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Iterative Tree Based Adaptive Threshold Techniques for Large MIMO System

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ABSTRACT

An iterative tree based decoding technique for large multiple-input multiple-output systems is proposed. The BER performance and computational complexity of the iterative tree based sphere decoder with adaptive threshold is analyzed and compared. Specifically, the adaptive threshold is based on the signal-to-noise ratio and index of the layer. The ratio between the first and second smallest accumulated path metrics at each layer is also exploited to determine the threshold value.

Keywords: MIMO, ML decoder, tree based approach, sphere decoder

INTRODUCTION

Of all communication services available today, wireless services are having a dramatic impact on our personal and professional lives. In wireless communication, single input single output system (SISO) came into action in the year 1948. Single input single output systems refer to a simple control system with only one input and one output, employing single antenna at both the transmitter and receiver ends. In the last few years, wireless services have become more and more important. The growing demand of multimedia services and the growth of Internet related contents lead to increasing interest to high speed communications, network capacity and performance. The available radio spectrum is limited and the communication capacity needs cannot be met without a significant increase in communication spectral efficiency. Several options like higher bandwidth, optimized modulation or even code-multiplex systems offer practically limited potential to increase the spectral efficiency. Significant further advances in spectral efficiency are available through increasing the number of antennas either at the transmitter or at the receiver and at the both ends.

Single input multiple output systems (SIMO) and multiple input single output systems (MISO) which consists of single transmitter antenna and multiple receiver antennae multiple transmitter antennae and single receiving antennae respectively. MIMO (Multiple Input Multiple Output) Systems consists multiple antennas both at the transmitter and the receiver ends. One of the several forms of Smart Antenna Technology is the use of multiple antennas at both the transmitter and receiver to improve the system performance. MIMO gives significant increase in data transmission without additional bandwidth or transmit power [1]. MIMO transmits and receives two or more data streams through a single radio channel. This means the system can deliver two or more times the data rate per channel. By allowing this multiple streaming, wireless data capacity is multiplied without any additional frequency spectrum. Some of the standards like IEEE 802.11n, 4G and IEEE 802.11 Wireless LAN standards use MIMO technology.

Large multiple-input multiple-output (MIMO) systems have received enormous attention from researchers in the field of wireless communication for their high spectral and power efficiency [1]. However, the promised benefits of large MIMO are expensive in terms of computational complexity at the receiver compared to the conventional MIMO systems [1,2]. In conventional MIMO systems, to simplify the exhaustive search of the optimal maximum likelihood (ML) receiver, a sphere decoder (SD) can be employed, which only searches for the ML solution inside a sphere to reduce computational complexity

Maximum likelihood (ML) detection over Gaussian multiple input-multiple output (MIMO) channels can achieve the lowest Bit Error Rate (BER) for a given scenario, but at the expense of prohibitive complexity [2]. Thus, there is a continuous search for computationally efficient detectors, such as the Sphere Decoding (SD) algorithms, which are a set of tree search detectors with reduced complexity compared to the ML exhaustive search detector due to setting a radius constraint [2]. These algorithms perform a closest lattice point search for each component of the received vector, which is feasible due to the fact that the constellation set to which the transmitted symbols belong is known in advance. The existing SD algorithms can be implemented to operate within a finite set of real numbers, thus called Real Sphere Decoders (RSD) [3], or to perform the search directly within a finite set of complex numbers commonly known as Complex Sphere Decoders (CSD) [4]. Since these detectors provide the ML solution to the detection problem, their evaluation focuses only on their complexity.

Recently, a fixed complexity sphere decoder (FSD) derived from the Schnorr-Euchner (SE) sphere decoder has been presented in [5]. This detector achieves quasi-ML performance with the advantage of predetermined runtime, thus it is applicable in time-constrained scenario[6]- [8].

II. PROPOSED ALGORITHM

Large MIMO systems pose new challenges for digital signal processing given that the processing algorithms are becoming more complex with multiple antennas at both ends of the communication channel. Sphere decoding algorithms are a subset of decision feedback tree-search-decoders. They perform the detection of MIMO data symbols by iterating through a detection tree, in which the tree levels, also referred to as dimensions, correspond to the elements of the received symbol. Those detectors differ basically in the way how they search along the tree. Any node that is not discarded is considered a visited node (VN). A subset of the VN is the explored nodes (EN). These are all VN with branching child nodes. The goal always is to visit and explore as little nodes as possible to keep the computational cost low.

