [3]) provides evidence that the U.S. trails Japan and Europe in deploying ISDN, the Integrated Services Digital Network, one of the most promising developments in digital communications. A recent EPI report (Ref. [4]) observes that Japan and the European Community (EC) have established programs to upgrade their telecommunications infrastructures, and that they are eyeing a growing international market for products and services over advanced networks. Nippon Telegraph and Telephone Company has a planned ISDN (called INS) that will cost $120 billion over 15 years. The overall market for INS is estimated at $250 billion (Refs. [5], [6]). The EC has established the Research in Advanced Communication for Europe (RACE), budgeted at $550 million European Currency Units (ECU) ($700M U.S.) for 1987-1991. RACE integrates ISDN services across the EC. The period of 1990-1994 has a component budget of $2.2 billion ECU (Ref. [7]).

In this Information Age, the demand for information and the technological capability to provide it when, where, and in the form desired, increases daily. Concepts such as Global Grid and the National Information Infrastructure reflect the government's increasing desire to employ new technologies creatively to address national issues. Technology is driving a commonness to military, civil, and commercial use of information service and communications/computer products, in that all the users will be selecting from the same commercial equipment offerings. Commercial off the shelf (COTS) products will be the norm. Worldwide interoperability will be absolutely essential. Common standards and equipment will be an inevitable, welcome effort. The stand-alone telecommunications systems of the past are rapidly becoming obsolescent, evolving into integrated distributed multi-media telecommunications networks with multiple users worldwide. Unique government and privately owned and operated telecommunications systems are evolving to leased service from a common carrier provider. Information flow among systems, once accomplished by well understood physical gateways, is now being accomplished through powerful interactive systems permitting enormous increases in operational efficiency, significant economic savings, and unprecedented data fusion. All these advances in Telecommunications technology are enabling businesses to perform better both domestically and internationally.

II. Technology and Industry Trends for Telecommunications

Although this document is directed at trends in telecommunications technology, the theme encompasses many technological issues. The burgeoning use of computers and other information processing systems means that telecommunications trends can no longer be treated in isolation from trends in other information areas. Thus, the technology trend of interest is not just communications alone, but an information trend, which can be characterized by:

- **Convergence of computation, communications and display:** The digitization and the increased bandwidth of telecommunications is enabling the convergence of what traditionally have been technologically distinct industries: computing, communication, and television. Workstations and personal computers are becoming individual communications and information engines that increasingly process imaged information (e.g., video and fax) along with the more conventional voice and data. In addition, the portability of compact computers such as the PDA as connected through wireless systems (e.g., Personal Communications Services [PCS]) means that users are no longer constrained to a particular location for access to information or communications.

- **Complexity of technology itself and information:** As telecommunications technologies become completely digitized and so enable the convergence of computation, communications and display, they become extremely complicated. Users can create and use complicated information objects and interactions not possible before via digital bit streams that support simultaneous video, voice, image and data services. Multi-media and hypertext are examples of such complex objects.

- **Complexity of services:** Digitization and the use of specialized computers as telecommunications switches have permitted the service providers to offer new integrated and bundled services which have complex implementations within the telecommunications systems. Users are therefore able to choose various menus of services to suit their purposes.

- **Diversity of industry:** Telecommunications is no longer the single industry it once was. The business has diversified along media (e.g., wireline, wireless, cable, fiber, etc.), along services (e.g., telephony, data, private network, entertainment) and along information systems (e.g., computer hardware and software), often within the same company. There is also a great number of small companies which produce equipment and services which complement these broader areas. New cooperative industry ventures will provide new arrangements and creative architectures for the delivery of information services.

• **Diversity of private and concatenated networks:** Gateways among networks are proliferating, in order to provide higher connectivity for users and access to a wider range of services. Users desiring greater control over their network resources are resorting to private networks, often not implemented using public services. The ever increasing need for standards and the serious difficulty with providing a multi-vendor seamless service are becoming a national challenge.

• **Sophistication and diversity of users:** A vast number of students graduating from high school and college today are completely computer and telecommunications literate. They are capable of producing extremely sophisticated applications, either for themselves or for others in industrial or other entrepreneurial environments.

These trends will provide the nation and its citizens unprecedented opportunities for the improvement of personal lifestyle, business and industries, education, health care and defense. Vast amounts of information will flow over these telecommunications systems, a great deal of it private or personal. Without some form of protection for that information, it is vulnerable to unauthorized access and invasion of privacy.

A. Introduction to Traditional Telecommunications and Related Access Methods

Traditional telecommunication systems were based on the transmission of voice traffic between two fixed locations, carried in analog form throughout the network. The signaling system, via mechanical switching, did little more than route the call. The telephone numbering system was based on hierarchical geographic locations. There was usually only one network provider per country. In the U.S. the network provider was AT&T, while in foreign countries it was the Postal, Telegraph and Telephone (PTT), which was usually government owned or controlled.

Telecommunications networks have changed continually since the development of the telegraph and the invention of the telephone. The current pace of technical evolution is accelerating because of increased competition among service and equipment providers, causing innovations to be made available in public and private networks. In some cases pro-competitive government policies have had a direct effect on the speed of technology deployment. For example, the requirements of the AT&T Consent Decree, that local phone companies provide long-distance companies with equal access to local networks, has accelerated the deployment of electronic switching throughout those networks.

Technical capabilities in network switching equipment have been increasing at an accelerating rate. Since the 1920s, when automatic step-by-step switching machines replaced systems that required human operators to establish connections, networks have incorporated a progression of more sophisticated switching equipment. As the demand for telephone service grew, the efficiency, speed, and flexibility of the early step-by-step switches proved inadequate, and engineers developed a new generation of switches termed crossbar systems. Early crossbar switches employed a matrix of switching elements, using electromechanical relays, that could be operated much faster than step-by-step machines. Later crossbar switches used common control systems that shared control equipment, reducing the amount of such equipment required. Crossbar switches had faster call setup times and lower maintenance costs than step-by-step switches. Telephone companies deployed crossbar switches widely over a thirty-year period, with installations occurring as late as 1976.

