

Chapter 2

Evolution from TD-SCDMA to FuTURE

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2.1 FuTURE Project in China

2.1.1 Background of FuTURE Project

In recent years, along with the continuous development of network and communication technologies and the global commercialization of the 3G (3rd Generation Mobile Communication System), the support for the data service and unsymmetrical service has encountered a greater improvement compared with the 2G (2nd Generation Mobile Communication System), and also the diversity of services is better. At the same time, the requirements for higher data rate and higher quality wireless communication service are brought forward by users. On the one hand, the conflict of rapidly growing numbers of users and limited bandwidth resources becomes outstanding, so the spectrum efficiency of system should be improved by adopting some advanced technologies. On the other hand, it has been proved in both theory and practice that some novel key technologies, such as MIMO (multiple input, multiple output) and OFDM (orthogonal frequency division multiplexing), can improve the performance of current mobile communications systems. Also, many problems need to be improved in the current system while providing service with high data rates and high performance. Therefore, the research of next-generation mobile communication systems has been put into the calendar.

Many countries and organizations have already carried out the research of next-generation mobile communication systems, such as ITU (International Telecommunication Union), European Commission FP (Framework Program), WWRF (Wireless World Research Forum), Korean NGMC (Next Generation

Mobile Committee), Japanese MITF (Mobile IT Forum), and China Communication Standardization Association (CCSA). Some international standards organizations are working for the standards of the E3G (enhanced 3G) and 4G (4th Generation Mobile Communication System), such as the LTE (long term evolution) plan of the 3GPP (3rd Generation Partnership Project) and the AIE (air interface of evolution)/UMB (ultramobile broadband) plan of 3GPP2. The ITU also made the calendar of the 4G communication system, IMT (International Mobile Telecommunications) Advanced. WRC'07 (World Radio-Communication Conference 2007), which was held at the end of 2007, has already allocated multiband spectrum resources for future 4G systems. The 4G is coming.

When research on next-generation mobile communications had just stepped into its startup period, a project called Future Technologies for a Universal Radio Environment (FuTURE) was launched in China. The goal of the project is to support theoretical research, applicable evaluation, and 4G trial system development of the proposed technologies for the Chinese Beyond 3G (B3G)/4G mobile communications. The FuTURE plan aims at the trends and requirements of wireless communication in the next 10 years, and it expects to play an active role in the process of 4G standardization. FuTURE is listed in the 863 Program of China's Science and Technology Development Plan in the Tenth Five Years and formally started in 2002.

The 863 Program is a state-level scientific program. It was proposed in March 1986 and launched in 1987. In April 2001, the China State Council agreed on further carrying out 863 programs on the tenth-five year period. Information technology is an important field of 863 programs. The FuTURE project was initially launched as a part of China's 863 Program in the wireless communications area.

At the end of October 2006, the FuTURE project was successfully tested and certified by the Ministry of Science and Technology (MOST) in Shanghai, representing China's first Beyond 3G mobile communication trial networks of TDD (time division duplex) and FDD (frequency division duplex) systems.

2.1.2 Features of FuTURE System

The next-generation communication system faces requirements beyond year 2010, which will be mainly mobile data service. It should have wider coverage and supports high mobility. The FuTURE system differs radically from the 3G system in the key technologies, where the core network may have a continuous evolution while the air interface should have a revolutionary development. The reason will be detailed as follows.

The packet data service will be in a dominant position, whose "percent occupied" in the overall traffic will increase from 10–20% currently to 80% in the future, while the market of voice service will shrink gradually. The traditional

cellular mobile communication system is designed for the requirement of voice service, and it is difficult to apply the code division multiple access (CDMA) technology directly to the 4G system because of its constraint in the aspects of acquisition and synchronization. This means that a fully new wireless transmission method and its corresponding network structure should be designed for the 4G system to meet the requirements of future mobile communication services. With respect to the evolution of E3G standards, this trend has emerged in the standardization process of 3GPP LTE, and OFDM technology has been accepted by E3G standards to accommodate the burst transmission of packet data. The function of CDMA is being weakened, and it is applied more in the allocation of radio resources. It can be predicted that the OFDM will be a competitive air interface technology in the 4G system because of its high spectrum efficiency and flexible spectrum usage.

The peak data rate of the 4G system should be tens or hundreds of times higher than that of the 3G system, and it will be 100 Mb/s–1 Gb/s or even more. The frequency band of 2 GHz for traditional cellular mobile communication is now not enough, so the spectrum resource with higher frequency will be used. But the problem is that the attenuation of electromagnetic waves will increase, and the transmitted power should be increased accordingly tens or hundreds of times, while the cell coverage would be decreased if the traditional cellular mobile communication technologies are still adopted. The novel cellular network infrastructure needs to be researched to solve this problem.

The frequency resource used by mobile communication is limited, and in order to provide higher data rates for users within the limited frequency bandwidth, the overall spectrum efficiency of the system should become 10 times higher by adopting some new technologies. It has been proved by information theory that multi-antenna technology such as MIMO can greatly improve the capacity of mobile communication systems, and the research result guides the development direction of the future mobile communication technologies. But in the practical system—especially in the mobile terminal with limited volume—there are still many challenging problems in theory and technology to be solved for implementing the MIMO.

The peak data rate of the 4G system will be 100 Mb/s or more, but the actual data rate the user requires may vary from 10 kb/s to 100 Mb/s dynamically. In order to meet this requirement, the radio resource allocation strategy of the future mobile communication system must be flexible enough to accommodate the dynamical variety efficiently.

For the convergence of network and service, many kinds of wireless access systems will be included in the 4G system, such as cellular mobile communication systems, wideband wireless access systems, satellite systems, and rover systems. To satisfy the mobility requirements of the user, the 4G system should support an open network interface, provide interconnectivity between all kinds of wireless access systems, support seamless roaming between different networks, and ensure continuity of service for users.

Based on the preceding considerations, the FuTURE system will have the following features in radio transmission technology:

- all-IP-based architecture on the interconnectivity of an IP v.6 core network;
- separated control plane and user plane and wireless access networks transparent to the core network;
- flat network structure and cellular network topology suites for high-frequency electromagnetic wave transmission and multi-antenna technology;
- air interface that suits the packet burst service, with the peak data rate of 100 Mb/s–1 Gb/s and service with dynamic range by allocating the radio resource flexibly;
- for high-speed movement, frequency spectrum efficiency reaching 2–5 b/s/Hz; for low-speed movement, reaching 5–10 b/s/Hz or higher;
- maximum frequency bandwidth of 20 MHz and frequency carrier of 3.5 GHz;
- for voice services, a bit error rate (BER) of no more than 1E-03; for data services, of no more than 1E-06;
- support of vehicular speed up to 250 km/h;
- peak-to-average ratio (PAR) of radio transmission signals of less than 10 dB;
- end-to-end QoS guarantee better than that of the current telecommunication real-time service;
- support of the characters of self-organization, relay, multihop, and reconfiguration; and
- easy-to-develop and -apply new services and support of service convergence.

The FuTURE mobile communication system will meet the users' requirements of communication with anyone, anywhere, in any way, and at any time, and the user will obtain versatile services, such as virtual reality, videoconferencing, accurate positioning, and high-definition real-time pictures. A lot of advanced technologies, including OFDM, MIMO, and distributed network structure, will be adopted in the 4G system, and a new air interface will be provided to bring better experiences for terminal users.

2.1.3 FDD and TDD Branches of FuTURE Project

The FuTURE project is composed of two branches: the FuTURE FDD system and FuTURE TDD system, both of which are investigating and demonstrating advanced techniques for systems to meet the application requirements around the year 2010. The two branches will be evaluated on a uniform trial platform. For both TDD and FDD, the trial platform contains six access points (APs) and 12 distributed antenna arrays; each AP is equipped with two spaced antenna arrays. With excellent radio transmission performance, high-definition reactive video services

have been performed and demonstrated on FuTURE trial systems. Although both TDD and FDD have their own advantages and disadvantages, TDD has some superiority in supporting asymmetry services and multihop functions.

2.2 FuTURE TDD System

Beijing University of Posts and Telecommunications (BUPT) is responsible for the uplink design and trial system integration of the FuTURE TDD system. The university has finished the work of researching and developing China's first 4G TDD mobile communication system with the cooperation of the UESTC (University of Electronic Science and Technology of China), the HUST (Huazhong University of Science and Technology), and the SJTU (Shanghai Jiaotong University). The FuTURE 4G TDD system adopts advanced link transmission technologies such as MIMO and OFDM, which provide the peak data rate of 122 Mb/s on the 3.45-GHz carrier frequency, with the bandwidth of 17.27 MHz and the spectrum efficiency of about 7 b/Hz. It supports IPv6, simultaneous multichannel VOD (video on demand), HDTV (high-definition television), high-speed data download (file transfer protocol, FTP), Internet browsing, instant messaging, and VoIP (voice over Internet protocol) with data rates up to 1,000 times higher and lower power consumption than before.

2.2.1 Main Features of FuTURE TDD System

The FuTURE TDD system employs time division duplex mode, where the uplink and downlink work on the same frequency but at different time slots, and then realizes bidirectional communication. Compared with the FDD system, the TDD system will bring advantages in many aspects:

- More flexible spectrum usage. The TDD system does not require paired frequency bands, so it has better flexibility without the constraint of spectrum usage that FDD systems have.
- Better support for unsymmetrical services. The TDD system is more suitable for unsymmetrical service by allocating the time slots for uplink and downlink adaptively according to the traffic.
- Reciprocity between the uplink and downlink. In the TDD system, the uplink and downlink work on the same frequency; hence, the electromagnetic wave propagation characteristics of uplink and downlink are almost the same, so as the channel parameters. This reciprocity makes it possible that the channel estimation of uplink can be directly used by the downlink and vice versa, and it brings many advantages to TDD systems in the aspects of power control, application of transmission preprocessing, smart antennas, and transmission diversity.
- The system offers better support for the technologies of multihop, relay, and self-organization.

