LONG TERM EVOLUTION

3GPP LTE Radio and Cellular Technology

Edited by Borko Furht ■ Syed A. Ahson

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Preface

This book provides technical information about all aspects of 3GPP LTE. The areas covered range from basic concepts to research-grade material, including future directions. The book captures the current state of 3GPP LTE technology and serves as a source of comprehensive reference material on this subject. It has a total of 12 chapters authored by 50 experts from around the world. The targeted audience includes professionals who are designers or planners for 3GPP LTE systems, researchers (faculty members and graduate students), and those who would like to learn about this field.

The book has the following objectives:

- to serve as a single comprehensive source of information and as reference material on 3GPP LTE technology;
- to deal with an important and timely topic of emerging technology of today, tomorrow, and beyond;
- to present accurate, up-to-date information on a broad range of topics related to 3GPP LTE technology;
- to present material authored by experts in the field; and
- to present the information in an organized and well-structured manner.

Although the book is not precisely a textbook, it can certainly be used as a textbook for graduate courses and research-oriented courses that deal with 3GPP LTE. Any comments from readers will be highly appreciated.

Many people have contributed to this handbook in their unique ways. The first and foremost group that deserves immense gratitude is the highly talented and skilled researchers who have contributed the 12 chapters. All of them have been extremely cooperative and professional. It has also been a pleasure to work with Rich

O'Hanley, Jessica Vakili, and Judith Simon of CRC Press, and we are extremely gratified for their support and professionalism. Our families have extended their unconditional love and strong support throughout this project, and they deserve very special thanks.

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Dr. Furht has received research grants from various government agencies, such as NSF and NASA, and from private corporations, including IBM, Hewlett Packard, Racal Datacom, Xerox, Apple, and others. He has published more than 25 books and about 250 scientific and technical papers, and he holds two patents. He is a founder and editor-in-chief of the *Journal of Multimedia Tools and Applications* (Kluwer Academic Publishers, now Springer). He is also consulting editor for two book series on multimedia systems and applications (Kluwer/Springer) and Internet and communications (CRC Press). He has received several technical and publishing awards and has consulted for IBM, Hewlett Packard, Xerox, General Electric, JPL, NASA, Honeywell, and RCA. He has also served as a consultant to various colleges and universities. He has given many invited talks, keynote lectures, seminars, and tutorials. He has been program chair as well as a member of program committees at many national and international conferences.

Syed Ahson is a senior software design engineer with Microsoft. As part of the Mobile Voice and Partner Services Group, he is busy creating new and exciting end-to-end mobile services and applications. Prior to joining Microsoft, he was a senior staff software engineer with Motorola, where he played a significant role in the creation of several iDEN, CDMA, and GSM cellular phones. Ahson has extensive experience with wireless data protocols, wireless data applications, and cellular telephony protocols. Before he joined Motorola, he was a senior software design engineer with NetSpeak Corporation (now part of Net2Phone), a pioneer in VoIP telephony software.

Ahson has published more than 10 books on emerging technologies such as WiMAX, RFID, mobile broadcasting, and IP multimedia subsystems. His recent books include *IP Multimedia Subsystem Handbook* and *Handbook of Mobile Broadcasting: DVB-H, DMB, ISDB-T, and MediaFLO.* He has authored several research articles and teaches computer engineering courses as adjunct faculty at Florida Atlantic University, Boca Raton, Florida, where he introduced a course on Smartphone technology and applications. Ahson received his MS degree in computer engineering in 1998 from Florida Atlantic University and received his BSc degree in electrical engineering from Aligarh University, India, in 1995.

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Chapter 1

Introduction

Borko Furht and Syed Ahson

Mobile users are demanding higher data rate and higher quality mobile communication services. The 3rd Generation Mobile Communication System (3G) is an outstanding success. The conflict of rapidly growing users and limited bandwidth resources requires that the spectrum efficiency of mobile communication systems be improved by adopting some advanced technologies. It has been proved, in both theory and in practice, that some novel key technologies such as MIMO (multiple input, multiple output) and OFDM (orthogonal frequency division multiplexing) improve the performance of current mobile communication systems. Many countries and organizations are researching next-generation mobile communication systems, such as the 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). International standards organizations are working for standardization of the E3G (Enhanced 3G) and 4G (the 4th Generation Mobile Communication System), such as the LTE (long term evolution) plan of the 3rd Generation Partnership Project (3GPP) and the AIE (air interface of evolution)/UMB (ultramobile broadband) plan of 3GPP2.

