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***Abstract*—This is a historical description about how Korea was transformed from the fringe to the global forefront in mobile telecommunications. It was an audacious challenge to develop a commercial CDMA(Code Division Multiple Access) cellular system which is technically more advanced, but not field proven hence risky, than TDMA cellular system that was the main trend of the times and opted by established majors. ETRI with Samsung, LG, Hyundai and Maxon pursed a co-development path to the national project supported by the Ministry of Information and Communication, Korea, at that time, in along with the joint development with Qualcomm, the original proponent of CDMA. After the successful commercialization first in Korea, CDMA turned into the major trend of the times, and Korean manufacturers became innovative leaders in the world.**

Keywords—CDMA development in Korea; commercialization of CDMA cellular system; CDMA field test

I. INTRODUCTION

Over the past few decades, mobile cellular communications in Korea has grown to become one of the leaders in the world. It all began with a bold initiative to develop a digital cellular system in 1989 at ETRI with the objectives of providing better services and bolstering the domestic mobile telecommunication industries [1] [7].

With no practical prior experience of developing even an analog mobile system but with strong expertise in network and switching, ETRI sought for international cooperation on radio access technology and found Qualcomm, the originator of CDMA air interface, willing to share their valuable experience in developing the CDMA commercial systems in 1991. The joint development was aimed at developing the commercial system, combining Qualcomm's CDMA technology and ETRI's network capability.

CDMA was still a novel concept, hotly disputed and challenged on its commercial feasibility from world's major mobile industries. Since the preferred technology at the time was TDMA, CDMA faced a significant amount of hesitation and opposition. The Korean government declared CDMA as the Korean Digital Cellular Standard in 1993 with a firm belief that only the ground-breaking technology based on sound engineering practice would give Koreans the opportunity to gain a foothold within the competitive world market.

In 1992, developing CDMA system became a national project for the Korean government, and ETRI formed the domestic co-development structure with Samsung, LG, Hyundai and Maxon. For the joint development, many engineers were sent to Qualcomm for collaboration. In 1993, government set up a separate Project Management Office (PMO) for timely commercialization. PMO set out to define the user requirements of CDMA system for field testing, and motivated participating manufacturers by encouraging competitions through autonomous design efforts and technology self-sufficiency.

In the late 1994, ETRI began field-test with their own system in Daejeon, and the 3 manufacturers under PMO guidance also began field-test in Seoul. Field tests were performed in accordance with the user requirement, and involved several months of sleepless nights for the engineers in the iterative process of testing and repairing. Throughout the development and field tests, the government did not lose its confidence and continuous support to the project. Finally the perseverant dedication and efforts from the participating engineers culminated in the world's first full-fledged commercial CDMA system by the end of 1995.

In January of 1996, as the first commercial CDMA services by SK Telecom began in Korea, the leading majors around the world continued to keep a skeptical eye on CDMA. But by the end of 1996, commercial CDMA services became a raving success with the number of new, happy CDMA subscribers in Korea exceeding over 1 million, in addition to proving CDMA's capacity gain of about 12 times more than that of the

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previous analog system [4]. The world was in shock and wondered, "How did the Koreans make such an excellent choice?"

This paper will chronicle the history of developing commercial CDMA cellular system in Korea, and how it transformed Korea from nobody in the world into the innovative pioneer at the frontier of the world of mobile telecommunications,

A. Major Events of CDMA development in Korea

- 1984: Analog AMPS service began by KTA (Korea Telecom Authority)
- 1988: KMT (Korea Mobile Telecom) spun off from KTA
- 1989: ETRI's initiation of developing digital cellular system
- May, 1991: JDA (Joint Development Agreement) between ETRI and Qualcomm
- Dec., 1991: CTIA meeting in Washington D.C. where CDMA excellency shown
- Sept., 1992: Co-development agreement with domestic manufacturers
- June, 1993: CDMA adopted as Korean Digital Cellular Standard
- Sept.,1993: PMO (Project Management Office) established under KMT, and User Service Requirement defined
- Oct., 1993: Shinsegi Telecom licensed with CDMA service
- Jan., 1994: CMS (CDMA Mobile System) as common platform designed
- Jan., 1995: CMS commercial field test started in Seoul
- June, 1995: CMS commercial field test completed
- Oct., 1995: Commercial system began deployed and tested
- Jan., 1996: Commercial CDMA service began in Incheon area by SK Telecom[1]
- Apr., 1996: Commercial CDMA service began in Seoul, Daejeon and interconnecting highways by Shinsegi Telecom[2] and by SK Telecom
- Dec., 1996: Number of CDMA subscribers exceeding over 1 million in Korea

