CHINA'S PERSPECTIVES ON 3G MOBILE COMMUNICATIONS AND BEYOND: TD-SCDMA TECHNOLOGY

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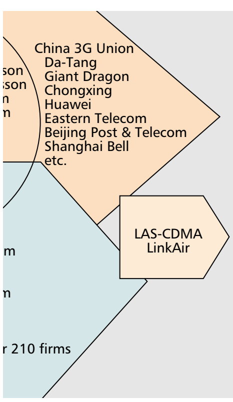

The TD-SCDMA standard has received the full blessing of the Chinese government and it will surely play a critical role in mobile communication development in China as well as in the world.

ABSTRACT

China, as the largest developing country in the world, has been emerging as a nation with the fastest penetration rate growth in mobile communications, exceeding the United States to become the largest single mobile cellular market in terms of subscriber population. The recent successful admission to the World Trade Organization (WTO) has given China new momentum for further development of its mobile communications infrastructure and fueled international competition as well in the mobile communication market of the country. Since the opening up of its economy, China has spent billions of dollars to purchase equipment from foreign telecommunication manufacturers, which has created a heavy burden to modernize its legacy industrial sectors. This is the situation China is eager to change. The TD-SCDMA standard was proposed by the CWTS of China to ITU in 1998 as an effort to bring China on a par with other developed countries in mobile communications system development and also to make the country less dependent on foreign vendors. The proposal was approved by ITU as one of the candidate standards for 3G mobile communications in May 2000 and accepted by 3GPP in March 2001. The TD-SCDMA standard makes use of TDD synchronous CDMA technology and offers several operational advantages. For instance, it allows the existing GSM core networks to be upgraded to the TD-SCDMA platform along a relatively easy path. Therefore, it can be very attractive to service providers in regions where worldwide popular GSM system is in operation. The TD-SCDMA standard has received the full blessing of the Chinese government and will surely play a critical role in mobile communications development in China as well as in the world; its impact should never be underestimated. In this survey article the historical background as well as the technical content of the TD-SCDMA standard will be addressed.

INTRODUCTION

December 11, 2001 will become a historical date for China and the world, when the World Trade Organization (WTO) finally admitted the country as its member together with 142 other nations worldwide, and ended China's 15-year "long march" toward the goal of reentry into the WTO. The date marked the beginning of a new round of Chinese economic reform, which was first initiated about 20 years ago by the patriarch Deng Xiao-Ping. The date will also become a milestone, with the Chinese economy departing irreversibly from its former socialist centralized market toward a free economy. By joining the WTO, China promises to further open its markets to the world, including its huge telecommunications sectors, especially the fast growing and lucrative mobile cellular markets. Whether you like it or not, the integration of China into the world market will bring a fundamental change to the world economy as a whole due to its large population with increasingly great buying power and the sheer size of its diverse markets.

In the last 10 years, China has spent billions of dollars to improve its legacy telecommunication infrastructure built mainly with the help of former Soviet Union experts in the 1950s. We have seen that China has enjoyed the fastest growth in the world in terms of fixed telephony lines, paging services, data networking, and optical backbone links. Recently, it completed its huge two-tier telecommunication network with grid-shaped interprovincial fiber optic trunk networks and ring-shaped intraprovincial fiber optic truck networks based mainly on synchronous digital hierarchy (SDH) technology (20–40 Gb/s), currently supporting about 180 million fixed telephone users and its fast growing demand on data services, although in some rural areas the fiber optic backbone has to be supplemented by microwave and satellite due to the vast land of the territory. The advancement of mobile communications in China is also phenomenal: the penetration rate for

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Service	Provider system	Coverage region	2000	2001
China Mobile	GSM900/1800	Whole country	107.2	142
China Mobile	GPRS	Beijing, Shanghai, Fujian, Gungdong, Hebei, Zhejiang, and Liaoning	NA	NA
China Unicom	GSM900/1800	Yangzhi and Pearl River delta areas	29.66	50
China Unicom	CDMA(IS-95)	Eastern coastal area and major cities in central China	0.75	13.3
China Unicom	GPRS	Beijing, Shanghai, Shengzhen, and Wuxi	NA	NA

Table 1. *The two current major mobile service providers in China with their subscribers (in millions) and systems.*

mobile cellular subscribers has increased extremely fast every year since 1998. From 1998 to 2001 the average yearly increase rate of mobile subscribers in China is about 26 percent, meaning that the user population has almost doubled in only about 2.5 years. The mobile phone networks today in China cover all major cities, 95 percent of small cities, and well developed counties, as well as main transportation links. Currently, mobile cellular phone subscribers in China have reached more than 200 million, only about 15 percent of its 1.3 billion total population, still leaving great potential to further augment its mobile communications market. China has now overtaken the United States to become the largest single mobile market in the world in terms of mobile user population. Analysts expect that mobile subscribers in China will exceed 300 million before 2004, making China the world's largest market for mobile communications related products at a total value of about US$150–200 billion and offering enormous business opportunities to all big telecommunication players in the world. Table 1 shows current mobile communication market shares for two major services providers, China Mobile and China Unicom, with their subscribers (in millions) and systems adopted in different areas. Figure 1 illustrates the increasing trend in mobile subscribers under currently operating and to-be-deployed mobile cellular systems in China.

It is clear that China has become a very important country in the world mobile cellular market. We must also note that China's great potential is not only due to its market size, but also because of its development and manufacturing capability for telecommunication related products in the foreseeable future. The development of China's third-generation (3G) mobile communications standard, time-division synchronous code-division multiple access (TD-SCDMA) technology, is one of the examples.

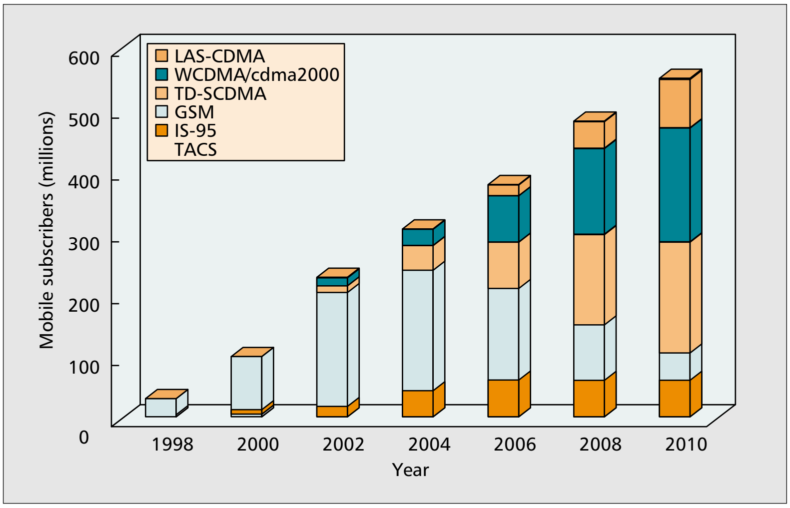


Figure 1. *The increasing trend in estimated population of mobile subscribers in China from 1998 to 2010. The total mobile communication related product value is estimated at about US$ 180–220 billions.*