The 3GPP LTE release 8 specification defines the basic functionality of a new, high-performance air interface providing high user data rates in combination with low latency based on MIMO, OFDMA (orthogonal frequency division multiple access), and an optimized system architecture evolution (SAE) as main enablers. At the same time, in the near future increasing numbers of users will request mobile broadband data access everywhere—for example, for synchronization of e-mails, Internet access, specific applications, and file downloads to mobile devices like personal digital assistants (PDAs) or notebooks. In the future, a 100-fold increase in mobile data traffic is expected, making further improvements beyond LTE release 8 necessary and possibly ending in new LTE releases or in a so-called IMT (international mobile telecommunications) advanced system. The LTE successor of the third-generation mobile radio network will delight customers more than ever. The need for radio coverage will be a primary goal in the rollout phase, whereas a high capacity all over the radio cell will be the long-term goal. High spectral efficiency is crucial for supporting the high demand of data traffic rates that future mobile user terminals will generate, while the available spectrum is still a scarce and limiting resource at each geographic location.

This book provides technical information about all aspects of 3GPP LTE. The areas covered range from basic concepts to research-grade material, including future directions. The book captures the current state of 3GPP LTE technology and serves as a source of comprehensive reference material on this subject. It has a total of 12 chapters authored by 50 experts from around the world.

Chapter 2 ("Evolution from TD-SCDMA to FuTURE") describes a project called Future Technologies for a Universal Radio Environment (FuTURE) that 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 Chinese beyond 3G/4G mobile communications. The FuTURE plan aims at the trends and requirements of wireless communication in the next 10 years and expects to play an active role in the process of 4G standardization.

The FuTURE project is composed of two branches: the FuTURE FDD (frequency division duplex) system and the FuTURE TDD (time division duplex) system, both of which are investigating and demonstrating advanced techniques for systems to meet the application requirements around the year 2010. 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. High-definition reactive video services have been performed and demonstrated on FuTURE trial systems.

In the research and development of the FuTURE TDD system, a series of innovations in basic theory has been proposed, such as the flat wireless access network structure that has been taken into practice; the group cell, which is a novel generalized cellular network architecture, and the slide handover strategy based on it; the soft fractional frequency reuse to improve the spectrum efficiency; the reliable end-to-end QoS (quality of service) mechanism; the antenna array based on the generalized cellular network architecture to increase the system capacity with the spectrum efficiency of 7 b/Hz; the modular MIMO to support various environments; and the scalable modular structure of system, which can support a data rate 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.

The LTE physical layer is targeted to provide improved radio interface capabilities between the base station and user equipment (UE) compared to previous cellular technologies like universal mobile telecommunications system (UMTS) or high-speed downlink packet access (HSDPA). According to the initial requirements defined by the 3GPP (3GPP 25.913), the LTE physical layer should support peak data rates of more than 100 Mb/s over the downlink and 50 Mb/s over the uplink. A flexible transmission bandwidth ranging from 1.25 to 20 MHz will provide support for users with different capabilities. These requirements will be fulfilled by employing new technologies for cellular environments, such as OFDM or multiantenna schemes (3GPP 36.201). Additionally, channel variations in the time/frequency domain are exploited through link adaptation and frequency-domain scheduling, giving a substantial increase in spectral efficiency. In order to support transmission in paired and unpaired spectra, the LTE air interface supports both FDD and TDD modes.

Chapter 3 ("Radio-Interface Physical Layer") presents a detailed description of the LTE radio-interface physical layer. Section 3.1 provides an introduction to the physical layer, focusing on the physical resources' structure and the set of procedures defined within this layer. This section provides a general overview of the different multiantenna technologies considered in LTE and its related physical layer procedures. Link adaptation techniques, including adaptive modulation, channel coding, and channel-aware scheduling, are described in Section 3.2. The topic of multiple antenna schemes for LTE is tackled in Section 3.3, which also provides an overview of the different multiantenna configurations and multiantenna-related procedures defined in LTE. Section 3.4 addresses other physical layer procedures like channel estimation, synchronization, and random access. This section is focused on those procedures that allow the reception and decoding of the frame under a certain bit error rate (BER) level: synchronization and channel estimation. Furthermore, this section also presents the random access (RA) structure and procedure necessary for initial synchronization in the uplink prior to UE data transmission.

Chapter 4 ("Architecture and Protocol Support for Radio Resource Management") discusses the radio resource management (RRM) functions in LTE. This chapter gives an overview of the LTE RAN (radio access network) architecture, including an overview of the OFDM-based radio interface. The notion of radio resource in LTE is defined, and the requirements that the 3GPP has set on the spectral efficient use of radio resources are presented. Section 4.2 gives an overview of the multiantenna solutions in general and then discusses the different MIMO variants in the context of LTE, also addressing the required resource management functions used for the antenna port configuration control. Section 4.3 discusses the most important measurements in LTE, grouping them into UE and eNode B measurements and, when appropriate, draws an analogy with well-known wideband code division multiple access (WCDMA) measurements.

