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History of Antenna Technology for Mobile Communications in Korea

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SUMMARY In this paper, we discuss the development of wireless and mobile communications in Korea, current technological trends, and the future outlook on technological developments. Since the introduction of the telegraph and the telephone in September 1885, Korea's wired and wireless communications industry has consistently developed for over 100 years. Since 1984, upon the provision of the mobile telecommunications service, the industry has seen drastic qualitative and quantitative growth in terms of both technical and economic aspects, which played a crucial role in the rapid growth of the digital industry in Korea. After the era of the analog cellular service based on the Advanced Mobile Phone System (AMPS), a precursor to the modern mobile service, Korea became the world's first country to commercialize Code Division Multiple Access (CDMA) in 1996 and succeeded in commercializing CDMA 2000 1x (IMT-2000) in 2001. With further developments in the mobile communication technology, the technology for antennas also saw drastic advancements. As the mobile antennas moved from the second to the third generation, they grew from external models to very small internal models. At the same time, they evolved into highly functional and high performance multiple band and wide band antennas. Furthermore, Korea was the first country to commercialize and offer the Wireless Broadband Internet (WiBro) service in 2006. By leading the wireless communications standardization and exerting remarkable efforts in research and development, Korea is consolidating its status as an Information Technology (IT) leader in the global market. The antenna's inherent importance will be further emphasized in the near future as it satisfies the performance and structural needs of portable terminals necessary for realizing the projected establishment of the ubiquitous world. It is thought that antenna technologies will not be limited to simple concepts as previously experienced but will utilize various kinds of materials that build the terminals' structure and framework. Moreover, studies will be performed with an emphasis on multiple band, multiple directivity, and ultra-wide band. Accordingly, antenna technologies to which new concepts are applied, such as SMART antenna and MIMO antenna technologies and meta-materials, will surely be effective alternatives.

key words: *Korea, antenna history, CDMA, AMPS, MIMO*

1. Introduction

Since the introduction of the telegraph and telephone in Korea, the wired and wireless communications industry has consistently developed for over 100 years under the stewardship of the government and the military. Until the 1980s, wireless communication was not available to the general public but was mainly used by the military or the police in special applications or private applications at sea or for aerial control. As the scope of Korea's activities expanded in every field and its people's living standards improved, thanks to economic growth, demand for advanced communications service also increased. Groundbreaking technologies developed in the USA and Japan introduced Korea to the commercialization of radio paging and cellular mobile services, and naturally, the public's interest in mobile communications service also increased.

Korea was the world's first country to commercialize Code Division Multiple Access (CDMA) in the period of the second generation mobile communication, which decisively contributed to the development of the country's IT industry as well as to its economic growth that eventually placed it well in a leading position in information and communications technology. Aside from playing a tremendous role in improving living conditions in Korea and bolstering the national income, mobile phone services are believed to have played a major role in ending Korea's foreign exchange crisis, which started in November 1997 and ended on August 23, 2001, when Korea redeemed the total amount of its loan from the International Monetary Fund (IMF).

Starting with 10,000 signal tone method lines in Seoul, radio paging service expanded to major cities such as Busan, Daegu, Gwangju and Daejeon as the phone number indication method was introduced in 1986. At the end of 1992, the number of lines for radio paging service soared to 2.45 millions, with 1.45 million subscribers, achieving a 59.0% acceptance rate. Most of the early subscribers to the radio paging service were working for or with special institutions such as the government or the media. With the surge in the popularity of the service among white collar workers and other individuals, the number of its subscribers reached 15.19 millions in 1997, which confirmed the popularity and business potential of mobile communications [1], [2].

The second generation Cordless Telephone (CT-2), a type of wireless phone developed in 1988 and first commercialized in 1989, was an advanced form of CT-0, a wireless home phone operating in the 46/49 MHz frequency band and along with a wired telephone often used at home, and CT-1, a wireless telephone operating in the 900 MHz frequency band that was developed for use within a limited distance (200 m) [3]. CT-2 could only send signals, which were then connected to a wireless relay device (telepoint) installed in public phone booths on the street. About 10 countries are currently offering this service, although it has few subscribers. In Korea, three companies first offered this service in 1997, but due to the emergence of digital mobile phones and Personal Communication System (PCS), the service was merged with that of Korea Telecom and eventually discontinued. Although the CT-2 service was competitive at

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various levels, the timing of its introduction in Korea was bad. It was soon set aside even before it could compete with other services.

