Mobile telephone history

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This article describes how mobile telephones, for decades a near dormant technology, became the dynamic and perhaps most important communication tool of our lives. Commercial mobile telephony began in 1946. The cellular radio concept was published in 1947. But only since 1995 have mobiles become low cost, rich in features, and used world wide. We first examine mobile telephony's early and bulky beginnings. Next, the long journey to analog cellular. Finally, full digital working, exemplified by GSM and now CDMA, providing services and features that make the mobile indispensable and ubiquitous. We'll see how early mobile telephony battled the same problems of today: government regulation, scarce spectrum, and hardware limitations. How Scandinavian, Japanese, and United States groups independently crafted their own radio-telephone solutions. At 58, the relatively recent, spectacular success of today's mobile telephone could hardly be guessed by its age. But its history reveals why this technology took so long to mature. And the present shows us that it was worth the wait.

Introduction

Public mobile telephone history begins in the 1940s after World War II. Although primitive mobile telephones existed before the War, these were specially converted two way radios used by government or industry, with calls patched manually into the landline telephone network. Many New York City fireboats and tugboats had such radiotelephones in the 1930s. These were private services. For this article, though, a mobile telephone is a wireless device which connects to the public switched telephone network and is offered to the general public by a common carrier or public utility. Further, mobile history is not just a study of the telephone, the handset itself, but a look at the wireless system it is connected to.

After World War II badly neglected civilian communication needs could finally be addressed. Many cities lay in ruin; their infrastructures need years of reconstruction. Post, Telephone and Telegraph administrations, the PTTs, and private telephone companies concentrated on providing landline telephones and services first, but some mobile radio research and development still went on. Americans lead this low priority movement for three reasons. The United States was physically intact after the war, Bell Telephone Laboratories had a large group of radio engineers and scientists to use, and the Motorola corporation had grown significantly during World War II. Consumer demand, research facilities, and manufacturing capability all existed for US mobile telephony. But was that enough? And what kind of mobile system would be created?

Already in 1924, Bell Labs tested mobile radio telephony (from http://www.bell-labs.com/history/75/gallery.html)

On July 28, 1945 a cellular radio or small zone system was first described in print. The head of the United State's Federal Communications Commission, the FCC, outlined a two way radio service in the 460 MHz band to the *Saturday Evening Post*. Commissioner J.K. Jett had just been briefed by AT&T personnel. They had speculated about American wireless communications after World War II. Deceptively titled "Phone Me by Air", Jett's *Post* interview didn't suggest connecting mobile radios to the landline telephone system. But he did describe frequency reuse within a small area, the main element of cellular radio. Millions of users, he said, could use the same channels across the country. Low powered transmitters using high band radio frequencies would keep signals in nearby cities from interfering with each other. Despite Jett's initial enthusiasm, the FCC never allocated the spectrum needed for this service. Still, radio engineers were thinking of cellular, even if they couldn't build such a scheme just yet.

A year after that landmark article, the first American commercial mobile radio-telephone service began. On June 17, 1946 in Saint Louis, Missouri, AT&T and one of its regional telephone companies, Southwestern Bell, began operating MTS, or Mobile Telephone Service.[1)] Motorola built the radios and the Bell System installed them. MTS was modeled after conventional dispatch radio. A centrally located antenna transmitted to mobiles moving across a wide area. The mobiles, all of them car based radio-telephones, transmitted to several receivers situated around the city. The traffic from the receivers and to the transmitter were connected by an operator at a central telephone office. MTS used six channels in the 150 MHz band with 60 kHz wide channel spacing. Unexpected interference between channels soon forced the Bell System to use only three channels. Waiting lists developed immediately in every one of the twenty five cities MTS was introduced.

Cellular telephone systems first discussed

In December, 1947 Bell Laboratories' D.H. Ring, with help from W.R. Young, articulated a true cellular radio system for mobile telephony in an internal company memorandum.[2)] Young said later that all the cellular radio elements were known: a network of small geographical areas called cells, a base station transmitter in each, cell traffic controlled by a central switch, frequencies reused by different cells and so on. He stated from1947 Bell teams "had faith that the means for administering and connecting to many small cells would evolve by the time they were needed."[3)] But more mobile telephones were always needed. Then, in 1947, and for decades after. Better technology would help, but more spectrum, more channels, were essential to developing a high capacity mobile telephone service.

Conventional mobile telephony

In 1947 the Bell System asked the FCC for more frequencies. The Commission allocated a few more channels in 1949, but they also did something unexpected. They gave half of those frequency allocations to other companies wanting to sell mobile telephone service. These firms were called Radio Common Carriers or RCCs. The FCC thus created wireless competition for the Bell System while allowing capacity to increase only slightly. These small businessmen, however, advanced early mobile telephony further and faster than AT&T. As proof of their competitiveness, the RCCs serviced 80,000 mobile units by 1978, twice as many as AT&T. This growth began with an excellent start, the introduction of automatic dialing in 1948.

On March 1, 1948 the first fully automatic radiotelephone service began operating in Richmond, Indiana, eliminating the operator to place most calls.[4)] AT&T by comparison didn't provide automatic dialing until 1964. Most systems, though, RCCs included, still operated manually until the late1960s. While these small, independent wireless companies could provide service to a few dozen customers at a time, they did not have the money or the resources to research, design, and then build a high capacity mobile telephone system.

On July 1, 1948 the Bell System unveiled the transistor, a joint invention of Bell Laboratories scientists William Shockley, John Bardeen, and Walter Brattain. It would revolutionize every aspect of the telephone industry and all of communications. Fragile and bulky vacuum tubes would eventually be replaced by transistors. Compact, low cost, rugged radios could now be speculated about. Vacuum tubes, though, would dominate the radio and telephone industry for another twenty years.

