TELECOMMUNICATIONS AND THE IEEE COMMUNICATIONS SOCIETY

BY AMOS JOEL
(CONTRIBUTIONS TO THIS ARTICLE BY DAVID HOCHFELDER AND STEPHEN WEINSTEIN ARE MUCH APPRECIATED.)

This article reviews the history of electrical telecommunications and of the IEEE Communications Society (ComSoc), founded 50 years ago as the Institute of Radio Engineers' Communications Group. The author felt it appropriate to include earlier communications history, since in communications there has been a never-ending drive to build new generations of technology upon earlier ones. The reader is also referred to the online history at (http://www.ieee.org/organizations/history_center/comsoc.html) from which much of the final section of this article is drawn.

Some of us have, in our lifetimes, witnessed the creation of extraordinary communications technologies, including radar, television, the digital telephone network, optical communications, the Internet, and cellular mobile telephony. Communications in the last 50 years is reflected in the publications, conferences, and general development of the IEEE Communications Society. Some seminal contributors are identified, but unfortunately only a fraction of the many communications scientists and engineers who have been responsible for the powerful communications infrastructure that covers the globe today, and for our own IEEE Communications Society, which generates and disseminates the knowledge on which this infrastructure is based.

INVENTION AND DEPLOYMENT OF THE TELEGRAPH

It is fitting that the first major technical undertaking and commercial application of electricity was in the field of communications, with the invention in 1839 of the first commercial telegraph by Cooke and Wheatstone in England. This was extended by Morse, who made the first commercial telegraph system in the United States in 1844 and invented the efficient Morse code.

From a technical standpoint, the most important attribute of the telegraph was its instantaneous operation across vast distances, separating the transmission of information from the physical movement of goods or people. From a social and cultural perspective, the rapid spread of the telegraph network throughout the globe showed that rapid and dependable communication was indispensable to modern life. The subsequent history of communications has continued these two trends: on the one hand, engineers have worked to make communications more rapid, reliable, and affordable; on the other hand, communications networks have become a necessary and vital infrastructure of modern society.

The second half of the nineteenth century saw efforts to increase the message-handling capacity of telegraph lines. Alexander Graham Bell was funded to work on this but did not, preferring to invent the telephone. Thanks to the work of Joseph Stearns and Thomas Edison, by the mid-1870s reliable systems existed for the simultaneous transmission of two and four telegraphic signals on a single wire (with ground return). Several "electricians" began to investigate harmonic telegraphy, or the use of several different tones to transmit many discrete telegraph signals on a single line. Using harmonic telegraphy Edison in 1874 achieved 500 bits/sec over a telegraph line.

In 1851, England was permanently connected to continental Europe by means of a cable laid between Dover and Calais, France and telegraph lines spanned much of Europe, North America, and the Middle East. Entrepreneurs in England and the United States began to consider ways of connecting the continents by means of submarine cables. After failed attempts to lay a cable in 1857 and in 1858, a working cable operated for about a month in the summer of 1858 before failing due to high signaling voltages. By 1861 entrepreneurs and governments alike had laid some 18,000 km of cable around the world, of which only 5,000 km actually worked. The American Civil War delayed a new attempt until 1865, but in 1866 the Anglo-American Telegraph Company permanently spanned the Atlantic Ocean with the successful laying of two cables. By 1899, cables connected every continent.

Submarine telegraphy was the premier engineering project of the 1850s and 1860s, and it led to many fundamental advances in shipbuilding, cable construction, and laying techniques, and even oceanography. It also revolutionized communications engineering and placed it on a firm scientific footing.

The major difficulty with submarine telegraphy was the attenuation and dispersion of signals passing through long cables due to the intrinsic capacitance of the cable. William Thompson (later Lord Kelvin), the first "electrician" to systematically study this phenomenon in an 1854 paper, borrowed Fourier's equations governing heat transfer to model the transmission of electrical signals through a long submarine cable. His insightful decoupling of the signal (the telegraphic pulse) from the medium (the cable) allowed him to optimize the dimensions of the cable conductor and insulation and to devise telegraphic sending and receiving equipment to shape and detect the pulses.

ORIGINS OF RADIO AND RADAR

Radio had its origins in the work of the celebrated British physicist James Clerk Maxwell during the 1860s. Maxwell's equations remained just an elegant mathematical formulation until the 1880s, when Heaviside discussed the propagation of electromagnetic waves, and the young German physicist Heinrich Hertz demonstrated the generation and detection of electromagnetic radiation in the laboratory. During the early 1890s scientists in several countries experimented with electromagnetic waves. In Russia Vladimir Popov built some of the earliest radio detectors, while the young Irish-Italian Guglielmo Marconi investigated radio communication systems.

In 1896 Marconi introduced his wireless signaling apparatus, and within a few years he could transmit over distances of several hundred miles. In 1900 he proposed radio tuning and in 1901 Marconi's radio spanned the Atlantic, receiving signals in Newfoundland transmitted from England. Until the rise of broadcasting after 1920 the major application of radio was for wireless telegraphy.

Radio aided directivity and ranging (RADAR) was invented before World War II, but saw most of its development during the war, stimulating technical advances that had far-reaching

impacts on post-war communications engineering. The first practical radar, introduced by British physicist Sir Robert Watson-Watt, was demonstrated in the U.K. in 1935. In 1939 the British military established the "Chain Home" network of radar stations to detect air and sea incursions, and in the same year two British scientists, Henry Boot and John T. Randall, developed the resonant-cavity magnetron that generated high-frequency, high-powered radio pulses and was eventually used in microwave ovens. By 1943 the Allies were using radars for early warning, battle management, airborne search, night interception, bombing, and anti-aircraft gun aiming. Wartime radar work yielded important peacetime dividends, especially in the fields of television, FM radio, and VHF and microwave communications, in addition to making all-weather air and sea travel routine.

THE TELEPHONE NETWORK

The worldwide telephone network was for more than a century the primary focus of communications innovation and the incubator of the communications engineering community that established the IRE Professional Group on Communications 50 years ago. It began with the invention of the telephone in the 19th century. Both Alexander Graham Bell and Elisha Gray realized that if a telegraph line could convey several musical tones, it could also transmit human speech. Bell filed his U.S. patent in 1876 just a few hours before Gray filed his, and that same year gave the first public demonstration of a two-way long-distance telephone conversation (16 miles) using a borrowed telegraph circuit. In 1878 the first commercial telephone exchange, capable of establishing three connections among 25 subscribers, was established in New Haven, Connecticut. This first deployment indicated what were to emerge as the three basic infrastructure components of telecommunications: subscriber equipment, transmission (outside plant and terminal equipment), and switching (manual and automatic).

Initially calls were addressed by name, much like the Internet today, with human "domain name servers" making the necessary translation into destination subscriber lines. Telephone numbers were first assigned in 1879. Party lines were devised to make more efficient use of the lines and the central office equipment. The first party line with selective ringing went into service in 1879. Party lines might be considered an early example of shared-medium local area networks. By 1891 there were 20-party lines with coded signaling.

The telephone quickly caught on for local service, and by 1880 the Bell Company leased nearly 100,000 instruments. Simple telephone service became a commodity, and was augmented by many other uses for the telephone, such as the 1887 simultaneous telephone and telegraph service on the same line and leased line service in 1881. The Smithsonian Institution in Washington exhibits rudimentary facsimile machines from the late 1890s. The first PBX (Private Branch Exchange) switch on a business customer's premises was placed in service in 1879. By 1925 there were 16 million telephone lines in the United States accounting for 21 billion local calls and 1 billion long-distance calls annually. The combined ringer and handset telephone (500 type) was introduced in 1949, the speakerphone in 1954, the DTMF tone dialer phone in 1963, and the first cordless phone in 1970. Video telephony (the "Picturephone") service was inaugurated in 1964 but has yet to succeed as a commercial service.

The history of service innovation in the telephone network is long and multi-faceted. Automatic number identification (ANI) first appeared in 1942. The U.S. nationwide numbering plan, with area codes, was proposed and adopted in 1945. Automatic message accounting was implemented in 1948. Tone signaling over trunks was also implemented in 1948, enabling wide-area customer dialing, introduced in Engelwood, New Jersey in 1951. In addition to tone dialing and a variety of custom calling services of the 1970s and 1980s, there were a number of important business-oriented service innovations, most notably the "800" family of services. In 1979, databases added to the signaling network supported the INWATS service for toll-free dialing by customers to service providers. "Intelligent network" capabilities, in which call requests are referred to a service control point that executes different call completion scripts, was built into the telephone network beginning with AIN (Advanced Intelligent Network) in 1987.

