RESEARCH PAPER

Enhancement and Evolution of TD-SCDMA Systems

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Abstract:
Time Division-Synchronous Code Division Multiple Access (TD-SCDMA), a home-grown standard for the third generation mobile communications, is already mature and ready for commercial deployment. The enhancement and evolution of the TD-SCDMA system is a hot topic recently. Many strategies for TD-SCDMA enhancements and evolutions have been proposed, but there are no integrated solutions that can jointly consider the development both in the short term and in the long term. This paper discusses four evolution phases, which are proposed according to the key technologies. Phase 1 is about the current TD-SCDMA system. Phase 2 is the short term evolution of TD-SCDMA, i.e., the period of HSxPA, including the evolution of High Speed Downlink Packet Access (HSDPA), High Speed Uplink Packet Access (HSUPA) and High Speed Packet Access plus (HSPA+). Phase 3 is the Long Term Evolution (LTE). Phase 4 is the Beyond 3G (B3G)/Fourth Generation (4G) mobile communication Time Division Duplex (TDD) system, which is based on TD-SCDMA. Key characters for every evolution phase are discussed, as well as the advanced technologies adopted in the evolution process such as Multiple Input Multiple Output (MIMO) and Orthogonal Frequency Division Multiplexing (OFDM).

Time Division-Synchronous Code Division Multiple Access (TD-SCDMA) is the third generation (3G) mobile communication standard proposed by China that has become an important part of 3rd Generation Partnership Project (3GPP) standards. In the TD-SCDMA system, many advanced wireless communication technologies have been adopted, including uplink synchronization, smart antenna, joint detection, software radio, baton handover and Dynamic Channel Allocation (DCA)[1]. As the Time Division Duplex (TDD) mode does not require symmetric spectrums, the radio resources can be flexibly allocated between uplink and downlink. Therefore, it is quite suitable for such asymmetric services as packet data transmission. Considering that the spectrum resources are becoming scarcer and scarcer nowadays, the TDD mode has gradually been the focus of researches on Beyond Third Generation (B3G)/Fourth Generation (4G) systems.

In China, the Frequency Division Duplex (FDD) systems, including WCDMA and CDMA2000, have been assigned a total bandwidth of 2×90 MHz while the TDD systems have been assigned 155 MHz. This indicates the Chinese government's great support to TD-SCDMA, as well as the bright future of the TD-SCDMA system in China.

Compared with WCDMA and CDMA2000 systems, the TD-SCDMA system have advantages in technologies, but have less experience in commercial deployment.

In the evolution of TD-SCDMA, the good compatibility between TD-SCDMA and WCDMA systems will provide a solid basis for handover and roaming between the two systems. In particular, both systems use the same Core Network (CN) of 3GPP, allowing mutual support and complement in their development. But in terms of investment, the CN only accounts for 30% of the entire system. Therefore, the research on the compatibility of the two systems in other fields is still an important topic in the evolution process.

As for TD-SCDMA and CDMA2000 systems, their architectures are quite different, but the compatibility between them has to be given focus in order to fulfill global communication service and to provide better service experience for mobile users.

The peak rate of the current TD-SCDMA system can reach 2 Mb/s in a hotspot, 384 kb/s in a moderate speed mobility environment and 144 kb/s in high speed mobility environment. However, as the mobile communication services grow rapidly, these transmission bit rates in 3G systems can not satisfy the service requirements. According to the estimatation made by

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the International Telecommunication Union (ITU), the peak rates in the B3G cellular system can reach 100 Mb/s to 1 Gb/s by the year 2015.

Similar to the CDMA2000 system, TD-SCDMA will be configured with single carrier or multiple carriers. The multiple-carrier configuration can deliver a higher transmission rate, but will increase the complexity of the system. Moreover, the integration of mobile communication technologies with Broadband Wireless Access (BWA) technologies, such as Wireless Local Area Network (WLAN) and Worldwide Interoperability for Microwave Access (WiMAX), has been in full swing. With WLAN integrated, the TD-SCDMA system can provide the peak rate of 54 Mb/s in indoor environments and hotspots, and effectively extend its coverage in hotspots. Meanwhile, the integration between TD-SCDMA and Wireless Metropolitan Area Network (WMAN) technology (generally called WiMAX), which is based on the IEEE 802.16 series standards, has also been put on the schedule, and has become a hot topic in the current technical research field. The peak transmission rate can reach 75 Mb/s within the 20 MHz spectrum allocation in the WiMAX system, which is a useful technology for TD-SCDMA enhancement.

In November 2004, 3GPP started its Long Term Evolution (LTE) project. The goals of the project include expanding the coverage and capacity, increasing its throughput, reducing costs and service delays, and improving the Quality of Service (QoS) so as to offer better user experience. This project will be based on the current 3G spectrums and adopt several new but mature B3G technologies to ensure a smooth transition from current 3G systems to B3G/4G systems and to fulfill sustainable development of the communication systems.

