1

Historical Sketch of Wireless Communications

The reason why humans have become the most advanced species is that they produce information, store it on paper or in electronic devices, and exchange it among them. Especially, the exchange and diffusion of information has changed people's lifestyle significantly. For example, let's assume a traveler is visiting a place. Before cellular phones were in use, the traveler had to plan his visit carefully. He should book the hotel and flight and collect the information about the location manually beforehand. To locate the hotel or attraction points, he should make use of a map. Some people find this difficult as they may be disorientated. After cellular phones have come into use, a traveler can book a hotel and flight on the website using his smart phone. Once he reaches the place, the phone can guide him to the attraction points and provide useful information such as about a nice restaurant or a nearby bargain sale shop. In addition, he can make use of his phone to check email or stock price anytime and at anyplace. This drastic change in lifestyle is due to high-speed wireless communication. In this chapter, we will trace back through successive stages of wireless communications development in technical and economical aspects.

1.1 Advancement of Wireless Communications Technologies

Smoke signals used by Indian tribes are considered to be the start of wireless communication systems. Transmitting and receiving, and sending a message from one place to another place are pre-planned by them. However, the transmission range is limited to visual distance and can be carried out only in good weather. There are similar alternatives such as communication drums, signal lamps, carrier pigeons and semaphore flags. All the above have been used for thousands of years and semaphore flags are still being used in maritime communications.

The innovative paper *On Physical Lines of Force* was published by Scottish physicist and mathematician J. C. Maxwell between 1861 and 1862 [1]. This paper mathematically describes

Wireless Communications Systems Design, First Edition. Haesik Kim.

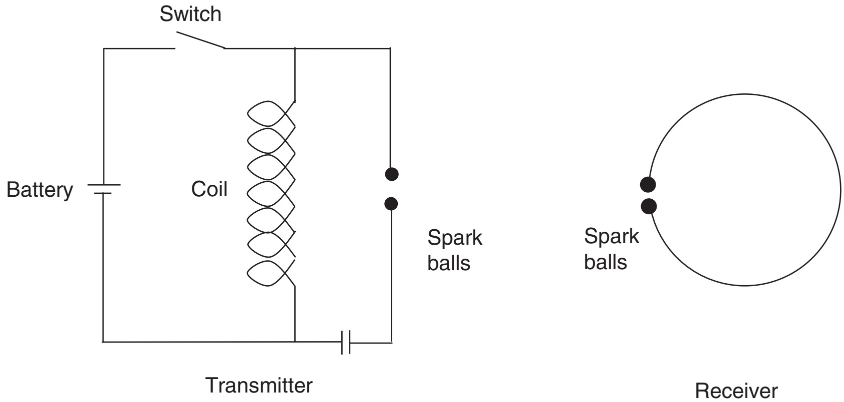

Figure 1.1 Hertz's experiment

how electromagnetic waves propagate. He predicted that the speed of electromagnetic wave is the same as that of the light waves. In 1880s, many scientists tried to prove the existence of electromagnetic waves. H. R. Hertz built an experimental apparatus to prove Maxwell's theory in 1887. The apparatus consists of simple transmitter and receiver with a small gap through which sparks could leap as shown in Figure 1.1. The transmitter can generate a spark and the receiver was placed several yards away from the transmitter. If the second spark appears in the receiver after the transmitter generates the first spark, it means the electromagnetic wave was transmitted and Maxwell's theory is correct. He published his work in the book *Electric Waves: Being Researches on the Propagation of Electric Action with Finite Velocity through Space* [2].

In the 1890s, many scientists continued Hertz's experiments. French scientist, E. Branly, invented the metal filings coherer which consists of a tube containing two electrodes. This device could detect the electromagnetic waves. Russian scientist, A. S. Popov, built a controllable electromagnetic system. On March 24, 1896, he demonstrated a radio transmission between two buildings in St. Petersburg. His paper "Apparatus for the detection and recording of electrical oscillations" [3] was published in the *Journal of the Russian Physical Chemical Society*. G. Marconi known as the father of long-distance radio transmission began his experiment in Italy contemporaneously. His experiment was nothing new but he focused on developing a practical radio system. He kept doing experiment with extending the communication distance. In 1901, he built a wireless transmission station in Cornwall, England, and successfully transmitted a radio signal to Newfoundland (it is now a part of Canada) across the Atlantic Ocean. His radio system was huge and expensive equipment with 150 m antenna, high power, and low frequency. In 1906, L. D. Forest invented a vacuum tube which made the radio system to become smaller. This radio system was used by the US government and purchased by many other countries before the Great War. After the end of the Great War, there were many efforts to find alternatives to fragile vacuum tubes. American physicist W. Shockley and chemist S. Morgan in Bell Labs established a group that worked on solid-state physics and developed a transistor. This device opened a new era of electronics. This revolution made the field of wireless communication systems to become narrower and closer to the public. A transistor radio developed in 1954 was a small portable wireless receiver and the most popular wireless communication device.