REGULATION AND THE BREAKUP OF THE BELL SYSTEM

Communications industry structure and the directions of communications technology and networking have been greatly influenced by government regulation. The breakup of AT&T at the beginning of 1984 was a turning point in global as well as U.S. telecommunications.

AT&T was incorporated in 1885 and the "Bell System" was introduced in 1908 by AT&T's Theodore Vail to provide nationwide long-distance service interconnecting the local Bell Operating Companies. AT&T concentrated on buying up local telephone properties and developing technology for long-distance service. In keeping with the word "Telegraph" in its name it also bought up the Western Union telegraph monopoly. Established in 1913, the U.S. Interstate Commerce Commission (ICC) was given jurisdiction over the rapidly expanding telephone companies and immediately became concerned about the monopoly that was forming in the telephone industry. AT&T argued that theirs was a "natural" monopoly because it overcame difficulties of interoperation between competing companies with their separate networks. In the "Kingberry Commitment" by which AT&T succumbed to the ICC pressure, AT&T sold its stock in Western Union, would no longer buy independent telephone companies, and would provide long-distance connectivity and service for them.

The U.S. Communications Act of 1934 established the Federal Communications Commission (FCC) and gave it responsibilities for managing the radio spectrum and regulating the overall networking aspects of the telephone system. State regulatory agencies were responsible for regulating public services and approving pricing structures (tariffs).

In 1936 the FCC initiated an investigation of the Bell System, which had grown as a vertical monopoly that both provided local and long-distance services and developed and produced products for its captive operating units. This investigation explored in detail the relationships between the manufacturer (Western Electric) and its most preferred customers, the Bell companies, but very little changed until the 1960s.

AT&T and its Bell System focused on reliable, universal, basic telephone service, but many critics charged that it was slow in adopting advances in fields like microwave transmission and data communications. Backed by FCC regulations, and with the explanation that it was necessary to ensure the reliability of the public switched network, AT&T did not allow users to directly attach devices to connect their telephones to two-way radios or computers. For a time network interface protection devices were proposed, but these attachment devices made it more expensive to provided service adjuncts not available through the telephone companies.

The first change in this policy came in 1968 when the FCC ruled in favor of the Carter Electronics Corporation, whose

Carterfone allowed customers to connect a radiotelephone into the telephone network. This decision opened up the terminal-equipment market to competition. A year later, the FCC granted Microwave Communications, Inc. permission to sell long-distance service over its own microwave phone links, and then connect into the AT&T network, prompting AT&T accusations of "cream-skimming" of the most profitable segment of the telephone business. Thus, by the early 1970s, AT&T faced competition that would eventually end its monopoly in terminal equipment and long-distance service.

In 1974, the U.S. Department of Justice filed an antitrust suit against AT&T, trying to force it to allow purchase by its operating units of telephone equipment purchasable on the open market instead of from its subsidiary, Western Electric, and to allow connection to other carriers of long-distance service. After ten years, hundreds of millions of dollars in legal fees, and millions of pages of documents, AT&T and the Justice Department came to an agreement. Under the jurisdiction of Judge Green, the Justice Department allowed AT&T to keep Western Electric and Bell Labs, but directed it to divest itself of all its local operating companies, who would thenceforth be free to buy anyone's telephone equipment.

AT&T exited the local telephone business in 1984 and began to move into non-regulated businesses such as computing. Deregulation spurred competition and lowered prices in the long-distance market, but initially created confusion among consumers, 64 percent of whom indicated in a 1985 poll that divestiture was a bad idea. Deregulation also eroded the preeminent position of Bell Labs as a leading research center in basic engineering and science, with staff members winning seven Nobel pries since the 1920s. Under the AT&T monopoly, Bell Labs enjoyed a protected source of operating revenue and its researchers had a great degree of independence. While the breakup of AT&T offered the telecommunications consumer more choices and lower costs, it also eroded an important component of the U.S. research infrastructure.

SWITCHING AUTOMATION

At first, human operators, usually women, connected calls manually. Some small switchboards were in operator's homes. The first automatic telephone switching system was described in a patent issued to Connelly and McTighe in 1879, but practical automatic switching began in 1891 when Almon B. Strowger, a Kansas City undertaker, patented an automatic machine switching system, later called "step by step." In a possibly apocryphal story, it is said that he was losing customers to his competitor whose daughter was a telephone operator.

The original installation of a step-by-step system was placed in service in LaPorte, Indiana in 1892. "dial" calling (by operators) was introduced into the step-by-step system in 1896, replacing an earlier push-button system. In 1897 switchboards were divided into originating and terminating sections with operators passing call information over "call-wires" or "order-wires" for signaling between central offices, replaced by over-the-trunk tone signaling in 1929. Control signaling was once again separated from the telephone trunk with the advent of common-channel signaling in the 1970s.

Step-by-step switches continued to be used in many American and European cities as late as the middle of the 1970s. Improved "panel" and "rotary" switching systems were introduced in the first decade of the twentieth century, as was incorporation of a central register that helped enable user dialing. In 1921 the first fully automatic panel switching office was placed in service in Omaha, Nebraska.

Crossbar switching, with relays at crosspoints, reduced connection time and the size of switches. The first switching office using crossbar switches and multicontact relays was introduced in 1938. In that same year, Claude Shannon, later founder of the field of Information Theory, formalized the design of relay and switch circuits. In 1941 the first tandem crossbar office, enabling connection among many different types of switching systems, was deployed. U.S.-wide operator dialing of long-distance calls began in 1949, utilizing the No. 4 Crossbar System. The No. 4A system, deployed in 1956, supported customer direct distance dialing.

A trial of electronic switching was conducted in Morris, Illinois starting in 1960. The Electronic Central Office used neon diodes as crosspoints in a space division fabric, with vacuum tube memories and a digital flying spot store for the first application of stored program control (SPC). The first commercial deployment of Electronic Switching System (ESS) No. 101 was in Cocoa Beach, Florida in 1963. By 1965 the first standard ESS, the No. 1, was in production, with an initial installation in Succasunna, New Jersey.

The switching fabric itself became digital in 1976, when a new generation of time-division multiplexed (TDM) SPC/ESS systems were developed and placed in service throughout the U.S. The larger switches were exemplified by Nortel's DMS and AT&T's No. 4 toll ESS.

TRANSMISSION IMPROVEMENTS AND THE NATIONAL NETWORK

The first commercial long-distance telephone service was instituted in 1881, covering 45 miles between Boston and Providence. Long-distance telephone service was extended in 1884 to New York, 292 miles from Boston. The first transcontinental (North American) telephone line was completed in 1915.

Long-distance telephone transmission, like submarine telegraphy, suffered from attenuation and dispersion. Intelligible speech could be transmitted over a copper wire pair for no more than 100 miles. Successful long-distance telephony required two major engineering advances: inductive loading to counteract line capacitance, and amplification. Columbia University professor Michael Pupin and AT&T's George Campbell independently invented inductive loading in 1900. The need for advances such as these led to the establishment of Western Electric's Central Engineering Department and, in 1925, its successor, Bell Laboratories.

Amplification came with the vacuum tube. In 1906 Lee de Forest placed a third electrode between the cathode and anode of the diode vacuum tube invented two years earlier by the British scientist Ambrose Fleming, and this device, the triode, became the fundamental building block of both amplifiers and oscillators. The transcontinental telephone line that AT&T built in 1915 between New York and San Francisco used electronic amplifiers, and higher quality four-wire transmission soon followed. Later radiotelephone and radio carrier systems also depended on electronic amplifiers. Edwin Armstrong used de Forest's triode to develop enhanced oscillator and amplifier circuits.

CARRIER SYSTEMS

Carrier systems for long-haul transmission of aggregated traffic were developed in wired and wireless versions. A four-channel FDM (frequency division multiplexed) carrier system for transmission between Baltimore and Pittsburgh was demonstrated in 1918, benefiting from Carson's 1915 analysis of single sideband transmission. G.A. Campbell's 1917 invention of fil-

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ters for carrier system development and Nicolson's 1918 development of piezo-electric crystals for sharp passband filters and oscillators, together with Harold Black's invention of negative feedback in 1930, made possible better systems with higher capacity and increased spacing of repeaters. The J Carrier in 1938, with 12 two-way analog channels capable of operating over open-wire, and the K carrier in 1946 (delayed by WW-II), with 12 two-way analog channels over cable, were two major systems. A "channel bank" of 12 channels became a standard.

In parallel, beginning in 1915 long-distance radiotelephone services were set up between cities in North America. Greater distances, such as New York to San Francisco, were made possible after the 1919 recognition by Espenschied of radio wave reflection from the ionosphere.

