ITC-CSCC 2010

The 25th International Technical Conference on Circuits/Systems, Computers and Communications

Program and Abstracts

July 4-7, 2010

Pattaya, Thailand

Information

Table Of Contents

Search This CD-ROM

CD-ROM Help

Exit

ECTI Association

사단법인 대한전자공학회
The Institute of Electronics Engineers of Korea

INTELLIGENT IMPLEMENTATION OF SCHNORR-EUCHNOR SPHERE DECODING FOR MIMO SYSTEMS

Junil Ahn, Donghun Lee, Heung-No Lee and Kiseon Kim

School of Information and Mechatronics (SIM)
Gwangju Institute of Science and Technology (GIST)
1 Oryong-dong, Buk-gu, Gwangju, 500-712, Republic of Korea

ABSTRACT

An intelligent implementation of Schnorr-Euchner sphere decoding (SESD) is presented in this paper. Proposed scheme prevents that invalid points are selected as candidate points during decoding. Simulations result shows the proposed scheme decreases complexity with keeping a maximum likelihood (ML) performance.

***Index Terms*—** MIMO systems, lattice decoding, sphere decoding, ML decoding.

1. INTRODUCTION

Sphere decoding (SD) has been researched to practically perform a maximum likelihood (ML) decoding for multiple-input multiple-output (MIMO) systems [1, 2]. The Schnorr-Euchner SD (SESD) [2, 3], the refinement version of SD in [1], is more promising technique due to its low complexity. Damen et al. in [2] proposed one implementation strategy for SESD. However, Damen's SESD sometimes computes the branch metric of invalid points; it brings redundant complexity. In this paper, we present the intelligent implementation of SESD by avoiding unnecessary operation to skip invalid point in the SE enumeration.

2. SYSTEM MODEL AND SCHNORR-EUCHNOR SPHERE DECODING

An equivalent real-valued MIMO linear model is described by

$$\mathbf{y} = \mathbf{H}\mathbf{x} + \mathbf{z} \tag{1}$$

where $\mathbf{y} \in \mathcal{R}^N$ is the vector of received signals, $\mathbf{x} \in \mathcal{A}^M$ is the vector of transmitted symbols which are selected from constellation set $\mathcal{A}$, $\mathcal{A} = \{2l - (L-1) | l = 0, 1, ..., L-1\}$ for L-PAM, $\mathbf{z}$ is the additive white Gaussian noise (AWGN) vector of which elements are independent and identically distributed (i.i.d.) with zero mean and variance $N_0/2$, and $\mathbf{H} \in \mathcal{R}^{\mathbf{N}\times\mathbf{M}}$ is a column full rank channel matrix whose elements are i.i.d. zero-mean Gaussian variables having 0.5 variance. We assume that $M = N$ for brevity.

In order to perform a ML decoding with much lower complexity than the exhaustive ML detection, the SD searches over only lattice points satisfying

$$\|\mathbf{R}(\hat{\mathbf{x}} - \mathbf{x})\|^2 \leq C^2 \tag{2}$$

where C is the constraint radius, $\hat{\mathbf{x}} = \mathbf{R}^{-1}\mathbf{Q}_1^T\mathbf{y} = \mathbf{H}^{\dagger}\mathbf{y}$ is the unconstrained least-squares (LS) solution, $\mathbf{H} = \mathbf{QR}$ from the QR decomposition of $\mathbf{H}$, $\mathbf{Q}$ and $\mathbf{R}$ is a unitary matrix and an upper triangular matrix with non-negative diagonal entries. Owing to the upper triangularity of $\mathbf{R}$, one can construct the search tree of depth M. Thus, (2) can be solved successively from depth 1 to M with a depth-first tree search manner. If the radius C is large enough to include the ML solution, the SD guarantees to provide the optimal ML performance.

The SESD leads to much faster shrinkage of search space than the conventional SD [1] by adopting the SE enumeration, which was proposed for an infinite lattice at first in [3]. The SE enumeration sorts the candidate symbols according to their branch metric in increasing manner. Hence, the path having shortest metric is searched with priority during the tree traversal; resulting in complexity reduction.

3. THE PROPOSED IMPLEMENTATION OF SESD

One of implementation methods for SESD was proposed by Damen in [2]. Damen's SESD (Algorithm II, Smart Implementation in [2]) was proposed by modifying the SE enumeration of [3] to be applicable for finite constellation set used in practical MIMO systems. It checks whether the current candidate point is valid, i.e., it is involved in $\mathcal{A}$ or not whenever visiting each depth k in the search tree. Since, however, this check operation is performed after computing the branch matric of the candidate point, there is probability that the metric computation of invalid point on $\mathcal{A}$ would be done; it causes redundant complexity.

In Damen's SESD, there are two kinds of cases that the branch metric of invalid point is computed: One happens when all possible valid points, i.e., the elements of $\mathcal{A}$, are

This work was supported by the International Joint R&D Program funded by the Ministry of Knowledge Economy (MKE, Korea).

not spanned yet, and the other occurs when all valid points are already explored. The first case is that the invalid point is chosen as the candidate point by ordering of a zig-zag manner for the SE enumeration, although the valid point is selected in next order, and the second case is that invalid point overflows, i.e., the invalid point becomes candidate until its path metric exceeds the constraint radius.

