Performance Analysis of Iterative Detection Scheme for the D-STTD System

Gil-Sang Yoon, Jeong-Hwan Lee, In-Sik Cho, Chang-Woo Seo, Sang-Jin Ryoo, Cheol-Woo You and In-Tae Hwang, *Member, KIMICS*

Abstract**—**This paper combines various detection techniques and analyzes their performances in detecting the transmission information of the D-STTD scheme that uses, in parallel, the STTD scheme known as the Alamouti code. The D-STTD scheme adopts one of the STTD schemes for transmission to acquire diverse effects and uses another form of STTD for multiplexing effects. Due to the multiplexing effect that transmits different data, it is difficult to apply D-STTD to the conventional STTD combining technique. This paper combines the D-STTD system with linear algorithm, SIC algorithm and OSIC algorithm known as multiplexing detection scheme based on MMSE scheme. And we propose the detection scheme of the D-STTD using MAP algorithm and analyze the performance of each system. The simulation results showed that the detector using iterative algorithm has better performance than Linear MMSE Detector. Especially, we can show that the detector using MAP algorithm outperforms conventional detector.

Index Terms— Iterative Detection, D-STTD, MMSE, MAP,

I. INTRODUCTION

The latest mobile communication technology is developing very fast. But these mobile communications go through fading, inter-channel interference, inter-symbol interference, and the other types of noises according to the conditions of the wireless transmission. Because of those problems mobile communication has low throughput and reliability. As it's been known well in the wireless communication for the past few years, with the use of multiple antennas we could solve above problems to some degree.

Multiple antenna technology can be divided into two: diversity scheme and multiplexing scheme. For the first one, diversity scheme is the method that gains data reliability sending the same data in each transmission antenna. There are many diversity schemes but in this paper we consider the Space Time Transmit Diversity (STTD) scheme known as the Alamouti code which acquires diversity gains by sending the data independently and repeatedly [1].

For the second one, multiplexing scheme is the method that gains enhanced data throughput by sending different data in each transmit antenna. As a result, this scheme has enhanced data throughput with the increase of the number of antennas. This ultimate use of multiple antennas has been known since the Bell Labs Layered Space Time (BLAST) was introduced by Foschini [2].

The Double-Space Time Transmit Diversity (D-STTD) that is trying to get both effects in the diversity scheme and multiplexing scheme was suggested by Texas Instruments Corporation. The D-STTD scheme connects, in parallel, the STTD scheme. Its basic structure consists of 4 transmit antennas. It binds 2 transmit antennas together using one the STTD encoder so it has two STTD encoders [3]. This parallel structure which has itself diversity effect acquires multiplexing effect with the existence of two antennas.

However this D-STTD scheme which has stable throughput has a shortcoming in detecting signals in receiver because when it is implemented, data that are transmitted by different encoder have different property. The Combining scheme which is applied to the STTD scheme has a difficulty because of signals that come from different encoders, while Maximum Likelihood (ML) scheme has a problem of complexity.

In this paper, we will cover the property of channel matrix of the D-STTD scheme and on the base of MMSE detection technique, we will analyze the performance of each algorithm combined with the D-STTD scheme. First we will consider linear MMSE detector, Successive Interference Cancellation (SIC)-MMSE Detector, and Ordered Successive Interference Cancellation (OSIC)-MMSE Detector. And later we'll consider the case we want to suggest at which Maximum A Posteriori (MAP) algorithm is applied.

