SPECIAL TOPIC

Multiple Antenna Technology and Its Application in WiMAX System

Abstract:
Worldwide Interoperability for Microwave Access (WiMAX) technology has rapidly developed in recent years. It is becoming one of the hotspots among broadband wireless access technologies. A WiMAX system can provide bandwidth efficiency higher than 2 bps/Hz. In order to improve coverage and reliability of the WiMAX system, the IEEE 802.16 standard supports multiple antenna techniques such as Alamouti Space-Time Coding (STC), Adaptive Antenna System (AAS) and Multiple Input Multiple Output (MIMO). The applications of the multiple antenna techniques improve system capacity and bandwidth efficiency significantly, and enhance the competence of the WiMAX technology greatly.

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Worldwide Interoperability for Microwave Access (WiMAX) is a wireless broadband access technology based on IEEE 802.16 standard family. A WiMAX system can provide high-speed data, audio and video services in both fixed and mobile environments.

Demonstrating its unparalleled advantages in improving spectral efficiency, supporting higher speed data transmission, enhancing signal quality, expanding system coverage, and providing extra-large system capacity where it is needed, the multiple antenna technology has become the focus of current research and is widely applied to all kinds of mobile telecommunications systems[1-5].

As the wireless broadband access technology to provide the best last mile access model, WiMAX needs to adopt the multiple antenna technology to enhance its own competence.

1 Advantages of Multiple Antenna Technology

With the rapid development of wireless communication technologies, the grave deficiency of radio spectrum resources is becoming the bottleneck for further development of wireless communications. How to fully develop and utilize the limited radio spectrum resources and increase spectral efficiency is one of the hottest research subjects in the telecommunications field .

The multiple antenna technology has won great attention from the world for its ability to increase transmission efficiency and spectral efficiency without additional bandwidth.

1.1 Advantages of Multiple Antennas over Single Antenna

(1) Array Gain

Multiple antennas can improve signals' coherence and generate array gain.

(2) Diversity Gain

Multiple antennas increase diversity gain through multi-path, in which malperformance of one path will not affect the entire system. In the wireless fading channel, reliability of data transmission can be improved by enhancing stability of the intensity of received signals. The diversity gain can be obtained in space, time and frequency domains.

(3) Elimination of Co-Channel Interference

By analyzing different channel responses to interference, the application of multiple antennas can eliminate co-channel interference signals.

1.2 Economical Multiple Antenna Technology

(1) The technology increases transmission capacity and decreases network establishment costs in busy call areas.

With the unceasing expanding of data services, especially applications like mobile phone TV and high-speed wireless Internet services, there has been increasing needs for such data services, however, services that can be offered are confined to the network capacity which lags far behind users' needs, particularly in busy call areas like city centers or hotspot places. Besides, due to imbalance in data services, the network capacity is often circumscribed by the downlink speed. Take the hybrid network

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as an example; a 2×2 spatial diversity receiving Multiple Input Multiple Output (MIMO) system can raise the single Base Station (BS) capacity by nearly 20%. Provided that the area coverage and capacity need are unchanged, using the 2×2 MIMO can save over 15% of the number of BS needed for the 1×2 MIMO. This significantly reduces the network establishment costs in busy call areas.

(2) It cuts cost for capacity expansion.

When using receivers that are based on the multiple antenna technology, 2×2 MIMO can raise the sector throughput by 40% to 60%. Particularly in city, downtown or indoor micro-cellular conditions with complicated multi-path environment, where there is higher demand on system capacity, sector throughput can be increased by nearly 60%.

Therefore, without increasing carrier frequency and the number of BS, the multiple antenna technology can be used as one of the capacity expansion solutions that can not only satisfy people's needs but also do it with a low cost so as to achieve a low-cost expansion.

(3) It increase costs of transceiver and antenna-feeder system.

The introduction of the multiple antenna technology makes transceiver's processing more complicated: the BS must not only support more than two independent transmitting antennas (each encoding, modulating, expanding frequency and transmitting independently), but also process the uplink feedback signaling of two spatial data flows (such as CQI and ACK/NACK). All these will increase the cost of BS and end equipment at a certain degree. Besides, the installation of multiple antennas and the antenna feeder system is more complex than that of normal antennas. Therefore, the costs of BS and antenna-feeder system will rise with the introduction of the multiple antenna technology.