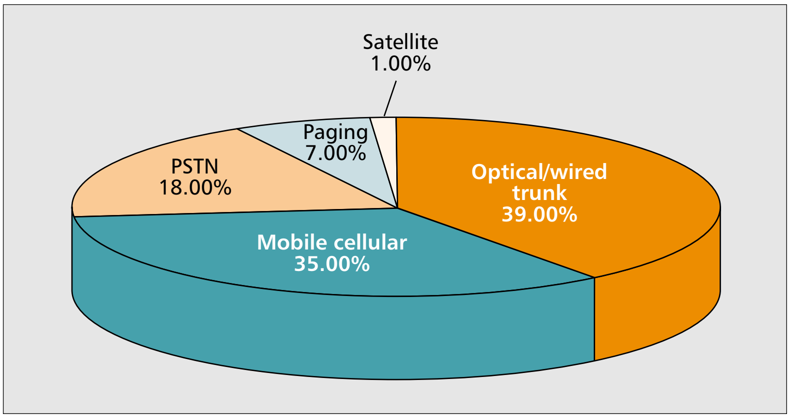
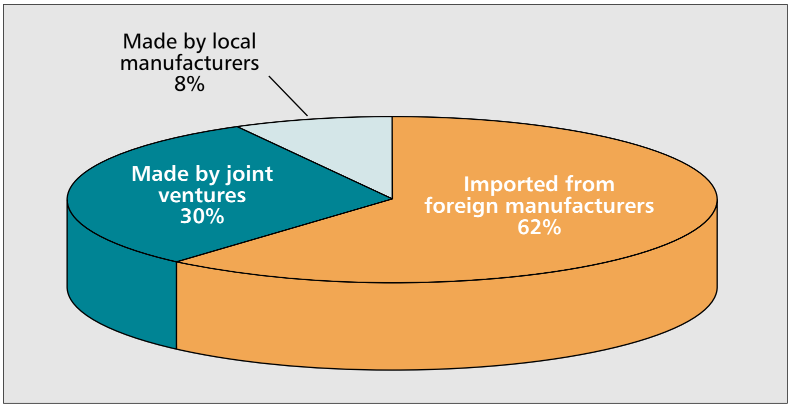


Figure 2. *Expenditures on China's telecommunications infrastructure in the last decade.*

The Motivation Behind TD-SCDMA

In the last 20 years China's mobile communications infrastructure was built basically on equipment/systems imported from foreign manufacturers or produced in local joint ventures with foreign telecommunication companies in China. In doing so, China had to pay off its hard-earned currency to overseas telecommunications giants, such as Nokia, Ericsson, Lucent, Siemens, Nortel, Qualcomm, and others to purchase their products and related intellectual property (IP) such as mobile phones, base stations, and switching equipments. The volume of purely locally designed and made equipment is insignificant in terms of total market share value due to the lack of cutting-edge knowhow and key module/component IPs, such as mobile system architecture development, high-end microelectronics technology, and handset/base station integrated circuit (IC) chip set design capability. The local grown industry today remains in a stage of mobile handset



■ Figure 3. *The breakdown of end equipment supply sources for China's current mobile cellular systems, including mobile handsets and base-station equipment.*

assembling and other low-end auxiliary devices manufacture, such as handset battery packs, chargers, and PCBs.

Figure 2 shows the investment percentages for China to build up its telecommunications infrastructure over the last decade, from which it is seen that the total expenditure on mobile communication systems ranks second at about 35 percent of the total investment on telecommunication infrastructure, only a bit smaller than that for optical/wired truck investment, which counts for 39 percent. Therefore, both government-owned and private telecommunication companies in China, most of which also have great shares held by the government, have invested heavily in its terrestrial mobile cellular systems, the majority of which run on GSM, supplemented in some areas by the IS-95 CDMA network. Figure 3 shows the breakdowns for mobile cellular equipment, including hand phones, base stations, and networking facilities, currently used in Chinese mobile communication networks, from which it is seen that the majority (about 62 percent) were made by overseas manufacturers or joint ventures in China (about 30 percent), and only 8 percent were made by purely local telecommunications firms. Therefore, current Chinese mobile service providers must rely heavily on overseas-transferred technologies and pay huge amounts in loyalty and license fees every year to those foreign manufacturers and institutions. This is the situation that China wants to change and was also probably the strongest motivation for China to eagerly join the world club of mobile communication technology IP holders by proposing its own International Telecommunication Union (ITU) IMT-2000 candidate standard, TD-SCDMA, in 1998 [1], at the same time the European Telecommunications Standards Institute (ETSI), ARIB, and Telecommunications Industry Association (TIA) proposed their proposals, ETSI/ARIB wideband CDMA (WCDMA) [2, 3] and cdma2000 standards [4].

China, as the largest country in the world in terms of its population, has a strong reason to develop its own mobile communication standard, driven by its own domestic market needs. China clearly realized that after its entry into WTO, foreign companies will not only sell their equipments to Chinese mobile cellular market, but also be allowed to provide mobile services in the country, directly competing with the two major existing Chinese services providers, China Mobile and China Unicom. This development will definitely complicate the situation in China. Like it or not, China will face ever stronger economic pressure from outside if China continues to be a pure importer of mobile technologies. A typical example is that the United States has pushed China very hard to further open its markets through various means, as shown in Table 2, the timetable for China to open its mobile communication market to U.S. firms in the Sino-U.S. bilateral agreement made in the negotiation for China's entry to WTO.

In fact, economic leverage is not the only reason for China to worry about reliance on foreign technologies for its mobile communication infrastructure. China also has political concerns. It has been a tradition for China to be reluctant to rely technologically on Western powers, due to historically strong concern of possible containment initiated by Western powers, which can be traced back to the Cold War period when Mao Zhedong called for self-reliance in establishing its own economy. In the

Service category	Start	Overseas investment up limit	Open regions
Value-added and paging	Immediately	30 percent	Beijing, Shanghai, and Gungzhou
Value-added and paging	2001	49 percent	Beijing, Shanghai, Gungzhou, and 14 other major cities
Value-added and paging	2002	50 percent	The whole country
Mobile	2001	25 percent	Beijing, Shanghai, and Gungzhou
Mobile	2003	35 percent	Beijing, Shanghai, Gungzhou, and 14 other major cities
Mobile	2005	49 percent	The whole country
Fixed-line	2003	25 percent	Beijing, Shanghai, and Gungzhou
Fixed-line	2005	35 percent	Beijing, Shanghai, Gungzhou, and 14 other major cities
Fixed-line	2006	49 percent	The whole country

■ **Table 2.** *The timetable for China to open its mobile and fixed line services market to the United States, which was initially proposed during Sino-U.S. bilateral negotiation for China's entry into the WTO.*

early '60s, the same concern made China a nuclear power by making use of its own technological research and development resources. The later success in China's space technology, marked by its successful launches of self-designed satellites and rocket space carriers, was also the result of this concern. Although mobile communications technology is basically for civilian applications, the systems can also play a critical role in military applications with or without modifications. The possibility of confrontation with the Western countries, especially the United States, due to ideological differences still exists. In particular, China's sovereignty claim over Taiwan will very likely become a flash spot in East Asia, which could become a trigger to bring China into a possible war with the United States and its allies in the future. It is almost certain that the possible technological boycott will jeopardize the successful operation of China's mobile communication services if war does break out. Therefore, with all those uncertainties, it is not difficult to understand why China needs its own mobile communication standards, such as TD-SCDMA [1] already proposed and perhaps LAS-CDMA [5] following very soon. Therefore, the introduction of the TD-SCDMA standard was not only economically motivated, but also driven by profound political reasons.