In the following chapters, we describe in detail technological developments and trends in Korea's mobile communications and antennas by generation, as well as the antenna technology required in the succeeding generation and future mobile communication. The categorization of generations described in the paper followed the usual generation categorization: the first generation was the analog era; the second generation, the beginning of the digital era; the third generation, the era in which more developed and differentiated services, such as multimedia, from those in the second generation were offered, thanks to the improvement in service speed; and the fourth generation, the era in which more advanced, larger amount of information is processed and heterogeneous kinds of services are integrated and offered to subscribers. It is believed, however, that this categorization may depend on the viewpoint or goal of such a categorization.

2. The Generations of Mobile Communication

In 1982, Korea's Ministry of Communications (now Ministry of Information and Communications) established the Korea Telecom Authority, which aims to satisfy the nation's need for new communications services and nurture its mobile communications industry. In December of the same year, Korea introduced NEC Corporation's systems of Japan, followed by the launch of the first radio paging service. Korea also began preparing for the commercialization of mobile communications, as, for example, by introducing AMPS, the advanced cellular communications technology developed in the USA, for the mass production of car phones, and by founding the Korea Mobile Telecommunications Services Company in 1984 for the efficient and professional management of mobile communications services and for users' convenience. After the company was founded, and as the overall technologies in car phone service stabilized, the Korea Mobile Telecommunications Services Company played a crucial role in popularizing mobile communications in Korea by promoting various projects, such as by revising its fee and usage systems and expanding its serviced regions nationwide. In 1988, the company was designated as a public electric communications services provider, which enabled it to offer the full range of mobile communications services. Thereafter, mobile communications services expanded throughout Korea. Mobile communications in the 1980s emerged as a new symbol of economic growth, and new business activities using mobile communications mushroomed in the country. Car phone service, which became popular soon after its introduction in December 1987, set a record of over 10,000 subscribers within 3 years and 7 months after its launch.

Fig. 1 The first mobile phone used in Korea.

2.1 The First Generation

Early mobile communications within the Improved Mobile Telephone Services (IMTS), which started in the 1960s, had a limited number of channels, and the scope of their service regions were determined by the maximum output of the transmitter [4]. Therefore, this service was often disconnected in regions where there were many obstructions such as mountains or buildings, or where there were no base stations to which the user could subscribe. Moreover, subscriber capacity was also limited.

The cellular mobile telephone system emerged as a solution to the aforementioned problems. First proposed by the US Bell Lab in 1947, the concept of the cellular mobile telephone was realized when AT&T launched the Advanced Mobile Phone System (AMPS) in 1978.

The first generation of mobile communications transferred voice signals at a speed of 10 kbps in the 200–900 MHz frequency band using AMPS (USA), Total Access Communications System (TACS, UK), and Nordic Mobile Telephony (NMT, Sweden) [5], [6]. AMPS was first commercialized in the USA in 1983, and in the following year, it was introduced in other countries, including Korea, which thereafter launched its mobile communications service based on AMPS. In 1993, Korea became the world's first country to use IS-41A, which offered interactive connection among heterogeneous mobile phone switchboards. This was followed by the launch of Gateway, a gateway switchboard, which was also called Cellular Gateway Switch (CGS) and which unified the connection structure of heterogeneous mobile networks such as Korea Telecom's Public Switched Telephone Network (PSTN) switchboard, Autoplex (APX), and Enhanced Mobile Exchange (EMX), thereby markedly improving switchboard applications technology.

Figure 1 shows the first true mobile phone in the world [7]. It is developed in 1983. This phone was introduced to Korea in 1984 and became the first mobile phone used in the country [1].