II. ETRI'S INITIATIVES ON DEVELOPING DIGITAL CELLULAR SYSTEMS

Though the subscription of analog AMPS car phone was slow due to the cost, at the end of '87, it reached barely over to 20 k as shown in Table 1. The government decided to spin-off KMT from then KTA in order to promote the mobile cellular business. But in '88 when the real portable phone were seen on the street, the acceptance of the people was completely changed and the subscription increased more than 100% a year thereafter shown in Table 1. ETRI made a proposal of developing a digital cellular communication system to the government with anticipation of frequency congestion for analog cellular system in near future, prompting new services and boosting domestic industry. The beginning was humble, but very audacious. Though ETRI did not have any experiences on analog cellular system development, ETRI had confidence on switching, computer and network technology. They thought that, by learning the air interface technology step by step, it might not be impossible to develop our own system. It was a kind of adventure worthwhile to challenge, but the problem was how long it took.

TABLE1. STATISTICS OF MOBILE PHONE SUBSCRIBERS DURING '80S IN KOREA

Year	'84	'85	'86	'87	'88	'89	'90	'91
No. of Users (mobile)	2,658	4,685	7,093	10,266	20,353 (784)	39,718 (5,665)	80,005 (20,206)	166,198 (91,980)

After some preparations for the new project involving many lectures sought from internationally recognized experts and scholars, ETRI came into conclusion that it would need some form of technical cooperation to make up the radio interface part that ETRI felt deficient of expertise. The immediate task ETRI faced was which multiple access system should be sought after.

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At that time, TDMA was the main technical trend, as Europeans had been maturing their development of GSM systems. In North America, they just had decided to go for TDMA (IS-54) over FDMA, and Japanese followed the similar path as North American. Naturally ETRI began to study TDMA, and just barely figured out how to prepare for CDMA when it heard about CDMA from Qualcomm. In order to adopt a specific access method, there might be some important factors for considerations. Capacity was the most important one to satisfy the future demands because Korea is relatively small in geography, but the population density is one of the highest in the world. Even considering Seoul metropolitan area where more than 10 million people reside and work in a small area of 600 km^2 with harsh terrestrial environments, ease of cell and frequency plan was the following big concern.

CDMA was a new system proposed by Qualcomm in '88 and was considered to be a maverick that many experts couldn't believe its feasibility for commercial application of CDMA. Many cited Dr. Viterbi's short tutorial in IEEE Communication Magazine in '85 arguing that there would be no advantage of applying CDMA into cellular communications [6], and surprisingly enough, he happened to be one of the founders for Qualcomm. Theoretical background for CDMA cellular system looked sound [4], but many experts pointed out several difficult implementation issues like power control and overall complexity. Qualcomm managed to assemble a field

[1] KMT was acquired by SK, and name changed to SKTelecom in '94.

[2] Shinsegi Telecom was merged into SK Telecom in '99.

trial CDMA system, and showed its potential successfully in Manhattan, New York in '90. Still, CDMA had been hotly disputed or challenged upon its commercial feasibility from world's major mobile industries, and some even criticized it severely in public.

III. Joint Development of CDMA with Qualcomm and Adoption of National Standard

As ETRI was seeking technical cooperation with international organization, weighing mainly on TDMA and less on new CDMA of which details were not known much. In Oct., '90, ETRI invited Dr. William C. Y. Lee [5], then CTO of PacTel, to give lectures on digital mobile communications intending to learn deeply on TDMA system. Dr. Lee came to ETRI accompanying with Mr. Allan Salmasi, then VP of Qualcomm. In his lecture to ETRI researchers, he didn't even mention anything about TDMA of which ETRI understood that he was very influential to settle TDMA over FDMA issues in North America. He lectured all about the excellence of CDMA, its technical characteristics, advantage on wideband multipath fading and universal frequency re-use, etc. ETRI engineers were somewhat surprised to listen to new fascinating stories about CDMA. Then, Mr. Salmasi told about Qualcomm and the status of on-going CDMA developments. In addition, he mentioned about possible opportunity to share their experiences with ETRI. That was a turning point for ETRI to consider CDMA with a little more favor.