A Great Opportunity for TD-SCDMA

Recently China has enjoyed probably the fastest economic growth rate in the world. However, its telecommunication research and development capability still lags behind Western countries, although in some areas it has shortened its distance from the West. The country's economic and political structure further complicates its mobile market perspectives:

- Increasingly great demand on mobile communication services vs. the inability to develop high-end mobile communication related products
- Fast penetration of foreign imported technologies vs. deep concern about heavy reliance on foreign vendors
- Wider open mobile services market post WTO entry vs. current dual monopoly reality of China Mobile and China Unicom

To deal with these problems, China has taken various initiatives, one of which is to strengthen support of the domestic telecommunication industry in various programs, such as its Digital Mobile Communication Made-in-China Program, which was initiated in 1999 in an effort to achieve the goal that half of total mobile handsets sold in China should be locally made by 2005. This program is to help local manufacturers stand well after China's admission to WTO. Another way is to establish comprehensive regulations on telecommunication services and investment activities of foreign companies in China to consolidate national telecommunications businesses. The ceiling for foreign investment in China's telecommunication manufacturer/services should be less than 50 percent even after its entry into WTO, as shown in Table 2. Yet another important effort is to develop its own mobile communication standard so that it can effectively control most of the related IPs for its own use and possible technology transfers to other countries. The most evident activity is its 3G proposal of TD-SCDMA to the ITU as well as the recent preparation work on the LAS-CDMA standard, which is claimed to be a proposal for its 4G system.

The milestones in the development of the TD-SCDMA standard are in Table 3. The China Academy of Telecommunication Technology (CATT) has played a critical role in TD-SCDMA proposals, and later system architecture design and prototyping. The "first mobile-to-mobile call" was made successfully in Beijing by CATT in May 2001, based mainly on a prototype system; there is still much work to do before the TD-SCDMA system can become commercially available. The time schedule for its formal service launch is very tight, planned to be between 2002 to 2003, within two years from now. At the moment, CATT is seeking technical partners to jointly develop TD-SCDMA systems, including mobile phones, base

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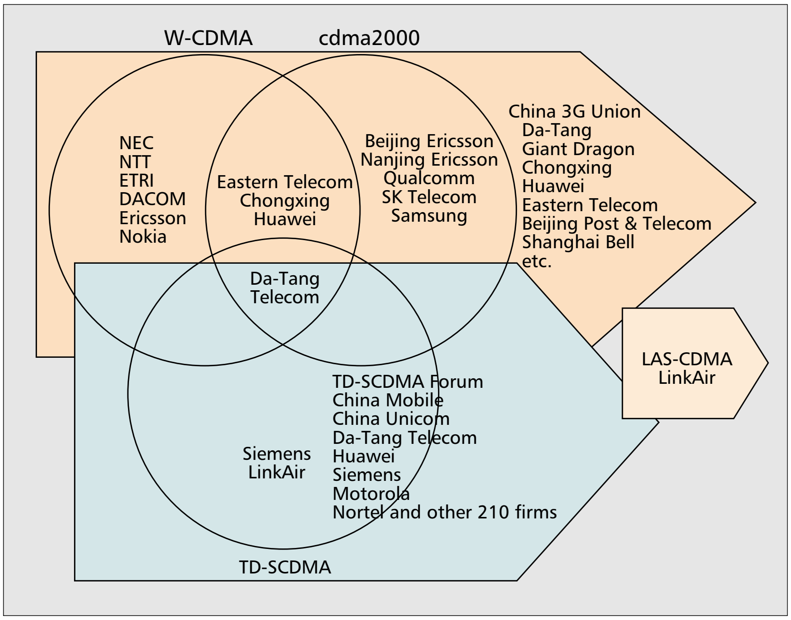
Year	Major progress
1998.06	Submission of TD-SCDMA standard by CATT of MII
1999.04	Agreed support by NTT DoCoMo, Panasonic, ARIB, Ericsson, Nokia, Siemens, and CATT
2000.05	Official approval of TD-SCDMA as 3G standard by ITU
2000.10	Three-party MOU signed by Siemens, CATT, and Huawei
2000.12	TD-SCDMA Forum established
2001.03	First call made in Siemens 3G Laboratory
2001.03	Official acceptance of TD-SCDMA by 3GPP
2001.04	First call in Beijing by CATT, China
2001.05	First mobile-to-mobile call in Beijing by CATT, China

CATT: China Academy of Telecommunication Technology
MII: Ministry of Information Industry
Huawei: a Chinese telecommunications equipment manufacturer

Table 3. *Milestones in the development of the TD-SCDMA technology.*



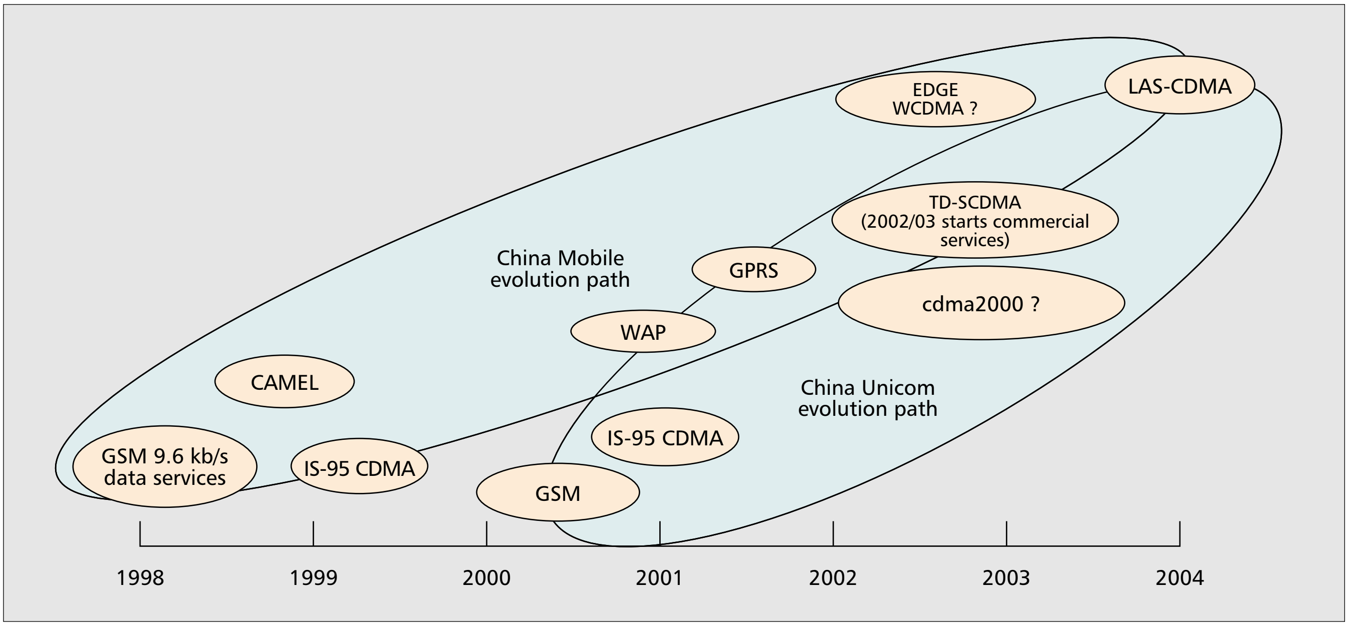
■ **Figure 4.** *The major companies/research institutions involved in the activities to develop China's 3G and 4G mobile communication systems.*