Chapter 4 shows that a number of advanced RRM functions are needed in today's wireless systems; these are being developed and standardized in particular for the 3GPP LTE networks, in order to fulfill the ever-increasing capacity demands by utilizing the radio interface more efficiently. Considering the facts that the available radio spectrum is a limited resource and the capacity of a single radio channel between the UE and the network is also limited by the well-known theoretical bounds of Shannon, the remaining possibility to increase the capacity is to increase the number of such "independent" radio channels in addition to trying to approach the theoretical channel capacity limits on each of these individual channels. Advanced radio resource management techniques play a key role in achieving these goals. This chapter presents methods and examples of how advanced RRM functions are realized in LTE and how these functions together make LTE a high-performance, competitive system for many years to come.

Multiple input, multiple output techniques have been integrated as one of the key approaches to provide the peak data rate, average throughput, and system performance in 3GPP LTE. Based on the function of the multiple transmission symbol streams in MIMO, the operation modes of multiple transmit antennas at the cell site (denoted as MIMO mode) are spatial division multiplexing (SDM), precoding, and transmit diversity (TD).

Based on the allocation of the multiple transmission streams in MIMO, the MIMO mode is denoted as single user (SU)-MIMO if the multiple transmission symbol streams are solely assigned to a single UE and multiuser (MU)-MIMO if the spatial division multiplexing of the modulation symbol streams for different UEs uses the same time-frequency resource. Because the LTE downlink is an OFDM system, the MIMO modes proposed in LTE are MIMO-OFDM schemes. Chapter 5 ("MIMO OFDM Schemes for 3GPP LTE") introduces the two main categories of MIMO-OFDM schemes in LTE—SU-MIMO and MU-MIMO—and the related physical channel procedures. The performance of selected codebooks is provided to show their advantages.

Uplink transmission in the LTE of the UMTS terrestrial radio access system (UTRA LTE) has numerous physical layer advantages in comparison to UTRA WCDMA, mainly to achieve two to three times better spectral efficiency. These include flexible channel bandwidth up to 20 MHz, flexible user resource allocation in both time and frequency domains, and a shorter time transmission interval (TTI) of 1 ms. Specifically challenging for the uplink is that these enhancements are to be achieved, preferably, with reduced power consumption to extend the battery life and cell coverage. The radio access technique is one of the key issues in the LTE uplink air interface. In LTE, OFDMA has been selected as the multiple-access scheme for downlink and single-carrier frequency division multiple access (SC-FDMA) for uplink. OFDM is an attractive modulation technique in a cellular environment to combat frequency selective fading channels with a relatively low-complexity receiver. However, OFDM requires an expensive and inherently inefficient power amplifier in the transmitter due to the high peak-to-average power ratio (PAPR) of the multicarrier signal.

Chapter 6 ("Single-Carrier Transmission for UTRA LTE Uplink") presents the key techniques for LTE uplink as well as the baseline performance. Radio access technology is the key aspect in LTE uplink, and two radio access schemes, SC-FDMA and OFDMA, are studied. The performance results are obtained from a detailed UTRA LTE uplink link-level simulator. The simulation results show that both SC-FDMA and OFDMA can achieve a high spectral efficiency; however, SC-FDMA benefits in obtaining lower PAPR than OFDMA, especially for low-order modulation schemes. A 1×2 SIMO (single input, multiple output) antenna configuration highly increases the spectral efficiency of SC-FDMA, making the performance of SC-FDMA with a minimum mean square error (MMSE) receiver comparable to OFDMA, especially at high coding rates. The peak spectral efficiency results for SC-FDMA confirm that it meets the requirement to achieve a spectral efficiency improvement of two or three times that of 3GPP release 6.

LTE uplink numerology is introduced in Section 6.2. The description of both radio access techniques is given in Section 6.3. The PAPR evaluation for each radio access scheme is discussed in Section 6.4. Section 6.5 describes the link-level model used for the evaluations in this work, including the specific parameter settings. Afterward, the LTE uplink performance with various key techniques is presented, including link adaptation (Section 6.6), fast H-ARQ (Section 6.7), antenna configuration (Section 6.8), flexible frequency allocation (Section 6.9), and typical channel estimation (Section 6.10). Finally, turbo equalization is presented in Section 6.11 as a performance enhancement technique for SC-FDMA transmission. The chapter concludes by showing the impact of the nonlinear power amplifier to both in-band and out-of-band performance.