ETRI and Qualcomm kept continuing talking about possible cooperation during early '91 and came up with JDA (Joint Development Agreement) in May, '91. Meanwhile, ETRI had been notified of the on-going negotiations with Qualcomm to MOC (Ministry of Communication) for approval. JDA was composed of 3 phases, where the 1st phase was to make ETRI engineers acquainted with CDMA and to investigate the feasibility study. The 2nd phase was for eventual joint design of CDMA cellular system combined with Qualcomm's CDMA air interface technology and ETRI's switching and network technology with participating Korean manufacturers. The 3rd phase was for full commercial development and testing.

In retrospect, JDA turned out to be perfectly matching between ETRI and Qualcomm. ETRI was a government-supported public research institute of which research results are shared with domestic manufacturers for commercialization, and Qualcomm, on the other end, was a technology company of which products are in the form of sharing IPR technology and selling ASIC chips for communication signal processing. ETRI had expertise in switching and network, and Qualcomm was excelled in CDMA air interface, so that they complemented each other in developing full commercial CDMA system. ETRI also tried to seek for technology cooperation on TDMA, but the major manufacturers with TDMA expertise or development did not respond, they were just interested in market share, not in technology sharing.

Meanwhile, in order to get the approval from the government, ETRI needed to persuade the Ministry about the advantage as well as the risk of CDMA over TDMA. Naturally, as CDMA was not field proven technology at that time, many government officials and professors preferred to go for proven TDMA system. ETRI argued that without any previous experiences in analog cellular system, the difficulties to face for ETRI whether developing TDMA or developing CDMA was not much different. One of the important persuading points of CDMA was its high capacity [4] and good voice quality because at that time KMT had been receiving many complaints from users about call dropping, failed call attempts, and poor voice quality. Ministry even set up a special task force team to find the facts and to correct the call problems. Finally ETRI got the Ministry's tentative approval for the 1st phase with the condition that after the 1st phase, the results should be closely evaluated and monitored by outside experts to decide whether to go or not for the 2nd phase of which goal was the main system design for commercial CDMA system.

ETRI and Qualcomm took every effort to enlist Korean communication experts to understand CDMA by holding several public technical workshops and meetings. There were very active debates and technical discussions on CDMA and TDMA, and many still favored on TDMA than CDMA. But the real breakthrough was coming from the CTIA(Cellular Telecommunications Industry Association) meeting in Washington, D.C., in Dec., '91. In North America, the situation was not much different, or even more severe than that in Korea. At that meeting, all major contending technologies like digital TDMA, GSM, Extended TDMA and CDMA were given opportunity to present their progress and prospect. Qualcomm had just successfully completed their larger-scale field test in San Diego to show full capability of CDMA, and at the CTIA meeting, the audiences were overwhelmed by Qualcomm's presentation with field-test video. Many from Korea attended that meeting and felt the similar enthusiasm for CDMA, and they began to support ETRI's proposal for CDMA development very ardently. In North America, CTIA, too, asked for a special committee to study CDMA for a second digital standard early next year. But, still CDMA was nothing but a promise.

After the completion of 1st phase of JDA, ETRI became more confident to go for CDMA system, and proposed to the Ministry to develop the full-scale commercial CDMA system for a national project with domestic manufacturers. Now, it was a turn for the Ministry to deliberate it over, it organized a group of experts like professors, engineers from telecom service operators and major manufacturers, and ETRI to discuss the possibility for successful development and alternatives. Gradually, all the participating members began to agree upon challenging adventure to jump into the new risky path to promote competitive mobile communication industry. If we chose then mainstream TDMA, we would have remained as followers for matured technologies. Since we took not-proven CDMA, we could meet high opportunities to become a leading country in this field, though we were exposed to very high risks. They showed their confidence in our research engineers' willingness and past experiences in developing digital switches and networks that made Korea achieving "One Home One Phone", a wireline evolution in mid-80's.

IV. Full Commercial Development of CDMA System

As the 2nd Phase of JDA settled down, ETRI sought to form the joint commercial development team with domestic manufacturers called as DM (Designated Manufacturer). Samsung Electronics, LGIC, and Hyundai were chosen for both of infrastructure and mobile phones, and Maxon was joined only for mobile phones in Sept., 1992. Some of DM's engineers were sent to ETRI, and others including ETRI researchers to Qualcomm for collaborations.

During initial development stage, there was some discrepancy between ETRI and DMs' direction. While ETRI as public research institute concerned more on technology development by taking step-by-step processes, DMs might have some reservations for CDMA, as well as they would not want other DMs to peek into their works. At that time, it was not possible to predict the target date for commercial service, because the needs of mobile service were abundant, but how about the supply?