stations, and networking solutions. The calls have attracted very positive responses so far, and many foreign firms have shown strong interest in participating in the TD-SCDMA Forum, which consists of about 210 members worldwide, including many major telecommunications end equipment suppliers such as Nokia, Ericsson, and Motorola, as shown in Fig. 4. In particular, Siemens has been involved in TD-SCDMA for a long time and has been working on chip set design for TD-SCDMA mobile handsets and base stations. Thus, it is clear that the company considers TD-SCDMA technology a vital 3G solution with a great opportunity to succeed in the world. Siemens has obviously led other competitors in TD-SCDMA system development. Currently, Siemens has invested more than 100 million RMB in TD-SCDMA R&D facilities in China, where it has recruited more than 500 research personnel working in TD-SCDMA. Several Korean companies and institutions, such as Samsung and ETRI, have also been very keen on TD-SCDMA systems development. In 2001, CATT also sent a large delegation to Taiwan to seek possible collaboration with Taiwanese high-tech companies in chip set design, silicon wafer production support, and so on. The trip was very fruitful and many Taiwanese electronics and telecommunication firms are keen to work jointly with CATT on developing commercial TD-SCDMA systems. Therefore, it is expected that China will succeed in making TD-SCDMA China's 3G mobile communication reality within two years.

Since China has the largest GSM subscriber population in the world, the technical similarity (especially in mobile core networks) between TD-SCDMA and GSM has a great advantage for GSM operators to upgrade their networks to the TD-SCDMA platform with minimum investment required compared to other 3G solutions. It was estimated by CATT that the cost savings in upgrade investment could be as much as 30 percent. Currently, both CATT and Siemens are developing dual mode and dual band terminals for use under both GSM and TD-SCDMA standards to meet the great needs in the transition period from GSM to TD-SCDMA systems in China as well as other regions. Figure 5 shows the possible evolution paths for China's two major service providers to upgrade their respective mobile core networks from 2G to 4G in the future.

TECHNICAL CONTENT OF TD-SCDMA

The effort to propose the TD-SCDMA standard can be traced back to 10 years ago when a team in CATT worked on a TD-based CDMA archi-



■ **Figure 5.** *The possible evolution paths from 2G to 4G mobile communication systems for China's two current major mobile service providers, China Mobile and China Unicom.*

	Cdma2000	WCDMA	TD-SCDMA
Multiple access	DS-CDMA/MC-CDMA	DS-CDMA	TDMA/DS-CDMA
CLPCF	800 Hz	1600 Hz	200 Hz
PCSS	1 dB (0.5, 0.25 optional)	0.25–1.5 dB	1, 2, 3 dB
Channel coding	Convolutional or turbo coding	Convolutional, RS, or turbo coding	Convolutional or turbo coding
Spreading code	DL:Walsh, UL:M-ary Walsh mapping	OVSF	OVSF
VSF	4…256	4…256	1…16
Carrier	2 GHz	2 GHz	2 GHz
Modulation	DL: QPSK, UL: BPSK	DL: QPSK, UL: BPSK	QPSK, 8-PSK (at 2 Mb/s)
Bandwidth	1.25*2/3.75*2 MHz	5*2 MHz	1.6 MHz
UL-DL spectrum	Paired	Paired	Unpaired
Chip rate	1.2288/3.6864 Mchips/s	3.84 Mchips/s	1.28 Mchip/s
Frame length	20 ms, 5 ms	10 ms	10 ms
Interleaving periods	5/20/40/80 ms	10/20/40/80 ms	10/20/40/80 ms
Maximum data rate	2.4 Mb/s	2 Mb/s	2 Mb/s
Pilot structure	DL: CCMP, UL: DTMP	DL: DTMP, UL: DTMP	CCMP
Detection	PSBC	PCBC	PSBC
Inter-BS timing	Synchronous	Asynchronous/synchronous	Synchronous

CCMP: common channel multiplexing pilot; DTMP: dedicated time multiplexing pilot; VSF: variable spreading factor; CLPCF: closed loop power control frequency; PCSS: power control step size; DL: downlink; UL: uplink; PSBC: pilot symbol based coherent; PCBC: pilot channel based coherent

Table 4. *A comparison of major physical layer operational parameters of TD-SCDMA, W-CDMA, and cdma2000 standards.*

tecture for a possible mobile communication standard for China. The China Wireless Technology Standard Group (CWTS) accepted the proposal from CATT and submitted the first version of TD-SCDMA [1] to ITU in 1998 as one of numerous candidate proposals for IMT-2000 (UMTS WCDMA, cdma2000, etc.), which was subsequently approved by ITU as a 3G standard in May 2000 and later also joined 3GPP in March 2001.

As its name suggests, the TD-SCDMA standard bears two major characteristics: one is to adopt time-division duplex (TDD) mode operation for up and downlinks separation; the other is to use synchronous CDMA technology. The use of TDD in TD-SCDMA offers several benefits. First, agility in spectrum allocation for mobile services is a great advantage of TDD over frequency-division duplex (FDD), which requires pair-wise spectrum allocation for uplink and downlink, causing a big burden for regions where spectrum resources are already very limited, such as the United States and Japan. Second, the use of the same carrier frequency in both up- and downlinks helps to implement smart antenna and other technologies that rely on identical propagation characteristics in both links. Third, TD-SCDMA facilitates asymmetric traffic associated with Internet services, where the transmission rates in up- and downlinks should be adjusted dynamically according to the specific requirements of the applications, such that the overall bandwidth utilization efficiency can be maximized. Finally, the TDD technology used in TD-SCDMA is credited with lower implementation cost of RF transceivers, which do not require high isolation for transmitting and receiving multiplexing as needed in an FDD transceiver; thus, an entire TD-SCDMA RF transceiver can be integrated into a single-chip IC. On the contrary, an FDD transceiver requires two independent sets of RF electronics for up- and downlink signal loops. The cost savings can be as much as 20–50 percent over FDD solutions. Some people believe that due to those merits TDD could become the mainstream for 4G solutions. A comparison of fundamental system parameters of CATT/TD-SCDMA, UMTS/WCDMA, and TIA/cdma2000 standards is given in Table 4. We also give a comparison between the UMTS Terrestrial Radio Access (UTRA) TDD and TD-SCDMA in Table 5, which shows the similarity and difference between the two.