The development of coaxial cable transmission systems responded to the bandwidth needs of rapidly growing telephony traffic as well as the anticipated future long-distance video transmission. By 1936 an experimental 1 MHz 3800 mile coaxial cable carried 240 telephone channels with 10-mile repeater spacing, and was used to transmit coarse video in 1937, with standard video demonstrated in a different system in 1941. A standard coaxial cable frequency multiplexed system developed after World War II served 480 channels. The "L carrier" systems subsequently developed ranged from L1, carrying 2000 voice channels, to L5, placed in service in 1974, carrying 130,000 channels.

Microwave radio relay systems, which had been proposed as early as 1941, had the goals of lower cost than coaxial cable and conservation of radio spectrum, compared with multidirectional radio systems. The first system (called TDX) was installed in 1947 between New York and Boston, 220 miles with an average of 27.5 miles between repeaters. It had two bi-directional 10 MHz channels and could carry a TV and 240 voice channels. Later systems such as TD2 and TD3 (1968) carried as many as 12,000 voice channels. By 1951 a radio relay network was in operation across the United States. Digital terminals were developed around 1967. Optical carrier systems began to be deployed in the 1980s, as described in the Optical Communications section below.

SUBMARINE TRANSMISSION SYSTEMS

There was a surprisingly long interval between the first deployment of an undersea telegraph cable and the first deployment of an undersea telephone cable, with its higher demands on bandwidth and signal level. The first underwater cables with repeaters went into service between Key West, Florida and Havana, Cuba in 1950. In 1952 AT&T and the British Post Office agreed to develop the TAT-1 transatlantic telephone cable, building upon research and development begun at Bell Labs in the early 1930s. TAT-1, deployed in 1956 with 36 4-KHz voice channels, was in use until 1979. It used long-life pentode vacuum tubes; it was not until 1963 that transistor amplifiers appeared in undersea cables. One interesting innovation of TAT-1, introduced in 1959, was TASI (time assignment speech interpolation), an electronic circuit multiplier used to expand transmission capacity by exploiting the fact that in a normal conversation the average speaker talks less than 40 percent of the time. By using fast switches and good speech detectors, the system permitted voice circuits to time-share a smaller number of channels. It provided the equivalent of 48 extra channels.

Other submarine cables followed by the end of the 1950s, including TAT-2 between France and Newfoundland and cables linking Alaska to Washington State and Hawaii to California. The new cables were enhanced with sharp filters permitting a reduced (3KHz) voice bandwidth to conserve capacity. In 1976 TAT-6, with transistor amplifiers, provided 4200 voice channels over a 3400-mile span. The latest transoceanic cable, TAT-12, is a digital system using optical fiber and optical amplifiers.

DIGITAL COMMUNICATION AND DIGITIZATION OF THE TELEPHONE NETWORK

Digital communication, for both media (voice, image, video) and computer communication, began early. A 1926 Rainey patent disclosed digital transmission for telephotography. While Rainey invented the idea of digitization of photographs, it was A. Reeves in 1937 who first proposed pulse-code modulation (PCM), the cornerstone of the digital transmission process, that relied on the earlier work of Carson (1920) and Hartley and Nyquist (1924) demonstrating that a band-limited analog waveform can be exactly represented by samples taken at a rate at least twice the maximum frequency present in the waveform. The AN\TRC16 digital microwave radio relay system delivered in 1945 to the U.S. Army during World War II for encrypted messaging was probably the first deployment of PCM.

The availability of transistors made it economical to implement a time-division multiplexed (TDM) carrier system for voice communications by 1962. This first interoffice digital transmission system, called T1, time-multiplexed 24 telephone channels sampled with 8-bit resolution eight thousand times per second for a total of 1.5 million bits per second. After the development of T1 carrier a complete family of digital transmission systems was eventually developed, including the 4000-channel DR18 digital radio system in 1969 and the 4000 channel T4 coaxial cable system in 1975. The separation of packet-switched control (signaling) traffic from the circuit-switched information stream was realized in common-channel signaling (CCIS) in 1976, and No. 4ESS, the first large-capacity digital time division toll switching system, was introduced in Chicago that same year. With the introduction in the U.S. of interoffice optical fiber in 1977 and digital crossconnect switches in 1978, with similar introductions in Japan and the U.K., the optical communications era began, with its promise of vast digital communication capacity in the core network.

DIGITAL BROADBAND NETWORKS AND ATM

Carrier systems became digital as the telephone network migrated, in the 1960s and 1970s, to digital communication, described in a separate section below. The later development of optical networking, also described in a separate section, vastly increased link capacities and made the radio and coaxial cable transmission systems largely obsolete. Optical communications also opened the possibility of broadband optical access networking from customer premises.

Traffic concentration in high-speed carrier systems was developed early, but broadband access for end users reached a conceptual height in the Broadband Integrated Services Digital Network (B-ISDN) pursued in the late 1980s and early 1990s. The proposed 155 Mb/s service would accommodate uncompressed 140 Mb/s digital video that was the state of the art at the time. B-ISDN was based on Asynchronous Transfer Mode (ATM), pioneered largely by CNET in France and Bellcore (now Telcordia) in the U.S. beginning about 1984. ATM uses small, fixed-size packets (called "cells") for a mixture of media on the same net-

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work, with connections set up with resource guarantees. ATM is still widely used but its popularity has declined in recent years as alternative means have been found to realize a reasonable quality of service for IP (Internet Protocol) traffic.

B-ISDN as a service failed because of many cost and service structure obstacles. It is replaced for the foreseeable future by less expensive ADSL and cable data broadband Internet access systems.

RADIO AND TELEVISION BROADCASTING

In 1916 Frank Conrad, an amateur radio enthusiast and Westinghouse engineer, began regular broadcasts of music from his Pittsburgh home. Westinghouse recognized the vast potential market and in 1920 launched KDKA, the first radio broadcasting station. Commercial broadcasting began in 1922, and by 1923 there were more than 500 U.S. broadcasting stations connected in a nationwide network of telephone lines. New York to London radio program transmission began that same year.

By 1924 nationwide North American coast-to-coast radio broadcasting networks were in operation, and by 1929 there were more than four million radio receivers in use in the United States. Amplitude modulation (AM) was and still is used in radio broadcasting, but the invention by Edwin Armstrong of frequency modulation (FM) introduced fading and static-resistant broadcasting. In 1940 Armstrong set up an FM broadcast network in the 42-50 MHz band.

Early television and videophone experiments were carried out in the U.K. and the U.S. In London John L. Baird used the long-established scanning disc technique in a crude (30-line) television demonstration in January 1926. Color television, stereoscopic television, and television by infra-red light were all demonstrated by Baird before 1930 (http://www.dfm.dircon.co.uk/tvhist1.htm). The BBC started broadcasting television on the Baird 30-line system experimentally in 1929, and replaced this crude system with 405-line television service in 1936. In the U.S., inventions by Philo Farnsworth and Vladimir Zworykin resulted in a number of experimental stations for mechanical television by the end of the 1920s, and H. Ives conducted video telephony experiments at Bell Labs beginning in 1927. The NTSC black and white television standard was adopted in 1941, but the Depression and World War II delayed any significant deployment of television broadcasting until 1948. Television became wildly popular, especially after the introduction of the compatible color system in the mid 1950s.

Over the air transmission still dominates radio broadcasting, but in developed countries television programming is more likely to be delivered through cable television (CATV) systems, and satellite delivery of digitized television programming is available all over the world. In recent years progress in media streaming through the Internet has encouraged the concept of Internet radio and television. Thousands of radio stations are already available to Internet users, and comparable availability of television programming streams is expected as broadband Internet access becomes more widely deployed.

Although most over the air broadcasting is still analog, the development in the 1980s and 1990s of highly compressive video coding/decoding equipment has spurred delivery of digital video programming over both satellite and CATV systems. The MPEG2 standard allows delivery of broadcast-quality video at rates on the order of 4 Mb/s, compared to the roughly 140 Mb/s that would be required for PCM-coded video. Using techniques similar to MPEG2, high-definition digital television broadcasting, at rates on the order of 20 Mb/s, has become available in several nations.

Data broadcasting was implemented in the "teletext" systems of the early 1980s, often piggybacking on television signals using the vertical blanking interval. Teletext supports closed captioning and, with cyclical transmission, entire electronic magazines. Although once viewed as a primary electronic medium, it has been largely displaced by the Internet's World Wide Web.

SATELLITE COMMUNICATIONS

Arthur C. Clark first proposed satellite communications in 1945, and John Pierce, also in the late 1940s, wrote several articles discussing how a satellite communications system could be realized by bouncing signals off of passive satellites. Echo I, launched in 1960 in a medium altitude orbit, successfully bounced signals back to earth, but required high transmission power to overcome path losses on the order of 180 dB. Telstar I (1962) was an active satellite, receiving and retransmitting signals, but it suffered unanticipated radiation damage from the Van Allen radiation belt and operated for only a few weeks. Telstar II, launched in 1963 with a capability for one TV channel as well as a number of telephone channels, was more radiation resistant.