Manuscript received March 16, 2009 ; Revised May 11, 2009. Corresponding Author : Sang-Jin Ryoo is with the Dept. of Computer Media, Hanyeong College, Yeosu, 550-704, Korea(Tel : +82-61-650-4229, Email : sjryoo@empal.com, sjryoo@hanyeong.ac.kr)

II. D-STTD SYSTEM MODEL

This paper considers basic D-STTD system that uses 4 transmit antennas and receive antennas as given Fig. 1. The D-STTD system connects STTD systems in parallel. We suppose that channel is constant during one symbol period on the basis of Flat Rayleigh Fading. The received signals are written as

$$\mathbf{y} = \mathbf{Hs} + \mathbf{n} \tag{1}$$

$$\begin{bmatrix} \mathbf{y}_1(n) \\ \mathbf{y}_2(n) \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & h_{13} & h_{14} \\ h_{12}^* & -h_{11}^* & h_{14}^* & -h_{13}^* \\ h_{21} & h_{22} & h_{23} & h_{24} \\ h_{22}^* & -h_{21}^* & h_{24}^* & -h_{23}^* \end{bmatrix} \begin{bmatrix} \mathbf{s}_1(n) \\ \mathbf{s}_2(n) \end{bmatrix} + \begin{bmatrix} \mathbf{n}_1(n) \\ \mathbf{n}_2(n) \end{bmatrix} \tag{2}$$

H is complex channel matrix, h_{ij} is the response between j-th transmit antenna and i-th receive antenna. Each channel response is independent and identically distributed (i.i.d.) and its mean is zero following complex Gaussian distribution. **s** is a 4×1 transmitted vector and s1 and s2 are symbols that come from each STTD encoder. **n** is a 4×1 noise vector, which is Additive White Gaussian Noise (AWGN) with E[**n**]=0 and $E[\mathbf{nn}^H]=\sigma^2\mathbf{I}$. **y** is a 4×1 received vector during one symbol period [4]. Other signals from different STTD encoder which act like noises are added to **y**.

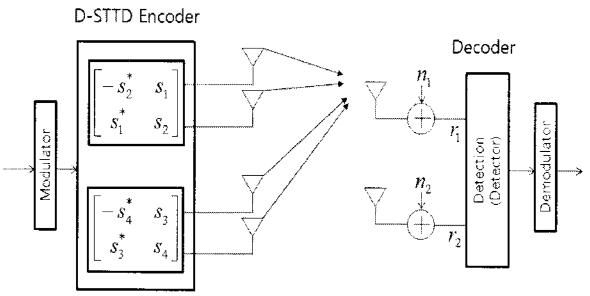

Fig. 1 D-STTD System model.

III. SEVERAL DETECTION SCHEMES WITH DIFFERENT CONVENTIONAL ALGORITHM

A. Linear MMSE Detector

MMSE is an algorithm that minimizes the error between transmitted and estimated vectors [5]. The result of Linear MMSE Detector where only MMSE characteristic matrix is applied is denoted by

$$\hat{\mathbf{s}} = Q(\hat{\mathbf{y}}_{MMSE}) \tag{3}$$

$$\hat{\mathbf{y}}_{MMSE} = \mathbf{Wy} \tag{4}$$

$$\mathbf{W} = \arg\min_{\mathbf{W}} \varepsilon\{ \|\mathbf{Wy} - \mathbf{s}\|^2 \} \tag{5}$$

And nulling vector W can be easily modeled by matrix H and be described as

$$\mathbf{W} = \mathbf{H}^H \left(\mathbf{H}^H \mathbf{H} + \frac{M_T}{\rho} \mathbf{I}_{M_T} \right) \tag{6}$$

Unlike linear ZF, a detector that adopts Linear MMSE cannot make an identity matrix with a multiplication of the nulling vector W and the channel vector. That means it cannot perfectly eliminate inter-channel interference. But Linear MMSE Detector can reduce noise power and get better performance while Linear ZF Detector has a less performance due to the increase of noise power.

Until now we have considered Linear MMSE Detector with linear property. For the next one let's take iterative algorithm SIC-MMSE, OSIC-MMSE into consideration.

