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As if in a flash

Ten years have gone by as if in a flash since ComSoc published “A Brief History of Communications” to celebrate its first 50 years. Only 10 years after the Introduction to that book was written by Celia Desmond, ComSoc President at the time, we are now updating it to reflect the last decade! Shouldn’t we have waited another 50 years?

Well, in a sense we have. Because these last 10 years look like 50 in terms of how our field has evolved. Moore’s law forecasts an evolution in the next 18 months that will double the number of transistors per chip. But it took us 50 years to come where we now stand so in the next 18 months progress should equal what was seen in the last 50 years!

Cell phone subscribers now number more than 6 billion worldwide and we are discussing how to define broadband: is 20 Mb/s enough to call it broadband or should we require at least 100 Mb/s? Well 10 years ago there were less than a billion cell phones and broadband was definitely defined as 2 Mb/s.

ComSoc 10 years ago had approximately the same number of members as it does today, but today most of our members—we had 51,155 as of 31 December 2011—are no longer in the United States.

Telecommunications is expanding rapidly in developing countries and, in a way, it is shrinking in mature markets, at least in terms of revenues. In reality, telecommunications is becoming ever more pervasive, and it has become so commonplace that it has disappeared from people’s everyday radar.

This is a great opportunity for ComSoc. Telecommunications today is a fraction of what it will be in 10 years’ time, and
our constituency will grow along with it.

We are starting to talk about an Internet *of* Things and *with* Things. This will multiply the number of telecommunications users by a factor of 100 and multiply the potential audience of ComSoc by a factor of 10.

Our past is our foundation. The building has to be built starting today and we trust our present and future membership will be at the hub of communications everywhere.

Vijay Barghava

*President,* IEEE Communications Society 2012-2013
What a year to be President!

In 2002 ComSoc celebrates our 50th anniversary. Over these 50 years we have seen tremendous changes to the telecommunications industry, and, as would be expected, to communications technologies. We have moved from black rotary dial sets and 4 digit numbers with location names for exchange codes, through analog modems and early packet switching for data, from in-band signaling through common channel signaling to intelligent networks to networks that will soon carry predominantly data traffic, from copper access and backbone facilities to fiber and too much dark fiber in the network, from many households enjoying the luxury of a single 4000-Hz line to teenagers “requiring” higher than ISDN speed access on extra phone lines, not to mention the cell, from predominantly voice services, through convergence of voice and data to services that integrate voice, data, video, and other content. We have experienced tremendous growth in the number of users connected to the network, and simultaneous growth in the volume of information each user transmits during a call. The drivers for this growth have included changes in technology and changes in regulation, plus changes in the mindset of users. And this has happened worldwide, in all cultures in all locations.

As communications professionals, we have enabled change in the world, in the way people work, manage their households, and spend their leisure time. Communications and the changing capability of communications networks have been a driver in
establishing the world business environment, and the habits of people in business and in life. These changes have permeated all aspects of our environment.

I would like to thank the many past Presidents of the Society who have encouraged and assisted me, and other volunteers. These are too numerous to be listed, but certainly include Roberto De Marca, Tom Plevyak, Steve Weinstein, Maurizio Decina, Paul Green, Jack MacDonald, Ray Pickholtz, and many more. They were great leaders, who cared deeply about the Society, and who gave their time, their knowledge, and their leadership to build the vibrant Society we have today.

Celia Desmond

President, IEEE Communications Society 2002-2003
The IEEE Communications Society commemorated its 50th anniversary in 2002 and its 60th anniversary in 2012. As you can read here in more detail, the society traces its roots back to the founding of the Professional Group on Communications Systems of the Institute of Radio Engineers (IRE) in 1952. Since then, the IRE merged with the American Institute of Electrical Engineers (AIEE) in 1963 to form the Institute of Electrical and Electronics Engineers (IEEE), and the IEEE Communications Society adopted its current name in 1972.

This short book provides a thumbnail sketch of the evolution and development of communications technology and the IEEE Communications Society. It also introduces some of the personalities who have made and in many cases are continuing to make communications and related information technologies a challenging profession, a rewarding career, and a foundation for the global economy and society.

For our 50th anniversary, which was a major milestone, planning began in 1998 by a Fiftieth Anniversary Advisory Board chaired by Jack McDonald. Celia Desmond, Roberto de Marca, Harvey Freeman, Jack McDonald, Tom Plevyak, Curtis Siller and Jack Howell did much of the implementation work. The 2002 commemorative events, in addition to release of the first edition of this book, included a Grand Reunion and a plenary panel session at ICC on “ComSoc at 50: A retrospective,” chaired by Robert Lucky.
For our 60th anniversary, this new volume, released at the 2012 International Communications Conference in June, significantly updates the history text, includes a new chapter on the history of communications in the sixth decade of ComSoc’s operations (2002-2012), and has new oral interviews with major figures in our field. Steve Weinstein, organizing the 60th anniversary activities, together with Jack Howell, John Pape, Ting Qian, and Roberto Saracco assisted Alfred Rosenblatt, former managing editor of *IEEE Spectrum* magazine in putting together this volume. Additional online and conference activities complement this publishing initiative.

The IEEE Communications Society would like to thank the IEEE History Center at Rutgers University for drafting the original (2002) text, modified and augmented in this volume, and locating numerous photos and illustrations. Special thanks go to the late Amos Joel for preparing and compiling much of the history of the society. Thanks also go to many distinguished ComSoc members and volunteers who contributed interviews for the oral histories section.
Communications Technology:
From the 19th to the 21st Century
Communications

Before 1952

Morse’s telegraph register
The inauguration of commercial telegraph service (by William Cooke and Charles Wheatstone in England in 1839 and by Samuel Morse in the United States in 1844) was the first major technical undertaking using electricity. From a technical standpoint, the most important attribute of the telegraph was its instantaneous operation across vast distances; it was the first technology to sever 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.

By the early 1850s overland telegraph lines spanned much of Europe, North America, and the Middle East. At this time electricians in England and the United States began to consider ways to connect the continents by means of submarine cables. In 1851 England was permanently connected to continental Europe by means of a cable laid between Dover, England, and Calais, France. The Atlantic cable was a joint Anglo-American project. After failed attempts to lay a cable in August 1857 and the spring of 1858, a working cable operated for about a month in the summer of 1858. Its failure, due to high voltages used in the signalling equipment, was not unusual. By 1861
entrepreneurs and governments alike had laid some 18 000 km of cable around the world, of which only 5000 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 the turn of the century cables connected every continent except Antarctica and spanned every major body of water.

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 electrical engineering and placed it on a firm scientific footing.
From a communications engineering standpoint, the major difficulty with submarine telegraphy was the attenuation and dispersion of signals passing through long cables. Dispersion due to the intrinsic capacitance of the cable especially limited the speed of long cables to just a few words a minute. William Thompson (later Lord Kelvin) was the first electrician to study this phenomenon systematically. In a paper published in 1854, Thompson borrowed Fourier’s equations governing heat transfer to model the transmission of electrical signals through a long submarine cable. To do so, he decoupled the signal (the telegraphic pulse) from the medium (the cable), an insight that 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. In the same way Claude Shannon’s work on information theory would be nearly a hundred years later, Thompson’s decoupling of signal from medium was a conceptual revolution: it was the theoretical basis for much subsequent work in communications and signal processing.
The next major advance in communications, the telephone, was a direct outgrowth of electricians’ efforts to increase the message-handling capacity of telegraph lines.
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. At this time several electricians began to investigate harmonic telegraphy, or the use of several different tones to trans-
mit many discrete telegraph signals on a single line simultaneously. Alexander Graham Bell and Elisha Gray of the United States both realized that if a telegraph line could convey several musical tones it could also transmit human speech. In early 1876 Bell had the good fortune to file his patent just a few hours before Gray filed a caveat for his. The telephone quickly caught on for local service, and by 1880 the Bell Company had leased nearly 100,000 instruments.

The two major technical problems of early telephony involved switching and long-distance transmission. At first, human operators, usually women, connected calls manually. However, this was slow and labor-intensive. In 1889 Almon B. Strowger, a Kansas City undertaker, patented an automatic dialing system. Strowger’s system was quite successful and was first installed in 1892. It continued to be used in many American and European cities as late as the mid-1970s.
The second major technical problem, long-distance transmission, was a much more daunting issue requiring several decades of research and development. Long-distance telephony posed a problem similar to that of submarine telegraphy: attenuation and dispersion degraded signals rapidly with distance. A copper wire pair could transmit intelligible speech for about 100 miles, but beyond this distance line losses and distortion due to the intrinsic capacitance of the line rendered speech unintelligible. Thus, successful long-distance telephony required two major engineering advances: inductive loading (to counteract line capacitance) and amplification.

In 1900 George Campbell of AT&T and Michael Pupin of Columbia University filed patents describing a method for inductively loading a telephone line. Since the patent situation was unclear, AT&T bought Pupin’s patent for an immediate cash payment of $185,000 plus another $15,000 per year during the seventeen-year life of the patent. The advantages of periodic loading were quite significant. Because it substantially reduced dispersion, it made possible the operation of a 4300-km line from New York to Denver in 1911.
Communications before 1952

Telegraph wires in Cincinnati

Long distance switchboard, 1892
However, this represented the limit through which an unamplified telephone signal could travel. Greater distances awaited the development of electronic amplifiers. Around the turn of the century the British scientist Ambrose Fleming devised an electronic “valve,” or diode vacuum tube, which proved useful as a radio detector. Lee de Forest of the United States placed a third electrode between the cathode and anode, and this device, the triode, became the fundamental building block of both amplifiers and oscillators. Within a few years electronic amplifiers had become reliable enough to enter telephone service, and in 1915 AT&T built a transcontinental telephone line between New York and San Francisco.

While technical advances such as inductive loading and electronic amplification were important, perhaps the greatest lasting significance of long-distance telephony was that it led to a permanent and sustained research and development effort at AT&T. Throughout much of the twentieth century, AT&T’s Bell Laboratories ushered in many fundamental advances in
electrical engineering and the physical sciences, including negative feedback, active filters, control theory, carrier transmission systems, semiconductor electronics, information theory, and even radio astronomy. Thus, the inauguration of fundamental corporate research and development may be the most important legacy of long-distance telephony.

The development of electronics after the turn of the century made possible another advance in communications engineering: radio. It is pointless and incorrect to credit any one individual with the invention of radio.

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 1888, when 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. One of these researchers was Nikola Tesla, a Serbian-American inventor best known for promoting alternating current power systems, who experimented with radio in 1894 and predicted its use for communication over long distances. The Russian scientist Alexander Popov gave wireless demonstrations in the mid-1890s, and his communication apparatus was used in early 1900 in a naval operation on the Finnish Gulf. The best known experimenter and entrepreneur was a young Irish-Italian named Guglielmo Marconi. Marconi introduced his wireless signaling apparatus in 1896, and within a few years he could transmit over distances of several hundred miles. In December 1901 Marconi spanned the Atlantic, receiving in Newfoundland signals transmitted from England.

Early radio equipment depended on cumbersome transmission and reception techniques. It was difficult to tune transmitters and receivers precisely, and the presence of many transmitters generated a great deal of troublesome interference. However, in 1908 Lee de Forest patented a three-element vacuum tube, or triode, which made possible more precise transmission and reception of radio signals. Edwin Howard Armstrong, perhaps the greatest electrical engineer of the early twentieth century, used de Forest’s triode to develop oscillator circuits. They enabled the transmission of a continuous carrier wave at a sharply defined frequency and led to amplifier circuits that increased both the selectivity and sensitivity of receivers.
Until the rise of broadcasting after 1920 the major application of radio was for wireless telegraphy. At the beginning of the 20th Century, rescue operations coordinated by radio telegraphy during three maritime disasters proved its worth. In January 1909, radio distress calls from the White Star liner Republic, which had been holed by a collision in fog with the passenger liner Florida, allowed the Baltic to rescue all 1650 people aboard in a brilliant display of seamanship.

In April 1912 the new luxury liner Titanic struck an iceberg and sank; of the 2200 passengers and crew, only about 700 were rescued. However, many more lives would have been saved had nearby ships maintained a round-the-clock radio watch. In October 1913 another passenger liner, the Volturno, caught fire in mid-Atlantic. Her distress call brought 10 ships to the scene, and all passengers and crew were saved. The use of wireless equipment during the First World War was a further demonstration of the utility of the new technology.
A new—and quite popular—use of radio came about a few years after these maritime disasters. In 1916 Frank Conrad, an amateur radio enthusiast and Westinghouse engineer, began regular broadcasts of music from his Pittsburgh home. Other amateurs in the area were able to tune in his “wireless concerts.” Westinghouse realized there existed a vast potential market for broadcasting and on 2 November 1920 the company established the first commercial radio station, KDKA. Other local broadcasters had been licensed earlier but not as commercial radio stations. By 1923 more than 500 stations were on the air, and by 1929 there were over 4 million radio receivers in use in the United States. Europe and other parts of the world were not far behind. For example, the British Broadcasting Corporation was founded in 1932. In 1933 Edwin Armstrong invented frequency modulation, a transmission technique that greatly reduced fading and static. By 1940 Armstrong had set up an FM broadcast network in the northeastern United States, using the 42-50 MHz band.

World War II brought another advance in electronics technology that would eventually be applied to communications: radar. The British physicist Sir Robert Watson-Watt introduced the first practical radar system in 1935, and by 1939 the British military established the “Chain Home” network of radar stations to detect air and sea aggressors. In the same year two British scientists, Henry Boot and John T. Randall, developed a significant advance in radar technology, the resonant-cavity magnetron. The magnetron was capable of generating high-frequency radio pulses with large amounts of power, thus permitting the development of microwave radar.

In September 1940 the British military decided to share its radar technology with the United States. The Americans moved quickly and opened the Radiation Laboratory at MIT under the leadership of Lee DuBridge. Radar proved crucial to the Allied war effort, and 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. Radar itself made all-weather air and sea travel routine. And today most kitchens in the developed world boast a cavity magnetron in a microwave oven, usually used for warming up leftovers.

Television, with mechanical scanning, was demonstrated by Bell Labs in New York in 1927, and may have been demonstrated in 1926 by Léon Theremin in the U.S.S.R. Commercial television was made practical by Philo Farnsworth's invention of an electronic scanner. Public broadcasts began as experiments in many countries so it is difficult to provide exact dates for initiation of commercial services in the U.S., Britain, Germany, and elsewhere, but it was largely in the early and middle 1930s. World War II delayed the development of a mass market for television broadcasts until the late 1940s.
As the story of radar suggests, the war and the immediate post-war period led to many far-reaching advances in electronics and communications. The year 1948 was noteworthy for two major developments: the invention of the transistor by Shockley, Bardeen, and Brattain around the beginning of the year, and the publication of Claude Shannon’s seminal paper “A Mathematical Theory of Communication.” All four researchers worked at Bell Laboratories. These two advances laid the foundations for a great many subsequent developments, including undersea cables for telephony, communications satellites, and the beginnings of digital and data communications.

In 1956 the Bell System in the U.S. and the British Post Office inaugurated service on a transatlantic telephone cable, TAT-1. By this time, submarine telegraph cables had been in operation for more than 100 years and the telephone for 80 years. However, before the installation of TAT-1, the dispersion and attenuation in long cables made the transmission of intelligible speech unworkable. In the early 1930s Bell began a long-range program of research and development to develop a reliable transatlantic cable, and by 1942 the company had a plan for a 12-channel system with repeaters at 50-mile intervals. America’s entry into World War II shelved this effort.
In 1952 Bell and the British Post Office began negotiations for a telephone cable connecting the U.S. and UK. The partners successfully installed the cable and terminal equipment in 1955 and 1956, and TAT-1, capable of transmitting 36 4-kHz-spaced channels, entered service on 26 September 1956. TAT-1 was taken out of service in 1979, having exceeded its 20-year design life. Other 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.

Between 1956 and the early 1960s spectral efficiency was improved by reducing the channel spacing from 4 kHz to 3 kHz and introducing Time Assignment Speech Interpolation (TASI). TASI was an electronic circuit multiplier used to expand the transmission capacity of telephone lines. It depends for its operation on the fact that in a normal conversation the average speaker talks less than 40% of the time. By using fast switches and good speech detectors, the system permits voice circuits to timeshare a smaller number of channels.
TASI equipment was expensive but cost-effective for undersea use. The first TASI system was installed in 1959.

In this period Bell engineers also developed solid-state circuitry for long telephone cables. TAT-1 had used a long-life pentode tube amplifier, but transistor amplifier circuits for a new wideband system were developed soon after and were installed after 1963.

Satellites were the next major development in long-distance communications. Developments in microwave circuitry during and after World War II, particularly waveguides and cavity resonators capable of operation up to 100 GHz, made satellite communications possible. The United States and U.S.S.R space programs began in the mid-1950s, and the U.S.S.R. placed the first artificial satellite, Sputnik, in orbit in October 1957. An American satellite, Explorer I, followed Sputnik into orbit four months later. It would still be some time before geostationary satellites, first proposed in 1945 by British scientist Arthur C. Clarke (later to become famous as a writer of science fiction) would be launched.

By the late 1950s, the two major ingredients of satellite communications, microwave transmission and reception and launch capability, were known quantities. In this period John Pierce wrote several articles extending Arthur Clarke's concept of how a satellite communications system might work. He was a member of the AT&T team that placed the first communications satellites, Echo I and Telstar, in orbit. In 1960 the world's first communications satellite, the passive reflector Echo I, was launched into a medium altitude (not yet geostationary) orbit. While Echo I demonstrated that transatlantic satellite communications was possible,
the major drawback of passive satellites was that they required very high transmission power to overcome path losses. As a result, communications engineers began work on active satellites that could receive and retransmit signals.

Telstar I, launched on 10 July 1962, was the world’s first active communications satellite. Engineers at the Goonhilly Satellite Earth Station at Goonhilly Downs in the UK built the first open parabolic antenna to link with it. Unanticipated radiation damage from the Van Allen radiation belt caused it to operate for only a few weeks. However, Telstar 2, made more radiation resistant, was launched on 7 May 1963 carrying telephone channels and one television channel. The Telstar project was an experimental venture and not a commercial system, but it demonstrated the utility and workability of satellite communications.

Also in 1962 the U.S. government adopted the Communications Satellite Act. This Act led to establishment of the Communications Satellite Corp. (Comsat), a quasipublic corporation. In 1964 Intelsat, an international organization to promote and coordinate the development of satellite communications, came into existence with 100 countries represented. The first communications satellite in geostationary orbit, Syncom 3, was launched that same year.

This period also saw the beginnings of data communications. 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. In 1949 the U.S. Air Force sponsored development of a computerized electronic defense network called SAGE (Semi-automatic ground environment). SAGE, built between 1950 and 1956, coordinated radar
stations and directed air defenses to intercept incoming bombers. Although the SAGE computers did not communicate directly with each other, the communications technology to connect them was innovative and established a technical base for computer communications for years to come. For example, the first large successful commercial computer network, the SABRE airlines reservation system built by IBM for American Airlines in 1964, owed a great deal to SAGE. The system used modems to transmit data signals over ordinary analog telephone channels at speeds of about 1200 b/s. Encrypted military vocoder systems used this same method of interconnection. The increasing importance of sending data via modems on telephone circuits led to a long series of improvements in modem technology and in telephone networks.

There was also, in 1961, the introduction by the Bell System of T1 carrier systems for digitized voice based on pulse code modulation (PCM), invented by the British engineer Alec Reeves around 1938. By approximating frequent enough samples of a voice waveform with finite-length digital words, a very robust transmission system, with considerable immunity to noise, became possible. Although it had limited use in World War II, it was not a fundamental part of the telephone network.
until both T-carrier for transmission and the much later digital switching systems were introduced.

With the early 1960s came a shift in thinking about data communications. Several researchers realized that traditional circuit switching methods were too cumbersome for use in computer communications. In May 1961 Leonard Kleinrock submitted a proposal for a Ph.D. dissertation at the Massachusetts Institute of Technology titled “Information Flow in Large Communication Nets.”

Kleinrock made a significant contribution to the development of computer networking by the skillful application of queuing theory to store-and-forward networks. At the same time Paul Baran, a young engineer at the Rand Corp., began thinking about how to build a communications network that could survive a nuclear first strike. In 1960 Baran described a technique he called “distributed communication” in which each communication node would be connected to several other communication nodes. Switching was thus distributed throughout the network, giving it a high degree of survivability. To move data through this network Baran adopted packet switching, which digitized the information to be sent, broke it into chunks of 1024 bits, and provided a header containing routing information. A message would then be reconstructed at the receiving node.

Baran described his proposed system in great detail in the summer of 1964 in an eleven-volume Rand publication titled “On
Distributed Communications.” At the same time, Donald Watts Davies in Britain independently developed a system similar to Baran’s. Davies also coined the terms “packet” and “packet switching” to describe the data blocks and message-handling protocol in both his and Baran’s system. Both Baran and Davies thus independently conceived of packet switching as the best means to transfer data in a computer network. A few years later their ideas were incorporated into the ARPANET, whose first project director was Lawrence G. Roberts. In 2000 the IEEE Internet Award went jointly to Kleinrock, Baran, Davies, and Roberts “for their early, preeminent contributions in conceiving, analyzing and demonstrating packet-switching networks, the foundation technology of the Internet.”

The Internet Protocol, of equal importance, came a little later, as described in the next section.
Communications

1964 - 1972

INTELSAT communications satellite
This period saw fundamental advances in four important areas of communications technology: data transmission through the analog voice channels of the telephone network, computer networking, satellite communications, and lasers and optical fibers. These years also witnessed the initial steps toward the breakup of the Bell telephone monopoly.

A major technical difficulty facing all data networks was their use of ordinary telephone voice channels for access to a digital backbone network or all the way to a host computer. Because of distortions in the transmission characteristics of these voice channels, errors crept into data transmissions at speeds above 2400 b/s. To counteract this problem, in 1965 Robert W. Lucky of Bell Labs developed an adaptively equalized modem that compensated for phase and amplitude distortions of telephone voice channels. Adaptive equalization made possible data rates of 9600 b/s in this period, and much higher in subsequent decades, at acceptably low error rates. Despite its strong innovation record, AT&T was not as nimble as other companies in selling advanced modem products. Codex Corp., for example, was a leader in the introduction of 9600 b/s modems.

Many other advances in data communications in this period complemented adaptive equalization to make much higher data rates possible, notably quadrature amplitude modulation (QAM) in high spectral efficiency versions, the initial development of orthogonal frequency division multiplexing (OFDM), which in the 21st century became a mainstay of digital subscriber line and broadband wireless systems, and the first big advances in coding/decoding technologies. Convolutional codes add redundancy that protects against transmission errors, and Andrew Viterbi’s 1967 invention of the decoding algorithm that bears his name was a major advance, applicable also to recovery of data passing through distorted transmission channels.

