WIRELESS COMMUNICATION TECHNOLOGY

PAST
PRESENT
AND
FUTURE

PREPARED FOR
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MEMORANDUM

TO: Dr. Paul Munro

FROM: Richard K. Gilbert

DATE: December 10, 2003

SUBJECT: Past, present, and future of Wireless Communication Technology

Here is the report you requested November 12, 2003, on Wireless Communication Technology for INFSCI 2000.

The purpose of this report is to analyze the past, current, and future condition of wireless communication technology in the world. As one can see, this field is very large and complex. From the humble beginnings to total market saturation, this report follows the path of development for wireless technologies in the United States and throughout the world.

I am grateful to our librarians at the University of Pittsburgh for helping me collect and sort through the countless numbers books and endless information. Their efforts were truly Herculean.

Thank you for allowing me the opportunity to work on this assignment. It has been a real enhancement to my education. If you have any questions about the report, please contact me.

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EXECUTIVE SUMMARY

The purpose of this report is to analyze the past, current, and future condition of wireless communication technology in the world.

PAST

Wireless communication technology has existed for less than 200 years. The roots of this technology range from the mid 1830's, which stem from Michael Faraday's early discoveries about electricity. The earliest formal theories are from James Clerk Maxwell. He theorized about the existence of EM waves, which were later proven by Heinrich Hertz in 1887. Discovery of these waves began development in the field of wireless communication technology. Guglielmo Marconi was first to succeed at transoceanic telegraphic communication in the early 1900's.

The next milestone to conquer was that of wireless telephony communication. Wireless telephony began to appear in 1907. Lee deForest is considered to be the father of wireless telephony. He popularized it by transmitting voice signals from the Eiffel Tower for a distance of over 500 miles.

In 1920, KDKA was the first AM radio station to go "on the air". This was made possible with the diligent effort of the Westinghouse Corporation. KDKA can still be heard today in Pittsburgh at the frequency of 1020 KHz. By 1935, Edwin Armstrong had invented FM radio. W1XOJ was the first FM radio station to obtain an FCC permit to broadcast.

By 1947, the theories of the first mobile telephony system were being theorized. Throughout the 1950's and 1960's both Bell Labs and the US military were instrumental in developing technologies such as Multi Carrier Modulation, which would eventually make cellular technology, as known today, possible. Dr. Martin Cooper is considered the father of the modern cellular telephone. In 1973, he and his team of scientists and engineers invented the first true personal mobile cell phone.

PRESENT

In 1979, the AMPS standard was revealed in the United States. AMPS was and still is the basis for almost all cellular telephones in the United States. NMT, the first multi-national cellular system, was launched in 1981.

Digital cellular was first unveiled in the United States in 1990. Digital standards were defined by IS-54 and allowed for a dual analog/digital system. GSM of Europe also launched digital service in the same time frame. Within a few years, GSM has spread service into 52 different countries.

The third generation of cellular telephones was soon to follow. The first details of CDMA technology were evident as early as 1993 in the United States. The framework for these "3g" systems was set in IS-95. The third generation cellular systems were the first cellular networks to utilize and implement a soft handoff feature.

Currently, four major wireless LAN standards exist in the world. They are Bluetooth, HomeRF, IEEE 802.11, and BRAN. All of these standards take advantage of a 2.4 GHz ISM spectrum that is globally unlicensed, allowing use in virtually any country. The IEEE 802.11 series of standards consists of a family of different wireless technologies, some of which are discussed in this section. The 802.11g and 802.11h standards are discussed in the chapter on future technologies.

FUTURE

A general rule of thumb is that the future of anything is very difficult to predict. This rule is also true for IT technologies. The future of wireless communication technologies is completely unknown. Though one can analyze market trends, review the past technologies, and postulate a guess as to what the future might hold, that individual would still be making a guess. It is almost guaranteed that the future holds great promise for the growth of the cellular and wireless markets. It is estimated that by 2010, approximately 20% of the global population will possess some form of wireless communication technology.

Brief discussion regarding future technologies is in this section. Wideband CDMA is a possible cellular communication standard with increased voice and data exchange rates on a 5.4 GHz band. The increase in satellite communication utilization will spawn new technologies. The satellite communication technology also will allow for increased communication in inhospitable terrain. In the future, Orthogonal Frequency Division Multiplexing (OFDM) will take a more dominant roll in combination with the fourth generation cellular systems.

This will only be possible with the development and implementation of new technologies. Fourth generation cellular systems and IPv6 are two of the future technologies that will eventually become the market standard; but presently, they are still years away. For the future, I predict, and I am sure many others would agree, long-term communication will produce technologies that are drastically different from current technology. Even the rough details of these new technologies are impossible to predict today. Technologies 20 years from now will be as different as today's technologies would have appeared to a person 100 ago.

WIRELESS COMMUNICATION TECHNOLOGY

PAST PRESENT AND FUTURE

INTRODUCTION

Wireless communication technology has recently attracted a significant amount of attention. There have also been many schools of thought regarding is the best technology. This report covers the past, present, and potential future of wireless communication technology.

PURPOSE, SCOPE, AND LIMITATIONS

The purpose of this report is to develop and discuss the past, present and future state of wireless communication technology being utilized in the United States and throughout the world. There was significant detail devoted to assure the accuracy of dates; unfortunately, ambiguity still exists with some dated material. Although this report outlines a number of possible future steps which could prove effective, the precise direction of these new technologies, as with anything, is difficult to predict. This information is only a "best guess" view of what could happen in the future IT world. Until the commercial market actually implements these technologies, the exact outcome remains unknown.

SOURCES AND METHODS

In preparing this report, various styles and techniques of wireless communication devices and technologies were analyzed. Intensive research of both printed text and electronic resources were used to determine both successful and unsuccessful methods of communication. Also analyzed were various magazine articles to see how other corporations and research institutes are dealing with this subject.

REPORT ORGANIZATION

This report reviews various methods or techniques of wireless communication technology in the areas of past, present, and potential future state. Also presented is a conclusion section, several quick reference appendices at the end, and footnotes to aid in comprehension of terms and definitions.

PAST

PRE WIRELESS, BEFORE 1867

Long before anyone fathomed ideas of wireless communication, critical discoveries were occurring in the field of electricity that would have profound impact on the future of wireless communication technology. One of Michael Faraday's most celebrated discoveries occurred in 1831. This was the theory of electromagnetic induction, which stated that electric current is induced in a circuit subjected to a changing magnetic field. To put this in plain English, when a magnet is spun around a metal core, the magnetic fields are excited and electricity is produced. This is the driving principal of modern generators, alternators, and dynamos (Encyclopedia Britannica, 18-274-1a). Michael Faraday discovered that under the action of an external magnetic force, all substances became magnetic to some extent. This research lead to the theory of magnetic fields in 1845.

EARLY DISCOVERIES

In 1864, James Clerk Maxwell predicted the existence of EM waves. The unification of electrical and magnetic principles in complete mathematical theory was published in 1864. This theory predicted the existence of electromagnetic (radio) waves by stating:

> *The index of refraction of a transparent medium is equal to the square root of the dielectric constant (a measure of specific inductive capacity) of the medium. (Encyclopedia Britannica, 18-295-2b)*

This theory showed light was such a wave and these waves moved at a speed close to the speed of light. This discovery opened the door for all future radio communications, which future generations of scientists and hobbyists approached with alacrity[1].

One of the first radio reception tools was invented by none other than Thomas Edison in 1885. Edison applied for a patent on a system of induction telegraphy. This system worked by affixing a tin-foil covered rectangular object on the top of a locomotive. By doing this, he was able to pick up the electro-magnetic frequencies (EMF) from the telegraph wires that paralleled that railroad bed. The important discovery was that it did not matter how fast the train was moving; as long as it remained close to the telegraph wires, the train continued to receive signals (Archer, 1938). Although Edison was able to receive these signals, he was unable to decipher them. The reason was, he was receiving all of the signals traveling down the multiple wires simultaneously. That would be like listening to every radio station in Pittsburgh at the same time, only in Morse-code, making the received messages completely undecipherable.