Outside of the United States mobile telephony developments came slowly. Most governments or PTTs did not allow the public radiotelephones. There were exceptions. In 1949 the Dutch National radiotelephone network inaugurated the world's first nationwide public radiotelephone system. And in 1951 the Swedish Telecommunications Administration's Sture Lauhrén and Ragnar Berglund designed a novel automatic mobile telephone system called the MTA. This scheme began with a Stockholm trial and soon encompassed the city and its surrounding area.
A similar system was soon set up in Gothenburg, although both networks did not become fully operational until 1956. As with all car mounted radio telephones, the equipment was huge and required much power. The transmitter and receiver were mounted in the boot or trunk, while the dial and handset went inside the cab. A car's headlights dimmed while a

1) *Peterson, A C, Jr.* Vehicle Radiotelephony Becomes a Bell System Practice. *Bell Laboratories Record, 137, April, 1947.*

2) *Roessner, D et al.* The Role of NSF's Support of Engineering in Enabling Technological Innovation: Phase II, Chapter 4: The Cell Phone. Final report to the National Science Foundation. *Arlington, Virginia: SRI International, 89, 1998. citing Ring, D H, "Mobile Telephony – Wide Area Coverage," Bell Laboratories Technical Memorandum, December 11, 1947. Online: http://www.sri.com/policy/stp/techin2/chp4.html*

3) *Young, W R. Advanced Mobile Phone Service: Introduction, Background, and Objectives.* Bell System Technical Journal*, 7 January, 1979.*

4) *McDonald, R. Dial Direct: Automatic Radiotelephone System.* IRE Transactions on Vehicle Communications*, 80, July, 1958.*

customer transmitted. On the other side of the planet, an electronics giant was gaining life.

In 1952 Japan regained its independence, seven years after World War II ended. Nippon Telephone and Telegraph became privatized, its research division strengthened, and various government sponsored laboratories escalated radio and telephone studies. Although private radiotelephones were not allowed, consumer demand for commercial radio and television broadcasting sets would come about quickly, and the Japanese soon looked to making this equipment for export. Quality control pioneer Edwards Deming had been lecturing Japanese industry leaders since 1950. He stressed quality first, something American manufacturers were not receptive to. But the Japanese took Deming's advice quite seriously. Japanese cameras, cars, and electronics became so good over the next thirty years that other countries were forced to rethink and often retool entire industries.

In 1953 the Bell System's Kenneth Bullington wrote "Frequency Economy in Mobile Radio Bands."[5] This dull sounding paper appeared in the *Bell System Technical Journal*, circulated around the world. For perhaps the first time in a publicly distributed paper, the 21 page article hinted at, although obliquely, cellular radio principles. Three years later the Bell System began providing a manual radio-telephone service at 450 MHz, a new frequency band assigned to relieve overcrowding on their lower frequency band. This system also filled to capacity wherever it was introduced.

In July, 1958 Jack Kilby invented the integrated circuit at Texas Instruments in Dallas, Texas. A toothpick size piece of germanium contained his complete electrical circuit or IC. It used no soldered connections and consequently was reliable and stable. He also showed how resistors, capacitors, diodes, and transistors could co-exist on a single block of semiconductor and that they could all be made of this same material. As Texas Instruments itself puts it, "The roots of almost every electronic device we take for granted today can be traced back to Dallas more than 40 years ago."

In 1958 the innovative Richmond Radiotelephone Company improved their automatic dialing system. They added new features to it, including direct mobile to mobile communications. Other independent telephone companies and Radio Common Carriers made similar, incremental advances to mobile telephony throughout the 1950s and 1960s. In this same year the Bell System petitioned the FCC to grant 75 MHz of spectrum to radio-telephones in the 800 MHz band. Despite the Bell System's forward thinking proposal, the FCC ignored their request for ten years.

During the late 1950s little cellular radio research and development was accomplished. Without enough spectrum to make it economically feasible, a high capacity cellular system could not be built in the United States. Still, two important papers by Bell System employees were published in 1960. They appeared in the *Institute of Radio Engineers Transactions on Vehicle Communications*. The articles discussed handoffs, that process of transferring a call from one cell to the next, with different frequencies used in adjacent cells.[6] This was the first time the entire cellular system concept was outlined in print to a worldwide readership.

In 1961 Ericsson subsidiary Svenska Radio Aktiebolaget, or SRA, reorganized to concentrate on building radio systems. This forerunner of Ericsson Radio Systems was already selling paging and land mobile or dispatch radio equipment throughout Europe. SRA would go on to become a central part of Ericsson, helping create their wireless consumer business.

In 1964 the Bell System introduced Improved Mobile Telephone Service or IMTS, a replacement to their badly aging Mobile Telephone System.[7] With IMTS people didn't have to press a button to talk. Conversations went back and forth just like a regular telephone. IMTS finally permitted direct dialing, automatic channel selection, and reduced bandwidth from between 25 and 30 kHz. Some regional telephone companies like Pacific Bell, owned by AT&T, took nearly twenty years to replace their old MTS systems. Again, although demand was great, there were not enough channels to accommodate more users.

Other countries in the mid 1960s were also replacing their first mobile telephone systems. The Swedish Telecommunication Administration began replacing their MTA system with MTB. Ragnar Berglund developed this new system and, thanks to the transistor, made possible smaller phones which required less power and were therefore less expensive. MTB was

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5) *Bullington, K. Frequency Economy in Mobile Radio Bands.* Bell System Technical Journal*, 32 (42) et. seq. January,1953.*

6) *Lewis, W D. Coordinated Broadband Mobile Telephone System.* IRE Transactions*, 43, May, 1960; and Schulte, H J Jr. and W A Cornell. Multi-area Mobile Telephone System.* IRE Transactions*, 49, May, 1960.*

7) *Douglas, V A. The MJ Mobile Radio Telephone System.* Bell Laboratories Record*, 383, December, 1964.*

available to the public from 1965. Like MTA, the MTB soon ran out of capacity with 660 customers served.[8)9)]

In 1967 Nokia was formed by consolidating two companies: the Finnish Rubber Works and the Finnish Cable Works. Nokia expanded Finnish Cable Works electronics division to include semi-conductor research. These early 1970s studies helped Nokia develop digital landline telephone switches. Also helping the Finns was a free market for telecom equipment, an open economic climate which promoted creativity and competitiveness. Unlike most European countries, Finland's PT&T was not required to buy equipment from a Finnish company. And other telephone companies existed in the country, any of whom could decide on their own which supplier they would buy from. Nokia's later cellular development was greatly enhanced by this free market background and their early research.

