INTRODUCTION

The History Column this month is the second in a series devoted to the history of our field. It has become a truism that to better understand the present and future, it is important to look back to the past. Does this hold true in a fast-changing field such as ours? I submit that it does, for a number of reasons. First, we have all seen examples of "re-inventing the wheel." Knowing past technological developments could save us lots of time and effort in coming up with solutions to problems already solved. Second, knowing the conditions under which systems were developed and/or introduced could help in avoiding problems possibly arising in introducing new ones. (Note that the "case study" method of teaching in business and law schools is often touted as being very effective as a teaching tool.)

But I also sense that pride in one's field, gained by a better understanding of its history, is a strong reason why many engineers are turning to a study of the history of engineering and science. This appears to be particularly true for the IEEE, which has for many years sponsored the IEEE History Center. It is true as well for the various Societies of the IEEE, many of which have, with the help of the IEEE History Center, organized commemorations of special anniversaries. Consider, for example, the 50th anniversary celebration, some years ago, of the organization of the current form of ComSoc. I am also pleased to note that a number of IEEE Societies have begun to run history columns such as this one in their respective magazines and journals. Thanks are therefore due to the ComSoc Board of Governors in establishing a new Communications History Committee and to Nim Cheung, Editor-in-Chief of this magazine, for, in turn, establishing this new column.

What do we plan to do with this column? We are in the process of commissioning articles of various types to be published in the column. One type will focus on honoring pioneers and practitioners of our field throughout the world who have, in the past, made outstanding individual contributions to the communications field. Another type will focus on the history of significant communication concepts, products, or systems. You, as readers, are urged to send in examples of the types of articles you would like to see appear here.

This month we are publishing two items. One, entitled "75, 50, and 25 Years Ago" and prepared by Jerry Hayes, a member of the Communications History Committee, provides a brief synopsis of significant developments in the communications field occurring in those years. We hope to continue this feature in future history columns. The second item is a full article on the early development of cellular telephony, prepared by Joel Engel, a contributor to that early work. This article, commissioned and written for this column, is an example of the category of article indicated above that describes the history of significant developments in our field. It is obviously timely as well, given the soaring interest in and widespread use, worldwide, of cellular and mobile communications in general. We hope you enjoy this article.

TELECOMMUNICATION MEMORIES: 75, 50, AND 25 YEARS AGO

Jerry Hayes, Life Fellow, IEEE; Member, ComSoc History Committee

75 YEARS AGO (1933)

Edwin Armstrong patents FM Radio Signaling System: United States Patent 1,941,066.

Issue date: December 26, 1933. The existing state of the art focused on conserving bandwidth. It was Armstrong's brilliant insight that increasing the bandwidth through wide modulation of the carrier could reduce noise. In attempting to exploit the technology, he became embroiled in patent disputes with RCA. The long dispute took a great emotional and financial toll; in 1954 the great engineer took his own life.

The October 1933 issue of the *Proceedings of the IRE* featured a paper with the intriguing title "Electrical Disturbances Apparently of Extraterrestrial Origin." The author was a Bell Laboratories engineer, Kurt Jansky, who was engaged in the study of interference to radio transmission. With this discovery the field of radio astronomy was born. Jansky's discovery presaged the measurement of the residue of the Big Bang by two other Bell Labs engineers, Robert Wilson and Arno Penzias, for which they were awarded the Nobel Prize for physics in 1978.

50 YEARS AGO (1958)

In 1958 physicists Charles Townes and Arthur Schawlow published a paper describing how a laser could be built, "Infrared and Optical Masers," *Phys. Rev. 112*, December 1958, pp. 1940–49. They also applied for a patent on July 30, 1958; subsequently, US Patent No. 2,929,922 was issued on March 22, 1960. As the title implies, this was an adaptation to optical frequencies of a technique for microwave frequencies. The term laser, an acronym for Light Amplification by the Stimulated Emission of Radiation, was later coined. In the following year Theodore Maiman built a solid-state realization of the process.

The Advanced Research Projects Agency (ARPA) of the U.S. Department of Defense was established. ARPA would play a key role in the development of the Internet.

