SPECIAL TOPIC

Evolution of Key Technologies for WiMAX Physical Layer

Abstract:
Despite the rapid development in Worldwide Interoperability for Microwave Access (WiMAX) technologies, key technologies for the Physical Layer (PHY) still need to be further improved so as to achieve highly efficient and reliable communication performance, as well as to support a mobile environment with a higher transmisison rate. As an amendment to IEEE 802.16d (for fixed broadband wireless access systems), IEEE 802.16e (for mobile broadband wireless access systems) introduces the Orthogonal Frequency Division Multiplexing (OFDM) and Multiple Input Multiple Output (MIMO) technologies into the PHY, doubling the transmission rate while supporting a certain degree of mobility. In the future, more advanced Air Interface (AI) technology is to be applied in the IEEE 802.16m standard.

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Wireless broadband technologies based on IEEE 802.16e have become the mainstream for Worldwide Interoperability for Microwave Access (WiMAX) technologies. Access to wireless networks has become a reality for many people. To satisfy people's needs for higher transmission rates and mobility, the Institute of Electrical and Electronics Engineers (IEEE) is making the next generation advanced Air Interface (AI) standard, namely 802.16m, on the bases of its previous editions of 802.16a, 802.16d and 802.16e. The formulation of IEEE 802.16m, in which many renowned telecommunication companies have joined efforts, has started in December 2006.

The technological features of WiMAX's Physical Layer (PHY) are as follows[1]:

(1) Orthogonal Frequency Division Multiplexing (OFDM) technology is applied to achieve efficient frequency utilization.

(2) Time Division Duplex (TDD), Frequency Division Duplex (FDD) and Half FDD (HFDD) are supported. FDD needs coupled frequencies, but TDD does not. TDD can realize flexible and dynamic allocation of uplink/downlink bandwidth. HFDD lowers the requirements on end transceiver.

(3) Both mobile and fixed situations are supported, with the highest speed supported reaching 120 km/h.

(4) The WiMAX system's bandwidth span is from 1.25 MHz to 20 MHz. WiMAX has defined two series of bandwidth: 1.25 MHz and its multiples, and 1.75 MHz and its multiples. The former series includes 1.25 MHz, 2.5 MHz, 5 MHz, 10 MHz and 20 MHz. The latter includes 1.75 MHz, 3.5 MHz, 7 MHz and 14 MHz.

(5) Advanced multi-antenna technology is used to improve system capacity and scope of coverage.

(6) Hybrid Automatic Repeat Request (HARQ) technology is adopted, which integrates the Forward Error Correction (FEC) function, so that every packet sending operation can contribute to the final correct decoding. HARQ can be divided into two types: Chase Combining and Incremental Redundancy.

(7) Adaptive Modulation and Coding (AMC) technology is adopted. The technology adjusts modulation, coding mode and coding rate of packets at times according to quality of signals received, so as to achieve the highest possible data transmission rate of the system while maintaining adequate reliability.

(8) Power control technology is used to maximize spectral efficiency when other system indicators are all met.

(9) Advanced channel coding technology is adopted to enhance communication performance and expand scope of coverage.

Regarding the technological demands for International Mobile Telecommunications (IMT)-Advanced and Next Generation Mobile Networks (NGMN), the future transmission rate for mobile communications should reach hundred Megabits per second, and even Gigabits per second. However, the highest transmission rate on the PHY acquired in the IEEE 802.16e standard is only 75 Mb/s. Therefore, the effective

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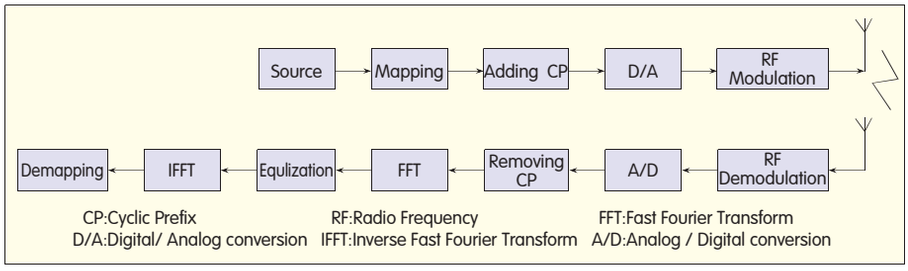

▲ Figure 1. OTDM system.

evolution of key technologies for the PHY must be achieved in the future standards in order to achieve both high data transmission rate and high communications quality.