B. SIC-MMSE Detector

The main point of SIC algorithm depends on the ability to separate data from each transmit antenna. While Linear MMSE Detector simultaneously and linearly detect transmitted data regardless of each layer, SIC algorithm first detect the data from the first antenna and the detected data are removed from the received data after that it detects the next antenna's data until the entire transmitted data are detected. These processes are performed iteratively. SIC algorithm can be simply written as

$$\begin{aligned}
&\textit{initialization:} && \mathbf{W}_1 = \mathbf{W}_{MMSE} \\
& && i = 1 \\
&\textit{recursion:} && \hat{y}_i = (\mathbf{W}_i)_i \mathbf{y}_i \\
& && \hat{s}_i = Q(\hat{y}_i) \\
& && \mathbf{y}_{i+1} = \mathbf{y}_i - \hat{s}_i (\mathbf{H})_i \\
& && \mathbf{W}_{i+1} = \mathbf{W}_{-i} \\
& && i = i + 1
\end{aligned} \tag{7}$$

Where, $(\mathbf{W}_i)_i$ is ith row vector, $Q(\cdot)$ is quantization, $(\mathbf{H})_i$ is ith column vector, and $\mathbf{W}_{-i}$ is the nulling vector after inserting zero into ith column vector of (i-1)-th channel matrix [6][7].

With introduction of iterative detective SIC algorithm we could expect better performance through the process of nulling and canceling. But in the case that the first detected data is not an error but correct data, it can go on without error propagation.

In addition, we consider OSIC algorithm that shows better performance in the aspect of error propagation.

C. OSIC-MMSE Detector

OSIC algorithm which is used in the V-BLAST (Vertical-Bell Labs Layered Space Time) receiver has the similar basic structure with SIC algorithm. But it is different from SIC algorithm. OSIC algorithm has ordering process while SIC algorithm has no that process. The ordering is determined in the order of Signal to Interference plus Noise Ratio (SINR): the highest one comes first. OSIC algorithm can be simply written as

initialization:

$$\mathbf{W}_1 = \mathbf{W}_{MMSE}$$
$$i = 1$$

recursion:

$$\begin{aligned} k_i &= \arg\min_{j \notin \{k_1 \cdots k_{i-1}\}} \left\| (\mathbf{W}_i)_j \right\|^2 \\ \hat{y}_{k_i} &= (\mathbf{W}_i)_{k_i} \mathbf{y}_i \\ \hat{s}_{k_i} &= Q(\hat{y}_{k_i}) \\ \mathbf{y}_{i+1} &= \mathbf{y}_i - \hat{s}_{k_i} (\mathbf{H})_{k_i} \\ \mathbf{W}_{i+1} &= \mathbf{W}_{-k_i} \\ i &= i+1 \end{aligned} \tag{8}$$

Where, $(\mathbf{W}_i)_{k_i}$ is k_ith row vector, $Q(\cdot)$ is quantization, $(\mathbf{H})_{k_i}$ is k_ith column, and $\mathbf{W}_{-k_i}$ is the nulling vector after inserting zero into k_i-th column vector of k_{i-1}-th channel matrix [6][7].

In the SIC algorithm, the first detected data has a high probability of being detected as an error if the channel has a low SINR. This causes less error performance. On the other hand, OSIC algorithm considers the channel SINR and has a less probability of error propagation as a result it has better performance.

IV. DETECTION SCHEME WITH MAP ALGORITHM

MAP algorithm is one of the optimal criterions that reduce error probability to the minimum in the statistical decision theory [8]. And the decision rule of MAP algorithm can be written as

$$P(s_2 \mid z) \underset{H_2}{\overset{H_1}{\gtrless}} P(s_2 \mid z) \tag{9}$$

Eq. (9) is the detection criterion to tell if z is s_1 or s_2 out of transmitting signal set s to detect received signal comparing a posteriori probability $P(s_1|z)$ with $P(s_2|z)$. MAP Detector with MAP algorithm which minimizes error probability has a similar entire structure and property with OSIC algorithm in the respect of using ordering and canceling process. But MAP Detector is a scheme to reduce error propagation introducing MAP algorithm in the ordering process. In the case of OSIC, the detection sequence depends on the channel's SINR while MAP algorithm detects received data in the order of a posteriori probability. There's no difference between OSIC and MAP but the way of ordering. After applying MAP algorithm, the additional equation can be described as

$$\begin{aligned} P(s_i \mid z) &= \frac{p(z \mid s_i) P(s_i)}{p(z)} \qquad i = 1, \ldots, M, \\ p(z) &= \sum_{i=1}^{M} p(z \mid s_i) P(s_i) \end{aligned} \tag{10}$$

Where, $P(z|s_i)$ is the conditional pdf of the received sample z, conditional on the signal set s_i.

