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A SURVEY OF MULTIPLE ANTENNA TX-RX METHODS FOR WIBRO/WIMAX

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ABSTRACT

WiBro/WiMAX is an OFDMA-based multiple access service for wireless broadband multimedia environment. Multiple antenna system has been considered to increase the capacity, service area, and data rate for WiBro/WiMAX base station system. In this paper, we compare the methods for multiple antenna system of WiBro/WiMAX and show the performance benefits of various multiple antenna methods. We examine the space time transmit diversity (STTD) and spatial multiplexing scheme for WiBro/WiMAX. We first describe the signal modeling and operations for STTD, spatial multiplexing. Then we explain advantages and disadvantages in each method, to summarize the differences among the methods. We also demonstrate various simulation results to show the performances of STTD and spatial multiplexing which are compared in various communication circumstances.

1. INTRODUCTION

Wireless communication using multiple input multiple output (MIMO) has recently emerged as one of the most significant technical issues to increase the system capacity with limited resources in modern communications. MIMO system has many benefits that increase the system reliability, increase the data-rate and enlarge the wireless service coverage. However, all MIMO systems have not these benefits. Each MIMO scheme has advantages and disadvantages compared to one another.

There are largely two algorithms of MIMO schemes: one is space time transmit diversity (STTD) and the other is spatial multiplexing (SM). STTD scheme transmits the orthogonal signals in each transmit antenna and is often called by Alamouti code or space time code [1]. This scheme can obtain a diversity gain like the maximum ratio combining in receive antenna, but data-rate is not increased which compared to single input single output (SISO). On the other hand, because SM scheme transmits different signals from each transmit antenna, data-rate is increased proportionally to number of transmit antennas. But SM scheme does not provide a diversity gain.

In this paper, the performance of many MIMO schemes and algorithms is compared and analyzed in OFDMA-based wireless communication standard, WiBro/WiMAX downlink environment. Based on IEEE 802.16-2004 [2] and 802.16e-2005 [3], WiBro (Wireless Broadband) is the next generation wireless communication standard that has been adopted in Korea.

This paper is organized as follows. In section 2, we examine the signal modeling of STTD, SM schemes and algorithms. In section 3, we examine the structure of WiBro/WiMAX downlink system. Simulation results to apply many MIMO schemes are shown in section 4. Section 5 concludes this paper.

2. MIMO SCHEMES

2.1. Space Time Transmit Diversity

2.1.1. 2×1 Space Time Code

There is MIMO system that has two transmit antennas and a single receive antenna in figure 1. If two symbols to be transmitted are s_1 and s_2, STC sends the following for two symbol times:

	Antenna 1	2
Time 0	s_1	s_2
1	$-s_2^*$	s_1^*

During two symbol times, transmitted symbols in each antenna are orthogonal with each other. Using matrix expression, received symbol vector is expressed in following (1). An assumption is that the channel h_1, h_2 remain constant over two symbol times.