The 1962 Communications Satellite Act in the U.S. established COMSAT as a quasi-governmental corporation. The advantages of geosynchronous orbits were realized and the first commercial satellite went into service in 1965. Echo cancellers using digital technology were introduced in 1979 to cope with long transmission delays. Intelsat was formed as an international body to design, develop, and maintain the operation of a global commercial communications satellite system, launching INTELSAT I (Early Bird) in 1965, which provided 240 circuits between the United States and Europe. INTELSAT II and III soon followed, and in the seven years following Early Bird's deployment INTELSAT launched and deployed four generations of satellite, reaching 6000 circuits in INTELSAT IV (1970).

Low-earth-orbiting satellite (LEOS) systems, with handoff of a call from one satellite to another, were perceived around 1990 as a solution for global coverage. Large investments were made in several projects, particularly Iridium, in which Motorola played the leading role. The systems failed as consumer-oriented businesses because of cost and other factors, but continue to exist on a smaller scale for vital services such as news reporting from remote locations.

Although the deployment of undersea optical fiber eventually displaced satellite communication as a major telephony carrier system, satellites quickly demonstrated their economic superiority as a media multicasting system. The first and still very important application was for distribution of broadcast radio and television programming to affiliate stations and cable systems, stimulated largely by HBO (Home Box Office) beginning satellite distribution of its programming to cable operators in 1975, via RCA's Satcom I. Direct satellite broadcasting to residences did not begin until the 1990s, when the technologies of high-compression digital video (primarily MPEG) and of a combination of high-powered satellites in the higher-frequency (Ku) band and the associated small, low-cost earth stations made it economically feasible. Direct satellite broadcasting continues as a primary entertainment distribution medium, and satellite broadcasting has many other critical applications such as transmission of earth monitoring and geopositioning data. Two-way satellite communica-

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tions has also found many applications, including telephone and video service to remote villages in undeveloped parts of the world, and as an Internet access system.

CATV AND CABLE ACCESS NETWORKS

The telephone network for a long time operated the only widely deployed communications access system, but this monopoly was broken with the development of the Data Over Cable Service Interface Specification (DOCSIS) in the mid-1990s. This is a system built on top of a CATV network to facilitate two-way data communication.

The original CATV systems of the 1950s were effectively community antenna networks pulling television programming off the air, amplifying the signals, and distributing them to subscribers over a spreading coaxial cable "tree" network. Because of the distortions and failure problems of distribution through multiple analog amplifiers, a major upgrading program carried out by many cable operators in the 1990s deployed hybrid fiber-coax (HFC) systems. These carried signals through optical fibers to district fiber hubs, each serving a subset of the total subscriber population through the remaining lower branches of the coaxial cable tree, utilizing only a few analog amplifiers.

These more robust distribution systems proved amenable to digital signaling, including both digital TV program distribution and two-way digital communication. Even before HFC systems there had been interest in interactive television, including an ambitious experiment in the early 1980s with the QUBE system in Columbus, Ohio. However, by the mid-1990s, broadband Internet access was the saleable product and DOCSIS proved very effective in stimulating the manufacture of standardized cable modems. Current modems send data downstream at about 30 Mb/s in a 6 MHz channel, and upstream in 1.5 Mb/s streams. Subscribers share capacity in both directions so that an effective downstream rate of 1 Mb/s is typical. With appropriate traffic engineering there is no more vulnerability to service degradation in cable data systems than there is in the ADSL access system described in the next section.

MODEMS AND DIGITAL ACCESS SYSTEMS

Despite digitization of the telephone network, access to computer communication networks and information systems began, and for millions of users continues, with use of an analog telephone voice channel connecting the user with a digital services provider. In 1958 the first modem (modulator/demodulator) that converted a digital data stream into an analog line signal for transmission through a telephone voice channel was designed and used in the SAGE project. The early frequency-shift keyed (FSK) modems did not support data speeds above 2400 bps, which requires compensation of voice channel distortions that vary considerably from one dialed connection to another. R. Lucky was the primary innovator, in 1965, of a data-driven adaptive equalizer that made possible much higher speeds, up to the current standard of 56 Kb/s, at acceptably low data rates. Many other innovations contributed to this success, including quadrature amplitude modulation (QAM) and offset frequency division modulation (OFDM) multichannel modulation systems, fractionally-spaced equalization, data-driven echo cancellation, and trellis-coded modulation.

It was recognized early that the use of telephone voice channels, with their voice band filters restricting the usable bandwidth to about 3 KHz, placed unnecessary constraints on the speed of residential access to computer communication networks and information systems. The twisted pair subscriber line supports signaling with much higher bandwidths, although it has many impairments that must be taken into account. To use this greater bandwidth, new digital systems were required in the telephone network to carry information signals originating in digital form, rather than analog voice signals converted to digital streams at telephone offices.

From the perspective of telephone engineers, still largely focused on voice and circuit switching but aware also of a future demand for data communication, the answer was the Integrated Services Digital Network (ISDN). Higher data rates are possible on the subscriber line because 3 KHz voice filters in the telephone network are avoided. Specified around 1980 by A. Habara of NTT and others, the ISDN "basic" interface provides two 64 Kb/s switched channels oriented to voice (but later used for data traffic as well) and a 16 Kb/s signaling and data channel. A worldwide trial was held in 1986. ISDN was widely deployed in Europe and Japan, but less so in the United States, where it has generally been considered too voice-centric and its data rate not generous enough for broadband access to the Internet.

Major advances to higher digital subscriber access speeds have been seen in the asymmetric digital subscriber line (ADSL) and cable data services. ADSL, like ISDN, uses the twisted pair subscriber line for higher speed transmission, but in contrast to ISDN focuses on data access, leaving voice as an analog subchannel on the same subscriber wire. Beginning with experimental development in the late 1980s, ADSL was not widely deployed until the late 1990s, and is still well behind cable data systems in market penetration. Unlike cable data systems, ADSL provides an individual access line to each subscriber, offering downstream rates from 0.5 Mb/s to 6 Mb/s (1 Mb/s effective rate is typical) depending on the distance and quality of the subscriber line. At the telephone office, ADSL traffic is concentrated and put into data networks.

OPTICAL COMMUNICATIONS

The overview paper by R. Ramaswamy in this issue gives a comprehensive review of the development of optical communications. The brief perspective here focuses on historical development of the technology and industry.

The development of the laser in 1959 suggested the possibility of an optical transmission system with very large bandwidth and information rate, but a suitable waveguide did not yet exist. A breakthrough occurred in 1966 when K. C. Kao and G. A. Hockham proposed a clad glass fiber and predicted that a loss of 20 dB/km should be attainable, a remarkable prediction given that the fibers of the time had losses on the order of 1000 dB/km. By 1968 researchers had prepared bulk silica samples with losses as low as 5 dB/km.

In 1970, F. P. Kapron, D. B. Keck, and R. D. Maurer of Corning Glass Works reported the development of a fiber with a loss of 20 dB/km. That same year I. Hayashi and others at Bell Labs demonstrated successful transmission at this attenuation figure using a semiconductor laser. Although actual installation in the field would not occur until the mid-1970s, these and other researchers had demonstrated the feasibility of using semiconductor lasers and optical fibers for communications. Nevertheless, there was an intensive competition at Bell Labs in the 1970s between optical fiber and milli-micrometer (radio) waveguide, which the radio system eventually lost.

One of the earliest field installations was the 1975 AT&T-Bell Laboratories experimental optical fiber trunk system in

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Atlanta, GA, using a 650m 144-fiber cable in a loopback configuration such that fibers could be interconnected to simulate longer transmission lengths. The data rate was nearly 45 Mb/s with repeater spacings up to 11 km. The success of this experiment led to commercial deployments, so that by the end of 1983 the Bell System had installed 300,000 km of cabled fibers capable of data rates of 45 or 90 Mb/s. The TAT-8 submarine cable, described earlier, was deployed in 1988.

Japan's Nippon Telephone & Telegraph (NTT) and the U.K.'s British Telecom also aggressively pursued optical fiber technology in this period. In 1978 NTT conducted a major field test involving 168 subscribers using fibers to bring broadband services to homes, including a very broad range of video services such as two-way video. NTT placed an 80-km trunk route into service in 1983, capable of carrying 400 Mb/s. After the successful installation of this system NTT announced plans for more than 60 such installations totaling nearly 100,000 km of fiber.

MOBILE COMMUNICATIONS

Mobile communications, now expanded into personal wireless mobility that may have nothing to do with vehicles, had a spectacular development in the last 40 years that continues at a fast pace. The article in this issue by Rappaport *et al.* on Wireless Communication provides a thorough review of the evolution of the technology. This section, like the one above, focuses on the historical developments.