In 1967 Televerket, now Telenor, began operating a public mobile telephone system known as the OLT. It was a manual system using the 160 MHz band. It, too, ran out of capacity soon after introduction. A few years later an additional system was introduced in the 450 MHz band in southern Norway.

By the late 1960s it is certain that every major telecommunications company and manufacturer knew about the cellular radio idea. In 1967, for example, NT&T may have begun research for a nationwide cellular system at 900 MHz for Japan.[10)] But how to make it work technically and economically? There was no way to evolve the existing radiotelephone infrastructure to cellular. New base station radio equipment and new customer mobiles were needed. Instead of a single, central antenna site with one fairly simple transceiver, several to dozens of cell sites would be required, each needing its own transceiver, all of them interconnected to each other, with a network switch to manage the traffic, and software to make everything work. The cost would be enormous.

The Federal Communications Commission in the United States in 1968 reconsidered the Bell System's ten year old request for more frequencies. They made a tentative decision in 1970 to grant them, asked AT&T to comment, and received the system's technical response in December, 1971. The Bell System submitted a frequency-reuse cellular radio scheme. Their proposal was based on the patent Amos E. Joel, Jr. and Bell Telephone Laboratories filed on December 21, 1970 for a mobile communication system. Six long years passed before the FCC allowed AT&T to start a trial.

Besides bureaucratic sloth, this delay was also caused by lawsuits and objections from radio common carriers, independent telephone companies, and their suppliers. All three groups feared the Bell System would dominate cellular radio if private companies weren't allowed to compete equally. They wanted the FCC to design open market rules, and they fought constantly in court and in administrative hearings to make sure they had equal access. And although its rollout was delayed, the Bell System was already working with cellular radio, in a small but ingenious way.

The first commercial cellular radio system

In January, 1969 the Bell System made commercial cellular radio operational for the first time by employing frequency reuse in a small zone system. Using public payphones. Passengers on what was called the *Metroliner* train service running between New York City and Washington, DC found they could make telephone calls while moving at more than 160 kilometers per hour. Six channels in the 450 MHz band were used again and again in nine zones along the 225 mile route. A computerized control center in Philadelphia, Pennsylvania, managed the system. Thus, the first cell phone was a payphone! As Paul described it in the *Bell Laboratories' Record* article on the project, "[T]he system is unique. It is the first practical integrated system to use the radio-zone concept within the Bell System in order to achieve optimum use of a limited number of radio-frequency channels."[11)12)]

Around 1969 the first all transistor mobile telephones appeared from a large manufacturer. The tube era for radio telephones was ending. Motorola's 'Mark 12' was an IMTS telephone designed to work in the 450 Mhz band. This transistor rig was still big and bulky and mounted in a vehicle. The first commercial

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8) *Online: http://www.tekniskamuseet.se/mobilen/engelska/1960_70.shtml*

9) *Olle Gerdes, citing* Dædalus 1991, The Yearbook of the National Museum of Science and Technology. *Stockholm.*

10) *Ikegami, F. Mobile Radio Communications in Japan.* IEEE Transactions On Communications*, 744, Vol. Com-20 No. 4, August, 1972.*

11) *Paul, C.E. Telephones Aboard the 'Metroliner'.* Bell Laboratories Record*, 77, March, 1969*

12) *For many more details on the* Metroliner *or "High Speed Train Project", please see http://www.privateline.com/PCS/metroliner.htm*

In the early 1970s Bell System tested the cellular concept, which had already been used in a commercial system since 1969. (Photo supplied by John Winward)

portable radiotelephones in the United States also appeared at this time. In 1969 or 1970 SCM Melabs, owned by Smith Corona, produced an attaché phone, a complete MTS telephone built into a briefcase. Almost immediately Canyon Communications and Livermore Data came out with their attaché phones. These were all MTS even though IMTS had been introduced in 1964. Only small firms made these units. Harris, Motorola, and GE never did. All these phones were essentially made by hand.[13)]

In November, 1971 Intel introduced the first commercial microprocessor, the 4004, a miniature computer on a silicon chip. The original contained 2,300 transistors and did 60,000 operations a second. Today's microprocessors can contain 5.5 million transistors, performing hundreds of millions of calculations each second. Intel's 4004 was designed originally for a desktop calculator, but microprocessors were soon improved on and eventually put into all kinds of electronics, including telephone switches and cell phones. That integration could have come sooner for one telecom group.

During the late 1960s and early 1970s the Nordic Mobile Telephone group was planning a Scandinavian wide mobile telephone network. Their 1970 report concluded that the microelectronics needed to build an analog cellular network would not be available until 1980. The group decided therefore that instead of using new technology, they'd design a conventional, manual mobile telephone system. It started in Örebro, Sweden in 1971. It required 400 operators to serve just 19,800 subscribers. MTD shut down in 1987, eclipsed, of course, by an automated cellular radio system made possible by microprocessor technology.[14)]

On October 17, 1973, Motorola filed a patent for its own cellular radio system.[15)] Although Motorola had supplied the Bell System with radiotelephones for decades, AT&T was now considered a threat, not a friend. Motorola's main business was dispatch radio systems for taxi companies, utility fleets, police departments, and so on. If cellular was successful then dispatch customers might move in whole or in part to the new service. So Motorola needed a cellular offering to compete with AT&T. A rivalry developed between the two companies to field working equipment. In 1973, after completing Motorola's first prototype cellular telephone and its base station, Dr. Martin Cooper called his competitors at Bell Labs. Ferranti says "Cooper couldn't resist demonstrating in a very practical manner who had won."[16)] What Cooper's team invented was the first handheld cell phone. But not the cell phone itself. That had already been done on the *Metroliner* train. Motorola's successful field work caused the American magazine *Popular Science* in July, 1973 to picture the portable phone on their cover. The accompanying article said that with FCC approval New York city could have a Motorola cellular system operating by 1976. No approval came.

