Novel Approach for ML Detection with Reduced Complexity

Jobi Jose and Anu K. Kuriakose

Abstract For orthogonal frequency division multiplexing (OFDM) technology, if the number of antenna or modulation increases, the most accurate maximum likelihood (ML) detection will become extremely complex. A new suggestion for an algorithm is introduced in this paper with a significantly reduced calculation complexity to perform an optimal ML detection. With the use of minimum mean square error (MMSE) criterion, the suggested method filtered and avoids undependable candidate signals from data streams. While using the metric probability to analysis the dependability of each and every symbol candidate with normalized likelihood functions, the most accurate ML detection is achieved. The authenticity of suggested method is strengthen with the performance examine. To offset a balance between system performance and calculation complexity, a threshold parameter is introduced. The suggested method achieved nearly comparable results as in the ML detection at a bit error rate (BER) of 10^{-4} with 29 and 16% of true calculations with the conventional QR methods.

Keywords Multiple-input multiple-output (MIMO) · Maximum likelihood (ML) detection · Spatial multiplexing (SM) · Orthogonal frequency division multiplexing (OFDM) · Symbol error rate (SER)

1 Introduction

The capability of MIMO channels to support a high system capacity opened a new area for intensive study on its practical implementation rather than theoretically

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proved analysis. The most optimal transmission and reception algorithm designs are one step towards the right direction to utilize the full channel capacity of the MIMO system. Spatial multiplexing (SM) technique can support number of separate data flow; while considering the symbol error rate (SER), the maximum likelihood (ML) detection is the ideal option [1, 2].

Normally, an intensive search should conduct over all symbol vectors, so the system having high detection complexity. There are many suboptimal reception method were introduced to minimize the calculation difficulty of ML reception in open loop methods. While based on zero forcing (ZF), linear equalization schemes or minimum mean square error (MMSE) are applied to calculate the vector symbol. Also, introducing to develop the execution of the linear equalization approaches, it is having non-linear methods like vertical Bell Labs layered space-time (V-BLAST) detection [3].

Mainly, the most favorable detection systems are lacking to exhibit the required development in actual hands-on systems; there are many ideas that has been introduced to reach the near-optimum performance. But all those have the same drawback, additional complexity. To minimize this issue, three search oriented detection algorithms like sphere decoding (SD) and QR decomposition with M-algorithm (QRD-M) are considered [4].

Many approaches mentioned are not in use with a coded systems because it depends its soft decision output. To create the soft decision output, the QRD-M dependent methods develop a critically selected existing group for candidates to creating the log likelihood ratio (LLR) values [5].

By this paper, a new detection algorithm is implemented with comparable optimal ML performance and a reduced complexity. By using an MMSE filter, it split the MIMO transmitting channel into many sub channels and minimize the search area by filtering each data stream and remove the unreliable candidate symbols. The evaluation of the ratio between performance and complexity is crucial to analyze the system performance; so, a threshold parameter is considered [6]. The simulation results prove that 85% reduced multiplications are possible with the designed model in 16-QAM in comparison with QRD-M 4×4 systems at a bit error rate (BER) of 10^{-4}. Which means its performance is considerably same as the ML solution [7].

2 Conventional Detection Methods

A multiple-input multiple-output arrangement with N_t transmitting antennas and N_r receiving antennas ($N_r \geq N_t$) as illustrated in Fig. 1. The bit-interleaved coded modulation (BICM) is used for channel encoding on the transmitter, and the single source data bits are initially de-multiplexed into N_t parallel sub-data flow. As in Fig. 1a, with a code rate R_c, each sub-data stream are independently encoded initially [1, 2]. Then, it undergoes bit-interleaving and then modulate to submit the transmitted vector symbol $s = \left[s_1 \ldots s_{N_t}\right]^T$