In the future, mobile network operators (MNOs) will have to provide broadband data rates to an increasing number of users with lowest cost per bit and probably as flat rates as known from fixed network providers. Intercell interference is the most limiting factor in current cellular radio networks, which means that any type of practical, feasible interference mitigation will be of highest importance to tackle the expected 100-fold traffic challenge. As the only means actually known to overcome interference, cooperation is therefore a very likely candidate for integration into an enhanced LTE system. In early 2008, a study item was launched at 3GPP searching for useful enhancements of LTE release 8, which might end in a new LTE release R9. In parallel, there are strong global activities for the definition of the successor of IMT2000, so-called IMT Advanced systems, where it is likely that some form of cooperation will be included. Accordingly, research on cooperative antenna systems has become one of the hottest topics, and it will form the input of ongoing standardization activities. In IEEE 802.16j, the relaying task group defines mobile multihop relay (MMR) solutions for WiMAX systems; meanwhile, cooperative relaying has been adopted as one type of relaying.

Chapter 7 ("Cooperative Transmission Schemes") introduces different cooperative antenna (COOPA) concepts like intra- and inter-NB cooperation and distributed antenna systems (DASs) based on remote radio heads (RRHs) or as self-organizing networks, addressing different aspects of the previously mentioned issues. This chapter is organized into five sections: The second section provides a basic analysis of cooperative antenna systems, the third classifies the basic types of cooperation systems, the fourth is concerned with implementation issues, and the fifth concludes the chapter. The motivation for cooperation, theoretical analysis, and simulation results is presented in this chapter, giving a clear view of the high potential of cooperative antenna systems and promising performance gains on the order of several hundred percent or even more. Different implementation strategies have been presented and some important issues for the core element of any cooperation area have been addressed for the example of intersector cooperation. The newly proposed COOPA HARQ (hybrid automatic repeat request) concept allows reducing feedback overhead and, at the same time, solves the critical issue of feedback delay.

In recent years, the interest in multihop-augmented, infrastructure-based networks has grown because relaying techniques help improve coverage and capacity without too much cost for infrastructure. Recently, radio technologies from industry and academia, such as IEEE 802.16 (WiMAX—worldwide interoperability for microwave access), HiperLAN/2, and the Winner-II system, have included multihop support right from the start.

Chapter 8 ("Multihop Extensions to Cellular Networks—the Benefit of Relaying for LTE") describes how relaying can be introduced into the LTE protocol stack, the basic blocks, and the extensions. Different approaches are covered for exploiting the benefits of multihop communications, such as solutions for radio range extension (trading coverage range for capacity) and solutions to combat shadowing at high radio frequencies. It is shown that relaying can also enhance capacity (e.g., through the exploitation of antenna gains, spatial diversity, or by suitable placement against shadowing due to obstructions). Further, multihop is presented as a means to reduce infrastructure deployment costs. The performance is presented and studied in several scenarios here.

In the 3GPP WCDMA/HSPA (high-speed packet access) standards, the radio link control (RLC) sublayer is defined on top of the MAC sublayer and under other, higher sublayers such as RRC (radio resource control) and PDCP (packet data convergence protocol). Its main function is to guarantee reliable data transmission by means of segmentation, ARQ (automatic retransmission request), in-sequence delivery, etc. The RLC layer has three functional modes: TM (transparent mode), UM (unacknowledged mode), and AM (acknowledged mode), which enable services with different speed and reliability for the upper layer.

Chapter 9 ("User Plane Protocol Design for LTE System with Decode-Forward Type of Relay") examines the legacy UMTS RLC protocols and discusses its evolution for the future broadband network. Different operating schemes of RLC for the multihop relay-enhanced cell (REC) are investigated. The AM mode of RLC for the unicast traffic on the downlink user plane is studied in detail. Because the AM mode incorporates the ARQ functionality, it is by far the most important operation mode for reliable data transfer. The conclusion is that the two-hop RLC scheme performs poorly compared to the per-hop RLC scheme due to the asymmetric capacity on the two hops. This chapter concludes that even with the more efficient per-hop RLC scheme, a flow control mechanism on the BS (base station)–relay node (RN) hop has to be developed. However, the topic of flow control, as well as the impact of the HARQ/ARQ cross-layer interaction, would be left for our future study.

Recently, there has been an increasing interest in using cellular networks for real-time (RT) packet-switched (PS) services such as voice over Internet protocol (VoIP). The reason behind the increased interest in VoIP is to use VoIP in all-IP networks instead of using circuit-switched (CS) speech. This would result in cost savings for operators because the CS-related part of the core network would not be needed anymore. In conventional cellular networks, RT services (e.g., voice) are carried over dedicated channels because of their delay sensitivity, while non-real-time (NRT) services (e.g., Web browsing) are typically transported over time-shared channels because of their burstiness and lower sensitivity to the delay. However, with careful design of the system, RT services can be efficiently transported over time-shared channels as well. A potential advantage of transmission speech on a channel previously designed for data traffic is the improved efficiency in terms of resource sharing, spectrum usage, provision of multimedia services, and network architecture. The challenge is to port VoIP services on wireless networks while retaining the QoS of circuit-switched networks and the inherent flexibility of IP-based services.