On May 1, 1974 the FCC approved an additional 115 megahertz of spectrum for future mobile telephone use. Cellular loomed ahead, although no one knew when FCC approval would permit its commercial rollout. American business radio and radio-telephone manufacturers begin planning for the future. The demand was certainly there. In 1976 only 545 customers in New York City had Bell System mobiles, with 3,700 customers on the waiting list. In the United States overall, 44,000 Bell subscribers had AT&T mobiles but 20,000 people were on five to

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13) *Geoff Fors. Personal correspondence.*

14) *Online: http://www.tekniskamuseet.se/mobilen/engelska/1970_80.shtml*

15) *US Patent Number 3,906,166, granted September16, 1975.*

16) *Ferranti, M.* Father of Cell Phone Eyes a Revolution. *IDG News Service, New York Bureau, 14 (31), October 12, 1999.*

ten year waiting lists. Demand always existed but licensed spectrum to accommodate them did not. Until now.

In1975 the FCC let the Bell System begin a trial. It wasn't until March, 1977, though, that the FCC approved AT&T's request to actually operate their cellular system. A new wireless industry was developing in America and the FCC sought to control every aspect. They'd decide the number of wireless carriers in each market, the companies allowed to operate, standards for the equipment, frequency assignments, channel spacing, and on and on.[17] Suffering less bureaucratic trouble, Japanese and Scandinavian manufacturers diligently worked on trialing first commercial analog cellular systems. The NMT group ran a satisfactory trial in Stockholm in late 1977 through early 1978. Nippon Telephone and Telegraph probably started field tests in Tokyo as early as 1975.[18]

NTT produced the first cellular systems for Japan, using all Japanese equipment. The Japanese also contributed important studies to cellular research. Y. Okumura's 1968 "Field Strength and its Variability in VHF and UHF Land Mobile Service," is an often cited, pioneering work. But Japan's greatest contribution to cellular radio was quality control. American industry and those who emulated its practices, in the final analysis, favored quantity over quality. The Japanese insisted on both.

In the mid to late 1970s, Japan's goal to produce electronic goods without defects forced manufacturers around the globe to ask themselves if they could compete. Self-examination was a wrenching but necessary process that for many companies would go on for years. Before completing the turn to better quality shipping dates would be missed, production quotas lost, profits reduced. It was all very necessary; assembly line production of mobiles by the millions could not have happened with the one at a time techniques of producing conventional mobile telephones.

In January, 1978 Andy Affrunti Sr. warned Motorola management that the biggest threat to their company was quality competition from the Japanese. He asked his bosses, "Do we have a quality organizational structure that could meet this Japanese competition and achieve zero defects?" As if to highlight the issue, the next week Affruniti found factory workers beating on warped metal housings with a board and mallet to make them true, and, to make a deadline, radios deliberately shipped with a missing part. Motorola immediately began institutional changes toward quality control.[19]

Analog cellular systems begin

In May, 1978 The Bahrain Telephone Company (Batelco) began operating the first commercial cellular telephone system. The simple two cell scheme had 250 subscribers, operated on 20 channels in the 400 Mhz band, and used all Matsushita (Panasonic) equipment.[20] Cable and Wireless, now Global Crossing, installed the equipment for Batelco.

In July, 1978 Advanced Mobile Phone Service or AMPS began operating near two American cities. The first area was around AT&T Labs in Newark, New Jersey, and the second place was near Chicago, Illinois. Ten cells covering 21,000 square miles made up the Chicago system. Oki Electric provided the mobile terminals. This equipment test started with 90 Bell System employees acting as customers. After six months, on December 20, 1978, a market trial began with paying subscribers who leased the car mounted telephones. This was called the service test. The system used the newly allocated 800 MHz band.[21] Although the Bell System bought an additional 1,000 mobile phones from Oki for the lease phase, it placed orders from Motorola and E.F. Johnson for the remainder of the 2,100 radios.[22] This early network, using large scale integrated circuits throughout, a dedicated computer and switching system, custom made mobile telephones and antennas, proved a large cellular system could work.

In 1979 INMARSAT was born, an international group fostering and coordinating satellite telephony. Originally developed for ships at sea, INMARSAT's charter later extended to telephone calls made on land

17) *Online: http://www.fcc.gov/Bureaus/OGC/Reports/cellr.txt*

18) *Ito, Sadao and Yasushi Matsuzaka. 800 MHz Band Land Mobile Telephone System – Overall View.* IEEE Transactions on Vehicular Technology*, 205, Volume VT-27, No. 4, November 1978, as reprinted from Nippon Telegraph and Telephone's* The Review of the Electrical Communication Laboratories*, Vol. 25, nos 11–12, November-December, 1977. (English and Japanese)*

19) *Affrunti, Andy.* A Personal Journey: 50 Years at Motorola*. 132–133. Motorola University Press, Rolling Meadows, Illinois, 1994.*

20) *Gibson, Stephen W.* Cellular Mobile Radiotelephones*. Englewood Cliffs, Prentice Hall, 141, 1987. See also online: http://www.privateline.com/PCS/Bahrain.htm*

21) *Blecher, F. Advanced Mobile Phone Service.* IEEE Transactions on Vehicle Communications*, Vol. VT-29, No. 2, May, 1980.*

22) *Fewer busy signals for mobile phones.* Business Week*, Industrial Edition, Number 2546: 60B, August 7, 1978.*

1984. The first portable units were really big and heavy. Called transportables or luggables, few were as glamorous as this one made by Spectrum Cellular Corporation

and from aircraft. MARISAT or Marine Satellite was the first mobile communications satellite service, beginning in 1976. Both satellite groups sought to make more dependable radio-telephone traffic which had previously gone over High Frequency or shortwave radio links. Shipboard satellite customers first talked with an international operator who then manually patched their call into the landline telephone system. Echo and reverberation problems were common in those days, an operator might need 6 to 9 call setups for 1 call.[23] Let's return now to terrestrial radio-telephony.

