The Future Trend of MIMO Technology in WiMAX

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1. Introduction

Recently, an IEEE 802.16-2009 Standard has been approved as new WiMax standard. This revision supersedes of IEEE 802.16-2004 and 802.16e-2005 [1]. This revision introduces new features that incorporate MIMO and beamforming technique that significantly improve system coverage and realibility comapare to previous standard [2], especially against fadding condition. This feature is also being advanced for the next WiMAX based on IEEE 802.16j and 802.16m [3]. This paper presents the current MIMO and beamforming techniques and their performances that are used in WiMAX 802.16-2009. Afterward, this paper also discuss about next advancement of beamforming techniques in WiMAX IEEE 802.16j and 802.16m.

2. MIMO-Beamforming WiMAX 802.16-2009

There are two MIMO techniques that are mandatory in Mobile WiMAX Profile System Profile, MIMO Matrix-A and MIMO Matrix-B [4]. MIMO Matrix-A is based on Space Time Coding (STC) method that has an objective to decrease system sensitivity to fading using multiple of antena system. MIMO-STC based on Alamouti's STBC (Space Time Block Codes). On the other hand, MIMO Matrix-B uses Spatial Multiplexing (SM) method to increase system capacity (data rate or user) and coverage area [5]. MIMO-SM is based on Foschini's VBLAST. Beamforming is signal processing techniques that leverage arrays of transmit and receive antennas to control the directionality and shape of the radiation pattern. This MIMO and beamforming processing are implemented as smart antena system in WiMax Baseband signal processing. Therefore, the technique can be easily implemented using digital signal processing techniques in Digital Signal Processors. MIMO is very promising technique to achieve high performance system. Using MIMO, performance can be improved twice the performance gain over a baseline 802.16-2009 system in term of sector throughput, average user throughput, and peak data rate, as well as cell-edge performance.

MIMO-STC

MIMO-STC improves the reliability of data transmission between Mobile Subscriber (MS) and Base Station (BS) by using multiple transmit antennas. Therefore, multiple redundant copies of data stream will be sent to the receiver. As a result, the probability of receiver to receive transmitted data will increase due to several physical paths between transmission and reception. Among those data paths, receiver may decode realible signal that having smaller fadding.

These rapid signal fading and multi-path reception conditions are most likely to occur while the terminal is highly mobile. By adding redundancy in both space and time [6] (by using multiple antennas), the receiver has more chance of receiving a good copy of the data. In stationary conditions, the gain provided by MIMO-STC is only +3dB, but in a fading conditions, such as when passing rapidly between buildings, the gain can reach up to +5dB for 16QAM, and +10dB for 64

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QAM (compared to a non-STC signal under the same conditions) [7]. As a result, the system can maintain a relatively high throughput under difficult conditions. Therefore Matrix A provides robustness for mobile users.

MIMO-SM

MIMO Matrix B or MIMO-SM provides capacity enhancements for stationary users using spatial multiplexing. It incorporates multiple antennas to sends multiple data stream simultaniously. Each antennas will send different data stream. Therefore the data rate can be doubled or more depend on the number of antenna.

MIMO-B relies on the presence of natural multipath to decorrelate (distinguish) the incoming signals. This is the key to the spatial multiplexing approach. Without naturally occurring multipath, MIMO-B signals can destructively combine which will result in no signal at the receiver.

Natural multipath is occurs in highly cluttered environments, such as dense urban or downtown areas. In these areas, MIMO Matrix B may double the number of receiver channels and result in much higher user throughput.

MIMO-Beamforming

Beamforming is also mandatory feature in Mobile WiMAX Profile [2]. Beamforming that is used in WiMAX is codebook-based precoding [1]. This codebook was not defined in the previous Standard IEEE 802.16e-2005. WiMAX adopted beamforming techniques in order to further increase system coverage and reliability. As a consequence, this technique may surpass the capabilities of MIMO only technique.

Beamforming in MIMO system was called Closed Loop Transmission. Closed Loop Transmission method offers several important advantages over traditional Open-Loop methods that did not make use of channel knowledge. In transmit antenna array applications, the knowledge of channel response can be used to increase the range and the coverage reliability by using coherent transmit beamforming.

In general, there are two methods for providing a BS transmitter with knowledge of the channel between the BS and MS. The first method is called **Uplink Channel Sounding**. The assumption used in this method is the uplink and downlink channels are reciprocal. This is generally the case in Time Division Duplex (TDD) system where BS and SS use the same channel for data transmission and they are appropriately calibrated. The second method is called Feedback. Feedback method is generally used in Frequency Division Duplex (FDD) systems where the uplink and downlink channel responses are usually independent.

The IEEE Std 802.16-2009 Closed Loop MIMO system provides 6-bit and 3-bit codebooks. In codebook-based precoding codebooks are available for most antenna configuration. The codebooks are used for the feedback of MIMO Tx beamforming. The Codebook codeword will be employed as the beamforming matrix in MIMO precoding. Selecting codebook by the number of bits are required for the index. It indicates any active vector in the codebook [1].

Table 1 Comparison Coverage of SISO, MIMO, and MIMO-Beamforming WiMAX [3]

number of antenna	Provides Gain	Cell sites/ BS requirement	Method
2	+3db D/L (over SISO)	28 / 122	MIMO non Beamforming
4	+6db D/L	18 / 72	Beamforming
8 (2 Tx)	+12db D/L	12 / 36	Beamforming w/ MIMO

Table 1 shows the comparison between MIMO and MIMO-Beamforming in the condition of covering a circle area with radius of 5 km (80 km^2) and using multiple antennas system. From Table 1, we can see that MIMO-Beamforming can maximize coverage, increases reliability and throughput of data transmission. The gain can reach up to 12 dB for MIMO-Beamforming method. As a result, it can effectively improve subscriber satisfaction.