Government stressed that new mobile services shall be based on CDMA and adopted CDMA as the only digital cellular standard in June, '93 [3]. While the incumbent KMT could afford to continue analog services until CDMA commercial services are ready, the new second operator called Shinsegi Telecom was licensed for digital CDMA service. So Shinsegi had requested the government very strongly to permit her the analog service tentatively for fair competition against KMT. The government was very determined to encourage CDMA development, and responded firmly that, if that is the case, Shinsegi shall be faced to return its license.

In order to coordinate the joint development works to meet the target, the government established a separate independent PMO (Project Management Office) supported by KMT in Sept.,'93 and determined to plan for new CDMA cellular services by '96. Fig. 1 shows the overall CDMA co-development structure for a national project in Korea. PMO released the user service requirement of commercial CDMA system in Dec., '93, and specified the test items for field test. It also set up several policies to enforce DMs such as promoting competitions, allowing independent design and implementation, and maturing CDMA technology.

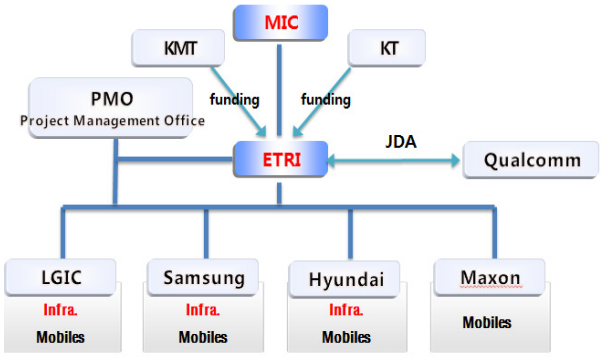

Fig. 1. Overall CDMA Co-Development Strucure in Korea

ETRI was leading DMs to configure the common platform model called CMS (CDMA Mobile System) based on TDX switching networks. Meanwhile Qualcomm proposed their system model a little differently, called QMS (Qualcomm Mobile System) that was based on ATM network. Afterwards, ETRI and Qualcomm agreed to pursue the separate paths on CDMA network sides.

The system design was required to consider the backward compatibility with existing analog AMPS, to support the network evolution trend, modularization of hardware to meet system capacity, new features and redundancy for system failure. The CMS is composed of mobile stations and the infrastructure of BS, MX, and HLR/AC as shown in Fig. 2 [1].

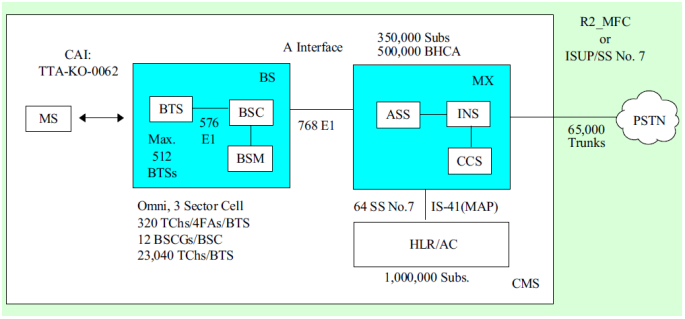

Fig. 2. Commercial CMS (CDMA Mobile System) Block Structure

A BS (Base Station Subsystem) consisted of a BSC (Base Station Controller) and a number of remotely located BTSs (Base Station Transceiver), and a BSM (Base Station Manager). BSC is collocated with an MX (Mobile Switch), and is responsible for allocation of radio channels, intra-BS handoffs and power control.

TDX-1, a switch, developed by ETRI was modified to serve as an MX. Mobile switching and VLR (Visiting Location Register) are combined in an MX. An MX is composed of ASS (Access Switching Subsystem), INS (Interconnecting Network Subsystem), and CCS (Central Control Subsystem). Conceptually MX can be divided mainly into telephony part and control part. A HLR (Home Location Register) is a location register for storing permanent and temporary user information such as user location, service profiles, and billings. An AC (Authentication Center) is implemented on the same platform for user security and fraud management. The prototype CMS composed of BTS, BSC and Mobile Switch developed by ETRI is shown in Fig. 3.