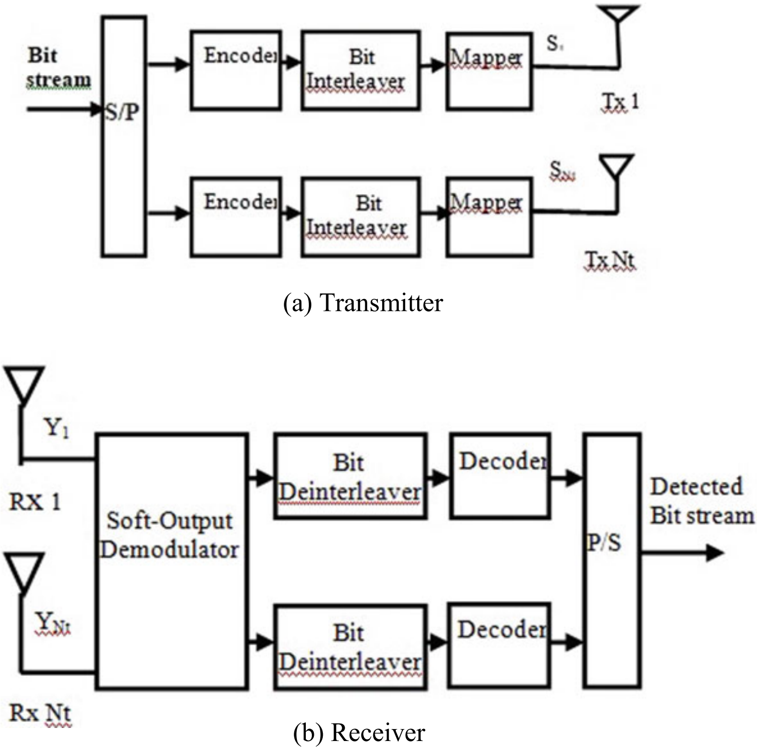

Fig. 1 Illustration of MIMO-OFDM systems with N_t transmitting and N_r receiving antennas. **a** Transmitter. **b** Receiver

On receiver end, the baseband reception model for flat-fading channels with discrete time frequency is expressed by

$$y = \left[y_1 \cdots y_{N_r}\right]^T = Hs + n \tag{1}$$

where $n = \left[n_1 \cdots n_{N_r}\right]^T$ constitute the complex additive white Gaussian noise (AWGN) vector whose matrix covariance is taken as σ_n^2 **I**, and **H** represents the $N_r \times N_t$ matrix channel whose (*i*,*j*)th input represents symbol fading coefficient in the middle of *j*th transmitting antenna and *i*th receiving antenna [8]. As illustrated in Fig. 1b, the log likelihood ratio values in the soft decision output demodulator is obtained as a information from the received signal vector **y**.

To estimating the transmitted vector symbol of an uncoded MIMO system, the most accurate ML detection is given as

$$s = \arg \min_{s \in C^{N_t}} \|y - Hs\|^2 \tag{2}$$

where C^{N_t} represent the group of constellation symbols in the complex dimensional space N_t.

3 Uncoded System with Proposed Detection Algorithm

In this new proposed MIMO detection technique, a nearly maximum efficiency can be achieved with much reduced number of calculations.

At the receiver, the MMSE criterion-based linear filter F is shown

$$F = \left[g_1 \cdots g_{N_t}\right] = H\left(H^H H + \frac{\sigma_n^2}{\sigma_s^2} I\right)^{-1} \tag{3}$$

Estimated MMSE vector symbol $\tilde{s} = \left[\tilde{s}_1 \cdots \tilde{s}_{N_t}\right]^T$ is calculated as

$$\tilde{s} = F^H y = F^H H s + v \tag{4}$$

In this $v = \left[v_1 \cdots v_{N_t}\right]^T$ represents noise vector of filtered output $v = F^H n$. Representing $\mathbf{h}i$ as the jth column of $\mathbf{H}$. We finally obtain a new search set D as $D = \hat{C}_1 \times \cdots \times C_{N_t}$.

4 Coded System with Reduced Complexity Algorithm

If the soft decision input channel detector is used in the coded systems, there is a considerable change for better performance. Utilizing the set which having less candidates, and the log likelihood ratio can be obtained as,

$$\mathrm{LLR}\left(b_{i,j}\right) = \log \frac{\sum_{s \in D_{i,j,1}} \exp\left(-\frac{\|y - Hs\|^2}{\sigma_n^2}\right)}{\sum_{s \in D_{i,j,0}} \exp\left(-\frac{\|y - Hs\|^2}{\sigma_n^2}\right)} \tag{5}$$

where $b_{i,j}(1 \le i \le N_t,\ 1 \le j \le \log 2\ K)$ represents the jth transmission bit of the ith data stream, and $D_{i,d}$ is defined as $D_{i,j,d} = \{\mathbf{s}\ |b_{i,j} = d, \mathbf{s} \in D\}$. While analyzing the LLR values in (5), the number of candidate many not be sufficient to generate all the LLR values of $b_{i,j}$. It is important that either $D_{i,\mathrm{j},0} = \phi$ or $D_{i,j,1} = \phi$. With these values, the calculation of log likelihood ratio $(b_{i},_{j})$ is not possible.

5 Analyzing the Complexity

While analyzing the complexity, it calculate the comparison between conventional method and analytical complexity of proposed new method. At first, the uncoded system is considered to analyzes the complexity by calculating the average count of necessary true calculations [9]. While considering SD, we choose the scheme based on MMSE criterion for the ordering and the filtering.