A major milestone was achieved in 1887 when Heinrich Hertz verified Maxwell's theories about the existence of electromagnetic waves. Today, these waves are better known as radio waves. By conducting experiments measuring the strength of oscillations at different points along a sheet of zinc, Hertz was able to calculate that not only did waves exist, but that waves moved incredibly fast, with a speed close to $3(10^8)$m/s. Today, it has been established that these waves do indeed move at the speed of light. Hertz utilized a spark transmitter to generate what is known today as EMP. The generated EMP spark was picked up by a receiver just meters away (Golda, 2003). Hertz was able to produce electromagnetic waves, demonstrate their reflection, refraction, and interference in complete accord with Maxwell's results. In his tests, Hertz also took steps toward proving a theory of radiation and relating waves to their source.

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[1] For more detailed information about Maxwell's theories about electro-magnetic waves, please reference: Theory of Magnetic and Electric Susceptibilities for Optical Frequencies by P.K. Anastasovski (1990).

With the increase in knowledge and understanding of radio frequencies, wavelength ranges were being defined. Today, radio waves have a wide range of applications, including communication during emergency rescues (transistor and shortwave radios), international broadcasts (satellites), and cooking food (microwaves), but in the early days, technology barely permitted radio communication technology to ring a bell. A radio wave is described by its wavelength, the distance from one crest to the next, or its frequency, the number of crests that move past a point in one second. Wavelengths of radio waves range from 100,000 m (270,000 ft) to 1 mm (.004 in). Frequencies range from 3 kilohertz to 300 gigahertz. (See *Appendix D* for a Frequency to Wavelength conversion)

Guglielmo Marconi is most famous for his invention of wireless telegraphy, which is considered the foundation of modern radio. Marconi had a remarkable ability to predict the future. He was one of few individuals able to fathom the future for the radio. It was very early in Marconi's life when he realized the potential of this emerging technology. In 1890, Marconi, only 15 years of age, demonstrated the wireless telegraph to the English telegraph office (Golda, 2003). Within one year, he used radio waves to control an electric bell a few yards away.

In the late 1890's, antenna technology had yet to evolve. Unable to find a suitable antenna, Marconi set out to create a better quality antenna. He discovered that tall antenna structures transmitted and received low-frequency signals better. Therefore, one of his many inventions was that of the "coherer" (Archer, 1938) or detector antenna. These adjustable antennas, utilizing an earthen ground plane, had greatly increased the range compared to anything previously invented. Large vertical antennas, with an earth ground, are still referred to as "Marconi Antennas".

By 1897, Marconi's development of the directional antenna allowed for longer distance transmissions by focusing the transmission in a specific direction. That same year, he received English Patent #7777 for tuned communication, at the age of 22. In 1898, wireless telegraphic communication was possible between England and France. One of the first commercial applications of Marconi's wireless telegraph was with the Price of Whales, who had his yacht equipped with the device. The prince used it to keep in contact with Queen Victoria's summer home on the Isle of Wright (Archer, 1938). Being successful to this point, Marconi set his next goal towards achieving telegraphic transoceanic communication. By 1902, the first wireless bidirectional communication was transmitting across the Atlantic Ocean.

TRANSOCEANIC COMMUNICATION

With the increase in technology and experience, the idea of wireless transoceanic communication was quickly becoming a reality. In 1901, Marconi crossed the Atlantic and "set up shop" on the Newfoundland shore; his goal was successful transmission and reception with England. When Marconi attempted this experiment, it was done in complete secrecy. Only a few of his assistants even knew of the project. Marconi asked one of his assistants to stay in England and transmit the letter "s" one time per hour at a specific time and date. At noon, on Thursday, December 12, 1901, the first successful transatlantic wireless message was received.

> *In the moment, faintly yet distinctly, there came the three little clicks or dots spelling out in Morse code the letter 's', which had been sent out a fraction of a second before from the sending station in England. Again and again the sign came thought until both Senatore Marconi and Mr. Kemp were positive that there could be no mistake. It was thus that history was made, for on that day the principle of wireless communication over great distances was established, constituting one of the greatest wonders of modern science (Evening Herald, 1901) .*[2]

[2] This newspaper conversation was found in Archer's book: The History of Radio up 1926.

In late 1901, Marconi was transmitting the first bidirectional (half-duplex) communications across the Atlantic Ocean. This milestone discovery proved the capability of an 1800 mile, non-repeated, wireless communication and it was accomplished by a 27 year old genius scientist (Hong, 2001).

The invention of transoceanic communication instantly created two fields. First being ship to shore communications, and second being coast to coast communications. Large demand for this new technology caused very rapid growth of the wireless communication field, especially for Marconi's company "The Marconi Wireless Telegraph Company". At that time, the explosive growth in the communication field must have been similar to that of the explosion of the internet in the mid 1990's. Undoubtedly, having the ability of ship to shore saved the ships, cargo, and lives of many ocean goers.

VOICE AND RADIO TRANSMISSION

Lee deForest was instrumental in the development of the wireless telephony system. The most basic components were alternating current, an antenna, and the vacuum tube. In early 1907, deForest filed for a patent on a three-electrode tube that did not require a grid, thereby creating the deForest Audion.[3] This led to the development of wireless communication for voice signals. By the summer of 1907, he was able to transmit using the deForest wireless telephony system from his private yacht to shore while cursing Lake Erie (Archer, 1938).

Recognizing that successful transmission of voice was possible by ship, the US Navy became a major customer to deForest and his deForest Radio Telephone Company. When the US Navy made its famous cruise around the world, all 20 ships were equipped with deForest's radio equipment; this allowed inter-ship contact to be maintained throughout a majority of the voyage.

Always the efficient and tactical business man, deForest jumped at the opportunity to broadcast a telephone conversation from the Eiffel Tower. This public stunt added copious amounts of "word of mouth" value to wireless communication with telephony technology. One summer night in 1908 deForest was able to broadcast[4] successfully what he thought to be almost 28 miles. In reality, deForest received a letter written by an engineer who successfully received the complete broadcast. The letter was postmarked Marseilles, 500 miles from Paris. This was a triumphant experience for deForest (Archer, 1938).

At this point, deForest realized that if it was possible to transmit voice, then, theoretically, it was possible to transmit music. Now fully motivated, deForest set out to transmit music. Unfortunately, the best the recording industry had to offer in music playback at that time was the phonograph. Though this storage device contained music, it did not posses the tonally qualities that deForest desired. So, deForest set out to broadcast the Metropolitan Opera Company live in New York City. The initial broadcast was on January 10, 1910. It is estimated that only about 50 people were in the radio audience that evening, but the idea of transmitting music was forever etched into the human mind.[5]

One of the key developing companies in the commercial market was Westinghouse. Though much of Westinghouse's development in wireless telephony occurred during WWI, they intensely continued development after the war. Most of Westinghouse's development occurred in the Pittsburgh area, which by radio standards, is a difficult area for broadcasting. Harry P. Davis, Vice President of Westinghouse Electric and Manufacturing Company, was responsible for the creation of the first commercial radio transmission. It was utilized to transmit information around his plant.

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[3] Audion: Invented by Lee deForest in 1907 to amplify wireless signals. It consisted of a vacuum tube with a control grid inserted between the filament and the anode plate of J.A. Fleming's Thermionic valve (Hong, 2001).

[4] Broadcast is the term used for a radio transmission intended for general reception (Graham, F 1938).

[5] A New York Times reporter claims to have only heard a ticking when listening to the 850 meter band, while many others claim to have heard much more. For the exact article, please reference The history of Radio to 1926 by Archer, 1938, section 61, page 99.