There are also some challenges to the TDD system. For example, it requires more accurate timing and synchronization. But it can be predicted that the TDD technology will be used widely in the 4G and that these problems will be resolved. At the same time, the FuTURE TDD system is backward compatible with the TD-SCDMA (time division–synchronous code division multiple access) standard proposed by China, which is one of the international 3G standards in some aspects such as frame structure. Thus, the 3G system based on the TD-SCDMA standard can easily evolve to the FuTURE 4G system.

2.2.2 Promising Technologies Implemented in FuTURE TDD System

In the research and development of the FuTURE TDD system, a series of innovations in basic theory has been proposed, such as

- flat wireless access network structure, which has been put into practice;
- group cell, which is a novel generalized cellular network architecture, and the slide handover strategy based on it;
- soft fractional frequency reuse to improve the spectrum efficiency;
- reliable end-to-end QoS (quality of service) mechanism;
- antenna array based on the generalized cellular network architecture to increase the system capacity, with a spectrum efficiency of 7 b/Hz;
- modular MIMO to support various environments; and
- scalable modular structure of the system, which can support data rates up to 330 Mb/s.

The FuTURE TDD system provides an overall solution that can fulfill the requirements of E3G/4G and adopts lots of key technologies in many aspects, including cellular network architecture, physical layer, medium access control (MAC) layer, radio resource management, and hardware design. As a result, some positive effects have been brought out in the areas of system design, pivotal algorithm, and trial system development.

2.2.2.1 Network Architecture and Cellular Topology

In the research of the FuTURE TDD system, the generalized distributed cellular architecture–group cell is brought out as a novel cellular network architecture; the slide handover strategy and the generalized distributed access network structure based on it are proposed. The cellular network architecture of the group cell can take full advantage of the multiantenna technology, and it fits for the advanced technologies in the physical layer to solve the problem of frequent handover results from higher carrier frequency and, consequently, smaller cell coverage. All the available resources in the system based on the group cell are scheduled and allocated

uniformly by the system, so it is easier to optimize the overall resource allocation and avoid the interferences to increase the system capacity and more favorable to use advanced digital signal processing (DSP) technologies to improve the system performance efficiently. In addition, the slide handover can be accomplished by the physical layer adaptively to avoid complex interactive high-level signaling and increase the handover speed. In this way, the user will always be in the center of cell, so the cell edge effect will be eliminated.

The generalized distributed radio access network is a flat and simplified one with high efficiency, where the control plane is apart from the user plane and the radio resources are managed mainly by the control domain. Compared with the network structure currently used, it can reduce the transmission latency of signaling and data to improve system performance, meet the requirement of all-IP, and save the cost of network construction.

The separation of control plane and user plane simplifies network architecture and the signaling load. The generalized distributed cellular structure enlarges the coverage and fully uses the advantages brought by multiantenna techniques. The slide handover strategy makes users always feel that they are at the center of the cell to avoid cell edge effect and resist intercell interference.

2.2.2.1.1 Generalized Distributed Radio Access Network

In a generalized distributed radio access network (RAN), the radio network controller (RNC) in the 3G UTRAN (universal terrestrial radio access network) is separated into two elements. The RAN-specific part migrates into the RAN server, whereas the cell-specific control functions become a part of the AP, which connects antenna elements by optical fiber. Cell-specific processing of user traffic (packet data convergence protocol, PDCP; radio link control, RLC; MAC; etc.) is exclusively performed by the AP. The antenna elements are only responsible for signal transmission and reception. Each AP selects some of them to serve a certain mobile terminal (MT) to construct a generalized distributed cell (group cell). This generalized distributed radio access network architecture is presented in [Figures 2.1](#) and [2.2](#).

2.2.2.1.2 Definition and Construction Method of Generalized Distributed Cell–Group Cell

Based on multiantenna transmission techniques, the generalized distributed cell is characterized by several adjacent cells that use the same resources (such as frequency, code, or time slot) to communicate with a specific MT and use different resources to communicate with different MTs. The generalized distributed cell is different from the cluster system in current cellular communication systems in that the cells in the cluster use different resources to communicate with MTs.

Figure 2.2 describes a typical generalized distributed cell-based wireless communication system in which each AP has several separated antenna elements (AEs).

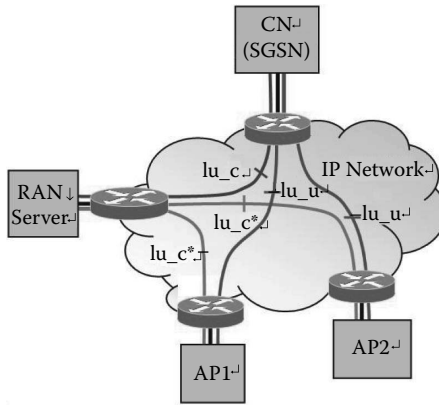


Figure 2.1 Generalized distributed radio access network.

AP1 has 9 AEs and AP2 connects with 10 AEs. If the AEs in the area are indexed by 1–9 and the size of the generalized distributed cell is 3, three generalized distributed cells are connected with AP1 in this area: generalized distributed cell 1 of AEs 1, 2, and 3 (▨ area), generalized distributed cell 2 of AEs 4, 5, and 6 (▩ area), and generalized distributed cell 3 of AEs 7, 8, and 9 (≡ area). This is a fixed

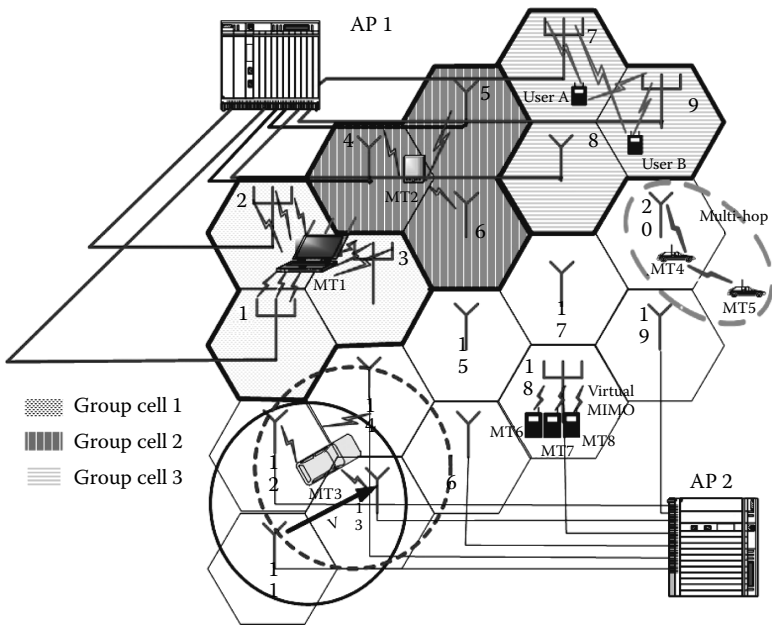


Figure 2.2 Generalized distributed cell structure.

generalized distributed cell structure and the AE of each generalized distributed cell is fixed. With the movement of the MT, different fixed generalized distributed cells will be selected.

Considering the situation in AP2, with the movement of MT4, the AE of the generalized distributed cell that serves the MT4 can also move, corresponding with it. As shown in [Figure 2.2](#), antennas 11, 12, and 13 of AP2 are used for MT4 in time slot 1. With the movement of the MT4, in time slot 2, antennas 12, 13, and 14 will be selected by AP2. The construction of the generalized distributed cell is dynamically changed instead of fixed. This is the slide generalized distributed cell structure.

The construction of slide generalized distributed cells may be viewed as the process of sliding windows. The several cells in one generalized distributed cell could be regarded as in one window and the window could change dynamically in size, shape, and slide speed due to the moving speed and direction of the MT. When the MT moves at relatively rapid speed, the size of the slide window will become larger so as to keep up with the movement of the mobile and decrease the number of handover times. When the speed of the MT is relatively slow, the size of the slide window will become smaller to reduce the waste of resources. If the MT changes its moving direction, the direction of slide window would change at the same time. As a new handover strategy, slide handover changes adaptively in correspondence with the generalized distributed cell structure. Different MTs may correspond to different generalized distributed cells.

Based on the generalized distributed cell architecture, the MIMO technique has many more applications, which indicate the unification of the physical layer and the network architecture. In the case of one antenna in each cell, the generalized distributed cell can be regarded as the spaced MIMO structure (generalized distributed cells 4, 5, and 6 in [Figure 2.2](#)). When there are AEs distributed in each cell connected to the same AP, it changes to another structure called a distributed MIMO (AEs 1, 2, and 3). Additionally, UWB technology helps to realize the communication among several MTs nearby. Based on this, an AE in a cell and MTs within the corresponding coverage compose virtual MIMO structure (AE 18 and MTs 6, 7, and 8).