The Chinese government has invested the evolution of TD-SCDMA to the future TDD system, as well as researched the critical technologies for the B3G/4G TDD system, including air interface and new network architecture, with aims to achieve full coverage of the entire 3G network and deliver a peak rate of 100 Mb/s to 1 Gb/s. By using Multiple Input Multiple Output (MIMO) and Orthogonal Frequency Division Multiplexing (OFDM), the first release of the future TDD system can achieve the downlink peak rate of 100 Mb/s and an uplink peak rate of 50 Mb/s within the 20 MHz spectrum bandwidth, which means a spectrum efficiency of 2-5 bps/Hz. Due to the advantages of the TDD system, the evolution from the current TD-SCDMA system to the LTE/B3G TDD system is urgently demanded[2].

This paper discusses the TDD system evolution process: from the current TD-SCDMA system to the future B3G/4G TDD system. Since the B3G/4G TDD system will not be commercially deployed until 2015, and the data rate has a sharp increase from the current TD-SCDMA, there should be some transition phases between them. In terms of new technologies and peak data rates, the evolution process can be divided into four phases, each of which can be further divided according to the key technologies: current TD-SCDMA system (single carrier and multiple carrier), HSxPA system (single carrier, multiple carrier, and integrated system with BWA technologies), LTE TDD system (single carrier and multiple carrier), and B3G/4G TDD system.

1 Evolution from Current TD-SCDMA to B3G/4G TDD

The goals of the evolution are to offer services with high rates, short time delays and low costs, as well as to expand the system's coverage and capacity. To achieve these goals, several advanced technologies have to be adopted, including Adaptive Modulation and Coding (AMC), Hybrid Automatic Repeat Request (HARQ), OFDM, MIMO and multiple carriers. Among these, some will play important roles in the evolution and be the basic drive for peak rate increase.

With the continuous growth of the users' demands, some cells (especially in bustling areas) of a signal-carrier system may be confronted with heavy traffic that they cannot bear. Therefore, new solutions, such as splitting a cell and adding carriers, have to be employed to improve the system's capacity. Considering the two solutions, the latter has less impact on network planning or design with lower costs. The multiple carrier technology can effectively solve the problem of insufficient system capacity. The HSxPA technologies (i.e., High Speed Downlink Packet Access (HSDPA), High Speed Uplink Packet Access (HSUPA), and High Speed Packet Access plus (HSPA+)), of which AMC and HARQ are the most notable ones, can further improve the downlink and uplink throughputs.

As the remarkable signs in the LTE TDD phase, MIMO and OFDM are the most revolutionary technologies in B3G/4G systems. OFDM can effectively improve the spectrum efficiency. With the development of computer science and the advancement of modern signal processing techniques, the Fast Fourier Transform (FFT) and Inverse Fast Fourier Transform (IFFT) algorithms are deduced, which considerably simplifies the realization of OFDM in the TDD system. On the other hand, the MIMO technology introduces the concept "space domain" into the air link. The space domain, together with time domain, frequency domain and code domain, obtains diversity and multiplexing gains, thus multiplying the capacity of the communication system, and speeding up the transmission rate. However, the MIMO technology is often suitable for flattened channels, while in broadband wireless communication, most channels are frequency selective. The combination of OFDM and MIMO can perfectly solve this problem: the Cyclic Prefix

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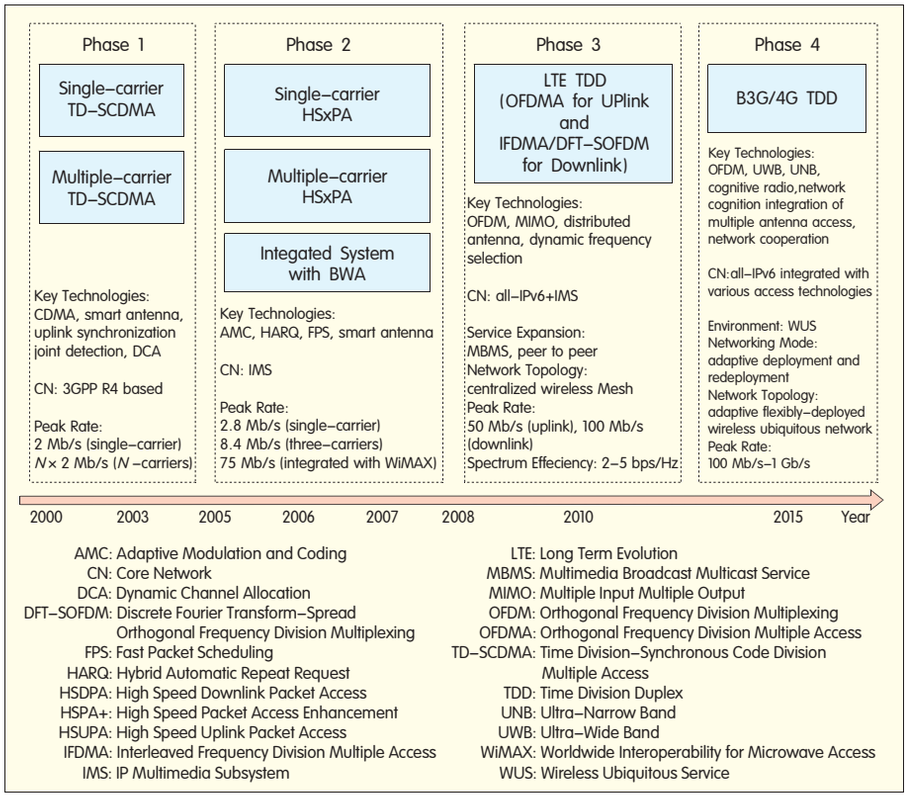