On November 20, 1920, KDKA was the first commercial radio station to go on the air[6] with a twelve month broadcast schedule (Archer, 1938). KDKA was also the first radio station to be on the air all the time. Today, KDKA is still broadcasting on the same frequency 1020 KHz from their Pittsburgh location. On clear nights, their signal can be received as far away as Florida. KDKA jumpstarted what is today a multi-billion dollar radio broadcasting industry.

In the development of technology, efficiency and size are always limiting factors. Users always want a smaller and more efficient product (just look at today's computer market). Each day the technology improved and the size shrank. By 1924, the technology had become small enough to fit into the trunk of a car. The first organized group of users to take advantage of this was the Detroit Police Department. By implementing this technology, the police were able to maintain communication with their local precinct. Still being a new technology, the police might have possessed the radio, but not all officers understood how to properly use it. Also, the radio components were, by today's standards, very large and inefficient. These radios, with very limited transmission capabilities, filled the entire trunk, leaving little to no room for anything else. Though this technology was a vast improvement over no in-car radios, a better technology system was needed.

FM RADIO TRANSMISSION

The next major development in wireless communication was the development of frequency modulation or FM radio. FM broadcasting was demonstrated by Edwin Howard Armstrong in 1935, (Wikipedia, 2003) another genius inventor of the early 20th century. The regenerative circuit was also patented by deForest in 1916. Because both inventors claimed to have the rights of the regenerative circuit and they both had patents, the soul control of ownership was a source of bitter debate for many years.[7] While Armstrong was debating the regeneration circuit lawsuit, he invented frequency modulation. AM radio works by measuring variances in the amplitudes of waves to generate sound. Armstrong devised a method to vary not the amplitude, but the frequency of the wave. These new FM receivers were like nothing seen before. FM provided static free, clear sounding transmission. The effects can easily be seen today just by tuning into your favorite AM station, then change to any FM station. It should be evident which style of broadcasting has a better transmission quality, that of FM.

The initial frequency band of FM radio, determined by the FCC was between 42 and 49 MHz. FM radio was now set; all that was needed was a broadcast station. W1XOJ[8], in New England, was the first FM radio station to receive an FCC Permit for FM broadcasting in 1937. FM radio broadcasted at a power of 50,000 watts, which provided virtually crystal clear transmission for over 75 miles (Halper, D. 2003).

In 1945, the frequency band was changed to the current spectrum between 88 ant 108 MHz. The 40 MHz band is utilized today as the VHF broadcast television band. When the FCC changed the broadcast frequencies, all FM receivers manufactured prior to 1945 were rendered useless, causing a major setback to the popularity of FM radio. This dealt a serious blow to the broadcast industry, but the quality of broadcast overtook the setback and FM became a staple transmission style still utilized today.

BIRTH OF THE MOBILE PHONE

In 1946, the first mobile users were connected to the Public Switched Telephone Network (PSTN) in the United States. The PSTN is a world wide voice telephone network accessible to all individuals with

[6] To this day, there still exists a debate over exactly which AM radio station went on the air first. The stations were KDKA in Pittsburgh, WWJ in Chicago, or 1XE/WGI in Boston. Because this paper was written in Pittsburgh, The author, rgilbert@sis.pitt.edu has chosen to go with KDKA as being the first.

[7] For more information about the discrepancies of Armstrong and deForest, please reference: http://en.wikipedia.org/wiki/FM_radio, The History of FM Radio.

[8] W1X0J still broadcasts today from the same location, though the call letters have changed to WSRS.

telephones and access privileges (Newton, 1995). In the United States, the PSTN network during this time period was called the Bell System Network or AT&T Long Distance Network. This network is also referred to as the Plain Old Telephone System (POTS). These initial wireless users were far from what one considers a cell phone user of today. These were nothing more than half-duplex FM radio transmitters/receivers which could be connected with POTS network.

In 1947, the first cellular communications systems were being discussed in the FCC and by 1949, the FCC recognized mobile radio as a new class of service. The number of mobile users in the US in the 1940's was fewer than 50,000. During the 1950's, the numbers grew to over 500,000, and during the 1960's, that number was approaching 1.4 million (Shea, 2000). These numbers represented a very small fraction of the market, but they were growing daily.

During the 1960's, the Improved Mobile Telephone Service (IMTS) was introduced. IMTS provided a full duplex[9], auto truncation support system. This enabled users to place an outgoing or receive an incoming call without the aid of an operator. Because the IMTS utilized electronic switching, no operator was involved, increasing the security of communicated information (Newton, 1995).

During the 1960's, Bell Labs was instrumental in developing many technologies still in use today. At that time, there was a feeling that anything could be accomplished. A huge step was undertaken, beginning the development of Multi-Carrier Modulation (MCM). MCM works by taking data to be transmitted and dividing it into several different bit streams. The individual bit streams to be transmitted are much less powerful than one single transmission stream. Also, by breaking the signal into many smaller streams, they can be modulated onto several frequencies, increasing security by making it more difficult for the non-intended receiver to intercept. This technology was being developed for the US military. Unfortunately, this technology was just out of reach for this time period, but it saw a reemergence in the 1980's in the Spread Spectrum (CDMA) and Orthogonal Frequency Division Multiplexing (OFDM) networks used today.

Dr. Martin Cooper, commonly referred to as the father of the cellular telephone, received the first US Patent for Motorola's Cellular Radio. He applied for it on October 17, 1973, and was granted US Patent Number 3,906,166 on September 16, 1975. The inventors on the patent were Martin Cooper, Richard Dronsuth, Albert J. Mikulski, Charles N. Lynk, Jr., James J. Mikulski, John F. Mitchell, Roy A. Richardson, and John H. Sangster (US Patent Office, 2003).

Though Dr. Cooper publicly claimed to be the father of the cellular phone, Bell Labs had created and implemented what would be thought of as a modern cellular service, the Metroliner, in 1969. That was four years before Dr. Cooper[10] and Motorola had released their mobile phone. Dr. Cooper received his recognition form the fact that the Metroliner was only available to be used as pay telephones (Farley, 2003).

May 1, 1974, the FCC opened the 115 MHz band for cellular telephone use. This frequency allowed for 2300 channel's of cellular telephone use. Though this frequency was open, it still was not available for commercial use. For the business market, the technology looked good, and futuristic thinking companies were able to see a profitable future ahead.

[9] Full Duplex: Allows the workstation to operate as a source and destination concurrently (Gibilisco, 1998).

[10] Dr. Martin Cooper was interview by Marc Ferranti, for the IDGN News Service. In his interview, he told of how Bell Labs produced the Metroliner four years before Motorola's cell phone, but the Metroliner was not entirely mobile, thus Dr. Cooper claims to be the father of the cellular telephone. Unfortunately, very little information exists about Bell Labs Metroliner, thus making confirmation of Dr. Cooper's information difficult.

PRESENT

CELLULAR MOBILE TELEPHONY

In 1979, the United States launched the Advanced Mobile Phone System (AMPS). AMPS, an analog system, operated in the 900 MHz band with 832 full duplex channels. AMPS was the official term utilized by AT&T's Bell Laboratories (prior to the 1984 break up) to refer to its cellular technology. In 1983, AMPS was released for worldwide use. Even though this technology has slowly evolved over the years, the AMPS Standard has been the foundation for the cellular industry in the United States. An "AMPS-Compatible" cellular telephone means the equipment has been designed to operate on virtually all analog cellular systems in the United States. AMPS utilizes Frequency Division Multiple Access for multiple access methods on the network (FDMA). FDMA works by allocating a certain amount of frequency bandwidth to each user. This divided allocation allows multiple simultaneous transmissions across a finite frequency allocation. (Newton, 1995). As the cellular technology evolved, AMPS soon spawned a child, and that was Digital Advanced Mobile Phone System (DAMPS). A "D-AMPS Compatible" cellular telephone is a cellular phone designed to operate on virtually any digital cellular system in use in the United States.