Undoubtedly, the multiple antenna technology, on one hand, can increase transmission capacity of the system, and can accordingly bring great profit potential for network operators who charge their services by data flow; on the other hand, it will make the BS and terminal equipment more complex. Except for signaling and measurement information, the multiple antenna technology actually affects the network slightly.

With regard to operation cost, the application of multiple antenna technology needs to be carried out after full consideration of the influence of more complicated system and equipment.

IEEE 802.16 standards support such multiple antenna technologies as Alamouti space-time code, Adaptive Antenna System (AAS) and MIMO. IEEE 802.16e, being able to effectively improve system's anti-fading performance, takes transmitting diversity, which is realized through space-time coding, as one optional item.

2 Application of Multiple Antenna Technology in WiMAX System

2.1 AAS

AAS can realize automatic adaptation of system parameters, obtain Signal-to-Noise Ratio (SNR) gains and reduce co-channel interference. It uses a certain digital signal processing technology to generate directional radio beam in space which can aim the main radio beam of the antenna at expected direction of arrival and suppress interference by null so as to achieve the best receiving of expected signals.

The design and application of AAS technology in WiMAX is based on the Time Division Duplex (TDD) mode. Since the uplink and downlink share the same frequency band resources in the TDD mode, the downlink/uplink channel information can be inferred from the uplink/downlink so that at the BS or terminal, the weighing value of radio beam can be easily calculated. Under the Frequency Division Duplex (FDD) mode, the uplink and the downlink channels are usually different and cannot recognize one from the other. In this case, the weighing value can only be calculated by feedback, which increases the overhead of the whole system.

In the WiMAX system, AAS is an optional technology that can be chosen for both the uplink and the downlink. Adoption of AAS can increase system capacity, expand scope of coverage, enhance communication reliability and cut operation costs. AAS can be fulfilled by either multiple radio beam selection or adaptation.

2.2 MIMO

MIMO technology was first put forward by Marconi in 1908. It equips the BS and terminals with multiple antennas to refrain from channel fading so as to increase channel capacity, coverage and spectral efficiency by a large margin. According to the number of transmitting and receiving antennas, MIMO includes Single Input Multiple Output (SIMO) and Multiple Input Single Output (MISO).

The most important part in MIMO is space-time signal processing, or in other words, using multiple antennas to process signals with combined time and space domain information. Therefore, MIMO technology can be regarded as an expansion of smart antenna. In its broad sense, MIMO technology includes transmit diversity technology and space multiplexing technology. Transmit diversity technology means sending signals with the same message through different antennas (although the form of the signals may not be the same) so as to achieve the spatial diversity, increase channel reliability and reduce Bit Error Ratio (BER). Different from transmit diversity technology, space multiplexing technology sends different messages through different antennas, thus obtaining space gains and accordingly increasing system capacity and spectral efficiency substantially. Therefore, the combined application of space-time coding and spatial multiplexing in WiMAX system can greatly increase system capacity and spectral efficiency.

Manifested in IEEE 802.16e, MIMO has become one of the options for multiple antenna technology in IEEE 802.16, which supports three MIMO modes: space-time transmit diversity, space multiplexing, and the combination of these two modes.

2.2.1 Space-time Transmit diversity

The biggest advantage of transmit diversity lies in the fact that multiple antennas can be used at the BS instead of receivers to avoid pressure on the terminal equipments, thus reducing the

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market hindrance to IEEE 802.16.

In MIMO, the space–time transmit diversity mode is mainly implemented by space–time coding. The main idea of space–time coding is to achieve a certain space diversity and time diversity by adopting coding with space and time domain information, thus reducing BER. When applying the space–time code, MIMO system can realize the biggest diversity gain even in a case where the sender has no idea about the channel condition. The commonly seen space–time codes include Space–Time Block Code (STBC) and Space–Time Trellis Code (STTC). STBC has won wider application for its relatively easier coding process.

Based on Alamouti Space–Time Code (STC), IEEE 802.16d standard adopts transmit diversity of two antennas to countervail deep fading caused by Obstructed Line of Sight (OLOS) and Non–Line of Sight (NLOS). The most important feature of this scheme is the orthogonal sequences of the two transmitting antennas. Alamouti coding can obtain the biggest diversity gain from the two transmitting antennas system. Besides, speaking from the history of coding development, Alamouti is a kind of space–time block code specially designed to offer full transmit diversity gain for a system with two transmitting antennas, and it only needs simple processing of the received signals when decoding, thus greatly simplifying the calculation process.