In the 1980s, when the first generation mobile communication services were first offered, the semiconductor tech-

Fig. 2 The first Korean-made mobile phone.

nology was in its inception, and therefore, parts used exclusively for mobile phones or other wireless communication devices were still rare. This caused a huge gap in performance among various commercialized communication devices. Korea was still taking baby steps in the technology for the wireless communication device, and usually imported devices from USA or Japan, then the two leading countries in the communication industry. The country eventually developed its own technologies based on these foreign-produced devices. Users of such devices also showed more interest in devices that had high performance and were durable mobile phones were expensive at the time rather than their design or portability.

Figure 2 shows the first Korean-made mobile phone developed and released in 1989 [8]. Weighing about 700 g and was 20 cm in length, it was too bulky to carry around.

The first generation of mobile communications had a shortcoming: if the signal of one's phone used the same frequency as that of another signal, cross-talk and inefficient use of the frequency occurred. In the early 1990s, demand for mobile phones soared worldwide, and the first generation mobile phone service, which was based on analog methods, could not overcome its limitations in its systems and frequency resources due to the increase in the number of users. This required the urgent development of a digital system that could process a large volume of communication processes. Consequently, Korea's second generation mobile communications service was born, which overcame the shortcomings of the first generation, that is, its limitations in capacity and security.

2.2 The Second Generation

The second generation of mobile communications services in Korea can be divided into three methods: IS-136 Time Division Multiple Access (TDMA) [9], Global System for Mobile Communications (GSM) [10], and IS-95 CDMA [11]. IS-136 TDMA, an advanced version of IS-54 based on AMPS, the analog system on the Frequency Division Multiple Access (FDMA), was first commercialized in 1994 and is still widely used in North America.

Fig. 3 External type antennas for cellular and PCS antennas.

The CDMA system, in which many users share one frequency, was standardized as IS-95 in 1993, and was first commercialized in 1996 in Korea. Due to this first commercial introduction of an original technology, the development of the CDMA system had to face numerous challenges before it succeeded.

Since the end of 1997, the existing CDMA cellular system, the frequency band of which was 800–900 MHz, was difficult to maintain due to the increasing demand by a soaring number of subscribers. To solve this problem, Korea introduced the CDMA Personal Communications Service (PCS), which offered the same level of digital service as the previous CDMA cellular service but at a frequency band of 1.7–1.9 GHz [12]. As such, the CDMA service saw full scale expansion, and with the discontinuation of analog services in 1999, the Korean mobile phone market finally entered the digital era.

As digital mobile communication services began full commercialization, many base stations and relay stations were built in order to resolve bad reception in shaded regions, and these base stations often used array antennas, which provided high efficiency and high profitability. Also, the stabilization of the systems were then considered more important, and therefore, antennas used for mobile phones used helical antennas, monopoles, and whips (which had been used in the first generation communication devices), retractable antennas (both helical and whip antennas), and sleeve antennas of which center is surrounded by sleeves. Many studies were conducted on these antennas. Figure 3 shows pictures of external linear antennas used for second generation mobile phones.

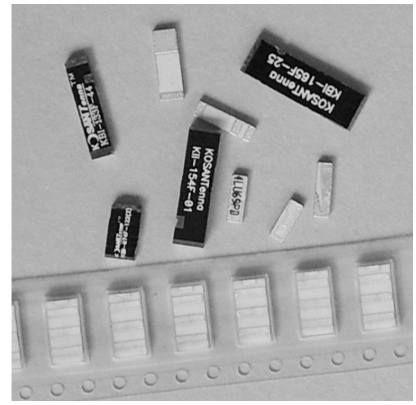
2.3 The Third Generation

The International Mobile Telecommunications 2000 (IMT-2000) is a next generation mobile communications technology that enables high speed multimedia communications services for voice, data and video with one mobile phone from anywhere in the world, based on the use of airwave frequencies and unified technology standards [13]. It was expected that the IMT-2000 technology would not only launch services that support high speed wireless data communications but also cause a significant paradigm shift in the information and telecommunications industry and of society as a whole. This expectation emerged because the existing analog-based mobile phones were limited in their portability due to their capacity limitations, caused by technical shortcomings and heterogeneous systems in different countries. Acknowledging such issues, Korea began developing broadband CDMA in 1994 and became the first country that succeeded in testing international long distance visual communications service based on IMT-2000. At this point, the said communications service was the first implementation of its kind in Korea that used an IMT-2000 system at a transfer speed of 128 kbps from a moving vehicle, and was the world's first successful case of roaming using the IMT-2000 system [14], [15].