1 OFDM and OFDMA

OFDM and Orthogonal Frequency Division Multiplexing Access (OFDMA) technologies are adopted by both IEEE 802.16d and IEEE 802.16e. In the future technological evolution on the PHY, OFDM and OFDMA technologies will remain the most important ones. Another technology that attracts people's attention recently is Orthogonal Time Division Multiplexing (OTDM), which might evolve into one of the major multiplexing technologies on the PHY in the future.

1.1 OFDM

The main idea of OFDM[2] is to divide a channel into a number of orthogonal sub-channels, and transform high-speed data signals to parallel low-speed sub-data flows which are then modulated and transmitted on each sub-channel. Orthogonal signals are divided in receivers by related technologies, which can reduce Inter-Channel Interference (ICI) in the sub-channels by a certain degree. As signal bandwidth is smaller than channel bandwidth in every sub-channel, each sub-channel can be regarded as a flat fading channel; therefore, Inter-Symbol Interference (ISI) is avoided. Since the bandwidth of each sub-channel accounts for only a small portion of the original channel, channel balancing becomes relatively easier.

OFDM technology is becoming more and more eye-catching because of the following unique advantages it has:

- High spectral efficiency
- Strong anti-multi-path interference and anti-frequency- selective fading ability
- The system can reach the highest possible bit rate with the Dynamic Subcarrier Allocation Algorithm
- Strong anti-fading performances with united coding of subcarriers
- Discrete Fourier Transform (DFT)-based OFDM has a fast algorithm. Both the Fast Fourier Transform (FFT) and Inverse Fast Fourier Transform (IFFT) that the OFDM applies for modulation and demodulation can be easily realized by Digital Signal Processor (DSP)

OFDM, however, also have the following disadvantages:

- Sensitivity to frequency offset and phase noise
- Peak-to-Average Power Ratio (PAPR) is high, which leads to low power and efficiency of the magnifier of the sender
- Auto-adapted modulation technology makes the system more complicated

As a modulation solution securing spectral efficiency, OFDM has been adopted by some standards and systems. It will become one of the best ways of modulation for the downlink of the next generation wireless telecommunications systems, and will integrate with the traditional multi-access technology to evolve into a possible solution for the next generation wireless telecommunications system.

1.2 OFDMA

In an OFDMA system, users only make use of some of the sub-carriers. As long as the user's timing offset and frequency offset in one frame are small enough, there will not be any intra-cell interference in the OFDMA system, which gives OFDMA an edge over Code Division Multiple Access (CDMA). Since the frequency hopping technology and the OFDM technology are combined in the OFDMA system, a more flexible multiple access solution can be developed on that basis. Besides, OFDMA can flexibly adapt to bandwidth requirement so it can work collaboratively with Dynamic Channel Allocation (DCA) technology to support high speed data transmission.

In the future development of the PHY technologies, OFDMA will continue to play a very important role.

1.3 Single-Carrier Frequency Domain Equalization (SC-FDE) Technology

Decreasing PAPR in the OFDM system is still an urgent problem that has to be solved. To avoid PAPR interferences, many evolution solutions have introduced SC-FDE technology[3-4], or what we call OTDM, in their development. Figure 1 shows the working theory of OTDM System.

SC-FDE becomes more and more popular because it has the following advantages:

- Strong anti-multi-path interference ability
- High spectral efficiency (similar to OFDM or even higher)
- No PAPR
- Small out-of-band radiation
- Simple implementation
- Adaptive technology adopted

Besides, SC-FDE is easy to be integrated into the following technologies:

- Cyclic Prefix (CP)-CDMA
- CP-Direct Sequence (DS)-CDMA
- OTDM plus Smart Antenna (Transmitter)
- OTDM plus Spatial Diversity Receiving (Receiver)

The new generation wireless telecommunications system has raised strict requirements on the system's performance, cost, size, power and energy consumption. SC-FDE system has a relatively strong capacity in resisting frequency-selective fading; thus, it has overcome the defect of OFDM system and made the implementation of receiver easier. SC-FDE can also co-exist with OFDM in a bidirectional transmission system so that advantages of both technologies can be achieved

