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V-BLAST Detection Ordering Method with H-ARQ

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Abstract—**This paper proposes a detection ordering method for vertical Bell Labs layered space-time (V-BLAST) systems with multiple hybrid automatic repeat request (H-ARQ) processes. The proposed method uses the H-ARQ combining gain at each recursion stage of V-BLAST for deciding V-BLAST detection ordering. Using the proposed method, we can fully exploit the H-ARQ combining gain. Simulation results show that the proposed method improves bit error rate (BER) and throughput performance.**

I. INTRODUCTION

In wireless communication systems, multiple-input multiple-output (MIMO) techniques provide substantial improvement of channel capacity by exploiting the spatial domain. To achieve spatial multiplexing (SM) in MIMO environments, the vertical Bell Labs layered space-time (V-BLAST) architecture transmits each data stream on each transmit antenna independently, and detects transmitted symbols for each data stream using the ordered successive interference cancellation (OSIC) algorithm [1], [2].

On the other hand, hybrid automatic repeat request (H-ARQ) are used for improving reliability of links in communication systems. H-ARQ incorporates ARQ mechanisms and forward error correction. Two types of H-ARQ are exist: Chase combining and incremental redundancy. Complexity and efficiency are the trade-off between two types.

Some studies are proposed to exploit MIMO channels with H-ARQ. In [3], Onggosanusi et al. compared performance of two H-ARQ combining schemes, pre-combining and post-combining in V-BLAST systems. Numerical results show that pre-combining is better than post-combining. Zheng et al. proposed SM MIMO systems with multiple H-ARQ processes, referred to as MIMO multiple ARQ (MMARQ) [4]. MMARQ prevents wasteful retransmissions because each H-ARQ process retransmits packets independently. Consequently, MMARQ improves throughput. However, the H-ARQ combining gain can not be fully exploited in MMARQ. Since MMARQ decides detection ordering using only the current channel gain, the H-ARQ combining gain is ignored in detection ordering decision.

This paper proposes a V-BLAST detection ordering method with multiple H-ARQ processes. At each recursion stage of V-BLAST, we use the H-ARQ combining gain for deciding detection ordering. Signal-to-noise ratio (SNR) and log-likelihood ratio (LLR) are used as decision metrics.

The rest of the paper is organized as follows. The system model is presented in section II. We propose a V-BLAST detection ordering method with H-ARQ in section III. Simulation results are shown in section IV followed by the conclusion in section V.

II. SYSTEM MODEL

We consider V-BLAST MIMO systems with N_t transmit antennas and N_r receive antennas, where $N_t \leq N_r$. We have the input-output model shown as

$$\mathbf{r} = \mathbf{H}\mathbf{x} + \mathbf{n} \tag{1}$$

where $\mathbf{H} = [\mathbf{h}_1 \, \mathbf{h}_2 \ldots \mathbf{h}_{N_t}]$ is the $N_r \times N_t$ MIMO channel matrix, and $\mathbf{h}_i = [h_{i1}, h_{i2}, \ldots, h_{iN_r}]^T$. The transmitted symbol vector $\mathbf{x} = [x_1, x_2, ..., x_{N_t}]^T$, the received symbol vector $\mathbf{r} = [r_1, r_2, ..., r_{N_r}]^T$, and the independent identically distributed (i.i.d.) complex Gaussian noise vector $\mathbf{n} = [n_1, n_2, ..., n_{N_r}]^T$ with zero mean and the covariance matrix $N_0 \mathbf{I}_{N_r}$.

At the V-BLAST receiver, linear detection methods such as minimum mean-square error (MMSE) or zero-forcing (ZF) are used to compute the nulling vector $\mathbf{w_i}$. We use ZF criterion for simplicity. Let

$$\mathbf{W} = \mathbf{H}^{\dagger} = (\mathbf{H}^H \mathbf{H})^{-1} \mathbf{H}^H = [\mathbf{w}_1 \; \mathbf{w}_2 \; ... \; \mathbf{w}_{N_t}]^T \tag{2}$$

where $\mathbf{H}^{\dagger}$ is a pseudoinverse matrix of $\mathbf{H}$, and $\mathbf{w}_i$ is a $N_r \times 1$ nulling vector. Then

$$y_i = (\mathbf{w}_i)^T \mathbf{r} = x_i + (\mathbf{w}_i)^T \mathbf{n}, \qquad i = 1, 2, ..., N_t \tag{3}$$

where y_i is a decision statistic for the symbol transmitted through the i-th transmit antenna. Therefore, SNR for x_i is

$$SNR_i = \frac{|x_i|^2}{E[\|(\mathbf{w}_i)^T \mathbf{n}\|^2]} = \frac{E_s}{\|\mathbf{w}_i\|^2 N_0}. \tag{4}$$