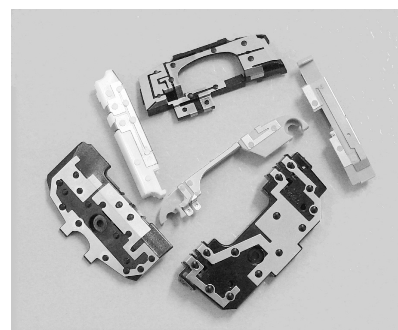
In 2000, Korea developed the world's first CDMA2000 1X Mobile Visual Communications Technology that fused the mobile protocol (Mobile IP), a core element in the commercialization of IMT-2000 service, and the visual communications protocol, which was first commercialized in 2001. Consequently, Korea laid the foundation not only for the offering of high speed data services at 144 kbps, which is 2–10 times faster than the speed of the existing IS-95A/B system, but also for the acceptance of diverse multimedia content depending on the functionalities of the phone receiving such content.

The launch of the CDMA2000 1X service made possible Korea's successful development of the CDMA 2000 1X EV-DO Commercialization System within a short time, which ushered in the era of the Synchronous IMT-2000 (CDMA2000 1X EV-DO) at the start of 2002. The CDMA2000 1X EV-DO service, thanks to its ultra high transfer speed of up to 2.4 Mbps, which is more than 16 times faster than the 144 kbps transfer speed of the CDMA2000 1X network, enables not only high speed Internet search but also interactive data transfer while in transit [16], [17]. The transfer speed of the CDMA 2000 1X was limited by its high speed packet data service, which was, in principle, based on a voice-oriented protocol. On the other hand, CDMA2000 1X EV-DO uses the ultra high speed data transfer technology of 1X EV-DO, which enables real time video service or multimedia downloads. Reflecting the development of this technology and trends in Korea's social and economic environments, Korea demonstrated asynchronous IMT-2000 during the opening ceremony of the 2002 World Cup in Korea and Japan, clearly showcasing the global image of Korea as a leading country in the mobile communications industry.

Along with the development of mobile communication technology, users' demand for high quality services has also greatly increased, and thus, as opposed to the previous era in which mobile phones were primarily used in making phone calls, today's mobile phones have become a daily necessity. The goal to satisfy an increasing number of various user demands and consolidate cell phones' competitiveness led the acceleration of research and development of internal antennas, which had been of little concern in the past. In this generation, antennas for mobile phone are rigorously changed from external to internal single to multiple band, small size, and light weight. Of representative internal antennas are the Planar Inverted-F Antenna (PIFA) (which was implemented to prevent the existing helical antennas to protrude), small roof antennas, chip antennas (which were made in the shape of semiconductor chips), Surface-Mounted Device (SMD) antennas (which were made by forming an antenna in a small volume using the existing method of producing multilayered substrate and dielectrics), and the Dielectric Resonator Antenna (DRA) (which acquires the characteristics of the antenna by using the resonating phenomenon of a dielectric) [18]. In Fig. 4, it shows some examples of single



(a) Chip type



(b) Internal type

Fig. 4 Internal type antennas for single frequency.

Fig. 5 Internal type antennas for multiple frequency band.

frequency band and internal antennas.

With the integration into mobile phones of such services as short distance communication using Bluetooth technology or Global Positioning System (GPS) service, antennas were developed in such a way that one antenna could play various roles in response to the growing trends in lightweight, miniaturization, and integration. Figure 5 shows general dual band or multiple functional (multiple resonating) antennas developed to satisfy these services.