Long term evolution of 3GPP work targeting to release 8 is defining a new packet-only wideband radio-access technology with flat architecture aiming to develop a framework toward a high-data-rate, low-latency, and packet-optimized radio access technology called E-UTRAN (evolved universal terrestrial radio access network). Its air interface is based on OFDMA for downlink (DL) and SC-FDMA for uplink (UL). Because E-UTRAN is purely packet-switched radio access technology, it does not support CS voice at all, stressing the importance of efficient VoIP traffic support in E-UTRAN. However, supporting VoIP in E-UTRAN faces the very same challenges as those for any other radio access technology: (1) the tight delay requirement and intolerable scheduling overhead combined with the frequent arrival of small VoIP packets and (2) the scarcity of radio resources along with control channel restriction. Thus, designing effective solutions to meet the stringent QoS requirements such as packet delay and packet loss rate (PLR) of VoIP in E-UTRAN is crucial.

Chapter 10 (“Radio Access Network VoIP Optimization and Performance on 3GPP HSPA/LTE”) aims to give an overview of the challenges faced in implementing VoIP service over PS cellular networks, in particular 3GPP HSPA and LTE.

Generally accepted solutions leading to an efficient overall VoIP concept are outlined, and the performance impact of various aspects of the concept is addressed. In Section 10.3, characteristics of VoIP traffic are given by describing the properties and functionality of the used voice codec in HSPA/LTE and by presenting the requirements and the used quality criteria for VoIP traffic. The most important mechanisms to optimize air interface for VoIP traffic in (E-) UTRAN are presented in Section 10.4. Section 10.5 provides a description for the most important practical limitations in radio interface optimization, and existing solutions (if any) to avoid these limitations are covered in Section 10.6. The chapter concludes with a system simulation-based performance analysis of VoIP service, including a comparison between HSPA and LTE. Thus, some optimized solutions addressing the VoIP bottlenecks in the leading cellular systems such as HSPA and LTE were proposed and studied. The control channel overhead reduction solutions adopted by 3GPP are especially attractive because they provide very good performance.

Chapter 11 ("Early Real-Time Experiments and Field Trial Measurements with 3GPP-LTE Air Interface Implemented on Reconfigurable Hardware Platform") verifies that the 3GPP LTE air interface can be operated indoors as well as outdoors, achieving very high data rates. Robustness to channel conditions has also been shown for coverage areas of up to 800 m with mobility. Furthermore, the chapter demonstrates the benefits of the new 3GPP-LTE air interface with a new cross-layer MAC architecture of link adaptation, transmit MIMO mode selection, and modulation and coding scheme (MCS) level selection, all of which are frequency dependent. The main focus of this chapter is on discussion of multiple antenna gains in the downlink for a single-user case and single-cell scenario. Measurement results with the authors' MIMO configuration test-bed have shown throughput exceeding 100 Mb/s, a significant increase over the existing single-antenna system.

The reverberation chamber has for about three decades been used for electromagnetic compatibility (EMC) testing of radiated emissions and immunity. It is basically a metal cavity that is sufficiently large to support many resonant modes, and it is provided with means to stir the modes so that a statistical field variation appears. It has been shown that the reverberation chamber represents a multipath environment similar to what we find in urban and indoor environments. Therefore, during recent years it has been developed as an accurate instrument for measuring desired radiation properties for small antennas as well as active mobile terminals designed for use in environments with multipath propagation.

Chapter 12 ("Measuring Performance of 3GPP LTE Terminals and Small Base Stations in Reverberation Chambers") uses a hands-on approach, starting by reviewing basic properties of reverberation chambers and giving an overview of ongoing research and benchmarking activities. It then describes how to calibrate reverberation chambers and how they are used to measure antenna efficiency, total radiated power (TRP), and total isotropic sensitivity (TIS)—important parameters for all wireless devices with small antennas, including 3GPP LTE terminals and small base stations. It also describes how diversity gain and MIMO capacity can be measured directly in the Rayleigh environment (in about 1 minute, compared to hours or more using other technologies), using a multiport network analyzer. The first-ever repeatable system throughput measurements in a reverberation chamber are described.

In order to evaluate the performance of multiantenna wireless communication systems, classical measurement techniques known from antenna measurements, such as anechoic chambers, are no longer sufficient. The measurement setups for (multi-) antenna measurements presented in the first part of this chapter show how reverberation chambers can be used as an alternative to current techniques. The accuracy of the reverberation chamber measurements has been analyzed and compared to classic antenna measurements when this is possible.