The next generation of switches, known as electronic or stored program control switches, was introduced in 1965 and relied on computer processing by stored software programs. With this technology, transistor-based electronic switching elements were operated by common control systems, consisting of computer processors executing machine instructions based upon software commands stored in electronic memories. Changes in machine instructions could be programmed according to changing service needs. Essentially, an electronic switch is a special purpose computer that allows service features to be added or changed more easily and flexibly than with earlier switching equipment.

All of the switches described above were analog switches. The next phase in the evolution of switching technology was the development of the digital switch. Digital switches combined stored program control with a switching fabric that allowed switching and processing of transmissions in a digital domain, creating a more cost-effective switching technology. A key advantage of digital switches over their analog predecessors is a lower cost structure, in terms of both first costs per line and annual maintenance costs. Growth costs per line for digital switches can be as much as 30 percent less than those for analog switches. While it is possible to upgrade the performance of, and add advanced features to, analog switches, it is becoming more cost effective to install a digital switch, rather than upgrade an existing analog switch, depending on the cost of specific analog upgrades. Since their appearance in 1976, programmable digital switches have become the equipment of choice for network expansion and large scale upgrades (Ref. [8]).

B. Recent Technology Developments

The most significant recent event in the telecommunications area for the U.S. was the divestiture of AT&T. This divestiture created multiple independent network providers. It also opened the way for new services and features, resulting in more feature-rich terminals. Some of the new features are the signaling and switching capabilities, transmission media, transmission methods, and traffic types.

Virtually all switches in the United States are now digital, stored program systems. The public interexchange (toll) networks are entirely digital and many are implemented on fiber optic cables. Some of the subscriber loops are digital. The regional Bell operating companies (RBOCs) are deploying digital services capabilities to local subscribers in the form of narrowband ISDN (see section II.C.1.a). In some selected areas, RBOCs are installing broadband ISDN on a trial basis.

Since larger volumes of traffic are moving through broadband transmission and switching facilities, a failure in one of these components could potentially result in a large service outage. Trouble may result from a variety of circumstances (e.g., fire, software error). It should be noted, however, that these failures have occurred in the context of a U.S. telecommunications system that, on an overall basis, has a track record of high quality and reliability. Call completion rates in the U.S. are now in the neighborhood of 99 percent. Moreover, the outages cited were largely the result of human errors: cable cuts, faulty software development and insufficient testing, and failure to adhere to company operating procedures (Ref. [8]).

Telecommunications networks consist of three topologies: signaling, transport, and Operation Support Systems (OSSs). Signaling is a supervisory network that establishes, maintains, and terminates calls. Such control networks typically operate out-of-band from the transport network. The transport network transmits and switches the actual communication data (voice, data, images, and computer data). The OSSs network is a management network that administers, provisions, maintains, and provides billing services for the transport network.

1. Signaling

The telecommunications networks have been evolving from an analog-based system designed strictly for carrying and routing voice traffic to a digital-based system for various traffic types. The digital conversion of the transmission facilities and switches within the telecommunication networks is well advanced. With a digital platform in place, many new switching applications are possible. One important part for these new applications is new network control mechanisms. Network control can not only route calls, but can provide capabilities for delivering enhanced services. The signaling systems needed to provide and control these new advanced capabilities have also changed.

The newest network control is called Signaling System 7 (SS7). This is an out-of-band signaling control system that allows for all control messages to be separated from transport traffic. These control messages carry information about a call (e.g., its destination, whether it needs special handling). The signaling network can access databases of customer instructions/information that enable the network to take many "intelligent" actions, such as routing calls to different locations at different times of the day. The SS7 provides for the ability for additional services which will be discussed presently (Ref. [9]).

2. Transmission Media and Methods

The transmission media inside the network may consist of wire, optical fiber, or may be wireless. The telephone handset need not be wired into the network, but instead could be mobile (e.g., cordless or cellular). Wireless terminals interface with the wired network through radio signals. Mobility of the telephone handset is achieved by this means. The vast proliferation of cordless and cellular telephones and pagers indicates the consumer's desire for wireless telecommunication capabilities.

Current cable television operators are also interested in increasing the capacity, service quality, and utility of their facilities through technical improvements such as the introduction of fiber optic transmission media.

Microwave radio has been used in both long-haul and shorter-haul telecommunications applications and can carry large amounts of analog and digital traffic. Commercial terrestrial fixed microwave radio operates at radio frequencies between 1.7 and 23 GigaHertz (GHz). These systems can carry large amounts of traffic. However, there are certain limitations in using microwave transmissions. Microwave radio signals propagate in a line-of-sight manner and are susceptible to fading from rain and other environmental conditions. Moreover, higher operational frequencies require shorter distances between repeaters.

Satellite transmissions also carry large amounts of traffic. The typical transponder bandwidth can accommodate as many as six television channels. Since satellite services are especially good for point-to-multipoint wideband applications, they are used, for example, to deliver television programming to a large number of cable television system headends around the country.

Fiber optic transmission is replacing copper and radio transmission systems because of its declining costs and extremely high capacity. Fiber systems deployed commercially at 1.244160 Gigabits per second (Gbps) and 2.488320 Gbps can carry 18,783 and 37,575 voice channels per fiber pair respectively[2]. The addition of wavelength division multiplexing will allow these capacities to increase even more. Compared to copper or radio-based alternatives, fiber optic transmission systems have greater immunity to interference, exhibit low signal loss, and can carry significantly more traffic accurately at greater distances. These systems also have lower maintenance and servicing costs than comparable terrestrial alternatives. As a result, fiber optic transmission facilities are increasingly used in public and private networks. This is particularly true in the competitive long distance market, but it is increasingly the case in local exchange and cable networks as well.

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[2]Voice channel capacity calculated using entire payload capacity of a concatenated frame.

Fiber optic systems make extensive use of optoelectronics, used for converting signals between the electronic and the optical domains when circuits are switched electronically, or at network termination points for connection to electronic customer equipment. Optoelectronic costs have been falling significantly in recent years and, if this trend continues, the attractiveness of fiber optic transmission systems for lower capacity applications will grow. Until recently, it has been significantly harder to splice fiber optic cable than copper media. However, as the industry has moved to develop field splicing gear, the exacting task of splicing fiber has become less difficult. Both the current cost of optoelectronics and such operations issues as splicing fiber in the field help explain, in part, why fiber deployment to the home has not yet occurred to any significant extent.