During the late 1960s and early 1970s the first computer network to use packet switching, ARPANET, came into exis-
ence. The work of Kleinrock, Baran, and Davies was essential to this project funded by the U.S. Department of Defense’s Advanced Research Projects Agency (ARPA). In 1962, with the formation of its Information Processing Techniques Office (IPTO), ARPA became a major funder of computer science research and was the driving force behind several advances in computing technology, including computer graphics, artificial intelligence, time-sharing, and networking. At the beginning of 1966 ARPA embarked on a program to connect computing sites at universities across the country. In 1966 Lawrence Roberts, a computer scientist who had conducted networking research at MIT, took over management of the ARPANET project.

From the beginning, its planners envisioned that ARPANET would use packet switching instead of more conventional circuit-switching or message-switching techniques to connect the several computers in the network. Many of the early pioneers of the ARPANET recalled that packet switching met with a great deal of resistance and skepticism from communications engineers.

The basic infrastructure of the ARPANET consisted of time-sharing host computers, packet-switching interface message processors (IMPs), and 56-kb/s digital transmission circuits leased from AT&T. The major development task was to build the IMPs. In early 1969 Roberts awarded this contract to the

“The fundamental hurdle in acceptance was whether the listener had digital experience or knew only analog transmission techniques. The older telephone engineers had problems with the concept of packet switching. ... I tried to explain packet switching to a senior telephone company executive. In mid sentence he interrupted me, ‘Wait a minute, son. Are you trying to tell me that you open the switch before the signal is transmitted all the way across the country?’ I said, ‘Yes sir, that’s right.’ The old analog engineer looked stunned. It was a conceptual impasse.’”

— Paul Baran, on the difficulty of accepting the concept of packet switching.
firm of Bolt, Beranek and Newman (BBN), a small consulting firm specializing in acoustics and computing systems. In September 1969 engineers from BBN and Leonard Kleinrock’s research group installed the first IMP at UCLA. By the end of the year BBN successfully installed and linked four initial nodes at UCLA, SRI, UC Santa Barbara, and University of Utah. Although the ARPANET was able to transmit test messages between the four sites, two more years of work lay ahead before the network could provide usable communications between the sites. In hindsight the development of the ARPANET was perhaps the most significant advance in communications in this period.

During the 1960s and early 1970s, however, satellite communications received much more public attention. While only a handful of electrical engineers and computer scientists were conscious of the ARPANET and its significance, most people were aware of the latest advances in space programs, including communications satellites.

In 1964, by international agreement among the space agencies and telecommunications agencies of more than 100 countries, INTELSAT was formed as an international body to design, develop, and maintain the operation of a global commercial communications satellite system. One of INTELSAT’s first major decisions was to use geosynchronous satellites instead of low-orbit satellites. In April 1965 the agency launched INTELSAT I (Early Bird), which provided 240 circuits between the United States and Europe.

INTELSAT II and III soon followed Early Bird into geosynchronous orbit. Although Early Bird’s planned operational life was only 18 months, it lasted four years with
perfect reliability. In the seven years following Early Bird’s deployment, INTELSAT launched and deployed four generations of satellites, each with increasing capabilities. Capacity increased from 240 telephone circuits in INTELSAT I to 1200 circuits in INTELSAT III to 6000 circuits in INTELSAT IV. The first INTELSAT IV was launched on 25 January 1970 and it brought the INTELSAT system to full maturity.

One problem with satellite communications was controlling the echo caused by the 550-ms round-trip delay. Although the echo problem was solved by the use of echo cancelers, the delay remained a weakness. After much debate, the International Telecommunication Union settled on standards that allowed only one satellite link in a connection.

A technological development of far-reaching importance—optical fiber—emerged in the mid and late 1960s. During 1959 and 1960 researchers developed the laser, a device capable of generating coherent, collimated, and monochromatic beams of light. At first the laser remained a laboratory research tool, but engineers realized it had great potential for transmitting enormous amounts of information through the wide bandwidths available at optical frequencies. However, this required the development of a low-loss, guided, and well-controlled optical transmission medium.

A breakthrough came in 1966 when K.C. Kao and G.A. Hockham, at Standard Telecommunication Laboratories (STL) in Harlow, England, proposed a clad glass fiber as a suitable waveguide. They predicted that a loss of 20 dB/km should be attainable, a remarkable prediction given that 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.

Alongside these significant technical advances, this era witnessed the beginning of a far-reaching development in telecommunications policy: the end of the Bell System telephone monopoly in the United States, and the later dissolution of telephone monopolies in other countries. Since 1913 AT&T had been a monopoly subject to strong federal and state supervision. It had focused on providing 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 Federal Communications Commission (FCC) regulations, AT&T did not allow users to attach devices to connect their telephone lines to two-way radios or computers and it did its best to block competition in the long-distance telephone market.

The first sign of change came in 1968 when the FCC ruled in favor of the Carter Electronics Corp., whose Carterfone allowed customers to connect a radiotelephone to the telephone network. This decision opened up the terminal equipment market to competition. A year later, the FCC granted Microwave Communications, Inc. (later just MCI) permission to sell long-distance service over its own microwave phone links, and then connect into the AT&T network. To the consternation of AT&T, this allowed MCI to skim the most profitable segment of the telephone business. Thus, by the early 1970s, AT&T faced competition in two markets, which it had previously held captive: terminal equipment and long-distance service. The potential of these new technologies had begun the process of unraveling the Bell System’s telephone monopoly.
These years saw continued advances in communications technology, especially in digitization of the telephone network, computer networking, optical transmission, and wireless communications. This period also saw introduction of call management “intelligence” into the public switched telephone network beyond that required to complete a call to a dialed termination. The first use came in routing 800 calls, but many other applications followed. Common channel signaling via data channels and switches, separate from the data transport channels, was the underlying technology. Also, during these years the federal government began antitrust proceedings against AT&T that concluded with the end of the Bell System’s monopoly in 1984.

Digitization of voice transmission in the core telephone network, following introduction of T-carrier systems, was completed with the introduction of true digital (not only program-controlled) switches. This occurred in 1976, when the Western Electric #4ESS (electronic switching system) was first installed, in Chicago. Digitized voice access from subscriber locations would have to wait for IP telephony in the 21st century.

In computer communications, local area networking made a big advance with the invention of the Ethernet in 1973 by Robert Melcalfe at Xerox Palo Alto Research Center. It was a descendant of the ALOHAnet wireless packet radio network deployed in Hawaii in 1971. Ethernet implemented a contention protocol, CSMA-CD, in which a station would sense “collisions” of packets and retransmit a packet some time later to avoid collision. Ethernet became a world standard implemented in tens of millions of local networks, later evolving “switched Ethernet” versions that avoided the collision problems.

Another major event in data communications networking was the adoption by the CCITT (later ITU-T) in 1976 of the X.25 protocol, a virtual circuit protocol for packet communications that, in contrast to the Internet Protocol (IP), which relies on the transport-level Transport Control Protocol (TCP) for
orderly and complete delivery of packets, delivers packets in proper sequence. X.25 became the foundation of a number of important national-scale data networks, notably Datapac in Canada, Transpac in France (building on the 1975 experimental RCP), and Tymnet initially in the United States. A number of prominent data networking researchers, notably Mischa Schwartz at Columbia University, helped drive progress in data networking standards and performance evaluation.

Despite these strong commercial deployments, it was ARPANET that evolved into the Internet. Between 1972 and 1983 ARPANET underwent two significant transformations: it became a network of networks, or an Internet, and it began to realize its commercial potential. At the end of 1971 ARPANET entered service with 15 sites connected to the network. In 1972 Robert Kahn and Lawrence Roberts decided to demonstrate ARPANET's capabilities at the First International Conference on Computer Communications, held in October in Washington, DC.

This demonstration made a powerful impression on the thousand or so attendees and marked a turning point in the use of the system. Traffic on the ARPANET jumped 67% during the month of the conference and maintained high growth rates afterward. Although ARPANET’s architects envisioned it as a system to facilitate resource sharing like remote file access and time-sharing, it soon became apparent that its most popular use was electronic mail.

The enthusiastic response among communications specialists and the large increase in traffic on the network encouraged some ARPANET contractors to leave BBN in 1972 to start the first commercial packet-switching company, Packet Communications 1972 - 1984
Communications, Inc., to market an ARPANET-like service. BBN also launched its own networking subsidiary, Telenet Communications Corp., and Lawrence Roberts left ARPA to become its president. Telenet was the first network to reach the marketplace, and it began service in seven U.S. cities in August 1975.

After Lawrence Roberts left ARPA to head Telenet, (BBN’s commercial spinoff of the ARPANET), Robert Kahn, a prominent BBN researcher, joined the Information Processing Techniques Office (IPTO) of ARPA as program manager. The major challenge IPTO faced was the design of a communications protocol that would facilitate packet transport among a wide variety of computers over a wide variety of physical networks.

In June 1973 Prof. Vinton Cerf organized a seminar at Stanford University to address the design of the proposed Internet. He and Robert Kahn together defined its host protocol, the Transmission Control Protocol (TCP), which at first included the network-level protocol that later was separately defined as the Internet Protocol (IP). A year later the initial version of TCP was specified and described in Cerf and Kahn’s paper, “A Protocol for Packet Network Interconnection,” published in May, 1974 in IEEE Transactions on Communications. In November the Stanford and BBN groups set up an experimental TCP connection between their sites. BBN also began installing experimental gateways to test TCP over satellite links in 1976 and 1977.

By late 1977 the various networks and test sites were ready to try out the improved TCP. Experimenters sent packets from a van on a California freeway through packet radio to an
ARPANET gateway, to a satellite networking gateway on the East Coast, by satellite to Europe, and finally back through the ARPANET to the van in California. This demonstration confirmed the feasibility of the Internet scheme and showed how connections between radio, telephone, and satellite networks could be used for networking.

To improve the flexibility of the communications protocol, in January 1978 Vinton Cerf, Jon Postel, and Danny Cohen proposed splitting TCP into two components: a host-to-host transport-level protocol (TCP) and an internetworking network-level protocol (IP). The pair of protocols became known as TCP/IP. IP would pass individual packets through a sequence of packet routers possibly in different networks, while TCP would be responsible for ordering these packets and providing reliable connections between communicating applications in host computers. Over the next five years ARPANET architects refined TCP/IP and in March 1981 they decided to replace the existing Network Control Program (NCP) with TCP/IP on all ARPANET hosts. By June 1983 every host was running TCP/IP.

After converting the ARPANET to TCP/IP, between 1972 and 1983 ARPANET underwent a number of significant transformations: the entire network switched to TCP/IP, the military users left for their own network, and the ARPANET became part of a larger system—the Internet. By 1984 the fledgling Internet connected over 100 universities and research facilities in the United States and Europe.

Just as the ARPANET and early Internet demonstrated the feasibility of large-scale computer networking, several significant projects in the mid and late 1970s proved the value of optical fibers for communications, as pioneered by Charles Kao. In 1975 AT&T Bell Laboratories installed an experimental optical fiber trunk system in Atlanta, GA, carrying out a full range of system experiments at a data rate of nearly 45 Mb/s and realizing an error rate less than $10^{-9}$ and negligible crosstalk at unrepeated spacings of up to 11 km. The first
non-experimental fiber-optic link may have been one installed for the Dorset (UK) police in that same year.

The success of the 1975 Atlanta experiment led to the installation of a similar system in the spring of 1977 in Chicago’s Loop. In September 1980, a second system entered service in the Atlanta-Smyrna region of Georgia, in the United States. AT&T also installed major long-haul routes, including a 776-mile route from Moseley, VA, to Cambridge, MA, and a 500-mile route from Los Angeles to San Francisco. By the end of 1982 more than 150 000 km of cabled fibers had been installed in the Bell System, and a year later that figure had risen to more than 300 000 km of cabled fibers capable of data rates of 45 or 90 Mb/s. Finally, in 1982 and 1983 AT&T Bell Labs began testing undersea light-wave systems, a research and development program that would culminate in a transatlantic fiber cable, TAT-8, in 1988.

Japan’s Nippon Telephone & Telegraph (NTT) 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.

Wireless communications also began its long route to universal popularity during this period. The Advanced Mobile Phone System (AMPS), the first cellular system, was developed by Bell Labs and deployed in North America in 1978. This first generation (1G) cellular system was not displaced by digital cellular systems until much later. Another important, though scarcely noticed, development in 1984 was publication of the early paper by Jack Winters describing multiple in-multiple out (MIMO) antenna systems, providing multiple spatial paths and holding out the promise of large increases in total capacity.

The beginning of true digital access to data networks for
a wide range of network users appeared in the Integrated Services Digital Network (ISDN) specification published by the CCITT (now ITU-T) in 1984. ISDN was later deployed in many countries, but never achieved great success, due to its limited data rates. It was, however, the predecessor for much faster digital subscriber line (DSL) services in later decades.

Alongside these important developments, a major shake-up occurred in the American telecommunications industry: the breakup of the Bell System. In 1974 the Department of Justice filed an antitrust suit against AT&T. Federal regulators wanted to force AT&T to allow interconnects to its system, competition in the long-distance market, and the purchase of telephone equipment on the open market instead of only from its subsidiary Western Electric. After 10 years, hundreds of millions of dollars, and millions of pages of documents, AT&T and the Justice Department came to an agreement: the Justice Department allowed AT&T to keep Western Electric, but directed it to divest itself of all the local operating companies.

On 1 January 1984 AT&T exited the local telephone business, spinning off seven regional Bell operating companies (RBOCs). AT&T kept its long-distance operations, Western Electric, and Bell Labs, and it began to move into non-regulated businesses such as computing. A research and systems engineering organization, later known as Bellcore (and still later as Telcordia), was established by the divestiture agreement. It provided technical support to the newly formed regional telephone companies on a shared ownership basis. Deregulation spurred competition and lowered prices in the long-distance market, but created some confusion among consumers. Before the breakup, 80% of the public said that they were satisfied with their telephone service; in 1985 64% of Americans thought divestiture was a bad idea and many called for the reconsolidation of Bell Labs as a leading research center in basic engineering and science. Under the AT&T monopoly, Bell Labs depended on a protected source of operating revenue and its researchers enjoyed a great degree of inde-
dependence. This environment helped Bell Labs researchers win seven Nobel Prizes since the 1920s, more than any other organization in the world, and to undertake far-reaching work in many areas of electrical engineering and basic science. Thus, while the breakup of AT&T offered the telecommunications consumer more choices and lower costs, it also eroded an important component of the nation’s research infrastructure.
Communications

1985 - 2002

Microwave communications tower
Two major trends shaped the telecommunications landscape in this period, with profound influence on technology, commerce, and society. In computing, the Internet became a ubiquitous and permanent infrastructure, as important as telephone and electricity service. In voice and data communications, wireless enhanced flexibility and convenience, with digital cell phones for voice mobility and Wi-Fi routers for data access in homes and offices.

Great progress was made in communication techniques, as well. High-performance error-correcting turbo codes were invented in 1993 by researchers at Télécom Bretagne in France. Gerard Foschini, Jack Salz and their colleagues pioneered BLAST and later MIMO systems. Viable ADSL (asymmetric digital subscriber line) modems, notably the OFDM-based technology developed by John Gioffi and his colleagues at Amati, were developed.

The Internet, developing in a largely decentralized way, saw explosive growth in the 1980s. At the end of 1985 about 2000 computers had access to the Internet; by the end of 1987 it was 30,000; and by year end 1989, 160,000. The growth of personal computing, which began as a hobbyist market in the late 1970s, paralleled the growth of the Internet. In 1983, for instance, some 3.5 million personal computers were sold and *Time* magazine named the personal computer “Man of the Year.”

During the early 1980s several companies, such as CompuServe, America Online, and Prodigy, introduced commercial online services for the home PC user. Subscribers accessed these services by means of a modem and software supplied by the service provider. At first these online services did not provide connection to the (as yet restricted) Internet but did provide users with information services, chat rooms, and online shopping. These online services helped to introduce large numbers of users to the practice of retrieving information and communicating with others by means of their home computers. In 1985 Stewart Brand set up the WELL
(Whole Earth ‘Lectronic Link) as an alternative to the commercial systems. The WELL soon became known as a gathering place for advocates of counterculture ideas and free speech. By the late 1980s, therefore, several million computer users could exchange mail and news over these networks.

In 1991 the National Science Foundation issued a plan in which Internet service would be taken over by competitive Internet Service Providers (ISPs) who would operate their own backbones. ISP subscribers would connect their computers or local-area networks to one of these backbones, and the ISPs would allow for intercommunication among their systems. On 30 April 1995 the U.S. government formally terminated its control over the Internet’s infrastructure. Privatization opened the Internet to a much larger segment of the American public. Commercial online services could now offer Internet connections, and the computer industry rushed into the Internet market.

A necessary precondition to large-scale public participation in the Internet was the development of network applications, particularly search engines. Without an easy-to-use search engine, an Internet user had no way to locate information or to transfer files easily. In the early 1990s the University of Minnesota introduced its Gopher system, which helped users organize and locate information. But the most significant advance in this area was the World Wide Web, developed by Tim Berners-Lee of the European high-energy physics establishment CERN. In December 1990 the first version of the Web software began operating within CERN, and CERN began distributing its Web software over the Internet to other high-energy physics sites. Among them was the National Center for Supercomputing Applications (NCSA) at the University of Illinois.

In 1993 an NCSA team led by Marc Andreessen developed an improved Web browser called Mosaic, the first system to include color images as part of the Web page. When NCSA officially released Mosaic to the public in November 1993, over 40 000 users downloaded copies in the first month; by the fol-
lowing spring more than a million copies were in use. In 1994 Andreessen and his team left NCSA to develop a commercial version of Mosaic called Netscape. The Web and browsers like Netscape completed the Internet’s transformation from a research tool to a popular medium.

The growing popularity of cell phones paralleled the explosion of the Internet. AMP analog service came earlier, but sustained development and market penetration occurred only after the mid-1980s with the deployment of digital (2G) services and cell phones. The first commercial deployment may have been in Finland in 1991. There were several major standards: GSM, a time division multiple access (TDMA) system from Europe; IS-136, a North American TDMA system; and IS-95, a code division multiple access (CDMA) system also from North America. CDMA technology, commercialized largely by Qualcomm, Inc., is a spread spectrum technique that shares the same wide spectrum among many users, separating them by the assignment of different codes applied to the modulation. A “frequency-hopping” form of spread spectrum had a much earlier origin, patented by Hedy Lamarr, who later became a famous Hollywood actress, and George Anheuil in 1942.

Cell phone usage boomed: the industry grew exponentially from 25,000 subscribers in the United States in 1984 to 1 million in 1987, to 4 million in 1990, 9 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.
The Rise of Broadband Wireless and Social Networks
2002 - 2012
The first decade of the 21st century witnessed an unprecedented global change in communications, fueled by technology and led by the transformation of the market and society. It is too early to say what historians looking back at our field 50 years from now will consider the main achievements of this decade, but a number of new things made possible by advances in telecommunications have already swept the world. In particular,

- The rise of visual communications and the shift of traffic to streaming from peer-to-peer
- The rise of social networks, in the form of diaries (like Facebook, My Space, Orkut) and instant followers (Twitter) with the progressive abandonment of the ordinary telephone number
- Acceptance of cellular communications by the developing world, which now has more users than the developed world
- Changes in industry structure such as the rise of Apple and Google, the growth of “over the top” application providing operators, such as Skype and Viber, and the emergence of “virtual” IT and communication resource providers, including Mobile Virtual Network Operators (MVNOs), and, finally,
- The shift from the network to the handheld terminal, with dramatic innovations and economic impact.

These changes are built upon a dramatic evolution in technology that will continue in the decade ahead—for example, the dematerialization of the network (now called the cloud) and the growth of the Internet of Things.

In the 20th century, telecommunication focused on “voice-only.” Voice became so
ingrained that when the possibility came along to communicate using video images, it created little interest and some resistance as an intrusion in privacy. This attitude changed in the 2002-2012 period as technology made available three components at very affordable prices: the camera, the broadband connection, and the display, leading to an amazing growth in “asynchronous” (deferred viewing) visual communications. At the end of 2011 YouTube was receiving 10 new videos each second—the equivalent of a half hour of new content. There was also a shift from peer-to-peer (mostly downloaded content like music, video, books) to streaming. The strong growth of broadband connections all over the world driven by hybrid fiber-cable (HFC) and asynchronous digital subscriber line (ADSL) technologies ignited a surge in video content.

The production of content shifted strikingly from the major broadcasters to the individual, which created demand for high-capacity uplinks. This accelerated the deployment of fiber access networks, most notably passive optical networks (PONs) providing rates both downstream and upstream of up to 10 Gb/s, typically shared among 32 users. In many developed countries the high cost of substituting fiber optics for copper pushed new technologies like DSL vectoring, which can provide on the order of 50/80 Mb/s to each user in the downlink and more than 20 Mb/s in the uplink.

Developing countries, on the other hand, usually lack a good fixed network (or its penetration is limited) and instead began turning to wireless infrastructure whose bandwidth is limited but is in most cases sufficient and growing rapidly. Long Term Evolution–Advanced (LTE-A) cellular services,
which were nearing deployment in 2012, were expected to offer subscribers 100 Mb/s data rates.

The 2002-2012 decade also saw major innovations in orthogonal frequency division multiplex (OFDM) signaling, multiple input, multiple output (MIMO) antennas and space-time coding, and low-power, high-speed VLSI, all significant technical contributions that made possible the transition to broadband wireless communications. At the higher levels, the explosion in “apps” for smart handheld devices, some linked to the global positioning system (GPS), became a new industry with profound implications for the way society and economies function.

This led to a shift in human-to-human communications and in the use of visual media. Video calls became more common, fueled by smart phones, tablets, and always-on connectivity. The submission and retrieval of video clips also became a large part of public and private life and a significant influence in politics.

The first uses of the Internet by the mass market, in the last decade of the 20th century, were for information browsing, email, shopping, and access to community services. These remained important but were supplemented by the emergence of social networks in the first decade of the 21st century. With Facebook, Google+, MySpace, Orkut, Apple’s Facetime and hundreds of more specialized communities, the Web became a set of “town squares” attracting the world. Communications was transformed from one-to-one to many-to-many. Communications also became a multichannel proposition: it may be tied to the computer at home, a smart phone on the move, or a connected television in a hotel room.

Communications also morphed into several new media,
with voice supplemented or replaced by texting, posting of clips and images, sharing of links, and one-to-many text communications via Twitter.

The communication infrastructures evolved with surprising speed from a design intended for voice (at 64 kb/s in three-minute slots a few times a day per user), to one able to stand the flood of video and images (requiring huge bandwidth for considerable periods of time) while also accommodating a tremendous number of short messages, a few hundred bytes each, tens of times a day per user (on average, with peaks exceeding 100 times a day for some).

Communications mediated by social networks also marked a progressive abandonment of the telephone number as the way to identify a calling/called party. Identity became associated with the name of the person, both on the network and at the perceptual level.