Figure 1 shows the performance comparison among MIMO-STC, MIMO-Beamforming and MIMO-SVD Precoding. MIMO-Beamforming used 6-bit code book in this comparison. We can see that MIMO-Beamforming can outperform MIMO-STC around 3 dB. This feature becomes an advantage of MIMO-Beamforming system for increasing coverage area and system realibility. We can also see, that MIMO-Beamforming is only 1 dB lower that ideal SVD precoding based system.

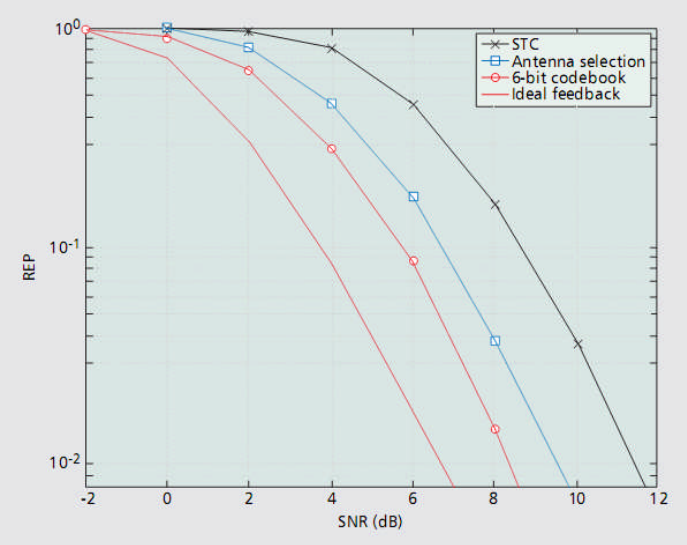

Figure 1. BER comparison among MIMO-STC, MIMO-Beamforming and Ideal SVD Precoding.

3. Advancement of MIMO-Beamforming Technique in Future WiMAX: 802.16j/m

WiMAX 802.16j introduces relay technology. Besides conventional relay operation, 802.16j also allows BS and Relay Station (RS) to forward the signal in an opportunistic or cooperative mode. This kind of MIMO system with all transmit antennas of BS and RS and receive antennas MS are shown in Figure 2.

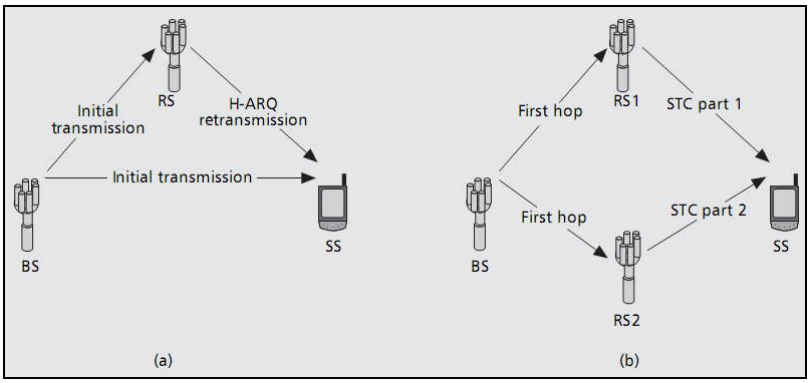

Figure 1. a) Opportunistic Relay; b) Cooperative Relay [3]

The opportunistic forwarding mode is also called RS assisted Hybrid Automatic Repeat Request (HARQ) in 802.16j. In this mode, BS and RS jointly transmit signal to MS using switched diversity scheme. The Figure 1 shows that BS send a packet, and on the other hand both MS and RS are asked to decode the sended data. If the RS fails to decode the packet but the MS misses it, the BS asks the RS to send an HARQ packet to the SS. Therefore SS can combine both the initial packet and the HARQ packet to be decoded. This significantly improve data transmission compare to BS sending the HARQ packet by itself. It is because if the channel from BS to MS is in deep fading, which causes the initial reception failure, retransmission over the same channel will most likely to fail. Therefore, the retransmission trough different channel, from RS will significantly enhance the data transmission reliability [3].

Further advancement of MIMO system is also on going in WiMAX 802.16m. The collaborative multicell MIMO is proposed as new scheme in this standard. This scheme enables multiple BSs collaboratively serve multiple MSs in the edge region of the BS's cell. This MIMO scheme has high potential to eliminate dominant intercell interferences. There are still some technical issue needs to be resolved to implement this scheme [3].

Advancement in beamforming is also worked up in the next WiMAX. The codebook-based linear precoding was developed by ideal SVD (Singular Value Decomposition) precoding that generalized codebook design with multi-stage vector quantizer [8]. A new beamforming method in 802.16m is proposed for 802.16m, transformation method for codebook based precoding. The transform method utilizes the channel correlation information to enhance the performance of the standard codebook especially in the highly correlated channel [9].

4. Conclusion

Current MIMO-beamforming significantly improves coverage and reliability WiMAX system compare to SISO and MIMO only system. It helps to minimize the required number of BS to cover certain cell area. The next WiMAX, 802.16j, will implement conventional relay and opportunistic-cooperation relay technology. Opportunistic relay enhance reliability because HARQ packet is retransmitted trough different channel. Furthermore, WiMAX 802.16m implements multicell MIMO to improve reliability in edge region of BS cell. The new beamforming, codebook-based linear precoding, utilizes the channel correlation information to enhance the performance of the standard codebook especially in the highly correlated channel.

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