OSIC determines detection order only considering channel state but MAP Detector uses not only channel state but the posteriori probability of received signal set. As a result it has an effect of reducing error propagation more. Of course because of the process of operation for the entire transmitted signal set, it has an increase of complexity.

V. SIMULATION RESULTS

In this chapter, we will analyze the performance through the simulation results of each detection scheme mentioned in chapter III and IV in the D-STTD system channel. The standard D-STTD system is performed in the D-STTD conditions suggested in chapter II. And the simulation results will be analyzed in the respect of SER vs SNR.

Fig. 2 shows the performance of Linear MMSE Detector, SIC-MMSE Detector and OSIC-MMSE Detector. Through Fig. 2 we will compare and analyze several detectors with different conventional algorithm. First comparing the result of Linear MMSE Detector with SIC-MMSE Detector, SIC-MMSE Detector shows better performance about 0.7dB over all. This can be interpreted as an effect of reducing inter-channel interference after SIC algorithm is applied. However, since the result of first detected data is not always correct, it has only 0.7dB enhancement.

And OSIC-MMSE Detector with OSIC algorithm shows better performance by ordering according to SINR. From 0dB to about 4dB period it shows less than 0.5dB performance gap and from 16dB to 20dB period it shows about 3dB performance gap. This result shows it has the almost same performance in the low SNR but it has bigger performance gap as SNR increases. This is because in the process of ordering if the channel condition is bad, the probability of correct detection becomes lower. In the case of good channel condition, however, contrastively through the ordering process the difference between SIC-MMSE Detector and OSIC-MMSE Detector becomes bigger.

For the next, Fig. 3 shows the performance of Linear MMSE Detector, SIC-MMSE Detector, OSIC-MMSE Detector and MAP-MMSE Detector. Through Fig. 3 we will compare several detectors with different conventional algorithm to MAP-MMSE Detector with MAP algorithm.

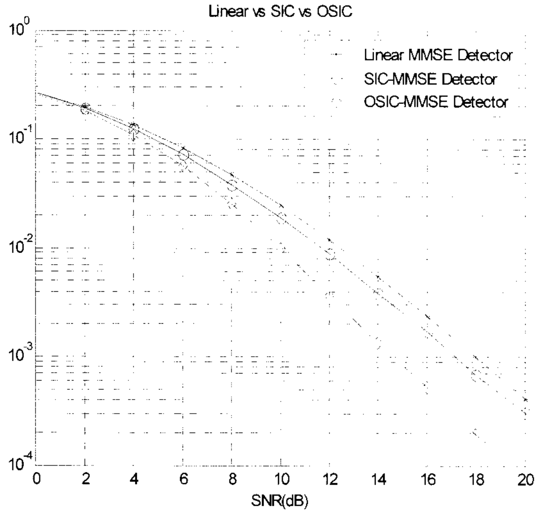

Fig. 2 The Performance of Linear MMSE Detector, SIC-MMSE Detector and OSIC-MMSE Detector.

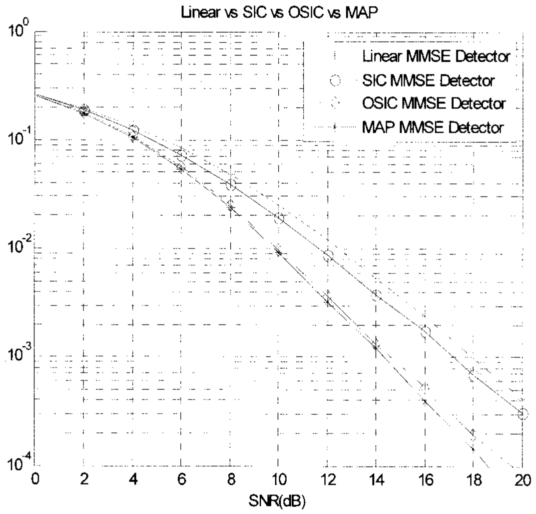

Fig. 3 The Performance of MAP-MMSE Detector and the detector applied conventional algorithm.