In the United States the FCC had long allocated a very limited amount of spectrum for single-cell two-way radiotelephone service, mostly reserved for special services such as police and dispatching services. In 1964 the MJ (VHF), and in 1969 the MK (UHF) analog radio telephone systems, known as improved wireless telephone service (IMTS), were introduced for general mobile telephone service. In general, 12 frequencies per band were available, giving satisfactory service to about 500 subscribers in a geographical area. IMTS introduced a telephony-like service, with automatic channel selection and dialing of calls to and from the public network.

In 1947 Reudink and Young of Bell Labs proposed the cellular mobile radio concept, in which frequencies could be reused in non-adjacent cells by mobile radios of limited power. The concept was revisited later, and by 1971 a proposal for Cellular Radio was sent to the FCC. A patent applied for by A. Joel in 1972 described the complete system operation. After further development, the first trial of the Advanced Mobile Telephone Service (AMPS) was held in 1978 in the Chicago suburbs. In 1981 the FCC permitted cellular wireless radio service to begin, allowing two licenses per wireline carrier area — one for the wireline carrier and the other for a competitor.

From its start in the early 1980s, cell phone subscribership boomed. The industry grew exponentially from 25,000 subscribers in the United States in 1984 to one million in 1987, to four million in 1990, nine million in 1992, and more than 50 million in 1999. Similar growth occurred in many other countries; in Hong Kong, for example, more than half the adult population operated cell phones by the end of 1991.

New digital technologies were introduced in the 1990s, particularly TDMA (time-division multiple access) and spread spectrum CDMA (code-division multiple access). TDMA was realized in the IS-136 standard used in the U.S. and Japan and in the GSM system deployed in Europe and more recently around the world. The GSM (originally Groupe Speciale Mobile) represents one of the great success stories of coordinated multinational development and deployment of a large new technology infrastructure. CDMA, the descendent of military spread spectrum systems designed to avoid jamming, was first realized in the narrowband (about 1.25 MHz) MIS-95 standard and initially developed by Qualcomm. It is widely deployed in Korea and the United States.

These second-generation (2G) digital systems are designed primarily for voice communication, as were the first-generation systems, and provide data services only at relatively low rates, using a voice-band modem, a data networking overlay, such as GSM's Generalized Packet Relay Service (GPRS), or a separate wireless data network such as NTT DoCoMo's iMode system. Deployments of third-generation (3G) systems, designed as much for data as voice, are just beginning, following a long preparation in which many governments auctioned new spectrum for incredible prices, sometimes as much as $2000 per subsriber. All of the 3G systems under consideration use some form of wideband (5 MHz or more) CDMA, and aim for data rates ranging from about 100 Kb/s to 2 Mb/s, depending on location and motion. They may be delayed by stiff competition from the already wildly successful IEEE 802.11 wireless LANs, which offer data rates up to 54 Mb/s in 802.11a and use free, unlicensed spectrum.

INFORMATION AND COMMUNICATION THEORY

The article by Ezio Biglieri in this issue provides a technical discussion of recent and prospective advances in modulation and coding. Modulation is an element in the models created by communication theory for signal design and transmission through noisy, distorted channels, and coding is a product of information theory that is now inextricably intertwined with modulation. This set of disciplines has provided the analytical and, to a considerable extent, developmental framework for physical-level data communication that underlies computer communication networks and services.

Work by H. Nyquist in the late 1920s on bandwidth-limited pulse shaping was complemented in the 1930s and 1940s by innovations in statistical communication theory (using probabilistic descriptions of signal and noise waveforms) from S. Rice, C. Shannon, V. Kotelnikov, and others. Data communication systems using bandwidth-efficient pulse designs, including signal equalization and detection techniques deriving from communication theory, were intensively developed throughout the second half of the twentieth century. Among the major advances were data-driven equalization, referred to above in the section on modems and digital access systems; the Viterbi Algorithm (A. J. Viterbi, early 1970s) for efficient implementation of maximum likelihood sequence estimation for recovery of the transmitted data stream (see the reprint paper by J. Hayes in this issue); and trellis-coded modulation innovated by G. Ungerboeck in the early 1990s.

The field of information theory is anchored in Claude Shannon's seminal 1948 paper, "A Mathematical Theory of Communication." Information theory provides a mathematical bound on the capacity of a band-limited, noisy channel, and proof that a data encoding exists that can reach that bound. Actually creating these powerful codes, without imposing inordinate encoding delays, has been the practical challenge for both information theorists (who have their own Information Theory Society within the IEEE) and communication engineers. Many useful codes have been implemented and are important in communication today, including Reed-Solomon codes implemented in the compact disk system in the 1980s, and the relatively recent turbo codes.

DATA COMMUNICATION, COMPUTER COMMUNICATION, AND EVOLUTION TO THE INTERNET

Data communication networks came into being long before computer communication and the Internet. Central telegraph stations regenerated signals and sometimes manually switched them from one line to another. In 1885 one of Edison's early inventions was a stock and news printer operated over a telegraph line. Multiple printers could be served by fanned-out lines from a data source.

Remote control teleprinters, first available in 1915 and operating at about 75 bps, were used in networks with selective calling, known in the U.S. as "teletypewriter" networks and in Europe as "teletex" networks. Networks were established in Europe where teleprinter stations were addressed by keyboard characters. The U.S. teletypewriter network, initially manually (operator)-switched with typed address messages displayed to operators, later adopted automatic switching using dials provided with teletypewriter stations.

Teletypewriter exchange service (TWX) started in the United States in 1931, with the initially manual switching system responding to typewritten rather than dialed addresses. By 1938 there were many private corporate teletypewriter networks, some using store-and-forward messaging. In 1932 teletypewriting was extended to teletypesetting, distributing copy simultaneously to several printing plants. In 1940 teletype "torn-tape" switching was introduced, responding to addresses entered on perforated tape.

The decades after World War II saw the gradual innovation of computer communication networking. Modern electronic computing arose as an outgrowth of high-speed calculating projects during World War II. Although computing applications quickly moved into the business world by the early 1950s, the first steps toward communication between computers was defense-related. For example, the first large successful commercial computer network, the SABRE airlines reservation system built by IBM for American Airlines in 1961, owed a great deal to the Semi Automatic Ground Environment (SAGE), a computerized electronic defense network, and involved many engineers who had worked previously on SAGE. Although SAGE computers did not communicate directly with each other, the communications technology was innovative.

Much of the early non-military work in computer communications was directed toward computer time-sharing, the remote use of large computers before desktop computing became a reality. The client-server paradigm was emphasized in computer time-sharing networks as well as in many industry-specific or company-specific transactional networks. Both terminal-computer and computer-computer transactions were invoked, with communication protocols exercised in front-end communication processors rather than in the "dumb" terminals. Major advances in computer communication were made in the 1970s in commercial networks such as TYMNET and in networking standards such as X.25. These advances included message and packet store-and-forward switching and sliding window flow control. Store-and-forward message and packet switching made possible statistical multiplexing, the mixing of traffic from different sources in a transmission stream that was well suited to "bursty" data sources and made much better use of transmission resources than dedicated circuits such as those long used in the telephone network. Significant advances were made in the application of queuing theory to store-and-forward communications, in order to reach appropriate balances of network efficiency and quality of service.

National computer communication networks were established in the 1970s and 1980s in Canada, France, and other countries, generally conforming to the X.25 standard. Despite the use of message or packet switching and the introduction of many of the techniques of computer communication, these networks did not implement full interoperability of computer communication among networks of diverse underlying structures, the great contribution of the Internet Protocol (IP) that is discussed in a later section.

Packet switching itself was the result of a paradigm shift in thinking about data communications that occurred in the early 1960s, when concerns arose for network robustness, in particular survival of a nuclear attack. Paul Baran, in 1960 (and publicly reported in 1964), described a "distributed communication" technique for data (in 1024-bit packets with routing headers) that went beyond centralized store-and-forward message communications. Each communication node would have its own switch and would be connected to several other communication nodes, providing opportunities for alternative routes and thus a high degree of survivability. Also in 1960, Donald Davies of Britain independently developed a similar system, and with Roger Scanttlebury also coined the terms "packet" and "packet switching" to describe the data blocks and message-handling protocol in both his and Baran's system. The packet concept was soon incorporated into the ARPANET. In 1961, Leonard Kleinrock described distributed "Communications Nets" for computers in a proposal for a Ph.D. dissertation at the Massachusetts Institute of Technology, and in 1964 published a book entitled "Communication Nets," making a significant contribution to the development of computer networking by applying queuing theory to store-and-forward networks.