Radio-based transmission systems also will have a major role in infrastructure development, including local loop designs. Even though fiber is replacing radio for many high-density traffic uses, the mobility that radio-based services permit makes such services increasingly attractive for customer loop applications. Dramatic growth in public mobile telephone and private radio services has occurred during the last 15 years. Radio-based services like cellular networks interconnect to public networks through mobile switching offices, while some private networks do not. The rapid growth of cellular service has generated substantial enthusiasm and activity in developing additional advanced wireless services (Ref. [8]).

The prospects for multimedia PCS using wireless technology is especially bright. The explosion of interest in this service takes the form of enhanced cellular, WLAN, wireless PBX, low earth orbit satellite and other applications. It is expected that $100 billion will be invested in North America in these services by the year 2000 and achieve $30-40 billion annual revenues.

In the aggregate, U.S. public and private networks use a mix of transmission media appropriate for different situations. Fiber is the transmission medium of choice in mid-to-high density traffic situations. Radio is used where the need for mobility (e.g., cellular service) or right-of-way constraints (e.g., fixed microwave service) make it a preferred alternative. Copper is still an attractive alternative for low density traffic situations. As the relative costs of these media change with innovation, preferences may also change. In the near term, however, it appears clear that fiber and radio will be used more often in fixed and mobile applications, respectively (Ref. [8]).

3. Services

An example of a new service group now available from some network providers is the Custom Local Access Signaling Service (CLASS^{SM}). CLASS provides new services to the user that were not available before the new signaling system's deployment. Some of these features allow for the ability to see the calling number of the arriving call, to call the last number that arrived without knowing its number, or to selectively reject calls as they arrive (Refs. [10] through [20]).

Another service made available through changes in a network's signaling system and transmission infrastructure is Bandwidth on Demand. Bandwidth on Demand allows the user to request in real time the amount of bandwidth required for an application, up to the maximum interface rate, for each call. Thus, the same interface can make a low-rate voice call, followed by a high-rate video conference call, with no change in equipment on the interface. Some public networks already provide the fractional T1 service which gives the user the ability to divide the T1 data rate. Fractional T1 is just the first step in offering in Bandwidth on Demand. The future of Bandwidth on Demand will apply to whatever data rate the user has for access to the network.

There has been a trend to provide multiple services over one facility. The ISDN is one network architecture that provides this capability. ISDN provides for a limited set of user interfaces to access multiple networks and a range of services. There are two types of ISDN: narrowband and broadband. Both follow the same architectural design, but have different user data rates and use different technical components in their structure. The multiple services are delivered to the user through signaling systems integrated into the network.

ISDN has been proposed for the future standard world-wide telecommunications network. ISDN uses a set of full-duplex channels to transmit digital signals over a variety of paths: circuit-switched, packet-switched, or dedicated. It features end-to-end digital connectivity. In addition, it gives customers access to an integrated network with control of access links and desired services and message-oriented digital signaling. Finally, ISDN includes a limited set of standard digital interfaces.

Added features to the basic routing of a call may be considered supplementary services. Supplementary services are like CLASS services. Supplementary services are not a stand-alone feature. They must be attached to some basic service feature (e.g., a voice call). Some examples of ISDN supplementary services are Call Forwarding, Call Waiting, Calling Line Identification, Message Waiting Indication and Control Notification, and User-to-User Signaling. Call Forwarding is the ability to transfer a call to another number without the user's intervention. Call Waiting is the ability to be notified of an additional call arriving on an interface that has been determined to be busy. Calling Line Identification displays the number of the incoming call. Message Waiting Indication and Control Notification are messaging systems that permit the network to record a message and to provide the user the means to retrieve the stored message. The User-to-User Signaling supplementary service allows the user to send messages before, during, or after a call is established. The user information transferred can be any information in any format the user may choose.

Narrowband ISDN services can already be obtained from local telephone companies, but the Asynchronous Transfer Mode (ATM) protocol (Ref. [21]) of the emerging B-ISDN standards (Refs. [22] through [25]) appears to be commercializing quickly. In addition to its initial definition using Synchronous Optical Network (SONET) media, this protocol is currently being considered for supporting Digital Signal level 1 (DS1) and DS3 twisted pair configurations. Such protocol is very likely to introduce new services such as multimedia that permit interworking between LANs, ISDNs, and other subnetworks (Ref. [26]). ATM is also being investigated for wireless networks in general and satellite transmission in particular.

4. Customer Premises Equipment (CPE)

Both public and private networks support and rely on a diverse variety of CPE, including wired and wireless telephone sets, key systems, PBXs, answering machines, facsimile (fax) machines, paging devices, videophones, data terminals, modems, multiplexing, diagnostic and control equipment, and most especially computers. The trend in CPE is towards integrating many of these CPE types into a computer system.

While CPE traditionally has been analog, digital equipment is now being marketed to permit direct interfaces with digital transmission and signaling facilities. Moreover, CPE performs many of the functions formerly associated exclusively with public networks. PBXs allow switching functions to be localized in private networks, and also offer stable interfaces between public and private networks. The introduction of touchtone signaling in telephone sets has expanded the number of signaling options available to customers equipped with these relatively simple devices, permitting more complex interactions with switching equipment and user services like audiotext services.

The recent explosion in CPE development, which is due in substantial part to deregulatory activities by the FCC that resulted in intense CPE competition, has multiplied the communications options of users. Users, for example, now have a choice between wired or radio-based telephone sets for traditional voice telephony. Callers can record messages on answering machines at customer locations, or use network-based answering services. Fax machines are now almost ubiquitous among business users and are penetrating the residential market as well.

The wide variety of CPE available provides opportunities and challenges for the development of telecommunication networks. CPE can be used to ensure the accuracy of transmissions and take advantage of the economies of multichannel transmission plant. Conversely, transmission networks must have the capabilities needed to support advanced CPE. Transmission networks also must be sufficiently flexible to accommodate diverse forms of CPE (Ref. [8]).