3. Recent Trends of Antenna Technologies in Wireless Communication

Wireless Local Area Network (WLAN), a popular wireless access technology for data transfer, was commercialized after the completion of the standardization of IEEE 802.11b and 11a/g. Its maximum transfer speed is 11 Mbps for the IEEE 802.11b standard and 54 Mbps for the IEEE 11a/g standard. Surpassing the existing concept that WLAN is an alternative to wired LAN, its application is expanding to airwave networks and wireless home networking. It is believed that through the linking and integration of mobile communications networks and WLAN, in the end, users will be able to be given access to high speed WLAN service in regions where WLAN service is offered. And when traveling outside the region, such users will be automatically connected to a mobile communications network.

Since the early 2000s, wireless communications technologies have seen an innovative evolution in services, resulting in the creation of various technologies such as Bluetooth, ZigBee, Wi-Fi, Fixed/Mobile WiMAX, High Speed Download Packet Access (HSDPA), and Ultra Wide Band (UWB). Such wireless communication technologies pursue faster data transfer, improved mobility, personalization and economic efficiency, and inter-network fusion and integration of mobile phones. These properties are being optimally realized through WiBro, which combines the advantages of high speed Internet access and of mobile phones while offering the convenience and utility of portable Internet access and convergence at a reasonable cost.

Wireless Broadband Internet (WiBro, 2.3–2.4 GHz) service that can be used in transit as easily as using a mobile phone, was commercialized in Korea for the first time in the world in 2006 [19], [20]. WiBro enables mobility at the speed of public transportation (within 100 km/h) and wireless Internet and multimedia services at a high transfer speed (uplink of up to 1 Mbps; downlink of up to 3 Mbps). WiBro standards are currently based on the version integrated with IEEE 802.16-2004, P802.16e/D7, and P802.16-2004/Cor/D2 standards. Continuous research and development is being conducted to support improved mobility of over 150 km/h with consistent standards improvement, and to improve frequency efficiency by employing various advanced technologies such as Multiple Input Multiple Output (MIMO). Figure 6 shows an example of the internal WiBro antenna for mobile phones, which implemented MIMO technology to enhance the transmission efficiency via temporal and spatial multiplex communication using two or more antennas [21].

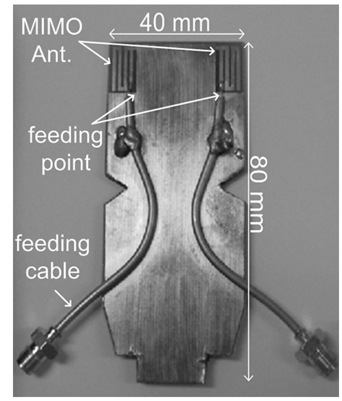
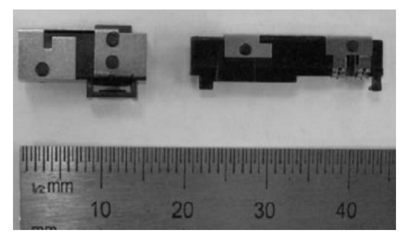
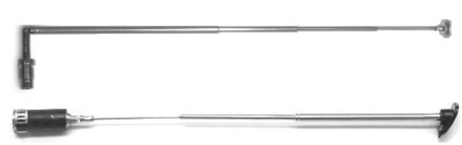


Fig. 6 Internal 1x2 MIMO antenna for WiBro.



(a) S-DMB



(b) T-DMB

Fig. 7 Antennas for DMB.

The rapid development of personal mobile communication technology and wireless data transmission technology intensified user demand for multimedia contents services.

The Digital Multimedia Broadcasting (DMB) service, which emerged based on the digital broadcasting technology, offers 24 hour reception of high quality radio, TV, video and text-based broadcasts from anywhere while in transit [22], [23]. DMB also called Digital Audio Broadcasting (DAB), Digital Audio Radio (DAR), Digital Radio Broadcasting (DRB), or Digital Sound Broadcasting (DSB) in the USA, Europe and Canada [24] is linked to the increasing demand for multimedia content services with the rapid development of personal portable communications technologies and wireless data transfer technologies. In Korea, the satellite DMB service (2.630–2.655 GHz) was launched in May 2005, and the terrestrial DMB service (174–216 MHz), in December of the same year. Figure 7 shows an example of an antenna that can receive either S-DMB or T-DMB. Having a very low frequency band of between 174 and 216 MHz and being provided in limited regions because it is still in the