▲ Figure 1. Evolution of TD-SCDMA systems.

(CP) technique in OFDM is used to overcome the effect of multipath and change the frequency selective channel into the flattened one; and then, the MIMO technology can be applied to improve the transmission[3].

Figure 1 shows the four evolution phases of the TD-SCDMA system, and each phase can be further divided into different levels. They are single-carrier/multiple-carrier TD-SCDMA system, single-carrier/multiple-carrier HSxPA system, LTE TDD system and B3G/4G TDD system.

1.1 Phase 1: TD-SCDMA System

The TD-SCDMA system is divided into single-carrier and multiple-carrier. The critical technologies adopted in this phase include CDMA, uplink synchronization, smart antenna, joint detection and DCA. With the core network based on 3GPP R4, the peak rate can reach 2 Mb/s with single carrier, and $N\times 2$ Mb/s with N carriers theoretically.

1.1.1 Single-Carrier TD-SCDMA System

The original TD-SCDMA system is focused on the single carrier, adopting some advanced technologies such as smart antenna, joint detection, DCA, uplink synchronization, baton handover, low chip rate, multiple timeslots, variable spreading, and adaptive power control, as well as the higher layer protocols proposed by 3GPP. Its core network is based on 3GPP R4. The TD-SCDMA system is not only well compatible with the WCDMA system, but it also meets the requirements specified by ITU and 3GPP for the 3G system to suit various 3G environments. As both the uplink and downlink work at the same frequency in TDD mode, their spatial physical properties are similar at the same time. With some adaptive radio signal processing technologies being used, flexible switching between the uplink and downlink can be realized. The advantage of TDD mode is that the timeslot allocation for the uplink and downlink can be flexibly changed by a conversion point to meet different service demands. By changing the switch points, all 3G symmetric and asymmetric services can be delivered. The introduction of joint detection technology can considerably increase the transmission capacity, which can be further improved by the smart antenna technology. With its directional and smart properties, the smart antenna technology can reduce the intercell and intracell interferences, thus allowing the system to offer better quality of services, increase its capacity and extend the coverage.

1.1.2 Multiple-carrier TD-SCDMA System

In a multiple-carrier TD-SCDMA system, one cell is configured with several carriers. If each carrier is regarded as a logic cell, the cell is then a combination of the logic cells that share the same common channels. Thus, the system's service bearing capacity can be dramatically increased. The purpose of introducing the multiple-carrier technology is to increase the network capacity, which is helpful for improving the system. Theoretically, the capacity of an N-carrier TD-SCDMA system should be N times of a single-carrier system. But the actual capacity may not be so large because there are inter-carrier interferences from the adjacent cell.

1.2 Phase 2: HSxPA System

In this phase, the HSDPA and HSUPA technologies will be introduced. Meanwhile, to support high speed data transmission, the integration of other BWA systems into the system will be taken into consideration (e.g., the integration of TD-SCDMA and WiMAX in terms of core network). The critical technologies adopted in this phase include AMC, HARQ and Fast Packet Scheduling (FPS), and the core network is an IP Multimedia Subsystem (IMS). The theoretical peak rate of a single-carrier HSxPA system is 2.8 Mb/s, and it is 8.4 Mb/s with three-carriers. When TD-SCDMA is integrated with WiMAX, its theoretical peak rate can reach 75 Mb/s (within a 20 MHz spectrum allocation).

1.2.1 Single-carrier HSxPA System

The current TD-SCDMA system can be transformed into HSxPA system so long as necessary modifications are made to the wireless access network to raise the downlink transmission rate to 2.8 Mb/s per carrier while keeping the network structure and the core network unchanged. The HSxPA technologies provide

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a wider development space for the operator, and lay the foundation for obtaining the target that data services exceed voice services. Being new UMTS Terrestrial Radio Access Network (UTRAN) transmission technologies, as well as enhancement of common transmission technologies, the HSxPA technologies adopt high-order modulation and fast retransmission mechanism to increase the system's throughput, decrease the transmission delay and improve the peak transmission rate.