The first Multi National Cellular System was launched in 1981, the Nordic Mobile Telephone (NMT450) System. In 1986, NMT-900 was launched. Both styles of NMT were analog systems. The NMT operated in Sweden, Norway, Denmark, Finland, and Oman. NMT-450 was able to support 200 channels and the NMT-900 system could support 1999 channels. Though this system is currently remains in use, it is slowly being phased out by GSM (Agar, 2003).

C-Netz was released in Germany, Austria, Portugal, and South Africa in 1981. C-Netz was an analog system that operated on the 900 MHz band. Comvik was released in Sweden in 1981 as a 900 MHz cellular system. Currently, Comvik is a major cellular provider in Vietnam. ARORA-400 was released in Alberta, Canada, in 1983. ARORA-400 operated on a 400 MHz band. RadioCom was released November 1985 in France; it has since been enveloped by GSM. In 1985, Total Access Communication System (TACS) was released in the UK, Italy, Spain, Austria, and Ireland. TACS had also been developed and implemented in Japan in 1991; this system is known as JTACS (Agar, 2003).

DIGITAL MOBILE TELEPHONY

In 1990, plans for the first digital cellular system were unveiled in the United States. Interim Standard 54 (IS-54) was a standard for a dual mode (analog/digital) cellular system in North America. The analog system conforms to the AMPS standard, while the digital half conforms to DAMPS. IS-54 is a TIA standard (Newton, 1995). Telecommunication Industry Association is a standards generating organization formed from the merger of the United States Telephone Service (USTA) and the Electronic Industries Association (EIA).

IS-54 standard became more commonly known as the second generation cellular system currently in use in the United States. It was formally introduced to the commercial market in 1991 and is currently the most popular cellular system. IS-54 utilized three channels and each channel has the capacity to handle 832 users for a total of 2,496 simultaneous users. The multiple access method utilized by IS-54 is TDMA.

Time Division Multiple Access (TDMA) operates by allocating a discrete amount of bandwidth to each user, in order to permit many simultaneous conversations. However, each user is assigned a specific timeslot for each transmission. TDMA has significantly increased the efficiency of cellular telephone systems (Shinder, 2001). As noted, the number of simultaneous users is much greater than any analog system can permit.

TDMA also utilizes a technology referred to as Sequenced Packet Transmission (SPT). With analog systems, all transmitted packets of data were uniform in size. Having uniform packets meant the packets had to be fairly large. The larger a packet of data, the more power required to transmit it. SPT allowed for custom sized packets of data to be sent. Custom sized packets meant smaller data packets, creating lower power requirements. If phones require less power, batteries could be made smaller. TDMA was one of the factors that allowed major shrinkage of the cellular phone. Now the race was on to see which company could make the smallest and "coolest" cellular telephones.

GSM

Groupe Spécial Mobile (GSM) defines the European digital cellular standards. GSM was created in 1982 as an analog phone system, but today exists as a digital phone standard. GSM currently is the digital standard available in both Europe and Japan. GSM is based on a set of ESTI[11] standards. For ensured interoperability between countries, GSM addresses standards based on wireless networks, radio interfaces at 900 MHz, switching, signaling, and intelligent networks. GSM supports 124 channels with 8 users per channel, bringing the total number of concurrent users to 1,024. This allows about half the amount of concurrent users as IS-54, but is still a very effective communication standard. The modulation is based on GSMK[12]. By the year 1994, GSM had extended its operation into 52 different countries all over the European and Asian continents. GSM subscriber's data is carried on a Subscriber Identity Module (SIM) or "Smartcard". A GSM user can just insert his or her card into a phone and they are up and running. This gives great flexibility to end users (Newton, 1995).

The only major disadvantage of GSM is their inoperability with hearing impaired users. With the current design of GSM phones, individuals who have hearing aids are subject to great interference between the phone and their hearing equipment.

GSM Transmits between 890.2 – 914.8 MHz and receives between 935.2 – 959.8 MHz. The multiple access methods utilized are TDMA and FDMA + Frequency Hopping. This provides redundancy and efficiency in both power utilization and spectrum utilization. There is also an optional additional interface encryption option available to users[13] (Morinaga, Kohno, Sampei, 2000).

DCS 1800

DCS 1800 is the next generation of GSM cellular telephones. Like the name implies, DCS 1800 is a 1.8 GHz band wireless communication network. DCS 1800 has been designed to easily facilitate implantation in the UK, where it has been successfully implemented. DCS 1800 utilizes TDMA for its multiple access method. The system utilizes 374 channels with 8 users per channels. This allows as many as 3,024 concurrent users. The system receives between 1805-1880 MHz and transmits between 1710-1785 MHz.

PDC

Personal Digital Cellular (PDC) was defined in 1990 by the Ministry of Posts and Telecommunications (MPT) in Japan. By May of 1990, Japanese Research and Development for Radio Systems (RCR) had organized subcommittees for the standardization of PDC. The commercial service was started by Nippon Telephone and Telegraph (NTT) originally in the 800 MHz band, and in 1994, the 1.5 GHz spectrum was opened for use. The PDC system, originally known in as Japan Digital Cellular (JDC) is only operated in Japan. PDC shares some similarities with IS-54 (Ojanpera, Prasad, 2001). The multiple access method utilized by PDC is TDMA.

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[11] ESTI: European Telecommunication Standards Institute.

[12] GSMK: See Appendix B for more information.

[13] For more information, please reference "The GSM System for Mobile Communications", by Michael Mouly and Marie-Bernadette Pautet.

PDC implements 1600 channels with three users per channel, total of 4,800 concurrent users. The modulation method is DQPSK[14]. The reception frequencies are between 810-826 MHz and 1429-1435 MHz and transmission frequencies are between 940-956 MHz and 1477-1501, respectively, for the two systems.

THIRD GENERATION MOBILE TELEPHONY

As anyone in the technology market knows, by the time a product makes it to the commercial market, its replacement is already being tested. IS-95 was the next generation of cellular technology. It was designed to replace the IS-45 standard. In 1993, Code Division Multiple Access (CDMA) was formally deployed in the United States. CDMA is the child of the MCM technology which was developed in the early 1960's by Bell Labs and the US military. CDMA is also referred to as Spread Spectrum. CDMA technology has a bandwidth of up to ten times analog systems and employs much more efficient use of the 900 MHz frequency spectrum. CDMA utilizes 20 channels that can support up to 798 users per channel. This is a total of 15,960 simultaneous users on the system.

CDMA works by combining each phone with a unique code. This code is issued and controlled by the broadcasted signal of a tower. As mentioned, CDMA allows many users to transmit data simultaneously on the same frequencies. How is this possible? It is possible because the transmission is broken up into many frequencies and is constantly rotated, resulting in very little cross correlation between frequencies. Therefore, the frequencies between two different phones will rarely interfere.

Spread Spectrum[15] operates by taking the transmission and breaking it into small bits of data. The data is scrambled and transmitted over multiple frequencies simultaneously. For added security, the frequencies modulate on a random time and frequency spacing. When the signal is received, it is reassembled and unscrambled to its original format. This entire operation occurs so rapidly that unless a major problem occurs, the end users are never aware how much technology is being utilized.

As previously mentioned, the basics of CDMA were developed for the US military, for security of transmissions. These stringent standards affected the end product, causing CDMA to be an incredibly robust technology. Because the frequencies are always changing, jamming[16] the signal is virtually impossible. With this added security, CDMA is the perfect tool for "Special Service Transmission". CDMA is applicable for data, fax, and integrated voice + data all over the same network.

CDMA was the first cellular technology to utilize a soft handoff feature. A handoff occurs when a phone service switches from one cellular transmission tower to another. On older systems, a hard handoff was utilized. A hard handoff occurs when the signal is too weak for tower one to maintain the connection. At this point, the call is dropped from tower one. Hopefully, tower two picks up the call. Though this system works, when users switch towers, a clearly discernable crack is audible in the line. The soft handoff of CDMA is a vast improvement over a hard handoff. For a soft handoff to occur, a user must travel to the limits of the broadcast area of tower one. As the user approaches the limit, tower two will begin to register the approaching cellular user. If there is an available channel for the user on tower two, a gradual process will begin to combine the two signals of the two different towers. Gradually, as tower two takes over the signal, tower one will drop the call. The switch between the two towers is virtually unnoticeable to the end users.