In the following subsections we focus on several advanced technologies introduced in the physical layer architecture of TD-SCDMA and will not touch on the conventional techniques commonly used by other standards as well, such as air link power control.

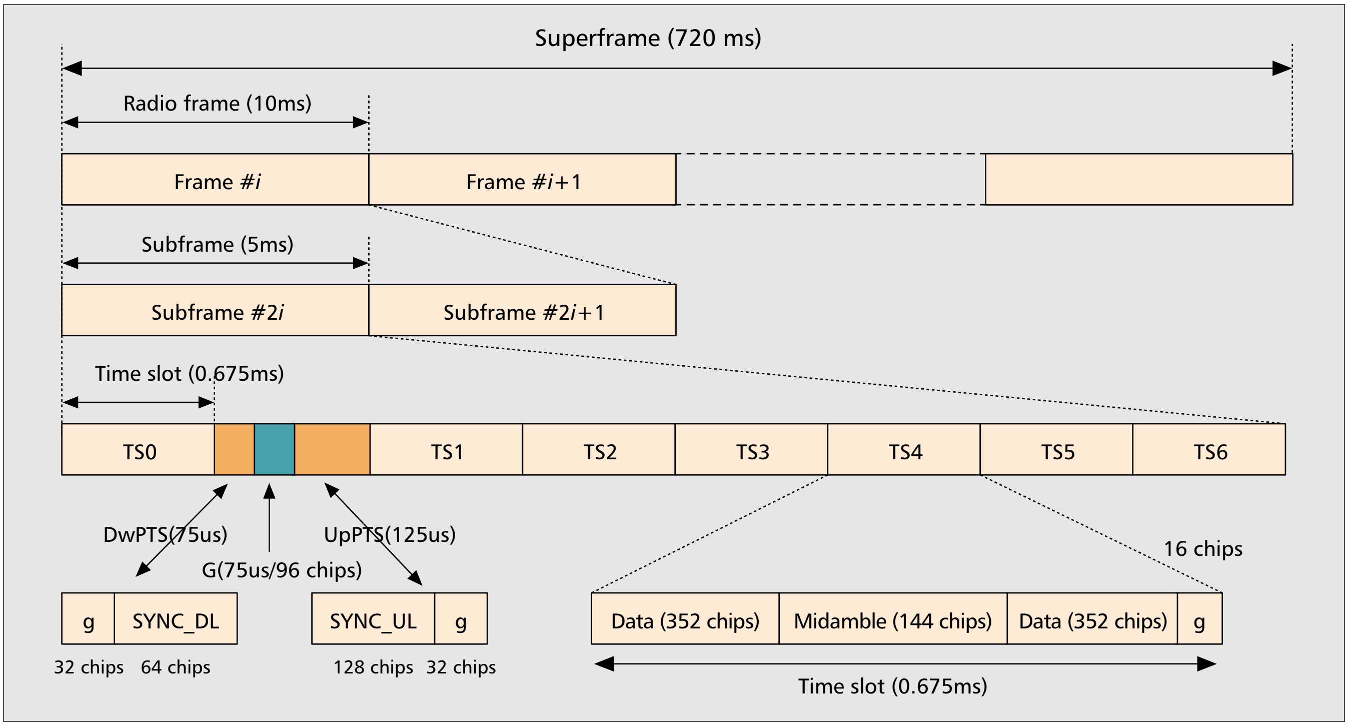
The TD-SCDMA Frame Structure

TD-SCDMA makes use of both TDMA and CDMA techniques such that channelization in TD-SCDMA is implemented using both time slots and signature codes to differentiate

	UTRA TDD	TD-SCDMA
Bandwidth	5 MHz	1.6 MHz
Chip rate per carrier	3.84 Mchips/s	1.28 Mchip/s
Spreading	DS, SF = 1/2/4/8/16	DS, SF = 1/2/4/8/16
Channel coding	Convolutional or turbo coding	Conv. or turbo coding
No of time slots/subframe	15*2	7*2
Burst structure	Midamble	Midamble
Frame length	Super frame = 720 ms/radio frame = 10 ms	Super frame = 720/ radio frame = 10 ms
No of channels/time slot	8	16
No of channels/carrier	8*7 = 56	16*3 = 48
Spectral efficiency	0.662 Mchips/s/MHz	1.232 Mchips/s/MHz

■ **Table 5.** *A comparison of major physical layer operational parameters between TD-SCDMA and UTRA TDD.*

mobile terminals in a cell. The frame structure of TD-SCDMA [6–11] is shown in Fig. 6, where the hierarchy of four different layers, superframe, radio frame, subframe, and time slot, is depicted. A subframe (5 ms) consists of 7 normal time slots and 3 special time slots, where TS0 is reserved for downlink and TS1 for uplink only; whereas the rest (TS2–TS6) should form two groups, the first (whose size can vary from 1 to 4 slots) for uplink and the second (whose size can vary from 4 to 1 slots) for downlink. The slot number ratio of the two groups can take 1/4, 2/3, 3/2, and 4/1 to suit particular traffic requirements. The agility in support of asymmetric traffic is a very attractive feature of TD-SCDMA, and of particular importance for Internet services with rich multimedia content in 3G applications. The other three special time slots are downlink pilot (DwPTS), guard period (G), and uplink pilot (UpPTS), respectively. DwPTS and UpPTS are used as a synchronization channel (SCH) for down- and uplink, respectively, which should be encoded by different pseudo-noise (PN) codes to distinguish different base stations and mobiles.



■ **Figure 6.** *The four-layered frame hierarchy in TD-SCDMA. TS: time slot; DwPTS: downlink pilot time slot; UpPTS: uplink pilot time slot; G/g: guard period. TS0 is reserved for downlink and TS1 is for uplink only; the rest of the time slots (TS2 to TS6) can form two groups, the first for uplink and the second (which can consist of 1-5 slots) for downlink to suit a particular symmetric/asymmetric traffic requirement.*

Common transport channels (CTC) (carry shared information of network)	Dedicated transport channels (DTC) (carry dedicated user/control signals between UE and network)
Broadcast channel (BCH)	Dedicated channels (DCHs)
Paging channel (PCH)	ODMA dedicated transport channels (ODCH)
Forward access channel (FACH)	
Random access channel (RACH)	
Uplink shared channel (USCH)	
Downlink shared channel (DSCH)	

Table 6. *Two types of transport channels defined in TD-SCDMA.*

Smart antenna technology has been integrated into the TD-SCDMA standard as an indispensable part of it, and has become the core of successful operations of the whole system, such as baton handover and uplink synchronization control.