The initial huge success in the nineties of wireless communications in the developed world led to high-volume manufacturing and, in turn, to a dramatic drop in the price of cell phones. Together with the relatively modest cost of establishing a wireless infrastructure compared to a fixed line infrastructure and its ease of deployment, this stimulated the rapid diffusion of wireless in developing countries in the first decade of the 21st century. Worldwide the number of cell phones increased from 1 billion to 5 billion, most in developing countries. China and India reached close to a billion cell phone users each.

The cell phone became a universal tool for economic growth. Mobile payment became more prevalent in Africa than on any other continent, filling a gap in the banking system. As cell phones evolved into smart phones they began to serve additional important applications such as health care, where apps can provide access to health records, monitoring
sensors on the body can be linked to a doctor’s office, and even changes in phone usage patterns can indicate health problems for the elderly and infirm.

The previously closed club of telecom operators was shaken in the 2002-2012 period by the entrance of several new players both at the infrastructure and services level. At the infrastructure level the strong emergence of Internet Protocol (IP) transport changed many architectures and led to the need for new skills, combining computer communications and other information technologies with physical communications. The meaning of Quality of Service also changed, and became perceived by the end customer as quick response and high-quality media whether or not the network can only deliver “best effort”. It became recognized that no single person or company could control a communication session end-to-end, which was a difficult conceptual change for telecom operators to accept. Furthermore, communications became independent of geographic boundaries, with information accessed without knowing where it is and services delivered across networks by enterprises and individuals having no control over any part of the network.

Regulation fostered this transition in several countries by imposing the unbundling of the local loop and by allowing third parties to act as virtual operators. Skype became the largest telecommunications operator for international calls, although it owns not a single copper pair. Viber moved a step further by hijacking telephone numbers, permitting use of the client’s own telephone number.

Much of the services and applications evolution in 2002-2012 was rooted in the progress of terminals, cell phones and tablets.

By the beginning of 2012 there were over 5 billion cell phones worldwide and 285 000 cell phones were being dis-
carded every day in the United States alone. The average lifetime of a cell phone was two years but only six months in South Korea. And the pace of the terminal’s evolution was matched and possibly surpassed by the evolution of services—the apps. These in turn fueled the transition from ordinary cell phones to smart phones.

Applications are as old as computing, but apps as small retail products were an extremely successful invention of the past decade. By the decade’s end, the three largest app families were associated with Apple, Android, and Facebook technologies. Over a million apps were available, with the average person’s smart phone packing 50 of them. Apps changed the way people looked at a cell phone and at communications, allowing people to access and visualize any kind of information, whether personal, global, business, or social. Some apps created an extended communications ambience by pulling several communication channels into a seamless communication fabric.

The 2002-2012 decade cannot be viewed as bringing to a close the first 150 years of communications. Rather, the decade introduced us to the next 50 years, although it is difficult to see beyond even the near horizon. It fixed attention on services and on the perception of a seamless communication and information technologies fabric, referred to as “the cloud”. It no longer mattered where you are, where the information is, nor where the resources are to process and store the data. Communications became so effective that these started to disappear from everyday perception. At the same time there arose a growing number of new connectivity users, sensors, RFID (radio frequency identification) tags, and communicating machines. This was just a prelude to the next decade for which many observers, at the beginning of 2012, anticipated a tremendous growth of users, applications, and human interactions far exceeding what’s possible today.
The IEEE Communications Society: A Sixty Year Foundation for the Future 1952-2012
On the Shoulders of Our Predecessors: Communications before 1952

In May 1844 Samuel F.B. Morse opened the first telegraph line in the United States. His famous transmission of the phrase “What hath God wrought” from Washington to his assistant Alfred Vail in Baltimore ushered in an electrical communications revolution which continues unabated today. Morse and Vail’s work showed that communications engineers have been at the forefront of the electrical engineering profession since its origins in the 19th century. Thus, forty years of advances in communications technology lay behind the formation of the American Institute of Electrical Engineers (AIEE) in 1884. The founding members and first officers of the AIEE reflected the centrality of communications to the new profession of electrical engineering. Over half of the founding members worked for telegraph or telephone companies or for firms supplying equipment to them. The first president of the AIEE was Norvin Green, president of the Western Union Telegraph Company. AIEE vice presidents included Alexander Graham Bell, inventor of the telephone; Thomas Edison, who made his reputation and first fortune as an inventor of telegraph equipment; and two veteran telegraph electricians.

However, soon after the founding of the AIEE in 1884, the locus of technical innovation shifted from the telegraph industry to the new technology of electric power. Furthermore, university trained engineers working for large research laboratories and engineering departments superseded inventor-entrepreneurs like Edison and Bell. By the turn of the twentieth century, the membership and leadership of the AIEE both reflected these two trends in the profession.
Although the AIEE tried to be an organization that reflected the full diversity of electrical engineering, power engineers had come to dominate it by 1900. The AIEE allowed “Special Committees” to be formed in areas of technical interest, which in 1915 came to be called “Technical Committees.” Most of the Committees were concerned with aspects of power engineering, but in 1903 a Committee on Telegraphy and Telephony was formed. The AIEE’s leaders also recognized the growing importance of radio communications, and in late 1912 approved a new Radio Transmission Committee. This committee, however, never formed, because the AIEE leadership could not find a chairman for the committee. Furthermore, the issue had already become moot: earlier in 1912 a group of wireless specialists had formed the Institute of Radio Engineers (IRE).

The IRE came into being because engineers in the new fields of radio and electronics did not feel at home in the AIEE, dominated on the one hand by power engineers and on the other by telephone and telegraph specialists. After World War I, radio communications and other types of electronics continued to expand at a greater rate than power engineering and wire communications, an expansion reflected in the robust growth of IRE membership. However, electronics also changed the state of the technical art in traditional fields of engineering like power and wire communications. So, perhaps to encourage membership by electronics engineers in those areas, in 1925 the AIEE Technical Committee on Telegraphy and Telephony became the Technical Committee on Communication.

Although the AIEE tended to focus on wire communications and the IRE on wireless communications, there was significant overlap in membership. For example, Arthur E. Kennelly, famous for his work on ionospheric radio propagation, was both president of the AIEE in 1898-1900 and of the IRE in 1916. Michael Pupin, a Columbia University physics pro-
Professor (the Pupin Building, which houses Columbia’s physics department, is named in his honor) highly regarded for his work on transmission lines, was president both of the IRE in 1917 and of the AIEE in 1925-1926. As early as 1922 Kennelly suggested merging the two organizations. Although such a merger would not occur for 40 years, the two societies sponsored some overlapping meetings in the coming years.

A major reason why the two organizations did not merge in the 1920s was that the IRE had little incentive to do so. It continued to grow so quickly that it started its own Technical Committee system in 1937. The first six such committees (Broadcast, Electroacoustics, Radio Receiving, Television & Facsimile, Transmitting & Antennas, and Wave Propagation) show the importance of communications to IRE members.

World War II and its aftermath led to further expansion and diversification of electrical engineering as a whole, and in particular in wireless communications and other electronics. As a result, the IRE continued to grow at a much more rapid rate than the AIEE. To stem this trend, in 1947 the AIEE revamped its organization and grouped their Technical Committees into Divisions. In 1950 the AIEE formed the Communication Division, originally consisting of Committees for Communications Switching Systems, Radio Communications Systems, Telegraph Systems, and Special Communications Applications. In the remaining years before the AIEE/IRE merger, the AIEE Communication Division added Committees on Television Broadcasting (1951), Communication Theory (1956), Data Communication (1957), and Space Communication (1960).

The IRE Professional Group on Communications Systems, 1952-1964

Meanwhile, the IRE allowed the formation of semi-autonomous Professional Groups as a way to deal with the increased growth and complexity of their field and organiza-
tion. In the early 1950s, two IRE members, J.L. Callahan and George T. Royden, were instrumental in organizing a new Professional Group in the field of communications. On 25 February 1952 this group, the IRE Professional Group on Radio Communications, came into formal existence. At first the new Group limited its scope to radio in order to avoid direct competition with the AIEE in the field of wire communications. Within a few months, however, the IRE Board of Directors recommended that the new Group expand its scope to cover all forms of communication and to change its name to the IRE Professional Group on Communications Systems (PGCS). In September 1952 the Group did so and expanded its scope to include “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 welded together and gave a common home to the several Technical Committees that had dealt with various facets of communications engineering since 1937. This group, the forerunner of the IEEE Communications Society, thus had an official founding date of 25 February 1952 and was the 19th such IRE Group to be formed. George T. Royden was the first chairman of the Group, with Murray G. Crosby, J.L. Callahan, and J. Hessel serving as vice chairman, secretary, and treasurer respectively.

The Group began with just under 600 members in 1952 and almost immediately established chapters in Washington, San Diego, Chicago, New York City, Philadelphia, and Cedar Rapids (home of Collins Radio) to accommodate its rapidly increasing membership. By early 1955 Secretary Callahan felt that PGCS had passed through its growing pains and had reached maturity as one of the important Groups in the IRE. Later that year the Administrative Committee (AdCom) formulated plans to publish a newsletter to keep its far-flung and growing membership informed of Group activities. By the end
of 1957 the Group had a membership of just over 2500, and a year later it had 11 active chapters around the country. In 1958 PGCS established two annual awards, an Achievement Award and an award for the best article in the IRE Transactions on Communications Systems (see below). PGCS selected Dr. Harold H. Beverage as the first recipient of the Achievement Award and co-authors R.T. Adams and B.M. Mindes for the Transactions Contribution Award. Also in 1958 the Board considered ways to increase membership by encouraging non-US engineers to join and by allowing AIEE members to affiliate with PGCS. These membership initiatives, coupled with the importance of communications engineering, helped PGCS to reach the impressive figure of just over 4200 members in 1962, just before the IRE-AIEE merger.

One of the first actions of the new Group was to inaugurate an ambitious array of conferences, such as the annual Aeronautical Communications Symposium (AEROCOM) held for its first four years in the Rome-Utica, NY, area. This conference was renamed the National Communications Symposium in 1959 and it continued under this name until 1963. PGCS also co-sponsored conferences with other IRE Groups and with the AIEE. Most importantly, PGCS co-sponsored the first GLOBECOM with the AIEE Communications Division in 1956. GLOBECOM continued to be a successful conference, and the 1961 meeting hosted 610 registrants, 240 speakers, and 25 exhibition booths. At the end of 1957 the Group began planning for a conference on modern electronic communications to be sponsored jointly with the Professional Group on Vehicular Communications. By 1959, with a membership of over 2700, the Committee decided that both the quantity and quality of technical papers were high enough to support two PGCS national meetings a year.

The new Group grew dramatically and began planning for a wide range of activities. Perhaps its most far-reaching decision was to begin publication of the IRE Transactions on Communications Systems, the forerunner of today’s IEEE
Transactions on Communications. At first, PGCS issued two Transactions issues per year, but because of the increasing volume of submissions the publication schedule increased to three issues a year in 1955 and four a year in 1959.

As early as 1956, the PGCS Administrative Committee explored ways to make the Group a professional home for engineers working in all fields of communications. In that year PGCS leaders viewed the overlapping fields of interest among the 23 IRE Professional Groups as both a problem and an opportunity. A.C. Peterson sent a letter to the chairmen of the other 22 Groups asking them to meet to discuss this overlap and what to do about it. Eighteen of 22 Group chairmen replied, 13 expressing interest in attending such a meeting and 5 declining to attend. PGCS’s AdCom looked favorably upon a proposal to merge PGCS with other Professional Groups like Antennas and Propagation, Marine Communications, Vehicular Communications, and Microwave Theory and Techniques.

Although nothing came of this effort, the AdCom again in 1960 took up the issue of the proliferation of Professional Groups. AdCom chairman Capt. Engleman noted that IRE officials had become concerned with the explosion of the Groups, which now numbered 27 and with several petitions for new groups pending. While Engleman credited the Professional Group system with keeping the IRE “free from internal explosion,” he and other IRE officials now worried that the proliferation of these groups “threatened” the IRE “with mediocrity because of dilution.” Engleman cited the decline in attendance at Professional Group chapter meetings and conferences as signs of this problem. PGCS, in particular, had “seen the formation of other groups that have slowly taken away bits and pieces of our broad interests in communications systems.” The
Professional Group on Military Electronics (PGMIL), for example, “took away much” of PGCS’s activity in military communications. Engleman suggested expanding the scope of PGCS, merging it with Professional Groups in closely related technological areas, and renaming the merged Group either the “Professional Group on Communications and Electronics Systems” or the “Professional Group on Electronics Systems.” As a first step the PGCS AdCom initiated discussions with the PGMIL AdCom regarding a merger. On 20 March 1961, the PGCS AdCom narrowly approved (by a vote of 7-6) a motion agreeing to the merger. Although PGMIL declined to enter into the merger, the two Groups continued to work closely together on jointly sponsored conferences.

While no mergers took place between PGCS and other IRE Professional Groups, these discussions in the 1950s and early 1960s showed that the Administrative Committee sought ways to overcome professional over-specialization by making PGCS the central organization for engineers working in the general field of communications. This willingness to accommodate a wide range of activities would prove valuable when the PGCS and the AIEE’s Communications Division merged in 1964.

The IEEE Group on Communication Technology, 1964-1972

When the AIEE and IRE agreed to merge on 1 January 1963, leaders of the new IEEE decided that the merged organization would use the IRE Group structure. They also decided for historical purposes that IEEE societies would be considered to date from the founding of their predecessor IRE Professional Group. Thus, the official founding date of the IEEE Communications Society is 25 February 1952, although the IEEE Communications Society adopted its current name in 1972.

While the IEEE came into existence on 1 January 1963, the AIEE Communications Division and the IRE Professional Group on Communications Systems did not formally merge
until 1 July 1964, a full 18 months after the formation of the IEEE as a whole. At the date of this formal merger, the new IEEE Group on Communication Technology had just under 4400 members. Seven former AIEE Technical Committees continued operations under the new Group, with members of the IRE joining Technical Committees reflecting their particular interests. The Technical Committees reviewed papers for a new IEEE Transactions on Communication Technology that was distributed free to all members, and organized and moderated sessions at various conferences. Ransom D. Slayton was the first publications chairman, editorial manager, and transactions editor (all one job!) in early 1964.

Although the merger between the AIEE and IRE was quite beneficial to the engineering profession and the members of both institutes, the merger did create some difficulties for the new IEEE Group on Communication Technology. Much of these difficulties arose because of the different characters and concerns of the AIEE and IRE generally. Communications engineers affiliated with the AIEE tended to be more interested in wire communications like telegraphy and telephony, while IRE members were active in wireless and newer fields of communications.

As a result, many former AIEE members felt that plans for a merged Group on communications slighted the fields of telephony and telegraphy. Difficulties with merging the technical groups and committees of the IRE and AIEE delayed the formation of a unified new Group on Communication Technology (ComTech) for a year and a half after the formal merger of the IRE and AIEE. However, the hard work and dedication of David Rau of RCA, chair of the IRE PGCS, and Leonard Abraham of Bell Labs, chair of the AIEE Communications Division, made the newly merged ComTech a success.

The new ComTech continued the tradition of technical excellence begun by its predecessor organizations in the IRE and AIEE. Engineers working in all facets of communications found a congenial home in ComTech, which contained eight

Indeed, the theme for the GLOBECOM VI conference in Philadelphia in June 1964 was “The Marriage of Communications and Data Processing.” The following year GLOBECOM VII, held in Boulder, CO, became also known as the First Annual IEEE Communications Convention. Under the leadership of ComTech member Richard Kirby of the National Bureau of Standards (Kirby later became director of the ITU for Radio, a position he held for 20 years), it was quite successful, with 885 paid registrants and nearly 200 papers presented in 48 sessions; ComTech also earned a surplus of about $4000 on the meeting.

A year later, in 1966, the conference was renamed the IEEE International Conference on Communications, or ICC. Its theme was “Communications in the Computer Age,” and a variety of IEEE Groups—ComTech, Information Theory, Audio, and Space Electronics and Telemetry—participated. ICC has been held annually ever since, usually in late spring or early summer. The name GLOBECOM re-emerged in 1980 as the name of a second major annual conference. Also in 1966, ComTech sponsored 11 sessions at the annual IEEE International Convention. These sessions reflected the diverse fields of expertise of ComTech’s members; topics ranged from traditional but rapidly digitizing wire communications concerns like switching to newer fields like data communications and advanced techniques in radio communications.

In 1967 the International Communications Conference, held in Minneapolis, adopted a new name, the International Conference on Communications. More important than this name change, the conference had a wide range of technical
activities, a range best shown by the nine Groups that partici-
pated along with ComTech: Microwave Theory and
Techniques, Vehicular Communications, Audio and
Electroacoustics, Circuit Theory, Aerospace and Electronics,
Information Theory, Electromagnetic Compatibility, Computer,
and Broadcasting.

In 1969 the IEEE Technical Activities Board considered a
restructuring of the various IEEE groups. ComTech AdCom
looked favorably upon this restructuring, and at first consid-
ered a grouping that would have placed ComTech in a techni-
cal cluster, or Division, along with four other Groups
(Broadcasting, Broadcasting and TV Receivers, Aerospace and
Electronic Systems, and Electromagnetic Compatibility). This
new Division would have consisted of 21,600 members, and
ComTech with its membership of 8,100 would have made up
the largest Group. Upon further discussion, however, the
AdCom decided to pursue the idea of a cluster consisting of
the Communications Technology, Aerospace and Electronics
Systems, and Information Theory Groups. If this cluster could
not be worked out satisfactorily, the ComTech AdCom directed
chairman Frank D. Reese to discuss a merger with the
Aerospace and Electronics Systems Group (AES). While this
merger did not occur, ComTech continued to work closely
with AES. For instance, ComTech and AES collaborated on a
joint Committee on Satellite and Space Communications and
AES participated in ComTech’s ICC. At the 7 December 1970
meeting, the AdCom expressed “much optimism” about
ComTech’s close relationship with AES.

Also in 1969, Richard Kirby, then vice chair of ComTech, asked Professor Donald
Schilling to become publishing editor of the Transactions and Newsletter. When Schilling
took over that position—one that he held until 1980—he appointed a new editorial
board, one that was responsible to the edi-
tor, and not to the Technical Committees.
In 1970, Schilling took over complete responsibility for all ComTech publications, and he introduced a series of special issues of the Transactions dealing with special topics of interest to ComTech members, such as Communications in Japan, and Computer Communications. When Schilling took over the management of publications, Transactions was a bimonthly publication of 900 pages per year; by 1973 it had become a monthly publication of 1500 pages per year.

In March of 1973, Professor Schilling introduced the new Communications Society Magazine. It had evolved from the original IRE PGCS (Professional Group on Communications Systems) Newsletter to the IEEE ComTech Newsletter, sent free to all members, which then became the IEEE Communications Society Newsletter, which finally became a magazine. Alan Culbertson, the Society’s president, wrote a guest editorial, as did Martin Nesenbergs, who was the magazine’s editor. Nesenbergs, Allen Gersho, and Stephen Weinstein were the three early editors who transformed the old newsletter into a real magazine that quickly became respected for its approachable technical content. One of the magazine’s publication requirements, intended to make it accessible to a broad range of ComTech members, was that an article contain no equations. The March, 1973 “Magazine in progress” contained only a single article on the “Impact of the ASCII Code...” The issue had no advertisements.

The IEEE Communications Society Takes Shape, 1972-1984

ComTech’s membership more than doubled from 1964 to 1972, from 4400 to just under 10 000. In addition, ComTech had over 40 chapters in the United States and Canada by the early 1970s. Its robust membership, coupled with the growing importance of the Group within the IEEE, prompted many of ComTech’s leaders to petition the IEEE for elevation to Society status.
As early as June 1970, the ComTech AdCom discussed a transition to Society status, and in March 1971 Chairman Richard Kirby appointed an Ad Hoc Committee on Technical Planning and Liaison headed by Ransom Slayton to investigate the impact of this on the Group. William Middleton came up with many of the structural and operational concepts. Slayton, who later served as ComSoc’s parliamentarian for many years, drafted the constitution and by-laws of the new Society.

Kirby and Slayton were optimistic that other Groups in closely related technical fields (such as Aerospace and Electronic Systems, Electromagnetic Compatibility, Broadcasting, and Broadcasting and TV Receivers) would become part of a new Communications Society with an expanded scope. In June 1971, however, Kirby reported that these Groups had expressed “some interest,” but a “watch and see attitude prevails.”

In light of this lukewarm interest on the part of other Groups, Kirby recommended proceeding with the petition for Society status while retaining ComTech’s present scope to avoid overlap with other Groups. Kirby believed that the scope could be expanded at a later date to accommodate Groups who wished to join. The AdCom unanimously agreed with Kirby’s recommendations and resolved to petition the IEEE Technical Activities Board for elevation to Society status on the basis of the existing ComTech scope.

The IEEE quickly granted this petition, and the new IEEE Communications Society (ComSoc) began operations on 1 January 1972 with 8636 regular and 1182 student members. The list of officers at the first formal meeting of the Board of Governors of the IEEE Communications Society on 20 March 1972 was:
Since its formation in 1972, ComSoc has embarked on an ambitious program of technical conferences and publications. In 1972 the Telemetering Conference, ComSoc's late fall meeting, became the National Telecommunications Conference. The 1974 NTC held in San Diego had more than 1000 attendees and earned a surplus of over $8000 for the Society. Although ComSoc emphasized technical excellence, it did not neglect the social opportunities the conference afforded.

In discussing planning for the 1975 NTC conference in New Orleans, for instance, R.L. Shuey of the ComSoc meeting and conference department told the Board of Governors, “We are continuing to stress technical quality. Because of the setting, however, the social program will be given abnormal emphasis.” In 1980 ComSoc’s two major conferences, ICC and NTC, each attracted about 1500 registrants. In 1980 NTC became international in scope and ComSoc renamed it the IEEE Global Communications Conference, or GLOBECOM. In 1987 it took place overseas, in Tokyo, for the first time. Since then, GLOBECOM has been held in Singapore, London, Sydney, and Rio de Janeiro. In
this period ICC also became more international and in 1984 it was held overseas for the first time in Amsterdam.

In 1981, Schilling became president of ComSoc. He formed the IEEE Military Communications Conference (MILCOM), which began in 1982 in Boston as an expanded version of the existing Spread Spectrum Conference. Although the new MILCOM embraced all military communications, it continued to focus on spread-spectrum communication techniques for its first several meetings. By 1986 nearly 1500 engineers attended the conference held that year in Monterey, CA, and the conference generated $40,000 for the Society.

Data communications had come into its own as an important field by the early 1970s, and, beginning in 1974, ComSoc, the IEEE Computer Society, and the Association for Computing Machinery jointly sponsored the annual Data Communications Symposium. In 1981, ComSoc arranged a joint IEEE ComSoc–IEEE Computer Society sponsored conference, INFOCOM, which focused on computer and data communications. The principal founder was Harvey Freeman, who is still the steering committee chair in 2012. The first INFOCOM, held in Las Vegas in 1982, was moderately successful. Although actual attendance was about 400, half the number anticipated, the meeting earned a modest surplus and its excellent technical content ensured that it would be held again on an annual basis.