If we assume the modulation scheme with equi-energy symbols such as QPSK, it is proved that selecting x_i with the smallest $\|\mathbf{w}_i\|^2$ at each stage in SIC is globally optimum ordering [2]. The full ZF V-BLAST detection algorithm is described as follows:

- **Initialization** (5)

$$k = 0$$
$$\mathbf{r}^{(0)} = \mathbf{r}$$
$$\mathbf{W}^{(0)} = \mathbf{W} = \mathbf{H}^{\dagger}$$
$$i_0 = \arg\min_i \left\|\mathbf{w}_i^{(0)}\right\|^2$$

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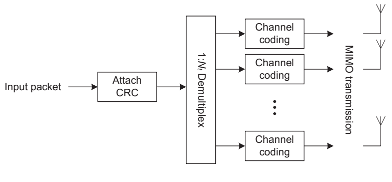
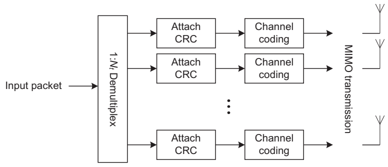


(a) MSARQ



(b) MMARQ

Fig. 1. Transmitter structures of MSARQ and MMARQ

- **Recursion** (6)

$$\begin{aligned} y_{i_k} &= \left(\mathbf{w}_{i_k}^{(k)}\right)^T \mathbf{r}^{(k)} \\ \hat{x}_{i_k} &= Q(y_{i_k}) \\ \mathbf{r}^{(k+1)} &= \mathbf{r}^{(k)} - \hat{x}_{i_k}\mathbf{h}_{i_k} \\ \mathbf{W}^{(k+1)} &= \left(\mathbf{H}_{\overline{i_k}}\right)^{\dagger} \\ i_{k+1} &= \arg\min\nolimits_{i\notin\{i_0,\ldots,i_k\}} \left\|\mathbf{w}_i^{(k+1)}\right\|^2 \\ k &= k+1 \end{aligned}$$

where $\mathbf{w}_i^{(k)}$ is transpose of the i-th row vector of $\mathbf{W}^{(k)}$, $\{i_1, i_2, \ldots, i_{N_t}\}$ is the ordering index, $Q(\cdot)$ denotes the quantization (slicing) operation appropriate to the constellation in use, and $\mathbf{H}_{\overline{i_k}}$ denotes the matrix obtained by zeroing columns $i_1, i_2, \ldots, i_k$ of $\mathbf{H}$.

This paper considers the MIMO system with multiple H-ARQ processes in [4]. In constrast to MIMO single ARQ (MSARQ), each H-ARQ process transmits and retransmits independently. Transmitter structures of MSARQ and MMARQ are shown in Figure 1. MMARQ uses H-ARQ symbol combining for detection and interference cancellation. However, since MMARQ decides detection ordering without considering the H-ARQ, the H-ARQ combining gain cannot be fully exploited.

III. V-BLAST DETECTION ORDERING WITH H-ARQ

In this section, we propose a V-BLAST detection ordering method with multiple H-ARQ processes. Assuming slow fading environments, we use only equal-gain combining.

A. SNR-based detection ordering with H-ARQ

The decision statistics during $L+1$ transmissions can be written as

$$\begin{aligned} \left(\mathbf{w}_i^{(\alpha_{i,0})}\right)^T \mathbf{r}^{(\alpha_{i,0})} &= x_{i,0} + \left(\mathbf{w}_i^{(\alpha_{i,0})}\right)^T \mathbf{n}_0 \\ \left(\mathbf{w}_i^{(\alpha_{i,1})}\right)^T \mathbf{r}^{(\alpha_{i,1})} &= x_{i,1} + \left(\mathbf{w}_i^{(\alpha_{i,1})}\right)^T \mathbf{n}_1 \\ &\vdots \\ \left(\mathbf{w}_i^{(\alpha_{i,L})}\right)^T \mathbf{r}^{(\alpha_{i,L})} &= x_{i,L} + \left(\mathbf{w}_i^{(\alpha_{i,L})}\right)^T \mathbf{n}_L \end{aligned} \tag{7}$$

where $x_{i,l}$ is the symbol transmitted by the i-th H-ARQ process at time l, $\alpha_{i,l}$ is the index of the recursion stage in which $x_{i,l}$ is detected, and $l = 0, 1, \ldots, L$. If we assume the H-ARQ operation with one transmission and L retransmissions, $x_i = x_{i,0} = x_{i,1} = \ldots = x_{i,L}$, then

$$\sum_{j=0}^{L} \left(\mathbf{w}_i^{(\alpha_{i,j})}\right)^T \mathbf{r}^{(\alpha_{i,j})} = (L+1)x_i + \sum_{j=0}^{L} \left(\mathbf{w}_i^{(\alpha_{i,j})}\right)^T \mathbf{n}_j. \tag{8}$$