The Internet Protocol architecture whose evolution is described below was not the only choice for an internetworking system. The International Organization for Standardization (ISO) developed in the 1980s an alternative system of standards called Open Systems Interconnect (OSI) that would enable interoperation of equipment from different manufacturers (http://www.wikipedia.com/wiki/Open+Systems+Interconnect). Most of these standards, including X.400 email, CLNP packet delivery, and FTAM file transfer, are rarely used, but the X.500 directory service survives in modified form. The seven-level ISO protocol reference model also survives as a way to visualize protocol stacking, although modern protocol stacks do not necessarily fall neatly into that model.

THE INTERNET

Much of the history and dates of Internet development can be found on the Internet Society's Web site [http://www.isoc.org/internet/history/] and on Robert Zakon's Web site [http://www.zakon.org/robert/internet/timeline/].

During the late 1960s and early 1970s ARPANET, the first computer network to use routed packet switching, came into being under the sponsorship of the U.S. Department of Defense's Advanced Research Projects Agency (ARPA). At the beginning of 1966 ARPA embarked on a program to connect scattered computing sites at universities across the country under the leadership of Lawrence Roberts.

The basic infrastructure of the ARPANET consisted of time-sharing host computers, packet-switching interface message processors (IMPs), and 56 kb/s leased telephone lines. The major development task, contracted in 1969 to Bolt, Beranek and Newman Corporation (BBN), was to build the IMPs. The first BBN IMP interworked with the first IMP at UCLA in 1969, and by the end of the year BBN successfully installed and linked

four initial nodes at UCLA, SRI, UC Santa Barbara, and the University of Utah. At the end of 1971 ARPANET offered service with fifteen sites connected to the network. In 1972 Robert Kahn and Lawrence Roberts decided to demonstrate the ARPANET's capabilities at the First International Conference on Computer Communications (ICCC), held in October in Washington, DC. This demonstration made a powerful impression on the thousand or so attendees. By 1984 this predecessor of the Internet connected more than 100 universities and research facilities in the United States and Europe.

The greatest achievement of ARPANET may have been the invention, by Vinton Cerf and Robert Kahn in 1973-74, of the Internet Protocol (IP), an unreliable (no arrival guaranteed) communication protocol for conveying a packet across a multiplicity of networks that might use different underlying switching and transmission mechanisms. This made possible true internetworking in ARPANET and was the foundation for both the name and development of the Internet. Originally combined with the predecessor of TCP (transport control protocol), which runs on top of IP to realize an ordered and reliable end-to-end connection-oriented service, the two protocols were separated in 1975, with BBN and Stanford University making separate implementations of TCP and setting up connections between their locations. Tests in 1977 with a route looping from California through Europe and back to California, with terrestrial and satellite networks, provided the efficacy of the TCP/IP protocol suite. By 1983 every host was running TCP/IP, and by 1990 TCP/IP was available for virtually every computer on the American market.

ARPANET, like other early computer communication research, was focused on the computer utility, but file transfers and electronic mail proved to be very popular services. This was the first indication that personal information retrieval and communications would become the main applications of the future consumer-oriented Internet. Encouraged by the growing traffic, some people left BBN to start Packet Communications, Inc. in 1972, and BBN launched Telenet Communications Corporation with Lawrence Roberts as its president, which began service offerings in seven U.S. cities in 1975.

Today's Internet evolved from two steps that ARPA made in the direction of a general-purpose network of networks. The first was to separate, in 1983, the ARPANET's military users and academic researchers by creating a separate defense-oriented system called MILNET, while responsibility for the backbone of the academic Internet was assumed by the National Science Foundation. The second step, in 1994 when the NSF backbone was decommissioned, was to allow commercial applications, leading to the incorporation of the Internet into the world economy and its present predominant status as a carrier of transnational traffic. Internet Service Providers (ISPs) took over regional data networks and established connections among themselves.

The Internet Configuration Control Board (ICCB) suggested technology directions for the Internet, set up in 1981 by program manager Vinton Cerf, at that time program manager at DARPA, to advise him on technical issues [http://www.iab.org/iab-history.html]. It was chaired by David Clark of MIT. The ICCB was replaced by the Internet Advisory Board (IAB) in September 1984, which changed its name (but not the acronym) to Internet Activities Board in 1986. IAB's Gateway Algorithms Task Force transformed into the Gateway Algorithms and Data Structures (GADS) Task Force, which split in 1986 into the Internet Architecture Task Force (INARCH) and the Internet Engineering Task Force (IETF). The first IETF meeting, in a long series of large open gatherings, was held in 1986. IETF Working Groups, first defined in 1987, became the generators for most new Internet standards.

Consumer access to data communication began in the early 1980s, before availability of the commercial Internet, with dial-up to various information services, chat rooms, and shopping services by companies including CompuServe, America Online, and Prodigy. Communication between their separate networks became possible as the Internet developed.

The utility of the Internet increased a great deal with the development, beginning in 1990, of the World Wide Web, an information linking (hypertext) and retrieval system based on the Hyper Text Transfer Protocol (HTTP) and on display of documents aided by the Hyper Text Markup Language (HTML). Other information-coordination systems, particularly the University of Minnesota's "Gopher," contributed to this development. The World Wide Web originated at CERN (European Nuclear Research Center), where Tim Berners-Lee implemented the first prototype in support of physicists' retrieving each other's papers. Their early Web browser was improved in the image-oriented "Mosaic" browser, developed by Marc Andreessen at the NCSA (National Center of Supercomputing Applications) at the University of Illinois in 1993, which led directly to the Netscape browser in 1994. The number of Web sites has grown exponentially from about 100 in 1992 to what may be about 40 million today [http://www. netcraft.com/survey/], although multiple site hosting has made it increasingly difficult to define what is a separate Web site.

Development of the Internet required much progress in Internet protocols. The performance of TCP has been greatly improved (see the 1989 article by D. Clark *et al.* reprinted in this issue), and mobility has been a prime concern (see the 1997 article by C. Perkins and the 1995 article by R. Katz, also in this issue). Signaling to reserve resources for communication sessions has been introduced in several formats (see L. Zhang's 1993 RSVP article, reprinted in this issue). The development of IPv6, supporting 128-bit addresses instead of the 32-bit addresses in IPv4 that still is most widely used, promises to solve the address depletion problem and allow endless numbers of computers, appliances, and sensors to have their own unique IP addresses. Much recent work in the Internet has concerned support of media traffic such as IP telephony and audio/video streaming (in support of multimedia conferencing, music file exchange and sales, and Internet radio and television broadcasting, among many other current or potential applications). Henning Schulzrinne of Columbia University, well known in the ComSoc community, has been a major contributor to technologies and standards such as the Real Time Protocol (RTP), Real Time Streaming Protocol (RTSP), and IP telephony gateways and signaling (http://www.cs.columbia.edu/IRT/topics.html).

The trend recently and into the future is for the Internet, already well integrated with local area networks including IEEE 802.11 wireless LANs, is to become well integrated with other communication infrastructures, including the public switched telephone network (PSTN), the cellular mobile system, and broadcasting systems. The core of the Internet is already the same DWDM optical transmission infrastructure used by the PSTN and others, with the Optical Internet increasingly designed to accommodate IP traffic in various granularities and interface with high-speed routers in metropolitan area networks. As time goes by, the wireless and optical Internets will become transparent to our appliances and communication devices, becoming a standard utility infrastructure for all of our information-centered activities.

THE PROFESSIONAL COMMUNITY: ORIGINS AND DEVELOPMENT OF THE IEEE COMMUNICATIONS SOCIETY

The originals of the IEEE Communications Society were in the predecessor organizations to the IEEE (Institute of Electrical and Electronic Engineers), the AIEE (American Institute of Electrical Engineers), and the IRE (Institute of Radio Engineers). The AIEE, largely concerned with electrical lighting and power and with wired communications, was founded in May 1884 by a group of prominent electrical engineers, including Thomas Edison. It largely ignored wireless communication, leading to the 1912 merger of two relatively small organizations, the Society of Wireless and Telegraph Engineers and the Wireless Institute, into the IRE, which had more of an international flavor than did the IEEE. Both the AIEE and the IRE had the structure of professional groups, geographical organizations, student organizations, member grades, publication and conference services, and standards activities that persist in the IEEE to this day. The evolution of common areas of interest, such as electronics, led to the 1963 merger of the AIEE and IRE into the IEEE and the melding together of their similarly structured activities. At the time of their merger, the new *Proceedings of the IEEE* published an article of predictions of the technology future by Fellow-grade members, largely misguided except for one individual's forecast of a "computer in a matchbox."