INFOCOM augmented, but did not replace, the existing Data Communications Symposium. The growing importance of the application of computers and database systems to communications and network management in the 1980s also lay behind the 1987 inauguration of the IEEE Network Operations
Management Symposium (NOMS), spearheaded by Doug Zuckerman.

ComSoc’s two major conferences, ICC and GLOBECOM, had been cosponsored since their infancy. In 1981 the ComSoc AdCom took over complete control of these conferences. By the mid-1980s ComSoc had established the GICB (Globecom-ICCC Conferences Board) to schedule, oversee, and grow these two flagship conferences. Ross Anderson, who was a key figure in GICB from 1985 to 2000, together with Ed Glenner and Doug Lattner, were influential volunteers who did much to realize the Society's goals for these conferences.

Following a general social trend among scientists and engineers in the 1970s, communications engineers also became concerned with the social implications of their work. In March 1972 ComSoc member Mischa Schwartz (who later was 1984-85 President) urged AdCom to form a special Technical Committee to investigate the social impact of telecommunications. Schwartz took the lead in this area and chaired an exploratory meeting in March 1974 of 16 interested engineers. As a result, ComSoc added a Technical Committee on the Social Implications of Communications Technology, and by 1975 ComSoc had also added Technical Committees on Educational Services and Technological Forecasting and Assessment.

In addition, the ComSoc Communications Policy Board became actively involved in regulatory and social issues during the early 1970s. One initiative was to sponsor an IEEE educational seminar on telecommunications technology for government regulators and officials. Another was a 1974 special issue of the Transactions on the theme of “Effects of Communications on Society,” followed by a 1976 issue on “Communications in Developing Nations.” Over the years social implications has become less of a separate issue and more imbedded in technical activities.
Since 1970 the new IEEE Transactions on Communications, with vigorous leadership and an independent editorial board first headed by renowned editor in chief Adam Lender, quickly developed a leading position among technical journals in its field. Joseph Garodnick as director of publications and Joseph LoCicero as publications editor from 1976 to 1988 (and 1992-1995 editor in chief) did much to make this possible. LoCicero, in 1992, famously eliminated a huge backlog of accepted submissions by arranging a special “printoff” of extra issues.

Within a few years its frequency of publication accelerated from quarterly to bimonthly to monthly, and it featured special issues from the start. By the mid-1980s it had a non-library circulation of nearly 15,000, a respectable figure for a technical journal. By 1981 ComSoc’s leadership debated splitting the Transactions into several different magazines based on areas of technical interest in order to accommodate the increase in the number of submitted and published papers. Indeed, in 1982 ComSoc spun off the well-respected IEEE Journal on Selected Areas in Communications (JSAC) with Adam Lender as its first editor in chief. JSAC soon went from quarterly to nine issues per year.

In addition to this impressive array of periodicals, ComSoc began sponsoring publication of books dealing with communications technology through the IEEE Press in 1975. An ambitious new cross-societies venture, the IEEE/ACM Transactions on Networking, was launched in 1993 with James Kurose as editor in chief, after long negotiations, initiated by Steve Weinstein, among the Association for Computing Machinery, the IEEE Computer Society and ComSoc.
Along with these impressive transactions and journals, ComSoc also continued to develop its flagship, *IEEE Communications Magazine*. In 1977, the magazine was offered to the general public (non-members) by subscription. In 1979 ComSoc hired a full-time managing editor, Carol Lof, and she soon hired Joe Milizzo as production editor, still with ComSoc in 2012 as head of the publications department. Under their leadership and the contributions of key volunteers on the editorial staff, the magazine quickly increased its annual number of pages from just above 100 to about 175. In the first year advertising increased 400% as well. The magazine became a monthly in 1983.

By 1984 advertising revenue had increased more than tenfold, to over $100,000 (and increased since then by another factor of 10 by long-time advertising manager Eric Levine) and the number of non-library subscriptions stood at just under 20,000. A 1985 readership survey found that nearly 90% of subscribers scan or read the magazine on a regular basis, a figure that was much higher than all of the magazine’s commercial peer publications such as *EDN* and *Data Communications*.

In addition to its roster of conferences and impressive list of publications, another sign of the technical vigor of the Society was the recognition that its members received. Between 1970 and 1981 ComSoc members won 10 IEEE Field Awards and 7 IEEE Medals. The National Academy of Engineering

While ComSoc continued to grow in the early and mid 1970s, its growth was not as robust as ComTech’s had been in the 1960s or as rapid as the growth of the telecommunications industry generally. ComTech had noticed a high dropout rate of about 10% among the members as early as 1970. Most of the members who left were recent college graduates who remained as group members for about two years. One significant cause of this high dropout rate among younger members was the perception that ComSoc continued to emphasize older forms of communications technology like telephony and did not pay enough attention to newer fields.

ComSoc’s leadership in this period also sought to attract and retain communications professionals from countries other than the United States. In 1972 ComSoc’s Board set up an International Activities Council headed by Richard Kirby to foster the development of the Society’s activities, membership, and member services outside the United States. The major objective of this Council was to explore the formation of an International Federation of Electrical Communication Societies with the purpose of sponsoring regular international conferences. Kirby also secured passage of an amendment to the ComSoc constitution to give members of recognized national
engineering societies outside North America the advantages of ComSoc membership without requiring them to join IEEE. ComSoc still has a modest affiliate membership, but other globalization initiatives became much more important. In particular, in 1980 and 1981 the Board of Governors approved the formation of three International Committees to serve the needs of members in IEEE Regions 8 (Europe, Middle East, and Africa); 9 (Latin America), and 10 (Asia and the Pacific). Conference organizers solicited and accepted more non-U.S. papers at ComSoc-sponsored meetings, and Transactions carried more articles with an international scope, including the August 1972 Transactions special issue on communications in Japan. This was followed by special issues in 1974 on communications in Europe, in 1975 on communications in the U.S.S.R., and in 1976 on communications in Latin America and in developing countries.

To increase membership the AdCom sought to attract more students and recent graduates, international members, and engineers working in cutting-edge fields of communications. These measures to attract and retain members paid off: membership grew at the healthy rate of 9% a year after 1978, and ComSoc enjoyed a growth rate within the IEEE second only to that of the Computer Society.

Lackluster membership growth in the mid-70s also caused concern over Society finances. The need to cover operating deficits in this period depressed ComSoc’s financial reserves from $236 000 in 1978 to $125 000 in 1983. Corrective actions AdCom took included a more aggressive promotion of the benefits of ComSoc membership, limiting the number of pages of Transactions to 1200 a year in 1979, and raising conference registration fees. By 1976 ComSoc’s financial picture had improved to the point where AdCom raised the number of pages of Transactions to 1400 a year and to 2100 in 1982. By the mid-80s ComSoc’s initiatives to grow the membership had paid off, and the Society regained a firm financial footing. By 1984 ComSoc had almost 20 000 members, the third largest number of members among all IEEE Societies, and its member-
ship growth rate stood second only to that of the Computer Society. ComSoc and its members were well poised to meet the regulatory and technical challenges of the 1980s and 1990s.

The IEEE Communications Society in an Era of Technological Change and Globalization, 1985-2002

In December 1982 the ComSoc Policy Board, under the leadership of Robert W. Lucky, undertook an exhaustive examination of the strengths and weaknesses of the Society in order to formulate its future direction. The Board discovered that ComSoc was a quite successful society in many ways. The size of its membership, about 15,000, and its international character were both solid signs of success. ComSoc journals were prestigious and well-respected, and *IEEE Communications Magazine* enjoyed a growing popularity. ComSoc meetings and conferences—four main meetings and a variety of specialized workshops—were also signs of success. About 10% of ComSoc members attended at least one conference a year. Despite these successes, the Policy Board noted that ComSoc faced two general problems. Its membership growth rate of about
3% per year was far less than the growth of the telecommunications industry generally and of the number of communications engineers specifically. The Society’s Policy Board speculated that this lackluster growth was the result of ComSoc not keeping up with the sweeping technical and business changes in the telecommunications industry. Indeed, the Board noted, “The leadership of ComSoc is telephony oriented. By and large our technical programs follow the structured discipline of public telephone network engineering. That is not a broad enough base on which to attract the engineering practitioners in new fields” like space satellites, computer networking, and fiber optics. ComSoc’s major task, therefore, was to reorient itself so that it would “become unquestionably the dominant society for communications engineering not only in telephony but in the other emergent fields.”

To reflect the new directions that communications engineering was taking in this period, the ComSoc Board 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.” In this period, as on other occasions in the following decades, ComSoc also sought to stimulate more interest in its activities among managers and engineers in industry. A 1986 report of ComSoc’s Policy Board, responsible for long-range planning, took heart that its membership was growing 10% annually, well over the IEEE average of 4%. However, Fred Andrews, head of the Policy Board, sought ways for ComSoc to “bring in more membership from outside the communications R&D community, which dominates ComSoc today.” Andrews recommended a greater emphasis on issues of interest to industry, such as quality assurance and network management.

Many ComSoc members who worked in industry found that the Transactions were “somewhat theoretical and of mar-
ginal value to working engineers.” As a result, in 1988 the Board of Governors investigated ways to make *Transactions* more relevant to engineers in industry and considered the formation of a new magazine aimed at this audience. The need to reach out to engineers and executives working in the communications industry continued to be a concern; in 1998 a survey revealed that ComSoc was strongest among academic researchers and weakest among industry executives.

In 1988 a committee chaired by Richard Skillen continued the work of the previous committees headed by Lucky and Andrews. Skillen and his colleagues sought to build a strategic vision for ComSoc for the next decade or so. The “Skillen Report” identified several problem areas and opportunities for ComSoc’s future. Skillen and his co-workers found that ComSoc attracted new members at its targeted rate of about 20%, but that it also lost members “at a record rate,” resulting in an “unsatisfactory” growth rate of only 5%. Much of this attrition occurred because ComSoc was “not adequately bringing student members into full membership status.” Another major concern was that many of ComSoc’s Technical Committees “are weak and must be revitalized.”

The issue of member retention was neither new nor surprising, and the Board of Governors recommended that a survey be distributed to the membership to identify ways to attract and retain members and that a new staff position be created for membership development. The Board of Governors also resolved to give the Technical Committees greater autonomy and influence in the activities of the Society. Indeed, the Board recommended that “they should move in the direction of becoming de facto mini-societies.”

In 1991 ComSoc wrote a Five-Year Strategic Plan that carried forward the work of the Skillen Report. On the positive
side, ComSoc had an active membership of 32,000, second only to the Computer Society, with an annual growth rate of 8% that made it the fourth fastest growing society in IEEE. ComSoc finances were in excellent shape, with an annual budget of nearly $5.5 million, a surplus of $1.8 million, and reserves of $1.4 million. Still, the Strategic Plan called for ways to retain existing members and to attract new and younger members. The report recommended that the Society focus on emerging technologies like software, wireless, photonic systems, and computer networking. By so doing, the report forecast that ComSoc would grow by 37,000 members in the next decade.

Another sign of the growth and maturity of ComSoc was the inauguration of a paid professional staff to manage the Society’s day-to-day affairs. ComSoc’s first staff member was Carol Lof, who became editor of *IEEE Communications Magazine* in 1979. In 1990 she was promoted to the post of executive director of the Society, and managed a staff of ten. Lof hired Carole Swaim as her administrative assistant. Swaim, who has helped legions of volunteers over more than two decades, is in 2012 the senior administrator for executive and volunteer services. Lof was followed as executive director in 1995 by Allan Ledbetter. In 1997, after Ledbetter was seriously injured in a traffic accident, he was succeeded by Jack Howell who became executive director of ComSoc and remains in that position in 2012, managing a staff of about 25 people.

During the late 1980s and early 1990s, the ComSoc leadership recognized the Society’s growth as a sign of its continued success. Yet they were aware of the need to attract and retain younger members and non-U.S. engineers. In addition to greater coverage of emerging technical fields, the broad and
accessible content of *IEEE Communications Magazine* helped stem the dropout rate among younger engineers.

In 1991 ComSoc set up an ambitious membership retention and recruiting program; executive director Carol Lof estimated that ComSoc had spent as much as $100,000 on membership recruitment and retention in 1992 alone. In 1997 ComSoc set up a Young Members’ Committee under the direction of Vice President–Membership Affairs Roberto DeMarca. ComSoc also in that year hired John Pape to lead its staff marketing function to address membership development and sales of ComSoc publications, conferences, and other services. Pape continues in 2012 to lead the marketing and creative services department.

In 1994 President Maurizio Decina and Vice President for Technical Affairs Stephen Weinstein reflected on the present status and future direction of ComSoc. They noted with satisfaction that the Society had “advanced the state of the art” in traditional fields of communications engineering like “switching, transport, modulation, protocols, control and operations systems”—the “foundation elements” of the modern communications and information infrastructure.

However, they continued, ComSoc and communications engineers have received scant credit for recent advances like the explosive growth of the Internet and wireless communications. “Perhaps,” they concluded, “we should admit that we have not had the breadth of vision to integrate our in-depth contributions to component subsystems into a broader perspective on information networks that could be recognized and appreciated beyond our own com-
munity.” To help instill this broader perspective ComSoc launched Technical Committees on Personal Communications, Broadband Delivery and Access Systems, and Gigabit Networking.

In addition to attracting younger engineers working in newer fields of communications, ComSoc increased its efforts to attract and retain more non-North American members. Indeed, by the early 1990s, ComSoc boasted the largest growth rate for international members among all IEEE societies. During the 1980s and early 1990s the percentage of U.S. members was decreasing while the percentage of European and Asian members was increasing.

By 1996 over 40% of ComSoc’s members were from outside the U.S., up from about 27% in 1978. Similarly, by 1988 non-U.S. authors presented 30% to 40% of the papers at GLOBECOM and ICC, ComSoc’s two major conferences. During the late 1980s and 1990s the globalization of the telecommunications industry and of ComSoc’s membership required the Society to serve its growing overseas membership better.

As of 2002, there were 14 sister societies around the world
Indeed, the opportunities and problems associated with the globalization of ComSoc were the central concerns of the ComSoc Strategic Plan issued in May 1992. To accommodate its growing international membership, 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. ComSoc’s globalization initiatives were a major concern of Maurizio Decina when he was president of the Society in 1995. He recommended a continued expansion of collaboration with sister societies and to open more regional offices.

A 1999 IEEE member survey discovered that nearly two-thirds of ComSoc’s members worked in private industry, with only 12% and 9% working in education and government, respectively. The major reason for joining was to obtain ComSoc publications. The major technical focus of nearly half the respondents was the Internet, with about 40% of the respondents citing computer network communications and personal communications as their major technical interests.

ComSoc publications in this period began to reflect these changes in communications technologies and in the technical interests of the Society’s members. In 1987 ComSoc started the bimonthly IEEE Network – The Magazine of Computer Communications, and by 1989 the journal became a self-sustaining monthly publication with a circulation of 12,000. In 1993 the IEEE/ACM Transactions on Networking was introduced, followed by IEEE Personal Communications Magazine in 1994. IEEE Personal Communications Magazine
(renamed *IEEE Wireless Communications Magazine* in 2002) covered all technical and policy issues relating to all forms of wired and wireless communications, with a particular focus on mobility of people and communicating devices. Also in 1994, the *Global Communications Newsletter* was initiated as a regular monthly feature in *IEEE Communications Magazine*, covering worldwide events related to communications and Society activities. In 1996, the Society's first electronically published journal—*IEEE Communications Surveys & Tutorials*—was launched. In 1997, *IEEE Communications Interactive* became available, the online multimedia, animated interactive version of *IEEE Communications Magazine*.


In 1999, the Society launched its Electronic Periodicals Package (EPP). Readers could get electronic access to six periodicals of their choice with a single subscription. By 2002, EPP had been expanded to a dynamic Digital Library which contains 28 000 articles from 1953 to the present. Included also
were conference proceedings from 1999. The “CommOntology” provided with the ComSoc Digital Library could automatically find relationships between items, allowing users to easily locate material within the collection related to the document of interest.

In January 2002, ComSoc introduced a new major quarterly journal *IEEE Transactions on Wireless Communications*. The new journal was a “spin off” of the Communications Society’s extremely successful *IEEE Journal on Selected Areas in Communications–Wireless Communications Series*

Other developments include the Society’s website, which was launched in 1996. *ComSoc e-News*, an electronic newsletter, was initiated in 1998 and is distributed to all ComSoc members who have listed e-mail addresses.
The IEEE Communications Society from Fifty to Sixty: 2002-2012

With 51,155 members at the end of 2011, the Communications Society is today the IEEE’s second largest professional Society. When the IEEE Group on Communications Technology began operations on 1 July 1964, it boasted 4400 members. Within a decade this figure had doubled; when ComSoc was elevated to Society status in 1972 it counted 8800 members. Continuing rapid growth brought us to a peak membership of 58,000 in 2000 just before the dot-com economic downturn, which was particularly hard on the communications industry. After a severe drop to about 41,000 in 2006, ComSoc’s membership had by 2011 returned to its upward trend.

ComSoc End-of-Year Membership, 1952-2011
The more than 50,000 ComSoc members currently participate in 24 Technical Committees, can avail themselves of 22 sponsored and co-sponsored technical publications, and can attend any of ComSoc’s eight core conferences, eight co-sponsored conferences, and 15 regional and small ComSoc-sponsored conferences and workshops at venues throughout the world. About 40% of ComSoc members are employed in industry or self-employed/consulting; 31% are affiliated with educational institutions; and 19% are students. ComSoc has 224 chapters worldwide, a 50% increase over 2002. Chapters benefit from a very popular Distinguished Lecturer Program that includes individual lectures and tours, with funding provided to help support the chapters’ activities and outreach.

**Geographic Profile of ComSoc Membership, 2002-2011**

Globalization of ComSoc membership accelerated during the past decade, with the result that more than half of ComSoc members are outside the United States. Most new members of the past decade reside in the Asia/Pacific and Europe-Middle-East-Africa regions. Twenty-eight sister society agreements, the
The overwhelming majority signed in the past decade, are in effect, associating ComSoc with national communications engineering societies in 28 countries. ComSoc also signed agreements with related organizations such as the East-West Institute and the Pacific Telecommunications Council.

Members of our society have continually contributed their leadership skills, technology, and expertise to the communications field, although over the last decade an increased proportion of members have come from academia. To balance this trend and attract greater industry involvement, ComSoc inaugurated several initiatives in the past decade to provide better service to members in industry and strengthen its ties there. This included expanding the Society’s awards program to recognize communications professionals who have made major industry-oriented contributions.

The *Distinguished Industry Leader Award* honors industry executives whose leadership has resulted in outstanding advances and provided new directions to the information and communications business area. More recently, ComSoc instituted the *Industrial Innovation Award* recognizing individuals for major industrial accomplishments, significant contributions to standards, and implementation of processes/products that substantially benefit the public in the fields of communications and information technologies.

Employment in the traditional U.S. telecommunications industry has declined by about 35% since reaching highs of more than 1.4 million in 2000, but there have been other, related areas of employment growth. While telecom employers have been shedding traditional full-time employees, technical consulting and scientific research employment increased by 50% in the last decade. With the elimination of several major U.S. telecom trade shows such as Supercomm and ComNet, a different profile, or pattern, of communications engineering employment has emerged.

ComSoc has adapted with increased attention to technologies supporting social engagement, energy efficiency, and
economic prosperity in the 21st Century. Our emerging technical committees and rapidly launched conferences are mechanisms developed in recent years to address newer technologies and applications such as cloud computing and networking, spectrum-efficient broadband wireless, nanotechnology, machine-to-machine communications, peer-to-peer content delivery, vehicular telematics, energy-conserving information and communication systems, and e-health.

ComSoc also made strong efforts in the 2002-2012 period to incorporate the best modern techniques for delivering its own services. This included launching two e-only periodicals, *IEEE Communications Surveys and Tutorials* and *IEEE Transactions on Network and Service Management*. The e-only “Best Readings” and *ComSoc Technology News* (CTN) complement traditional publications, and ComSoc’s series of industry-sponsored webinars is reaching large audiences. Many members access content through ComSoc’s Digital Library (75 000+ documents), which incorporates up-to-date features such as patent references and MyComSoc customization. IEEE Xplore offers access to all ComSoc published papers and articles, with over two million views of ComSoc published papers recorded each year.

Every member receives a digital version of *IEEE Communications Magazine* as a default membership benefit, with print available for an extra fee. Members vote electronically for Society and IEEE officers. Many virtual society groups have a presence on ComSoc’s Community website, with options for limited or public access. ComSoc members can see linked tables of contents through a monthly
e-issue of *Publications Digest*. All important society documentation, including the annual “ComSoc Community” directory, can be viewed via a robust ComSoc website. Over 75 recorded conference tutorials are available through the Tutorials Now program. The webcast program includes live streaming of selected keynotes, sessions, and workshops directly from events. ComSoc has a strong presence on major social media venues—LinkedIn, Twitter—with more than 100,000 followers on FaceBook.

ComSoc also endeavored to measure and enhance the value of membership. Recent member surveys indicate that 90% agree that professional networking is crucial to a successful career, 88% believe free industry publications do not provide information needed for the job, and 93% feel that contributing to the profession is important. Members expect ComSoc to provide information on “hot” technologies, innovative applications, and standards. Collections of online tutorials, technical monographs, and online or DVD publications attract considerable member interest.

The Society has also been asking itself what it really wants to be and do for its members and the world. Strategic planning took on new importance, with both short-term and “2020 vision” strategic plans completed at the end of 2011. Throughout the 2002-2012 decade, ComSoc publications dominated the annual telecommunications rankings of the Thomson Reuters Journal Citation Reports® (JCR) that evaluates the influence and impact of scholarly research journals. The *Transactions on Communications*, *Communications Magazine*, *JSAC*, *Network Magazine*, *Transactions on Wireless Communications*, *Wireless Magazine*, *IEEE/ACM Transactions on Networking* and, most recently, *Communications Surveys and Tutorials* enjoyed high ratings and rankings. The *Transactions on Wireless Communications* increased its frequency to monthly in 2006 and *Wireless Communications Letters* was added in 2012.

Cosponsored periodicals include *IEEE/OSA Journal of Optical Communications and Networking* and *Journal of*
Communications and Networks (JCN) with the Korean Information and Communications Society (KICS). In 2007, ComSoc issued The Best of the Best book, a compilation of classic journal papers published in the past by the Society. ComSoc also released a DVD of Leonard Kleinrock’s History of the Internet and Its Flexible Future and Communicrostics, a collection of reprints of 30 years of technology crossword puzzles authored by ex-president Paul Green. At IEEE Press-Wiley, a new book series was initiated—ComSoc Guides to Communications Technologies. During the decade, three editions of a compendium of ComSoc papers were issued in DVD format as Communications Engineering Technology: A Comprehensive Collection of Papers.