5. Operations Support Systems

These computer-based management systems interface to various network elements to perform functions such as billing, fault isolation, testing, provisioning of services, and performance monitoring. Some of these OSSs, in addition, provide mechanized records for common carrier personnel involved in operations, maintenance, provisioning, and dynamic reconfiguration scenarios. Common carriers today use about 110 types of such OSSs to provide various telecommunications services. Such OSSs are linked by a network and have various types of access to different network elements. Therefore, these systems introduce a serious network security problem that can be categorized as follows:

- OSSs include operating systems, processors and subsystems from a large variety of vendors, therefore, increasing the complexity of the management of services on an end-to-end basis

- Multiple access mechanisms, which create multiple access points for unauthorized users, are provided for each OSS: dial, dedicated, Local Area Networks (LANs), WAN, X.25 packet, another OSS

- Remote login, execution and remote file sharing abilities are used extensively and easily acquired

- Many OSSs provide on-line documentation, help menus, and directory services, which accelerate the learning curve for authorized and unauthorized users alike.

There is also a market trend to develop similar and smaller OSSs for customer premise networks (e.g., LANs) and for private networks in general.

C. Short, Intermediate, and Long Term Trends (5, 5-10, 10+ years)

1. Media Related Technologies

a. Wireline

The wireline technologies will continue to play an important role in the access to telecommunication networks. The single twisted pair of copper wires that provided for only a single voice call has now been increased to support more. Over the last 25 years, however, the rapid development of digital technology has made the transmission and switching of signals in digital form more attractive. Bell Atlantic, for example, intends for all of its switches to be digital by 1998 with more than 70 percent of its access lines served by digital switches in 1995. BellSouth plans to grow from 62 percent digital offices to about 82 percent by 1995 (Ref. [8]).

The Narrowband ISDN access provides a standard interface to simultaneous digital services. However, there is currently a maximum rate at which data is transmitted over twisted wire pairs, the T1 bandwidth of 1.54 Mbps. As users demand greater access rates, the use of fiber optic in the local loops is foreseeable[3]. Most of the fiber is deployed within the network. Local phone companies have begun a series of trials using fiber media for service to residential customers. These experiments include both fiber-to-the-home (FTTH) configurations, which require running dedicated fibers and optoelectronics to homes, and fiber-to-the-curb (FTTC) configurations, which employ fiber between switching centers and curbside pedestals, and copper links between the pedestals and individual customer locations.

Transmission systems, regardless of the media used, have become increasingly digital. Fully digital networks reduce the need for modem equipment for data transmission and allow voice and data traffic to be carried in an integrated fashion. With these advantages and the declining cost of digital electronics, digital transmission systems have become commonplace in private and public networks. Public network providers and equipment manufacturers have deployed mature multichannel private line digital services (e.g., T1 services), and they have been developing implementations of all-digital ISDN for over a decade. Recently, some RBOCs such as Bell Atlantic and Ameritech have launched a serious deployment effort of the standard National ISDN-1 (Refs. [2] and [27]).

Coincident with the deployment of digital facilities has been the continued evolution of innovative encoding, processing, and transmission messaging techniques, each designed to improve the movement of voice, data and video traffic over the ever-changing mix of media used in public and private networks. Voice compression technology already permits reduced digital transmission capacity requirements for high-quality voice messages; technical research shows substantial progress toward further reductions.

Other improvements in transmission continue. Most switched voice networks still use circuit switching and conventional multiplexing for digital and analog transmission. However, the successful development of digital packet transmission techniques for data applications has been followed by efforts to devise fast-packet transmission techniques for voice, broadband data, and video applications. The technical literature is replete with discussions of the merits of transmission messaging techniques such as frame-relay for common digital transmission speeds, and cell-relay or Asynchronous Transfer Mode (ATM) for speeds at the Gigabit level. Telecommunications transmission techniques are being refashioned constantly to deliver messages faster and more efficiently.

As the move toward higher speed and higher capacity networks evolves, photonic switches are receiving more and more attention. All commercially available switches to date switch electrical signals. To switch the optical signals now carried over fiber, current switches must first convert them to electronic form and then, after the signals have

[3]This limit was imposed years ago for telephone voice usage; it was not substantially changed for subsequent data transmission practice. Current FDDI wiring schemes for unshielded twisted pair permit 100 Mbps for distances of up to 100 meters. There are also products for Ethernet at 100 Mbps over twisted pair.

been processed through the switch, convert them back to optical form so that they can be transmitted again over fiber. A key objective of photonic switch research is to allow the large volumes of traffic that can be carried over fiber to be switched and processed optically or photonically, thus reducing the need for optoelectronic conversions. The probable substantial future growth in fiber optic transmission plant could well lead to deployment of photonic switches by the end of the century (Ref. [8]).

b. Wireless

Wireless telecommunications include a diverse set of technologies and services, such as cellular communications, paging, and wireless LANs and PBXs, evolving towards PCS, which is targeted at providing a user with access to the worldwide public switched telephone network (PSTN), without the customary constraint of a wired connection. PCS has been defined to be a wide range of communications services based on radio access technology that provides people-oriented services (Ref. [28]). It is based on microcell and other technologies that enhance spectrum capacity to the point where PCS will offer essentially ubiquitous and unlimited, untethered communications. The focus for PCS is on person-to-person rather than station-to-station communication. Each individual would be assigned a personal number which would provide the basis for freedom of movement. Using a low-power personal terminal, a user could access wireless connections through PBXs, LANs, and mobile public telephone service to acquire various services, such as facsimile and other voice and data applications. PCS is currently in the developmental stage and various projections show the potential for 60 to 115 million users by year 2000 (Refs. [29], [30]). Because this is a radio frequency (RF) based technology, user authentication and privacy of data will be key factors.

The network elements needed to provide wireless access to a fixed information network are: mobile (or wireless) terminals, base stations, and switches. A base station exchanges radio signals with the wireless terminals and connects to the switch for access to the PSTN. Each base station serves multiple mobile terminals simultaneously. The mobile switching center is responsible for connections to the PSTN and for controlling the assignment of radio channels to mobile terminals. In order to serve roamers (mobile users remote from their home service area), databases (home and visitor location registers) containing information enabling call delivery are necessary (Ref. [31]).