Worldwide commercial cellular deployment blossomed in the late 1970s and then continued into the early 1980s. An 88 cell system in the challenging cityscape of Tokyo began in December, 1979, using Matsushita and NEC equipment. The first North American commercial system began in August, 1981 in Mexico City. It was a one cell system. The world's first Nordic Mobile Telephone network started on September 1, 1981 in Saudi Arabia. It used 20 cells and operated at 450 MHz. The next month, starting on October 1, 1981, and opening in stages until March, 1982, Sweden, Norway, Denmark, and Finland, began operating a Scandinavian wide NMT network. It also operated at 450 MHz, and used three Ericsson switches. The first multi-national cellular system, the NMT450 had 600 cells and offered roaming, an important first. As the Scandinavians operated the most advanced cellular system in the world, rollout of cellular radio in America was stopped again by government bureaucracy.

New regulations and AT&T's impending breakup caused American cellular to be delayed once again. The Federal Communication Commission in 1981 required the Bell System regional operating companies, such as Bell Atlantic, to have competition in every cellular market. The FCC thought this would provide better service and keep rates low. In reality prices between the wireline and non-wireline carriers were always about the same, and service no better between the two. Rules governing this state imposed duopoly were many: Applications to operate in each city were required and a lengthy licensing award process needed to be followed.

On March 25, 1980, Richard Anderson, general manager for Hewlett-Packard's Data Division, shocked American chip producers by saying that his company would henceforth buy most of its chips from Japan. After inspecting 300,000 standard memory chips, what we now call RAM, HP discovered the American chips had a failure rate six times greater than the worst Japanese manufacturer. American firms were not alone in needing to retool. Ericsson admits it took years for them to compete in producing mobile phones. Let's skip ahead five years to make this point.

In 1987 Panasonic took over an Ericsson plant in Kumla, Sweden, 120 miles west of Stockholm to produce a handset for the Nordic Mobile Telephone network. Meurling and Jeans explain: "Panasonic brought in altogether new standards of quality. They sent their inspection engineers over, who took out their little magnifying glasses and studied, say displays. And when they saw some dust, they asked that the unit should be dismantled and that dust-free elements should be used instead. Einar Dahlin, one of the original small development team in Lund, had to reach a specific agreement on how many specks of dust were permitted."[24] Let's go back now to the early 1980s, when telecom changed forever.

On August 24, 1982, after seven years of wrangling with the American federal Justice Department, American Telephone and Telegraph was split apart, succumbing to government pressure from without and a carefully thought up plan from within. The Bell System, serving 80 % of the American population, and custodian of Bell Laboratories, was broken apart. Complete divestiture took place on January 1, 1984. After the breakup new companies, products, and services appeared immediately in all fields of American telecom, as a fresh, competitive spirit swept the coun-

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23) *Online: http://www.privateline.com/Snyder/TSPS_history_recollections.htm*

24) *Meurling, John and Richard Jeans.* The Ugly Duckling: Mobile phones from Ericsson. *Stockholm, Ericsson Radio Systems AB, 46, 1997.*

try. The AT&T divestiture caused nations around the world to reconsider their state owned and operated telephone companies, with a view toward fostering competition in their own countries.

European analog systems

Europe saw cellular service introduced in 1981, when the Nordic Mobile Telephone System or NMT450 began operating in Denmark, Sweden, Finland, and Norway in the 450 MHz range. It was the first multinational cellular system. In 1985 Great Britain started using the Total Access Communications System or TACS at 900 MHz. Later, the West German C-Netz, the French Radiocom 2000, and the Italian RTMI/RTMS helped make up Europe's nine incompatible analog radio telephone systems. All services used analog for sending voice, signaling was done with a variety of tones and data bursts. Handoffs were based on measuring signal strength except C-Netz, which measured the round trip delay. Early C-Netz phones, most made by Nokia, also used magnetic stripe cards to access a customer's information, a predecessor to the SIM cards of GSM/PCS phones. All of these mobiles were car phones.

The Motorola Dyna-TAC from 1983 was the first handheld cellular phone (from: http://www.motorola.com/mediacenter/graphics/)

On October 12, 1983 the regional Bell operating company Ameritech began the first United States commercial cellular service in Chicago, Illinois. This was AMPS, or Advanced Mobile Phone Service. United States cellular developed from this AT&T model, along with Motorola's system known as Dyna-TAC, first introduced commercially in Baltimore and Washington DC. AMPS or Dyna-Tac, often both, were soon installed and operating within three years in each of the ninety largest markets in America.[25)]

Cellular's popularity in the United States was unexpectedly strong. Estimates say there were 340,213 customers in 1985; 681,825 by 1986, and 1,300,855 by 1987.[26)] Conventional mobile telephones by comparison served less than 100,000 subscribers before cellular began. This 100 % growth each year attracted overseas equipment makers. Ericsson supplied switches and eventually base station equipment, while companies like Nokia sold handsets. AMPS systems were sold throughout the world. One country was especially interested in the technology, not just to use but also to develop as an industry.

In March, 1984 the government KMT or Korea Mobile Telecommunications Company was formed. On May 1, 1984 KMT began AMPS service in South Korea. They had some experience with mobile telephony; a Motorola IMTS system had been operating in Korea since the late 1960s. But cellular was new and something the Koreans thought they could participate in. They started with manufacturing. In 1984 Nokia and Tandy formed Tandy Mobira Corporation in Korea. The Finns wanted to sell AMPS phones in America. The Tandy corporation had electronics stores across the United States which could distribute those phones. By 1992, 824,000 handsets had been sold under the Tandy label and 885,000 under the Nokia brand.[27)] South Korea thus entered the mobile telephone business, taking the first step toward becoming a leader in cellular radio.

Analog cellular was also booming in Europe by the mid-1980s. The main problem was that systems worked well by themselves but they wouldn't work together. A German customer, for example, couldn't operate their mobile in Italy. Planning began during the early 1980s to create a single European wide digital mobile service with advanced features and easy roaming. While North American groups concentrated on building out their robust but increasingly fraud plagued and featureless analog network, Europe planned for a digital future.