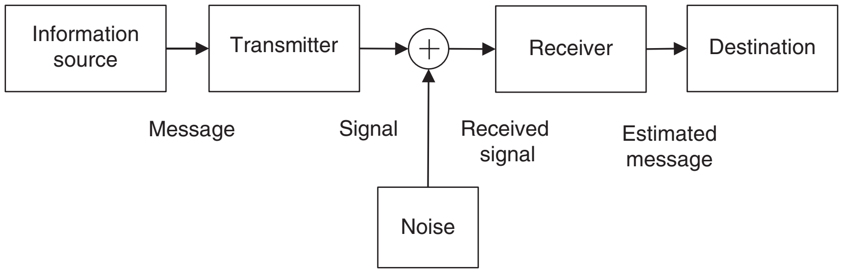

Figure 1.2 Shannon's communication architecture

Another revolution came from Bell Labs at the same time. Bell Labs scientist, C. E. Shannon, proposed information theory and published the landmark paper "A mathematical theory of communication" [4] in *Bell System Technical Journal*. Scientists at that time wanted to know how to measure information and how much information can be sent in a channel. Shannon adopted the concept of entropy to measure information, which was used in thermodynamics. Entropy of information theory means a level of the uncertainty of a random variable. He defined the channel capacity as the maximum rate of reliable communications over a noisy channel. In addition, he designed the communication architecture and is shown in Figure 1.2.

All of the current communication systems are based on Shannon's communication architecture. This architecture was innovative because a communication system designer can treat each component of the communication system separately. The time information theory was proposed became the golden age for the communication society. Many scientists developed new communication theories and implemented a new communication system. Another driving force of wireless communication systems came from the evolution of electronics. In 1958, engineer J. Kilby from Texas Instruments invented the Integrated Circuit (IC) and another engineer R. Noyce from Fairchild developed it independently a half year later. Noyce's IC chip was made of silicon while Kilby's IC chip was made of germanium. Noyce's IC chip was close to practical solutions and became an industry standard of the modern IC chips because silicon is much cheaper and easier to handle than germanium. As electronic devices evolve, wireless communication systems could be portable. The weight of the world's first mobile phone was over 30 kg. However, wireless communication systems reached greater levels due to IC technology and gradually the weights of mobile phones were significantly reduced.

A cellular system which has hexagonal cells covering a whole area without overlaps was introduced in the paper "The cellular concept" by V. H. MacDonald [5]. This paper produced another landmark concept and overcame many problems in wireless communication system such as power consumption, coverage, user capacity, spectral efficiency, and interference. The frequency reuse is one of the key concepts in the cellular network. The coverage of the cellular radio system is divided into hexagonal cells which are assigned different frequencies (F1–F4). Each cell does not have adjacent neighboring cells with same frequency as shown in Figure 1.3. Thus, cochannel interferences can be reduced, cell capacity can be increased, and cell coverage can be extended.

In each cell, it is necessary to have a multiple access scheme that enables many users to access a cellular network. Several multiple access schemes such as Frequency Division Multiple Access