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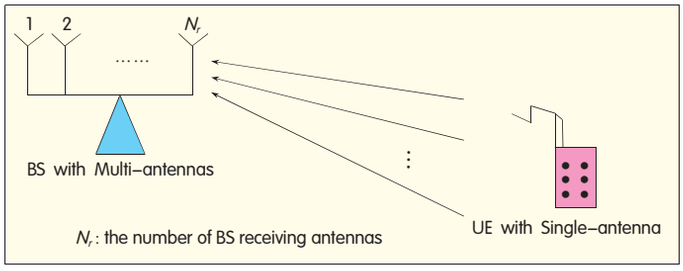
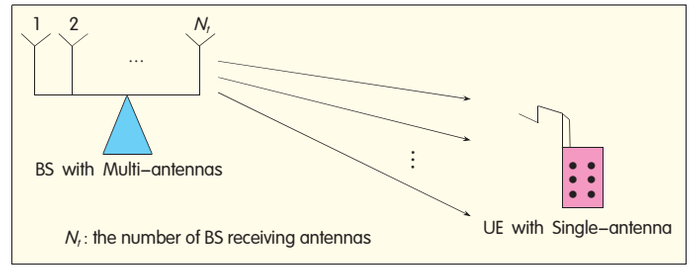


▲Figure 2. Single input multiple output.



▲Figure 3. Multiple input single output.

flexibly and efficiently. Besides, SC-FDE can integrate with Multiple Input Multiple Output (MIMO) technology to raise spectral efficiency and improve system performance. Therefore, SC-FDE is a very competitive solution for future high speed wireless telecommunications, and it enjoys wide application prospects in the field of broadband wireless telecommunications.

2 Frame Structure

IEEE 802.16e has defined TDD, FDD and HFDD for the PHY. These three duplex use the burst data transfer format, which supports the adaptive burst service data, and can dynamically adjust transmission parameters like modulation mode, coding mode and transmitting power with the assistance of the MAC Layer.

In the TDD mode, the length of each physical frame is fixed, and the shifting point of uplink and downlink can be automatically adapted with downlink being the priority. In this way, competition from the uplink can be avoided. Meanwhile, the transceiving time slot can be laid between the uplink sub frames and the downlink sub frames to leave necessary protective space. Resources management and distribution can be controlled at the Base Station (BS) so that channels can be flexibly used in the uplink or downlink, according to real need. Besides, multiple permutations are defined for different scenarios in the frame structure to raise spectral efficiency, support variable mobility and resist multi-path fading. IEEE 802.16e also adopts OFDMA of 128/512/1 024/2048 changeable sub-carriers, which enables the channel bandwidth to flexibly move from 1.25 MHz to 20 MHz. In this way, the equipment can have stronger channel balancing capability and anti-fast fading ability, which assures the normal utilization of WiMAX end equipment in a mobile environment.

The future frame structure has to make the scheduling of different multi-antenna applications simple and effective, and it has to support the evolution of key technologies for the PHY.

3 MIMO

Frequency resource is limited. Channel capacity will not exceed Shannon Limit whether in time domain, frequency domain or code domain. Utilization of multiple antennas makes it possible for different users' signals to be expressed by different space features, and the space domain resource may accordingly be used. Space domain utilization can multiply channel capacity while maintaining bandwidth at the same level, and it can also improve communication quality and transmission reliability.

3.1 Application Modes of Multiple Antennas

The application of the multiple antenna technology in the future must be flexible and changeable, and major application modes are as follows:

(1) Spatial Diversity Receiving (in case of Single Input Multiple Output (SIMO)) Affected by factors like size, power and cost, some end equipment only have one antenna in their sending part; however, BS use multiple antennas to implement reception diversity. In ideal circumstances, 10log$N$r (dB) increment can be gained. Nr stands for number of BS receiving antennas. Therefore, the value increases as the logarithm of Nr increases. The case is shown in Figure 2.

(2) Spatial Diversity Transmitting (in case of Multiple Input Single Output (MISO))

In ideal circumstances, one receiving antenna at the terminal and multiple transmitting antenna at the BS can obtain the gain of 10log$N$t (dB). Nt stands for number of BS transmitting antennas. Therefore, the value increases as the logarithm of Nt increases. The case is shown in Figure 3.

(3) Beamforming (in case of MISO)

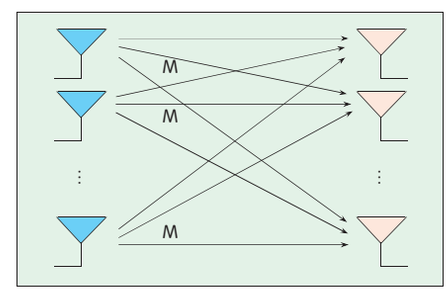
One antenna at the terminal and multiple transmitting antenna at the BS can implement beamforming Since the transmitting end has got $\boldsymbol{H}$ matrix , the Signal-to-Noise Ratio (SNR) of wave packet is 3 dB more than that of transmit diversity. So, wave packet forming can be carried out only after channel information is collected either through uplink measurement or uplink feedback.