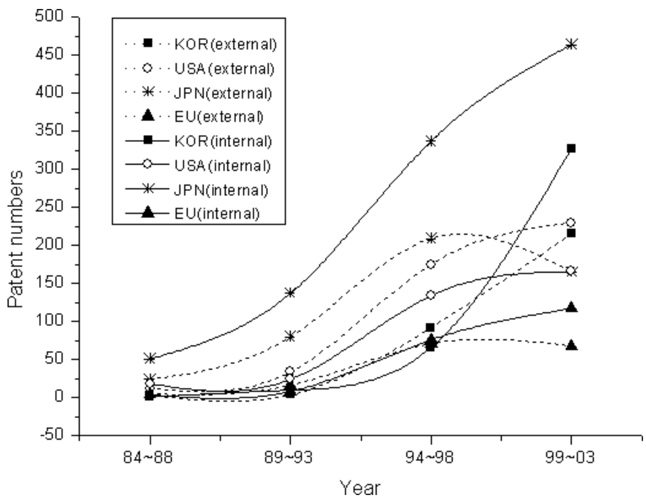


Fig. 8 Number of patents covering mobile antennas. (External type - - - - - - Internal type ———)

early period of its service, T-DMB antennas often have to be externally protruded when users watch DMB with their cell phone. Currently, many studies are being actively conducted to develop internal antennas with a simple structure.

In Fig. 8, it shows a graph of the number of patents for mobile phone antennas applied for by country [18]. Japan, which possesses advanced mobile phone antenna technologies, focused on the development of internal antennas instead of external antennas from 1999 to 2003, whereas the USA focused more on the development of external antennas. Due to the trend in miniaturization among mobile phones, Korea is also focusing more on the study of internal antennas.

4. Prospects for Antenna Technologies in Next Generation

Unlike the devices used during the infancy of the mobile communications systems, when mobile phones were used mainly for making phone calls, modern mobile phones are remarkably multifunctional. As a result, the types of antennas used in these mobile phones have greatly diversified. Mobile phones that are currently being developed integrate various types of antennas, such as the cellular PCS antenna for communicating with mobile phone users, the GPS antenna, the S-DMB and T-DMB, Bluetooth, the mobile Radio Frequency Identification (RFID) antenna, and the WiBro antenna. Modern antennas are becoming smaller and smaller, yet at the same time, are being designed for broadband and multiple band applications. The current trend in the development of antennas is integration. In the early period of mobile communication services, each antenna was used for its own purpose. However, these antennas have become integrated so that one small internal antenna could accept three or four bands. However, the distribution of band for the services to be integrated are becoming wider, and it is believed that these bands will be even farther away from the bands for services yet to be implemented. Therefore, it will certainly be more difficult to construct small antennas based on the existing antenna theories which are dependent upon the wavelength of frequencies that can satisfy all the requirements. For this reason, recent studies are focusing on developing antennas made with high permittivity and low loss media [25], [26]. In particular, research and development of antennas made with Doubly Negative Material (DNG), meta-material [27], which is called Negative Refractive Index (NRI) or Left-handed Material (LHM), or magneto-dielectric [28] media are actively being conducted both in Korea and abroad [29], [30].

Additionally, it is believed that more advanced SMART antennas and MIMO antenna systems will be implemented in next generation mobile phones to overcome the limitations of service channel capacity, and much attention is being paid to this direction.

ITU-R's Vision Committee refers to the next generation mobile communication not as "the fourth generation," but as "IMT-Advanced" or "Systems beyond IMT-2000." The fourth generation of mobile communications services will incorporate improvements in frequency efficiency, an increase in cell coverage, adjustment in the transfer rate per cost by differentiating the QoS according to grades of service, the necessity of reconstructing a mobile device H/W for efficient services support, the realization of the packet exclusive system for the ALL-IP environment, and establishing harmony and integration with existing systems or different media [31]. ITU proposes that such fourth generation mobile communications services have a transfer speed of 100 Mbps when the user is moving fast in a spacious location and 1 Gbps when the user is moving in a confined location.