A modem for the transmission of data over analog voice channels was introduced by AT&T. The data rate was 300 b/s using frequency shift keying (FSK). At this time, only AT&T terminal equipment could be connected to the telephone network. Ten years later the Carterfone decision struck down this restraint.

Stereo for LP records was introduced.

25 YEARS AGO (1983)

In 1983 the Internet, as we know it today, took shape. The foundation for this network was the Arpanet, which grew from four nodes in 1969 to about 100 at the beginning of the year, largely consisting of either university or military sites. On January 1, 1983, all sites were required to switch over to Transfer Control Protocol/Internet Protocol (TCP/IP). This was a wrenching time for many who were quite comfortable with the obsolescent Network Control Protocol (NCP). For purposes of security, the military nodes were formed into a separate network, Milnet. The remaining research-oriented nodes came to be called the Internet. In the same year the name server, which translated IP numbers into words, was introduced into the Internet.

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THE EARLY HISTORY OF CELLULAR TELEPHONE

Joel S. Engel

I have been asked to write a piece on the early history of cellular telephone, as one who was a participant in the earliest system studies. As I describe shortly, I do not use the phrase, "in/at the beginning," because there really is no identifiable beginning to the cellular concept.

In 1967 I was assigned to a group at Bell Laboratories with responsibility for the switching systems for mobile telephone. At that time there was a mobile telephone service, but it was extremely limited. There were 11 channels in the 150 MHz band assigned to the wireline telephone companies, and a similar set of channels assigned to competitive radio common carriers. The system design consisted of a high-power transmitter (and a receiver) mounted on the tallest building available at roughly the center of the desired coverage area. Nearby systems interfered with one another and could not use the same channels. For example, Newark and Belle Meade, New Jersey, Hempstead, Long Island, and White Plains, New York, all interfered with Manhattan, and the 11 channels had to be distributed among them. As a result, only three channels could be assigned to Manhattan, allowing only three simultaneous telephone calls; all other attempts would be blocked. There were long waiting lists for service, but, even allowing for high blocking rates, not enough subscribers could be allowed on the system for it to be economically feasible. A second block of 12 channels was allocated, in the 450 MHz band, but, given the economics of the 150 MHz system, very few of the 450 MHz systems were deployed.

Mobile radios also consumed significant battery power. There were some portable units, mounted in attache cases, but the unit was generally mounted in a vehicle and used its electric system. A common saying at the time, probably an exaggeration, was that if the vehicle engine broke down, and one used the mobile telephone to call for assistance, the call had better succeed the first time, because there would not be enough battery for a second call.

I have already laid the groundwork, above, for explaining the long history of the cellular concept. Although the interfering systems required different channels, the channels could be reused in systems that were far enough removed, and were reused many times across the country. This was, in concept, a cellular system, except that the cells were very large and not contiguous, with large gaps in coverage. On reflection, it is obvious that the concept of reusing frequencies in geographically separated areas goes back to the earliest days of broadcast radio, and continued with the assignment of channels to broadcast television stations across the country, also without providing continuous coverage.

At Bell Laboratories at that time, one was expected to go beyond one's immediate assignment and explore possibilities in related areas. Although my assignment was in switching, I had a background and interest in radio transmission, and I soon made contact with two engineers in the radio systems development department, Dick Frenkiel and Phil Porter, who were already conceptualizing a cellular system reusing channels within a metropolitan area, and I joined them in that work. And even they were not the first; there had been earlier suggestions that such a system might be possible.

For the next couple of years, we wrote internal Bell Laboratories memoranda on various aspects of cellular system design, including analyses of how close co-channel cells could be spaced, how cell size could be varied depending on telephone traffic, and various methods of identifying the cell in which a mobile unit was located. And then lightening struck.