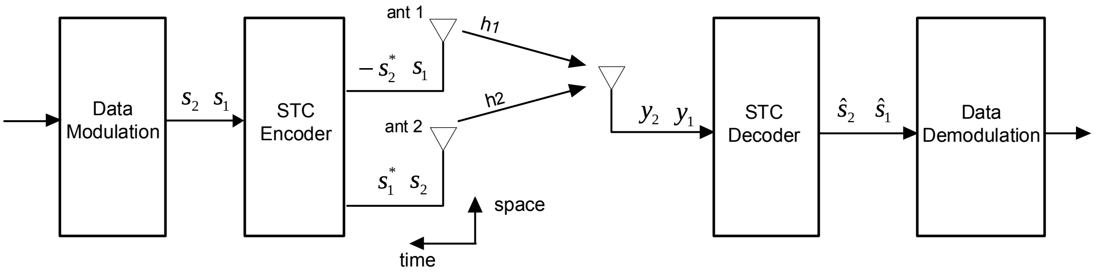

Fig. 1. 2×1 space time code

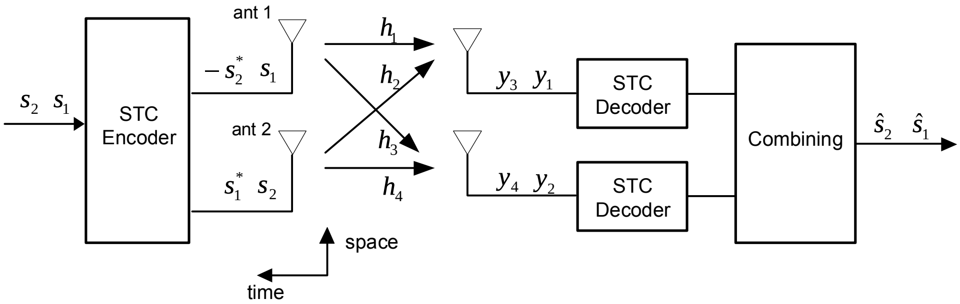

Fig. 2. 2×2 space time code

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{bmatrix} \begin{bmatrix} h_1 \\ h_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \quad (1)$$

where n_1, n_2 are additive white Gaussian noise.

Received symbols are decoded as below.

$$\begin{bmatrix} \hat{s}_1 \\ \hat{s}_2 \end{bmatrix} = \begin{bmatrix} h_1^* & h_2 \\ h_2^* & -h_1 \end{bmatrix} \begin{bmatrix} y_1 \\ y_2^* \end{bmatrix} = \begin{bmatrix} (|h_1|^2 + |h_2|^2) \cdot s_1 + N_1 \\ (|h_1|^2 + |h_2|^2) \cdot s_2 + N_2 \end{bmatrix} \quad (2)$$

As (2), we can see that 2×1 STC obtains a diversity gain like the maximum ratio combining (MRC) of 1×2 receive diversity system. In summary, the 2×1 STC achieves the same diversity order and data-rate as a 1×2 receive diversity system with MRC but with 3dB penalty, owing to the redundant transmission required to remove the spatial interference at the receiver.

2.1.2. 2×2 Space Time Code

Figure 2 is 2×2 STC and STC encoding is operated as follow.

$$\begin{bmatrix} y_1 & y_3 \\ y_2 & y_4 \end{bmatrix} = \begin{bmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{bmatrix} \begin{bmatrix} h_1 & h_3 \\ h_2 & h_4 \end{bmatrix} + \begin{bmatrix} n_1 & n_3 \\ n_2 & n_4 \end{bmatrix} \quad (3)$$

2×2 STC decoding is operated like (2) in each receive antenna and then, decoded results are combined as below.

$$\begin{bmatrix} \tilde{s}_1 \\ \tilde{s}_2 \end{bmatrix} = \begin{bmatrix} h_1^* & h_2 \\ h_2^* & -h_1 \end{bmatrix} \begin{bmatrix} y_1 \\ y_2^* \end{bmatrix} = \begin{bmatrix} (|h_1|^2 + |h_2|^2) \cdot s_1 + N_1 \\ (|h_1|^2 + |h_2|^2) \cdot s_2 + N_2 \end{bmatrix},$$

$$\begin{bmatrix} \bar{s}_1 \\ \bar{s}_2 \end{bmatrix} = \begin{bmatrix} h_3^* & h_4 \\ h_4^* & -h_3 \end{bmatrix} \begin{bmatrix} y_3 \\ y_4^* \end{bmatrix} = \begin{bmatrix} (|h_3|^2 + |h_4|^2) \cdot s_1 + N_3 \\ (|h_3|^2 + |h_4|^2) \cdot s_2 + N_4 \end{bmatrix} \quad (4)$$

$$\begin{bmatrix} \hat{s}_1 \\ \hat{s}_2 \end{bmatrix} = \begin{bmatrix} \tilde{s}_1 + \bar{s}_1 \\ \tilde{s}_2 + \bar{s}_2 \end{bmatrix} = \begin{bmatrix} (|h_1|^2 + |h_2|^2 + |h_3|^2 + |h_4|^2) \cdot s_1 + N_1 + N_3 \\ (|h_1|^2 + |h_2|^2 + |h_3|^2 + |h_4|^2) \cdot s_2 + N_2 + N_4 \end{bmatrix} \quad (5)$$

We can see that data-rate of 2×2 STC is the same with 2×1 STC.