Fig. 3. CMS prototype installed in ETRI

V. Field Tests and Commercialization of CDMA System

Field test by ETRI was carried out in Daejeon for the purpose of subsystem integration, system parameter optimization, verification of additional features, evaluation of system capacity and performance [2]. One HLR/AC, one MX, two BSCs, and three BTSs (one omni and two three-sector cells) were installed. A three-sector cell site with two frequency assignments, a BSC, the MX, and HLR/AC were collocated at ETRI. Such minimum system configuration was to test soft handoff among BTSs, softer handoffs between sectors, hard handoff between BSCs, power control during soft handoff, and to evaluate the BTS capacity. Also, ETRI developed test equipment such as mobile call simulator and logging data analysis tool for field test purpose.

The measurement system was consisted of a test van and BS performance measuring system to test the performance of CMS system, and field strength and delay measuring system for CDMA propagation characteristics. Test van was configured to gather the received data during capacity and performance test of the BTS. The test van was carrying 6 MSs, two mobile diagnostic monitors, and a GPS receive

The commercial field test had been executed in Seoul simultaneously under the guidance of PMO. Four BTSs (three 3-sector cells and one omni cell) were installed each by three manufacturers so that three densely populated urban areas could be covered by different manufacturers' test system. The commercial test for over 940 items that PMO defined were successfully carried out. The test included the hardware characteristics, MX functions, BS interface modules and their functions, HLR/AC functions, interoperability, and performance. For the performance call delays (M-M, L-M, M-L), signal strength and voice quality were measured in accordance with the requirements.

Followings were brief schedule for commercial field test proceeded in Seoul.

- July, '94: PMO released about 1,000 test items to DM for field test.
- Aug., '94: preliminary test had been tried for 54 items.
- Jan., '95: PMO began commercial field tests
- May, '95: LG had passed the 1st commercial field test and was chosen to deploy the commercial system in Seoul and surrounding metropolitan area for SK Telecom.
- June, '95: CDMA call was demonstrated at COEX Telecom Exhibition by SK Telecom

Fig. 4. CDMA Network Operation and Management Center in SK Telecom

The deployment for the commercial service was started in along with the successful field test at late 1995 by two service operators. SK Telecom launched CDMA commercial service in Jan., '96 in Incheon and Bucheon area at the beginning as Fig.4 shows its network operation center. Shinsegi Telecom began its new CDMA service in Apr., '96 in Seoul, Daejeon and connecting highways. Fig. 5 shows the opening ceremony of CDMA commercial service held at ETRI on Apr. 26, '96. Soon the service area was being extended over nationwide rapidly.

User's reception was very enthusiastic, especially they were fascinated by good voice quality and many users were willing to test the system by themselves. While the major global mobile manufacturers had kept their skeptics on CDMA to wait and see what would be happening in Korea, SK Telecom and Shinsegi Telecom had enjoyed hard times to respond for new subscription demands.

In the CDMA mobile phone market in '96, commercial models were only available from 3 domestic vendors (Samsung, LG and Hyundai) and Qualcomm. Other global mobile phone majors had not yet ready to bring CDMA phones to Korean market, for either they had predicted that Korean CDMA service should be delayed for some time, or they paid no attentions in CDMA at all arguing that it would not work. Soon, Qualcomm gave up the mobile phone business, and this gave Korean manufacturers earn the valuable time for taking-off.

By the end of '96, the number of CDMA subscribers were reaching over 1 million, and the operation of CDMA system had been working successfully to reach close to the limit predicted, and expanded steadily for wider coverage and increasing capacity. Suddenly all the international majors became wondered about Korean achievements, and finally agreed to accept the potentials and advantages of CDMA technology so that for IMT-2000 system, CDMAs were adopted dominantly.

Fig. 6 shows how the CDMA cellular has been diffusing deeply into everyday Korean life. Reaching 1 million at the end of '96, and in '97, CDMA PCS services in 1.8 GHz were provided from 3 new PCS operators. By the end of '99, analog mobile service was terminated. In 2000, mobile subscriptions overtook wireline subscriptions, and mobile phone became the necessity, not the luxury for ordinary peoples.