The signals could be transmitted and received by all the antennas of the group by techniques such as MIMO, STC, and OFDMA (orthogonal frequency division multiple access). Therefore, the system's ability to resist interference could be improved, the handover times could be greatly decreased, and the system capacity could be increased. Furthermore, because the signal sources of the same generalized distributed cell are identical, the MT does not need handover in intrageneralized distributed cells. Only if the MT moves out of coverage of the current generalized distributed cell does the handover between the generalized distributed cells—generalized distributed cell handover occur. The generalized distributed cell handover can effectively avoid the frequent handover between cells. Generalized distributed cell handover is also classified into fixed handover and slide handover,

corresponding to the construction method of generalized distributed cells. Based on the slide handover strategy, the generalized distributed cell after handover could have some common areas with former generalized distributed cells. As shown in Figure 2.2, with the movement of MT₄, the current generalized distributed cell (AEs 11, 12, and 13) that serves MT₄ changes into other generalized distributed cells (AEs 12, 13, and 14).

2.2.2.1.3 Separation of Control Plane and User Plane

Because the control plane and user plane scale differently in future data communication, they need to be processed and carried separately. In this contribution, the control traffic from CN will address a (centralized) RAN server, whereas the user traffic is directly routed to an extended AP. This AP terminates the Iu interface for the user traffic and performs the necessary radio-specific processing. The control part of Iu is terminated in the RAN server.

In order to optimize the access system and to reduce network cost, a strict separation of control and user plane is necessary. The evolved architecture should take this into account and offer the flexibility for future adaptation. The proposed generalized distributed cell architecture uses a centralized node (RAN server) only in the control plane and decentralizes the user plane handling in AP.

Iu traffic should be split into a control part (Iu_c) and a user part (Iu_u). Iu_c terminates at the RAN server and Iu_u at the AP. Control information between the RAN server and AP should be transferred via the new Iu_c* (new interface to be further specified) interface.

2.2.2.1.4 Entity of Generalized Distributed RAN

RAN server. Except for the user traffic handling, the RAN server behaves similarly to the former RNC. It manages mobility inside the RAN and the necessary Iu bearers for control and user traffic (Iu_c and Iu_u). For the control part of the Iu interface, the RAN server behaves like a regular RNC from the CN point of view. For the user part of the Iu interface, the AP acts as the former RNC. Furthermore, the RAN server manages micromobility (i.e., mobility inside RAN such as paging and AP relocation) and radio mobility (i.e., mobility between adjacent APs) via Iu_c*.

AP. When antenna arrays are distributed in each cell connected to the same AP, they change to another structure called distributed MIMO (antennas 1, 2, and 3). Each AP connects several antenna elements and, by selecting some of them to serve a certain MT, constructs a generalized distributed cell. Antenna elements are responsible only for signal transmission and reception. The signal process is done in the signal processing unit. AP also contains the cell-specific radio resource management. This enables the AP to manage its radio resources autonomously. On demand, they are requested from the RAN server via the Iu_c* interface.

2.2.2.2 Physical Layer Techniques

To obtain the peak data rate of more than 100 Mb/s, the FuTURE TDD system adopts many key technologies in the physical layer, such as OFDM, MIMO, PAPR (peak-to-average power ratio) reduction, and link adaptation. To realize the transmission data rate up to 1 Gb/s, deep studies have been carried out on the physical layer technologies by introducing some basic theories, such as information theory, norm theory, and matrix theory.

In the FuTURE TDD system, the technologies of OFDM combined with MIMO are used to utilize the characters of OFDM fully under the MIMO structure. The OFDM technology has better capability of anti-multipath interference and higher spectrum efficiency than nonorthogonal multicarrier solutions. Moreover, it can be realized by simple discrete Fourier transform (DFT), so it will be an important technology in the next mobile communication system. Meanwhile, the system adopts the turbo code with bit rate of 100 Mb/s coupled with puncturing and soft demodulation technologies to enhance the system performance and decrease the transmission power; it realizes wideband wireless access with low power consumption and high peak data rate. Additionally, in order to utilize fully the spatial resource to transmit data, the MIMO detection technology, which has good performance, is used at the receiver. Four antennas in the MT and eight in the AP form a 4×8 MIMO system. At the same time, the technology of V-BLAST (vertical Bell Laboratory layered space-time) codes, combined with interference cancellation, is adopted. The technologies mentioned earlier increase spectrum efficiency and improve system performance because of the spatial multiplex and spatial diversity. The overall system performance has a further improvement by adopting other key technologies.

Considering the application of OFDM and MIMO in B3G mobile communication systems, the FuTURE TDD Special Working Group pays much attention to the following topics:

- frame design;
- multiple access schemes; and
- key physical layer techniques, such as MIMO and LA.

2.2.2.2.1 Frame Structure

The frame structure has a drastic influence on system performance, and the wireless frame structure designed here is depicted in [Figure 2.3](#). The frame is composed of eight burst time slots (TSs), where TS0 is designed for the downlink dedicated signaling, including the system information broadcast, paging, etc. The dedicated time slot (TS1) is used for both uplink and downlink frame and frequency synchronization. The remainders are designed for data transmission. Moreover, advanced techniques such as LA (link adaptation) and JT could take advantage of the fact that

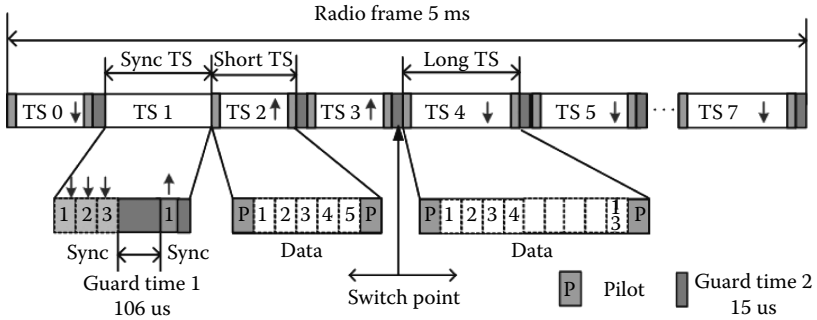


Figure 2.3 Frame structure for FuTURE TDD system.

CSI (channel state information) is reciprocal for the TDD system. The backward compatibility with one of 3G standards—TD-SCDMA—is considered in system design, especially in frame structure design. The reason is that the large-scale field test of TD-SCDMA with TDD will be finished in 2004. It will be a promising standard supporting 3G services. Obviously, smooth evolution from 3G to B3G system is also an important consideration.

The parameters and characteristics of wireless frames are listed as follows:

- The duration of a radio frame is 5 ms, and it could reduce the complexity of adaptive modulation.
- The guard time between uplink and downlink is 106 μ s, and it is possible to support a cellular radius as large as 15.9 km. If a multi-antenna technique is adopted, it is possible to enlarge the cellular radius.
- There are two types of time slots: short and long. The unequal length for downlink and uplink not only can decrease the cost for guard time, but also can guarantee the flexibility of resource allocation.
- The alterable switch point can flexibly support the service requirements. The change of data ratio after changing switching point can be seen clearly in Figure 2.3. Regarding the asymmetric tendency of future services, the time slot ratio between the uplink and the downlink is about 1:4. This is a default mode.

2.2.2.2.2 Block Structure for Link Layer

In Figure 2.4, the block structure for uplink design is plotted. Here, MIMO, OFDM, and LA are adopted for FuTURE TDD radio transmission, in which P/S is the parallel-to-serial transform module and S/P is the converse operation. CP represents the adding of cyclic prefix (CP).

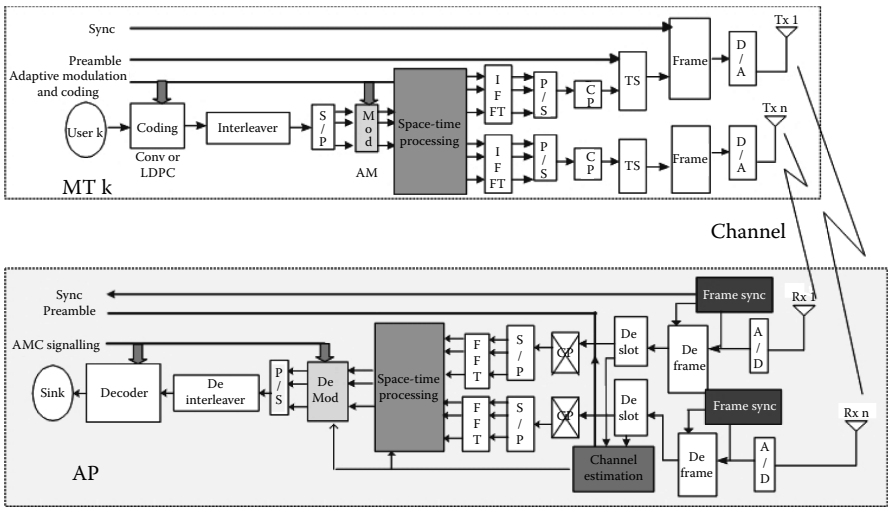


Figure 2.4 The block structure of FuTURE TDD uplink.

2.2.2.2.3 Multiple Access Techniques

Multicarrier transmission, such as OFDM, should be exploited in the FuTURE TDD system to support high data rate transmission. A group of subcarriers is employed as the basic resource unit in an OFDMA system. A subcarrier group is not necessarily composed of adjacent subcarriers; the interleaved subcarriers in frequency domain are also supported, as shown in [Figure 2.5](#). In addition, OFDMA can be combined with time division multiple access (TDMA) and spatial division medium access (SDMA) in order to provide flexible multiple access and resource allocation, as shown in [Figure 2.6](#).