Why didn't America build a fully digital system earlier? The United States suffered no variety of incompatible technologies as in Europe. Only AMPS or an AMPS compatible system existed in America. Roam-

[25)] *Gibson, Stephen W.* Cellular Mobile Radiotelephones. *Englewood Cliffs, Prentice Hall, 19–22, 1987.*

[26)] *Online: http://ctia.org/research_statistics/index.cfm/AID/10030*

[27)] *Haikio, M. Nokia: The Inside Story. Prentice Hall, London, 160, 2001.*

ing agreements between operators and a common networking standard, IS-41, allowed customers to make calls from whatever city or state they were in. Little desire existed to design an all digital system when the present one was popular and working well. To keep the current phones working (and producing money for their carriers) any new system would have to accommodate them. Chances lessened for an all digital future with each analog phone sold.

The size and weight of cellular telephones shrank considerably between 1990 and 2000

The Rise of GSM

Europeans saw things differently. No existing telephone system could accommodate their different cellular systems. They decided instead to create a new technology in a new radio band. Cellular radio but fully digital, the new service would incorporate the best thinking of the time. No backward compatibility with existing systems. They patterned their new wireless standard after landline requirements for ISDN, hoping to make a wireless counterpart to it. The new service was called GSM.

GSM first stood for Groupe Speciale Mobile, after the study group that created the standard. It's now known as Global System for Mobile Communications, although the "C" isn't included in the abbreviation. In 1982 twenty-six European national phone companies began developing GSM. This Conference of European Postal and Telecommunications Administrations or CEPT, planned a uniform, European wide cellular system around 900 MHz. A rare triumph of European unity, GSM achievements became "one of the most convincing demonstrations of what cooperation throughout European industry can achieve on the global market." Planning began in earnest and continued for several years.

By the late 1980s the American wireless industry began searching for a higher capacity system. In September, 1988 the Cellular Telecommunication Industry Association published a set of User Performance Requirements, urging a new digital technology be built with 10 times the capacity of existing analog schemes. Two choices quickly emerged, one digital, one analog, but neither came close to the capacity goal.

In 1990, cellular telephones were typically like this "Bag phone" from Motorola

In December 1988 Japan's Ministry of Posts and Telecommunications ended NTT's monopoly on mobile phone service. Although technically adept, NTT was also monolithic and bureaucratic; it developed a good cellular system but charged too much to use it. Growth was slow. They also required customers to lease phones, not to buy them. After 1989 competition and new networks increased cellular sales. But not until 1994, when telecom was completely deregulated, did cellular prosper. In the late 1980s Japan was also studying the next generation of cellular. Their first generation systems were modeled after AMPS but it was unclear if their second systems would be analog or digital.

In 1989 The European Telecommunication Standards Institute or ETSI took responsibility for further developing GSM. In 1990 the first recommendations were published. The specifications were published in 1991. The United States cellular industry knew time based systems would work well but wanted a digital system of their own, a dual mode technology that could keep existing analog phones working.

In January, 1989 the Telecommunication Industry Association (TIA) selected a time based or TDMA approach to North American digital cellular radio. The Cellular Telecommunication Industry Association (CTIA) also endorsed the TIA's pick, although it did not contain the 10 time capacity gain it asked for the year before. The CTIA hoped that eventually capacity gains would increase. The TIA next wrote a standard for this new digital system, soon to be called IS-54. It was unofficially called D-AMPS or Digital AMPS. After publishing the standard manufacturers would know how to build for the system. Few suspected the technology to get the most gain was already being developed.

On November 3, 1989 in San Diego, California, Qualcomm successfully demonstrated a prototype CDMA cellular system to a group of 250 network operators and suppliers from around the world. Three months later they repeated this demonstration in New York City. Code Division Multiple Access had come to mobile telephony. It appeared too late to be considered as the digital choice for new North American cellular networks. Over the next few years, however, it would come into the American market and show the wireless industry that CDMA, in one form or another, would eventually replace time division systems.

North America goes digital: IS-54

In March, 1990 the North American cellular network formally adopted a digital standard: IS-54. It worked with existing AMPS systems. This choice won over Motorola's Narrowband AMPS or NAMPS, an analog scheme that increased capacity by reducing channel size. IS-54 by comparison increased capacity by digital means: sampling, digitizing, and then multiplexing conversations, using a technique called TDMA or time division multiple access. It tripled call capacity. GSM also uses time division.

An operator had great flexibility with IS-54. It could convert any of its analog voice channels to digital. Customers got digital service where available and analog where it wasn't. Existing customers weren't left without service; they simply couldn't access IS-54's new features. CANTEL started IS-54 in Canada in 1992. Many other AMPS countries also adopted TDMA as a digital choice, like Japan in 1994 with their Personal Digital Cellular or PDC system.

Commercial GSM networks started operating in mid-1991 in Europe. On July 1, 1991 Finland's Radiolinja launched the first commercial GSM network. Radiolinja was the wireless consortium of privately owned regional telephone companies. Nokia provided the equipment. The all digital GSM increased capacity three times over analog. Every mobile contained or accessed encryption to prevent eavesdropping, authentication to prevent fraud, short messaging services or SMS, and a SIM card to easily add accounts to a handset. GSM would go on to be installed around the world and become the most popular cellular radio service. In February 2004 it was announced that GSM had one billion customers.

In the summer of 1991 Pacific Telephone, a former regional Bell System telephone company, decided to invest in Qualcomm. This was an unusual and controversial decision for a regulated telephone company. Pacific Bell's Los Angeles wireless customers were growing by 200 % a year. A CDMA solution seemed the only way to handle that growth. But Qualcomm didn't have the equipment yet to build a network; they needed money to finance production and for research and development. Besides funding them, PacTel advised Qualcomm throughout the standards making process. They also gave them vital consulting and contacts in Korea, where the government was deciding on what digital system should replace their analog cellular network. The Koreans were eager to use a scheme they played a role in. They were reluctant to buy more equipment from Japan, Scandinavia, or the United States. Manufacturing chips and handsets for Qualcomm and sharing in their research and development efforts would strengthen Korea's wireless industry.[28)]

In July 1992 Nippon Telephone and Telegraph created a wireless division called NTT DoCoMo, officially known as NTT Mobile Communications Network, Inc. It took over NTT's mobile operations and customers. And as noted before, in April 1994 the Japanese market became completely deregulated. Japanese cellular took off.