(4) Space Time Coding (in case of MIMO)

In the future communications systems, end equipment will be diversified and some of them could have many antennas so that the uplink and downlink in the communication process can both realize MIMO, like what is shown in Figure 4. Space Time Coding is one of the main application forms of MIMO. The orthogonal space time packet codes can have full diversity gain. Space time trellis code can acquire both partial diversity gain and code gain.

(5) Space Multiplexing (in case of MIMO)

Another main application mode of



▲Figure 4. Multiple input multiple output.

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MIMO is Space Multiplexing. Space Multiplexing technology makes increasing the channel capacity by several times possible. Premises for applying Space Multiplexing technology include: $N_r \geqslant N_t$; using zero-forcing and interference cancellation to execute signal by signal test; the channel information and channel correction is unnecessary for the transmitting side. When channel capacity drops, the multiplexing coefficient can make auto-adaptive changes accordingly.

(6) Smart Antenna (an advanced multi-antenna system)

One of the major tasks for smart antenna is to improve the system's performance by acquiring and utilizing signal's space information and improving signal's quality through array signal processing. Weighing of antenna array is processed and completed by digital signals at baseband. As an important part of the advanced multi-antenna system, adaptive array technology is the key and future trend of the smart antenna research.

3.2 Space Domain Adaptive Multi-Antenna Technology

The future multi-antenna technology will surely fulfill the space domain adaptive link. According to channel changes, it can realize the adaptive link with the highest data transmission rate and largest average channel capacity.

Design principle for the adaptive link aiming at the highest data transmission rate:

(1) Under mobile circumstances, MIMO channel is changing, and so is channel capacity.

(2) As far as low rank channel is concerned, more transmitting antennas unnecessarily bring the channel capacity, and the system capacity can be increased by reasonably selecting the right transmitting antenna.

Design principle for the adaptive link aiming at the largest average channel capacity:

(1) When the fading coefficients of the transmitting antenna and the receiving antenna are not compatible, but have the same distribution pattern, the MIMO system obtains a considerable channel capacity. However, limited by antenna array element spacing and real communication environment, the coefficients of transmitting antenna and receiving antenna are often correlated. It is unveiled by research that channel capacity will fall dramatically when the coefficients are closely correlated.

(2) In related fading channels, it is necessary to reasonably design antenna array space and array pattern, so as to reduce the related coefficients that affect channel response between antennas.

4 HARQ

HARQ is a new PHY technology combining Automatic Repeat Request (ARQ) with Forward Error Correction (FEC). It can be divided into three types. HARQ Type I only makes a simple combination of FEC and ARQ. Though it solves the innate defects of FEC and ARQ at a certain degree, it causes low data transmission efficiency in general because it does not make full use of the helpful information in the wrong data packets but simply abandons those data packets and requests the data packets again. Basing on Type I, HARQ Type II introduces the idea that code combining generates decoding gain, and it makes full use of the helpful information in every data packet sent. However, the resent data packet in Type II includes new redundant information (a new data packet generated from the integration of helpful information), and not the original data information, so it does not possess a self-decoding capability. If the original data packet is seriously damaged or is missing, resending it, no matter how many times, will not lead to correct decoding. This is a big disadvantage of HARQ Type II. To overcome defects in I and II, HARQ Type III includes the original data information in both the original data packet and the resent one, and can restore original data information simply through decoding the resent data packet. The system performance can be well improved by flexibly adopting the HARQ Type III and Chase Combining.

5 AMC

The basic idea of AMC is to allocate transmission power and coding rate according to channel conditions, so as to upgrade the transmission rate or system throughout. There are two steps for implementing AMC:

(1) Measuring transmission channel parameters

(2) Selecting one or more transmission parameters on the basis of optimizing preset cost function

Only the selected channel parameters can be compatible with the practical scenarios if the channel varies less fast. Therefore, the adaptive technology can only apply to the case where there is no significant expansion of Doppler. The technology has a prominent strength when applied in indoor circumstances where transmission delay is short, and the relative speed of both the transmitter and receiver is slow. Given this case, the adaptive technology can be used frame by frame.

The major adaptive technologies include:

- Adaptively adjusting power rating
- Adaptively adjusting the size of constellation chart
- Adaptively adjusting coding rate
- Adaptively adjusting both power rating and the size of constellation chart
- Adaptively adjusting both the size of constellation chart and symbol rate
- Adaptively adjusting both power and transmission rate
- Adaptively adjusting coding rate, symbol rate and the size of constellation chart simultaneously.