The ML detection method having $4N_rN_tK + 2N_rK^{N_t}$ necessary multiplications, in which the initial and the second phrase represents, the calculation of Hs. In the QRD-M, the method having $4\left\{\left(\sum_{i=1}^{N_t-1} i + K(N_t-1)\right)M + K\right\} + 2(MK)(N_t-1) + K$ necessary calculations in which the initial phrase represents the metric analysis and the following phrase represents the square calculation for each node.

Table 1 exhibit analytical difficulties of different MIMO decoding methods. The SNR values are considered as 18 dB for 4-QAM and 26 dB for 16-QAM, to obtain the bit error ratio of about 10^{-4} for uncoded methods.

Now, calculate the computational difficulty of the suggested method with coded systems. The ideal log likelihood ratio value is calculated by intensive search. The intricacy of both the LSD and the suggested scheme are exhibited in Table 2.

Compared to uncoded systems, the coded systems have increased complexity even though the illustrated result of proposed system is having considerably reduced complexity than other soft output schemes.

Figures 2 and 3 exhibit the comparison of different methods for 16-QAM and 4-QAM, in uncoded method. Unlike the traditional SD, the MMSE-based SD cannot perform a competitive ideal ML detection even though it has infinite radius.

The evaluation of different methods for coded MIMO system can be considered now. Figures 4 and 5 exhibits the FER plot of coded systems for 16-QAM and 4-QAM, respectively, with $R_c = 1/2$.

Table 1 Different Methods of 4×4 uncoded OFDM systems with number of multiplication

Detection scheme	4-QAM	16-QAM
ML	2304	525,312
EM	408	5088
Proposed ($\alpha = 0.9995$)	116	770
Proposed ($\alpha = 0.999$)	110	609

Table 2 Different methods of 4×4 coded OFDM systems with number of multiplication

Code rate	Schemes	4-QAM	16-QAM
1/2	Proposed ML	258	1026

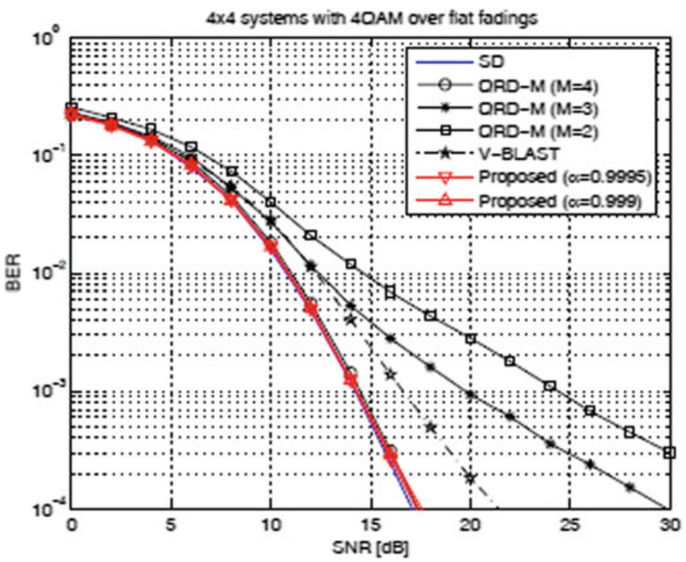

Fig. 2 Bit error ratio of 4 × 4 system with 4-QAM in an uncoded detection method

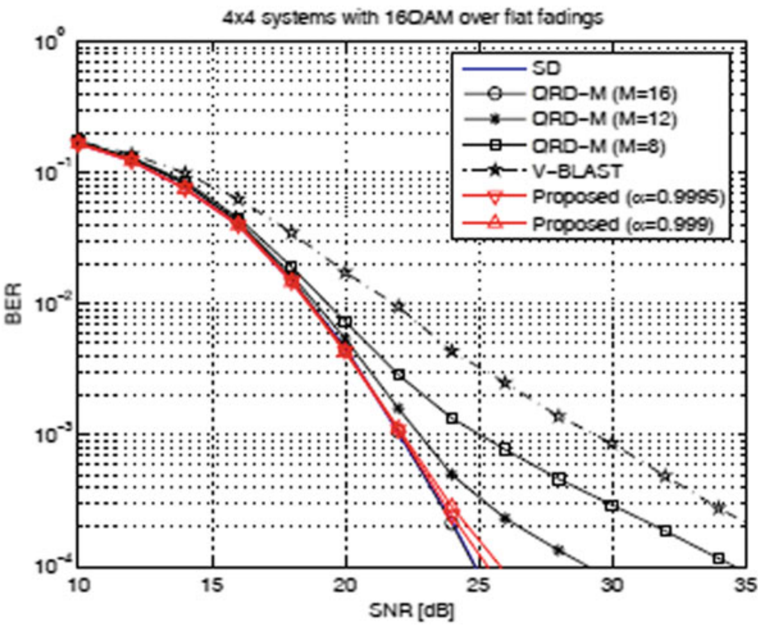

Fig. 3 Bit error ratio of 4 × 4 system with 16-QAM in an uncoded detection method