By 1993 American cellular was again running out of capacity, despite a wide movement to IS-54 or D-AMPS. Subscribers grew from one and a half million customers in 1988 to more than thirteen million subscribers in 1993. Demand now existed for other technologies, like GSM, and spread spectrum, to handle the growing number of customers. Qualcomm continued working to get their CDMA system approved as another American interim standard. If sanctioned, manufacturers and carriers would have confidence to build for and use Qualcomm's system. GSM specifications were already published and their technology was continuing to spread around the globe. But GSM hadn't come to America. Yet.

In July 1993 the Telecommunication Industry Association approved Qualcomm's CDMA scheme as an alternative digital standard for the United States. It was called IS-95 and it was a two mode system. As with D-AMPS, IS-95 defaulted to the analog AMPS protocol where the primary signal, in this case CDMA, was not present. A mobile could thus work throughout most of North America where there was cellular coverage, even in places where IS-95 hadn't been installed yet. Qualcomm's system traded greater capacity for complexity in the network and in the mobile. Also known as narrowband CDMA, each channel's bandwidth is 1.25 MHz. IS-95A later gained the trade name cdmaOne.

[28)] *Mock, D.* The Qualcomm Equation. *New York, Amacon, 82, 2005.*

[29)] *Meurling, J. and R. Jeans. The Mobile Phone Book: The Invention of The Mobile Phone Industry. London, Communications Week International, Ericsson Radio Systems, 78–179, 1994.*

The Nokia 9000 Communicator was introduced in 1996. It was the first mobile phone and handheld computer, a PDA (from http://www.nokia.com)

In August, 1993 the carrier Nextel Communications began operating a new, proprietary wireless network in Los Angeles. They used Motorola phones which combined a dispatch radio with a cellular telephone. Even though Nextel established a nationwide network, their iDEN technology proved unpopular within the wireless industry. iDEN's chief legacy is the push to talk button (PTT), something emulated on many of today's mobiles.

As mentioned before, Japan in 1994 began operating their own digital standard called PDC in the 800 MHz and 1.5 GHz frequency bands. Ericsson, Motorola, AT&T and Japanese suppliers all furnished different equipment for PDC to different wireless carriers. Modeled after IS-54, PDC was a D-AMPS system, it accommodated existing analog customers. Based on TDMA, carriers hoped to eventually replace their three analog cellular systems with digital working and thereby increase capacity.[29)]

A new cellular band and systems in America

In the mid-1990s more wireless channels and carriers were allowed in America. The FCC auctioned off new blocks of frequencies at 1900 MHz starting on December 5, 1994 and ending on January 14, 1997. A new, lucrative market opened for GSM and CDMA. Several carriers were licensed in each metropolitan area. CDMA, TDMA, and GSM proponents spread out across the United States, urging license holders to use their systems.

GSM vendors quickly tailored a system for the American 1900 MHz band. In November, 1995 American Personal Communications, eventually an affiliate of Sprint Spectrum, launched the first commercial GSM service in the US. This network operated in the Washington-Baltimore area. After just six months there were 15 more GSM 1900 networks in the United States. In perhaps a hint of things to come, Sprint PCS in 2000 replaced APC's GSM network with a CDMA system.

IS-136 started shortly after these new spectrum blocks were opened. This was the successor or evolution of IS-54. It again used TDMA and offered a number of new services. AT&T Wireless was its chief proponent. It is still used in America and other countries but its use is declining. In the places it remains it is slowly being cleared out for GSM systems.

On July 1, 1995 the NTT Personal Communications Network Group and DDI Pocket Telephone Group introduced the Personal Handyphone System or PHS to Japan. Also operating at 1900 MHz, sometimes referred to as 1.9 GHz, PHS is an extremely clever system, allowing the same phone used at home to also roam across a city. A cordless phone acting like a mobile.

In September, 1995, Hong Kong's Hutchison Telecom turned on the world's first commercial CDMA/IS-95 system. A year later in San Diego, California, the operator NextWave PCS launched the first American IS-95 system on August 16. The next ten years might well be called the Triumph of CDMA.

The mid-1990s: Fundamental change

On August 15, 1996, Nokia introduced the Communicator, a GSM mobile phone and handheld computer. It had a QWERTY keyboard and built in word processing and calendar programs. Besides sending and receiving faxes, the 9000 could check e-mail and access the internet in a limited way. But its effectiveness was limited since cellular networks were optimized for voice, not data.

To be a telephone an instrument must convey speech. By the mid-1990s, however, delivering quality speech was assured with every cellular radio scheme. Voice, with adjustments, was as good as it needed to be. With the speech requirement settled, data became the first interest of system designers. Voice remained

In the mid-1990s, the Blackberry, essentially a two-way pager only capable of sending and receiving e-mail or SMS, forced us to rethink what a cellular phone was (http://www.blackberry.com) the essential service for the large majority of mobile phones, but developing better and faster data networks over cellular radio became the priority.

To best conduct voice cellular had always used circuit switching, just as the landline telephone network did. But data isn't efficiently conducted by circuit switching. An example is the GSM service called High Speed Circuit Switched Data or HSCSD. It needs four GSM channels to achieve, in theory, speeds between 28.8 kbits and 43.2 kbits a second. Actual speeds are lower. A fundamental change was needed, therefore, from circuit switching to packet switching. And the kind of packet switching needed was obvious from the start.