The analog cordless telephone provides the consumer the opportunity for movement within range of the residential base station while communicating. Cellular phones extend the cordless concept, allowing movement into separate geographic areas, or "cells," by handing off communication and signaling to the new cell's base station. The same transmission frequencies are reused repeatedly in non-contiguous cells with carefully controlled power output and signal direction (Ref. [32]). Cellular systems were initially deployed using analog transmission techniques, but the move to digital techniques has begun. The U.S. has adopted a dual-mode cellular standard, which will accommodate both analog and digital techniques used with digital terminals for the interim period before the digital transition is complete. The use of cellular phones has experienced tremendous growth, and therefore currently suffers from saturation of the radio spectrum. Enhanced wireless capacity has been accomplished by the introduction of new technology which includes voice compression, Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA), and cell splitting.

Mobile Satellite Systems (MSSs) initially became popular because of their capability to provide service to users in regions where such service cannot be reliably provided by terrestrial systems due to geographical location or lack of infrastructure (Ref. [33]). Today, however, MSSs have advanced to the point where they can compete with terrestrial-based wireless systems. MSSs are capable of delivering voice and data services to a variety of terminals, such as land vehicles, aircraft, marine vessels and portable handheld terminals. The Inmarsat system is an example of an MSS. It covers every location on earth except the North and South Poles, and was used during the Persian Gulf War by CNN correspondents in Baghdad to report on the Allied air attack. Low earth orbit satellites represent a new class of satellite services that will enhance and expand services to the user. These systems will deploy a grid of orbiting satellites and require much less power and less delay than traditional geostationary satellites. This will enable handheld devices similar to cellular phones and will likely support combined services. Motorola's Iridium, INMARSAT's Project 21, and Loral/Qualcom's Globalstar are three proposed offerings in this area.

LANs have also become mobile by providing wireless access. Wireless LANs (WLANs) offer significant advantages such as quick establishment and LAN access from portable computers, which avoids the investment in costly cabling systems. The IEEE 802.11 committee is developing standards for WLANs with data rates up to 20 Mbps. Similarly, wireless PBXs or customer premise switching units are appearing on the market. Typically, WLAN and wireless PBX access is restricted to a building or a small campus (Ref. [34]).

Wireless technologies have different transmission rates. The transmission rate is dependent on the frequency used and the encoding technique. A variety of encoding techniques have been employed in various wireless systems. Frequency Division Multiple Access (FDMA) multiplexes users onto different frequencies and is used by current analog systems. Digital encoding schemes include Time Division Multiple Access (TDMA), Code Division Multiple Access (CDMA) and Enhanced-Time Division Multiple Access (E-TDMA). TDMA interleaves users on the same frequency using time slots, achieving a capacity increase sixfold depending on slot scheme. CDMA uses spread spectrum coding techniques to increase channel sharing up to 20 times that of FDMA (Ref. [32]). E-TDMA is being developed for encoding future generation cellular applications. E-TDMA combines TDMA with dynamic channel assignment to achieve 10 to 15 times more capacity than FDMA. Time slots are only assigned to users when they have information to transmit. Transmission is accomplished using a frequencyhopping wideband technique. The reader should note that numbers provided in this paragraph are the subject of controversy within industry.

In terms of spectrum scarcity, the FCC has recently proposed allocating 220 Mhz of spectrum between 1.85 and 2.2 GHz for emerging technologies such as PCS. Pioneer's Preference licenses have been tentatively granted to several companies for work in PCS (Ref. [28]). Reallocation of the spectrum will require that existing users operate at some other frequency or share the spectrum with new users. Congressman John Dingell has authored legislation that would transfer a limited amount of spectrum currently allocated to the federal government to the private sector. It is unclear at this time that if the bill passes, how the bands will be reallocated, or if the bands are appropriate for PCS due to propagation characteristics.

The transmission quality of digital wireless signal is not lossless. Due to noise, multipath fading, and interference, bits of information can be lost or corrupted. Data can also be lost in the brief interruption that occurs during the message handoff process in cellular systems. The handoff process may only involve a blank of about a hundred milliseconds, but this can destroy many message bits (Ref. [32]). Some loss of message bits can be tolerated for voice communications, but the problem is more significant for data communications. If data is encrypted and transmitted and each bit is necessary for correct decryption, bit loss or gain can jeopardize the integrity of the entire message. The same problem will result for compressed data (e.g., compressed images) as well. Error detection and correction techniques are employed to compensate for the loss and/or repetition of bits. Techniques such as Forward Error Correction and Automatic Repeat Request use redundancy bits to locate and correct transmission errors. Such schemes result in a lower effective data transfer rate.

Timing and synchronization is also important for data or encrypted services. As data is carried across network boundaries or across cell boundaries in a handoff, adjustments in timing are required to maintain bit count integrity.

2. Network/Service Evolution

a. Networks and Services

Technological advances and business requirements will continue to push the demand for higher transmission bandwidth and access capacity. Deployment of fiber to customer premises will accelerate and the use of digital signal for wireless communication will soon be widespread. In the short term, ISDN services will become ubiquitous. New services will emerge as Advanced Intelligent Networks (AIN) become mature (Ref. [35]). With full integration of wire and wireless technologies, under the control of an AIN software, truly mobile personal communications will become a reality.

The development of the Advanced Intelligent Network (AIN) builds on the deployment of computer-controlled digital switching and advanced signaling technology (Refs. [36] through [38], [9]). It facilitates and speeds up the provisioning of new services and features and allows the design of highly customized services tailored to individual need. AIN, in conjunction with adjunct processors, enables service providers to shift network management capabilities out to network users and gives the users more control over their network facilities.