Another major innovation of the past decade was the IEEE WCET (Wireless Communication Engineering Technologies) Certification Program, launched in early 2008. Developed by ComSoc and an international collection of industry experts, it addresses the worldwide wireless industry’s growing need for professionals with real-world problem-solving skills. Successfully negotiating the 150-question exam in the allotted four hours results in an IEEE Wireless Communications Professional (WCP) credential reflecting a broad knowledge of vendor-neutral, transnational wireless communication technology. To support the program, a handbook, a practice exam, recorded tutorials, a bimonthly e-newsletter, a column in Communications Magazine, and a Guide to the Wireless Engineering Body of Knowledge (WEBOK) have been developed. The Mobile Computing Promotion Consortium (MCPC) represents WCET in Japan.
ComSoc training in practical wireless engineering has become attractive to the broader community as well as to those focusing on the WCET certification exam. Begun in 2010, these courses are offered as on-site events at trade shows or as live Internet-based virtual courses. These courses can be customized for specialized groups.

ComSoc-sponsored and co-sponsored conferences continued during the past decade to be an essential and growing activity for thousands of volunteers. A three-tiered registration fee structure offers steep discounts for ComSoc members. New conferences were implemented to reflect member and industry needs. These included the Consumer Communications and Networking Conference (CCNC), Dynamic Spectrum Access Networks Conference (DySPAN), International Conference on Smart Grid Communications (Smart Grid Com), International Conference on e-Health Networking (Healthcom), International Symposium on Power Line Communications (ISPLC), and, in 2012, the International Conference on Communications in China (ICCC).

In 2005, the Optical Fiber Communications Conference (OFC) merged with the National Fiber Optics Engineers Conference (NFOEC) to form OFC/NFOEC, an industry/engineering event co-sponsored by ComSoc, the IEEE Photonics Society, and the Optical Society of America. In 2006, the Military Communications Conference (MILCOM) commemorated its 25th anniversary. In 2011, ComSoc launched its first online-only conference, GreenCom.

In January 2010, President Byeong Gi Lee noted that the key to success would be “ComSoc’s Golden Triangle” (see illustration), with vertices for Globalization, Young Leaders, and Industry. Inside this triangle is IEEE’s and ComSoc’s most important goal, that of “Serving Humanity.” Recent initiatives include patron programs and a special Industry Now program for
multiple memberships from companies in developing countries, corporate sponsorship opportunities, more elaborate coordination with Graduate of the Last Decade (GOLD) members, and an “open call” system to provide opportunities for new volunteers from around the world. The creation of a new Vice-President of Standards Activities as an elected volunteer office reflects increased attention to and cooperation with industry. ComSoc’s 2012-13 President Vijay Bhargava leads a successful professional organization, but one that can and will become stronger and better able to meet the needs of its members.

Changes in the world and in our professional community that ComSoc will face in the next 10 years are likely to be even greater than those experienced in the last decade. They will present both hard challenges and opportunities for growth. The skills needed to address new challenges will go well beyond traditional engineering, and ComSoc will be working with many disciplines outside communications to build the knowledge base for new networks and applications. Our products and services will continue to serve our current constituency, but will also address many professionals who are not currently within the “expected profile” of a communications engineer.

ComSoc’s wide array of publications, conferences, and technical interests will continue evolving to meet the challenges and opportunities of communications and the information society it supports in the 21st century.
The IEEE Communications Society: An Oral History
Fred Andrews

Oral history conducted in November 1999 by David Hochfelder, at IEEE Headquarters, Piscataway, NJ

“The point contact transistor was invented in 1947, and the junction transistor in 1948, but they were very, very crude devices at that time. I can remember that when I was working in New York at the West Street location of Bell Laboratories, the director entered our research laboratory with a Mason jar in hand. Mounted on the inside surface of the lid was the first junction transistor. He said, ‘Look, you guys, see what you can do with this thing.’

“Over the seven years that I worked for Bellcore I believe that everyone became much more comfortable with our generic requirements process. A lot of new vendors successfully entered the local telephone network business. At the same time we maintained some pretty tough standards of performance. By and large, the integrity of the network was maintained while the market became very open to all competent vendors. I take pride in helping to make the massive breakup of AT&T work, and that may well have been the high point of my career.”

Fred Andrews. Fred Andrews received his B.S. degree in electrical engineering from the Pennsylvania State University in 1948 and joined AT&T Bell Laboratories that same year. He remained at Bell Labs until 1983, where he worked on research related to switching circuits and systems and obtained ten patents. Named Executive Director in 1979, he was responsible for resolving systems issues related to the evolution of digital telephone networks. When Bellcore was established in 1984 to serve the needs of the newly created regional telephone companies, he was one of the founding corporate officers. He retired from Bellcore in 1990 and has since been a committed IEEE and ComSoc volunteer. He has served on ComSoc’s Board of Governors (1972-1978) and as Vice President (1982-1985) and President (1986-1987) of the Society. In addition to winning two prestigious IEEE Communications Society awards, the Edwin H. Armstrong Achievement Award in 1980 and the Donald W. McLellan Meritorious Service Award in 1992, Andrews became a Fellow of the IEEE in 1973, and a member of the National Academy of Engineering in 1988.
Paul Baran

*Electrical engineer, an oral history conducted in 1999 by David Hochfelder, IEEE History Center, Rutgers University, New Brunswick, NJ*

“Today, the all-pervasive worldwide communications networks weave together the strands of commerce, ideas and shared common interests. The payoff to society for the development of the new communications technology during the last fifty years cannot be overestimated. And, let us not forget that the IEEE has been a major factor in the development of communications technology.

“On acceptance of packet switching: “The fundamental hurdle in acceptance was whether the listener had digital experience or knew only analog transmission techniques. The older telephone engineers had problems with the concept of packet switching. On one of my several trips to AT&T Headquarters at 195 Broadway in New York City I tried to explain packet switching to a senior telephone company executive. In mid sentence he interrupted me, ‘Wait a minute, son. Are you trying to tell me that you open the switch before the signal is transmitted all the way across the country?’ I said, ‘Yes sir, that’s right.’ The old analog engineer looked stunned. He looked at his colleagues in the room while his eyeballs rolled up sending a signal of his utter disbelief. He paused for a while, and then said, ‘Son, here’s how a telephone works….’ And then he went on with a patronizing explanation of how a carbon button telephone worked. It was a conceptual impasse.

“On the other hand, the computer people over at Bell Labs in New Jersey did understand the concept. That was insufficient. When I told the AT&T Headquarters folks that their own research people at Bell Labs had no trouble understanding and didn’t have the same objections as the head-
quarters people. Their response was, ‘Well, Bell Labs is made up of impractical research people who don’t understand real world communication.”

**Paul Baran.** Mr. Baran has had a distinguished career in computer communications for over half a century, including a stint at the pioneering Eckert Mauchly Computer Company, Hughes Aircraft, and the RAND Corporation, where he developed digital packet switching as the basis for a distributed and decentralized communications network. He received his B.S. in electrical engineering from Drexel Institute of Technology in 1949, and obtained his M.S. from UCLA working under the renowned Prof. Gerald Estrin in 1959. He has received widespread recognition for his pivotal role in the development of packet switching and computer communications, including election to the American Association for the Advancement of Science in 1994 and to the National Academy of Engineering in 1996. The IEEE awarded him the Edwin H. Armstrong Achievement Award in 1987, the Alexander Graham Bell Medal in 1990, and in 2000, he shared the IEEE Internet Award with Donald W. Davies, Leonard Kleinrock, and Lawrence G. Roberts for “their early, preeminent contributions” to the development of packet switching, “the foundation technology of the Internet.”

**Vinton Cerf**

*Oral history interview conducted in 1999 by David Hochfelder, IEEE History Center, Rutgers University, New Brunswick, NJ, USA.; updated 2012*

“…around 1988, I realized that the Internet would not likely get very big if it didn’t become a self-supporting system. It had to become a commercial engine, as opposed to simply being something that the government bought and paid for. The problem was that the Internet at the time was strictly for use by research and education organizations. Government and appropriate use policy had strong restrictions on it. By 1988, the National Science Foundation had already launched its NSF Net backbone program. So, we had a growing network, but it was limited in its scope.
“…the Internet has certainly had its share of politics, as you may well imagine, particularly as it became more economically important. Politics seems to go up as a function of the economic value of things. I knew Internet was going to get big when the attorneys started getting interested in it.

“In the early stages, of course, even in the predecessor, ARPANET, people thought we were crazy, because packet switching didn’t make a whole lot of sense to them. I think Internet was almost as difficult to sell to ARPANET people, because they were comfortable with the protocols they had. They worked and they got their email, and they could do file transfers. You know, who needed this new Internet thing?

“The IEEE has done some really good things though. First of all, its publications are very good. I still subscribe to a number of them, in addition to *Communications Transactions* and *IEEE Communications Magazine*. It’s also done some very interesting work on standardization with the 802 series of standards. IEEE 802.xx has exploded with many new wired and wireless mechanisms that aid widespread networking in an array of scenarios. That has been an important contribution. I think, on occasion, the Communications Society in particular, has been very helpful in formulating policy, or at least explaining what the policy implications are of various technical choices to members of Congress. Also, the conferences put on by IEEE are almost invariably very interesting and useful.

“Where today [1999] there are about 50 million devices on the Internet, my projections are that there will be 900 million devices on the Net, almost a billion, by about the year 2007. Now, in 2012, there are over 2 billion users, many of whom access the Internet by way of their mobile phones. A lot of them won’t be classical desktops, laptops, and so on, but personal digital assistants. It’ll be cell phones. In 2012 there are 5.5-plus billion mobiles in use, and perhaps 20% or more are ‘smart’ when it comes to the Internet. It’ll be Web television sets. [Think Apple TV, Google TV, Netflix online, YouTube, ...]
Hulu, etc.] It’ll be appliances around the house. [Think Smart Grid!] Mark Wieser’s notion of the ubiquitous computing environment is really going to happen. It’ll be fully networked, so we need to learn how to adjust to that kind of a world where many, many devices and sensors are a part of the Network.

“…revolutions like this don’t come along very often. They have consequences that we can’t necessarily see. Therefore, it would not hurt for us to be constantly on the lookout for what the implications are, to be looking back and asking ourselves what’s happened over the last ten years. And is it good, bad, or indifferent?...I’m an eternal optimist, and I think this revolution is going to be one that will be beneficial in the long run. It’s already opened a dialogue among people on the planet whose voices never would have been heard, who might never have met each other or discussed a particular topic. Those are all amazingly powerful tools for stimulating human discourse. Frankly, it’s my hope that increased level of discussion and debate will help us manage what is obviously a very complex global society.

“Of course, reality has a way of creeping into even the most optimistic scenarios. As the Internet expanded, and new devices became part of its eco-system, a full range of uses and abuses have emerged that require responses for the protection of citizens and society. Some governments try to censor the Internet or use it for surveillance purposes to discourage freedom of speech and assembly. Criminals and troublemakers generate and spread viruses, worms, Trojan horses, denial of service attacks, fraud, and spam—in a dizzying array of socially and legally unacceptable behaviors.

We are only beginning to recognize there are only a few ways to combat these abuses: through technical means of prevention, through mechanisms for detection and attribution and through persuasion (moral suasion and business models that inspire preferable behavior). International cooperation is essen-
tial to cope with these problems, as are treaties to avoid national scale cyber-aggression.”

**Vinton Cerf.** Dr. Cerf is a co-developer of the computer networking protocol TCP/IP, widely used for Internet communications. He received his B.S. in mathematics from Stanford University in 1965, and his M.S and Ph.D. in computer science from UCLA in 1970 and 1972, working with the renowned Gerald Estrin. After serving a brief stint (1972-1976) as an assistant professor at Stanford, Cerf made his professional mark in both the public and private sectors. As Program Manager and Principal Scientist at the U.S. Defense Advanced Research Projects Agency (DARPA) between 1976 and 1982, he helped develop the ARPANET, forerunner to the Internet. He has guided the development of the Internet as an officer of both the Corporation for National Research Initiatives (1986-1994) and the Internet Society (1992-2001). He has also helped develop commercial applications for the Internet as an officer of MCI Telecommunications Corporation (1982-1986 and 1994 to 2005). He has been widely recognized for his achievements, entering the National Academy of Engineering in 1995 and receiving the National Medal of Technology in 1997. The IEEE has honored him jointly with IEEE Fellow Robert E. Kahn with the Koji Kobayashi Award in 1992 and the Alexander Graham Bell Medal in 1997. Both were further honored with the Charles Stark Draper Prize in 2001, the A.M. Turing Award in 2004, the Presidential Medal of Freedom in 2005, and the Japan Prize in 2008. Each has also separately received the Marconi Fellowship award and many honorary degrees.

**Donald Cox**

*interviewed by David Hochfelder, Sept. 28, 1999, New Brunswick, NJ*

On ComSoc: “I think it’s been very valuable. The *Transactions*, the major meetings that they hold and the other meetings they support have been very important. They also support a lot of specialty meetings that have been very helpful...The involvement of IEEE has been extremely important to the technology. Without IEEE *Communications Magazine*, *Personal Communication Magazine* and the *Transactions*, it would be much harder to disseminate the information.

“One thing that had a significant impact on communications engineering was the breakup of AT&T. Bell Labs was a very
dominant force in communications, and there’s no way to deny that. As a result of some of the constraints that were on AT&T and Bell Labs, there was a policy of free publication. Papers were looked at before they went out, but most things got published, and in a fairly timely manner through IEEE publications. Many of the articles published in the Communications Society journals have been written by Bell Labs authors. Bell Labs people participated very heavily in the Communications Society and in the IEEE in general and were generally permitted to do that as part of their work. Since then there has been somewhat of a retrenchment on free publication. Articles tend to be more cryptic, less revealing and less timely. I doubt if there is data to support it, but there’s probably less free labor provided to the IEEE because competition has caused a tighter control over time and money. It’s much harder now for people to devote the quality of activity they once did, though there are individual cases that are an exception.

“I think we are going to see most of our voice communications carried on with wireless in some part. I think we are going to see low data rate messaging, e-mail, and you are going to be able to get at least short messages on your wireless communicator. I think we are going to see increased reliability in performance as the firestorm subsides. About all that’s been going on in the last ten years is trying to get as much wireless equipment in the field as possible, because it’s been very difficult for the industry to keep up with demand. I think that wireless is going to have a significant impact on the backbone networks. There is no doubt that the basic infrastructure is going to be fixed network. Wireless is just a network attachment, an access technology, but if you have mobile users everywhere that has a significant impact on the processing, data storage and protocols that are used in the network. That’s going to have a profound effect on the way these networks are built and operated.”
Donald Cox. Dr. Cox received his B.S. and M.S. degrees in electrical engineering from the University of Nebraska in 1959 and 1960, respectively, and his Ph.D. from Stanford University in 1968. He has had a varied and accomplished career in wireless mobile and personal communications, including nearly 25 years at AT&T Bell Labs and Bellcore. In 1993 he became a Professor of Electrical Engineering at Stanford, where he also directs the Center for Telecommunications. Dr. Cox holds over a dozen patents, is a member of the National Academy of Engineering, and is a Fellow of both the IEEE and American Association for the Advancement of Science. In 1993 the IEEE awarded him its Alexander Graham Bell Medal for “pioneering and leadership in personal portable communications.”

Joel Engel

*an oral history conducted on Sept. 30, 1999 by David Hochfelder in New York City*

“I was put into a group working on the systems engineering aspects of mobile telephone. At that time mobile telephone was not a high priority subject at Bell Labs, and the group was somewhat out of the mainstream. There were two rather primitive systems, operating at 150 MHz and 450 MHz, with only 11 channels at 150 MHz and 12 channels at 450 MHz. These channels could not all be used in any one location because nearby systems interfered with each other.

“For example, in the greater New York area, the eleven channels had to be parceled out among Manhattan, Newark, White Plains, Hempstead, and Belle Mead, because these locations all interfered with one another. Manhattan got three channels, which meant that in the entire New York City coverage area, only three mobile telephones could be in use at any given time. Anyone else wanting to make a call would be blocked and get a little red light indicating all three of the allocated channels were busy. Since there were about 300 people riding around with telephones in their cars, this happened most of the time. There were long waiting lists of people who wanted the service, but adding them would have made the problem
even worse. Another problem was that not enough revenue could be collected from 300 subscribers to support the cost of the system. The systems at 150 MHz, which were developed first, were not profitable, so very few telephone companies implemented any at 450 MHz. That was the state of affairs for mobile telephones in the late ‘60s.

“There was also skepticism at Bell Labs as to whether the system would work. Some thought that the system was too complicated; others were concerned that it relied on a number of very new technologies, such as microprocessors. Some radio experts questioned the cellular concept, saying, ‘Radio waves don’t travel in hexagons.’ With some highly regarded technical people at Bell Labs questioning whether the system would work, and the marketing people being advised that there was no market for it at any price, AT&T and Bell Labs are to be admired for allowing us to proceed. Fortunately, we were allowed to design and build a test system, and it worked. And, when the FCC finally allowed a commercial service, it has proven to be a tremendous market success. In 1987, three of us from Bell Labs were awarded the Alexander Graham Bell Medal of the IEEE. Then, in 1994, two of us received the National Medal of Technology from President Clinton.

“Use of telecommunications exploded, and because of that we ran out of telephone numbers. You would think that the change from having a three-digit area code that has to have a zero or one as a second digit to a three-digit area code that could be any three digits would be a trivial thing in this age. It isn’t. The change in our network caused by that was just incredible, because the developers of the switch software had taken shortcuts to take advantage of the fact that that second digit was always zero or one (very much like the Y2K problem). Undoing that was a phenomenally big job.

“Remember I said we were supposed to devote up to 50 percent of our time to things that were related to our field? Radio
astronomy at Bell Labs was very much related. It grew out of trying to understand where the noise was coming from that was getting into our microwave systems. Arno Penzias and Robert Wilson didn’t develop the Big Bang Theory, but they found the noise that supported the Big Bang Theory. They were not intending to do that. They were trying to find the source of the noise and concluded that it was the residual noise from the Big Bang. It had a telecommunications purpose behind it, but they were allowed to branch out. There was also the issue of publications. When I first started out, publication was encouraged. It enhanced the image of Bell Laboratories. Now it’s, ‘Why do I want to give my intellectual property to my competitors?’ The external environment changed and Bell Laboratories had to change with it.

“I see where a lot of this drive toward non-real time communications will increase, even between just two people communicating. They’re going to communicate by sending messages back and forth in one medium or another. Moving pictures are the most captivating, so that’s going to be a medium of choice. I don’t know if personal telephone calls with picture phones will become the norm, but the communication of information by sending moving pictures is going to increase.

“The ubiquity of communications is going to grow even more. People like me who are annoyed by seeing people sitting in restaurants or driving cars with cell phones glued to their ears are going to have to get used to it. In the streets of Manhattan everybody’s got them. People are never going to be away anymore, will always be in touch. That’s okay because of non-real time communications, making it so that even though people will always be in touch they’ll be in touch by choice. We don’t feel the compulsion anymore to jump up and answer the phone when it rings. If we’re doing something else, we do something else. If it’s important enough, they’ll leave a message. All of that is going to continue, and costs will be driven
down. Moore’s Law, that applies to capability doubling every eighteen months for roughly the same price, is happening in telecommunications as in other technology applications.”

**Joel Engel.** Dr. Engel received his B.S. in 1957 from the City College of New York, his M.S. from Massachusetts Institute of Technology in 1959, and his Ph.D. from the Brooklyn Polytechnic Institute in 1964, all in electrical engineering. He spent the first half of his career, between 1959 and 1983, at Bell Labs, where he was one of the original architects of the cellular mobile telephone system. In 1983 he joined Satellite Business Systems, an IBM venture into telecommunications, as vice president of engineering, and in 1987 joined Ameritech to build and lead its research and development efforts. He retired from Ameritech in 1997, and since then has remained active as a telecommunications consultant. Among his numerous awards, he shared the IEEE’s Alexander Graham Bell Medal in 1987 with two other researchers from Bell Labs, and President Clinton honored him with the National Medal of Technology.

**G. David Forney, Jr.**


“As Yogi Berra is supposed to have said, ‘Everybody knows it's hard to predict, especially about the future...

“There’s a very famous vignette in the history of our business that occurred at the very first Communication Theory Workshop in 1970 in Florida. Everybody knows about this workshop because during the workshop there was a session on coding. Ned Weldon made a talk in which his principal illustration was a slide with lots of rats all crowding into the corner of some cage that they were in. God knows what they were doing in that corner. He said basically this is what coding theorists are doing, we’re all scrabbling around the same small set of problems, and they aren't really the relevant problems anyway.
“It became known as the ‘coding is dead’ talk, session, workshop. Coding is dead, it's a played-out field; we ought to stop research. This has been a recurring theme. I've said a number of times I've spent my whole career working in fields that have been declared to be dead. Anyway, this was the ‘coding is dead’ workshop. Later Bob Lucky wrote a column on it for *IEEE Spectrum*. It grew to say modems were dead and so forth, when actually these things were just at the take-off point.

“I didn't agree that coding was dead. Irwin Jacobs was in the back of the room, and he rose to say this is absolutely wrong. He held up a 14-pin dual in-line (DIP) package, which contained probably a four-bit shift register or something, medium scale integration, and he said ‘This is where it's at. This new digital technology out there is going to let us build all this stuff.’ And he was absolutely right. Elwyn Berlekamp chimed in to the same effect, and I think that I may have said something similar. Elwyn went on to found a coding company called Cyclotomics where he did some fantastic things in hardware. As for Irwin, a very important reason for Linkabit's success was that they were riding on the first real wave of digital technology...”

“In the 1990s, the error of this prediction was shown with a vengeance when several people (none of them coding theorists) came forward with capacity-approaching codes. The first were turbo codes, presented by Claude Berrou at the 1993 ICC in Geneva. By combining a couple of relatively simple codes with a 'turbo' iterative decoding algorithm, he claimed to be able to get within about 1 dB of Shannon's capacity. Of course, everyone thought that he must have made a 3-dB error or something. But it didn’t take long for people to simulate his codes and see that he was right.

“Low-density parity-check codes were then rediscovered by David MacKay and others, and shown to have similar performance. This was even more embarrassing for us, because these codes had originally been invented by Bob Gallager in his
1960 MIT thesis. Bob was one of the founders of Codex in 1962, and Codex could have had the rights to LDPC codes. But these codes were far too complicated for the technology of the time, and we at Codex forgot all about them, even in the 80s and 90s, when they could have been implemented. We kicked ourselves again.

“Nowadays, capacity-approaching codes such as LDPC codes are routinely incorporated in all new standards, and are even being proposed for optical channels at amazing rates like 100 Gb/s.

“To me, the moral is not so much that it's hard to predict, but more that it's very hard for the human brain to comprehend what a factor of a thousand or a million in processing power is going to make possible...”