Much earlier, shortly after World War II had ended, AT&T had made a request to the FCC for the allocation of a broad band of spectrum in the 450 MHz band. At the same time, there was a competing request from the television broadcasters for the same spectrum, and the FCC gave the allocation to UHF television, channels 14 to 83. Twenty years later, in 1968, the FCC observed that UHF television had not developed as expected, and the channels were sparsely used. Opening Docket 18262, they requested comments on a potential reallocation of channels 70 to 83, providing 84 MHz of contiguous spectrum in the 900 MHz band (plus about 31 MHz of spectrum in some other smaller segments) to mobile telephone. The FCC made it clear that they wanted proposals for systems that were much more efficient in their use of spectrum than the then current systems described above. The opening of the Docket stimulated interest across the industry, and papers began to be published.[1]

The proposed reallocation of spectrum met with considerable political opposition. The television broadcasters did not want any spectrum to be taken away. On another front, the manufacturers of mobile radio equipment, led by Motorola, opposed the assignment of a large block of spectrum to the common carriers. At that time, while mobile telephone, allowing connection to the public telephone network, was a very limited service, there was a very significant use of mobile radio for dispatch systems, in which a central dispatcher could communicate with a fleet of, for example, taxis, delivery trucks, or repair crews. The suppliers of such systems argued for the spectrum to be assigned for dispatch use.

Although AT&T was eager to reply with a proposal for a system that was spectrally efficient, there was some concern within Bell Laboratories as to whether the cellular system was technically feasible, and not only because the sole technical support for the concept was the product of three very young engineers. One needs to recall the state of technology at that time. The very earliest (4-bit) microprocessors were being explored in the laboratory, and the functionality of a cellular mobile telephone would require significant data processing within the unit. At that time, the transmitted frequency of a mobile radio was maintained by a crystal in a temperature controlled oven,

[1] The attached Bibliography lists a number of the papers, special issues of journals, and even a book on cellular mobile radio. I am indebted to Dick Frenkiel for searching out many of them (as well as for reviewing this article and filling the gaps in my memory). At this late date, it is certainly not comprehensive.

approximately 1 in^2 and 2–3 in tall, one such for each channel for which the radio was equipped. Clearly, a mobile radio having access to 800 channels was not feasible using the current technology, and the earliest digital frequency synthesizers were also just being developed in the laboratory. The most advanced telephone switching systems were still analog, and although they were controlled by digital processors, these were special-purpose machines, very different in architecture from general-purpose computers. For the system to work, a number of emerging technologies all had to mature successfully at the time they were needed. Based on the experience I have since acquired over my career, I would have been concerned as well. Many years later, I was interviewed about those early days, and I was asked when, in the course of the development, we realized that the system was actually going to work. I answered that we were very young at the time, not yet scarred by failure, and we always knew that it would work.

The culture at Bell Laboratories was to encourage innovation and provide nourishment to new ideas, and an exploratory development program was initiated. Dick Frenkiel, Phil Porter, and I formed the nucleus of a systems engineering group to which others were recruited under a radio pioneer named Rae Young. The treaty had just been signed banning anti-ballistic missile systems, and work on such systems at Bell Laboratories was discontinued. A department of state-of-the-art microwave engineers from that work, headed by Bob Mattingly, supported by Jerry DiPiazza, Reed Fisher, and George Smith, was reassigned to develop the early proof-of-feasibility prototypes of the radio system. A group of switching systems engineers, headed by Zack Fluhr, was assigned to explore the hardware and software necessary to control the cellular system and connect the calls to the public telephone network. Comprehensive measurements and characterization of propagation at these frequencies had been performed in Japan by a team led by Y. Okumura, and he visited Bell Laboratories to discuss his work with the team. Over the next two years, experimental mini-systems consisting of a few base stations were built, and a system design was developed. In December 1971 AT&T submitted to the FCC a Bell Laboratories Technical Report that presented the system design for the Advanced Mobile Phone Service (AMPS) system that ultimately was deployed.

The system would initially be built covering the service area with hexagonal cells as large as possible while providing reliable coverage. The size of the largest cells would depend on terrain and, in the Technical Report, was conservatively estimated to be 5 mi in radius. (In the later trial system, covering the flatlands of Chicago, they were 10 mi in radius.) An important contribution by Phil Porter was that the base stations would be placed at alternate corners of the cells, each base station having three directional antennas radiating into the three coterminous cells. Analyses indicated that sufficient spacing between co-channel cells to avoid interference could be achieved with a repeating pattern of seven cells, each assigned a unique set of channels. In addition to the voice channels, there would be paging and control channels to locate the mobile units by signal strength, assign the channels, and hand the call off to a new base station on a new channel when the mobile unit crossed a cell boundary.