2.2.2.2.4 OFDM Modulation

OFDM is an attractive method of transmitting high-rate information over highly dispersive mobile radio channels by dividing the serial input data stream into a number of parallel streams and transmitting these low-rate parallel streams simultaneously. As unquestionable proof of its maturity, OFDM was standardized as the European digital audio broadcast (DAB) as well as the digital video broadcast (DVB) scheme. It was also selected as the high-performance local area network (HIPERLAN) transmission technique as well as part of the IEEE802.11 wireless local area network (WLAN) standard. Furthermore, it has become the E3G mobile radio standard.

OFDM converts a frequency-selective channel into a parallel collection of frequency-flat subchannels. The subcarriers have the minimum frequency separation

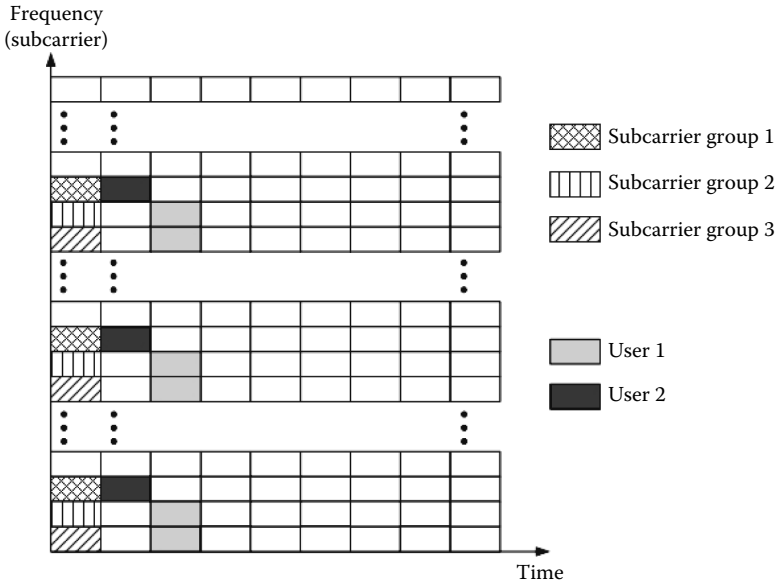


Figure 2.5 Two-dimensional resource allocation.

required to maintain orthogonality of their corresponding time domain waveforms, yet the signal spectra corresponding to the different subcarriers overlap in frequency. Hence, the available bandwidth is used very efficiently. OFDM is robust against multipath fading because the intersymbol interference (ISI) is completely eliminated by introducing a CP or a guard interval of each OFDM symbol. Meanwhile, the intercarrier interference (ICI) is also avoided, which is so crucial in high data rate transmission. Moreover, the CP enables the receiver to use fast signal processing transforms such as a fast Fourier transform (FFT) for OFDM implementation, thus dramatically reducing the complexity.

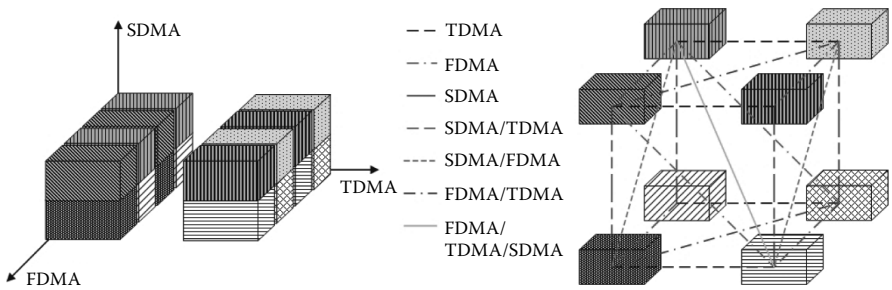


Figure 2.6 Flexible combinations of multiple access schemes.

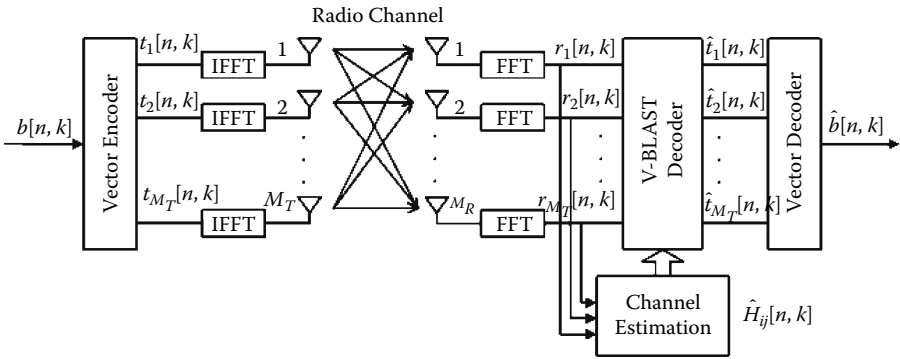


Figure 2.7 The structure of the MIMO-OFDM system.

OFDM offers fully scalable bandwidth to suit varying spectrum allocation and frequency-domain scheduling. Meanwhile, OFDM could be easily combined with other multiple schemes, including FDMA (frequency division multiple access), OFDMA, TDMA, CDMA, and SDMA, in order to support multirate services and to achieve a frequency reuse factor of one. OFDM-CDMA assigns a subset of orthogonal codes to each user; thus, information symbols are spread in either frequency domain or time domain. In OFDMA systems, the signal of each user is transmitted via a set of subcarriers within the duration of several OFDM symbols. In our proposal, the interleaved OFDMA/TDMA is employed in forward link and the localized OFDMA/TDMA in reverse link.

OFDM is also very suitable for MIMO transmission. As each subcarrier is flat fading, the MIMO signal processing for the frequency selective fading channel can be performed for each subcarrier, which is substantially simplified. The structure of the V-BLAST-based MIMO-OFDM system can be expressed as in Figure 2.7.

2.2.2.2.5 Modulation Scheme

The FuTURE TDD system supports QPSK (quadrature phase shift keying), 16 QAM (quadrature amplitude modulation), and 64 QAM. Even higher-order modulation, such as 128 QAM, is also considered for the downlink.

2.2.2.2.6 MIMO and Transmit Diversity

MIMO structure should be adopted in the FuTURE TDD system in order to achieve high data transmission rates. As a research hotspot and potential technique for future communication, MIMO is able to enhance the spectrum efficiency and improve transmission performance by taking advantages of spatial resources. Analysis and simulations prove that MIMO can provide high spectrum efficiency

of 20–40 bits/s/Hz. As an important branch, MIMO techniques based on transmit diversity (such as STTC; space–time block code, STBC) can obtain performance gain by repetition. MIMO techniques based on spatial multiplexing (such as D-BLAST and V-BLAST) increase the system capacity significantly by serial-to-parallel transmission.

For correlated MIMO environments, channel information should be fed back and precoding is performed at the transmitter. As another kind of MIMO structure application, beam-forming should also be considered and analyzed according to practical requirements. Furthermore, advanced MIMO techniques should be paid more attention because the number of receiving antennas may be fewer than those of transmitting antennas in the forward link.

Based on some special network architectures, such as generalized distributed antenna architecture, the MIMO technique could embody its superiority in more application forms (e.g., spaced MIMO, distributed MIMO, and virtual MIMO). Additionally, adaptive MIMO schemes should be considered in the FuTURE TDD system.

2.2.2.2.7 Link Adaptation

The FuTURE TDD system should allow for link adaptation, which involves not only AMC but also adaptive MIMO and other advanced adaptive transmission techniques. In addition, the signaling overhead in both forward and reverse link should be considered.

Adaptive modulation and coding (AMC). Adaptive modulation and coding as one of the effective link adaptation schemes should be considered and adopted in the FuTURE TDD system to improve the system capacity with high spectral efficiency. Systems in TDD mode have channel reciprocity because both forward and reverse links are accommodated in the same frequency band. Consequently, the system can estimate the CSI from reception. Hence, TDD systems are more suitable to adopt the AMC technique.

By employing the AMC technique, the power of the transmitted signal is held constant over a frame interval, and the modulation and coding schemes (MCSs) can be chosen adaptively according to channel conditions. The bearer service (BS) may compute the best combination of MCSs either based on postdetection SNR measurement reported by AT or based on signal-to-noise (SNR) measurement of the (reciprocal) reverse channel. Some MCSs and their MCRs (modulation coding rates) are listed in [Table 2.1](#). In a system with AMC, users in favorable positions (close to the cell site) are typically assigned higher-order modulation with higher code rates (e.g., 64 QAM with $R = 3/4$ turbo codes), while users in unfavorable positions (close to the cell boundary) are assigned lower-order modulation with lower code rates (e.g., QPSK with $R = 1/2$ turbo codes).

AMC can benefit the system from several aspects. A higher data rate is available for communication under good channel conditions, which consequently

Table 2.1 AMC Schemes and Modulation Coding Rates

<i>MCS</i>	<i>Modulation</i>	<i>Coding</i>	<i>MCR (bits/symbol)</i>
MCS1	QPSK	1/3	0.667
MCS2	QPSK	1/2	1
MCS3	QPSK	3/4	1.5
MCS4	16 QAM	1/2	2
MCS5	16 QAM	3/4	3
MCS6	64 QAM	3/4	4.5

increases the average throughput of the system. Communication quality is guaranteed in cases in which selection of MCSs is in accordance with channel condition. Interference variation is reduced due to link adaptation based on variations in the modulation/coding scheme instead of variations in transmission power. In systems with TDD mode, AMC is more convenient for application and the scheduling of various MCSs is flexible with low latency.