From (8), SNR for x_i is expressed as

$$\begin{aligned} SNR_i{}' &= \frac{\left|(L+1)x_i\right|^2}{E\left[\left\|\sum_{j=0}^{L}\left(\mathbf{w}_i^{(\alpha_{i,j})}\right)^T \mathbf{n}_j\right\|^2\right]} \\ &= \frac{(L+1)^2 \cdot E_s}{\sum_{j=0}^{L}\left\|\mathbf{w}_i^{(\alpha_{i,j})}\right\|^2 N_0}. \end{aligned} \tag{9}$$

Letting L_i be the number of retransmission for the i-th H-ARQ process. We use the H-ARQ combining gain in each H-ARQ process for deciding detection ordering, by modifying the selection criterion in each recursion stage (6) as

$$selected\ index = \arg\min_{i\notin P} \frac{1}{(L_i+1)^2} \sum_{j=0}^{L_i} \left\|\mathbf{w}_i^{(\alpha_{i,j})}\right\|^2 \tag{10}$$

where P is the selected index set in previous recursion stages.

B. LLR-based detection ordering with H-ARQ

In [5], V-BLAST detection ordering based on LLR is proposed. For M-ary signals such that $s_m \in S = \{s_1, \ldots, s_M\}$ and $\sum_{m=1}^{M} P(x_i = s_m|\mathbf{w}_i^T\mathbf{r}) = 1$, LLR is

$$\Lambda_{i,m} = \ln\frac{P(x_i = \hat{x}_i|\mathbf{w}_i^T\mathbf{r})}{P(x_i = s_m|\mathbf{w}_i^T\mathbf{r})}. \tag{11}$$

When we assume transmit symbols with equal probability, LLR is represented as

$$\Lambda_{i,m} = \ln\frac{P(\mathbf{w}_i^T\mathbf{r}|x_i = \hat{x}_i)}{P(\mathbf{w}_i^T\mathbf{r}|x_i = s_m)} \tag{12}$$

where

$$P(\mathbf{w}_i^T\mathbf{r}|x_i = s_m) = \frac{1}{\pi\|\mathbf{w}_i\|^2 N_0} e^{-|\mathbf{w}_i^T\mathbf{r} - s_m|^2/(\|\mathbf{w}_i\|^2 N_0)}. \tag{13}$$

Therefore, we have

$$\Lambda_{i,m} = (|\mathbf{w}_i^T\mathbf{r} - s_m|^2 - |\mathbf{w}_i^T\mathbf{r} - \hat{x}_i|^2)/(\|\mathbf{w}_i\|^2 N_0). \tag{14}$$

To exploit the H-ARQ combining gain, we modify LLR using the combining gain in (8), expressed by

$$\begin{aligned} \Lambda_{i,m}' = \; & (\left|\frac{1}{L_i+1}\sum_{j=0}^{L_i}\left(\mathbf{w}_i^{(\alpha_{i,j})}\right)^T \mathbf{r}^{(\alpha_{i,j})} - s_m\right|^2 - \\ & \left|\frac{1}{L_i+1}\sum_{j=0}^{L_i}\left(\mathbf{w}_i^{(\alpha_{i,j})}\right)^T \mathbf{r}^{(\alpha_{i,j})} - \hat{x}_i\right|^2)/ \\ & \frac{N_0}{(L_i+1)^2}\sum_{j=0}^{L_i}\left\|\mathbf{w}_i^{(\alpha_{i,j})}\right\|^2. \end{aligned} \tag{15}$$

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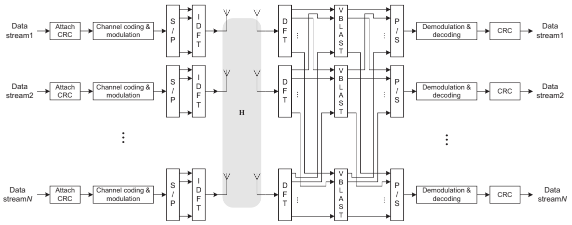

Fig. 2. The V-BLAST MIMO system in OFDM

Thus, the proposed method uses the selection criterion as

$$selected\ index = \arg\max_{i \notin P} \Lambda_{i,m}^{'}. \tag{16}$$

To reduce complexity, we can consider envelope-based LLR [5] by using LLR represented as

$$\Lambda_{i,m}^{''} = \frac{2(L_i+1)\left|\sum_{j=0}^{L_i} \left(\mathbf{w}_i^{(\alpha_{i,j})}\right)^T \mathbf{r}^{(\alpha_{i,j})}\right| d_{min}}{N_0 \sum_{j=0}^{L_i} \left\|\mathbf{w}_i^{(\alpha_{i,j})}\right\|^2} \tag{17}$$

where d_{min} is the minimum Euclidean distance.