2.2. Spatial Multiplexing

SM is a scheme that a set of independent symbols are transmitted in each transmit antenna, which make the data-rate be doubled. Mathematical expression is as follows.

$$\underline{\mathbf{y}} = \underline{\underline{\mathbf{H}}}\underline{\mathbf{x}} + \underline{\mathbf{n}}, \qquad \text{i.e.}$$

$$\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_M \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1N} \\ h_{21} & h_{22} & \cdots & h_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ h_{M1} & h_{M2} & \cdots & h_{MN} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_N \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ \vdots \\ n_M \end{bmatrix} \quad (6)$$

where M is the number of receive antennas, N is the number of transmit antennas and $\underline{\mathbf{n}} \sim N_c(0, \sigma^2 \underline{\underline{\mathbf{I}}})$. $\underline{\underline{\bullet}}$ term indicates a matrix, $\underline{\bullet}$ term indicates a vector.

Figure 3 is the structure of 2×2 SM. In SM scheme, to detect received symbols, the detection processing is required.

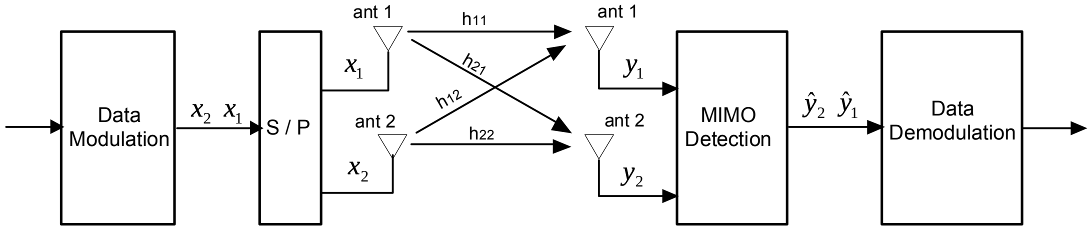

Fig. 3. 2×2 spatial multiplexing

There are many algorithms that are used to detection processing and in this paper we examine maximum likelihood (ML), zero forcing (ZF), minimum mean square error (MMSE), and successive interference cancellation (SIC), ordered SIC (OSIC).

2.2.1. Maximum Likelihood

The following equation is criterion for ML detection.

$$\hat{\underline{\mathbf{x}}} = \arg\min_{\underline{\mathbf{x}}} \left\| \underline{\mathbf{y}} - \underline{\underline{\mathbf{H}}}\underline{\mathbf{x}} \right\|^2 \tag{7}$$

where $\underline{\mathbf{x}}$ is a transmitted symbol vector, $\underline{\mathbf{y}}$ is a received symbol vector, $\underline{\underline{\mathbf{H}}}$ is a channel matrix and $\hat{\underline{\mathbf{x}}}$ is a estimated transmit symbol vector.

If channel information is known at the receiver, estimated transmit symbol vector is obtained when $\underline{\mathbf{x}}$ is substitute for all possible input vector. But if the order of the modulation (e.g., 4 for QPSK) is large, the computational complexity is very high. Therefore ML detection is very optimal but has a disadvantage of computational complexity.

2.2.2. Zero Forcing

As in other situations in which the optimum decoder is an intolerably complex ML detector, a sensible next step is to consider linear detectors that are capable of recovering the transmitted vector $\underline{\mathbf{x}}$. The most obvious such detector is the zero forcing detector, which sets the receiver equal to the inverse of the channel, or more generally to the pseudo-inverse.

ZF detection is as below.

$$\hat{\underline{\mathbf{x}}} = \underline{\underline{\mathbf{H}}}^{+}\underline{\mathbf{y}} \quad \text{with} \quad \underline{\underline{\mathbf{H}}}^{+} = \left(\underline{\underline{\mathbf{H}}}^{\mathbf{H}}\underline{\underline{\mathbf{H}}}\right)^{-1}\underline{\underline{\mathbf{H}}}^{\mathbf{H}} \tag{8}$$

where upper subscript H is complex transpose operation.