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14 DQPSK: See Appendix B for more information.

15 Spread Spectrum is also referred to as Frequency Hopping. This is a technique first developed by Hedy Lamarr, the actress. Lamarr developed this during the early years of WWII to prevent enemy jamming of eaves dropping on US Intelligence Communications (Newton, 1995).

16 Jamming a signal is the process by which one attempts to interfere, distort, or block the communicated signal. With CDMA, this process is very difficult as the signal is constantly changing and the transmission is occurring across multiple signals simultaneously, providing large amounts of redundancy in the transmitted signal.

CDMA also utilizes multipart signal processing techniques to allow increased talk time for the end user. This is very similar to TDMAs SPT technology. Increased talk time per battery charge allows for more use out of the cellular telephones, all of which makes the phone companies more revenue. A happy customer utilizes the phone more often. The more calls placed by a user, the more money the cellular companies make.

PERSONAL COMMUMICATION SYSTEMS

In 1995, the FCC auctioned off the 1.8 GHz Personal Communication Service (PCS) band for mobile telephony. PCS is a low powered, high frequency, and highly competitive technology to cellular (Kuruppallai, Dontamestti, Cosentilo, 1997). The cellular phone typically operates around 900 MHz, whereas the PCS networks operate between 1.5 and 1.8 GHz frequencies. The higher frequencies travel farther, thus requiring fewer transmission towers and a lower amount of power required to transmit. The lower overhead cost to operate PCS networks was the driving force for the development PCS networks. The goal was a less expensive network that was readily available. This style of network was made popular mostly by Sprint. The original design of the PCS networks was for use of paging, it has been integrated into the voice market seamlessly (Stamper, 1999). PCS Technologies also utilize a soft handoff technology similar to that of CDMA networks.

WIRELESS LAN COMMUNICATION STANDARDS

Currently, there exist five major standards for wireless communication systems available on the commercial market. In this section, a brief overview of these five technologies is presented. The first four technologies are Bluetooth, HomeRF (SWAP), IEEE 802.11, and BRAN. These technologies all operate on the 2.4 GHz Industrial Scientific Medical band. The 2.4 GHz band is a globally unlicensed frequency spectrum, thus allowing use of this spectrum anywhere in the world. The fifth technology is Wireless 1394. IEEE 802.11 and Wireless 1394 are very similar, but there are some differences. Further discussion is in the IEEE 802.11 section.

BLUETOOTH

Bluetooth is an open specification technology for short range wireless data and voice communication, available anywhere in the world. Bluetooth operates on the 2.4 GHz band, a globally unlicensed band, allowing the anywhere to come into effect. Open specification is from the Bluetooth Special Interest Group (SIG)[17]. SIG produced a specification for Bluetooth which is royalty free and publicly available. It is an effective radio transmission communication standard effective for transmission of data and voice for distances under thirty feet.

Virtually all short range communication between devices today is conducted through some physical medium, such as a cable. As computer users know, there exists a multitude of cables and a plethora of different connectors. These ambiguous connectors have produced copious amounts of issues for almost all computer users. So, how can Bluetooth help? Because of the short range effectiveness of Bluetooth, it is the ideal communication standard for wireless peripheral computer devices. Also, Bluetooth requires very little power to transmit the data, meaning extended battery life. Therefore, Bluetooth enabled wireless peripheral devices to be effectively be utilized on computers, creating the possibility of the “Wireless Computer”. The only wire on the computer would be the electric plug to the wall; all other communication between devices would take place via Bluetooth. Because Bluetooth is radio based, it does not need line-of-sight to work, unlike infer-red technologies. (Bray, Struman, 2002). As technology advances, the once clear line between voice and data networks is becoming more and more ambiguous. One simple example is Voice over Internet Protocol (VoIP). Though this is a data network technology only, to the majority of users, it appears to be a voice-based technology box working on a data network, thus blurring the line between analog and digital.

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[17] For more information about SIG, please reference http://www.bluetooth.com.

Bluetooth supports both data and voice transmission, making it an effective technology in today's fast and ever-changing telecommunication world.

As mentioned already, Bluetooth operates on the 2.4 GHz ISM band. The frequency spectrum is divided into 79 channels. When Bluetooth was originally released in 2000, France and Spain only utilized the first 23 channels. Later that year, Japan became the first country to utilize all 79 channels. The bandwidth is limited to 1 MHz per channel and spread spectrum (CDMA) communication standards need to be employed (Miller, Bisdikian, 2002).

Bluetooth is an effective standard that can be utilized in the consumer market, but it is most often utilized for direct network access onto LANs, which is popular in the enterprise sector. For this direct access to work, the network must employ Access Points[18]. The connection to these wireless data access points is virtually the same as that of any IEEE 802.11 wireless connection. This data Access Point simply provides a "connection" to the network.

Bluetooth also supports the formation of ad hoc networks. An ad hoc network is a spontaneously created network, considered to be a Personal Area Network[19] (PAN) (Miller, Bisdikian, 2002). A PAN is considered a sub part of a LAN. LANs are considered to be a larger cluster of communicating devices, whereas a PAN is usually only a very few local machines. An ad hoc network is a network that shares devices without a central control device. For example, an instructor might create an ad hoc network with his class. If the instructor is giving a lecture and he or she is utilizing a PowerPoint presentation, the instructor might share the presentation to anyone in the local area with the ability to receive a Bluetooth communication. This transmission takes place separate from any formal LAN, weather wired or wireless.

HOME RF / SWAP

HomeRF, or Shared Wireless Access Protocol (SWAP) is a common air interface that supports wireless LAN data service and wireless voice in the home environment. SWAP is based upon existing Digital Enhanced Cordless Telecommunication (DECT) and IEEE 802.11 standards. (Morinaga, Kohno, Sampei, 2000) SWAP also utilizes TDMA for efficiency purposes of both power management and frequency use efficiency. Also by utilizing TDMA, SWAP can support VoIP and streaming audio/video.

SWAP utilizes Carrier Sense Multiple Access Collision Detection/Collision Avoidance (CSMACD/CA) technology. (Schnider, 2001) By utilizing CSMACD/CA high speed communication protocols can be utilized on the network. The most common example of this is SWAP taking advantage of utilizing Transmission Control Protocol/Internet Protocol (TCP/IP), a fast, efficient, redundant, and routable protocol. SWAP also supports many other transmission protocols, such as Internet Packet Exchange/Sequenced Packet Exchange (IPX/SPX). IPX/SPX is not commonly utilized today, but it still exists on some older Novell networks and is properly addressed.

Swap has the ability to operate both as an ad hoc network and under the control of a Connection Point[20]. When SWAP is in the ad hoc mode, only data communication can occur. When SWAP is in the Connection Point mode, TDMA standards are enforced, allowing the system to coordinate all interaction between transmitters and receivers, giving the ability for sequenced packet transmission. Again, as with TDMA, there is also an increase in power management efficiency.

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[18] Though the exact specifications of Access points are beyond the scope of this report, for more information, please reference Bluetooth 1.1, Connecting Without Cables, 2nd ed. by Jennifer Bray and Charles Sturman.

[19] For more information about PANs, please see IEEE 802.15, Wireless Personal Area Networks.

[20] A Connection Point in SWAP is the equivalent to an Access Point in IEEE 802.11.

IEEE 802.11

International Electronic and Electrical Engineers Standard 802.11 defines the standard for over-the-air protocols necessary to support networking in the local area. There are two possible configuration designs with 802.11 standards. That of an ad hoc communication configuration allows nodes to communicate directly with other nodes. The second configuration is that of an Access Point configuration. (Morinaga, Kohno, Sampei, 2000) These Access Point style configuration networks are the most common type of wireless network used in the United States. Some examples are the wireless network supported by the University of Pittsburgh in public areas and the wireless network supported in the SIS building.