6 Channel Coding

Channel coding technology is indispensable for wireless communications. For high speed commuications, the error is a key technology for fulfilling error control. 802.11d/e standards adopt such error correction coding technologies as RS packet code, convolution coding, convolution Turbo code, packet Turbo code and Low Density Parity Check Code (LDPC). Moreover, the Woven convolution coding has been written into the Guideline of New Air Interface Technology in Wireless Communications by China Communications Standardization Association (CCSA).

There are detailed descriptions about RS packet coding, convolution coding, convolution Turbo code and packet Turbo code in Reference [5]. As a new

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approach for error correction coding, LDPC is a linear packet coding that can be defined by low density odd–even proof–test matrix; it has become a key technology for Next–generation Satellite Digital Video Broadcast Standard (DVB–S2). If the LDPC is used in WiMAX, with its good anti–fading performance and high coding gain, the receiver can still acquire a low rate of coding error in spite of low SNR, expanding the scope of coverage. Although it is sill optional in the current Enhanced Wireless Consortium (EWC) draft, it is reasonable to believe that LDPC would play an important role in the IEEE 802.16 series standards in the future. In 1997, Host, Johannesson and other persons put forward Woven Convolution Coding[6], which cleverly weaves member convolution codes together. Therefore, it can not only carry on many merits of convolution coding along with considerable free space, but it can also be compatible with traditional technologies like packet coding, convolution coding and various Turbo coding. Woven coding is the expansion of Serial Concatenated Convolutional Code (SCCC) that uses convolution code as a component code. We are convinced that Woven convolution code will be widely applied in the process of technological standard development in the future.

7 Conclusions

As a broadband network solution, WiMAX has been widely accepted by many network operators. The 802.16d/e standards have grown out of the WiMAX family, and they will soon be joined by 802.16m when time is ripe. 802.16m will integrate quite a lot of state–of–the–art technologies in the fields of wireless communications, and will generate products with ultra–high data transmission rate and considerably large scope of coverage. It will also be easy to use in other wireless communication networks. WiMAX standard will be a great push to the wireless broadband market in a dramatic way. With increasing application and development of multimedia technologies in Internet, it is certain that lots of wireless network equipment with higher transmission rate will emerge, and we are very optimistic about the promising prospects of investments in wireless broadband equipment and services. Driven by the wireless broadband users and many international network operators, high speed WiMAX will become one of the most important network technologies in the coming several years.

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Biographies

Liu Qiaoyan received her Master's Degree from Xidian University. She is now working at Xi'an R&D Department of CDMA Research Institute, ZTE Corporation, and has taken part in the pre–study work of B3G, TD–SCDMA and WiMAX. Her research interest is about air interface technology for wireless communications. She, together with other researchers, has applied for 15 patents. She has also published three technical papers.

Yu Qiuxing received his Doctoral degree from Northwestern Polytechnic University. He is now working at Xi'an R&D Department of CDMA Research Institute, ZTE Corporation, and has taken part in pre–study work of B3G, TD–SCDMA and WiMAX. His research interest is about air interface technology for wireless communications. He, together with other researchers, has applied for 10 patents. He has also published 10 technical papers.

Roundup

ZTE Shows Compliance with the MSF Release 3 Architecture

July 23, 2007, Shenzhen, China – ZTE Corporation, a leading global provider of telecommunications equipment and network solutions, announced today that after extensive tests, its IMS product portfolios support the MultiService Forum (MSF) R3 "NGN Guidelines" and comply with the MSF Release 3 Architecture. ZTE, one of the most active members of MSF, began its Global Multiservice Interoperability (GMI) testing at Verizon's lab in Waltham, Massachusetts in October 2006.

In addition to the support of MSF architecture, ZIMSTM, the IMS solution from ZTE, focuses on service creation and fixed–mobile convergence, and complies with 3GPP, 3GPP2 and TISPAN standards. This end–to–end solution encompasses terminal, access, core and service platforms.

The GMI Program, initiated by the MSF, provides an opportunity to put the components together in a multi–vendor, end–to–end network deployment scenario, and validates the current release of the architecture. The GMI event in 2006 (GMI 2006), jointly hosted by five of the top international carriers – British Telecom, Korea Telecom, NTT, Verizon and Vodafone – and The University of New Hampshire Interoperability Laboratory, focused on testing multi–vendor interoperability to achieve fixed mobile convergence supporting the IMS service framework. (ZTE)

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