IV. SIMULATION RESULTS

In this section, we present simulation results to demonstrate performance of the proposed method. We assume the OFDM system with N_{sc} subcarriers. The channel bandwidth is 200KHz, the carrier frequency is 3.5GHz, the number of subcarriers is 64, and the Doppler frequency is 10Hz. We use the QPSK modulation scheme and rate 1/2 convolutional turbo code for error correction. Assuming the low Doppler frequency, we ignore intercarrier interference. Therefore N_{sc} independent V-BLAST MIMO systems in OFDM are considered as in Figure 2.

SM MIMO systems show the best performance in uncorrelated MIMO channels. However, spatial correlation appears in real channel environments due to antenna configuration and scatters between the transmit and receive antennas. Thus, we use the MIMO channel model formulated as

$$\mathbf{H} = \mathbf{R}_r^{\frac{1}{2}} \tilde{\mathbf{H}} \left(\mathbf{R}_t^{\frac{1}{2}}\right)^{\dagger} \tag{18}$$

where $\mathbf{R}_r = \mathbf{R}_r^{\frac{1}{2}}\left(\mathbf{R}_r^{\frac{1}{2}}\right)^{\dagger}$, $\mathbf{R}_t = \mathbf{R}_t^{\frac{1}{2}}\left(\mathbf{R}_t^{\frac{1}{2}}\right)^{\dagger}$, $\mathbf{R}_t$ is the transmit correlation matrix, $\mathbf{R}_r$ is the receive correlation matrix, and $\tilde{\mathbf{H}}$ is the generated stochastic independent multipath MIMO channel impulse response [6]. MIMO channel correlation parameters are shown in Table I, where D is the distance between antennas, λ is the wavelength, AoD is the angle of arrival, AoD is the angle of departure, and σ is the angle spread [7].

TABLE I
MIMO CHANNEL CORRELATION PARAMETERS

Parameter	*Value*
D	$\frac{\lambda}{2}$
AoD	0.346314033 -0.05257642 -1.817837659 -0.836999548
AoA	1.737577272 -1.55645 -1.049078459 0.345571431
σ_{tx}	20°
σ_{rx}	35°

TABLE II
DIFFERENCES BETWEEN THREE SCHEMES

	Detection with combined symbols	*Detection ordering using the combining gain*
Scheme 1	x	x
Scheme 2	o	x
Scheme 3 (proposed)	o	o

In our simulation, we compare performance of three schemes. In scheme 1, H-ARQ symbol combining is performed after detection and interference cancellation, which is similar to post-combining in [3]. Scheme 2 is the same as MMARQ in [4], which uses H-ARQ symbol combining only for detection and interference cancellation. Scheme 3 uses H-ARQ symbol combining for V-BLAST detection ordering as well as detection and interference cancellation. The differences between three schemes are shown in Table II. Performance metrics are bit error rate (BER) and throughput. Throughput is defined as

$$throughput = 1 - packet\ error\ rate\ (PER). \tag{19}$$

Figure 3 represents BER performance of three schemes with SNR-based detection ordering and LLR-based detection ordering in various MIMO channel environments. The proposed method shows better performance over the others. As the number of transmit and receive antennas increases, error propagation in SIC becomes important. Consequently, performance is more dependent on detection ordering algorithms in 4×4 MIMO channel than in 2×2 MIMO channel.

Figure 4 shows throughput performance of three schemes. The proposed method with SNR-based detection ordering achieves up to maximum 10% throughput improvement in 2×2 MIMO channel, 15% in 3×3 MIMO channel, and 20% in 4×4 MIMO channel over the others. The proposed method with LLR-based detection ordering achieves up to maximum 8% throughput improvement in 2×2 MIMO channel, 12% in 3×3 MIMO channel, and 15% in 4×4 MIMO channel. Throughput gain of the proposed method also becomes higher as the number of transmit and receive antennas increases. In addition, the schemes with LLR-based detection ordering show better performance than those with SNR-based detection ordering.