G. David Forney, Jr. Dr. Forney received the B.S.E. degree in electrical engineering from Princeton University in 1961, and the M.S. and Sc.D. degrees in electrical engineering from the Massachusetts Institute of Technology in 1963 and 1965, respectively. From 1965-99 he was with Codex Corp., which was acquired by Motorola Inc. in 1977, and its successor, the Motorola Information Systems Group, Mansfield, MA. Since 1996, he has been an adjunct professor at MIT. He was President of the IEEE Information Theory Society in 1992 and 2008. Among his many honors, he has received the 1992 IEEE Edison Medal, the 1995 IEEE Information Theory Society Claude E. Shannon Award, and the 1997 Marconi International Fellowship. He was elected a member of the National Academy of Engineering in 1983, and of the National Academy of Sciences in 2003.

Gerard J. Foschini

Interviewed by Alfred Rosenblatt, Feb. 13, 2012

“How did I come up with the idea for MIMO [Multiple input, multiple output]?” The idea was to get as much data capacity as possible in wireless communications. The effort dated back a long time. Around the late ‘60s, I was working at Bell Labs on the problem of crosstalk
between pair of wires in phone cables. Sometimes as many as 1700 pairs were bundled together. I had worked at Bell Labs before and had left for grad school. When I returned seeking a job with more of a theoretical component I was pleased to be hired to work on the equations having to do with the coupled pairs.

“Then jump ahead about 25 years, I was still at Bell Labs when I was called into a boss's office—Rich Gitlin was his name. ‘Jerry,’ he says, ‘we’re changing your job. We want you to work on the fundamental limits of communications. What is the greatest capacity—the number of bits per second or bits per second per Hertz of bandwidth—that can be sent over a medium? We want you to find out the best that the laws of physics allow.’

“Well, I wasn’t so sure I wanted to work on this for wireless systems. I’d heard of experiments being done at very high speeds and I was thinking, ‘Wow! They’re already doing very well. Maybe they’re already achieving close to what the laws of physics allow.’ But then I spoke to, I’ll never forget, Prof. Peter Driesen, of the University of British Columbia who often came for extended visits at Bell Labs and he said to me ‘Jerry, we don’t understand the fundamental limits according to the laws of physics. You’d be making a mistake by not working on that problem.’

“So I got to work and quickly realized I really had to know more about antennas. This led me to a conversation that changed everything. I walked into the office of a colleague, Mike Gans, and told him, ‘I’m going to work out the fundamental limits of communications between one volume of space and another, but I don’t know enough about antennas. Why not work with me and we can figure out the best antenna?’

“Mike gave me a really wonderful piece of advice. He said not to think of it in terms of a single antenna but as an antenna built from a lot of simple basic antennas much like describing a function in mathematics through a lot of basic functions. This
gave me an entirely different view of the problem. We now had a volume of space with many of these basic antennas communicating to another volume of space at the receiver, also with many antennas—like we had K antennas at the transmitter and K antennas at the receiver.

“The question then was what is the most that can be transmitted? With wireless you're often communicating through a very heavily scattered environment.

“What then do the laws of physics tell us for such an environment? With the transmit power and bandwidth both fixed, what is the best data rate we can achieve? As for bandwidth, you can separate the signals in bandwidth or you can, as we did, strive for more efficiency by having them all communicate in the same band. So we set the problem up. But the thing was I knew how to deal with it because of the experience I had dealing with those coupled pairs some 25 years earlier. Not only that, but when you deal with signals bouncing off buildings, streets, sidewalks, vehicles, people and whatever, what you're receiving is modeled as random rather than deterministic. What's important about that is the transmitter and receiver in many situations do not know what channel is going to be encountered. You send out a message and you don't know what is going to be encountered and somehow you have to deal with this randomness.

“I already knew back in the '60s how to solve the problem if the transmitter knew the channel. But now we went off in the new direction of suppose you don’t know it, suppose the channel is random. Mike Gans and I worked on that problem. His suggestion that the way to get at the best means of transmission was to look at the issue in terms of what you get from the two arrays of those fundamental antennas brought in the MIMO aspect.

“MIMO was already well known in the '50s. It referred to a circuit that had multiple inputs and multiple outputs. But here was a very special MIMO, one for wireless where the random-
ness of the propagation medium had a prominent role. I knew how to deal with those equations. I put them in a form appropriate for the wireless problem and plotted the results. That was a very special moment.

“Once we plotted the results we saw something very interesting. As we scaled upward in the sense of using more and more antennas, the capacity—that is the bit rate—for a fixed amount of power and a fixed amount of bandwidth went up linearly with the number of antennas. From the plots, we saw the capacities were spectacular. People were saying, ‘Oh, this is crazy, you know. You'll never be able to achieve this.’

“And here’s where Rich Gitlin who had given me the job in the first place came in. He and my department head Reinaldo Valenzuela could see the skepticism and so they said, ‘Let’s build it and see if we can get a significant fraction of what your calculations show.’

“We had a big problem even before we could talk about going into the lab and building it. We had uncovered this great capacity that had wonderful scaling properties. The capacity would keep growing the more antennas you stuff into the volume until they start getting too close to each other. Even though the processing at the receiver could theoretically make sense of the input, the processing that seemed necessary for a demonstration was getting totally out of hand. The complexity of making sense of what was received was exploding exponentially with the number of antennas. It seemed impossible to deal with it. That was a big obstacle—knowing what the bit rate could be but not knowing how to deal with the complexity of what was required to get close to that rate.

“You could call what happened next my Eureka! Moment. I have a Ph.D. in mathematics and the mathematician in me wasn’t satisfied with the formula we had. It was great for computing the results according to the laws of physics, but in terms of a nice closed form that a mathematician likes, it wasn’t very nice. It was kind of a big messy determinant. And it
seemed mum about how the data rate could be achieved.

“One day I noticed I could break the determinant down into a sum of terms and each one of them was something wireless engineers knew how to deal with. I was able to decompose the formula into the formulas for these constituent subsystems. It was where one transmitter antenna was received by one receiver antenna. Another transmit antenna was received by two and finally the Kth transmitter was by all K receiver antennas.

“Somehow the formula was deconstructing in this way. It was still a puzzle, though the decomposition was giving me a hint that the processing that went with it was manageable. And then finally it came to me, and that was the Eureka! Moment. The answer turned on viewing the radiated signals emanating from the transmit antennas along the diagonals in space-time instead of in a horizontal, vertical kind of arrangement. And when I did that, I got a formula for the sum of capacities that was exactly what the engineers could handle. You were no longer dealing in a world of exponential complexity. It was nice and simple compared to what it was before, but we wanted to make it simpler still.

“By that time I was working with some of the engineers who would actually build it, including a fellow named Glen Golden. He and I found a simpler way to do it. It didn’t have as great a capacity as before. But it offered an extremely substantial improvement and was much easier to build. Initially it was called Vertical BLAST.

“Where did the word BLAST come from? In a paper I wrote, I displayed the writing of a signal on the space-time diagonals. I called each diagonal a layer. And I called the whole arrangement layered space-time. So that gave me an LA, for layered, then ST for space-time. So you had these layers in space-time. Glen put Bell Labs in front of it and used the word “BLAST.” I said we couldn’t do that. But somehow it caught on, and there was no stopping it. And so it was called Bell Labs layered space-time, or BLAST, for short. In the initial experiments
exhibiting huge data rates we had transmitter and receiver arrays of 12 by 16 respectively.

“What I’ve given you is sort of a high level description of what happened. Specifically, what is being built today or how is it being applied in my cellphone? Well I can’t really speak to products, which continue to evolve. I can say that wireless MIMO certainly has had an important beneficial effect on the long-term evolution (LTE) of cellular systems. Indeed, in preparation for continuing demand for higher bit rates, for the last year, new base stations and terminals for LTE have been equipped with multiple antennas for MIMO. And wireless MIMO is playing a significant role in Wi-Fi systems as well.”

Gerard J. “Jerry” Foschini. Dr. Foschini received the B.S.E.E. degree from New Jersey Institute of Technology, the M.E.E. degree from NYU, and the Ph.D. degree in mathematics from Stevens Institute of Technology. He has been at Bell Laboratories for nearly 50 years, where he holds the position of Distinguished Inventor in the Wireless Research Laboratory at Crawford Hill, N.J. He has done extensive research on both point-to-point and network communication systems for wired, wireless and optical applications.

Foschini is best known for contributions to the science and technology of multiple-antenna wireless communications. He has taught at Princeton and Rutgers. He has published over 100 papers and holds 16 patents. A Fellow of IEEE and Bell Labs, he received the 2000 Bell Labs Inventor’s Award, and the 2002 Thomas Alva Edison Patent Award. He has also won the 2006 IEEE Eric E. Sumner Award, the 2008 NJIT Distinguished Alumnus Achievement Award and the 2008 IEEE Alexander Graham Bell Medal. He has been elected to the National Academy of Engineering. He also won the 2006 IEEE Eric E. Sumner Award, the 2008 IEEE Alexander Graham Bell Medal, and was elected to the National Academy of Engineering. In 2010 he received IEEE Communication Theory Committee Technical Achievement Award.
Paul Green

interviewed by David Hochfelder,
Oct. 15, 1999, Hawthorne, NY

“The pace of technological change has been steadily accelerating and continues to accelerate. If you were to plot technological progress, there’s probably a curve that starts fairly slowly after World War II building almost entirely on the technologies unearthed during the war. Then it accelerates and gets faster and faster to the point where now all sorts of things are doubling in months rather than years, such as bandwidth consumption, individual bit rate and the amount of information presented to users on CRT displays....I think what’s behind it is both the push of technology and the pull of demand. Technology push is the kind of thing the IEEE does when presiding over a technical innovation, but the consumer doing the pulling is apparently insatiable and there is an unlimited demand for more and more bandwidth and new services....The applications don’t even need to be defined. Give people a little bit more bandwidth and they’ll find something for which that bandwidth is not nearly enough.

“...wireless and fiber optics are the two big Cinderella technologies. Wireless goes everywhere but won’t do much when it gets there because of bandwidth limitations; whereas fibers can do almost anything you want when they get there because of their gigantic bandwidth and low attenuation, but, because they have to be strung on poles or run underground or whatever, they can’t go everywhere. These two mutually complementary technologies are making all the headlines and they’re defining where we’re going.

“I’ll tell you, this fiber optic world is the place to be. It’s the most astonishing thing imaginable. Here is this medium with a thousand times the bandwidth of the whole RF spectrum on the planet earth, where bandwidth is limited by oxygen
absorption. Each fiber has a thousand times that much bandwidth, and it’s all ours, it’s already installed and it’s all over the place. By getting more and more clever technologies to divide up that spectrum into different wavelengths there seems to be no limit as to what can be created.

“In a sense, spread spectrum is a real life exploitation of some ideas of a famous 1949 Shannon paper about the use of noise waveforms as an alphabet for encoding data. You could see in that paper, if you looked at it the right way, that it was really a spread spectrum system he was talking about.”

Paul Green. A native of North Carolina, Dr. Green earned his A.B. from the University of North Carolina in 1944, his M.S. from North Carolina State University in 1948, and his doctorate from the Massachusetts Institute of Technology in 1953. In his long and distinguished career he has received widespread recognition for his contributions to wireless communications and his pioneering work in planetary radar astronomy, and he was elected to the National Academy of Engineering in 1981. He served as President of ComSoc in 1992-1993 and has served on the editorial boards of several IEEE publications. Among his numerous awards, he was elected a Fellow of the IRE in 1962, received ComSoc’s Donald W. McLellan Meritorious Service Award in 1986, the Edwin Howard Armstrong Achievement Award in 1989, and the Simon Ramo Medal in 1991.

Irwin Jacobs

interviewed by David Morton, Oct. 29, 1999, San Diego, CA

“When you’re teaching you’re always trying to keep abreast of what is new, and the Transactions and Proceedings are an important part of that. In industry it’s even more important. It can be easy to get locked into a narrow view while working on a given project and keeping to a time and dollar schedule. If you don’t keep yourself looking around and make sure the whole company is open to new things you have problems. We always provided employees with paid memberships and so on to make sure they stayed active.”
Irwin Jacobs. Dr. Jacobs received his B.E.E. from Cornell University in 1956 and his M.S. and doctorate from the Massachusetts Institute of Technology in 1957 and 1959, respectively. He has received widespread recognition for his work in communications theory and code division multiple access techniques for wireless communications. He received the U.S. President's National Medal of Technology in 1994. In addition, he was selected as a Fellow of the IEEE in 1974, and received the IEEE Alexander Graham Bell Medal in 1995.

Amos Joel
interview conducted on Feb. 4 and 18, 1992 by William Aspray, South Orange, NJ

“We held the first of the international switching symposia…in 1957, where we had the world people come and also Bell System people….

Every three years since then we’ve held an international switching symposium…So I’m considered ‘the father of the International Switching Symposium,’ …But this is good because things have changed a lot, you see, since the days I started in switching, when nobody knew what the heck was going on. And here now these people want to hear about what’s going on. You’ve got comrades from all over the world. I gave a talk in Sweden in 1990, one of the introductory talks of the whole symposium. There were 3500 people in the auditorium and, I don’t know, another 500 outside some place else—they couldn’t fit them in—at the opening session. And I said, ‘As I look over this room, I just can’t believe it. Here you’ve got 3500 people interested in switching. The days when I started in switching, there wouldn’t be this many people in the whole world—in fact, there wouldn’t be even a tenth of this in the whole world—interested in switching and knowing what switching is all about. And now you’ve got this many people in one place.’

Unbelievable what’s happened and, you know, I’m glad that I had something to do with it.

“Well, the Communications Society was quite new when I took
it over. Of course I had been going through the ranks, you
know, in earlier jobs in what was then the Communications
Group, I guess it was called. And so I had been in charge of
technical activities and meetings and conferences. Most of this
work we were doing in those days in the Society was to get
our bylaws straightened out, and getting our manuals—various
kinds of manuals of practice, and things of that kind. …And
also the direction. We spent a lot of time—today as then—
looking at what technology should we be setting up commit-
tees for and looking at to stimulate conference papers and ses-
sions in various disciplines? Or even should we have special
workshops and so forth? During the early period of the
Communications Society we were setting up these procedures
for working this out, having workshops and how we’d pay for
them, and that kind of thing.”

Amos Joel. A native of Philadelphia, Mr. Joel received his B.S.E.E. and
M.S.E.E. degrees from the Massachusetts Institute of Technology in 1940 and
1942. In his long career at Bell Telephone Laboratories, Joel conducted far-
reaching work on telephone switching systems. In recognition of his work,
Joel was elected to the National Academy of Engineering in 1981, and he
received the National Medal of Technology in 1993. The IEEE has also recog-
nized his contributions by selecting him as a Fellow in 1962 and by awarding
him the Alexander Graham Bell Medal and the IEEE Medal of Honor in 1976
and 1992, respectively. Joel served as president of the Communications
Society in 1974-1975, and he received the Society’s Edwin Howard Armstrong
Achievement Award in 1972.

Richard Kirby

interviewed on Dec. 18, 1999, by David
Hochfelder, Seattle, WA

On the merger of the AIEE Communications
Division and the IRE PGCS, Hochfelder asked:
“Did the fact that you had one individual from
RCA and another individual from AT&T reflect
a sort of split between the wired and the wire-
less folks?”
Kirby: “Yes indeed. That was the main split, and this was the bringing together. And of course there was lots of foresight by some people who couldn't conceive of the two major societies existing separately into the future. In those days it was a new challenge. Thankfully, the leadership at that time—Leonard Abraham, the Chair of the AIEE Communications Division, and David Rau, the Chair of the Professional Group on Communication at IRE—wanted to make it work.

“IEEE has always been the primary source for the fundamental scientific literature that guided the future of telecommunications. Information theory has been especially noteworthy, but many aspects have been covered, including radio wave propagation. There was no big commercial market for studying radio wave propagation except for its underlying impact on systems. These contributions which were published in IEEE were always eventually used as references in international telecommunication work. Kernels were taken from many IEEE publications, and of course other Society publications, in making the ITU recommendations.

“At the same time IEEE publications and conferences were my main outlet and learning platform for the basic technology. The people I met through the IEEE are very important to the field. There is a certain synergy which builds in the technology and in careers all the way through. I owe the IEEE a lot for all of those contacts.”

Richard Kirby. Mr. Kirby's radiocommunications career spans over 50 years. He was first licensed as an amateur radio operator in 1938 and he served a stint as a Western Union telegrapher in 1940 and 1941. During World War II he served in the U.S. Army Signal Corps, specializing in radio propagation studies and frequency utilization, and after the war he was Assistant Radio Officer and frequency manager in Gen. Douglas MacArthur's Pacific Headquarters. Between 1948 and 1995 he was active in the U.S. National Bureau of Standards and the International Telecommunication Union (ITU) in radio propagation, technical standards, and frequency utilization. In 1974 he was elected Director of the ITU's CCIR (International Radiocommunication Consultative Committee). Mr. Kirby has also been quite active in the IEEE and the Communications Society. On the merger of the AIEE and IRE in 1964, the
leadership of both communication groups asked Kirby to organize and chair a new International Communication Conference, and he was instrumental in transforming the old IEEE Group on Communication Technology into the full-fledged IEEE Communications Society in 1971. ComSoc has recognized his achievements and leadership on several occasions, most notably by giving him the Donald W. McLellan Meritorious Service Award in 1979 and the Award for Public Service in 1990.

Robert W. Lucky

Electrical engineer, an oral history conducted in 1999 by David P. Hochfelder, IEEE History Center, Rutgers University, New Brunswick, NJ

“I went to Bell Labs because there were so many famous people there, and the environment there in the 1960s was very special. Shannon was supposed to be there, but I learned later on that he was not. He was listed in the phone book and his secretary would answer and say, ‘He’s not in today,’ but in truth he was at MIT and never came around Bell Labs as far as I know. There were a lot of people that to me were really famous, like Steve Rice who was famous for his work on the statistical theory of noise. He inspired me. He was a little guy, meek, modest, one of the nicest people you could imagine. He always wore a sweater even on the hot days of summer. John Pierce headed a lot of the research at that time and was a real famous guy.

“I was at a meeting just a year ago when the head of a big telecommunications laboratory said, ‘Putting voice on packets is an unnatural act.’ I think the same thing applies to putting voice on digits. It seems like an unnatural thing, because it expands the bandwidth by something like a factor of ten. You change a 3-kilohertz audio signal into a 64-kilobit digital stream, and expand the bandwidth by a factor of ten or twenty. You wonder why the hell you should do that, and the answer is because instead of having to go 3000 miles you only have to go a mile and a half—because then you regenerate it.
You can regenerate the digits; you cannot regenerate the analog. Instead of having to preserve that analog signal in the face of noise and distortion over 3000 miles, you only have to preserve it for approximately a mile and a half. Therefore you can put more voice channels in the same bandwidth, because you don’t have to go very far.

“I used to have a Bell Labs phone directory from 1956, and when I left Bell Labs I willed it to my successor Arun Netravali, so I don’t have it anymore. Those old phone books are hard to come by and I’m not even sure that they actually exist anymore. They’re very interesting because if you look at the directory of research in Bell Labs, essentially everybody was famous or became famous. It was a small research area, and from the distance of 25 or 30 years you can see that this person won a Nobel Prize, this person won the Medal of Honor, this person became president of this university, another of that university, this person made a famous invention, and so on. Everybody knew everybody else, and if you could find a good problem like the equalization problem you could make your mark a lot easier than you can today.”

“I made a good invention driving home one night while waiting at a red light in Red Bank, New Jersey. Sometimes I think about that when I’m stopped at that red light, because the idea just came to me in a flash. I don’t think very many inventions really happen that way, but this one did. I had the problem in my head of looking for a way to adapt this filter in a way to eliminate or minimize intersymbol interference. I didn’t have any algorithm where you could automatically adjust the filter to do this. It was a very difficult problem. The mathematics were very difficult, and I needed to find some algorithm that would automatically adjust an adaptive filter to do that minimization. The two problems, the mathematical problem and the problem of adjustment algorithms, came together in my mind for a hill climbing approach – to continue to adjust the knobs automatically to try to climb this hill to get to the top of
the hill where it would be minimized. It all came together with the realization that looking at the problem in a certain way there was only one hill. You didn't have to think there was a surface with a lot of little hills and that if you climbed one of them it would be the wrong one. In this particular problem there was only one hill, so if you adjusted the knobs to always go uphill you would eventually get to the top. This is what came to me while I was sitting at a red light. I also saw a really easy way of doing this adjustment so that you would always go up the hill—incredibly easy. I went home that night, and I just couldn't wait to go to work the next morning. I sat up all night just waiting to run in to work and tell people how to do this....

“We made those first adaptive equalizers out of relays. We had hundreds of relays on a big rack. Digital logic was not cheap. It was great, because we had a rack of equipment about six feet high that was the adaptive filter and made out of about a hundred relays. You’d turn on the modem and hear all these relays click-click. What would happen is that when you first turned it on the clicks would be very sporadic, click, click, click-click, click, click, click-click-click, click. This was because the equalizer would be wandering around in parameter space with no idea where it was going. Then suddenly it would get an idea and get hot on the track. All of a sudden you would hear click-click, click-click-click, click-click-click-click-click-click, and it would race up the hill. Then it would get to the top of the hill and go into an adaptive mode where it would just circle around the top of the hill trying to stay there, and the clicks would become sporadic again. It gave you a real feel for what was going on.

“One of the most memorable points in my career was the AT&T antitrust trial. I was on the stand for a couple of days. It was very interesting. The issue of Bell Labs didn’t receive a lot of press during the antitrust trial. My involvement was almost coincidental.... Saunders was the chief lawyer defending AT&T
in the antitrust trial. He was a very famous lawyer from Chicago hired from the outside by AT&T to head the defense of the case. I went in and met with Saunders in a hotel suite in Washington, and he had a legion of other lawyers with him. He started talking to me, and turned to his assistant lawyers and said, ‘We’re going to put him on the stand.’ The assistant lawyers were saying, ‘You can’t do that.’ Everyone was arguing about me, most saying that they couldn’t put me on the stand because it would be too dangerous. Saunders said, ‘No, I’m going to do it. I’ll take the responsibility. We’re going to wing this.’ As it turned out, I was the only witness that did not have a prepared written testimony in the whole antitrust trial.

Saunders did wing it. He put me on the stand and for two days we talked, with Judge Greene joining in. We talked about Bell Labs and the role that Bell Labs filled in science, and so on. Later I asked Ian Ross, who was then president of Bell Labs, why we alone were allowed to keep the name Bell Labs when the divestiture happened. I said, ‘Obviously Greene had a lot of respect for Bell Labs, because he allowed us to keep the name,’ and Ross said, ‘Don’t kid yourself. He just didn’t care.’

“When the old timers get together now, the ‘60s are regarded as the golden years at Bell Labs. This may be partly because people who were there in the ‘50s are not around so much anymore. In the ‘60s, there was an atmosphere that science was everything and that we would try to do the right thing. When asked how research was managed Bill Baker once replied, ‘We hire the best people and let them do their thing.’ That was what was done. The people who were famous there were respected for their scientific accomplishments. Whether or not they had any effect on commercial practices was never a consideration. There was respect for innovation, brilliance, mathematics, and there were artists in residence. Shannon was a prototypical person of that time period. He rode a unicycle in the halls, and after him Alan Berlekamp did the same thing. Ron Graham was a juggler and had a net in the top of his
office so he could pull it down, put it around his waist and juggle balls without hitting the floor.