As discussed earlier, wireless technologies provide the user with freedom of movement while engaged in telecommunications activities. The terminal, through which the user accesses services, has become portable, resulting in terminal mobility. Some wireless technologies such as cordless telephones and some MSSs limit the usefulness of a mobile terminal by enabling operation only within a restricted geographical area. Other systems such as cellular telephones enable a larger geographic coverage by performing handoffs between switching elements. The goal derived from the achievement of terminal mobility and personal mobility is person-to-person rather than station-to-station communication. This is the goal of Universal Personal Telecommunications (UPT), in which each user would be assigned a personal number which would provide the basis for freedom of movement (Ref. [39]). The personal identifier, rather than the terminal identifier, provides the basis for the addressing, routing and charging of calls across multiple networks. Based on the personal identifier and a personal service profile (user-defined set of subscribed services), a user would be able to obtain access to telecommunication services at any terminal. By activating these profiles as users move from location to location, networks will track user movements to route calls to the proper terminals. Users will be able to make use of their customized set of service features at the currently activated terminal. UPT is under development in the standards arena.

As user applications evolve to a mix of voice and data, operating over wireless and wired networks, and supporting personal and terminal mobility, the networks will be continually challenged to support these applications transparently across networks. Today the focus is on supporting data services such as facsimile and file transfer on cellular networks connected via modems across the public network. Networks such as ARDIS, RAM, and CDPD support data service on today's analog cellular networks. Network interworking is required to accommodate the protocols of each network in support of the application. In some cases this means converting a digital radio signal into a compatible analog modem signal. In future digital networks, the networks will be called upon to interwork a growing set of services and networks. Intelligent Networks' capabilities will be essential to accommodate the various combinations of user terminals, applications, network access, preferences, and privileges. Neither the technology nor the responsibility for accomplishing multiple protocol, multiple network services has been addressed by today's deregulated industry.

Telecommunications switches today are large, sophisticated, special purpose computers. As such, they are operated by exceptionally complicated software systems which typically contain 15-20 million lines of program code. In addition to the primary switching function, the entire management, operation, protection and accounting functions for the network are built into the software. Upgrades and maintenance of this software are tightly controlled by the switch manufacturer and the switch-owner, typically a regional telephone company (although, increasingly, switches are being purchased for private networks by U.S. government agencies and other large organizations).

The switch software and the digital nature of the networks on the provider side (and more and more on the customer side) imply the ability to provide a very wide set of services and capabilities that simply were not possible when the network operated in the analog mode. The telecommunications networks are rapidly evolving into multi-service systems which can provide the user with the ability to tailor the services to their own requirements, rather than the single service (voice or data) systems of the past, where the users' requirements were either adapted to or severely limited to what the network could provide.

Private telecommunications networks are beginning to proliferate, because users want more control over the services and costs of communications. However, the need to interconnect over wide areas or with a variety of communicants outside a given user's community has spawned concatenation of public and private networks. Since the private network services are determined by the capabilities of the switch and the requirements of the user, services in the concatenated network do not necessarily carry from enduser-to-enduser. This is especially true when wireless and wireline technologies are concatenated. There are several reasons, other than technology differences, why this can and does occur. First, the manufacturer of the switch for the private network may not adhere to the same standards as do those of the public network switches. Second, the owner of the private switches may have selected a different set of services than did the public network owner. Finally, the private network may have protection controls on its services installed by the manufacturer because its owner wishes for the network to remain private.

b. User-side Technology

As discussed earlier, there is a convergence occurring among computation, communications and display. It soon will not be possible to treat any of these areas in isolation. This convergence has been enabled and encouraged by the digitization of telecommunications, advances in processor power, and image processing. As this convergence completes, users will impose complex new requirements, based on the ability of the networks, computers and display systems to provide the services to support them. These requirements will come from a very wide set of applications, representing manufacturing (e.g., concurrent engineering), electronic commerce (e.g., EDI), entertainment (e.g., movies on demand), news (e.g., multimedia presentations), merchandizing (e.g., home shopping) and health care (e.g., teleradiology), to name only a few obvious ones. Portability of systems (e.g., portable offices and PDA) connected through wireless systems (e.g., PCS) means that users will no longer be constrained to a particular location for access to information or communications. This will result in significant amounts of data being processed, stored and transmitted. Users will require that the telecommunications systems handling this data be dependable and that the data be capable of being protected.

Some of the newer networks will be driven by usage profiles provided by the user application. The intelligence in the network will parse this profile to determine how to provide what the user application has asked for. This profile does not need to remain fixed within a user session. For example, a user could begin a session with text data and voice, later add video, and still later add a high-volume image transfer, and finally close out with voice only. The network would adapt its services in response to each new request profile. Applications of the new technologies are likely to use far more than one channel (or circuit) in a given session for communicating with other communicants and resources. Thus, it is possible that at the single user interface to the network the user could be carrying on hundreds of "conversations" on the network simultaneously.

Because of the capabilities and services of the new broadband telecommunications technologies, particularly higher bandwidth and multicast, user applications will be radically different from those in use today. Most user terminals will be multimedia, integrating data, video, voice and imagery in one physical system. This means that applications in the terminals will be sending forth not just two-party calls, but possibly hundreds to thousands of transactions over the user session to services and resources located on the network, and accepting responses, arriving asynchronously and in random order, to those transactions. Fixed subscriber service profiles will be used only for the very simplest of applications. The human user will have little or no knowledge of the transmissions being made. The terminal may send many different user service profiles to the network in the space of a single session, with possibly radically different quality requirements.

User applications will be sending complex information objects, not just simple messages. Such objects could contain voice, video, fixed image and text information in a structure known only to the users. Typically, the voice, video, text and image objects will be compressed to conserve bandwidth, each using a different compression methodology. The compression techniques used may be proprietary or custom-designed to fit the particular characteristics of the information being compressed.

Encoding and compression are used in communications to make efficient use of the transmission medium and channels. Encoding techniques are typically determined by the channel and transmission medium physical characteristics, while compression is more application-oriented and typically determined by the data characteristics and the channel transfer speed. An algorithm is used to transform the data from its original presentation to another suitable for transmission. Techniques for encoding and compression are often proprietary, since they aim to wring as much efficiency out of a channel as possible. This clearly is of interest from a marketing perspective, so that such techniques are classified as intellectual property and often are patented. There are, of course, standard encodings and compression techniques, and these are typically used when wide interoperability, such as for video conferencing, is desired (Ref. [40]).