The methods developed for single-antenna characterization can be taken a step further to evaluate the performance of different multiantenna setups and algorithms—for example, diversity combining. These diversity measurements require a fading environment and are therefore perfectly suited for reverberation chambers. If base-station simulators are used for measurements, it is even possible to investigate the performance of different antenna setups—not only in terms of power gains, but also in terms of BER. Current state-of-the-art measurements in reverberation chambers even include throughput measurements of wireless systems.

Although link measurements of wireless systems in reverberation chambers are nowadays well established and even made their way into standardization, there are still many ongoing research activities that relate, for example, to improving the accuracy of the chamber further. With the evolution of wireless standards, the attractiveness of reverberation chambers for link/system evaluation increases. Possible extensions of existing measurement techniques with focus on LTE and beyond systems are presented at the end of this chapter. A lot of potential for further development lies particularly in manipulating the channel in the reverberation chamber to a larger extent and to using the chamber for multiple terminal and multiple base-station setups.

The chapter ends by describing several new ways of measuring 3GPP LTE parameters and technologies that mainly are simulated in software today as real-life measurements (e.g., drives tests) are too complicated and time consuming. However, many of these parameters (e.g., multiuser MIMO, opportunistic scheduling, and multiple base-station handovers) should be easy to measure in the reverberation chamber.

Chapter 2

Evolution from TD-SCDMA to FuTURE

Ping Zhang, Xiaodong Xu, and Lihua Li

Contents

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 multiantenna 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 multiantenna 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).

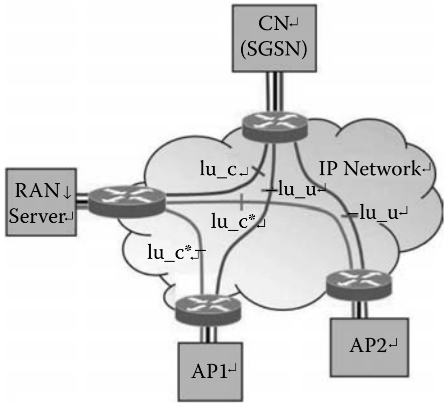

Figure 2.1 Generalized distributed radio access network.

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

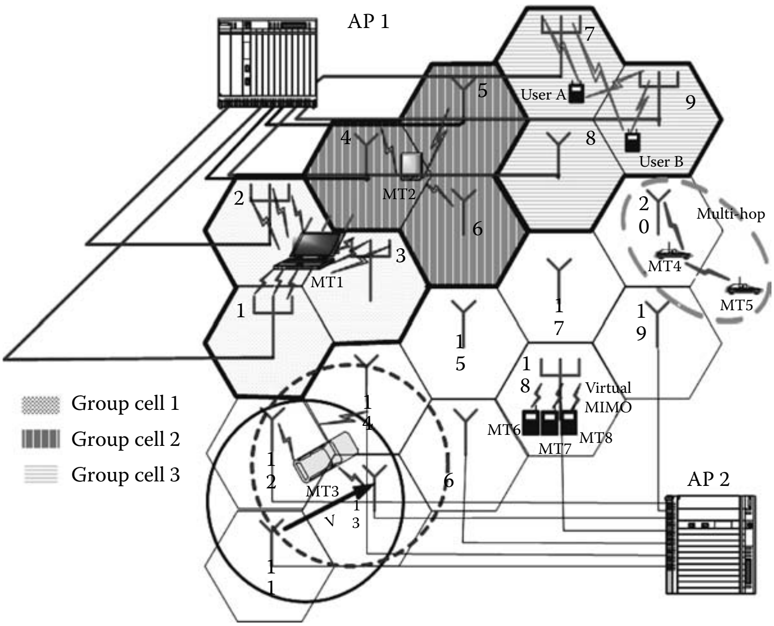

Figure 2.2 Generalized distributed cell structure.

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

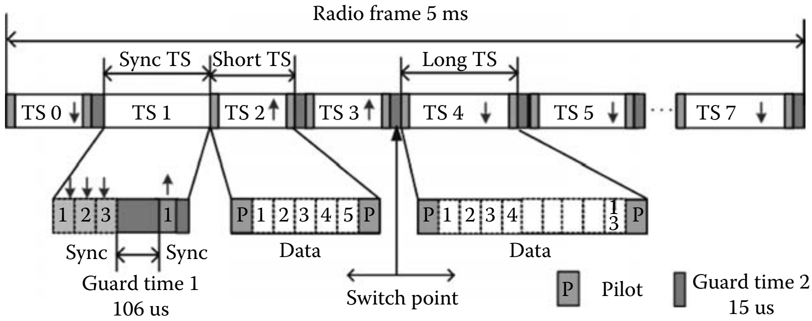

Figure 2.3 Frame structure for FuTURE TDD system.