ZF detection is easily operated because of the pseudo-inverse of channel matrix, but the bad spatial subchannles can severely amplify the noise and its performance is not good.

2.2.3. Minimum Mean Square Error

A logical alternative to the zero forcing detection is the MMSE detection and the algorithm is as follow.

$$\begin{aligned} \tilde{\underline{\underline{\mathbf{W}}}} &= \arg\min_{\underline{\underline{\mathbf{W}}}} E\left[\left\| \underline{\underline{\mathbf{W}}}\underline{\mathbf{y}} - \underline{\mathbf{x}} \right\|^2\right] = \underline{\underline{\mathbf{H}}}^{\mathbf{H}}\left(\underline{\underline{\mathbf{H}}}\underline{\underline{\mathbf{H}}}^{\mathbf{H}} + E\left[\underline{\mathbf{n}}\underline{\mathbf{n}}^{\mathbf{H}}\right]\right)^{-1} \\ \hat{\underline{\mathbf{x}}} &= \tilde{\underline{\underline{\mathbf{W}}}} \cdot \underline{\mathbf{y}} = \underline{\underline{\mathbf{H}}}^{\mathbf{H}}\left(\underline{\underline{\mathbf{H}}}\underline{\underline{\mathbf{H}}}^{\mathbf{H}} + E\left[\underline{\mathbf{n}}\underline{\mathbf{n}}^{\mathbf{H}}\right]\right)^{-1}\underline{\mathbf{y}} \end{aligned} \tag{9}$$

Because noise effect is considered, its performance is better than ZF. But the computational complexity is larger than ZF.

2.2.4. Successive Interference Cancellation

The earliest known SM receiver was invented and prototyped in Bell Labs and called Bell Lab layered space/time (BLAST) [4]. Like other SM MIMO systems, BLAST consists of parallel "layers" supporting multiple simultaneous data streams. The layers (substreams) in BLAST are separated by interference cancellation techniques that decouple the overlapping data streams. The most important technique is vertical BLAST (V-BLAST) and we examine subsequent interference cancellation, SIC.

SIC detection process is as follow.

$$\begin{aligned}
&1: \underline{\underline{\mathbf{H}}} = \left[\underline{\mathbf{h}}_1 \quad \underline{\mathbf{h}}_2 \quad \cdots \quad \underline{\mathbf{h}}_N\right] \\
&2: \underline{\underline{\mathbf{H}}}_1^{+} = \left(\underline{\underline{\mathbf{H}}}^H\underline{\underline{\mathbf{H}}}\right)^{-1}\underline{\underline{\mathbf{H}}}^H = \left[\underline{\mathbf{w}}_1^{1^T} \quad \underline{\mathbf{w}}_1^{2^T} \quad \cdots \quad \underline{\mathbf{w}}_1^{N^T}\right]^T \\
&3: \tilde{x}_1 = \underline{\mathbf{w}}_1^{1^T}\underline{\mathbf{y}} \\
&4: \hat{x}_1 = Q(\tilde{x}_1) \qquad \text{(Quantization)} \\
&5: \underline{\mathbf{y}}_2 = \underline{\mathbf{y}} - \hat{x}_1\underline{\mathbf{h}}_1 \qquad \text{(Interference cancellation)} \\
&6: \underline{\underline{\mathbf{H}}}_2 = \left[\underline{\mathbf{h}}_2 \quad \underline{\mathbf{h}}_3 \quad \cdots \quad \underline{\mathbf{h}}_N\right] \\
&7: \underline{\underline{\mathbf{H}}}_2^{+} = \left(\underline{\underline{\mathbf{H}}}_2^H\underline{\underline{\mathbf{H}}}_2\right)^{-1}\underline{\underline{\mathbf{H}}}_2^H = \left[\underline{\mathbf{w}}_2^{2^T} \quad \underline{\mathbf{w}}_2^{3^T} \quad \cdots \quad \underline{\mathbf{w}}_2^{N^T}\right]^T \\
&8: \tilde{x}_2 = \underline{\mathbf{w}}_2^{2^T}\underline{\mathbf{y}}_2 \\
&9: \hat{x}_2 = Q(\tilde{x}_2) \\
&10: \underline{\mathbf{y}}_3 = \underline{\mathbf{y}}_2 - \hat{x}_2\underline{\mathbf{h}}_2 \\
&\quad \vdots
\end{aligned}$$

In each layer, the transmitted symbol is estimated based on zero forcing algorithm and in next layer interference is removed from received symbol vector. SIC algorithm is progressed in the order of layers.