MAP-MMSE Detector shows less than 0.5dB performance gap from 0dB to 4dB, from 16dB to 20dB shows 0.7dB gap with OSIC-MMSE Detector. This is because MAP algorithm reduced the error probability than OSIC algorithm which determines detection order only by channel condition. Moreover it shows 3.7dB performance gap than SIC-MMSE Detector and 4.4dB than Linear MMSE Detector.

Finally, SIC-MMSE with iterative algorithm shows better performance than linear MMSE. OSIC-MMSE with ordering process shows much better performance. Applying MAP algorithm which minimizes the probability of detecting wrong, MAP-MMSE Detector could reduce error propagation, as a result, it has better performance about 4.4dB than Linear MMSE Detector.

VI. CONCLUSIONS

We have considered the detector scheme of the D-STTD system which consists of, in parallel, the STTD system known as the Alamouti code. The combining scheme which was detection scheme of the STTD system has a difficulty using it because of effect of multiplexing in the D-STTD system. This paper has covered the combination of Linear MMSE Detector, SIC-MMSE Detector and OSIC-MMSE Detector and analyzed their results. In addition, we newly suggested MAP-MMSE Detector with MAP algorithm and analyzed its result.

In conclusion, the case which iterative algorithm applied to has better performance than the case of linear algorithm. Among them MAP-MMSE Detection with MAP algorithm which we want to suggest in this paper showed the best performance.

ACKNOWLEDGMENT

This work was supported by the Korea Research Foundation Grant funded by the Korean Government (MOEHRD, Basic Research Promotion Fund) (KRF-2008-331-D00374).

REFERENCES

[1] S. M. Alamouti, "A simple transmit diversity technique for wireless communications," IEEE J. Select. Areas Commun., vol. 48, pp. 1451-1458, Oct. 1998.

[2] G. J. Foschini, "Layered space-time architecture for wireless communication in a fading environment when using multiple antennas," Bell Labs Tech. J., vol 1, pp. 41-59 Autumn 1996.

[3] Texas Instruments, "Double-STTD scheme for HSDPA systems with four transmit antennas:

Link Level Simulation Results," proposed TSGR1#20(01)-0458, May. 2001.
[4] Sooyoung Hur, Jongsub Cha and Joonhyuk Kang, "Fano-based iterative sequential detection algorithm for Double-STTD system," PIMRC'06, Set. 2006.
[5] James R. Schott, "*Matrix Analysis for Satatistics*," Wiley Interscience Publication, 1997.
[6] G. D. Golden, C. J. Foschini, R. A. Valenzuela and P. W. Wolniansky, "Detection algorithm and initial laboratory results using V-BLAST space-time communication architecture," Electronics Letters. vol. 35, pp. 14-15, Jan. 1999.
[7] A. Paulraj, R. Nabar, and D. Gore, "Introduction to Space-Time Wireless Communications," Cambridge, 2003.
[8] Bernard Sklar, "*Digital Communications*," Prentice-Hall, 2001.

Gil-Sang Yoon received the B.S. degree in Electronics & Computer Engineering from Chonnam National University, Gwangju, Korea in 2008. He is currently in Chonnam National University, Gwangju, Korea doing his master's program in the School of Electronics & Computer Engineering. His current research activities are in wireless communication for next generation, physical layer software for mobile terminal, efficient algorithms for MIMO and MIMO-OFDM.