A time slot can exactly fit a burst, which consists of two data parts separated by a midamble part and followed by a guard period, as shown in Fig. 6. Multiple bursts can be sent in the same time slot. If so, the data parts of those bursts should be encoded by up to 16 different OVSF channelization codes, whose spreading factor is fixed to 16 for downlink and can vary from 1 to 16 for uplink. However, each mobile can send up to two OVSF channelization codes in the same slot to enable multicode transmission. The data parts of the burst should always be spread by OVSF codes and scrambling code combined to distinguish mobile and base station, respectively.

A TD-SCDMA physical channel is uniquely defined by carrier frequency, channelization code, time slot, and radio frame allocation jointly.

Embedded Signaling for Smart Antenna

Smart antenna technology has been integrated into the TD-SCDMA standard as an indispensable part [1], and has become the core of successful operations of the whole system, such as baton handover and uplink synchronization control. A smart antenna system is composed of an array of multiple antenna elements and coherent transceivers with an advanced digital signal processing unit. Instead of a single fixed beam pattern from a traditional antenna, the smart antenna can dynamically generate multiple beam patterns, each pointed to a particular mobile; such beam patterns can adapt to follow any mobile intelligently. As a result, co-channel interference can be minimized to increase the reception sensitivity and thus the capacity of the whole system. It can also effectively collect multipath components to combat multipath fading. It is very important to implement fast beamforming to follow the time variation of mobile channels. The 5 ms subframe structure in TD-SCDMA is particularly designed based on the smart antenna request, which is a compromise taking into account both the number of time slots and the switching speed of RF components used in a transmitter. It was reported that an 8-element circular array antenna with 25 cm diameter has been considered for the use in TD-SCDMA base stations, which can offer an 8 dB gain over an omnidirectional antenna. TDD mode operation in TD-SCDMA ensures an ideally symmetric beam pattern for both transmitting and receiving at the same base station, which greatly improves the channel estimation and beamforming accuracy due to the same propagation characteristic of the up- and downlink signals.

A TD-SCDMA burst contains a 144-chip midamble, which contains a training sequence for a beamforming algorithm carried out in a smart antenna system. The midamble is encoded by basic midamble codes. There are in total 128 different basic midamble codes of length 128 for the whole system, which are allocated into 32 code groups with 4 codes in each code group. The choice of code group is determined by base stations, such that four basic midamble codes are known to base stations and mobiles. The midambles of different users active in the same cell and same time slot are cyclically shifted versions of a single basic midamble code.

Due to the provision to apply transmitter diversity, TD-SCDMA can also take advantages of space-time coded signaling to further improve the capacity.

Channel-Dependent Beamforming

Two categories of transport channels are defined in TD-SCDMA: dedicated transport channels (DTCs) and common transport channels (CTCs) [6–11]. DTCs can be further divided into dedicated channels (DCHs) and ODMA dedicated transport channels (ODCH); CTCs are divided into six subtypes, as shown in Table 6.

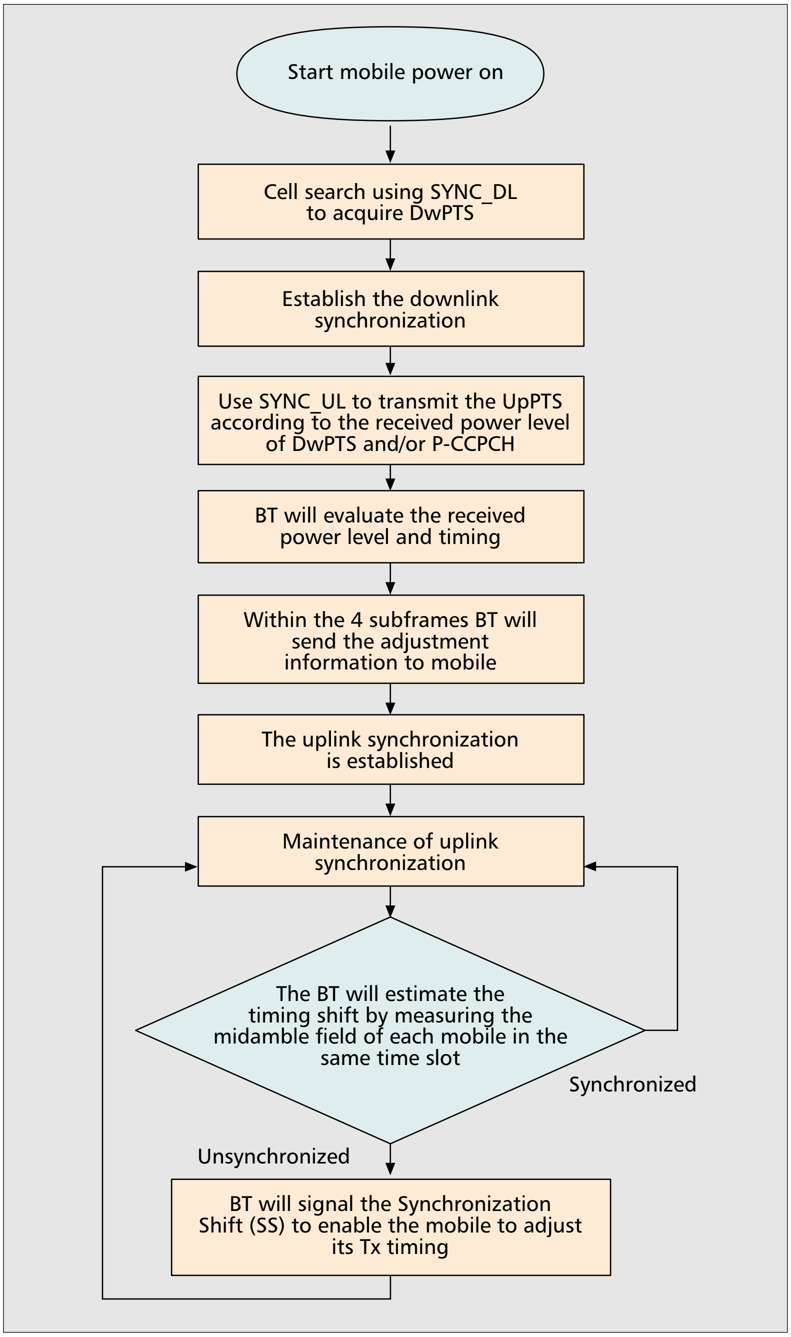
It is specified in TD-SCDMA that in downlink transmissions from a base station all CTC' (SCH, pilot, BCH, PCH, etc.), which usually carry shared information of the core network, should use an omnidirectional beam pattern to send their signals; all DTCs, which carry dedicated user or control signals, should use directional beam patterns with the help of smart antenna technology adopted in the TD-SCDMA system. On the other hand, all receiving channels in a base station should also use directional beam patterns to suppress interference from unwanted transmissions. The use of different beam patterns for different transport channels in the TD-SCDMA system can effectively increase utilization efficiency of the transmission power from base stations and reduce the co-channel interference in the cell, which contributes to improved cell capacity. The introduction of beamforming in all receiving channels can also facilitate mobile location positioning, based on which numerous new features (baton handover, etc.) can be added but otherwise are impossible.