“The Communications Society has always been a kind of fraternity house for communication engineers. The amazing thing about it to me—and I appreciate this more as I approach retirement myself—is I see retired people like Amos Joel continuing to come to the conferences of the Communications Society. I often marvel at that, that people have these associations. I think it happens in technical careers that you make your friends and your connections early in your career, and those serve you throughout your career regardless of what directions you move in.

“I don’t like to predict the future these days, because I think it’s unknowable. We’ve screwed up so many times and gone totally bankrupt by trying to do this. Starting with the Picturephone, ISDN, home information systems and video-on-demand, every vision of the future that has compelled the industry has been wrong. I think there’s a chaotic phenomenon at play here. A lot of people disagree with me, but I’m old enough and I can say what I think. There’s a chaotic element at play that makes some of the very important things unpredictable. I do think that technological advances are predictable, because they follow their own Moore’s Laws. Optics is following a Moore’s Law, wireless is following a Moore’s Law, and all those are amazingly predictable, but the big things—the World Wide Web and what people do with communication—are social discoveries that can go one way or the other. A butterfly flaps his wings in Brazil and you get a web, or not.”

**Robert W. Lucky.** Dr. Lucky joined AT&T Bell Labs in 1961, after receiving his B.S.E.E. (1957), M.S.E.E. (1959), and Ph.D. (1961) all from Purdue University. He has spent his entire career at Bell Labs and Bellcore, where he is currently Corporate Vice President, Applied Research. He is the author of about 70 technical publications and has received 11 patents. He is most noted for his work on data communications, particularly his invention of the adaptive equalizer, which is a key enabler for high-speed data modems today. He is the
author of *Principles of Data Communications; Silicon Dreams*, a popularized science book; and *Lucky Strikes Again*, a collection of his “Reflections” column he wrote for nearly two decades in *IEEE Spectrum*. Dr. Lucky has been a leader in IEEE and ComSoc for over three decades. In addition to serving as president of ComSoc in 1978-1979, he has also served as editor of the *Proceedings of the IEEE* (1974-1976), Vice President for Publications (1978-1979), and Executive Vice President (1981-1982). He has received widespread recognition for his engineering achievements, including election to the prestigious National Academy of Engineering and American Academy of Arts and Sciences. The IEEE awarded him the Centennial Medal in 1984 and the Edison Medal in 1995, and the Communications Society awarded him the Edwin Howard Armstrong Achievement Award in 1975.

John Mayo

Dec. 9, 1999, Chatham, NJ, by David Hochfelder

“Clearly, the greatest milestone in communications in the last 50 years was the creation of solid-state electronics based on the transistor. Other great milestones came as a consequence of the potential of solid-state electronics. This includes breakup of the telephone monopoly, the merging of communications and computing, recent restructuring of industry, and the increasing availability of advanced services and electronic commerce....The three killer technologies are solid-state electronics, photonics, and software. Software is the means for putting electronics to work. Photonics based on the solid-state laser and glass fibers is probably the second greatest creation of the last 50 years.

“It's been referred to as the ‘last mile problem.’ I like to think of it as the ‘last mile challenge.’ We have the technology to do it. Fiber, coaxial cable, and broadband radio can be brought into every home. Coaxial cable is already in a large fraction of homes. The challenge is to do this in a way that appeals to the customer and the community....We have powerful technolo-
gies that can bring whatever bandwidth is needed to the user’s fingertips, ears or eyes. We don’t have the economic, social, or political issues resolved completely. But, I must say we have made a lot of progress in recent years.

“We were fully prepared to market the Picturephone, and we introduced it at the 1964 World’s Fair. I had it on my desk for quite a few years. We used it internally. It added a new dimension to telecommunications, but it never really caught on somehow. If you asked how many picture phone calls did I make, I would say about 25 percent. I tended not to use the picture phone when I was in a hurry and just had a simple question to ask. It’s a generational thing too. If I’d had a picture phone all my life, I probably couldn’t have lived without it.

“After Information Age hardware and software technology matures, the frontier will move into how these systems and technologies are used for the good of society. Bold new frontiers will open up, and the Internet is at the leading edge. I was just out Christmas shopping and every time I got back in the car I told my wife, ‘The Internet is the answer.’”

John Mayo. Dr. Mayo received his B.S., M.S., and Ph.D. degrees from North Carolina State University in 1952, 1953, and 1955, respectively. He spent his entire career at AT&T Bell Laboratories, culminating in his becoming President in 1991. Upon his retirement in 1995 he became President Emeritus. Throughout his career at Bell Labs, he has played an important role in development of the digital technologies that have brought the world to the threshold of the Information Age. His early research was with the team that produced the first transistorized digital computer. He then worked on digital transmission technology, using the transistor to show the feasibility of the T-1 carrier, the first system for high speed digital transmission in the telephone plant. Dr. Mayo has been involved in many other Bell Labs projects, including the Telstar satellite and the 4ESS switching system. The IEEE has recognized his achievements by electing him as a Fellow and by awarding him the Alexander Graham Bell Medal shared in 1978 for his role in the development of the T-1 carrier system, and the IEEE Simon Ramo Medal for his work in digital communications.
Laurence Milstein
interviewed by David Hochfelder, Nov. 2, 1999, Atlantic City, NJ

“Seemingly, people have an insatiable demand for more and more, as well as easier and easier, access to communication systems. What I’ve found somewhat surprising about, for example, wireless communications is that while I could understand it catching on rapidly in underdeveloped countries (because they have no infrastructure), it has also caught on very rapidly in developed countries where an infrastructure does exist. I see people walking around with handsets and there’s a wired-line telephone two feet away.”

Laurence Milstein. Dr. Milstein received his B.S. from the City College of New York in 1964, and his M.S. and doctorate from the Polytechnic Institute of Brooklyn in 1966 and 1968, respectively. An expert in the fields of spread-spectrum and wireless communications, he has been a professor at the University of California, San Diego since 1976. In addition to his numerous publications, he has served in several editorial positions for IEEE journals, including Senior Editor and Editor-in-Chief of the IEEE Journal on Selected Areas in Communications (1993-1997). In addition, he has served as a member of the Board of Governors of both the Communications Society and Information Theory Society and as Vice President for Technical Affairs of ComSoc (1990-1991). Among his numerous professional honors, he was selected as a Fellow of the IEEE in 1985 and received the Edwin Howard Armstrong Achievement Award in 2000.

John O’Reilly
Interviewed by Alfred Rosenblatt, Feb. 8, 2012

“How did I come to be in communications? By chance. I started as a technician apprentice but was fortunate to be picked and sent off to college where I specialized in communications. Graduating in 1969 I worked on optical fiber communications (Charles Kao at Standard Telecommunication
Laboratory had written the first paper three or four years before) and then in 1972 I took up an academic appointment at the University of Essex. There were strong links between Essex and the Post Office Research Centre—this was before post and telecoms in the UK were separated. Toward the end of the 1970s, I was invited to join the Post Office Research Centre on attachment to help initiate a program on optical fibers for undersea systems.

“On returning to the university I continued my research and teaching and then in 1985 I was appointed Professor and Head of the School of Electronic Engineering Science at the University College of North Wales in Bangor. We developed our activities in communications engineering and I found myself interacting yet more strongly than previously with IEEE and other international organizations.

“I was then invited to serve on the communications subcommittee of the Science and Engineering Research Council (SERC—approximately the UK equivalent of the National Science Foundation), funding research and graduate students in universities. We initiated a special Integrated Multi-service Communication Networks (IMCN) program, which I chaired. It was not about better ways of getting a signal from A to B but about networks supporting a wide range of services, including those not yet thought of. New digital network technologies were emerging in telecommunications, but computer networking was progressing rapidly, too. This provided a rich environment for research on multi-service networking. Over time we progressed to the situation today, with widespread adoption of the Internet Protocol (IP) in telecommunications supporting a wide range of services—very much realizing the vision of the IMCN program.

“There was another very important development in telecommunications in the mid-’80s that I found myself involved in—and it wasn’t technology! I’m referring to liberalization: the breakup in the United States of the Bell System—with the
modified final judgment in 1984—and in the UK the privatization of British Telecom (BT) with our Telecommunications Act. Prior to that BT was a government-owned, virtual monopoly, telecommunications provider. With liberalization came a ‘duopoly’ in the UK with just two main fixed network providers. Five years later the UK government initiated a review of the telecommunications duopoly and I chaired one of the review committees. The desire was for a more competitive market—‘Competition and Choice’ was the title of the resultant government white paper; the next few years saw the number of telecommunications licenses burgeon.

“Meanwhile, having moved back and forth between academia and industry, I then took up the Chair of Telecommunications at University College London. In London I found myself asked to play a yet greater part in and around telecommunications regulation. I was appointed by the Secretary of State for Industry to chair the Network Interoperability Consultative Committee (NICC), an industry group with representatives from telecommunications operators, service providers, equipment suppliers, and government. This had been set up to advise the Director General of the Office of Telecommunications (Oftel), recognizing that formal coordination was needed in a liberalized telecommunications environment: the networks and services had to interoperate effectively.

“Yet access was predominantly through the BT network. Calls might get handed across to other licensed operators (OLOs) to do the long lines bit, but if it was a telephone call it would almost certainly get delivered at the far end via BT. Internet access was different. You would go in through BT, but then the call might be handed across to an OLO and thereby to an Internet service provider (ISP). The regulator had introduced a charge-sharing arrangement whereby a certain amount of the charge that BT levied for access had to be passed to the OLO. This was such that the OLOs could afford to hand a share to an ISP. That was attractive because if an ISP chose to be host-
ed by a network other than BT it attracted calls, and revenue, to the serving OLO. That was the origin of ‘Freeserve’—an Internet service offered as ‘free’ because there was no charge levied to the user by the ISP, which made its money through getting a share of the basic call charge.

“This triggered rapid growth in Internet use over a dial-up network designed for voice calls with an average duration of three minutes. Traffic volume was growing with Internet call durations more like 20 minutes. And that was before the introduction of FRIACO: Flat Rate Internet Access Call Origination, or unmetered Internet access, which was expected to increase call duration by another factor of 4. By around 2000 the network was under extreme stress; the 60 or so core switches in the BT network were running out of capacity. The position was serious: 25 percent of the port capacity of these core switches was already consumed with IP—and it was doubling every 10 months. Not a sustainable situation. So I was asked to chair a special ‘experts group’ for Oftel to look at this problem.

“The industry came together very well. The BT switches were swapped out to get much more capacity and we started the journey to strip off as much IP traffic as early as possible, get it away from the core switches and onto the parallel data networks we had at the time, although we’d only just started to roll out ADSL (asymmetric digital subscriber line).

“This brings us back to the IMCN, a network designed to support services with widely varying characteristics. What have we seen over the last 10 years? A rollout across the world of so-called next-generation networks (NGNs) essentially based on IP. In the UK this is under the purview of NICC, which I still chair albeit it’s now set up as a not-for-profit funded by the telecommunications industry. What we’ve achieved is captured in the phrase ‘pervasive technology’: technology you only notice when it’s not there. Or perhaps that should be ‘pervasive service availability’. It’s the progression to pervasiveness that to me is so significant in this long journey through
telecommunications; it’s become almost cultural.

“Of course, this is all standard stuff and you would find similar experiences around the world. But at the personal level, I’ve been privileged to be involved in communications research, in research policy and funding, and in telecommunications regulation and standards. It’s been a special time. No sector of modern life can function well without excellent information and communications technology—the vital enabler for a knowledge economy.

“Through all this the IEEE Communications Society played a seminal part, providing the forums where this stuff has been able to be advanced so rapidly. Now that may sound odd—advances occur in industry, don’t they? That’s not how I see it; advances occur between people. Interactions are what stimulate the next idea, the next advance, and so on. The global reach of the IEEE Communications Society, the way it reaches out to engineers and others, is so very important in that respect.

**John O’Reilly.** Sir John O’Reilly is Vice-Chancellor of Cranfield University, a position he has held since December 2006. Prior to joining Cranfield he was Chief Executive of the Engineering and Physical Sciences Research Council (EPSRC). He has held academic appointments at Essex, Bangor, and University College London (UCL), as well as positions in industry and government. He is currently Chairman of NICC (Standards) Ltd and a Director of the ERA Foundation Ltd.

A Chartered Engineer, he is a Fellow and member of Council of the Royal Academy of Engineering, an International Fellow of Académie Hassan II des Sciences et Techniques and of Academia das Ciencias de Lisbon, a former President of the Institution of Electrical Engineers and of EUREL, the Confederation of European Professional Electrical Engineering Societies. He holds honorary doctorates/fellowships from Essex, Bangor and UCL and is an Honorary Fellow of the Institution of Chemical Engineers. Widely published, with over 350 research papers and three books, he was awarded the J.J. Thomson Medal of the IEE for “distinguished contributions to electronic engineering”. He was awarded a knighthood for contributions to science in 2007.

In the wider international arena he chairs the President’s Academic Advisory Committee of Khalifa University and is a Board Member of A*STAR, the Agency for Science Technology and Research (A*STAR) in Singapore.
“When I finished my doctoral work, which was in 1966, it was a question of going back to industry or staying in academia. Brooklyn Poly made me an offer I could not refuse—not because of a lot money but because it was just an ego trip to stay in an institution where you got your degree and where you had such high opinions of the people who were there. Additionally, the communications group around Mischa Schwartz was rather unique....The interesting thing about the experience at Poly in the communications group is that it was an extremely active group. There were about seven full-time faculty members and many graduate students. Some did experimental work and others did theoretical work. We had a regular seminar that anybody with any semblance of permanence at Poly gave....Bell Labs was just around the corner practically, and many of their research staff gave courses at the school.....So, it was a period when you could get direct instruction from people who were very smart at thinking, ideas, formulations and mathematical models; it was first-rate.

“I think telecommunications is by far the fastest growing industry in the world. Number one, it is not localized...It is worldwide. Number two, because of the Internet, it has changed the paradigm of business and even human interaction.

“If I were to venture to make a prediction, I would say if the 1990s was the telecommunications decade, the next decade will be the decade of wireless telecommunications. Almost everything you can do with wires, you might be able to do with wireless. It is not going to be easy. It will take a lot of sophistication to overcome hostile channels. Wire lines, especially fiber optic channels, are very clean and very cooperative. But fiber optic lines are very expensive to deploy where you
are only going to reach a village of 40 people. In fact, it is even difficult to put it into a modern London or New York or Paris apartment building that is 50 to 100 years old. As a result, there is a lot of incentive to provide a mechanism for doing a lot of the things that were traditionally thought of as wired.

“That was a period of very rapid growth for the Communications Society. The late ‘80s had arrived by the time I had finished my presidency. In that intervening time, we increased from maybe 10 000 members to close to 40 000. I do not know what the number is now, but I read Tom Plevyak’s intentions of going to 100 000 and you can see why. This is the decade of telecommunications. The society sponsors over a score of conferences and publishes three archival journals and several magazines.

“We now have joint conferences with the Computer Society. We have Infocom, and various other joint workshops. We have now a journal that we publish jointly with the Computer Society and ACM. Some of those initiatives were started while I was still a vice president, so it took a while for them to jell.

“When I was president, we started opening offices overseas, and we hired our first executive director. Initially, we did not have an executive director. We would have three or four paid staff and we did not run our own conferences. It was the volunteers who made sure that they got a hotel and the staff helped out in negotiating. So, the Communications Society has come a very long way.

“I am still actively involved in the Society, but I am a firm believer in give the next generation a chance. There now has been a non-US, or non-Canadian President: Maurizio Decina. But I think of Maurizio not as an Italian, but as a fine communications engineer. The Society is deliberately transnational and the leadership reflects that.”

Raymond Pickholtz. A native of New York City, Prof. Pickholtz received his B.E.E and M.E.E degrees from the City College of New York in 1954 and 1958 and his doctorate from the Polytechnic Institute of Brooklyn in 1966. He
currently teaches at George Washington University and has held a variety of positions in academia and the business world. He has published scores of papers and holds six U.S. patents. He is a Fellow of the IEEE and of the American Association for the Advancement of Science, and has served as Vice President (1987) and President (1990-1991) of the IEEE Communications Society. Among his honors, he has received the IEEE Centennial Medal in 1984 and the Donald W. McLellan Meritorious Service Award in 1994.

John R. Pierce

*Electrical Engineer, an oral history conducted in 1992 by Andrew Goldstein, IEEE History Center, Rutgers University, New Brunswick, NJ*

On Bell Labs: “It was a benevolent autocracy. I was one of the autocrats. And people were delighted when people did good work and praised them and encouraged them. They didn’t so much tell them off if they weren’t doing good work, but they tried to see if they couldn’t help them to do good work.”

**John R. Pierce.** Dr. Pierce received his Ph.D. degree in 1936 from the California Institute of Technology and then joined Bell Laboratories where he remained until returning in 1971 to Caltech as Professor of Engineering. As Executive Director, Research Communications Sciences Division at Bell Laboratories, Dr. Pierce was in charge of work on mathematics and statistics, speech and hearing, behavioral science, electronics, radio and guided waves. His chief work was in electron devices, especially traveling-wave tubes, microwaves, and various aspects of communication. He proposed unmanned passive and active communication satellites in 1954. The Echo I satellite embodied his ideas; he was instrumental in initiating the Echo program and the East-Coast ground station was constructed in his department. Telstar resulted from satellite work he had initiated. At Caltech he has been concerned with energy consumption in personal transportation, auditory perception, satellite systems, synthetic aperture radar, and problems in the general area of communication. Dr. Pierce is the holder of more than 90 patents, and author of 14 technical books and over 200 technical or semitechnical articles. He has received many awards including the IEEE Medal of Honor in 1975 and, the Founders Award of the National Academy of Engineering, in 1977. His many professional responsibilities have included serving on the President’s Science Advisory Committee.
Don Schilling

interviewed by David Hochfelder,
on Sept. 7, 1999, Sands Point, NY

“My role in the Communications Society goes back to about 1968….In 1969 I became the Publishing Editor of the Transactions Editorial Board and Ran Slayton was the Editorial Manager. The vice chairman was Dick Kirby, and he became chairman in 1970. It was Dick Kirby who asked me to take over the job. Then I became the Editorial Manager in 1970, a year later. When I took over I appointed all of the editors to serve with me and to help me. I changed the policy of ComSoc (it was called CommTech at that time) to be very responsive to the authors. Indeed the authors then started getting their reviews back within a month. I really laid down the law….I initiated the ComSoc magazine, and the first magazine was in 1973. It was a very small magazine at the time. Al Culbertson was the president. Steve Weinstein, was foreign abstract editor and later was editor of the magazine and helped significantly to ‘grow’ the magazine.

“The original idea of the magazine was to produce articles without equations that the average engineer could understand. The people on the Board of Governors of ComSoc told me the only way that they would give me more money for my budget was if I produced a magazine that they could understand—not just for the ‘elite.’ Indeed, the Transactions is for the researchers. We put out two issues of the Transactions, one a regular issue covering all topics, and one dealing with a particular area in selected topics. Around 1980 I decided we should have a separate journal for these ‘selected topics,’ and we did that in the journal, JSAC….As President in 1981, I set up several conferences, MILCOM and Infocom.

“ComTech was really telephone-company oriented: it was run by people from the telephone company and it had everything
to do with the telephone company. The ComTech and subsequently the ComSoc technical committees, editorial board, and conference board were initially ‘telephone’ oriented....A small division of ComSoc dealt with wireless, but it was not given much substance. It was really put in a class of telemetry. As time evolved, this evolved. More university people became involved and their research was supported by the military and included spread spectrum. It was a fight, like any kind of change is a fight. But it did evolve and it went more and more towards the wireless end.

“Particularly while I was editor and through my presidency, we tried to be in the forefront of all changes. Any change that looked hot and promising we put an editor in charge and we created a special issue and gave special attention to it....I think that is why the membership has grown tremendously. During the time that as I was editor through the time that I was president, the membership rose to about 35 000 members. Now it is really very large, over 50 000. We have become a major organization and an international organization....The combination of workshops, big conferences, the Transactions and magazine have really made ComSoc what it is today—the international communications organization.”

**Don Schilling.** Dr. Schilling received his undergraduate degree in electrical engineering from the City College of New York in 1956, his M.S.E.E. from Columbia University in 1958, and his doctorate from the Polytechnic Institute of Brooklyn in 1962. He has taught at both the Polytechnic Institute of Brooklyn and the City College of New York, and has held a variety of private-sector positions to develop commercial applications of spread-spectrum technology. Dr. Schilling has written or co-authored 12 textbooks, over 200 papers, and 50 patents. He has been very active in the IEEE and the Communications Society. He helped start the Society’s *IEEE Communications Magazine* and the *IEEE Journal on Selected Areas in Communications* (JSAC) and served as Editor of the *Transactions on Communications* and Director of Publications (1968-1978). He was President of the IEEE Communications Society from 1980-1981 and was a member of the IEEE Board of Directors from 1982-1983. Among his honors, he is a Fellow of the IEEE and has received the Donald W. McLellan Meritorious Service Award in 1978 and the Edwin Howard Armstrong Achievement Award in 1998.
“How I finally made the switch from Sperry to teaching is very interesting. On my plane coming back from Chicago from the National Electronics Conference, the year after I got my doctorate, was Ernst Weber, one of my teachers at Brooklyn Poly, who was a pioneer in the field of electrical engineering....So, I see him on the plane. I go over to him and say, ‘Dr. Weber, do you happen to have any openings?’ It turned out he had, so he offered me a job at Brooklyn Poly in September of 1952 as assistant professor.

“Nowadays, when people complain about one course that they have to teach I had 18 contact hours. I had two three-hour lectures and twelve hours of laboratory. I said to myself, ‘Gee, what do I do with all the free time that I’ve got?’ Because I was used to working a 40-hour week at Sperry and maybe overtime as well. One of my colleagues that joined the same time as I did, Athanasius Papoulis, went on to become very well-known in the field. He’s published many books. We even shared a desk. They had no room for us when we first joined.....

“I had a number of very fine doctoral students at the time: Don Schilling, Ray Pickholtz, Bob Boorstyn, Ken Clark, Don Hess, and a number of others...

“I am very proud of one incident while an IEEE Director. People have forgotten this by now, but I’m the guy who proposed the idea of President-Elect. It’s not mentioned anywhere. I’m not sure that anybody would recognize it. But when I first became a Director, it became apparent to me that it was difficult to be a President for one year. You come and go and that’s it. You need some training. I knew other organi-
izations had that, like the AAAS of which I was a member. So I proposed that at one of our meetings. We instituted the idea of President-elect and that was accepted. So now a guy comes in, is trained for a year as President, and then is able to go on as President the year after.