Fig. 5. Prime Minister is making a CDMA call at the opening ceremony of commercial CDMA service at ETRI, Daejeon

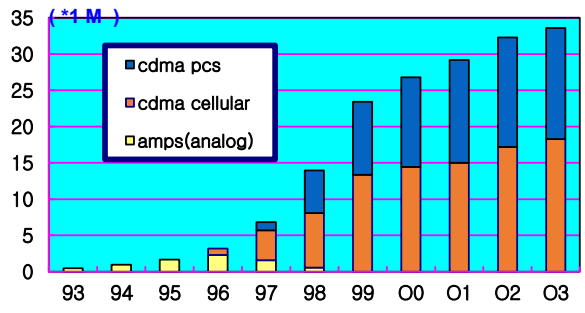

Fig.6. Cellular Subscribers during '90s in Korea

Severe competition to attract subscribers resulted in better service and new features to make domestic mobile manufacturers as well as mobile service operators catching up in along with major international manufacturers. There was about 2 years lead time in Korean domestic CDMA market to sharpen their skills to make good mobiles, and that makes them having competitive edge even in producing good GSM phones which is shown clearly in Table 2.

TABLE 2. GLOBAL MOBILE PHONE MARKET SHARES BY MANUFACTURERS [9]

Rank	'96	'98	2002	2005	2008	2012	2016
1	Motorola	Nokia	Nokia	Nokia	Nokia	**Samsung**	**Samsung**
2	Nokia	Motorola	Motorola	Motorola	**Samsung**	Nokia	Apple
3	Ericsson	Ericsson	**Samsung**	**Samsung**	Motorola	Apple	Huawei
4	NEC	Panasonic	Siemens	**LG**	**LG**	ZTE	OPPO
5	Panasonic	Alcatel	Ericsson	Ericsson	Ericsson	**LG**	vivo
6		**Samsung**	**LG**	Siemens	Apple	Huawei	

VI. LESSONS AND CONCLUSION

There were several factors to the successful CDMA technology innovation [7]. First, the government pursued the national project consistently to support ETRI in collaboration with domestic manufacturers to commercialize the high potential, but risky CDMA technology when the paradigm was shifting from analog to digital communication globally. Second, development methodology and management expertise learned from the previous TDX switching system contributed significantly to successful CDMA project. Third, the PMO defined the scope and specifications for commercial system requirement to reduce uncertainty in the project, and to give manufacturers assurance for the market. Above of all, the dedication and willingness of the engineers at ETRI and participating manufacturers for challenging and unproven goals, and Qualcomm's near faultless radio interface design with provision of ASIC chips for complicated CDMA signal processing.

CDMA project was the turning point for Korea's capability of technology innovation, and helped Korea reform from a follower into one of the leaders in ICT world. Korea is now in the position to independently set the direction of service and technology, define technological visions and to contribute actively for standardization of the next mobile communication generations. One of the aspects from Korean valuable experiences taking audacious approach to develop the CDMA system would be to examine the statistics of worldwide mobile phone market shares after '96, which points out the Korean mobile manufacturers' achievements as shown in Table. 2, the other aspect is the dominance of CDMA in the following generation mobile system as an article quoting, "*From the Fringe to the Forefront"* [8], and as Dr. Viterbi's quoting, *" I strongly believe that if Korea had not come onboard, CDMA would not have gotten strong enough traction to make it*" [10].

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REFERENCES

[1] Youngnam Han, Hang Gu Park, and Seungtaik Yang, " CDMA Mobile System Overview: Introduction, Background, and System Concept," ETRI Journal, volume 19, number 3, pp 83-97, Oct. 1997

[2] Dongseung Kwon, Youngkwon Hahm, Inmyoung Jeong, and Duckbin Im, "CDMA Mobile System Testbed and Field Trial," ETRI Journal, volume 19, number 3, pp 259-280, Oct. 1997

[3] TTA-KO-0062, Interim Standard for Common Air Interface for Digital Cellular in the 800 MHz Band, Nov, 1994

[4] K. S. Gilhousen, et al., "On the Capacity of a Cellular CDMA System," IEEE Trans. On Vehicular Tech., vol. 40, no.2, pp.303-312, 1991

[5] William C.Y. Lee, Mobile Communications Engineering, New York: McGraw-Hill, 1982

[6] A. J. Viterbi, "When not to Spread Spectrum – a Sequel," IEEE Comm. Mag. Vol.22, pp. 12-17, Apr. 1985

[7] Inn Chan Lee, Successful Innovation of the Korean Mobile Communications Industry and SK Telecom's Role, SK Telecom Report

[8] Maxine Carter-Lome, "From the Fringe to the Forefront," CDG Report, CDMA World Oct. 1999

[9] Wikipedia, List of best-selling mobile phones, Internet search.

[10] Andrew Viterbi, Intervew coducted by the Library, UC Sand Diego, June 15, 2004