The main difference between common transmission technologies and HSxPA technologies lies in the compensation made for the channel quality. In common transmission technologies, a constant data rate is kept by way of fast power control, so they are suitable for transmission of real-time data, such as voice services. In HSxPA technologies, the total downlink transmit power of any user is maintained at a constant value. As we know, if the powers of all users are the same, the user near the base station will have less loss and less interference; thus, its channel capacity is relatively large. On the contrary, the user, far away from the base station, will have a lower channel capacity. By adopting AMC and HARQ mechanism, the HSxPA technologies enable the data rate to change with the channel capacity. Obviously, these technologies are suitable for data services rather than real-time services. In the case of good channel quality, the theoretical peak rate of the HSxPA system can reach 2.8 Mb/s for a carrier. If N carriers are configured, the peak rate can reach N x 2.8 Mb/s, theoretically. In this phase, which is based on 3GPP R5, the all IP-based core network will be constructed and put into use, and the IMS will be introduced to provide IP-based QoS.

1.2.2 Multi-carrier HSxPA System

In the TD-SCDMA system, each carrier is allocated a spectrum of 1.6 MHz. As a result, even if 5 downlink timeslots are employed, the HSxPA system can only achieve a downlink peak rate of 2.8 Mb/s. But the theoretical peak rate of an FDD system is 14.4 Mb/s and that of a WLAN system is 54 Mb/s. Therefore, the TD-SCDMA system is far less than the other two kinds of systems in peak data rate, although it has better spectrum efficiency.

If multiple carriers are configured for the HSxPA system, the data can then be sent or received on these carriers simultaneously. For example, in the case of a three-carrier configuration, the data will be transmitted through the three carriers at the same time; thus, the peak rate can reach 8.4 Mb/s. The more carriers, the higher the peak rate will be. The advantages of multiple-carrier configuration are high peak rate and flexible configuration. When there is a small demand for data services in an area, it is enough to configure only some of the carriers for HSxPA services. But as the demand grows, the network may have to be re-planned and more carriers may have to be configured to provide HSxPA services.

In a WCDMA system, if HSDPA services are to be provided in a spectrum of 10 MHz, the respective 5 MHz for uplink and downlink must be consecutive while in a TD-SCDMA system, 6 independent 1.6 MHz carriers can be used. Taking the availability of carrier resources into account, this is no doubt a great competitive advantage.

1.2.3 MIMO Technology

With multiple antennas, a communication system can realize space diversity, spatial multiplexing, and beam forming in the space domain; thus, the system performance and transmission capacity are greatly improved, especially during transmission and reception. As the fadings of different antennas are relatively independent, the channel capacity will increase linearly with the number of antennas. In 3GPP R5, many MIMO schemes, like the antenna-based rate control, have been proposed to enhance system performance, and in 3GPP R6, the MIMO technology is introduced into the TD-SCDMA system, allowing a peak rate of 14.4 Mb/s for a three-carrier configuration. The evolution and enhancement of HSxPA is still under standardization. However, it is suggested to use MIMO and high-order modulation and coding scheme to get a higher transmission rate.

1.2.4 Distributed Antenna System

Once smart antenna and joint detection technologies are used in the TD-SCDMA system, the system capacity is mainly limited by the intercell interference rather than intracell interference. As the breathing effect of a TD-SCDMA cell is not great, the decreasing of intercell interference can increase system capacity. The use of distributed antennas can expand system coverage and reduce the impact of fast fading. In a distributed antenna system, several adjacent antennas use the same processing unit to form a logic antenna array, which will serve the user simultaneously: in the downlink, the distributed antennas will transmit the same signals to the user at the same time; while in the uplink, they will receive the same signals and send them to the processing center. The antenna end should be simplified as far as possible to lower the cost. As a result, only the basic components will be configured there, and signal processing will be centralized at the processing center.

In addition to coverage expansion, the distributed antenna system has other advantages. First, it allows an even coverage over the service areas; thus, the system performance, especially the handover performance, can be improved. When a user moves within a service area, no handover is required even though several antennas are serving it. Second, as the signals are received via the antennas at different locations, macro diversity can be realized to resist the effect of shadow fading. Third, the resource management of the distributed antenna system will be more flexible: its processing center dynamically allocates the resources in a uniform way, so the resource utility can be optimized and the spectrum efficiency is greatly increased. Finally, the software configured- and managed- cell structure can better cope with service changes in different times and different locations.

1.2.5 MBMS Technology

Multimedia Broadcast Multicast Service (MBMS) is an enhancement of the current WCDMA network. Seamlessly integrated into current mobile network, this technology enables the operator to deliver mobile television services. MBMS is proposed for TDD systems in 3GPP R6. Unlike other digital television broadcasting technologies, MBMS offers a set of

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broadcast/multicast channels that are completely operated and controlled by the mobile operator.

Taking advantage of the two-way channel of the cellular network, MBMS services can interact with the users. In addition to broadcast service, MBMS can offer other services: multicast, highly reliable downloading with the point-to-point fix mechanism, flexible charging via interactive channels, mobile television services, and various kinds of PUSH services, many of which have been offered by current networks. Besides, MBMS can bring the operator profits by means of increasing the transmission capacity.