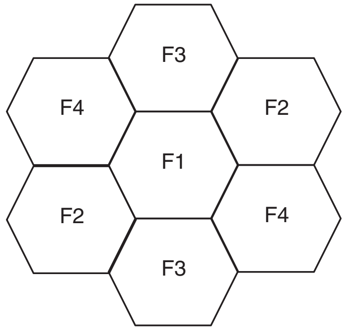

Figure 1.3 Example of frequency reuse

(FDMA), Time Division Multiple Access (TDMA), Code Division Multiple Access (CDMA), and Orthogonal Frequency Division Multiple Access (OFDMA) are widely used in cellular systems. This new concept opened another new era of wireless communications. Based on this concept, many commercial wireless communication systems were deployed. In 1979, Nippon Telegraph and Telephone (NTT) Corporation deployed the first commercial cellular network in Tokyo. Nordic Mobile Telephone (NMT) was launched in Finland, Denmark, Norway, and Sweden in 1981. Advanced Mobile Phone System (AMPS) developed by Bell Labs was deployed in Chicago, USA, on October 13, 1983, and Motorola mobile phones were used. These cellular networks were analogue-based systems. The analogue cellular phones were not popular due to high cost. After the digital Global System for Mobile Communications (GSM) called the 2nd Generation (2G) was launched in Finland in 1991, the mobile phone finally became an essential device. The huge success of GSM attracted many people to wireless communications. With wireless communication technologies advancing at a fast-growing rate, many new wireless communications were developed in not only long ranges but also short ranges. The 2G system provided voice service to users but the 3rd Generation (3G) focused on data service. The Universal Mobile Telecommunication System (UMTS) was one of the 3G systems standardized by the 3rd Generation Partnership Project (3GPP). The UMTS based on Wideband Code Division Multiple Access (W-CDMA) provided a high data rate service by including many new technologies such as turbo codes and adaptive modulation coding. High-Speed Packet Access (HSPA), Long-Term Evolution (LTE), and Long-Term Evolution-Advanced (LTE-A) kept achieving a high data rate because the volume of data service in wireless communication systems was getting bigger. In addition, the advent of smart phone brought the upheavals in wireless communication industry. The voice call is no longer the main feature of a mobile phone. Data services such as web browsing, video call, location service, internet games, and email service have become more important. Thus, the data rate has become the key metric to evaluate wireless communication systems. Table 1.1 shows us the evolution of 3GPP standards.

1.2 Wireless Communications, Lifestyles, and Economics

Let's imagine we have to send a message (100 alphabets) across the Atlantic Ocean. Before the advent of wireless communication systems, we had to deliver it by ship and it took about three weeks. The data rate was (100 alphabets × 8bits)/(3 weeks × 7 days × 24 hours × 60

Table 1.1 Evolution of 3GPP standards

	Data rate	Key features	Release date
GSM	DL: 9.6 kbps UL: 9.6 kbps	Digital, TDMA	1991
GPRS	DL: 14.4–115.2 kbps UL: 14.4–115.2 kbps	TDMA, GMSK, convolutional coding	1999
UMTS (Release 99)	DL: 384 kbps UL: 384 kbps	WCDMA, turbo coding	March 2000
UMTS (Release 4)	DL: 384 kbps UL: 384 kbps	Higher chip rate than release 99	March 2001
HSDPA (Release 5)	DL: Up to 14 Mbps UL: 384 kbps	HARQ, fast scheduling, channel quality feedback, AMC	June 2002
HSUPA (Release 6)	DL: Up to 14 Mbps UL: Up to 5 Mbps	Multimedia broadcast multicast service (MBMS), integration with WiFi	March 2005
HSPA+ (Release 7)	DL: Up to 28 Mbps UL: Up to 11.5 Mbps	MIMO, higher order modulation, latency reduction	December 2007
LTE (Release 8 and 9)	DL: 140 Mbps (10 MHz)/300 Mbps (20 MHz) UL: 25 Mbps (10 MHz)/75 Mbps (20 MHz)	OFDMA, dual carrier HSPA, SON, femtocell	December 2008 (Release 8) December 2009 (Release 9)
LTE-A (Release 10)	DL: 1 Gbps (peak download) UL: 500 Mbps (peak upload)	Carrier aggregation (CA), coordinated multiple point transmission and reception (CoMP), relay	March 2011

minutes × 60 seconds) = 0.00044 bps. After wireless telegraph was invented, the transmission time was reduced to about 2 minutes and the data rate was reduced to (100 alphabets × 8bits)/(2 minutes × 60 seconds) = 6.67 bps. Now, let us compare these with the modern wireless communication technology such as GSM. The data rate of GSM is 9.6 kbps. Thus, it was raised by a factor of about 20 million times and about 1440 times, respectively. When comparing GSM with LTE-A, the data rate of LTE-A is 1 Gbps and LTE-A was raised by a factor of about 104,000 times. In terms of the transmission rate, we made great strides in the wireless communications technologies. It took 150 years to build the current cellular system from telegraph. Especially, it took only 20 years from GSM to LTE-A. The data rate improvement of wireless communications is summarized in Figure 1.4.