The standards of IEEE 802.11 standard set transmission and reception to the 2.4 GHz band. It supports a data rate of 1 and 2 Mbps and the modulation is based upon spread spectrum (CDMA) technology and Direct Sequence Spread Spectrum (DSSS) modulation. DSSS is a frequency spectrum communication technology, operating at the 2.4 GHz band which supports 1 and 2 Mbps communication speeds. DSSS utilizes DBPSK[21] and DQPSR[22] modulation techniques.

Inherent to the design of Access Point style networks is the ability for soft handoffs to occur. This process is very similar to that of CDMA technology, but some terms should be defined here. Each access point (the equivalent to a cellular tower) has a limited coverage area, referred to as the Basic Service Set (BSS). When you have two or more access points that complement each other, there now exists an array of Basic Service Sets. These BSSs jointed together create what is called the Extended Service Set (ESS) similar to having multiple cellular telephone towers. When there is more than one BSS, the two or more Access Points need to be coordinated. This is the job of the Inter Access-Point Protocol (IAPP). IAPP coordinates the access points to ensure seamless soft handoffs. Of course, all the handoff rules described to this point stand as rules for handoffs with IEEE 802.11.

Wireless 1394 is similar to IEEE 802.11, but it differs with some key components. Wireless 1394, also referred to as IEEE 802.11a or Multimedia Mobile Access Communication (MMCA), operates on the 5.2 GHz band U-NII (Universal National Information Infrastructure) (Newton, 1995). The communication speed of Wireless 1394 is 1, 2, 5.5, and 11 Mbps. Modulation is based on that of OFDM[23]. As read previously, OFDM was generated from the MCM technology of the 1960's. Packet communication is based on CDMACD/CA technology, which allows high speed data exchange.

IEEE 802.11g is the most recent standard to be released on the commercial market. The g standard supports transmission speeds up to 54 Mbps while operating on the 2.4 GHz band. It has a transmission range of 300 feet and is fully backwards compatable with IEEE 802.11b (Mallick, 2003).

BRAN

Broadband Radio Access Network (BRAN) is a family of four network standards. Collectively, they are referred to as the High Performance Radio Local Area Networks or HIPERLAN. BRAN technology supports a vast variety of applications and has many functional uses. (Morinaga, Kohno, Sampei, 2000) BRAN is a project of ETSI[24]. The family includes:

1. HIPERLAN Type 1: A high speed wireless LAN. Though HIPERLAN 1 is fully developed, it remains virtually unutilized.

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[21] *Differential Binary Phase Shift Keying:* A data bit (0 or 1) is signaled by two possible phase values; the significance is placed on the phase change.

[22] *Differential Quadrature Phase Shift Keying:* Reference Appendix B for more information.

[23] More information about OFDM can be found in the chapter on Future Topics.

[24] European Telecommunication Standards Institution.

2. HIPERLAN Type 2: A short range wireless technology that allows access to IP[25], ATM[26] and UMTS[27] Style networks. At the time of this paper, HIPERLAN 2 was still underdevelopment.
3. HIPERACCESS: A fixed wireless broadband point-to-multipoint radio access technology. HIPERACCESS provides a connection speed of 25 Mbps.
4. HIPERLINK: A wireless broadband point-to-point interconnection providing very high data rates. HIPERLINK provides a connection speed of 155 Mbps.

[25] IP: Internet Protocol.
[26] ATM: Asynchronous Transfer Mode.
[27] UMTS: Universal Mobile Telecommunication Systems.

FUTURE

In this chapter, focus will be on the current third generation technologies that appear to have a good chance of remaining in use for the near future. Focus will also be on the new fourth generation cellular systems and IPv6 standards currently under development.

WIDEBAND CDMA

Wideband CDMA is one possible technology that will exist in the future. Currently, WCDMA is defined under the IS-95b standard. WCDMA operates at the 5 GHz band and allows data transfer speeds of over 2 Mbps. With increases in technology, speeds of over 5.4 Mbps are possible for both voice and data transmission (Ojanpera, Prasad, 2001).

The original standards for WCDMA were set in 1998 by a group of cellular operators referred to as the Operators Harmonization Group (OHG). Their drive was for global harmonization of third-generation cellular standards for complete interoperability between the existing 3g systems.

The deployment of the WCDMA technology will be broken into two phases. In the first phase, the system will handle only data transmission. The second phase will be a dual system for transmission of both voice and data. The frequency trends are to push for higher and higher frequency bands with finer spread spectrums, creating more available communication channels. The future of WCDMA most likely will follow these trends onto the future.

SATELLITE

Satellite communication already provides coverage into virtually every visible corner of the earth. This allows for a network to exist where it would be too inhospitable or too costly to build a network. An excellent example is the US military's use of satellite communication on the battlefield.

The use of non-geosynchronous (non-GSO) satellites[28] will take a precedent roll in the future of communication.[29] Even though radio waves travel at the speed of light, it still causes a significant delay if the cellular signals are bounced off these satellites. By utilizing the non-GSO satellites, the signal only has to travel a few miles up, reducing travel distance and travel time. The US Government's GPS-ONE system is an example of a low-orbit satellite system.[30] This system consists of 21 GPS transmission satellites, providing a virtual blanket of coverage to all corners of the planet. Low-orbit satellites sit in an orbit of between 200 miles and 800 miles. It only takes about 90 minutes to orbit the earth (Comins, 2001). A second class of non-GSO satellites, medium-orbit satellites, has an orbital altitude of approximately 5000 miles.[31] Other examples of non-GEO systems are Globalstar, Iridium, and Odyssey (Comparetto, 1997).

OFDM

Orthogonal Frequency Division Multiplexing (OFDM) is a technology first pioneered by the US military from late 1950's to early 1960's. In the 1980's, a reemergence of research on OFDM technology began. The

[28] Any non-GSO satellite is one that as it orbits the earth, it moves without respect to one specific spot. US weather satellites are usually high-orbit GSO satellites, which allow the tracking of weather patterns without changing their respective position.

[29] A GSO is a satellite whose orbit resides at an altitude of 23,600 miles.

[30] To step out of context, the author of this paper is an astronomy guru, and studies this material all the time.

[31] A satellite is any object in orbit around the earth, not just what is commonly knows as a satellite transmitter. All debris caught in the earth's gravitational field that is floating up there is considered to be a satellite object. For more information please reference: Discovering the Universe by Neil F. Comins.

future of this technology is currently unknown. The push of OFDM is for digital audio broadcasting, data transmission over POTS, and advanced mobile technology. It appears that the development field is on the verge of many breakthroughs in OFDM techniques. Many of the implementation problems of OFDM are currently solvable (Morinaga, N. Kohno, R. Sampei, S. 2000). One possible future for OFDM is for extensive utilization in future fourth generation systems. OFDM looks to be the promising technology in developing 4g systems (Hara, Prasad, 2003)

FOURTH GENERATION CELLULAR

The first three generations of cellular systems along with POTS were shaped by two things. First, POTS provide service for a single circuit consisting of switched voice communication across an analog network. The network takes a considerable amount of technology to operate at the core, but at the end user, there is relatively little. Any additional service that could be squeezed out of the network could be considered a bonus. Second, operators are required to have the ability to charge for network services used, based upon network usage on destination and duration of call. Interoperability between local operators[32] was solely based upon the possibility of financial gain. Some thoughts on how to develop the 4g systems would be to allow a natural evolution, yet others believe in a more futuristic view of 4g systems (Dixit, Prasad, 2003).

The future of fourth generation systems will be the first of many radically different network designs. The future of these IP based networks will be based upon current and future customer desires of the network. The new network must be able to flex and adapt to the ever changing market trends. Cellular communication will become as popular a communication method as POTS, if not more popular. Based on this, the new 4g systems will assume that all users are potentially wireless users.