In view of so many services offered by MBMS, how to multiplex MBMS with cellular network data has become a great concern of the researchers. The new proposals basically fall into two modes: Time Division Multiplexing (TDM) and Frequency Division Multiplexing (FDM). In the TDM mode, long cyclic prefixes can be used to combat multipath interference. But this mode does not support variable spectrum and can only work in the spectrum of 10 MHz. In the FDM mode, only the cyclic prefixes of the cellular system (which are relatively short) can be used owing to the fact that MBMS and the cellular network data are multiplexed into an OFDM symbol. But this mode supports variable spectrum and can work in different, selected spectrums.

The MBMS technology is no doubt an effective supplement to the current cellular system. With it, more services can be delivered to the users by way of adding or improving some functional entities in the current network.

1.2.6 Integration with BWA Systems

When the TD-SCDMA system and BWA networks are compared, the former has wider coverage area, but the latter has a higher peak rate and can offer high rate services in a low mobile environment. (For example, the IEEE 802.11a-based WLAN can achieve a peak rate of 54 Mb/s.) A system integrating WLAN and TD-SCDMA can make use of the advantages of both: deliver high rate transmission in hotspots using WLAN, and provide wide network coverage with TD-SCDMA.

Meanwhile, the integration of TD-SCDMA with WiMAX has been placed into the agenda and has become a focus in technical discussions. WiMAX can provide a peak rate of 75 Mb/s in the spectrum of 20 MHz, which is a powerful and effective supplement to the large coverage of the TD-SCDMA system in hotspots. Moreover, the proposal of 802.16e (expansion release of WiMAX) brings a great enhancement in mobile speed of the integrated system. To integrate TD-SCDMA systems with BWA, the TD-SCDMA terminals are required to support both kinds of accesses, and some special functional entities should be added to support the protocols for the integrated system[4].

1.3 Phase 3: LTE TDD System

The third phase in the evolution of TD-SCDMA systems is LTE TDD, which is a transitional period to 4G TDD systems. In this phase, the technologies for 4G systems will be used on the 3G platform so as to lay a solid foundation for smooth transition from the 3G system to the 4G system. Currently, most researches on LTE TDD focus on the physical layer. The transmission performance and communication parameters of this phase are similar to those of the next phase. Many of the technologies adopted in this phase are for the purpose of enhancing the system performance, including MIMO, OFDM, flexible spectrum selection (1.25 MHz, 1.6 MHz, 5 MHz, 10 MHz, 15 MHz and 20 MHz) and distributed wireless access networks. With MIMO and OFDM technologies, the peak rate of the system can reach 100 Mb/s in the downlink within the spectrum of 20 MHz, and 50 Mb/s in the uplink. All of its services will be delivered on the shared and common channels, and its core network will be based on IPv6.

As the Peak-to-Average Power Ratio (PAPR) is quite high in the OFDM scheme for the uplink, the OFDM technology will be used only in the downlink. In the uplink, the single carrier technologies will be used, for instance, Interleaved Frequency Division Multiple Access (IFDMA) and Discrete Fourier Transform-Spread Orthogonal Frequency Division Multiplexing (DFT-SOFDM); while in the downlink, the Orthogonal Frequency Division Multiple Access (OFDMA) will be used. The IFDMA technology is designed to be without any multiple access interference. Each user in the system has its own set of sub-carriers, which will interleave with the sub-carriers of different users. In IFDMA, the sub-carriers of each user will be evenly distributed on the transmission band to get the maximum frequency diversity gain. In addition, as the IFDMA signal is in time domain, a low PAPR is achieved.

In the LTE TDD phase, the integration of TD-SCDMA systems with other BWA networks is further strengthened, from the IP core network to the wireless access network. The core network of this phase is based on the IMS of All IPv6, and its services include not only traditional Peer-to-Peer (P2P) multimedia data services, but also the MBMS services and more flexible P2P services. With the employment of advanced processing mechanism for the physical layer, the spectrum

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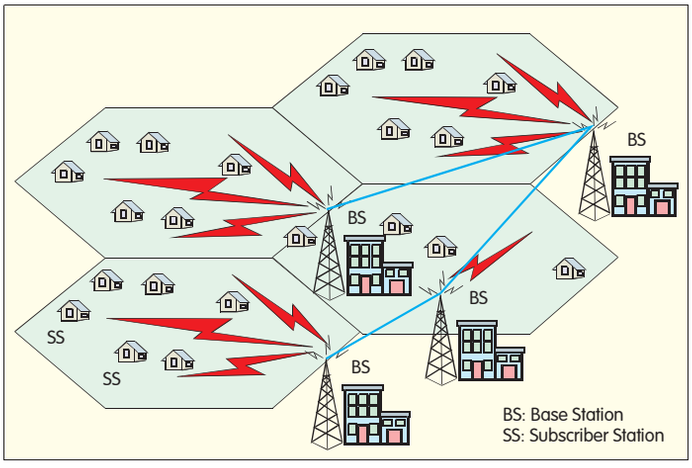

▲Figure 2. Topological structure of traditional point-to-multipoint network.

efficiency will range between 2 bps/Hz and 5 bps/Hz.