Hybrid automatic repeat request (HARQ). Hybrid ARQ is an important link adaptation technique. In AMC schemes, C/I measurements or similar measurements are used to set the modulation and coding format; in HARQ, link layer acknowledgments are used for retransmission decisions. AMC by itself does provide some flexibility to choose an appropriate MCS for the channel conditions according to measurements either based on AT measurement reports or network determined. However, an accurate measurement is required and there is a delay. Therefore, the ARQ mechanism is still required. HARQ automatically adapts to the instantaneous channel conditions and is insensitive to the measurement error and delay. Combining AMC with HARQ leads to the best of both fields: AMC provides the coarse data rate selection, and HARQ provides for fine data rate adjustment based on channel conditions.

Adaptive MIMO. In realistic wireless transmission environments, channel characteristics of MIMO systems behave in time, frequency, and space dimensions. In order to guarantee system performance in various channel conditions, adaptive MIMO, which is able to choose appropriate MIMO schemes adaptively based on different channel environments, should be supported in the FuTURE TDD system. Technology of transmit beam-forming (TxBF) is an advisable choice in high spatial correlated channels. In low correlation cases, technology of spatial division multiplexing (SDM) is more suitable.

Therefore, adaptive MIMO should be supported to maintain high performance under various channel environments. The switching criterion according to different channel conditions for choosing appropriate MIMO schemes such as TxBF or SDM should be further discussed. For simple demonstration, the primary diagram of adaptive MIMO is shown in [Figure 2.8](#).

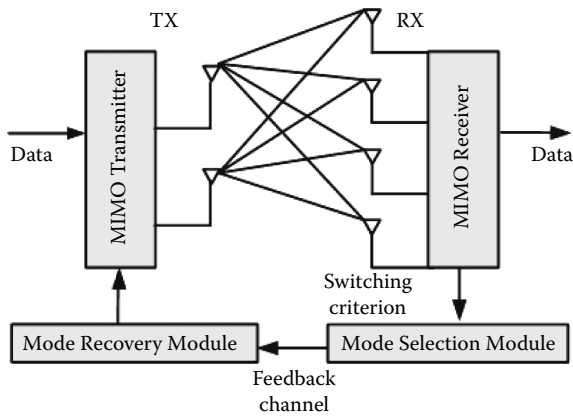


Figure 2.8 Primary diagram of adaptive MIMO.

Additionally, the adaptive power allocation can be combined with the V-BLAST technique to bring good performance. Because the overall bit error rate (BER) performance of spatial multiplexing systems is limited by early detection stages, allocating a low data rate for early detection stages may reduce the probability of error propagation and thereby improve the averaged BER performance for all detection stages. Thus, different transmit antennas of the V-BLAST system should be allocated different transmit data rates if better BER performance is expected. One important advantage of the method is that the optimal ordering does not need to be determined because the allocation of the data rate assumes the receiver detects the streams in a predefined order. When the data rate on different transmit antennas increases by degrees in some predetermined order, detection order at receivers would execute at the same order. Consequently, the complexity of the conventional successive cancellation receiver of V-BLAST systems is greatly reduced. A simple way for the modified V-BLAST is to select a different modulation constellation for each transmit data stream. Then the first decoded stream will typically have the smallest constellation size because it is decoded first. Similarly, employing channel coding with different data rates would also be effective. In this case, the first stream to be decoded would adopt the channel-coding scheme of the lowest rate.

Adaptive MIMO can guarantee system performance and throughput under various MIMO channel conditions and make full use of the MIMO channel. Adaptive MIMO is more convenient and needs less time delay in TDD mode.

Adaptive antenna selection. As an effective technique to fulfill different service requirements of users, adaptive antenna selection should be considered in B3G-TDD systems. According to various kinds of services, the transmit antennas could be selected for transmission adaptively based on channel conditions and data rates required.

Adaptive power allocation. The FuTURE TDD system should support adaptive power allocation. Different proportions of power could be allocated to different

subcarrier groups to exploit system performance optimization. In forward link, the scheme for power allocation can be adjusted according to channel information fed back from AT. In TDD mode, taking advantage of reciprocal radio channels, adaptive power allocation can be carried out more flexibly with little time delay.

2.2.2.2.8 Random Access Procedure

Scheduled access and contention-based access should be supported. The contention-based random access scheme is based on the contention windows (CWs) strategy. The length of the CW is decided by the number of retransmission requests and the QoS levels of MTs' services. The advantage of this scheme is that we can get lower frame delay with a small number of users' access requests, even if the user number increases and collisions arise; the frame delay is also controlled in an acceptable range.

The dynamic allocation scheme is that BS increases the number of random access channel (RACH) subchannels of the next MAC frame if collided RACH subchannels exist in the current frame and decreases it with the proper weighting factor in the case of successful attempts. Thus, it can dynamically increase the subchannels' number of random access channels in the case of a large number of access attempts and decrease the subchannels when there are fewer access requests. The proposed scheme, based on results of access attempts, can get higher throughput compared to fixed allocation schemes. The scheme is also adoptable into this system.

2.2.2.2.9 Link Performance of FuTURE TDD System

In the simulation, 3.5-GHz carrier frequency and 20-MHz system bandwidth are considered. The bandwidth of each subcarrier is 19.5 kHz and 832 subcarriers are employed to transmit information. In order to provide a guard band for D/A conversion, nulls are placed at the end of the spectrum. To implement OFDM modulation/demodulation, 1,024-point inverse fast Fourier transform (IFFT)/FFT is used. Some of the service-specific parameters are presented in Table 2.2. The simulation channel is a six-path Rayleigh fading channel with an exponential power-delay profile defined by FuTURE. The maximum delay spread is 10 μ s.

Table 2.2 Parameters for Different Services

	30 Mb/s	50 Mb/s	100 Mb/s
Data Rate	30 Mb/s	50 Mb/s	100 Mb/s
Modulation	QPSK	16 QAM	16 QAM/64 QAM
Channel coding	Turbo	Turbo	Turbo
Coding rate	1/2	2/5	3/5
Antennas at AP	8	8	8
Antennas at MT	4	4	4

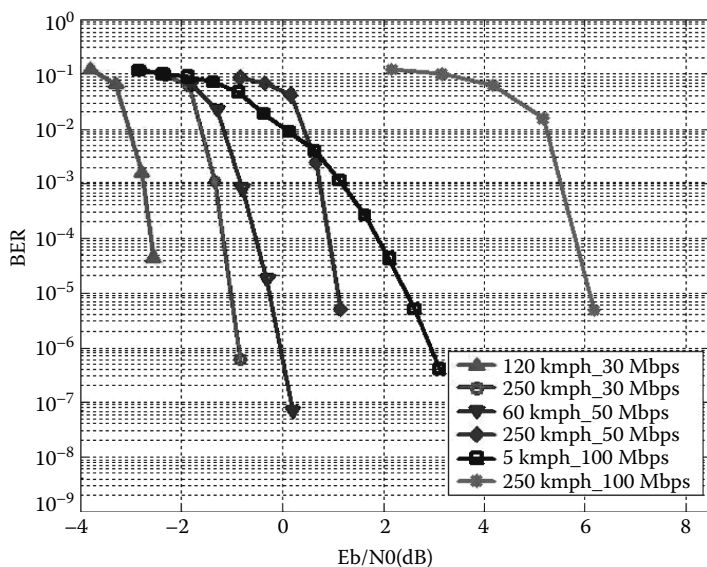


Figure 2.9 Performance of various data services (outdoors, 250 km/h).

Simulation results of various data services at different mobility are shown in Figure 2.9. It is proved by simulation that the FuTURE TDD radio transmission link can support more than 100-Mb/s data rate transmission. Meanwhile, supporting high vehicle speed (250 km/h) with large delay spread (10 μ s) is required. At the same time, the B3G link can provide reliable transmission for a large scale of high data rate transmission.

2.2.2.3 Layer 2 and Layer 3 Techniques

The FuTURE TDD system has proposed a series of innovations in the field of radio resource management and has obtained many achievements in the technology of resource allocation and management for next-generation wireless communication systems based on the basic theories of extension set, fuzzy set, game theory, and joint optimization. Such achievements are mainly concentrated in the aspects of high-efficiency frequency reuse strategy, access control strategy for multiantenna systems, and cell edge user performance improvement.

Physical layer (PHY) techniques establish a high-speed radio transmission platform, while radio resource management (RRM) techniques ensure high reliability and high efficiency for radio transmission. The target for RRM design is to provide the highest system capacity and data throughput through optimizing limited radio resources. The main issue is to investigate efficient QoS-oriented resource allocation strategies to optimize jointly the usage of radio resources, such as time, frequency,

space, and power. Radio resource management algorithms should support various classes of traffic while guaranteeing their required QoS.

The basic requirements to MAC layer include:

- support of TDD evolution and compatible TDD/FDD hybrid systems;
- support of a much higher data rate;
- support of much higher spectrum efficiency;
- support of a wide range of QoS and mobility;
- reasonable complexity and cost; and
- trade-off between backward compatibility and performance improvement.

The services and functions of MAC include:

- mapping between logical channels and physical channels;
- selection of appropriate transport format for each transport channel, depending on source rate;
- priority handling between data flows of MT;
- priority handling between MTs by means of dynamic scheduling;
- identification of MTs on common transport channels;
- multiplexing/demultiplexing of upper layer protocol data units (PDUs) into/from transport blocks delivered to/from the physical layer on common transport channels;
- multiplexing/demultiplexing of upper layer PDUs into/from transport block sets delivered to/from the physical layer on dedicated transport channels;
- traffic volume measurement;
- transport channel type of switching;
- ciphering for transparent mode RLC; and
- access service class selection for RACH and CPCH (common packet channel) transmission.