With wireless communication, current 2g and 3g systems allow for handoffs to occur within the same network. If you try to cross networks, I.E. stay on the phone while in your network and then try to change to a roaming network, your call will be dropped. On the 4g systems of the future, systems will be distributed, allowing users to change networks effortlessly. Users will be allowed to handoff to any available network in any topology. This means all future 4g cellular phones must be able to integrate and utilize all current cellular technology, along with the future technologies. This is a huge technological step, but with the increases in technology, this colossal step might begin to shrink.

Security is another primary concern of the 4g systems. Current 2g and 3g system rely on encryption for secure exchange of information. In the future, 4g systems will utilize a style of authentication between cellular devices that ensures true identity confirmation to permit the communication desired. Though much of this technology still needs defined and developed, this is one of the possible future paths of 4g systems.[33]

INTERNET PROTOCOL V.6

With the future fourth generation systems being based upon IP technology, a larger IP network is needed. IPv6 is based off a 128-bit addressing scheme. The current IPv4 systems are based off a 32-bit addressing scheme. This much larger, new addressing schema will allow for much new growth over the current schema. Local machines will have the ability to contain multiple IP addresses, each within its own scope.

IPv6 will support a technology called Stateless Address Autoconfiguration, a technology that allows network devices to automatically obtain an IP address automatically based upon an interface identifier (Dixit, Prasad, 2003). This technology operates in a fashion very similar to Boot Strap Protocol (BootP) or Microsoft's

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32 Operators could be thought of as the different cellular companies.

33 Unfortunately, there is not enough space to fully develop 4g systems in this report. For more information, please reference MulitCarrier Techniques for 4G mobile Communication by Shinsuke Hara and Ramjee Prasad.

Dynamic Host Configuration Protocol (DHCP), but is driven at the core levels of the network, not at the operating system level[34].

MARKET CONSIDERATIONS

The focus of this report has been mostly on technology; however, some consideration must be paid to the current conditions of the market. For predictions of possible future technologies to have any validity, the current conditions of the market must be reasoned. Future predictions are inherently difficult and the wireless field is no exception. Today's companies find tremendous difficulty in envisioning the short-term future; therefore, a long-term future prediction is virtually impossible. Some estimates by the UTMS Forum have estimated over 1.7 billion cellular users by 2010. This equates to approximately 20% of the global population. Though an exceedingly large number, that is not seemingly out of range. Just look around, and attempt to think of someone you know without a cell phone. In today's world, this can prove to be a very difficult task. According to Shosteck[35], cellular phone sales have maintained an average growth rate of 50.9% annually for worldwide marketing from 1992 to 2002.

System traffic engineering is the process of determining the physical and logical resources that need to be in place at various node locations within the network to support the potential future traffic. If solid estimates can be produced as to what the future traffic will be, this determining process is quite easy (Smith, Grevelis, 2003). Unfortunately, the future is not as easy to predict as could be thought.

THE UNKNOWN

The future is unknown. Human nature will always want the newest fastest and "coolest" technology available. As previously stated, third generation systems will be around for a long time; their market saturation will not permit them to disappear. Their eventual demise will be from the futurist styles of the fourth generation systems. With the integration of 4g systems and their horizontal distributed system design, the future looks great for open systems. IP networks will allow almost instant access to virtually all information. The new future devices might implement more than just hearing and seeing, they might include all five of the human senses.

For the future, I predict, and I feel certain many others would agree, long-term communication will bring technologies that are drastically different from current technology. Even the rough details of these new technologies are impossible to predict today. The technologies in 20 years will be as different as today's technologies would have appeared to a person 100 years ago.

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[34] The definition of IPv6 is unfortunately beyond the scope of this report. Also, IPv6 still is not fully defined currently.

[35] Shosteck, H. (1998). The Explosion in World Cellular Growth. *The 2nd Annual UWC Global Summit,* Vancouver, British Columbia, Canada, April 15-17, 1998. *Found in:* Ojanpera, T. Prasad, T. (2001).

CONCLUSION

Wireless communication technology has existed for less than 200 years. In these few recent years, technology has changed at an incredible rate. From the earliest discoveries of Michael Faraday and proposals of James Maxwell, the field of wireless communication has been expanding. Heinrich Hertz proved Maxwell's theories of EM waves in 1887 and opened the field to all future scientists and engineers. Guglielmo Marconi was the first person to succeed at transoceanic telegraphic communication.

In the early 1900's, as the wireless telegraph was being perfected, Lee deForest was working on a wireless transmission of voice. The first popular transmission of voice was from the Eiffel Tower in 1907. This successful transmission was broadcast for over 500 miles.

By 1920, the first AM radio stations were "on the air". KDKA in Pittsburgh is considered to be the first public broadcast radio station to operate on a twelve month schedule. KDKA can still be heard in Pittsburgh at the frequency of 1020 KHz. In 1935, Edwin Armstrong had successfully invented FM radio. W1XOJ was the first FCC licensed FM radio station in the United States.

In 1947, the first theories about wireless mobile telephony systems were being discussed. During the 1950's and 1960's, Bell Labs and the US Military were instrumental in developing transmission technologies such as Multi Carrier Modulation, eventually leading to the cellular technologies of today. Dr. Martin Cooper is considered the father of the modern cellular telephone. He and his team of scientists invented the first cellular telephone in 1973, Motorola's Cellular Radio.

The first cellular standards began to emerge in the late 1970's in the United States. AMPS was and still is the basic standard for analog cellular telephone systems utilized in the US. The Nordic Mobile Telephone System, launched in 1981, was the first cellular system to become a multi-national cellular system.

The first digital cellular systems were being released in the United States in 1990. These systems were designed around and defined by IS-54. IS-54 allowed for a dual analog/digital system. GSM of Europe also launched digital service in a similar timeframe. Within a few years, GSM has spread into 52 different countries.

Third generation cellular systems were soon to follow. CDMA technologies, the basis of third generation systems, were first to appear in the United States as early as 1993. These new 3g systems were defined by IS-95. The 3g systems were also the first cellular systems to employ a soft handoff feature.

Currently four wireless LAN standards dominate the market in the world. Bluetooth, HomeRF, IEEE 802.11 and Bran are the standards. All of these systems utilize the 2.4 GHz ISM spectrum, a globally unlicensed band, allowing use in almost any location.

The general rule of thumb for anything is, the future is very difficult to predict. This rule is also true for IT technologies. The future of wireless communication technologies is completely unknown. Though one can analyze market trends, review the past technologies, and postulate a guess as to what the future might hold, that individual would still be making a guess. It is almost guaranteed that the future holds great promise for the growth of the cellular and wireless markets. It is estimated that by 2010, approximately 20% of the global population will possess some form of wireless communication technology.

A brief discussion on the following possible future technologies is in this section. Wideband CDMA is a possible cellular communication standard with increased voice and data exchange rates on a 5.4 GHz band. The increase in satellite communication utilization will spawn new and more utilized technologies. The satellite communication technology also will allow for increased communication in inhospitable terrain. Orthogonal Frequency Division Multiplexing (OFDM) will take a more dominant roll in the future in combination with the fourth generation cellular systems.

This will only be possible with the development and implementation of new technologies. Fourth generation cellular systems and IPv6 are two of the future technologies that will eventually become the market standard, but presently, they are still years away. For the future, I predict, and I am sure many others would agree, long-term communication will produce technologies that are drastically different from current technology. Even the rough details of these new technologies are impossible to predict today. Technologies in 20 years will be as different as today's technologies would have appeared to a person from 100 years ago.