V. CONCLUSION

This paper proposes a V-BLAST detection ordering method using the H-ARQ combining gain with multiple H-ARQ processes. In each recursion stage of V-BLAST, we use the H-ARQ combining gain for detection ordering decision. SNR and LLR are used as decision metrics. Simulation results show

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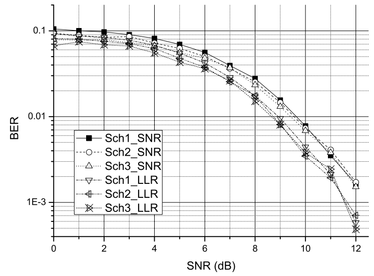
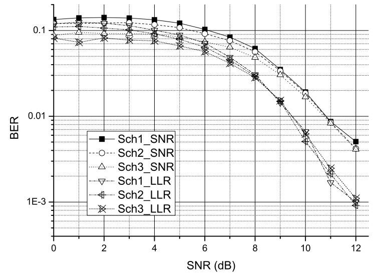
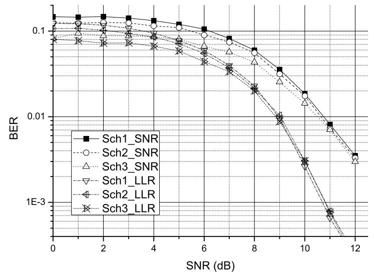


(a) 2 × 2 MIMO channel

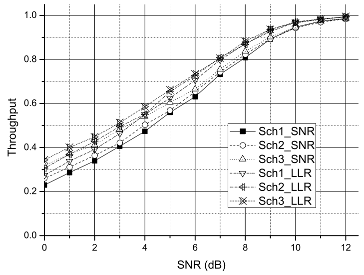


(b) 3 × 3 MIMO channel

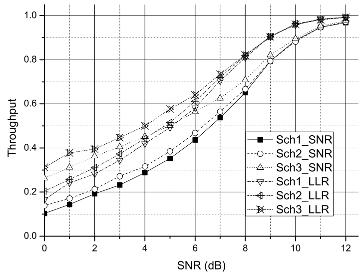


(c) 4 × 4 MIMO channel

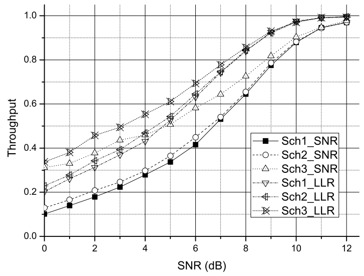
Fig. 3. BER of scheme 1, scheme 2, and scheme 3 with SNR-based detection ordering and LLR-based detection ordering in various MIMO channels



(a) 2 × 2 MIMO channel



(b) 3 × 3 MIMO channel



(c) 4 × 4 MIMO channel

Fig. 4. Throughput of scheme 1, scheme 2, and scheme 3 with SNR-based detection ordering and LLR-based detection ordering in various MIMO channels

that the proposed method improves performance over the other schemes. Especially, as the number of transmit and receive antennas increases, performance gain of the proposed method becomes higher.

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REFERENCES

[1] G. J. Foschini, “Layered space-time architecture for wireless communication in a fading environment when using multiple antennas,” *Bell Laboratories Technical Journal*, vol.1, Autumn 1996, pp. 41–59.

[2] P. W. Wolniansky, G. Foschini, G. Golden, and R. A. Valenzuela, “V-BLAST: an architecture for realizing very high data rates over the rich-scattering wireless channel,” *IEEE URSI International Symposium on Signals, Systems, and Electronics*, Sept. 1998, pp. 295–300.

[3] E. N. Onggosanusi, A. G. Dabak, Y. Hui, and G. Jeong, “Hybrid ARQ transmission and combining for MIMO systems,” *IEEE International Conference on Communications*, vol.5, May. 2003, pp. 3205–3209

[4] H. Zheng, A. Lozano, and M. Haleem, “Multiple ARQ processes for MIMO systems,” *IEEE International Symposium on Personal, Indoor and Mobile Radio Communications*, vol.3, Sept. 2002, pp. 1023–1026.

[5] S. W. Kim, “Log-likelihood ratio based detection ordering in V-BLAST,” *IEEE Transactions on Communications*, vol.54, Feb. 2006, pp. 302–307

[6] F. Shu, L. Lihua, and Z. Ping, “A general stochastic spatial MIMO channel model for evaluating various MIMO techniques,” *International Journal of Applied Science, Engineering and Technology*, vol.3, 2006, pp. 152–156

[7] Draft IEEE 802.16m Evaluation Methodology Document (IEEE C802.16m-07/080r1), Apr. 2007

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