2.2.2 Space Multiplexing

Space multiplexing technology sends mutually independent signals at the transmitters, and decode at the receivers with the interference restraint approach in order to increase transmission rate of the system. Currently, the ways that use space multiplexing to increase channel capacity are mainly different layered space–time codes such as Bell Labs Layered Space–Time (BLAST). The BLAST structure does not introduce orthogonality by signal changes like coding and modulation, but by fully utilizing the multi–path feature of channels to eliminate the correlations between signals.

The BLAST structure is mainly divided into two categories: Vertical Bell Labs Layered Space–Time (V–BLAST) and Diagonal Bell Labs Layered Space–Time (D–BLAST). V–BLAST sends *M* bit flows out by mutually independent antennas after they are encoded, mapped and interleaved, so that the diversity gain is fully tapped, and each message flow can be tested separately. D–BLAST goes through the same procedure as V–BLAST, but coding blocks are assigned to different antennas for sending, thus reducing the possibility of performance degrading of the entire system due to the unsatisfactory transmission effect of an independent channel. However, this implies that transmitting and receiving equipment will become more complicated.

Though the BLAST structure reaches higher spectral efficiency than other structures, it normally requires that the number of receiving antennas is bigger than or equal to that of the transmitting ones, which can hardly be realized in the downlink. Besides, since the BLAST structure sends different signals in different routes, if one route is damaged there will be an irrevocable mistake.

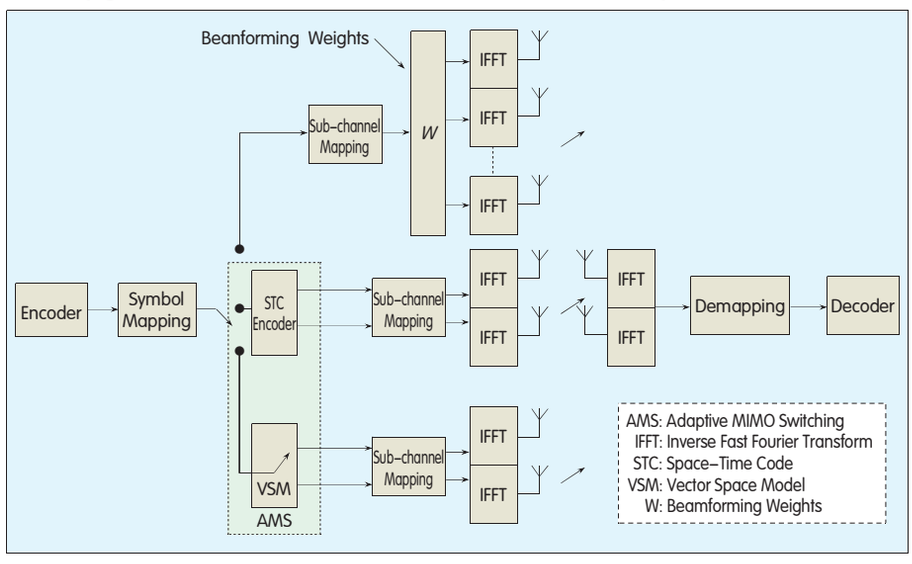
2.2.3 Integration of Diversity and Multiplexing

Space–time transmit diversity can obtain additional diversity gain and coding gain, but cannot increase data transmission rate; space multiplexing can maximize the average transmission rate of the MIMO system, but can only get limited diversity gain. A solution that combines these two technologies can offer diversity gain and system capacity increase at the same time, thus providing a nice compromise between high spectral efficiency and good transmission quality. However, this solution is more complicated than using diversity and multiplexing separately.

2.2.4 Intelligent MIMO

Mobile WiMAX supports Adaptive MIMO Switching (AMS) between different MIMO modes. AMS, as shown in Figure 1, is also called intelligent MIMO. Intelligent MIMO can select the most suitable MIMO mode according to the channel conditions, and increase the spectral efficiency without reducing the scope of coverage. The adoption of intelligent MIMO can overcome uncertainty brought by different application scenarios, making the MIMO technology widely accepted. For instance, different terminals in one network may have different number of antennas, and if just one MIMO mode is used in a cell, the network optimization can hardly reach the design goal. Besides, different users experience different signal fading. Different MIMO technologies are selected to adapt channel changes, which can optimize system performance. To support the AMS, the transmitting end needs more feedback information about channels or weight.