Due to the availability of technical products, such as PCs, modems and Ethernet interfaces, and information services, such as Prodigy, Compuserve and numerous bulletin boards, the public is becoming much more technology literate. Moreover, nearly every high school and college student today comes out of school completely computer and communications literate. All of this means that the public, in 10 to 15 years, will be much more sophisticated in the use of technology than now. Where once computer and communications were the province of the technical sophisticated elite, they are rapidly becoming the province of the common person. The user will no longer be totally dependent upon expert software developers in software houses to develop complex applications. In fact, the users soon will be able to access, on a pay-per-use basis, reliable software components from sources on the networks and construct their own applications. Such a capability already exists in Japan and is under research in the U.S. (Refs. [41], [42]).

The implications of this for criminal activities are enormous. Already techno-crimes are being committed, aside from network "hacking" and telephone fraud. Recently, an automated teller machine was placed in a mall in New York by some persons who had programmed the machine to extract the customer's PIN along with the account number from the magnetic stripe on the bank card and return a null transaction. The thieves were then able to withdraw any sums they desired from the unsuspecting bank customers' accounts. This example shows the growing resourcefulness of lawbreakers in using technology for illegal purposes.

Feature interactions represent a new class of vulnerabilities in telecommunications systems. Feature interactions occur when one feature (e.g., call forwarding, call waiting) interferes with or subverts the operation of another feature. Feature interactions can occur in Intelligent Networks, ISDN and other feature-rich telecommunications environments. During the past few years, feature interactions have come to be recognized as a significant issue in telecommunications service deployment, yet very little attention has been paid to the security and privacy implications of feature interactions. In fact, research has shown that feature interactions can have significant security implications including the potential for eavesdropping, denial of service and the use of some features to defeat the operation of other features (Ref. [43]).

Current domestic and international standards activities appear to reflect increased future reliance on the following capabilities, many of which we have discussed above:

- Digitization of networks and higher capacity of signaling, switching, transmission, and terminal components, with the design goal of meeting user needs by providing greater flexibility, accuracy, and efficiency.

- Separate, out-of-band signaling networks, such as SS7, to speed call processing by several orders of magnitude and increase the efficient use of network resources.

- Greater user control of network facilities and a variety of integrated voice, video, and data services, perhaps including services that can be customized for each call.

The substantial standard-setting and technical activity in these areas suggests that the greatest question concerning such developments is availability (Ref. [8]).

D. Encryption

As the amount of critical data available in computers and communications systems continues to rise, the potential for damage will expand. In particular, the growing prevalence of local and wide area networks within and among organizations of all types, while enhancing efficiency and speed of data transfer and processing, is simultaneously increasing the potential for abuse of individual privacy and the likelihood of commercial/industrial espionage. The result is an increasingly heightened need for information system security. This fact has not gone unnoticed with users of Automated Information Systems (AIS). The results of a survey, conducted on a randomly selected subset of members from the Association of Computing Machinery, show a demand exists for more comprehensive security systems. Over one-fourth of the respondents indicated dissatisfaction with their current security system. In most current private sector applications, security employed consists exclusively of password entry systems. In some cases, file encryption is also used.

To be secure, different AIS applications require different security devices. For example, security services needed for Electronic Data Interchange (EDI) would include message authentication and digital signature, as a minimum. A recent survey conducted by the National Automated Clearing House Association projected annualized growth rates of up to 80 percent for corporate EDI payments sent through their network. The U.S. Government is also striving to achieve an EDI capability. An example is the Defense Department's activities toward paperless transactions in invoicing and in all aspects of the solicitation and bid process, especially for small quantity, low total value transactions where the paperwork reduction payoff is significant.

The transmission of sensitive or private information requires the application of the data confidentiality (encryption) security service. U.S. privacy requirements exist to protect individuals' medical records, financial data, and proprietary information. More of these kinds of information will be electronically transmitted in the future. Driven by all the factors, the domestic and foreign markets for data encryption equipment will increase. A 1987 study by International Resource Development (IRD) predicted that the worldwide data encryption market would be approximately $3 billion (with the U.S. market being

50 percent) by 1991. However, a 1991 study by the same company refined their estimates to only $800 million worldwide ($450 Million for U.S. domestic) in 1992 and $1.8 billion worldwide ($1 billion U.S. domestic) by 1996. The IRD predictions illustrate the uncertainty in attempting to quantify accurately the potential market for encryption devices. However, the increased demand is certain and at least half the potential market continues to be domestic.

Telecommunications security includes two fundamental aspects: protection of the telecommunications network itself and protection of user information being transmitted by the network. The former consists of protecting the network against denial of service threats and loss of information (destruction, modification, induced errors) relevant to operation of the network (billing, routing, security tables, etc.). The latter consists of protecting proprietary or confidential information of the user from unauthorized disclosure and undetected, unauthorized modification or destruction.

Encryption is the only technology that can provide this confidentiality and integrity protection in a distributed telecommunications environment, especially advanced technologies environments. Encryption in telecommunications technology will mean encipherment of digital (or digitized) information before transmission and decipherment after reception by an intended receiver. This is accomplished through some mathematical or logical technique, called an algorithm, that is implemented in either hardware, firmware or software (or a combination thereof). Both the transmitter and intended receiver must use the same algorithm, one in encryption mode and the other in decryption mode. The implementations need not be identical (e.g., software can be used to encrypt and hardware to decrypt) as long as all aspects of the secure communication are interoperable.

Many characteristics of advanced telecommunications affect, and are affected by, encryption. The following outlines these interactions:

- Speed: High speed telecommunications (millions or billions of bits per second) require high speed encryption. A current implementation will sustain a throughput of 1-3 million bits per second. Hardware implementations capable of encrypting millions or billions of blocks per second will be required at each end of a communication path in a high speed system.

- Error extension: Some encryption modes extend errors (bit changes) sixty-four fold and other modes extend errors (bit slips) indefinitely. Bit slips, however, should be part of the network transparency, since the network should deliver the data exactly as it was given to the network. Various applications may require one mode while other applications may require the other mode.