2.2.5. Ordered Successive Interference Cancellation

Unlike SIC, the ordered SIC is performed in the order of decreasing SNR. This algorithm is as follow.

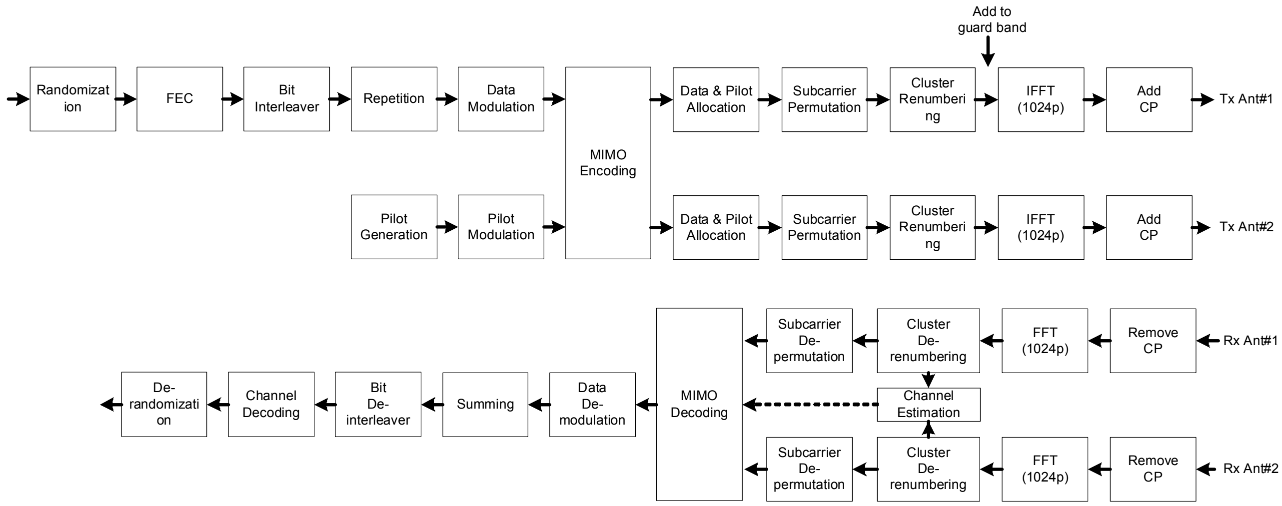

Fig. 4. WiBro/WiMAX MIMO downlink block diagram

$$\underline{\mathbf{y}} = \underline{\underline{\mathbf{H}}}\underline{\mathbf{x}} + \underline{\mathbf{n}} \qquad \underline{\underline{\mathbf{H}}} = [\underline{\mathbf{h}}_1 \quad \underline{\mathbf{h}}_2 \quad \cdots \quad \underline{\mathbf{h}}_N]$$