Jeong-Hwan Lee received the B.S. degree from School of Electronics and Computer Engineering at Chonnam National University, Gwangju, Korea in 2008. Since Mar. 2008, he has been M.S. student in Information and Telecommunication Research Lab, Chonnam National University, Gwangju, Korea. His research interests are the area of wireless communication system design, efficient algorithms for AMC and MIMO system.

In-Sik Cho received the B.S. degree from School of Electronics and Computer Engineering at Chonnam National University, Gwangju, South Korea in 2009. Since Mar. 2009, he has been M.S. student in Information and Telecommunication Research Lab, Chonnam National University, Gwangju, South Korea. His areas of interest are wireless communication for next generation, efficient algorithms for AMC, MIMO system, OFDM scheme, and antenna selection.

Chang-Woo Seo received the B.S. degree in Information Technology and Communications Engineering from Sangmyung University, Cheonan, Korea in 2009. He is currently in Chonnam National University, Gwangju, Korea doing his master's program in the School of Electronics & Computer Engineering. His current research activities are in wireless communication for next generation, physical layer software for mobile terminal, efficient algorithms for MIMO-OFDM.

Sang-Jin Ryoo received the B.S., M.S., and Ph.D. degrees in electronics engineering from Chonnam University, Kwangju, Korea, in 1991, 1994, and 2007, respectively. Since March 1994, he has been with the Department of Computer Media, Hanyeong College, Yeosu, Jeonnam, Korea. This author became a Member of IEICE in 2007. He is currently interested in mobile communication, channel coding, AMC, MIMO, and MIMO-OFDM systems.

Cheol-Woo You received the B.S., M.S., and Ph.D. degrees in electronics engineering from Yonsei University, Seoul, Korea, in 1993, 1995, and 1999, respectively. From Jan. 1999 to April 2003, he worked as a Senior Research Engineer with the LG Electronics, Gyeonggi, Korea. During 2003-2004, he was a Senior Research Engineer at the EoNex, Songnam, Korea. From August 2004 to July 2006, he was with the Samsung Electronics, Suwon, Korea. Since September 2006, he has been with the Department of Communications Engineering, Myongji University, Gyeonggi, Korea. He is currently interested in new Multiple Access schemes, Adaptive Resource Allocation, AMC, MIMO systems, advanced FEC, and Relay schemes for 4G communication systems.

In-Tae Hwang received the B.S. degree in Electronics Engineering from Chonnam National University, Gwangju, Korea in 1990 and the M.S. degree in Electronics Engineering from Yonsei University, Seoul, Korea in 1992, respectively and the Ph.D. degree in Electrical & Electronics Engineering from Yonsei University, Seoul, Korea in 2004. He had been as a senior engineer at LG Electronics from 1992 to 2005. He is currently in Chonnam National University, Gwangju, Korea from 2006 as a Professor in the School of Electronics & Computer Engineering. His current research activities are in digital & wireless communication systems, mobile terminal system for next generation, physical layer software for mobile terminal, efficient algorithms for AMC, MIMO, MIMO-OFDM and ICIM, and Relaying scheme for wireless communication.

[4] (Journal Online Sources style) K. Author. (year, month). Title. *Journal* [Type of medium]. Volume (issue), paging if given. Available: http://www.(URL)
[5] R. J. Vidmar. (1992, August). On the use of atmospheric plasmas as electromagnetic reflectors. *IEEE Trans. Plasma Sci.* [Online]. *21(3)*. pp. 876–880. Available: http://www.halcyon.com/pub/journals/21ps03-vidmar

2.5cm x 3cm

First A. Author (M'76–SM'81–F'87) and the other authors may include biographies at the end of regular papers. Biographies are often not included in conference-related papers. This author became a Member (M) of IEEE in 1976, a Senior Member (SM) in 1981, and a Fellow (F) in 1987. The first paragraph may contain a place and/or date of birth (list place, then date). Next, the author's educational background is listed. The degrees should be listed with type of degree in what field, which institution, city, state or country, and year degree was earned. The author's major field of study should be lower-cased.