The keyword for the next generation of wired and wireless communications technologies is inarguably "ubiquitous." Because ubiquity is based on wired and wireless networks, a very stable communications system is essential. Therefore, mobile phones or Personal Digital Assistants (PDAs), which function both as mobile phones and computers, have become the core of the phenomenon of ubiquity. The ubiquitous communications market includes state-of-the-art infrastructure technologies such as portable Internet, DMB, home network, telematics, RFID-applied service, WCDMA, terrestrial digital TV, WiBro service, and IT devices and software [32]. Digital convergence, which pursues ubiquity, emerged as a keyword in the future communication industry as various types of networks for voice and data, for wired and wireless, are integrated to offer users comprehensive services [25]. With the increasing user demand for a product equipped with many integrated functions, digital convergence products have emerged, and primary examples are today's mobile phones. Surpassing the simple fusion of various technologies, the mobile phone technology evolved toward the fusion of services, generating high value-added by offering multimedia contents and integrated services. The scope of such applications is expanding more rapidly than any one expected.

To satisfy the performance and construction of information terminals of which wireless communication is essential for realizing an ubiquitous world pursued by the next generation communications system, it is essential to consider the importance of antennas for such terminals, and therefore, it is believed that research and development of antenna technology should depart from existing studies based on simple concepts and should focus more on materials related to the construction of terminal devices, multiple band and multiple directivity, and ultra wide band characteristics. For this reason, antenna technologies that make use of new materials, such as the SMART antenna, the MIMO antenna, or the meta-materials, which were discussed earlier in this paper, can be proposed as alternatives, and studies should focus on such a direction.

5. Conclusion

In this paper, we have discussed the history of the development of mobile communications and the antenna technology in the development of advanced mobile communications technologies in Korea. Since 1984, Korea's mobile communications industry has posted unprecedented technological and economic advancements, leading Korea's IT industry.

Korea is the first country in the world to have commercialized the cellular system, the second generation of mobile communications technologies in 1996, and the third generation of mobile communications technologies in 2001. The third generation of mobile communications technologies is evolving towards CDMA2000 1X EV-DO (maximum transfer speed: 3.1 Mbps), a synchronous method. Korea launched the world's first commercialized HSDPA service in 2006 with its introduction of WCDMA, an asynchronous method. In the same year, the country commercialized, again for the first time in the world, WiBro, which is considered the fundamental technology leading towards the fourth generation of mobile communications technologies. Korea is thus leading the standardization of the fourth generation of mobile communications.

For the last 20 years when modern mobile communication services began, the antenna technology for mobile phones was in its inception. However, thanks to users' increased level of recognition of portability and the diversification and integration of mobile phones and other communication devices due to the fusion of heterogeneous services since the beginning of the 2000s, much attention began to be paid to the importance of antennas for mobile phones. Now, antenna technology is emerging as a core technology for high-end mobile phones.

Surpassing the existing concept of phones, today's mobile phones are products of integration combining the features of a phone, a computer, a short distance communication module, and a sensor with the advancement of digital convergence. Accordingly, it is believed that antenna technology will become more and more important as a core technology in realizing an advanced ubiquitous society. Thus, studies on antenna technology will focus on materials that form the construction of terminal devices, multiple band and multiple directivity, ultra wide band characteristics, and miniaturization. Antenna technologies, such as the SMART antenna, the MIMO antenna, and the meta-material, which utilize concepts of new materials, can be proposed as alternative technologies, and studies in the future should be carried out in this direction.

Furthermore, the fourth generation mobile communication system requires studies on improving frequency efficiency, increasing the channel capacity, and widening cell coverage, as well as the development of numerous new devices and technologies that facilitate the connection among various existing and new networks. In particular, it is believed that the fourth generation mobile communication system will be combined with artificial intelligent computer systems including the robot system to lead the rapid changes in the industry in the future.

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