$$\begin{aligned}
&\textit{initialization}: \underline{\underline{\mathbf{G}}}_1 = \underline{\underline{\mathbf{H}}}^+ \qquad \underline{\underline{\mathbf{G}}}_i = [\underline{\mathbf{g}}_i^1 \quad \underline{\mathbf{g}}_i^2 \quad \cdots \quad \underline{\mathbf{g}}_i^N]^T \\
&\qquad i = 1 \\
&\qquad \underline{\mathbf{y}}_1 = \underline{\mathbf{y}} \\
&\textit{recursion}: \ k_i = \arg\min_{j \notin \{k_1, \ldots, k_{i-1}\}} \left\| \underline{\mathbf{g}}_i^j \right\|^2 \\
&\qquad \underline{\mathbf{w}}_{k_i} = \underline{\mathbf{g}}_i^{k_i} \\
&\qquad \tilde{x}_{k_i} = \underline{\mathbf{w}}_{k_i}^T \underline{\mathbf{y}}_i \\
&\qquad \hat{x}_{k_i} = Q(\tilde{x}_{k_i}) \qquad \text{(Quantization)} \\
&\qquad \underline{\mathbf{y}}_{i+1} = \underline{\mathbf{y}}_i - \hat{x}_{k_i} \underline{\mathbf{h}}_{k_i} \quad \text{(Interference cancellation)} \\
&\qquad \underline{\underline{\mathbf{G}}}_{i+1} = \underline{\underline{\mathbf{H}}}_{\overline{k_i}}^+ \quad (\underline{\underline{\mathbf{H}}}_{\overline{k_i}} = \underline{\underline{\mathbf{H}}} \text{ with columns } k_1, \ldots, k_i, k_i \text{ set to } 0) \\
&\qquad i = i + 1
\end{aligned}$$

3. STRUCTURE OF WIBRO/WIMAX SYSTEM

Based on IEEE 802.16-2004 and IEEE 802.16e-2005, WiBro/WiMAX standard specification has options about MIMO schemes. When MIMO schemes are applied to WiBro/WiMAX system, the system has advantages of increasing system capacity and spectrum efficiency. Figure 4 is block diagram of WiBro/WiMAX MIMO downlink system.

In the specification of WiBro/WiMAX, STTD and SM are optionally supported. For example, in the circumstance having good channel quality, SM may be selected and in cell edge circumstance having poor channel quality, STTD may be selected.

4. SIMULATION RESULTS

Table 1. Simulation parameters

Parameters	Value
Subcarrier Permutation Mode	PUSC
Carrier Frequency	2.3 GHz
Channel Bandwidth	8.75 MHz
FFT Size	1024 point
Number of Data Subcarriers	720
Number of Pilot Subcarriers	120
TDD Frame Length	5ms
CP(Cyclic Prefix) Ratio	1/8
Doppler Frequency	127 Hz
Data Modulation	QPSK
Channel Coding (Coding Rate)	Convolutional Coding (1/2)
Number of Tx Antennas	2
Number of Rx Antennas	1 or 2
Number of Used Slots	20

Under WiBro/WiMAX MIMO downlink environment, computer simulation is progressed on many MIMO schemes. There are simulation parameters on Table. 1. An assumption is that channel information is perfectly known at receive antenna.

In case of 2×1 and 2×2 STTD, figure 5 is simulation result. As shown in figure 5, if the system has more transmit antennas and receive antennas, it obtains a diversity gain like MRC of diversity system.

Figure 6 is a simulation result of 2×2 SM for many SM schemes and figure 7 is a throughput curve of ML, ZF, MMSE, SIC, OSIC. As shown in figure 6, ML detection is the most optimal and based on zero forcing, SIC and OSIC seem to be better performance than ZF detection. But MMSE has a better performance than SIC and OSIC. In figure 7, when applying many SM schemes, their