Consider a MIMO system with M transmit and N receive antennas, the received signal $\boldsymbol{r}$ is rewritten as

$$r = H s + n$$

where $\boldsymbol{s}$ denotes the transmitted vector, and n is a $N \times 1$ random vector of white Gaussian noise. H is an $N \times M$ channel transfer matrix, which generates the lattice. Each time the algorithm finds a k-dimensional layer, the distance to which is less than the currently smallest distance, this layer is expanded into (k-1) -dimensional sub layers. Conversely, as soon as the distance to the examined layer is greater than the lowest distance, the algorithm moves up one step in the hierarchy of layers. Then this lattice point is stored as a potential output point, the lowest distance is updated, and the algorithm moves back up again, without restarting.

The received vector can be written as,

$$R = H s + n$$

The maximum likelihood decoding algorithm is given by

$$\|c\|^2 = \|y - Ax\|^2 = (x - \hat{x})^* A^* A(x - \hat{x}) + \|y\|2 - \|A\hat{x}\|^2$$

where $\hat{x}$ is the unconstrained maximum likelihood estimate of x, and defined as

$$\hat{x} = A^{\dagger} y = (A^T A)^{-1} A^T y.$$

Rewrite the maximum likelihood metric as follows:

$$\hat{x}_{ML} = \text{argmin } \|y - Ax\|^2$$
$$= \text{argmin } (x - \hat{x})^* A^* A(x - \hat{x})$$

A lattice point which lies inside the sphere with radius d has to fulfil the condition

$$d^2 \geq \|c\|^2$$

A new constant can be defined as $d'^2 = d2 - \|y\|2 + \|A\hat{x}\|$, can be rewritten as

$$d'^2 \geq (x - \hat{x})^* A^* A(x - \hat{x})$$

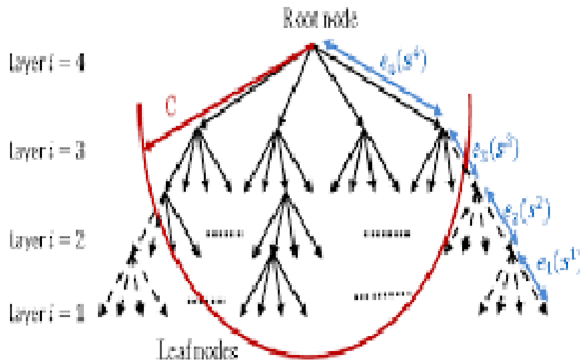
The matrix A*A can be decomposed to triangular matrices with Cholesky decomposition (A*A = U*U), where U is an upper triangular matrix

$$U = \begin{bmatrix} u_{11} & u_{12} & \cdots & u_{1n-1} & u_{1n} \\ 0 & \vdots & \ddots & u_{2n-1} & \vdots \\ 0 & 0 & \cdots & 0 & u_{mn} \end{bmatrix}$$

where $u_{i,j}$ denotes element (i, j) of the matrix U. Further simplification gives

$$d'^2 \geq (x - \hat{x})^* A^* A(x - \hat{x})$$

The flowchart of the sphere decoding algorithm has been described in detail in Figure 2.



Tree Based search

III. Performance Analysis:

A MIMO system with 4 transmit and 4 receive antennas is considered for simulation. Quadrature Amplitude Modulation is performed to transmit the bits though the channel. The received vector is decoded by employing the iterative tree based sphere decoder at the receiver end. The Bit Error Rate of the proposed scheme and ML decoder is tabulated in table 1. From this, it is evident that sphere decoder offers better Bit Error Ratio (BER) performance in comparison with the other detection schemes.

Complexity of sphere decoding detection

The complexity of ML detection is exponential and is given by solving

$$x = \arg min||r - Hx||^2$$

Tree search detectors theoretically can achieve optimal performance. However, the complexity of these detectors may become prohibitive at low SNR. Most tree-search-based MIMO detection techniques often have limited performance because of the required hardware implementations; large memory requirement or high computational complexity of sophisticated algorithms.

SD achieves a tremendous reduction in the average complexity; its instantaneous complexity depends on the noise variance and channel conditioning. However, it should be noted that this improvement come at the cost of increased computational complexity.

Performance metric for 16 QAM MIMO system with Nt = Nr =4

Sphere Decoding Approach	SNR	2	5	7.5
	BER	10^{-1}	10^{-2}	10^{-3}

	Average of visited nodes	Maximum visited nodes
ML	4369	4369
SD	19	676

IV. CONCLUSION

In this paper, the complexity of sphere decoding techniques has been analyzed and calculated. This computational complexity could allow to estimate the potential cost of the algorithm and to identify possible bottlenecks for the hardware implementation. The linear detection techniques have an efficient computational complexity but with low performance. The tree-search techniques have significant achievements in reducing computational complexity. SD achieved a lower average complexity; but its worst case complexity is comparable to that of MLD when channel is ill-conditioned.

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