2.2.2.4 *Intercell Interference Mitigation*

According to the features of next-generation mobile communication systems, the theory and the corresponding implementation method of soft fractional frequency reuse (SFFR) were first proposed based on the theories of extension set. FuTURE TDD employed SFFR to ensure the QoS for those users at the cell edge under; to resolve the problem of intercell interference exists in the next-generation mobile communication system, which mainly adopted FDMA technology; and to greatly improve the utilization of limited frequency resources.

As an important strategy to avoid intercell interference, frequency reuse has already been studied for tens of years. Although CDMA-based systems, with a

frequency reuse factor of one, have been developed in 3G systems, it appears that OFDMA-based systems will still play a dominant role in the next-generation mobile systems. Therefore, an efficient frequency reuse strategy, as well as enhancing performance for the cell-edge users, is still left as an open research issue for those FDMA-based systems.

To use the spectrum resource more sufficiently and enable the cell-edge users to obtain better performance, SFFR is proposed for OFDMA-based systems. Based on SFFR, the basis of mitigating intercell interference through resource planning/coordination is to classify the users into cell-edge users and inner-cell users according to their geometry factor. The threshold of the geometry factor can be determined by actual traffic distribution in one certain cell.

Considering the following rules, users in each cell are divided into two major groups. One group is for cell-edge users, and the other group is for inner-cell users. Assign the whole frequency band for all users in each cell as follows: Split the whole frequency band into two parts, G and F. According to SFFR, frequency is assigned as follows: Frequency set G and a subset of F are available for inner-cell users; for cell-edge users, SFFR strategy is illustrated by Figure 2.10.

Frequency reuse is a basic technology in wireless systems. In this proposal, SFFR strategy is proposed for intercell interference mitigation based on extension set theory. SFFR can improve spectral efficiency and improve performance of cell-edge users. It can also be used to accomplish the frequency plan for the whole network.

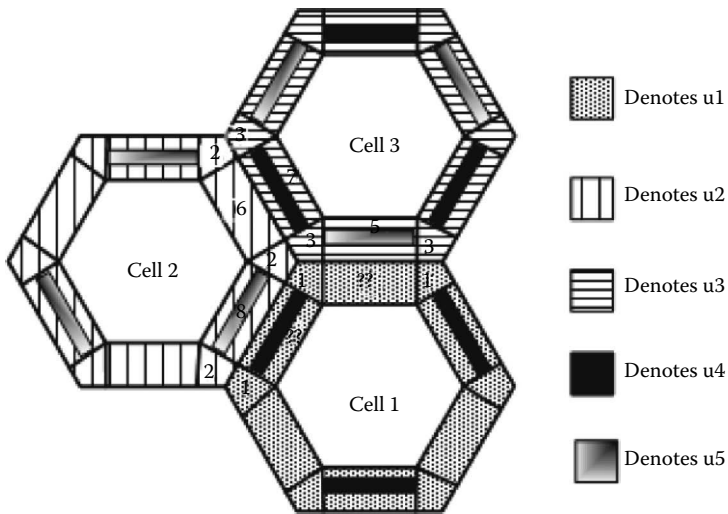


Figure 2.10 SFFR scheme for three-cell model.

2.2.3 FuTURE TDD Trial System and Trial Network

2.2.3.1 Hardware Implementation for FuTURE TDD Trial System

Based on the research of basic theories for the FuTURE TDD system, the hardware demonstration system has been developed and field tested in multicell networks. This hardware platform supports the peak data rate of more than 100 Mb/s and can meet users' requirements for various future services with different QoS, including HDTV, VoIP, data, video, FTP, and Internet.

The FuTURE TDD system adopts an overall infrastructure of the general hardware platform, standard ATCA (advanced telecommunications computing architecture) case, and backplane and flexible modular board structure. This kind of hardware platform structure is suited not only for the TDD mode but also for the FDD mode—not only the AP, but also the MT—and it can be used to research wireless transmission technology and test new wireless network structures. Based on the concept of modular design, the system is divided into various modules according to their functions, so it is easy to improve a module's design or update its functions without affecting other boards. The main modules are connected by using the peer-to-peer distributed interconnection structure based on the exchange; therefore, it is convenient to add or remove a module and adjust the system scale.

The system scale and system performance are scalable. Although extreme reduction of the direct coupling between various factors in the overall infrastructure design has been considered, the system can provide the required abilities of expanded connectivity and processing (for example, two four-element antenna arrays can be united into an eight-element one). The concept of modular MIMO is also proposed to adjust or expand flexibly the number of antenna arrays, the element number of every antenna array, the number of users, and the user data rate.

The technology of fully distributed parallel processing is adopted to reduce the dependence on CPUs and to avoid the bottleneck of network throughput and processing performance introduced by centralized processing technology. As a result, it increases the system's effective throughput capacity and improves the system's flexibility, expandability, and adaptability.

The whole trial system is based on SDR (software-defined radio) technology, where the baseband signal is processed in FPGA and DSP while the processing of control, wireless, and network protocols is implemented in programmable communication processors. This infrastructure based on SDR can sufficiently meet the system's requirement for further evolution. The system supports reconfiguration/dynamic configuration, dynamic update of the system function and signal processing algorithm (reloadable), remote update through network, and the OTA (over-the-air) and dynamic update technologies for the signal processing and control software of the MT.

2.2.3.2 Multicell and Multiuser Trial Network

The 4th Generation Mobile Communication System of the FuTURE TDD plan and the corresponding field trial system were checked and accepted in Shanghai City in October 2006 by a group of experts from the Ministry of Science and Technology of China, the Ministry of Information Industry of China, the Chinese Academy of Sciences, and the Chinese Academy of Engineering. They verified that the first B3G TDD system of China was implemented successfully. The field test results of the corresponding trial system had already validated its advantages in the aspects of multicellular network, support for high mobility, and high-speed data service.

In the research and development of the FuTURE TDD system, a series of advanced technologies was adopted, such as distributed network architecture based on RoF, slide handover, soft fractional frequency reuse, modular MIMO, and future generation computer services (FCGS). Also, the first 4G field trial system based on a distributed radio network was established in Shanghai, where a scheme of a combined network of TDD and FDD was introduced and then some key technologies in the system were analyzed, including the unification of software and hardware trial platform, wide coverage for 40- to 100-Mb/s data rate, a high mobility test, spectrum efficiency of 2–10 b/s/Hz, low power consumption, and good electromagnetic compatibility (EMC) performance.

Figure 2.11 shows the overall structure of FuTURE TDD trial systems, with three APs and three MTs included, where the distributed network structure was

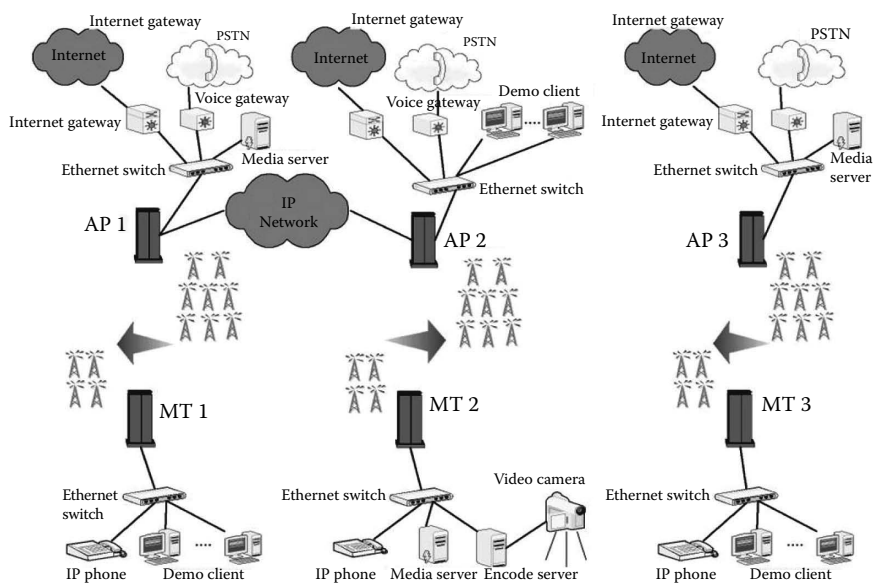


Figure 2.11 The overall structure of the FuTURE TDD trial system.



Figure 2.12 The hardware and antenna unit in the FuTURE TDD trial system.

introduced. The mobility test was performed between AP1 and AP2, including a handover test and a high-speed mobile performance test for the terminal. Figure 2.12 shows the antenna deployment in the FuTURE TDD trial system, including the AP, MT, antenna unit, and its field allocation. Figure 2.13 shows the



Figure 2.13 The test vehicle of the FuTURE TDD trial system.

test vehicle of the FuTURE TDD trial system, which supported vehicle speed up to 50–100 km/h.

2.2.3.3 Field Test Results of FuTURE TDD Trial System

For the FuTURE TDD trial network, the campus of Shanghai University of Engineering Science was selected as a typical urban environment with low vehicle speed. The campus map is shown in Figure 2.14. In this map, two-dimensional labels are used for location identifiers in order to facilitate the test process.

2.2.3.3.1 BLER Performance Test

In the FuTURE TDD trial network, just as Figure 2.14 shows, four distributed antenna array sites are located at each corner of the campus. For each site, four antennas are set up and eight antennas from two sites are connected to one AP. The test vehicle is equipped with four antennas and moves from point (1, 1) around the campus to point (5, 1). According to instant measurement results, the BLER performance of uplink is demonstrated in Figure 2.15. It can be seen that the FuTURE TDD trial system could support a peak data rate of 100 Mb/s along most paths around the campus. However, the data transmission rate should be reduced on the road between the rest house and the library, which also requires the application of seamless adaptive MIMO transmission.