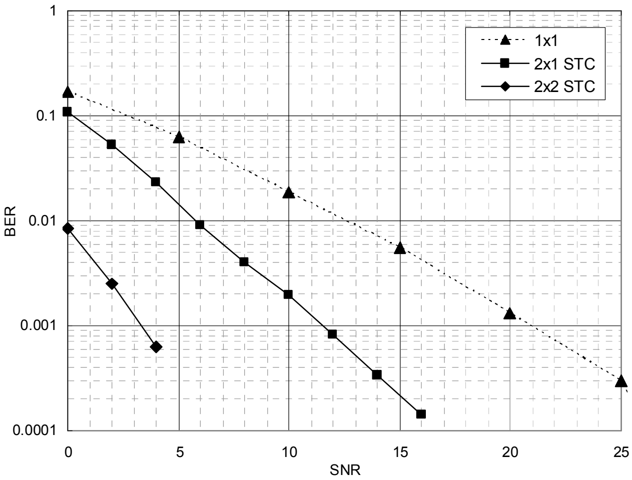

Fig. 5. WiBro/WiMAX STTD downlink performance

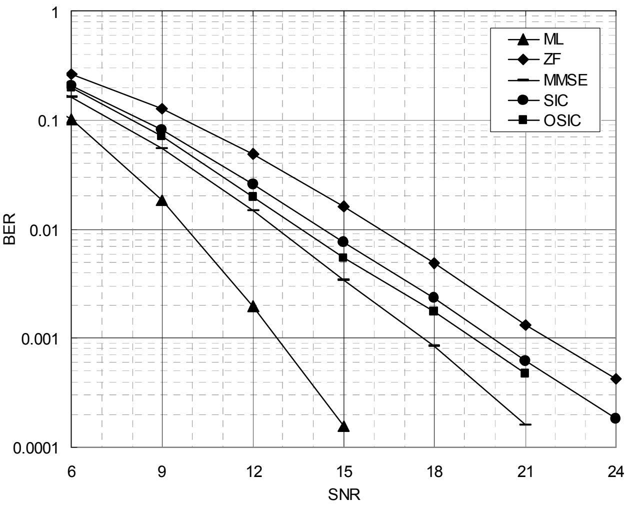

Fig. 6. WiBro/WiMAX 2×2 SM downlink performance

throughput is doubled than SISO system. This result coincidences with mentioned before in this paper.

5. CONCLUSION

In this paper, STTD and SM schemes leading MIMO technology are viewed from signal modeling and simulation performance of WiBro/WiMAX wireless communication environment. As shown in simulation results, in a good channel circumstance, we prefer the SM scheme due to increase data-rate. On the other hand, in an adverse channel circumstance, the STTD scheme seems to be better due to obtain a diversity gain.

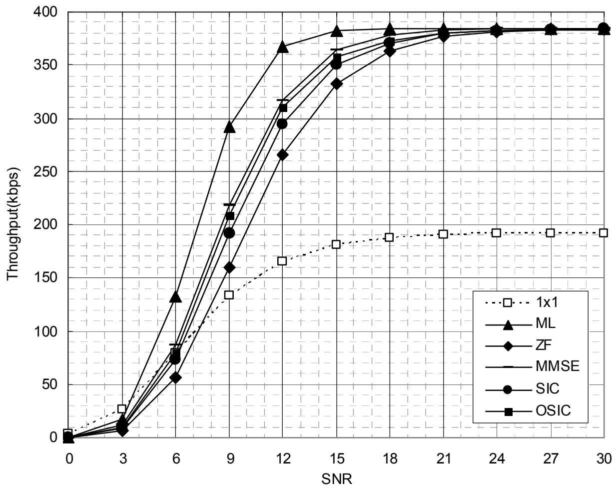

Fig. 7. WiBro/WiMAX 2×2 SM downlink data throughput

In this paper, we have investigated the MIMO algorithms which are interested for commercial application. MIMO technology is accepted as the standard for multiple antenna scheme of WiBro/WiMAX system. This paper analyzed the performance of MIMO under WiBro/WiMAX signal environments through computer simulations.

6. ACKNOWLEDGEMENT

This work was supported by the HY-SDR Research Center, Hanyang University, Seoul, Korea, under the ITRC program of MIC, Korea and was partly supported by the IT R&D program of MIC/IITA [2007-S001-01, Advanced MIMO system].

7. REFERENCES

[1] S.M. Alamouti, "A simple transmit diversity technique for wireless communications," *IEEE Journal on Selected Areas in Communications*, Vol. 16, No. 8, pp. 1451-1458, October 1998.

[2] IEEE 802.16-2004, "IEEE Standard for Local and metropolitan area networks, Air Interface for Fixed Broadband Wireless Access Systems," October 2004.

[3] IEEE 802.16e-2005, "IEEE Standard for Local and metropolitan area networks, Air Interface for Fixed and Mobile Broadband Wireless Access Systems, Amendment 2:Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands," February 2006.

[4] G.J. Foschini, "Layered space-time architecture for wireless communication in a fading environment when using multiple antennas," *Bell Labs Technical Journal*, Vol. 1, No. 2, pp. 41-59, 1996.