The IRE Professional Group on Communication Systems was authorized on February 25, 1952, largely through the efforts of John L. Callahan and George T. Royden. Its initial limitation to radio was ended in September 1952 following a recommendation by the IRE Board of Directors that it expand its scope to cover all forms of communication and to change its name to the IRE Professional Group on Communications Systems (PGCS). Its new scope covered "communication activities and related problems in the field of radio and wire telephone, telegraph and facsimile, such as practiced by commercial and governmental agencies in marine, aeronautical, radio relay, coaxial cable, and fixed-station services." This broadened scope joined together several IRE Technical Committees that had dealt with various facets of communications engineering since 1937. George T. Royden was the first Chair of the Group's Administrative Committee, with Murray G. Crosby, John L. Callahan, and John Hessel serving as Vice Chairman, Secretary, and Treasurer, respectively.

The Group began with just under 600 members in 1952 and established its initial chapters in Washington, San Diego, Chicago, New York City, Philadelphia, and Cedar Rapids, Iowa, where Collins Radio was located. Publication of the *IRE Transactions on Communication Systems* began soon after, followed by the launching of a newsletter in late 1955. The *IRE Transactions on Communication Systems* was first published in 1956; it became the *IEEE Transactions on Communications Systems* in 1963, the *IEEE Transactions on Communications Technology* in 1965, and the *IEEE Transactions on Communications* in 1972. It remains one of the major publications of the IEEE Communications Society. The *IRE Transactions on Communication Systems* began with two issues per year, increasing to three issues in 1955, four issues in 1959, and finally 12 issues in 1973 as the *IEEE Transactions on Communications*.

By the end of 1957 the group had a membership of just over 2500. In 1958 PGCS established two annual awards, an Achievement Award and an award for the best article in the Transactions, selecting Harold H. Beverage as the first recipient of the Achievement Award and co-authors Robert T. Adams and B. M. Mindes for the Transactions Contribution Award.

The Administrative Committee also sponsored conferences, notably the Aeronautical Communications Symposium (AEROCOM), held annually from 1955 to 1958 in the Rome-Utica area, which was renamed the National Communications Symposium in 1959 and continued under its new name until 1963; and the GLOBECOM conference, co-sponsored with the Communications Division of the AIEE, which began in 1956 and became the IEEE International Communications Conference (ICC) in 1966 and the IEEE International Conference on Communications in 1967. In 1959, with a membership of over 2700, the Administrative Committee launched the Telemetering Conference, to be held toward the end of each year, which in 1972 became the National Telecommunications Conference (NTC). The particularly successful 1974 NTC held in San Diego had more than 1000 attendees and earned a surplus of over $8000 for the Society. In 1980 NTC was renamed the IEEE Global Communications Conference (GLOBECOM), borrowing the name used by the predecessor of ICC.

The Administrative Committee decided in 1958 to enlarge membership by soliciting non-U.S. members and by allowing AIEE members to affiliate with PGCS. These initiatives and the growth of the industry made it possible for PGCS to have 4200 members in 1962, just before the IRE-AIEE merger. The Administrative Committee also explored possible mergers with related IRE Professional Groups such as Antennas and Propagation, Marine Communications, Vehicular Communications, and Microwave Theory and Techniques, but nothing came of them and consolidation remains an elusive goal within the IEEE.0

The AIEE/IRE merger on 1 January 1963 retained the IRE Group structure, with the IEEE Group on Communication Technology emerging as the successor to the IRE Professional Group on Communication Systems, after a difficult year and a half to join the wireline-oriented AIEE members with the radio-focused and more academic IRE contingent. Dedicated work by David Rau of RCA, chair of the IRE PGCS, and Leonard Abraham of Bell Labs, chair of the AIEE Communications Division, made the merger happen. The *IRE Transactions on Communication Systems* similarly became the *IEEE Transactions on Communication Technology* in 1964, under the leadership of Ransom D. Slayton, who served as Publications Chairman and Editorial Manager as well as Editor-in-Chief of the Transactions. Soon after the IRE/AIEE merger, Slayton was member and parliamentarian of the administrative committee of IEEE's Group on Communication Technology. When the Group prepared to create the IEEE Communication Society, he was invited to lead the drafting of the Constitution for approval by IEEE's Board of Directors. Ran's "Constitution Group" of six members took account of the vision of many members. The Communication Technology Group and the IEEE Board of Directors approved the Constitution, which broadened the objectives, structure, and regulations for the new Communication Society.

The initial Technical Committee structure consisted of eight committees: Communication Systems Disciplines, Communication Switching, Communication Theory, Data Communication and Telegraph Systems, Radio Communication, Space Communication, Telemetering, and Wire Communication. Computer communication was just becoming visible, as evidenced by the theme for the GLOBECOM VI conference in Philadelphia in June 1964: "The Marriage of Communications and Data Processing." GLOBECOM VII, held in 1965 in Boulder, Colorado under the vigorous leadership of Richard Kirby of the National Bureau of Standards and with

the theme "Communications in the Computer Age," had a large attendance of 885 paid registrants and a technical program of 200 papers in 48 sessions. These conferences illustrated the efficacy of the system of Technical Committee sponsorship of technical sessions.

In the IEEE Communication Group's decade of existence before becoming the IEEE Communication Society, the Chairs of the Administrative Committee were R. K. Hellman (1964-65), W. B. Jones (1966-67), Frank D. Reese (1968-69), and Richard Kirby (1970-71). Publication directors were also influential, especially Donald Schilling, appointed in 1969 by Vice Chair Richard Kirby as Editor of the Transactions and Newsletter. He made the Editorial Board responsible to the Editor and only indirectly to the Technical Committees. He also innovated special topical issues and brought the Transactions from a bimonthly 900-pages-per-year journal in 1969 to a monthly 1500-pages-per-year publication in 1973. He also pressed the conversion of the newsletter into the new *IEEE Communications Magazine* in March 1973. This was carried out by Martin Nesenbergs, the Newsletter editor who became the founding Editor-in-Chief of *IEEE Communications Magazine*, designed to appeal to a broad readership without sacrificing technical substance. The first issue contained only one article, on the "Impact of the ASCII Code." Building on this accomplishment, substantial enhancements were made by the two following Editors-in-Chief, Stephen Weinstein and Alan Gersho.

The Communication Group's membership reached 10,000 in the early 1970s, and it had more than forty chapters in the United States and Canada. It had become a significant organization within the IEEE, and in March 1971 Chairman Richard Kirby appointed an Ad Hoc Committee on Technical Planning and Liaison headed by Ransom Slayton to investigate conversion into a full-fledged IEEE Society. With the help of William Middleton, Slayton, who later served for a lengthy period as ComSoc's parliamentarian, drafted the constitution and by-laws of the new Society. Although hoping to merge with other Groups in related technical fields, it was soon clear that that was not to happen, and Kirby recommended that the Administrative Committee submit a petition to the IEEE Technical Activities Board for elevation to Society status with the existing scope of the Communication Group. The IEEE agreed, and the new IEEE Communications Society (ComSoc) began operations at the beginning of 1972 with 8636 regular and 1182 student members.

The first set of officers included Alan Culbertson (President), Amos Joel, Jr. (Vice President), Anthony B. Giordano (Secretary), David Solomon (Treasurer), W. B. Jones (VP-Technical Affairs), Richard Kirby (VP-International Affairs), Donald Schilling (Director-Publications), Walter Noller (Director-Meetings and Conferences), Ed Doyle (Director-Administration), and Frank Reese (Past President and Chair of the Advisory Council). Subsequent Presidents of the Society were Amos Joel (1974–75), Walter Noller (1976–77), Robert Lucky (1978–79), Donald Schilling (1980–81), Eric Sumner (1982–83), Mischa Schwartz (1984–85), Fred Andrews, Jr. (1986–87), John McDonald (1988–89), Ray Pickholtz (1990–91), Paul Green, Jr. (1992–93), Maurizio Decina (1994–95), Stephen Weinstein (1996–97), Thomas Plevyak (1998–99), Roberto DeMarca (2000–2001), and Celia Desmond, the current President (2002–2003).

The major conferences reached their mature size by 1980, when ICC and GLOBECOM each had about 1500 registrants. The major conferences also began to take place outside of North America, with ICC '84 held in Amsterdam and GLOBECOM '87 in Tokyo, and later conferences in Singapore, London, Sydney, Rio de Janeiro, and Helsinki. Strategic planning of ICC and GLOBECOM conferences was assumed by the GLOBECOM-ICC Conference Board (GICB) in 1985. Much of the prestige of GICB was generated in the 1985–2000 period when Ross Anderson served as Chair.