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 μs, and it is possible to support a cellular radius as large as 15.9 km. If a multiantenna 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).

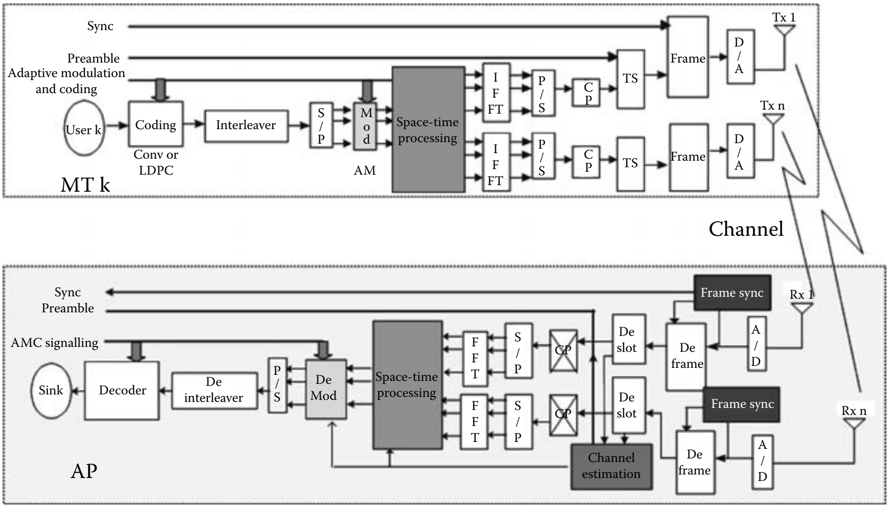

Figure 2.4 The block structure of FuTURE TDD uplink.

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

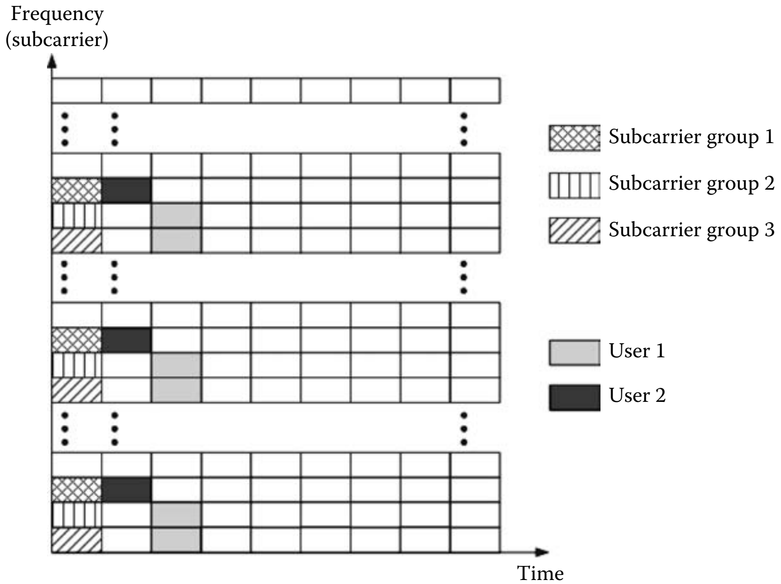

Figure 2.5 Two-dimensional resource allocation.

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.

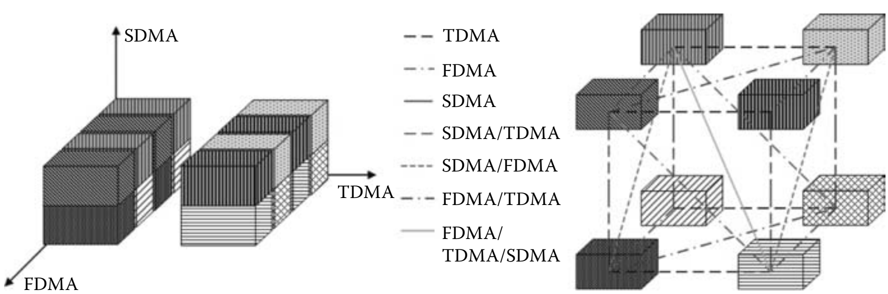

Figure 2.6 Flexible combinations of multiple access schemes.