It was recognized that the telephone traffic would not be uniform over the service area, and vehicular traffic density and population density were studied, first for greater Philadelphia and then extrapolated to other metropolitan areas. As the number of users and their usage increased, the cells with the highest traffic would reach the limit of the capacity of their assigned channels, and would be split to one-half the radius by adding intermediate base stations, requiring a redistribution of the channels to the cells. A second split to one-half the radius again would occur after even further growth. An essential algorithm was developed by Dick Frenkiel that allowed the growth to occur smoothly, without requiring quantum steps in system cost.

Following the filing of the Bell Laboratories Technical Report, interest further intensified. An annual Symposium on Microwave Mobile Communications was held at the Bureau of Standards in Boulder, Colorado. In November 1973 a joint special issue of *IEEE Transactions on Communications* and *IEEE Transactions on Vehicular Technology* was dedicated to cellular mobile radio. In January 1979 an issue of the *Bell System Technical Journal* was devoted to the Advanced Mobile Phone Service.

The use of the word "ultimately" to describe the deployment is appropriate. The opposition by the television broadcasters and manufacturers continued, but, even after that was settled, thanks to the skills of Lou Weinberg, the regulatory guru on mobile radio at AT&T, and the spectrum was allocated, there was an additional long delay. This was an era when the FCC was committed to introducing competition into the telecommunications industry, and mobile telephone was a prime candidate. The FCC allocated one half of the spectrum, which came to be called the "A" channels, to the radio common carriers, and the other half, the "B" channels, to the wireline telephone companies. The carriers were requested to submit detailed applications for assignment of the spectrum in the various metropolitan areas, including demonstrations of technical and financial qualifications. That split assignment created a classic example of the law of unintended consequences.

The wireline telephone companies were regulated utilities, chartered to provide service in specified areas. As a general rule, in any given geographical area there was one wireline telephone company that was chartered to provide service. Even in cities such as Los Angeles, where both Pacific Telephone and General Telephone provided service, the boundaries between them were well defined. As a result, each application by a wireline telephone company for the B channels faced no competing application. But in the major metropolitan areas there were multiple competing applications for the A channels. The radio common carriers argued that if the wireline telephone companies were allowed to begin offering service while the competing radio common carrier applications were being resolved, the wireline companies would capture the market and the radio carriers would not be able to catch up. The FCC agreed, and held up the wireline carrier applications until the radio carrier applications were resolved. After many years of attempting to resolve the competing applications, the FCC instituted a lottery for the A channels in order to break the logjam, and in 1984 allowed commercial service. By that time, the breakup of the Bell System had taken place, and the makeup of the entire U.S. telecommunications industry was vastly altered.

During this hiatus, the FCC did allow AT&T to build a trial system in the Chicago area, large enough, and with sufficient users, to test both the technical and market feasibility of the service. Chicago was chosen because the Bell Laboratories engineers responsible for the switching system were located there and could perform any early troubleshooting that would be required. When, in 1984, the FCC allowed commercial service, that system, operated by Illinois Bell, became the first commercial cellular telephone system in the United States.

That qualifier, "in the United States," is necessary because the 13-year delay only occurred in the United States. By filing the Bell Laboratories Technical Report with the FCC, AT&T had put the design of the AMPS system into the public domain. Common carriers in other countries, most notably the Scandinavian countries and Japan, quickly implemented the system and began offering service.

Since this piece is intended for publication by a technical organization, I will leave it for others to expound on the irony that the FCC, in its commitment to the belief that competition would foster innovation, actually delayed innovation in the United States for over a decade, while other countries allowed their citizens to enjoy the benefits of the technology developed here.

In the years since cellular telephone has evolved in many ways. The transmission is now digital, and new bands of frequencies have been allocated. New data, messaging, and even video services have been developed. And the size, weight, and power requirements have been reduced to the point that portable units have replaced vehicle-mounted units. But all of these advances still rely on the cellular concept of reusing frequencies in multiple small cells within a contiguous service area to achieve the necessary capacity within a limited spectrum.

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