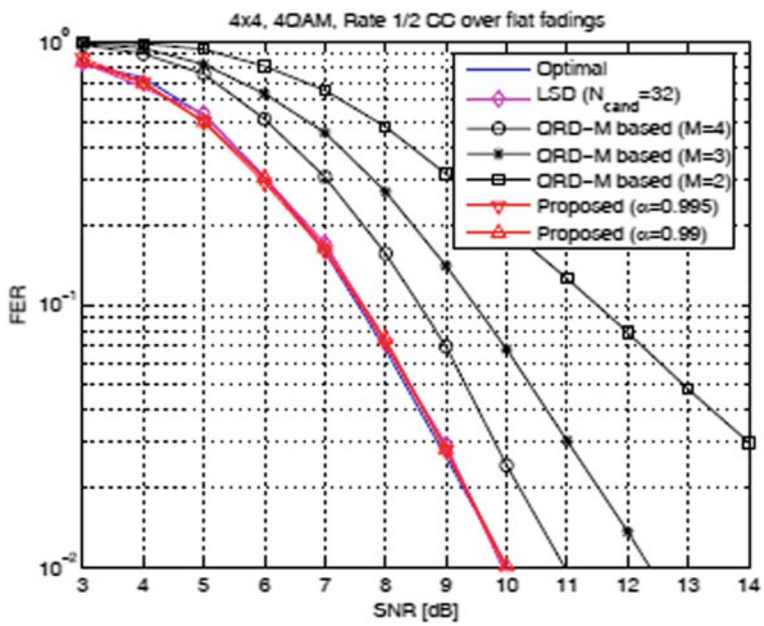

Fig. 4 FER of 4 × 4 system with 4-QAM in a coded method

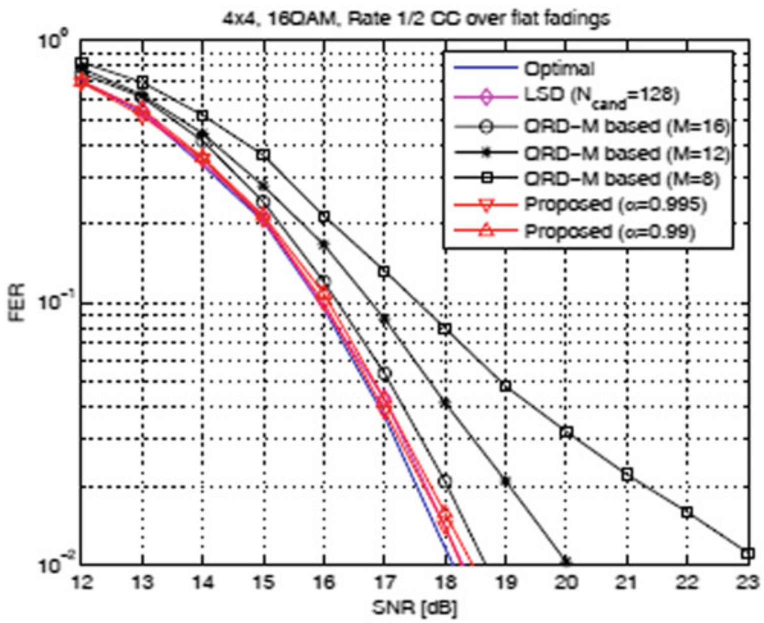

Fig. 5 FER of 4 × 4 system with 16-QAM in a coded method

6 Conclusions

This paper focused on multiple antenna systems and it suggested an advanced low-complexity ML detection method. The required candidates are chosen in every data signal flow with respect to calculated conditional probabilities by the application of MMSE criterion. The outage probability of selected candidate group $\hat{C}_i$ for the suggested model is also calculated. In order to keep the balance between the performance of system and calculation complexity, a threshold parameter is introduced.

The complexity of proposed method is considerable reduced in proposed method with limited search candidates while compared with traditional near ML detection algorithms.

Along with that, it suggests an advanced way for creating the log likelihood ratio for coded systems from selected candidates with considerably low calculation difficulty. The convolution coded systems with ½ rate for 16-QAM and 4-QAM, only 53 and 37% of true calculations.

Simulation results:

See Figs. 2, 3, 4 and 5.

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