1.3.1 SC-FDMA

Two schemes have been proposed for the uplink of 3GPP LTE: OFDMA for multiple carriers and SC-FDMA for single carrier. And the later is finally chosen due to the high PAPR problem in the OFDMA scheme. The SC-FDMA system, which can be further divided into IFDMA and SOFDM systems, has many advantages: low PAPR, minimal intercell interference due to orthogonal processing of frequency domain between users, less complicated frequency domain balance, and variable chip rates. The IFDMA system and DFT-SOFDM system are time domain processed and frequency domain processed, respectively, and the comparison of the two systems has become the focus of the industry. The PAPR of IFDMA is lower than that of DFT-SOFDM, and so is its spectrum efficiency. The DFT-SOFDM system is much complicated to realize, but is more compatible with the OFDMA system. Therefore, the DFT-SOFDM system is a better choice for the uplink.

1.3.2 OFDMA

In the downlink of 3GPP LTE, the OFDMA system is adopted. In either 3GPP LTE or WiMAX, the OFDMA scheme has, beyond question, been chosen for the downlink because of its better spectrum efficiency and less realization complexity. As to the high PAPR problem in the multiple-carrier system, it can be solved by complicated processing at the base station. In the final scheme chosen for the LTE TDD system, it is necessary to take into account the balance between the extra complexity arising from reducing the PAPR and the improvement in link performance. The combination of MIMO multiple antenna technology and the OFDMA can bring the system more gain and better performance.

1.3.3 MIMO-OFDMA Technology

The MIMO-OFDMA technology, the most revolutionary technology in the next generation communication system, is the basis for 3GPP LTE systems to enhance the peak rate and QoS. The MIMO multiple antenna technology performs quite well in improving the spectrum efficiency. But the wider the spectrum it uses, the greater the multipath interference is. In traditional single-carrier systems, the receiver is designed considerably complex in order to perform MIMO detection. The introduction of OFDM technology solves this problem. OFDM can effectively mitigate the effect of frequency selective fading and decrease the inter-symbol interference, making it quite suitable for the high rate data transmission in wireless broadband channel. With FFT/IFFT, OFDM can be easily realized. Moreover, OFDM applies the AMC technology in each sub-carrier, which allows the spectrum to be effectively utilized. These characteristics of OFDM make it competitive in the LTE and B3G systems. By integrating MIMO and OFDM, the frequency selective MIMO channel can be divided into many flattened sub-channels, and the MIMO detection system is simplified.

1.3.4 Dynamic Frequency Selection Mechanism

Nowadays, the spectrum resources are extremely limited. To make effective use of the cellular spectrum resources, the LTE TDD system will adopt variable spectrum to enable a good-quality and high-rate transmission at each spectrum. This is called dynamic frequency selection technology. The TD-SCDMA system will definitely be deployed before the LTE TDD system. This means 1.6 MHz is likely to be used in future systems. On the other hand, the spectrums 1.25 MHz, 5 MHz, 10 MHz and 20 MHz will also be taken into consideration in the LTE TDD system in China. Thus, a flexible spectrum selection can be realized, enabling the communication system to cope with the changes in time and area, and effectively use different spectrums.

1.3.5 Wireless Mesh

The traditional cellular network is a point-to-multipoint structure, as shown in Figure 2. This structure is a centralized mechanism where each Base Station (BS) takes charge of the communication of all users within a cell.

In the LTE TDD system, in order to expand the system coverage and capacity, the"multi-hop" concept is introduced. Multi-hop means to use the user terminal in the topology as a relay to forward the signals to a farther node. In this way, the coverage is extended. Meanwhile, the system capacity increase is achieved due to the relay gain. In traditional point-to-multipoint network structure, the communication of any link has to go through the base station. No matter how near two terminals are, they have to send the signals to the base station they belong to first, and then the base station transmits the signals to the target terminal. If the overhead spent on the signaling interaction is also taken into account, this link will waste much of the resource. To avoid this waste, the multipoint-to-multipoint structure is introduced. That is to say, any two points in the network can communicate with each other. In this case, the data can be transmitted in a quicker, easier and more economical way.