Additional major conferences began in the 1980s. The IEEE Military Communications Conference (MILCOM) began in 1982 in Boston as an extension of the existing Spread Spectrum Conference. IEEE INFOCOM focused on computer communications and, managed by a Steering Committee led for many years by Harvey Freeman, is a joint IEEE Communications Society/IEEE Computer Society event that began in Las Vegas in 1982. It remains the premier meeting in this field, with a great deal of Internet-oriented content. The IEEE Network Operations and Management Symposium (NOMS) began in 1987. It is co-sponsored by the International Federation of Information Processing Societies (IFIPS) and alternates from year to year with the similar IFIPS conference in which the IEEE Communications Society is the co-sponsor. Many other, smaller meetings are also deeply ingrained in the Communications Society culture, especially the renowned Communication Theory Workshop, which observed its 30th anniversary in 2001.

The Society's publications also developed substantially in the 1970s, 1980s, and 1990s. The authority of the *IEEE Transactions on Communications* increased under the editorial leadership in 1978–1984 of Adam Lender. In 1982 a new journal, the *IEEE Journal on Selected Areas in Communications* (JSAC), was separated from the *IEEE Transactions on Communications*, which was inundated with submissions. JSAC soon went from quarterly to nine issues per year, and in 2001 increased to 12 issues per year with three specialized wireless issues. In 1993 the *IEEE/ACM Transactions on Networking* was introduced, co-sponsored by the IEEE Communications Society, the IEEE Computer Society, and the Association for Computing Machinery (ACM) Special Interest Group on Communications. Jim Kurose and Steve Weinstein of ComSoc and Harold Stone of the IEEE Computer Society negotiated this pioneering collaboration from the IEEE side. *IEEE Communication Letters*, dedicated to fast publication of short papers, was stimulated by Ezekiel Bar-Ness and launched in 1997.

ComSoc has been deeply committed to magazines since the birth of *IEEE Communications Magazine*. A decision was made in the 1980s to do in-house publication, so that the Society is responsible for the full range of editorial and production tasks. After considerable success with *IEEE Communications Magazine*, three new magazines were launched: *IEEE Network — The Magazine of Computer Communications* (NET, 1987), *IEEE Lightwave Communication Systems* (later *IEEE Lightwave Technology Systems*) (LCS/LTS, 1990), and *IEEE Personal Communication Systems Magazine* (PCS, 1994). LCS/LTS, launched largely through the initiative of Paul Green, was plagued by a name conflict with a trade publication and appeared a few years before the boom in the optical networking industry, resulting in low circulation and cessation of publication after two years. In retrospect, a case could be made that it should have been sustained. PCS changed its name in 2002 to *IEEE Wireless Magazine*.

ComSoc also began co-sponsoring journals and magazines with other IEEE societies. These initiatives included *IEEE/OSA Journal of Lightwave Technology* (with the Optical Society of America, in 1988), *IEEE Multimedia Magazine* (with the Computer Society, 1994), *IEEE Internet Computing* (with the Computer Society, 1997), and the *IEEE Transactions on Applied Superconductivity* (with eight other societies, in 1991).

Electronic publications and information sources became an

important area of development in the mid 1990s. ComSoc's first Web site was designed by Joseph Milizzo and Stephen Weinstein in December 1993 and deployed in early 1994. *IEEE Communications Interactive*, the on-line version of *IEEE Communications Magazine*, was available to members in October 1996, and *IEEE Network Magazine* and *IEEE Personal Communications Magazine* went on-line in January 1997. *IEEE Communications Surveys*, the Society's first electronically published journal, became available on ComSoc's Web site in 1998. The Society is currently developing and deploying an evolutionary series of Web portal enhancements intended to make its Web site the best place for quickly locating any kind of information on communications technology and networking.

The Society began acquiring a staff when, in 1979, Donald Schilling hired a full-time managing editor, Carol Lof. She developed a staff for the production of *IEEE Communications Magazine* and helped it grow into a major publication, becoming a monthly in 1983 and earning $100,000 in advertising revenue in 1984.

The staff grew over the years in size and responsibilities, and in 1990 Carol Lof was appointed the first Executive Director of the staff, which at that time had 10 members. Today it has 23 members and occupies offices on 47th street in New York City not far from the former headquarters of the IEEE in the United Engineering Center. Subsequent Executive Directors were Alan Ledbetter (1995-96), Charles Stewart (who served in an interim role for several months following Alan's serious accident) and, since 1997, Jack Howell. These Executive Directors worked closely with a series of Presidents to develop new services for Society members and a new model for staff-volunteer collaboration. Currently reporting to the Executive Director are the Publications, Meetings and Conferences, Marketing, and Information Systems departments, as well as smaller Finance and Administration, Executive and Volunteer Services, and Advertising Sales organizations.

"Globalization" has also been a recurring theme in the Society's history. In 1972 the Board of Governors set up the International Activities Council headed by Richard Kirby to foster the development of the Society's activities, membership, and member services outside the U.S. This Council stimulated the offering of affiliate membership in the Communications Society and the creation of three International Committees (Europe, Middle East, and Africa; Asia-Pacific; Latin America) to better represent the interests of members outside of North America. Publications made special efforts for international content, exemplified by special issues of the Transactions focused on communications in Japan, Europe, the U.S.S.R., and Latin America.

By 1996 more than 40 percent of ComSoc's members were from outside the U.S., up from about 27 percent in 1978. Similarly, by 1988 non-U.S. authors presented 30 to 40 percent of the papers at GLOBECOM and ICC. ComSoc held more of its conferences overseas, improved distribution of Society publications to overseas members, opened offices in Brussels and Singapore, and signed Sister Society agreements with technical societies in Australia, Brazil, China, France, Germany, India, Israel, Italy, Japan, Korea, Russia, Switzerland, Taiwan, and Vietnam. Much of the leadership for globalization came from Maurizio Decina during his term as President in 1994–95, and was continued by the Presidents who followed (Stephen Weinstein, 1996–97; Thomas Plevyak, 1998–99; Roberto DeMarca, 2000–2001; and Celia Desmond, 2002–2003).

Over the years, the Communications Society made a number of strategic reviews to assess its directions and services, notably the studies led by Robert W. Lucky in 1982, Fred T. Andrews in 1986, and Richard Skillen in 1988. In the December 1982 study made by the ComSoc Policy Board under Lucky's leadership, it was discovered that ComSoc was a quite successful society in many ways, with approximately 15,000 members and prestigious publications and conferences. However, the Society was growing more slowly than the telecommunications industry and was too telephony-oriented, giving insufficient attention to new fields such as satellites, computer networking, and fiber optics. The Society needed to reorient itself to "become unquestionably the dominant Society for communications engineering, not only in telephony but in the other emergent fields."

To this end, the ComSoc Board of Governors revised the Society's scope at the end of 1985 to "embrace all aspects of the advancement of the science, engineering, technology, and applications for transferring information among locations by the use of signals." The scope was modified again this year (2002) to more clearly express the inclusion of networking and media topics, embracing "all aspects of science, technology, and applications supporting the transfer and organization of information through communication networks and channels via diverse media types and formats." In between, efforts were made to generate more activity on emerging fields, such as the establishment of new Technical Committees on Personal Communications, Broadband Delivery and Access Systems, Gigabit Networking, and the Internet, encouraged, beginning in 1994, by President Maurizio Decina and Vice President–Technical Affairs Stephen Weinstein.

The studies also determined needs for greater emphasis on issues of interest to industry and our industry-based members, leading to the launching of new magazine and conference initiatives; devoting greater attention to gaining and retaining student members; and for strengthening the Technical Committee structure. In 1991 ComSoc wrote a Five-Year Strategic Plan addressing the concerns of the Skillen Report, and recommending an increased focus on emerging technologies including software, wireless, photonic systems, and computer networking. Approximately $100,000 was spent on membership recruitment and retention in 1992. In 1997 a Young Members' Committee was created under the direction of Vice President–Membership Affairs Roberto de Marca.

Recognizing the impracticality of a growing number of officers reporting directly to the President, the operational structure of the Society was significantly revamped in 1998, largely according to recommendations made by a committee chaired by Douglas Zuckerman. A Vice President for Member Services was created, to whom separate Directors for Magazines and for Journals, as well as the Director of Meetings and Conferences, now report. A Vice President for Membership Development was made specifically responsible for recruiting and retaining members. The Vice President for Technical Activities remained responsible for the Technical Committee structure and additional initiatives, and a new Vice President for Society Relations was made responsible for both "sister society" collaborations and relationships with other IEEE societies and societies in related fields outside of the IEEE. Development of the staff organization, described above, paralleled these changes in the volunteer structure.

In the twenty-first century as in the twentieth, ComSoc remains a volunteer-focused organization in which a skilled support staff plays a vital role. In the face of the current financial crisis in the IEEE as well as in the entire communications industry, we must continue to evolve our technical concentrations and electronic services in order to survive and prosper. The rich foundation of ComSoc's first 50 years provides guidelines and inspiration for a successful future.