- Network transparency: Once data has been encrypted, additional processing of the data (e.g., compression) may not be possible. For decryption to be successfully accomplished, all network operations must be transparent. Format and bit count (timing) integrity is essential to recovery of the data.

• Key management: Encryption systems require the same key, or a matched pair of keys, to be at the two ends of a communication path in order to encrypt and decrypt data.

E. Diversification of the Telecommunication Industry

The telecommunications portion of the infrastructure—the transmission, switching, and terminal equipment that make up telecommunications networks—support a wide array of services. As the infrastructure changes, so, too, do the services provided through it. The expanding capabilities of public and private networks reflect choices made possible as a result of continuing technical progress. Competition in equipment and service markets is feeding this expansion. Public and private network services and features are developing in response to technical progress and changing demand. Changes in the services and features available to users reflect, in part, changes in the underlying technology of U.S. networks.

Today's public and private networks are comprised of a wide variety of older, mature technologies and newer, highly advanced technical alternatives. As new technologies and media become cost-competitive compared to existing plant, they become preferred alternatives to the degree they increase the ease of accommodating new growth or adding service features. For widespread deployment, new technologies must also reflect lower total plant life cycle costs. As a result of the wide variety of conditions in which U.S. networks operate, telecommunications services and features are built and depend on a blend of new and older technologies, in a mix capable of delivering the desired performance (e.g., in terms of capacity, accuracy, or speed) at a particular cost.

Voice traffic is still the principal component of residential and business traffic over public and private networks, and thus continues to exert a strong influence on network planning. For example, local phone companies have made single party telephone service very widely available, reducing multiparty service to about 2.5 percent of access lines. Specialized forms of voice services, such as 800 and 900 services, have grown rapidly in popularity over the past decade. To supplement traditional voice services, however, users are demanding a host of other options, including call handling features. call conferencing, facility control and switching functions, and traffic aggregation capabilities.

While voice calls continue to represent the largest share of traffic on most networks, data communications traffic has grown dramatically with the increasing presence of computers and data processing in everyday life. As a result, users are demanding networks that send larger quantities of data at faster rates than previously required. Moreover, users are increasingly demanding the transport of images, either fixed or in motion, with reproduction in hard copy or video form. Such demand has fueled spectacular growth in fax equipment sales. Demand for video entertainment has fed the growth of cable television, and has increased local phone company interest in providing video programming in their service areas, an activity from which they are currently barred.

Residential users obtain service primarily from the public networks of traditional common carriers. Many businesses meet their needs through public networks, which may include the facilities of both traditional common carriers and alternative service providers. Businesses may also build private networks that combine network equipment purchased competitively, and private line services obtained from common carriers. Further, private network users commonly interconnect their facilities to public networks for wider communication.

As home computer use becomes more prevalent, customers are demanding user-friendly gateways, offering access to information service providers. These providers already offer such services as database retrieval, voice messaging, and credit verification. Information service providers are themselves major users of public network services and features, because public networks and gateways permit these providers to obtain wide access to customers. The needs of information service providers and others are stimulating the development of new interconnection arrangements and the offering of network capabilities previously available only to public carriers.

The growth of competition in service and equipment markets and the pace of technical development underscores the importance of standards development for customers and the industry. Standard interfaces and protocols can make it easier for public and private networks to pass traffic and signaling across network boundaries. Public network providers coordinate their interactions and improve service quality with the proper use of standards. With proper standards, other service providers could use network-provided technical modules or building blocks to develop information services for consumers. By defining stable interface points and organizing the passage of traffic and signals across these points, the industry can facilitate the interworkings of various industry segments competing in the marketplace, both in day-to-day operations and in the face of technical change.

Standards can also benefit private and public network operators. With standard interfaces for networks, network operators can change specific components, taking advantage of improvements in technology without extensive network modifications. Advantages can also accrue to equipment manufacturers, who can bring individual pieces of equipment to the market without introducing a complete new family of network equipment. Manufacturers also can make internal improvements to individual devices as long as compatibility requirements are met.

The robust U.S. telecommunications industry has stimulated substantial standards development activities. For example, the proliferation of fiber optic transmission systems and the demand for high bandwidth transmission capabilities have led U.S. industry to develop Synchronous Optical Network (SONET) standards (Ref. [44]). SONET standards will allow fiber optic transmission equipment and high bandwidth digital equipment built by different vendors to be used together efficiently and with low transmission error rate performance. The SONET standards already specify physical and hardware requirements. Also under development are communications protocols that will allow better management and monitoring of network performance. These standards should facilitate the further development and use of fiber optic equipment (Ref. [8]).

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Acronyms

ADP	Automated Data Processing
AIS	Automated Information Systems
ATM	Asynchronous Transfer Mode
CAD/CAM	Computer Aided Design/Computer Aided Manufacturing
CDMA	Code Division Multiple Access
CLASS	Custom Local Access Signaling Service
CPE	Customer Premises Equipment
DS1	Digital Signal level 1
DS3	Digital Signal level 3
E-TDMA	Enhanced-Time Division Multiple Access
ECU	European Currency Unit
EDI	Electronic Data Interchange
fax	facsimile
FCC	Federal Communications Commission
FDMA	Frequency Division Multiple Access
FTTC	Fiber to the Curb
FTTH	Fiber to the Home
Gbps	Gigabits per second
GEO	Geosynchronous Earth Orbit
GHz	GigaHertz
IN	Intelligent Network
ISDN	Integrated Services Digital Network
LAN	Local Area Network
LEO	Low Earth Orbit
MAN	Metropolitan Area Network
Mbps	Megabits per second
MSS	Mobile Satellite System
OSI	Open Systems Interconnection
OSS	Operations Support System
PBX	Private Branch Exchange
PC	Personal Computer
PCS	Personal Communications Service
PDA	Personal Digital Assistant
POTS	Plain Old Telephone Service
PSTN	Private Switched Telephone Network
PTT	Postal Telegraph and Telephone
RBOC	Regional Bell Operating Company
SMDS	Switched Multi-Megabit Data Service
SONET	Synchronous Optical Network
SS7	Signaling System 7
TDMA	Time Division Multiple Access
UPT	Universal Personal Telecommunications
WLAN	Wireless LAN