The internet became commercial in the mid-1990s with the advent of graphical browsers like Mosaic and then Netscape. Internet user growth rivaled cellular telephony between 1995 and 2000. The internet runs on the aptly titled Internet Protocol or IP, a packet switching technique cellular data network operators quickly chose to adopt. Today's General Packet Radio Service (GPRS), its improvement, EDGE, and short range wireless networks like Bluetooth all employ IP. All 3G systems use IP as all of us head toward "an all IP world."

By the mid 1990s the mobile became as small as practically possible. The keypad and display limited any more reduction in size. Cell phone circuitry started getting built into laptops and PDAs and instruments like the Blackberry, forcing us to rethink what a cellular telephone was. Is an SMS only device a mobile telephone or a two way pager? Handsets evolve to provide a variety of services, mostly non-voice, such as ring tones, image capturing, text messaging, gaming, and so on. While cell phone services seem limited only by the imagination, the systems they run over become fewer.

GSM and CDMA systems would continue to be installed around the world but by 2005 no new cellular radio scheme would emerge. Flarion's technology was tested extensively by the American carrier Nextel but the system was not adopted. The lone exception was China. To keep its market closed they choose a hybrid technology called TD-SCDMA, a cross between TDMA and CDMA. The history of cellular telephones from the mid-1990s, therefore, is mostly a chronicle of improvements to existing systems.

In Europe, the idea of a 3rd generation mobile system called UMTS or Universal Mobile Telecommunications System, was developed in the early 1990s through several European Union funded research projects. In 1991, ETSI established a new group, SMG5, to be responsible for standardizing the system. From 1999, the standardization of UMTS has been done by the 3rd Generation Partnership Project – 3GPP. UMTS is a wideband CDMA standard. A 5 MHz channel spacing is used with data rates up to 2 Mb/s. ETSI and 3GPP provided more than just a European response to Qualcomm's narrowband CDMA technology. While acknowledging that future capacity gains could only be achieved by using CDMA, a step by step migration plan to WCDMA for GSM, PDC, TDMA and IS-95 operators was provided. This evolution plan was carefully planned to use most of GSM's core components.

On December 1, 2001 Telenor Mobil trialed a UMTS system in Oslo. Commercial UMTS systems followed, with the technology now installed in different parts of the world. Rollout of UMTS tends to be slow and expensive, since the change from time division to code division requires more than software updates. Hardware changes are needed, especially at the cell site. One can't, for example, reuse existing antennas without severe performance problems. The radio spectrum is an inherently fragile, vexing medium, of course, and operators are struggling to bring data rates close to those promised. While the UMTS Forum assures us that 384 kbps is a minimum for UMTS, and only then in "high mobility situations", 300 kbps may be the working, upper limit for this technology.

In November, 1998 the greatest mobile telephone disaster began when the Iridium project was launched. Using 66 satellites, and costing almost 5 billion US dollars, the service went bankrupt after only 16 months. The lead design firm and largest investor was Motorola. Hoping to make satellite phone service a mass market item, planning for the system began before cellular became widespread and reduced demand. Iridium gathered only 10,000 customers before it folded. Due to the high cost of handsets and services, and an inability to work indoors, satellite telephone service remains a niche market to this day.

In October 2000 Sharp produced the first integrated camera phone. It supplied them to the Japanese Operator J-Phone. The J-SH04 mobile phone let users take, send, and receive images by email.[30] (The Nokia 9110 Communicator in 1998 was the first mobile to enable image transfers but the device relied on a camera supplied by each user.) At the end of

[30] *Online: http://sharp-world.com/corporate/info/his/h_company/2000/*

2004 it was estimated that 75 % of the mobiles sold in Japan were camera phones.

The CDG or CDMA Development Group promotes narrowband CDMA. They are the equivalent to the wideband CDMA oriented UMTS Forum. During the late 1990s and early 2000s, the CDG outlined coming improvements to IS-95. They gave these system changes, unfortunately, names which look and seem alike. They even changed the name of IS-95. cdmaOne is now the marketing term for IS-95A, the original CDMA scheme. cdmaOne includes IS-95B which is little implemented. We can look at these evolutions by the dates they debuted.

CDMA2000 1X was first launched by SK Telecom in Korea in October, 2000. Building on an existing IS-95 network, CDMA2000 1X, doubles the voice capacity of cdmaOne networks. It delivers packet data speeds of, supposedly, 307 kbps in mobile environments. But it's doubtful this rate is maintained while the mobile is at speed or while conducting handoffs from one cell to another.

In May, 2002 SK Telecom again made another first, introducing CDMA2000 1xEV-DO service in May, 2002.[31] This is a high speed data only service and an odd one at that. It's actually a CDMA/TDMA hybrid, and uses various modulation techniques, depending on the data rate.

On August 27, 2003, Nokia announced it completed a call using CDMA2000 1xEV-DV, and that they achieved a peak data rate of 3.09 Mbps. In a San Diego, California laboratory. CDMA2000 1xEV-DV combines data and voice, something UMTS does already. The CDG claims speeds up to 3.09 Mbps. Perhaps. Both DO and DV are backward compatible with CDMA2000 1X and cdmaOne.

In April 2004 Cingular became the first carrier in North America to offer UMTS. They now cover six markets in the United States. Acceptance is slow due to limited coverage, bulky handsets, and the high cost of service. UMTS and CDMA upgrades are very expensive for the carriers. Operators around the world are now spending billions for networks that won't pay for themselves for quite some time. The potential demand for service is certainly there, as cell phone subscriber levels attest.

In January, 2005 industry analysts Deloitte & Touche predicted mobile phone users will top 2 billion by the end of 2005. They say mobiles currently number over 1.5 billion. Many countries have over 100 % penetration, as people have second phones or multiple SIM cards, one for business, another for personal use. As throughout its history, regulatory, technical, and competitive problems remain for mobile telephony. But the desire for people to communicate, and for business to cater to that need, insures an imaginative and successful future for the mobile. What will the future look like? I'll leave that for the other authors in this issue to answer.

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31) *Personal correspondence, Hanjoo Kim of the IITA (Korean Institute of Information Technology Assessment) July 13, 2004.*