One of the major questions and research focuses on future mobile communication systems is how to



▲Figure 1. AMS.

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guarantee the Quality of Service (QoS) in the case of NLOS and bad channels. For a Single Input Single Output (SISO) system, QoS guarantee requires quite much spectral resources and complicated coding and modulating technologies, which restrict the development of SISO. Therefore, MIMO is a key technology for future mobile communications. MIMO technology is implemented by either space multiplexing or space–time coding, which have all been applied in the WiMAX system. WiMAX also allows another MIMO option, that is, to use space multiplexing and space–time coding simultaneously.

2.3 Comparison between AAS and MIMO

AAS and MIMO are both multiple antenna technologies written in the 802.16 standards, but their working theory and application scenarios are different. Hereafter is the comparison between the two technologies.

(1) System Capacity

Both the AAS and MIMO technologies use multiple antennas to strengthen signals and acquire additional system capacity. AAS generates single highly–energy–concentrated radio beam. Theoretically speaking, the system's capacity is geometrical to the strength of the radio beam. In the WIMAX system, the BS throughput is 25 Mb/s when equipped with the basic SISO configuration. An AAS with four array elements can raise the throughput by 50% and reach 33 Mb/s, and an AAS with eight array elements can reach 38 Mb/s. Different from AAS, MIMO system's capacity is linear to the number of antennas, so 2×2 MIMO system's capacity is 2 times SISO and 4×4MIMO system's capacity is 2 times 2×2 MIMO. Therefore, MIMO can get more system capacity than AAS.

(2) Mobility

Compared with IEEE 802.16d, the biggest improvement that IEEE 802.16e has made is its ability to support mobile environment. AAS depends heavily on accurate and reliable estimation about the channel to get the weighing value of the radio beam. However, in mobile environments, the channel estimation will become very complicated. For example, at 30 km/h and at 3.5 GHz, channel estimation would need to occur every millisecond to maintain best performance, which will cause quite a large system overhead. Therefore, in a high speed mobile environment, AAS can hardly work, while in the MIMO mode, the channel information is not necessary at the transmitting end, making MIMO a better fit for mobile environments.

(3) Others

Since AAS needs channel information, it is, in some degree, confined to work in the TDD mode, while MIMO can work normally in both the TDD and FDD modes. MIMO can also be integrated with OFDM technology to reach better performance—one of the development trends for mobile communication technologies in the future.

MIMO technology meets the requirements for wireless signal processing in urban multi–path conditions very well. It can provide space diversity and parallel transmission in multiple channels. It is a well–designed technology to increase coverage and throughput of the WiMAX system. AAS is good at raising the directional gains of the BS and the moving object, as well as at directional restraint to interference signals. However, in the urban multi–path environment, MIMO is more likely to be welcomed by equipment developers. In other words, MIMO technology suits WiMAX better. Only when WiMAX supports the basic MIMO working mechanism can it be compatible with other technologies and become more competitive.

3 Conclusions

WiMAX is the special technology for mobile broadband wireless access. It is developed with sound performance, high efficiency and low cost, and it can meet requirements of various application scenarios by flexible system configuration.

Faced with the highly intense competition in the wireless communication market, WiMAX, in order to win a solid footing, has to adopt the most advanced technologies and convert the technological advantages to product advantages to enlarge its commercial use scale, and in the meantime, to maintain its strengths in big capacity, large coverage, NLOS and unified standard.

Of all the key technologies for WiMAX system, multiple antenna technologies, such as AAS and MIMO, have attracted great attention from the market because they are able to substantially enhance the capacity of wireless communication systems. Different multiple antenna technologies fit different scenarios well; so, a proper technology should be selected to enable the system to perform at its best. Meanwhile, more consideration should be given to the cost of the technology in real application, as well as its integration with other technologies, such as OFDM. WiMAX is expected to surpass Long Term Evolution (LTE) and Air Interface Evolution (AIE) and develop into the best wireless broadband access technology for last mile access.

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Biographies

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