Uplink Synchronization Control

Another critical technique used in the TD-SCDMA is synchronous CDMA transmission in both down- and uplink, both of which use OVSF codes for channelization due to their ideal orthogonality. In order to achieve synchronization in the uplink, TD-SCDMA employs open loop and closed loop synchronization control [6–11].

During a call setup procedure, a mobile should first establish downlink synchronization with the base station by looking for DwPTS, based on which it will initiate uplink synchronization. In the beginning a mobile can estimate propagation delay from a base by received power level of DwPTS. Its first transmission in uplink is performed in a UpPTS time slot to reduce interference in normal time slots. The timing used for SYNC_UL burst are set according to the received power level of DwPTS, accomplishing open loop synchronization. On detecting the SYNC_UL burst, the base station will evaluate the received power level and timing, and reply by sending the adjustment information to the mobile to modify its uplink transmission timing and power level in the next transmission, executing closed loop synchronization control.

To maintain uplink synchronization, the midamble field of each uplink burst will be used. In each uplink time slot, the midambles from different mobiles in the cell are distinct. The base station can estimate the power level and timing by measuring the midamble field from each mobile in the same time slot. Then in the next available downlink time slot, the base station will signal the Synchronization Shift (SS) and Power Control (PC) commands, which occupy part of the midamble field, to enable the mobile to properly adjust its transmission timing and power level, respectively. The uplink synchronization can be checked once per TDD subframe, and the step size in the uplink synchronization can be adapted from 1/8 chip to 1 chip duration, which is sufficient to maintain the orthogonality of OVSF codes from different mobiles. Figure 7 shows the flow chart of the open loop and closed loop synchronization procedures used by TD-SCDMA.



■ Figure 7. *A flow chart of the open and closed loop synchronization control adopted in TD-SCDMA for both uplink and downlink, which illustrates that downlink synchronization should be established before uplink synchronization.*

Intercell Synchronization

TD-SCDMA specifies the technique used to achieve synchronization among neighboring base stations in order to maximize system capacity and to facilitate cell search in handover procedure. A typical example for such a need is a scenario for coordinated operation with overlapping coverage areas of the cells (i.e., there is contiguous coverage for a certain area). In fact, a TDD system requires such intercell synchronization, especially in the handover procedure, where a mobile will communicate with two or three base stations simultaneously. In such a scenario, a common clock source is a must to maintain intercell synchronization. Synchronization among base stations is very important for TDD mode to avoid excessive interference from nearby cells.

In TD-SCDMA there are several possible ways to achieve synchronous transmission among neighboring cells. The first possible way is to achieve synchronization via the air interface, in which a special burst, the network synchronous burst, is employed. This burst should be sent on a predetermined time slot at regular intervals. The base stations involved should adjust their respective downlink signal timing in phase with the network synchronous bursts. The second alternative way is to use another cell's DwPTS as a timing basis for the synchronous transmissions of base stations involved. Yet another way is simply to use GPS as a common clock to synchronize the base stations. It is likely that the first-generation TD-SCDMA network will work on GPS to achieve intercell synchronization, letting the base stations have a common timing reference for transmitting and receiving. The accuracy for such intercell synchronization is required at about 5 μs [6–11].

With intercell synchronization, the transmission time for each cell can be determined in system planning and controlled by the TD-SCDMA core network. The time offset in nearby cells is separated by at least one fixed time delay, which should be approximately 80 percent of the propagation delay between two neighboring cells.

BATON HANDOVER

Baton handover [6–11] is another salient feature implemented in TD-SCDMA, used to take advantage of both hard and soft handover, and is particularly suitable for TDD mode operation. Baton handover, similar to the procedure of handing over a baton in a relay race, is based mainly on mobile positioning capability provided by TD-SCDMA base stations with a smart antenna system.

In an urban pedestrian environment, it may obtain wrong information on position of a mobile by use of a single base station because of serious multipath. Therefore, it must be aided by cell search, based on the report of the mobile to make a decision on which is the target base station. Successful operation of baton handover is based on the following preconditions:

- The system knows the position of all mobiles.
- The system knows and determines the target cell for a handover.
- The system informs mobiles about the base stations in neighboring cells.
- Mobile measurement helps the system make the final decision.
- After the cell search procedure, the mobile has already established synchronization to the base station in the target cell.

The procedure of baton handover supported in TD-SCDMA can be explained as follows. Assume that BTS0 is the base station to which the mobile is connected, and BTS1 is the base station to which the mobile wants to hand over. First, the mobile should listen to the broadcast information from BTS0: data related to nearby cells including position, operating carrier frequency, transmitting time offset, short code distributed, and so on. The mobile will search the nearby cells based on the above received information. With this information the mobile is able to send relevant information to BTS1 via some common transport channel such that BTS1 can also measure the location of the mobile by burst exchange between them. The handover procedure can be initiated by either the mobile or BTS, but the network will decide when to execute the handover. Therefore, baton handover is different from soft handover such as that applied in IS-95, which makes use of macro-diversity.

Under the baton handover concept, the system is able to support both intra- and interfrequency (in TD-SCDMA) handovers, ensuring higher handover accuracy and shorter handover delay for operations either within a TD-SCDMA system or between different systems. There are several different handover procedures defined in TD-SCDMA, which include intrasystem and intersystem handovers. Intersystem handovers can be further divided into TD-SCDMA/GSM handovers and TD-SCDMA/UTRA-FDD handovers in order to provide future cooperation among different networks, which is extremely important, especially in the initial deployment of TD-SCDMA network when TD-SCDMA may coexist with GSM and other possible 3G networks (UTRA-TDD, etc.).

INTERCELL DYNAMIC CHANNEL ALLOCATION

Channel allocation in TD-SCDMA can be made very flexible due to the use of synchronous TDD technology. It is possible that each TD-SCDMA base station can use three different carriers to work on about 5 MHz bandwidth (each takes 1.6 MHz), which is the same as the bandwidth required by one carrier in UTRA-TDD. On the other hand, TD-SCDMA can also operate in a mode in which each cell uses only 1.6 MHz bandwidth and three neighboring cells can take three different carriers. On the other hand, each TD-SCDMA time slot can support 16 simultaneous code channels, and each subframe has 7 normal time slots, which can be made symmetric or asymmetric for down- and uplink traffic. Therefore, the physical channels in TD-SCDMA can be considered a "pool," each element of which can be uniquely determined by three indices: carrier frequency, OVSF code, and time slot. In this way, dynamic channel allocation can be implemented for each cell within three neighboring cells to further increase the bandwidth utilization efficiency of the overall system.