Figure 2.14 Test map of campus for test of FuTURE TDD trial system.

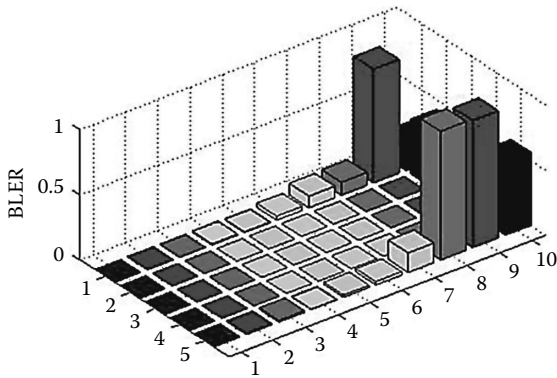


Figure 2.15 BLER performance around the campus.

2.2.3.3.2 Single-Frequency Networking Test

In the FuTURE TDD trial network, a simplified form of the SFFR scheme was performed and tested based on the distributed cellular network. Figure 2.16 shows the scenario of networking and the test procedure with a stationary terminal and a mobile terminal. According to the figure, when MT2 moves around the campus, it is first located in the same cell with MT1, but then in different cells. Taking advantage of SFFR, the two terminals first occupy half of the frequency resources

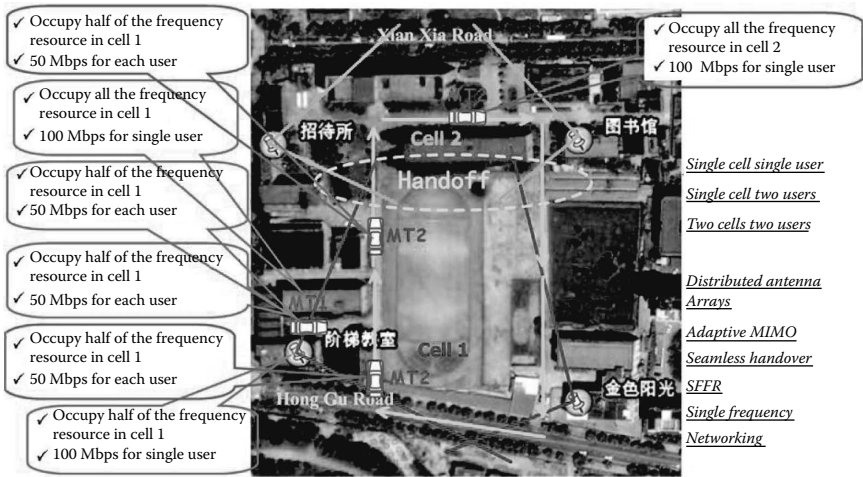


Figure 2.16 Test of SFFR with single-frequency networking.



Figure 2.17 HDTV service demo and videoconference service demo.

in one cell and then occupy all the frequency resources in each cell, which makes the scheme of single-frequency networking feasible.

2.2.3.3.3 Service Demonstration Test Results

In order to test the capability of the service load of the FuTURE TDD trial system, several kinds of different services were performed simultaneously on the platform in which HDTV service, videoconference, and high-speed FTP download services were all supported by wireless communication.

2.2.4 Achievements and Significance of FuTURE TDD System

The ITU has named the 4G system “IMT Advanced” and will start its standardization around 2008. The research in basic theory and development of a corresponding trial system for the FuTURE TDD system has been accomplished. The first field trial system based on a distributed radio network has been established successfully in Shanghai, and it has the basic characteristics of the 4G TDD mobile communication system. This system can provide radio transmission with a peak data rate of 100 Mb/s for high-mobility terminals and the demonstration of HDTV (Figure 2.17); the hardware platform can support wireless transmission with a data rate up to gigabits per second. It has the highlights of high spectrum efficiency and low transmission power, which represent the evolutionary trends of the next-generation mobile communication technologies. There are many innovations in radio network architecture, transmission, and radio resource management technologies for the next-generation wireless communication.

In the development of the trial system, the FuTURE TDD special working groups proposed 129 advanced technologies with independent intellectual properties, and most of them have been taken into practice. At the same time, some accumulated intellectual properties are devoted to 3GPP LTE and 3GPP2

AIE/UMB, and several standard proposals have been submitted to CCSA, 3GPP, and 3GPP2. Among them, BUPT has submitted more than 10 proposals to CCSA with 6 accepted, 3 proposals to ITU, 10 proposals to 3GPP2, and 30 proposals to 3GPP. Among them, three proposals have been accepted by ITU, seven by 3GPP, and one by 3GPP2 UMB release v2.0. Such work has pushed the evolution of the 3G technology, including TD-SCDMA, and laid the foundation of developing next-generation wideband wireless mobile communication technologies and participating in international competition on behalf of China. Additionally, the FuTURE TDD special working group plays an active role in the FuTURE Forum and maintains several documents about wireless transmission technology, spectrum management, radio resource management, and network structure.

The successful implementation of the FuTURE TDD system indicates that China is now in an advantageous position in the research and development process of the 4G Mobile Communication System. Based on this platform, commercial products can be developed to enter the R&D services market of wideband mobile communication technology and realize new types of multimedia services impossible before, such as the HDTV and super-high-speed download services. It will provide strong support for the successful development of the Chinese mobile communications industry and national socioeconomic level. The key technologies in the FuTURE TDD system can greatly improve the performance of high-speed wideband wireless access for users and are valuable to improving people's cultural lives, with the result of bringing positive social benefits.

2.3 TD-SCDMA, LTE, and FuTURE TDD

TD-SCDMA was proposed by the Chinese Academy of Telecommunication Technology (CATT) in 1998, accepted by the ITU as a 3G standard in November 1999, and accepted by the 3GPP as the low chip rate (LCR) TDD mode of universal terrestrial radio access (UTRA) in March 2001. TD-SCDMA has adopted many advanced technologies, such as synchronous CDMA, smart antenna, joint detection, SDR, baton handover, and dynamic channel allocation (DCA). TD-SCDMA originated in China and is strongly supported by the Chinese government. It is one member in the 3G family.

LTE is a project launched by 3GPP. It began in 2004 and aims to accompany a brand new standard to satisfy the requirements for the next 5–10 years. After the study item and work item, one version for such a system has been worked out. TDD and FDD modes are supported. It takes MIMO, OFDM, etc. to bring to the system the ability to raise data rates as high as 100 Mb/s. It can be seen as a system midway between 3G and 4G systems. The two standards support TDD mode; hence, it is necessary to make a comparison between them and FuTURE TDD.

Table 2.3 Comparisons of TD-SCDMA, LTE TDD, and FuTURE TDD Systems

<i>Aspects</i>	<i>TD-SCDMA</i>	<i>LTE TDD</i>	<i>FuTURE TDD</i>
Duplex	TDD	TDD	TDD
Multiple access	TDMA, CDMA	TDMA, OFDMA	TDMA, OFDMA
Bandwidth	5 MHz	1.4–20 MHz	20 MHz
Peak data rate	2 Mb/s	100 Mb/s	100 Mb/s
Frequency efficiency	0.4 b/s/Hz	5 b/s/Hz	5 b/s/Hz
Antenna configuration	Smart antenna	MIMO	MIMO
Supported services	VoIP, basic multimedia services, etc.	VoIP, high data rate multimedia services	VoIP, high data rate multimedia services
Channel coding	Turbo coding	Turbo coding	Turbo coding
Modulation	QPSK, 8 PSK, 16 QAM	QPSK, 16 QAM, 64 QAM	16 QAM
MIMO technique	Beam forming	CDD, STBC, precoding	V-BLAST
Retransmission	HARQ	HARQ	HARQ

2.3.1 Similarities among TD-SCDMA, LTE TDD, and FuTURE TDD

The FuTURE TDD system can be seen as an evolution system for TD-SCDMA. Because the same advanced techniques are adopted as in LTE, they exhibit the same transmission ability. The three systems have much in common and are shown in Table 2.3, in which the main technical configurations can be found.

From Table 2.3, we can find the similarities among all the systems. From the basic aspects, they can all support TDD mode; hence, the advantages of TDD (such as flexible frame structure, high efficiency, and flexible frequency band utilization) can be obtained when one of the systems is employed. The three systems can all support TDMA when a multiple access scheme is concerned. On the other hand, we investigate some specific techniques. The three systems all adopt turbo coding as the channel coding technique, support high-order modulation such as 16 QAM, and employ HARQ as the retransmission strategy. As far as other specific techniques are concerned, FuTURE TDD is more like LTE. The same 20-MHz bandwidth is adopted as the maximum bandwidth. Because of the same adoption of MIMO and OFDM techniques, high-frequency efficiency can be achieved—as high as 5 b/s/Hz—for both LTE and FuTURE TDD. They can both support 100-Mb/s transmission and high data rate multimedia services.

2.3.2 *Enhancement of FuTURE TDD to TD-SCDMA*

Many similarities can be found between FuTURE TDD and TD-SCDMA, but FuTURE TDD can outperform TD-SCDMA because it is designed as a Beyond-3G system. The conclusion can also be proved from [Table 2.3](#).