How does the improvement of wireless communication technologies affect people's life? If we consider the cost of delivery, it must be a significant impact. When we sail across the Atlantic Ocean in order to deliver a short message, we should spend for labour, fuel, ship maintenance, and so on. Besides the cost of delivery, we already have experienced the big change caused by the developments in wireless communication. The invention of a transistor radio made people listen to brand new music and the latest news in real time. Especially, when a weather centre issues a storm warning, radio is the most efficient way to distribute

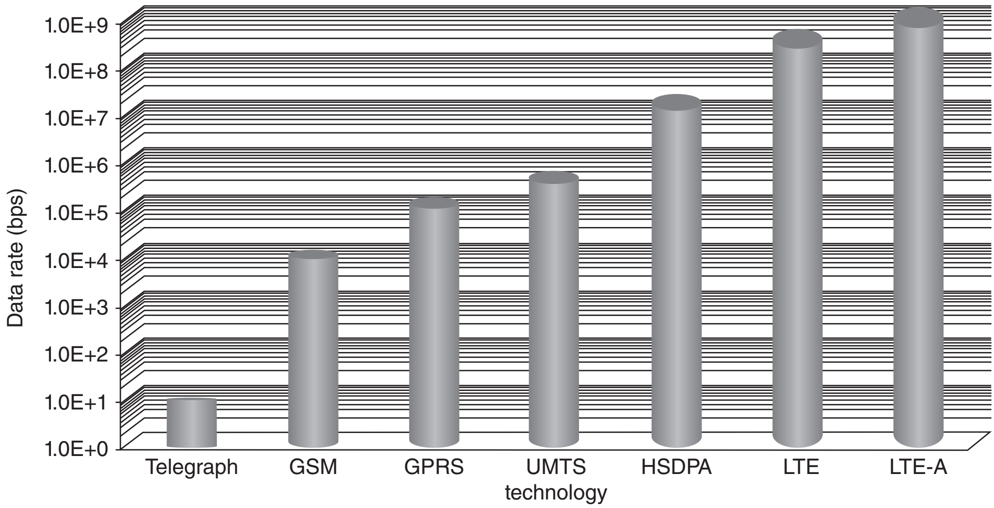

Figure 1.4 Data rates of wireless communications

information. The advent of the point-to-point communication brought another drastic change in our life. The first popular personal wireless communication device is a pager. This device can receive a short message consisting of a few digits that could be telephone numbers or some codes. After receiving the digits, people should find a landline phone to make a call. This device enables people to connect more freely. However, this device is one-way communication and does not support voice calls and relies on a landline phone. Today, the digital 2G system has become more popular and useful personal wireless communication device. The voice quality it provided is almost the same as a landline phone service. People were connected wirelessly and could work inside and outside. The 3G system made a revolution in the usage of Internet and the advent of smartphones, thereby drastically changing lifestyle. It supports broadband service and can access mobile web. Smartphone is mobile terminal supporting voice call and mobile computing. This device enables mobile users to trade stocks, browse webs, download files, exchange emails, trace locations, play video games, and so on. Regardless of time and place, people can access Internet.

Now, let’s take a look at commercial usages and economics of wireless communications. When the electromagnetic waves are actively researched, many scientists didn’t realize their commercial value. H. Hertz who proved the existence of electromagnetic waves was one of them. He said *It is of no use whatsoever this is just an experiment that proves Maestro Maxwell was right. We just have these mysterious electromagnetic waves that we cannot see with the naked eye. But they are there* [6]. When he was questioned about their commercial importance, he said “*Nothing*.” However, G. Marconi was different. He applied for a patent for his invention and was awarded famous British patent No. 7777 “Improvements in apparatus for wireless telegraphy” [7]. He established his company, Wireless Telegraph and Signal Company, in 1897, and provided telegraphic service. Until a transistor radio was invented, wireless communication systems were of limited usage because it was bulky and expensive, and therefore, it was operated among wireless stations. The invention of transistor radio made advertisers more fascinating about the device. Radio commercial is still one of the most important modes of marketing. Their interest in wireless communication systems has been sped-up since the advent of television. The wireless communication device having become a personal device, spectrum shortage problem started to occur. Therefore, the International Telecommunication Union (ITU) started coordinating the use of radio spectrums and building communication standard. The role of ITU is to allocate frequencies to some wireless communications in overall point of view, and national regulators such as the Office of Communications (Ofcom) of the United Kingdom allocates frequencies to specific uses with complying with ITU guidelines. The usage of frequencies differs across counties. For example, Britain operates frequency bands from 88 MHz to 1 GHz for TV broadcasting (40%), defence (22%), GSM (10%), and maritime communication (1%) [8]. As the number of different wireless communication systems is rapidly rising, the price of the frequency band is getting higher and there is an increased shortage of frequency band. Basically, a government sells them to telecommunication operators by spectrum auction. The Britain sold the 3G frequency bands to telecommunication operators in 2000 and the total winning bid was €38.3 billion. Thus, wireless resources have become one of the most valuable natural resources in the world.

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