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FLEXIBILITY IN NETWORK DEPLOYMENT

TD-SCDMA shares many technical similarities with GSM and UTRA-TDD standards, which makes it possible for a TD-SCDMA network to be deployed in an evolutionary instead of revolutionary way. It has been suggested that a TD-SCDMA network can be implemented in two steps, taking into account the networks currently operating in many countries around the world. The initial step could implement TD-SCDMA physical layer functionalities only, while keeping most of the existing second and third layers of GSM core networking with some necessary modifications to make them compatible with TD-SCDMA upper layer requirements. Such an initial TD-SCDMA deployment can offer maximum 284 kb/s data rate services, comparable to 2.5G applications. If compared to a direct upgrade from GSM to WCDMA, such an initial deployment of TD-SCDMA can save up to 50–70 percent cost, as estimated by the analysts. The savings in the initial deployment phases is significant in the business viewpoint, because it can greatly reduce the risk of investment of service providers and pave the way for future network evolution toward 3G networks. The second step involves the use of the fully functional TD-SCDMA physical layer, and layers 2 and 3 should use 3GPP compatible upper layers to meet the full functions required by IMT-2000. In this way, the maximum transmission rate can reach 2 Mb/s.

On the other hand, TD-SCDMA can also support the coexistence of different mobile net-

There have been signs that China will likely support its own 3G or future 4G standard and encourage its service providers to adopt them. If so, the impact will be significant in the global mobile communication industry due to the sheer size of the Chinese market.

Mobile communications market	Main driving force
United States	Market
Europe	Technology
Japan	Mobile operators
China	Government/market

Table 7. *A comparison in terms of the main driving force behind mobile communication market development in the United States, Europe, Japan, and China.*

works, such as GSM and UTRA-TDD, discussed in the above sections on handover procedures across different mobile networks. Therefore, TD-SCDMA is particularly attractive for homogenous evolution from existing GSM to 3G mobile networks at relatively low upgrade cost and investment risk.

Technical Limitations of TD-SCDMA

Although TD-SCDMA offers many operational advantages, it also bears some limitations. First of all, the use of TDD operation in TD-SCDMA could produce a relatively high peak-to-average power (PTAP) ratio. Because a CDMA transceiver requires very good linearity, a relatively high PTAP ratio will limit effective transmission range and thus the coverage area of a cell. Nevertheless, TD-SCDMA's PTAP ratio is 10 dB less than that of UTRA TDD CDMA [2]. In addition, the discontinuity of slotted signal transmission in the TDD mode also reduces its capability to mitigate fast fading and Doppler effect in the mobile channel, thus limiting the highest terminal mobility supported by the TD-SCDMA system to 120 km/h. Fortunately, the highest mobility supportable by TD-SCDMA can be increased to 250 km/h with the help of antenna array beamforming and joint detection algorithms, which is comparable to the specification of WCDMA (about 300 km/h). It was revealed in a simulation study released by CATT recently that a smart antenna base station adopting an 8-element circular array can provide satisfactory performance for vehicle mobility as high as 250 km/h.

Second, TD-SCDMA will operate at a spreading factor equal to one at the highest data rate (i.e., 2 Mb/s). In such a case, the system will not provide any processing gain, resulting in a relatively low interference rejection capability. It may cause some problems in receiving signals in strong multipath fading scenarios.

Third, the TD-SCDMA uses exactly the same OVSF spreading code as proposed in ETSI/ARIB WCDMA [2,3]. OVSF codes are notoriously inefficient in handling rate-matching problems for multimedia traffic due to the OVSF code generation tree structure. The rate change can be made only in multiples of two units of the basic rate. For instance, if a service requires 5 units of the basic rate, the system has to offer 8 units of the basic rate, wasting about 40 percent bandwidth in this case. Besides, in order to accommodate more users with varying rate demands in a cell, OVSF code assignment to different channels is subject to frequent reshuffling, consuming a great amount of DSP power and time.

Fourth, TD-SCDMA requires open loop and closed loop uplink synchronization control to avoid the co-channel interference caused by asynchronous operation in the uplink. It certainly increases the complexity of the system hardware. Similarly, intercell synchronization in TD-SCDMA also needs a network-wide common clock source (e.g., GPS), causing a more costly system implementation. The successful operation of baton handover relies on an accurate mobile positioning functionality provided by a smart antenna system. Therefore, the TD-SCDMA system architecture is indispensably based on these costly advanced technologies, without which the system would not work. The cost spent on those advanced modules could effectively offset the savings achieved for a GSM core network to upgrade to TD-SCDMA.

The Global Impact of TD-SCDMA

At the time of this writing, China has not finally decided which standard will be adopted as the main national 3G solution. However, there have been signs that China will likely support its own 3G or future 4G standard and encourage its service providers to adopt them. If so, the impact will be significant in the global mobile communication industry due to the sheer size of the Chinese market. Foreign mobile manufacturers must closely watch China's decision on 3G standard selection processes and act accordingly if they want to gain their market shares in China. For instance, the current technological leader in developing WCDMA systems, NTT DoCoMo, Japan, has invested a great deal in WCDMA related products. If China shifts to its own standard, NTT DoCoMo will feel a possible negative impact on its potential market share in China if it does not follow up on TD-SCDMA system development quickly. The same will also affect other major players in the world, except for Siemens, which has been involved for a long time with China in developing TD-SCDMA systems. Figure 4 shows the companies actively involved in TD-SCDMA system development. Table 7 compares the four different types of mobile markets in the world, where it is seen that China's mobile communications market was driven mainly by the government.

TD-SCDMA may be one of the most cost-effective solutions to upgrade existing GSM networks to 3G systems, due to its unique technical features. In this sense, the possible market for TD-SCDMA can be enormous, simply because of the huge success of GSM worldwide. Therefore, TD-SCDMA in principle is suitable not only for China, but also for any country as long as its 2G services are running on GSM. Thus, a competition for market access with WCDMA (both TDD and FDD schemes) can be expected.

China will play a more and more important role in the world mobile communications industry with its own proposed 3G and later 4G standards being put into operation. China will not be content with only making the TD-SCDMA its national 3G solution. Its ambition is eventually to share the world telecommunication market with other big powers, such as the United States, the European Union, Japan, and Korea. The implication of its TD-SCDMA technologies to other countries will be far beyond technical significance. The success of TD-SCDMA from proposal to operational system will bring China into the world club, which used to be limited to the Western powers only.

Conclusions

Since the submission of the TD-SCDMA proposal to ITU in 1998, China has undergone a critical path in developing its own 3G mobile standard, which can be expected to be ready within one or two years. China has become the largest single mobile communication market in the world, and its great potential for further development in mobile communications has attracted all the major telecommunication companies in the world, especially after China's entry into the WTO. The China's market is widely open to foreign investment in mobile communication equipment and services; so is China's mobile technology to the world. To cope with emerging ever more severe competition, China wants to promote its own mobile standard to save the cost of purchasing foreign IPs and technologies, and eventually to gain a world market share. TD-SCDMA adopts numerous advanced technologies and offers a relatively cost-effective way to upgrade existing GSM networks into fully functional 3G core networks. Therefore, it provides a very attractive solution not only to China but also to worldwide GSM service operators to accomplish an evolutionary upgrade from 2G to 3G networks. It can substantially reduce the investment risk, which is the most serious concern to almost all mobile service operators with 3G licenses in hand, on which they have spent too much money. After its entry into WTO, China is to be fully integrated into the world trading system, under which TD-SCDMA has also been offered a great opportunity to be introduced to many other countries adopting the GSM standard. The impact of TD-SCDMA should never be underestimated.

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