In the traditional network structure, supposing the transmit power is certain, the higher the data transmission rate is, the smaller the coverage is. Once the maximum allowable transmit power is exceeded, the transmitter has to lower its transmission rate so as to extend the coverage distance. Generally, the transmit power is limited by the standard specifications and the

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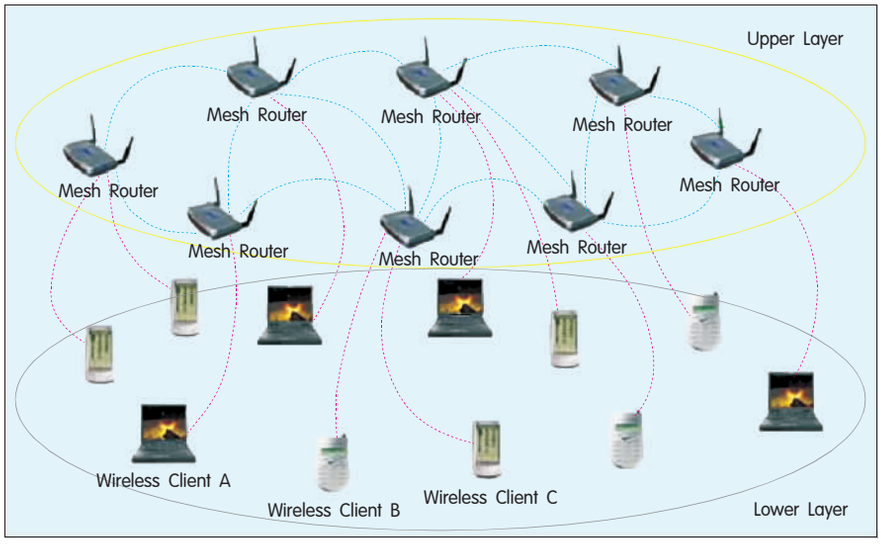


▲Figure 3. Topological structure of Mesh network.

user equipment battery. Therefore, the adaptive technologies are necessary in the cellular system in order to offer the users of adjacent base stations with a higher rate. However, the data rate will drop sharply as the space between base stations increases.

The Mesh structure is not the case. It is integrated with multi-hop and multipoint-to-multipoint technologies. As shown in Figure 3, the Mesh structure can not only provide a long-distance end-to-end communication with a series of intermediate nodes, but also offer a data transmission rate which is high enough. Compared with the distance between the transmitter and the receiver, the distance between nodes (i.e., distance of a hop) is much shorter, so the transmission rate of each hop will be much higher than that of the transmitter-receiver communication. In this way, a high transmission rate is obtained in the long-distance communication system. The Mesh networking mode effectively solves the contradiction between high transmission rate and wide coverage, which have long been a contradictory pair. In addition, as each node in a Mesh network is required to transmit the signals for a very short distance, its transmit power can be very low; thus, the interference within the system decreases dramatically, and the frequency can be multiplexed in a denser way. Moreover, because the data can be transmitted via the intermediate nodes, a robust routing can be established by avoiding the obstacles or blocks.

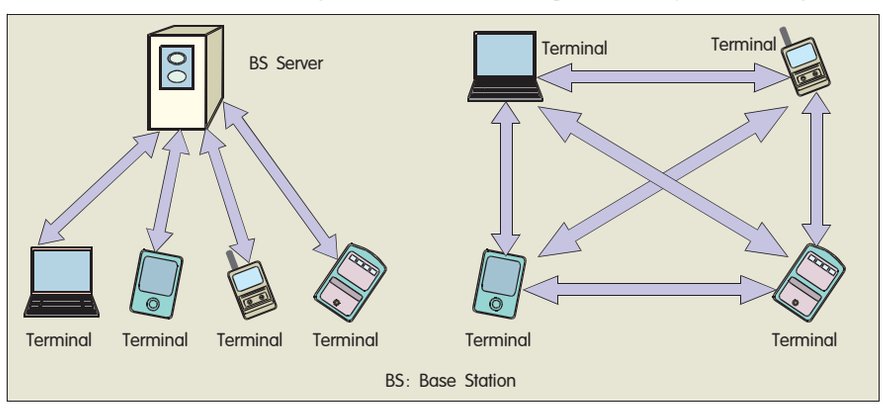
The Mesh structure can be divided into two kinds: centralized and distributed. The centralized Mesh structure, based on the traditional point-to-multipoint structure, expands the coverage and system capacity by using the user terminals as relays. The distributed structure is more flexibly configured to reduce the system delay, avoid network bottlenecks and node faults, improve QoS and deliver comprehensive services. In the distributed structure, the user information and the control signaling messages are separated, so service delays are reduced and the costs incurred in system integration and deployment are lowered. As a result, the investment can be directly turned into the growth of network scale, saving the expenses needed for network deployment in the initial period. The multiple choices of structures enable a flexible and efficient transmission, and the entire network can thus be optimized. Therefore, the B3G and 4G wireless access networks can be introduced into the LTE TDD system with small modifications at the base stations and the terminals[5].

1.3.6 P2P Communication Technology

The P2P technology has been widely applied in computer networks, such as network phone and Bit Torrent (BT) downloading. And this technology will eventually be introduced to the wireless communication network. 3GPP has included the P2P services into its agenda, which means the combination of P2P technology with Mesh topology will be enhanced in the LTE and next generation network. In 802.11, the distributed Ad Hoc network adopts multipoint-to-multipoint structure, which will be surely connected with the P2P technology. In Figure 4, the left is a traditional point-to-multipoint structure, where the communication between terminals is impossible and has to go through the base station. Due to the base station's spectrum availability, many user requests cannot be granted. As a result, its download efficiency is quite low on the whole. The right of Figure 4 is a P2P communication structure, where all the nodes are peers rather than in a server/client architecture, so any two points can freely communicate with each other. The essence of the P2P system is "node cooperation". Any system where there is no administrators and tasks are completed by switching and cooperation between nodes can be called a P2P system.