“In 1984-’85, I was elected president of ComSoc....I was president for two years. One of our meetings was held abroad in Amsterdam. I think it might have been one of the first meetings we held abroad and that worked out very nicely. We had a couple of anecdotes. In Amsterdam, they threw out the red carpet—they opened up the city for us...The queen came down to greet us. My wife tells a funny story where she came into this room where the ComSoc governing group was gathered to meet with her, and somebody had said to us, ‘Number one, be careful how you greet her—she is a queen, remember. Number two, just these people here, nobody else.’ So I’m very different, I guess. She walks in, I shook her hand rather than bowing or something like that. In America, we don’t do things like that, right? She’s a queen—so what? Secondly, I beckoned for my wife, ‘Come on. Come meet the queen.’ I wasn’t supposed to do that by protocol either. So what! Why can’t my wife meet the queen? Anyway, it was very nice.

“I see more and more the need for bringing societies together. The communications field now spans many organizations. Steve Weinstein, who was president of ComSoc a couple of years ago, has done a lot of this. He tried to bring different societies together, and was very successful. When I was president of ComSoc I tried bringing the Communications and Computer Societies together in the area of computer communications.

“I don’t like to predict things, because I am always wrong! I can’t tell what’s going to happen. But clearly, the Internet is driving the show now. That and wireless. Those are the two major activities. Of course, Internet is moving now to the wireless domain as well too.... Wireless terminals will be expected
to carry, using limited bandwidth, multimedia traffic, which means video, voice, and images from the Internet. Now, how do you do this with battery-operated devices which have limited power? Devices of this type are already starting to appear. More are expected. There is currently a lot of work going on in this area. I find wireless networking incorporating such devices one of the major engineering challenges now.

“In 1973, I left Poly to join Columbia as a professor of electrical engineering and computer science. At Columbia, my colleague Tom Stern and I organized extensive academic and research programs in telecommunications focused on computer networking. In 1984, the National Science Foundation announced a competitive program to set up interdisciplinary Engineering Research Centers designed to maintain competitiveness in areas of national concern. We submitted a proposal for major funding, one of 42 proposals submitted from throughout the United States. Ours was one of seven approved, the only one in the field of telecom.

“The Center for Telecommunications Research, founded in 1985, received major NSF support for 11 years. At its peak, CTR supported 85 graduate students and close to 30 faculty from a number of Columbia departments. Research covered the gamut from electronic and optical devices to software to systems. It was a tremendous learning experience for all of us, particularly when we carried out inter-disciplinary activities across departments. CTR was the forerunner of many such interdisciplinary academic telecom research centers throughout the world. Industry was heavily involved in CTR activities from the beginning through financial support and service by engineers on an Industrial Advisory Board, which met regularly to provide guidance to research activities.

“I retired at the end of the 1996 academic year, but have continued to teach and carry out research, although on a reduced scale. Most recently, I’ve been involved in research on the history of telecom, writing a number of papers on the subject,
and editing the History column of *IEEE Communications Magazine* from 2008-2010."

**Mischa Schwartz.** Prof. Schwartz received his B.E.E. degree from The Cooper Union in 1947, the M.E.E. degree from the Polytechnic Institute of Brooklyn in 1949, and his doctorate in Applied Physics from Harvard in 1951. During his distinguished career he made significant advances in the fields of communication theory and computer networks. He is currently Charles Batchelor Professor Emeritus at Columbia. He authored the popular undergraduate textbook *Information Transmission, Modulation, and Noise*. First published in 1959, the book has gone through four editions and sold over 150,000 copies. He has written or co-authored six other texts in networking, signal processing and, most recently, mobile wireless communications.

In addition to his teaching, research, and consulting activities, Dr. Schwartz has been very active in IEEE affairs. He served on the committee that established ComSoc in the early 1970s, was on the Board of Governors for many years, and was elected Vice President and then President (1984-1985). During 1978-79, he served as an IEEE Director. He received the IEEE Education Medal in 1984, and was chosen for membership in the National Academy of Engineering in 1992.

ComSoc recognized his engineering achievements with its Edwin Howard Armstrong Achievement Award in 1994. He is proudest, however, of the fact that the 1984 centennial issue of *IEEE Spectrum* listed him among the top 10 most outstanding electrical engineering educators since 1884. Of his 51 doctoral students, two have gone on to serve as ComSoc presidents, one has received the (U.S.) President's Medal of Honor in Technology, at least two are members of the National Academy of Engineering, and a substantial number have been elected IEEE Fellows.

**Jack Sipress**

*interviewed by David Hochfelder, on Sept. 10, 1999 at New Brunswick, NJ*

“I arrived in Brooklyn Poly in 1952….We had some very, very outstanding students. Most of the students in those days, as it still is at Brooklyn Poly, were first-generation students. Most of Brooklyn Poly continues to be that way; only the faces have changed. Likewise I was a first-generation immigrant. I was able to get a New York Regents scholarship, which enabled me to come up with the funds to pay the tuition to
Brooklyn Poly so I wouldn’t have to go to City College…. They had a very powerful EE department. It was the highest rated in the country, and they turned out some very, very good students.”

**Jack M. Sipress.** Dr. Sipress received his bachelor, master, and doctorate degrees from the Polytechnic Institute of Brooklyn in 1956, 1957, and 1961, respectively. In 1958 he joined AT&T Bell Laboratories, where he spent most of his career. His most significant technical accomplishment was in the field of submarine fiber optic cables, and he provided the technical leadership for the lightwave systems installed in 1988 to span the Atlantic and Pacific oceans. In addition to his technical accomplishments, Dr. Sipress has been active in the IEEE, serving as Chair of the IEEE Technical Fields Award Council and as a member of the IEEE Awards Board, ComSoc Board of Governors, and the Publications Board. Dr. Sipress has received widespread recognition for his achievements, including the Edwin Howard Armstrong Achievement Award in 1988, the IEEE Award in International Communication in 1991, and the IEEE Simon Ramo Medal in 1994.

**Richard Snelling**

*interviewed by David Morton, April 25, 2000, Atlanta, GA*

“My first professional activity with the AIEE was in 1956….All of the Bell System was AIEE. The only people who were in IRE were electronics types. The AIEE was principally composed of the power industry and the telephone industry. AT&T had been a very strong supporter of AIEE. In fact, there was quite a lot of rivalry between the two….So the wedding of those two was not particularly easy, by any stretch of the imagination. There were some people who had been in both organizations, but they were rare.

“One of the notions that I had over the years—and it goes back to some of the original information theory—was that landline is good for bulk and reliability, and wireless is good for flexibility and portability. Just that simple. You need a combination of the two to do an overall telecommunication job.”

**Richard Snelling.** Mr. Snelling received his B.E. degree from the University
Oral History of Florida, and became an IEEE Fellow in 1992 for his contributions to digital switching and fiber optic transmission systems. He was an active member of the Communications Society.

Keiji Tachikawa

_interviewed by David Hochfelder, Sept. 11, 1999, New York City_

“Fiber optics was introduced in 1981, and currently most long distance telephone services use fiber optics. The construction, installation and implementation of fiber optics in telecommunications is happening in the 1990s. Currently the number of telephone subscribers in Japan is over 60 million. Another important technology in data transmission systems is microwave technology. This technology was first introduced in the late ‘40s, and in the ‘70s it became digitized. Currently most of this technology being introduced is digital microwave. In the 1980s additional mobile telecommunications were introduced, which has attracted a lot of attention and is reaching its peak in the ‘90s.

“In terms of mobile telecommunications, the first cellular type of portable or automobile telephone was introduced in 1979, and Japan was one of the first countries to introduce this. I think it was a little bit earlier than the United States, where it was introduced about 1980-81. In 1987 the current form of portable or cellular telephone was introduced, and from 1993 onward the digital cellular phone has become popular. Around this time the number of subscribers increased dramatically, and now the number of cellular phone subscribers in Japan is over 46 million. In the past three years we have had an increase of more than 10 million subscribers each year. Another important technology that had a fairly early introduction in Japan is satellite communications. Unfortunately, the land area in Japan is rather limited, so that satellite communications is not very use-
It is used mainly for communication in case of disaster. Two things that Japanese technology and research and development have contributed are microwave satellite technology and fiber optics.

“I was involved in the creation of future visions for NTT on several occasions. The first time was in 1979 when NTT came up with the vision for the Integrated Services Digital Network (ISDN) in Japan. ISDN was part of the ITU vision, and Japan was one of the earlier countries to get involved in this process. At that time the plan was laid out for development of ISDN by the year 2000, and a tremendous effort was made for early introduction of ISDN. Actual introduction was made in 1984. I think that now the whole world is going in the direction of ISDN. Perhaps the highest penetration of ISDN now is in Germany, and I believe the second highest penetration is in Japan. About 4 million subscribers have ISDN in Japan…. In the 1990s much effort has been made to promote and develop multimedia. That was my second involvement with the creation of a long-term vision.

“I have become involved in a third vision since joining NTT DoCoMo, which is something that was worked on for two years before its completion in March of this year. This is a vision for mobile communications for 2010 which we call MAGIC. The letters stand for the five pillars or concepts of the vision. M stands for ‘Mobile multimedia’; A stands for ‘Any way, anywhere, anyone’; G stands for ‘Global mobility support’; I stands for ‘Integrated wireless solution’; and C stands for ‘Customized personal service.’ These are the things that will be needed for the development of mobile communications in the future. Being a part of the creation of these three visions are perhaps the most unique features of my career.

“A fourth vision is the introduction of competition in Japanese telecommunications. I got involved in that as well. The study of this possibility started in 1981, but competition was not introduced into the Japanese market until 1985. At the same
time, the public telecommunications entity was privatized. The splitting of AT&T in 1984 was a strong influence. I was also involved in the creation of a new legal structure and system for this new competitive environment, and I was involved in the reorganization of NTT after privatization. These are some of the more interesting experiences in my career.

“I have been a member of the IEEE since 1965, and became a senior member in 1987. When I was involved in research and development, I participated in IEEE activities and utilized IEEE resources to get information. From 1975 to ‘78 I was in New York City, and during that time I actively participated in various IEEE meetings and academic conferences. At that time Japan was still basically catching up with the rest of the world, and close observation of IEEE activities was very important for Japan…. The role of IEEE in standardization is important because when these standardization activities are carried out in international bodies like ITU it takes so much time that often the outcome is not really appropriate for the current situation. Another factor we cannot really ignore is the political influence in the activities of international bodies, whereas something like the IEEE might not be so burdened. We are hoping that the IEEE will come to have more influence in terms of standardization activities.

“I believe that wire line and wireless will coexist. First of all, the wireless spectrum is finite, so we really cannot cover everything with wireless. The fixed line with fiber optics has a tremendous advantage in terms of high-speed data transmission…. I think users will utilize these two modalities for different purposes. For things like high-speed transmission and television they will probably use the wire line, whereas with voice transmission wireless might be more popular. This is not the end of the road. In a fourth-generation system they are talking about a 20-Mb/s transmission speed for the wire line. The target for implementation of this is around the year 2010. In the year 2001 when we introduce the system it will be at 2 Mb/s,
and around the year 2020 it will reach 20. I believe that there is a tremendous changeover in technology every 10 years in mobile communications. In other words, the first generation, 1979-80, was analog; 1992-93 was digital; 2001 will be the third generation; and 2010 will be the fourth generation. In that sense the year 2020 will be the fifth generation. We will have to start studying the fifth generation soon.

“On this occasion of the 50th Anniversary of the IEEE, its past achievements have already been outlined. I would like to see the organization make continuous progress in the next 50 years as well.”

Keiji Tachikawa. A leader in the Japanese telecommunications industry, Dr. Tachikawa is currently President and CEO of NTT Mobile Communications Network Inc. He received his B.S. and doctorate from University of Tokyo in 1962 and 1982, respectively, and his M.B.A. from the Massachusetts Institute of Technology in 1978. He is the author of numerous technical books, articles, and patents in the field of wireless technology, and is a Senior Member of the IEEE.

Andrew Viterbi

interviewed by David Morton, Oct. 29, 1999,
San Diego, CA

“What really gave everything a boost, both for the military and clearly for the space program, was satellite communication. Now we were looking for efficiency in systems that could transmit from very far away. These were geosynchronous ranges, which meant 40 000 kilometers. All the technology for the military spread spectrum became even more important because the geosynchronous satellite is a sitting duck and anybody could jam it, whereas on the ground the antenna can often be positioned to avoid being jammed. Commercial satellites, which in the very beginning were analog, were already using digital technology by the ‘70s. Digital communications got a big boost from satellite communication.
Some of the heritage from the digital satellite systems of the ‘60s and ‘70s into even some cellular systems in the ‘90s can be traced to that.

“In the spring of 1985 Irwin Jacobs and I quit within a week of each other. After taking it easy for all of two or three months, we started Qualcomm in July of ‘85. A number of people immediately joined us. We didn’t know exactly what we would do.

“I’m a member of Clinton’s Presidential Information Technology Advisory Committee, and we just put out a report six months ago urging the government to continue doing basic R&D. Not application oriented research, but fundamental research. There’s no one to develop the transistor equivalent of the 21st century. Research that brought ARPANET and the Shannon Information Theory fueled our information economy, which is the fastest growing segment of our economy. Fundamental research also developed the transistor and radio astronomy. This kind of research is not going to be carried on by industry because shareholders won’t allow it. GE and RCA gave up on pure research 30 years ago. Bell Labs and IBM gave up on pure research about five to ten years ago. None of them are doing really basic research. If they are, it’s minuscule…. In the past AT&T could afford to keep Bell Labs doing pure research because they were a monopoly. There was a lot of foresight there, and there were no constraints.”

Andrew Viterbi. A co-founder of QUALCOMM Incorporated. He has spent equal portions of his career in industry, having also co-founded a previous company, and in academia as a professor of engineering first at UCLA and then at UCSD, at which he is now Professor Emeritus. His principal research contribution, the Viterbi Algorithm, is used in most digital cellular phones and digital satellite receivers, as well as in such diverse fields as magnetic recording, speech recognition, and DNA sequence analysis. In recent years he has concentrated his efforts on establishing CDMA as the multiple access technology of choice for cellular telephony and wireless data communication. He has received numerous honors both in the United States and internationally. Among these are three honorary doctorates and memberships in both the National Academy of Engineering and the National Academy of Sciences. He currently serves on the President’s Information Technology Advisory Committee.
Major Contributors to Communications History
IEEE Awards

Alexander Graham Bell Medal

2012 – Leonard Kleinrock: Packet-Switching Networks
2011 – Arogyaswami J. Paulraj: Multiantenna Technology
2010 – John M. Cioffi: Modem Technology
2008 – Gerard J. Foschini: Multiple Antenna Wireless Communications
2007 – Norman Abramson: Data Networks
2006 – John M. Wozencraft: Digital Communications
2005 – Jim K. Omura: Communications Theory
2003 – Joachim Hagenauer: Soft Decoding
2002 – Tsuneo Nakahara: Fiber Optics
2000 – Vladimir A. Kotel’nikov: Signal Theory
1999 – David G. Messerschmitt: Communications Theory
1998 – Richard E. Blahut: Coding
1997 – Vinton G. Cerf, Robert E. Kahn: Packet Networks
1996 – Tadahiro Sekimoto: Digital Communications
1995 – Irwin M. Jacobs: CDMA Commercialization
1994 – Hiroshi Inose: Time Slot Interchange
1993 – Donald C. Cox: Mobile Communications
1992 – James L. Massey: Coding
1990 – Paul Baran: Packet Communications
1989 – Gerald R. Ash, Billy B. Oliver: Dynamic Nonhierarchical Routing
1988 – Robert M. Metcalfe: Ethernet
1985 – Charles K. Kao: Optical Waveguides
1984 – Andrew J. Viterbi: Coding Theory

Note: Awards may not be presented every year.
1983 – Stephen O. Rice: Noise Theory
1982 – Harold A. Rosen: Satellite Communications
1981 – David Slepian: Information Theory
1980 – Richard R. Hough: Telephone Networks
1979 – Christian Jacobaeus: Switching
1977 – Eberhard Rechtin: Space Communications
1976 – Amos E. Joel, Jr., William Kiester, Raymond W. Ketchledge: Electronic Switching

**Medal of Honor** (Selected)

2010 – Andrew J. Viterbi: Communications Technology
2004 – Tadahiro Sekimoto: Satellite Communications
2001 – Herwig Kogelnik: Lightwave Communications
1996 – Robert M. Metcalfe: Ethernet
1977 – H. Earle Vaughan: Digital Switching
1975 – John R. Pierce: Satellite Communications
1966 – Claude E. Shannon: Information Theory
1960 – Harry Nyquist: Communications Theory
1955 – H. T. Friis: Radio Research

**Edison Medal** (Selected)

2009 – Tingye Li: Optical Fiber Communications
1995 – Robert W. Lucky: Automatic Equalization
1992 – G. David Forney: Coding

**Founders Medal** (Selected)

1992 – David Packard: Instrumentation
1991 – Irwin Dorros: Intelligent Networks

**Hamming Medal** (Selected)

2003 – Claude Berrou and Alain Glavieux: Turbo Codes
1995 – Jacob Ziv: Coding
1994 – Gottfried Ungerboeck: Coding
1989 – Irving S. Reed: Coding

Simon Ramo Medal (Selected)

2007 – Victor B. Lawrence: Data Communications Networks
1996 – Donald J. Leonard: SPC Networks
1991 – Paul E. Green, Jr.: Multi-path, Optical Communication

IEEE Communications Society Awards

Edwin Howard Armstrong Achievement Award

2009 – H. Vincent Poor
2008 – Sergio Benedetto
2007 – Norman C. Beaulieu
2006 – Larry J. Greenstein
2004 – Hussein Mouftah
2003 – Hikmet Sari
2002 – Michael B. Pursley
2001 – Ezio Biglieri
2000 – Laurence B. Milstein
1999 – Al Gross
1998 – Donald L. Schilling
1997 – Marvin K. Simon
1996 – Joachim Hagenauer
1995 – Adam Lender
1994 – Mischa Schwartz
1993 – Paul Schumate
1992 – Hisashi Kaneko
1991 – Burton R. Saltzberg
1990 – Jack K. Wolf
1989 – Paul E. Green, Jr.
Awards & Recognitions

1988 – Jack M. Sipress
1987 – Paul Baran
1986 – Gottfried Ungerboeck
1985 – Robert Charles Terreault
1984 – Bob O. Evans
1982 – Tadahiro Sekimoto
1981 – Robert Price
1980 – Frederick T. Andrews
1979 – Arthur A. Collins
1978 – Andre Pinet
1977 – William H.C. Higgins
1976 – Walter B. Morrow
1975 – Robert W. Lucky
1974 – Frank D. Reese
1973 – S. G. Lutz, C.E. Shannon
1972 – Amos E. Joel, Jr.
1971 – A.C. Dickieson
1970 – R.K. Hellmann
1969 – D.S. Rau
1968 – P.G. Edwards
1967 – J.Z. Millar
1966 – W.T. Rea
1965 – A.G. Kanoian
1963 – I.S. Coggeshall
1962 – A.G. Clavier
1961 – E.I. Green
1959 – K. Bullington
1958 – H.H. Beverage

Donald W. McLellan Meritorious Service Award

2011 – Stefano Galli
2009 – Nim K. Cheung
2008 – Shri K. Goyal
2007 – Roberto Saracco
2006 – Alexander D. Gelman
2005 – Mark J. Karol
2004 – Harvey A. Freeman
2000 – Douglas N. Zuckerman
1998 – Roberto de Marca
1997 – Curtis A. Siller
1995 – Thomas J. Plevyak
1994 – Raymond L. Pickholtz
1993 – Joseph L. LoCicero
1992 – Frederick T. Andrews
1991 – Celia Desmond, Jack C. McDonald
1990 – Richard P. Skillen
1989 – William H. Tranter
1988 – Richard A. Alston, John Limb
1987 – Noriyoshi Kuroyanagi
1986 – Paul E. Green, Jr., John S. Ryan
1985 – M.R. Aaron, Bruce DeMaeyer
1983 – Allen Gersho, Adam Lender, Stephen Weinstein
1980 – Edward J. Glenner
1979 – Richard Kirby
1978 – Donald L. Schilling
1977 – David Solomon
1976 – Ran Slayton, Anthony B. Giordano

Award for Public Service in the Field of Telecommunications

2011 – Sasi Pilacheri Meethal
2009 – David Falconer
2007 – Sam Pitroda
2000 – David D. Clark
1993 – George E. Brown, Jr.
1992 – Mansoor Shafi
1990 – Richard C. Kirby
1987 – Hubert Zimmerman
1984 – Mohammed Mili
1982 – Joseph R. Fogarty
1981 – Henry Geller
1978 – Alphonse Ouimet
1977 – Benjamin L. Hooks
1976 – Senator J.O. Pastore

Harold Sobol Award for Exemplary Service to Meetings & Conferences (formerly the Meetings & Conferences Exemplary Service Award)

2011 – Khaled B. Letaief
2010 – Abbas Jamalipour
2009 – Heinrich Stuttgen
2008 – J. Roberto B. de Marca
2007 – Raouf Boutaba
2006 – Paul R. Hartmann
2005 – Jaafar M.H. Elmirghani
2003 – Doug Lattner
2002 – Douglas N. Zuckerman
2001 – Harvey A. Freeman
2000 – Ross C. Anderson

Joseph LoCicero Award for Exemplary Service to Publications (formerly the Publications Exemplary Service Award)

2011 – Vijay Bhargava
2010 – Larry Greenstein
2009 – Raouf Boutaba
2008 – Andrzej Jajszczyk
2007 – Khaled Ben Letaief
2006 – James F. Kurose
2005 – Yeheskel (Zeke) Bar-Ness
2004 – Desmond P. Taylor
2002 – Curtis A. Siller
2001 – William H. Tranter
1999 – Joseph L. LoCicero
1998 – Paul E. Green, Jr.

**Distinguished Industry Leader Award**

2011 – Suk-Chae Lee
2009 – Kaoru Yano
2007 – Arun Sarin
2006 – Henry Samueli
2004 – Ki Tae Lee
2004 – Irwin M. Jacobs
2003 – Jorma Ollila
2002 – John T. Chambers
2001 – Keiji Tachikawa

**Industrial Innovation Award**

2011 – Lawrence Bernstein
2009 – David Belanger

**IEEE Communications Society/KICS* Exemplary Global Service Award**

2011 – J. Roberto B. DeMarca
2010 – Roberto Saracco
2009 – Tomonori Aoyama
2008 – Maurizio Decina
2007 – Stephen B. Weinstein

* Korean Information and Communications Society
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<td>AT&amp;T cable-laying ship <em>Long Lines</em></td>
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The last 60 years has witnessed the creation of extraordinary communications technologies, including radar, television, the digital telephone network, optical communications, the Internet and cellular mobile telephony. These efforts reflect a never-ending drive to build new generations of technology upon earlier ones.

In this small volume, the reader will find a brief synopsis of historical developments in communications technology and in the creation of the IEEE Communications Society, which generates and disseminates much of the knowledge on which the technology is based. Seminal contributors tell the stories of their experiences, but they are only a fraction of the many scientists and engineers responsible for today's powerful global communications infrastructure.