We propose the intelligent strategy for solving above two problem as follows: To avoid the first case, the proposed scheme performs valid test on $\mathcal{A}$ in the SE enumeration step, and if the invalid point is detected, the SE enumeration turns to next order before computing metric, and it continues until valid point is appeared. Also, in fact, the number of possible valid points is same with the size of constellation, *viz.*, L. Hence, we set the count parameter to prevent the overflowing of invalid points. As a result, using above solutions, the proposed SESD can remove unnecessary computations thoroughly and evaluates only valid point on $\mathcal{A}$. The proposed implementation for SESD is in TABLE 1 for completeness.

Table 1. The proposed implementation for SESD

Input:	Upper triangular matrix $\mathbf{R}$, Unconstrained LS solution $\hat{\mathbf{x}}$, Radius square C^2, Constellation $\mathcal{A}$, Constellation size L.
Output:	Solution vector $\mathbf{s}$
Definition:	$\lfloor\cdot\rceil$: Rounding to the nearest lattice point of its argument in $\mathcal{A}$. Δ : Distance between two closest lattice points in $\mathcal{A}$. $\mathrm{sign}(\cdot)$: Return $+1$ if its argument is positive, else return -1. T_k: Counting of enumeration at level k.
Step 1:	Set $k = M$, $\hat{x}_{k\|k+1} = \hat{x}_k$, $P_{k+1} = 0$.
Step 2:	Set $x_k = \lfloor \hat{x}_{k\|k+1} \rceil$ and $\Delta'_k = \mathrm{sign}\left(\hat{x}_{k\|k+1} - x_k\right)\Delta$, $T_k = 1$.
Step 3:	$B_k = r_{k,k}^2\left(\hat{x}_{k\|k+1} - x_k\right)^2$, $P_k = P_{k+1} + B_k$; **If** $P_k \leq C^2$, go to **Step 4**; **Else**, go to **Step 5**.
Step 4:	If $k = 1$, let $C^2 = P_k$, $\mathbf{s} = \mathbf{x}$, $k = k+1$ and go to **Step 6**; Else if k $\neq 1$, set $k = k-1$, $\hat{x}_{k\|k+1} = \hat{x}_k + \sum_{j=k+1}^{M} \frac{r_{k,j}}{r_{k,k}}(\hat{x}_j - x_j)$, and go to **Step 2**.
Step 5:	If $k = M$, terminate algorithm; Else, let $k = k+1$ and go to **Step 6**.
Step 6:	**(SE enumeration)** If $T_k = L$, go to **Step 5**; Else while $(x_k \in \mathcal{A})\{$ $x_k = x_k + \Delta'_k$, $\Delta'_k = -\Delta'_k - \mathrm{sign}(\Delta'_k)\Delta\}$; Let $T_k = T_k + 1$, then go to **Step 3**.

4. SIMULATION RESULTS

We present simulation results to compare computational complexity of the proposed SESD with that of Damen's SESD. The complexity is measured by average computation time using MATLAB. The initial radius C is set to infinity in both schemes to guarantee the optimal ML performance.

Fig. 1 illustrates the complexity ratio of the proposed SESD and Damen's SESD for various system configurations. (The complexity ratio is defined as the ratio of the complexity of the proposed SESD and that of Damen's SESD.) The propose SESD requires only about $60\% \sim 80\%$ of complexity compared to Damen's SESD. The complexity reduction in proposed scheme is remarkable in low SNRs and small size of constellations such as 2-PAM.

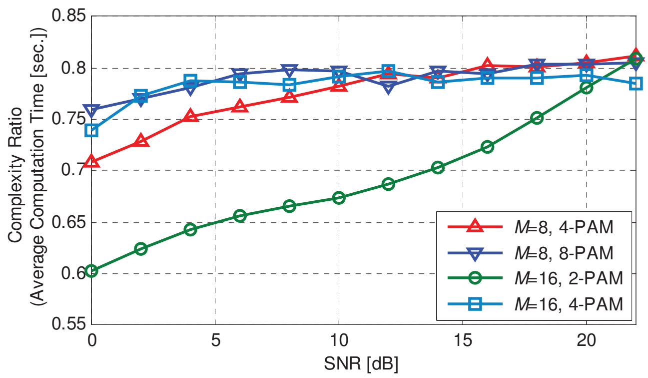

Fig. 1. Complexity ratio of the proposed SESD and Damen's SESD for various MIMO systems with versus SNR.

5. CONCLUSIONS

In this paper, we developed the improved implementation strategy, which has low complexity due to avoiding unnecessary operations related with invalid points. Our scheme shows low complexity compared to Damen's one, while keeping a ML performance.

6. REFERENCES

[1] M. O. Damen, A. Chkeif, and J.-C. Belfiore, "Lattice code decoder for space-time codes," *IEEE Commun. Lett.*, vol. 4, no. 5, pp. 161-163, May 2000.

[2] M. O. Damen, H. E. Gamel, and G. Caire, "On maximum-likelihood detection and the search for the closest lattice point," *IEEE Trans. Inf. Theory*, vol. 49, pp. 2389-2402, Oct. 2003.

[3] C. P. Schnorr and M. Euchner, "Lattice basis reduction: Improved practical algorithms and solving subset sum problems," *Math. Programm.*, vol. 66, pp. 181-191, 1994.