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http://en2.wikipedia.org/wiki/Edwin_Howard_Armstrong

APPENDIX A: ANALOG CELLULAR TELEPHONES

System Name	Common Name	Start Date	Region operated in
AMPS	Advanced Mobile Phone Service	1979, 1983	United States, worldwide
ARORA-400		1983	Alberta, Canada
C-Netz		1981	Germany, Austria, Portugal, South Africa
Comvik		August, 1981	Sweden
ETACS	Extended TACS	~1987	UK, worldwide
JTACS	Japan TACS	June, 1991	Japan
NMT 450, 900	Nordic Mobile Telephone	1981, 1986	Sweden, Norway, Denmark, Finland, Oman
NTT	Nippon Telephone and Telegraph	December 1979	Japan
NTT Hi Cap	Nippon Telephone and Telegraph High Capacity	December 1988	Japan
RadioCom		November, 1985	France
RTMS	Radio Telephone Mobile System	September, 1985	Italy
TACS	Total Access Communication System	1985	UK, Italy, Spain, Austria, Ireland

APPENDIX B: COMMON TECHNOLOGIES

	Analog Cellular Telephones			Digital Cellular Telephone				
Standard	AMPS Advanced Mobile Phone Service	TACS Total Access Communication System	NMT Nordic Mobile Telephone	IS-54/-136 North American Digital Cellular	IS-95 North American Digital Cellular	GSM Global System for Mobile Communications	DCS 1800	PDC Personal Digital Cellular
Mobile Frequency Range (MHz)	Rx:869-894 Tx:824-849	ETACS: Rx:916-949 Tx:871-904 NTACS: Rx:860-870 Tx:915-925	NMT-450: Rx:463-468 Tx:453-458 NMT-900: Rx:935-960 Tx:890-915	Rx: 869-894 Tx: 824-849	Rx: 869-894 Tx: 824-849	Rx:925-960 Tx:880-915	Rx: 1805-1880 Tx: 1710-1785	Rx: 810-826 Tx: 940-956 Rx: 1429-1453 Tx: 1477-1501
Multiple Access Method	FDMA	FDMA	FDMA	TDMA/ FDM	CDMA/ FDM	TDMA/ FDM	TDMA/ FDM	TDMA/ FDM
Duplex Method	FDD	FDD	FDD	FDD	FDD	FDD	FDD	FDD
Number of Channels	832	ETACS:1240 NTACS:400	NMT-450: 200 NMT-900: 1999	832 (3 users /channel)	20(798 users /channel)	124 (8 users /channel)	374 (8 users /channel)	1600 (3 users /channel)
Channel Spacing	30kHz	ETACS: 25kHz NTACS: 12.5kHz	NMT-450: 25kHz NMT-900: 12.5kHz	30kHz	1250kHz	200kHz	200kHz	25kHz
Modulation	FM	FM	FM	(π/4 DQPSK)[36]	QPSK[37] /OQPSK	GMSK[38] (0.3 Gaussian Filter)	GMSK (0.3 Gaussian Filter)	(π/4 DQPSK)
Channel Bit Rate	n/a	n/a	n/a	48.6 kb/s	1.2288 Mb/s	270.833 kb/s	270.833 kb/s	42 kb/s

[36] *Differential Quadrature Phase Shift Key:* Similar to QUSK, but two data bits are signaled by phase change of the phase change between three possible values.

[37] *Quadrature Phase Shift Keying:* A Modulation scheme which uses phase values to encode two data bits per modulated symbol.

[38] *Gaussian Mask Shift Keying:* A modulation technique that represents a data bit by a shift in phase.

These definitions courtesy of Jennifer Bray's and Charles Struman's book, Bluetooth 1.1 Connection Without Cables (Bray, Struman, 2002).

APPENDIX C: IEEE STANDARDS

The IEEE can be accessed online. This includes a catalog of all standards, at http://standards.ieee.org

IEEE 802.1: High-Level Interface Subcommittee:
: Address matters relating to network architecture, management, and interconnections.

IEEE 802.2: Logic Link Control Subcommittee:
: Defines the functions of the logical link controller sub layer of the OSI reference model data link layer. The objective of the LLC is to provide a consistent, transparent interface to the media access control (MAC) layer, so the network layers above the data link layer are able to function correctly regardless of the MAC protocol.

IEEE 802.3: Standard:
: A standard that covers a variety of CSMACD/CA architectures that are generally based on the Ethernet.

IEEE 802.4: Standard:
: A subcommittee that sets standards for token bus networks.

IEEE 802.5: Standard:
: A subcommittee that sets standards for token-ring networks.

IEEE 802.6: Standard:
: A MAN standard to the FDDI family of technologies. The IEEE 802.6 standard has also been adopted by ANSI. The standard is also called the distributed queue dual bus (DQDB) standard. The name DQDB indicates the architecture used two buses. Each bus is unidirectional, indicating that data is transmitted in one direction on one bus and in the opposite direction on the second bus.

IEEE 802.7: Broadband Technical Advisory Group:
: Provides guidance and technical expertise to other groups who are establishing broadband LAN standards, such as the 802.3 subcommittee for 10broad36.

IEEE 802.8: Fiber Optic Technical Advisory Group:
: Provides guidance and technical expertise to other groups that are establishing standards for LANs using fiber optic cable.

IEEE 802.9: Integrated Data and Voice Networks Subcommittee:
: Sets standards for networks that carry both voice and data. Specifically, it is setting standards for interfaces to integrated services digital networks.

IEEE 802.10: LAN Security Subcommittee:
: Address the implementation of security capabilities such as encryption, network management, and the transfer of data.

IEEE 802.11: Wireless LAN Subcommittee:
: Sets standards for multiple wireless transmission methods for LANs.

IEEE 802.12: Demand Priority Access Method Subcommittee:
: Developed the specifications for the 100VG-AmyLAN protocol. The protocol specifies 100-Mbps speed over twisted-pair wires.

IEEE 802.13: not yet assigned

IEEE 802.14: not yet assigned

IEEE 802.15: Wireless Personal Area Networks:

Sets standards for information exchange between systems on both local and metropolitan area networks. Part 15.1 specifically for Wireless Medium Access Control and Physical Layers for Personal Area Networks

IEEE 802.16: Wireless MAN:

Air interface specification for MANs. This standard attempts to replace "The last mile wired access" with cable modems and digital subscriber lines by broadband wireless access (BWA).

APPENDIX D: FREQUENCY / WAVELENGTH

Radio Frequencies and Corresponding Wave Lengths (Graham, 1938)					
Frequency, KHz	Wavelength λ	Frequency, KHz	Wavelength λ	Frequency, KHz	Wavelength λ
300,000	1	2,500	120	750	400
150,000	2	2,000	150	700	429
100,000	3	1,700	177	650	462
75,000	4	1,600	188	600	500
60,000	5	1,500	200	550	545
50,000	6	1,450	206	500	600
40,000	8	1,400	214	450	667
30,000	10	1,350	222	400	750
25,000	12	1,300	231	350	857
20,000	15	1,250	240	300	1,000
15,000	20	1,200	250	250	1,200
12,000	25	1,150	261	200	1,500
10,000	30	1,100	273	150	2,000
8,000	38	1,050	286	100	3,000
6,000	50	1,000	300	50	6,000
5,000	60	950	316	40	7,500
4,000	75	900	333	30	10,000
3,000	100	850	353	20	15,000
		800	375	10	30,000

APPENDIX E: WIRELESS LAN STANDARDS

List of proposed wireless LAN standards					
	Bluetooth	HomeRF (SWAP)	IEEE 802.11	BRAN	Wireless 1394 / IEEE 802.11a / MMCA
Frequency (GHz.)	2.4	2.4	2.4	2.4	5
Data Rate (Mbps)	1	2	1,2	155	1, 2, 5.5, 11, 54
Modulation	Frequency Hopping Spread Spectrum	Frequency Hopping Spread Spectrum	Frequency Hopping Spread Spectrum / Direct Sequence Spread Spectrum	Orthogonal Frequency Division Multiplexing	Discrete Multi-Tone / Orthogonal Frequency Division Multiplexing