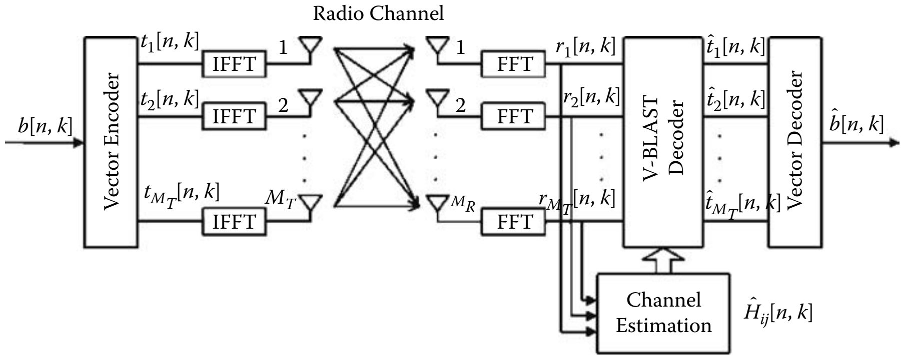

Figure 2.7 The structure of the MIMO-OFDM system.

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

MCS	*Modulation*	*Coding*	*MCR (bits/symbol)*
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.

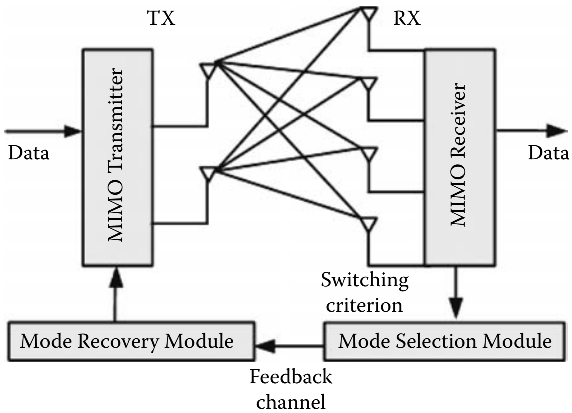

Figure 2.8 Primary diagram of adaptive MIMO.

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 μs.

Table 2.2 Parameters for Different Services

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

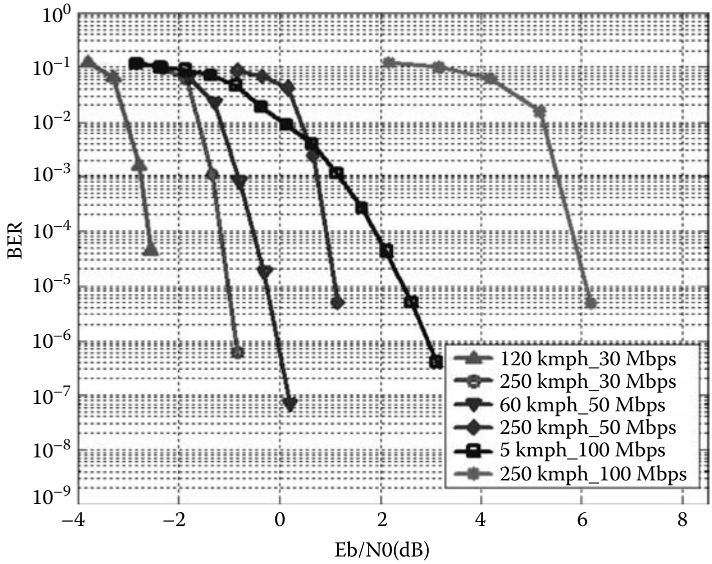

Figure 2.9 Performance of various data services (outdoors, 250 km/h).

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 μs) 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 exits 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.

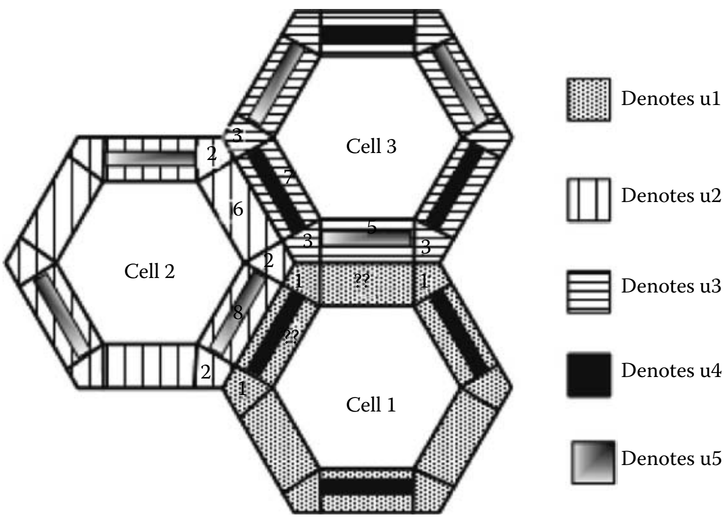

Figure 2.10 SFFR scheme for three-cell model.

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.