- The frequency efficiency for FuTURE TDD is 5 b/s/Hz—much higher than for TD-SCDMA. This gives FuTURE TDD the ability to support high data rate multimedia services. The data rate can achieve 100 Mb/s, which can surely satisfy the requirement for all kinds of services in the future.
- A new multiple access scheme is employed, which is named OFDMA. With the scheme, more users may access the wireless network because different users can be distinguished in both time and frequency domains. Hence, FuTURE TDD can solve the problem of wireless access for a very large number of users.
- FuTURE TDD was developed after TD-SCDMA; hence, it can obtain more advanced techniques. The employment of MIMO and OFDM techniques brings FuTURE TDD better performance. This helps FuTURE TDD support wireless transmission even in environments with high moving speed and large distances from the base station. It can save much power, improve transmission quality, and bring better service experience to users.

2.4 *Evolution Map from TD-SCDMA to FuTURE*

Due to the difference between TD-SCDMA and FuTURE, the course of evolution will be long. In this section, we will introduce the evolution, where key technology and system evolutions will be introduced.

2.4.1 *Key Technology Evolution Map*

TD-SCDMA is based on CDMA, utilizes a single antenna on the user equipment (UE) side, adopts low chip rate transmission, and employs joint detection to bring performance improvement. In comparison, the MIMO-OFDM technique is adopted in FuTURE, the sampling rate is relatively much higher, and FuTURE adopts advanced detection techniques to benefit the system. Hence, the evolved systems should be gradually equipped with some techniques.

2.4.1.1 *Generalized Distributed Antenna Arrays Combined with Dynamical Channel Allocation*

The capacity of TD-SCDMA is mainly limited by intercell interference, rather than by the intracell interference for the smart antenna with joint detection

adopted; thus, the effect of cell breadth is not serious. If the intercell interference can be decreased, then the system capacity will be further improved. A distributed antenna can be used to improve the coverage in indoor scenarios and mitigate fast fading. For the generalized distributed antenna arrays (GDAA), the whole cell is divided into several subcells and every subcell is centrally covered by an independent antenna array. The radio resource of one cell is shared by three of its subcells. Then the transmit power of every subcell is reduced for a small coverage radius and the intercell interference is reduced as well; thus, the capacity can be improved. Furthermore, DCA can be combined with a smart antenna and GDAA so as to improve the system performance using SDMA.

2.4.1.2 Improved Joint Detection

Joint detection is one of the key techniques of TD-SCDMA; it can eliminate MAI and ISI. The enhancement and improvement of joint detection can provide the potential for further performance improvement. When SDMA is implemented with a smart antenna, the same codes can be reused in the same cell, and interference may exist between different users who use the same codes because the smart antenna cannot eliminate the side lobe perfectly. If joint detection can take into account this kind of interference and eliminate it, then SDMA can obtain higher efficiency. Furthermore, if joint detection can eliminate the intercell interference from the neighboring cells, then the system capacity and spectrum efficiency will be improved greatly. Thus, the enhancement of joint detection has potential for improving the system performance.

2.4.1.3 Higher Spreading Factor and Chip Rate

The potential benefits of higher chip rate include system-level gains from trunking efficiency, link-level gains from the ability to better resolve channel paths, the ability to support more accurate location services, higher peak bit rate and cell throughput, and an improved ability to reject narrowband interferers. Thus, with a higher spreading factor and chip rate—for example, SF = 32 and 2.56 Mc/s—more gain from spreading processing, multipath resolution, and interference elimination can be obtained for TD-SCDMA, and better system performance can be expected. The benefit of 7.68 Mc/s for UTRA TDD has been investigated in detail. Therefore, a higher spreading factor and higher chip rate TD-SCDMA can provide a possible solution for further improving the system performance.

2.4.1.4 Virtual Antenna Array

Usually, due to limited size and cost, it is difficult to mount multiple antennas at the UE. By using a virtual antenna array (VAA), several idle UEs near the master UE can cooperate to work for the master UE and construct a VAA to improve the

system coverage and data-transmission capability. When the distance among UEs is quite large compared to the wavelength, fading on the antennas of VAA is independent and thus the spatial multiplexing and diversity gain can be exploited to improve the system performance. The connection among UEs can be built through Bluetooth or ultrawideband (UWB) technology in a free-frequency band.

To obtain the gain of the VAA, the received baseband signal of the VAA must be forwarded to the master UE and processed centrally there. However, the transmission of the baseband signals from the VAA to the master UE requires quite a powerful UWB air interface. Here, two examples of two supplementary UEs with two antennas each are presented. It is assumed that the quantification of the baseband signal needs 12 b for one floating number of the I or Q signal. The sampling rates of the baseband signal are 1.28 and 5 MHz, respectively, for these two examples. To forward the baseband signals from the VAAs to the master UE, the data rate needed is calculated as follows.

2.4.1.5 MIMO OFDMA

MIMO is a very promising technology to improve the spectrum efficiency. However, because the much broader frequency band will be used, more multipaths will be separated, and thus the conventional single-carrier system will have much higher complexity in MIMO detection. OFDM is a good candidate to solve such problems. Due to the excellent capability of mitigating frequency-selective fading and ISI, OFDM is very suitable for high data rate transmission in wideband wireless channels. Meanwhile, the implementation of OFDM is very simple using IFFT/FFT, and AMC on every subcarrier can theoretically make full use of the spectrum. (Actually, AMC on every subcarrier will consume too much signaling; AMC usually is based on a group of subcarriers, called a chunk in 3GPP, in order to reduce the signaling consumption. The optimal size of a chunk is a trade-off between the AMC efficiency and the signaling consumption.) All these features make OFDM very competitive for LTE and B3G systems. Combining OFDM with MIMO, the frequency selective fading MIMO channel can be separated into many flat fading MIMO subchannels, and thus MIMO detection can be simplified. On the other hand, the dynamic range of the service data rate is quite large (e.g., from several kilobits per second to 100 Mb/s) and flexible multiple access (MA) methods are necessary to provide a flexible data rate (e.g., OFDMA/TDMA).

2.4.2 System Evolution Map

When we consider the system evolution, we have to take technology, requirements of users, and other factors such as the consideration from the manufacturers into

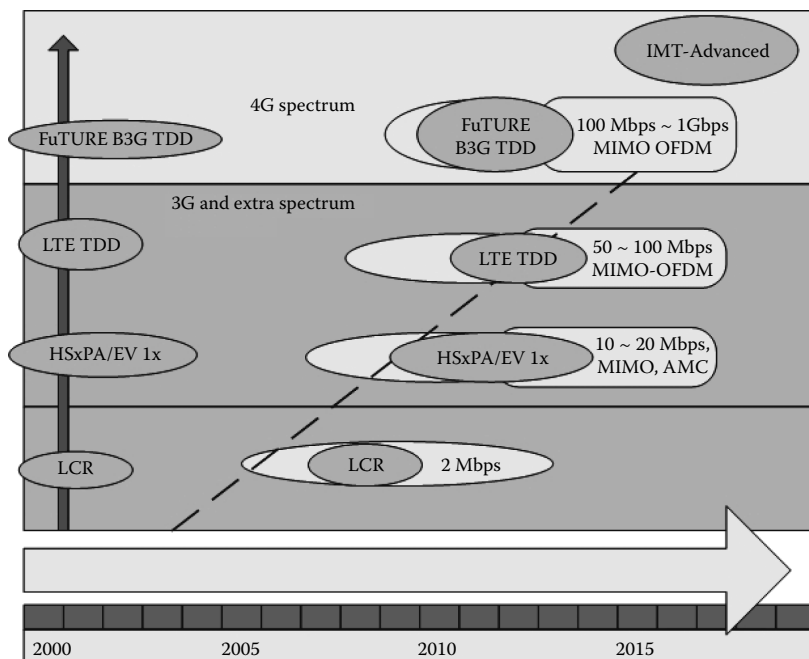


Figure 2.18 Evolution map from TD-SCDMA to FuTURE TDD system.

consideration. We can illustrate the evolution map from Figure 2.18. There should be three steps for evolution from TD-SCDMA to FuTURE TDD:

1. TD-SCDMA will evolve to HSxPA/EV 1x. Nowadays, the deployment of TD-SCDMA is under way in China. People in the 2G age will experience the multimedia services provided by TD-SCDMA very soon. It can support services with data rates up to 2 Mb/s, and the chip rate is 1.28 Mc/s. This course will last for several years. Then the requirement for wireless access will be higher. In order to satisfy the requirement without completely updating the services, it is best for operators to evolve the system to HSxPA/EV 1x, which can adopt more advanced techniques such as MIMO and AMC to achieve higher transmission capability. The chip rate will be higher accordingly.
2. HSxPA/EV 1x will evolve to LTE TDD. As multimedia, Internet, etc. develop, further higher data rate services will be required (as high as 50–100 Mb/s). CDMA cannot perform better due to its technical disadvantages. Hence, MIMO-OFDM will act as the main technique, and LTE-TDD will gradually replace HSxPA/EV 1x. This step is of great importance,

which can be seen as a kind of revolution for wireless access. The operators have to make great changes to equipment. Due to the employment of MIMO, there will be new problems in placing the evolved BS.

3. LTE TDD will evolve to FuTURE TDD. FuTURE TDD has much in common with LTE TDD. Hence, the two systems may exist at the same time. With the development of software-defined radio and the commonality of the systems, it is easy for operators to change between FuTURE TDD and LTE TDD. On the other hand, FuTURE TDD adopts many more advanced techniques, such as GDAA and virtual MIMO. Hence, it can bring many good points, which are the characteristics of 4G, named IMT Advanced. Hence, the evolution from LTE TDD to FuTURE TDD is also necessary.

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