1.4 Phase 4: B3G/4G TDD System

IMT-Advanced has proposed peak transmission rates of 100 Mb/s and 1 Gb/s in the high and low mobile environments respectively. The main purpose of using the TDD mode in the B3G/4G system is to achieve its goal. In this phase, the system



▲Figure 4. Traditional point-to-multipoint structure vs. P2P structure.

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will adopt such critical technologies as cognitive radio and network cognition, and support the integration with various wireless communication mechanisms in the Wireless Ubiquitous Service (WUS) environment. In the WUS architecture, several advanced technologies including Ultra-Wide Band (UWB), Ultra-Narrow Band (UNB) cognitive radio and network cognition, will be used to deliver high speed data transmission and develop an optimal network access and deployment scheme. A new subject as it is, the network information theory will play a very important role in the B3G/4G system and become a guide for networking and deployment of the WUS system.

In the B3G/4G TDD phase, the variety and coexistence of air interface networks allow diversified services to be delivered to the users, but on the other hand, they bring many inconveniences in handover and roaming. In particular, one terminal has to satisfy all kinds of access networks, and the realization process should neither be too complicated, nor cost too much. With software radio technology, the terminal can download access network modes and processes of different standards to be compatible with different networks. In the future, the modularized, open and distributed architecture will be the mainstream mode for service generation and offering. This mode, trying to shield the details of lower-layer network implementation, provides a framework for the services to be generated and deployed in an easier way. In ubiquitous networks, the service types will be very rich and the service offering will be user-oriented, and the QoS will be guaranteed. Other advantages of the ubiquitous architecture include: each network can provide the user-centered multi-medium services; support the seamless handover and roaming between networks; balance the different networks' load; and determine the optimum network to ultimately meet the users' demands.

In this phase, to meet the high transmission rate and the ubiquitous coverage requirements, radio relay and multi-hop transmission technologies will be adopted. The basic concept of radio relay is to use relays to process and send the base station signals. This process may be simple, where the relay just receives and amplifies the signals, or it may be complex, where the processing above MAC layer is required. The introduction of radio relays, either fixed or mobile, can save the transmit power of the terminal, thus prolonging the battery life. The application of multi-hop can not only expand the coverage of a cell to the extent that the blind angles, such as building shadows and underground, will be eliminated, but also balance the load by transferring the hotspot services to other areas.On the other hand, to simplify radio spectrum management, the cognitive radio technology is used to cognize the radio environment. The essence of the environment cognition is to extend the network to every corner, use the cognitive ability of the new wireless communication network node to cognize the status of current network environment and the user scenario and surroundings, especially the spectrum information, and finally make plans, decisions and reactions based on the status and the scenario by means of several advanced physical layer technologies. The spectrum information of one node will be shared among the adjacent nodes so as to make full use of the spectrum resources. In this way, the coverage will be expanded and the utilities of spectrums and powers will be enhanced.

2 Conclusions

The goal of TD-SCDMA system evolutions is to offer the systems with high data rate, short time delay, low cost, optimized coverage and capacity, as well as high mobility. The rapid growth of mobile services in recent years has promoted the evolution of mobile communication systems to have some advanced features, such as broadband and wireless. In the process of such an evolution, the increasing demands for high data rate and QoS are inevitable. The evolution process are divided into four phases: single carrier/multiple carrier TD-SCDMA system, single carrier/multiple carrier HSxPA system integrated with BWA technologies, LTE TDD system (single-carrier configuration in the uplink and multiple-carrier configuration in the downlink), and B3G/4G TDD system. The entire process will be quite smooth, allowing technology update, network structure optimization and maximum user satisfaction to be achieved at the lowest cost.

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Biographies

Peng Mugen received his Ph.D from the Telecommunication Engineering School of Beijing University of Posts and Telecommunications (BUPT). Now he is a staff of this university and a team manager at the Wireless Signal Processing and Network Lab. He has led and taken part in many R&D projects funded by the National High Technology Research and Development Program of China (863 Program), the National Natural Science Foundation of China and several international/ national famous manufacturers. Currently, his research focuses on wireless network coordination information theory, algorithms and protocols used in radio resource management for next generation broadband communication systems, multi-hop wireless relay and network coding techniques. He has translated 2 books and authored 4 books. Moreover, he has published more than 60 papers, of which more than 20 can be indexed by SCI and EI.

Li Yong is a Ph. D candidate studying at the Wireless Signal Processing and Network Lab of BUPT. His research interest includes the wireless resource management in next wireless communication system. At present, he is engaged in the research on wireless packet scheduling algorithm and link adaptive algorithm.

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