Link Adaptation Technique for MIMO-OFDM systems with Low Complexity QRM-MLD Algorithm

C. Suganya, S.Santhiya, K.Jayapragash

***Abstract*—MIMO-OFDM becomes a key technique for achieving high data rate in wireless communication. To enhance the MIMO link performance Adaptive modulation and coding (AMC) is used which chooses the suitable modulation and coding schemes appropriate to the current channel conditions. Maximum likelihood detection (MLD) employing QR decomposition and M-algorithm (QRM-MLD) can significantly improve the bit error rate (BER) performance of the Multi Carrier (MC) transmissions in a frequency-selective fading channel. In this paper a new link performance estimation technique is proposed for MIMO–OFDM systems with QRM-ML receiver. Simulation results are obtained for signal-to-noise ratio (SNR) and the corresponding bit error rate (BER), using QRM-ML receiver. A comparative study of ML and QRM ML receivers are performed. Simulation results show that QRM MLD performs superior to MLD with low computational complexity.**

***Index Terms*—Link adaptation, QRM-MLD, MIMO-OFDM**

I. INTRODUCTION

In modern wireless cellular systems it is a great challenge to support high-speed packet data services for high quality multimedia applications. Those high speed packet services can be provided by employing efficient usages of the transmission bandwidth and mitigating intersymbol interference in frequency selective fading channels [1]. In those environments we consider multi input multi-output (MIMO) systems and orthogonal frequency division multiplexing (OFDM). MIMO systems combined with OFDM, which is called as MIMO-OFDM, can provides high spectral efficiency and better link error performance. Orthogonal frequency-division multiplexing (OFDM) modulation techniques which do not require complicated equalizers which is feasible for frequency selective fading channels [2]. In an OFDM system, the transmitter modulates the message bit sequence into PSK/QAM symbols, performs IFFT on the symbols to convert them into time-domain signals, and sends them out through a (wireless) channel. The received signal is usually distorted by the channel characteristics. In order to recover the transmitted bits, the channel effect must be estimated and compensated in the receiver.

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In multi-carrier systems such as orthogonal frequency division multiplexing (OFDM), however, the frequency selective fading over the transmission channel introduces large SNR variations across the subcarriers, thus making link performance prediction a demanding task [3]. Link adaptation is to adapt the link efficiently in the actual channel conditions by varying certain transmission parameters [4]. AMC (Adaptive Modulation and Coding) is one of the link adaptation techniques that can adapt the modulation and coding schemes according to the current channel conditions [5].

Maximum likelihood detection (MLD) provides the optimum MIMO detection performance, the MLD or near- ML detectors have widely been considered to be adopted as a powerful receiver algorithm [6]. MLD achieves the best performance but it has a limitation of computational complexity [7]. QRM-MLD is a signal detection algorithm that can overcome the drawbacks of MLD. It has less computational complexity because only M points that have small Euclidean distance are calculated [8]. In [9] a novel reduced complexity QRM-MLD scheme was proposed for higher order QAM system with MIMO-OFDM scheme. [10] showed that QRM-MLD can obtain larger uplink cellular capacity compared to the minimum mean square error detection (MMSED) at the cost of the increased computational complexity, but with much less than MLD. However, increase in the number of surviving symbol candidates increases computational complexity. By using antenna diversity reception[11], the probability of removing correct symbol candidates at early stages in QRM-MLD can be reduced and therefore, antenna receive diversity have a potential to reduce of the number of surviving symbol candidates, thereby reducing the computational complexity.

In this paper link adaptation is performed for MIMO–OFDM systems with QRM-ML receiver. Maximum likelihood detection (MLD) employing QR decomposition and M-algorithm (QRM-MLD) can significantly improve the bit error rate (BER) performance of the Multi Carrier (MC) transmissions in a frequency-selective fading channel. Simulation results shows that QRM MLD performs superior to MLD with low computational complexity. The remainder of this paper is organized as follows: In Section II, we describe the system model of MIMO-OFDM systems which is combined with AMC schemes. Section III we discuss on

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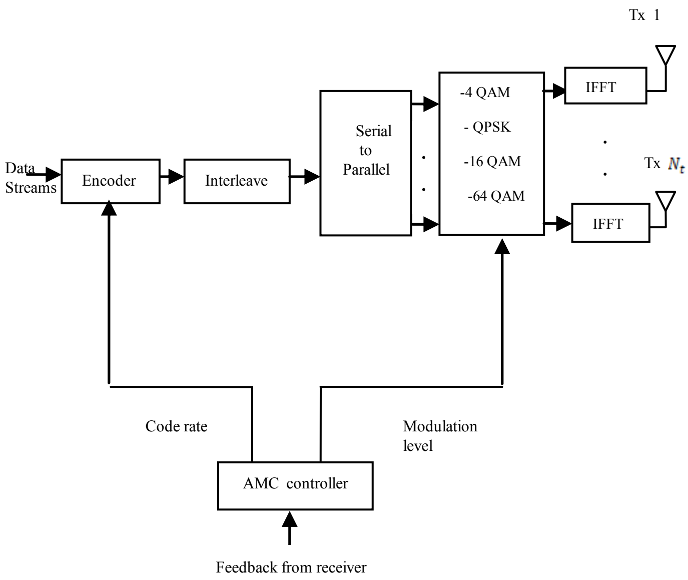
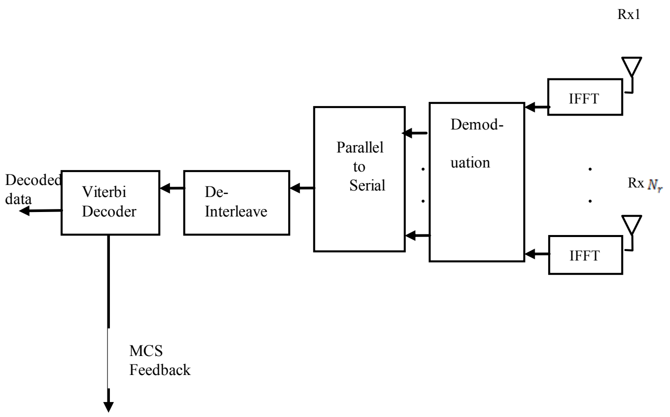
the working of MLD and its limitation. In Section IV, we discuss on our proposed method of link adaptation using QRM-ML. The proposed method is verified for simulation in section V and we confirm that the proposed method is quite accurate in the MIMO-MLD link performance evaluation with low computational complexity. We conclude our paper in section VI



a) Transmitter section



b) Receiver section

Fig.1 MIMO-OFDM systems with QRM-ML receivers

II SYSTEM MODEL

Fig.1 illustrates a MIMO-OFDM systems with QRM-ML receivers. The system consists of N_t transmit antennas and N_r receive antennas. In the a) transmitter section the data streams are encoded by means of a convolutional encoder. There are 2 types of encoding techniques namely i) *Vertical encoding* in which all data streams are encoded by a single channel encoder, ii) *Horizontal encoding* in which the data streams are connected to separate channel encoders. The type of encoding can be chosen depending upon the application. The encoded data are interleaved and mapped into individual constellations after serial to parallel conversion. 4 different modulation schemes are considered namely QPSK, 4QAM, 16QAM, 64 QAM. For general OFDM operations IFFT process is carried out and transmitted through each antenna. In order to prevent inter-symbol interference (ISI), cyclic prefix (CP) is appended to the front of each IFFT output block. At the receiver QRM-MLD detects the signal and chooses the appropriate modulation and coding schemes as per the current channel conditions and sends the feedback information to the transmitter by means of an AMC controller. The Quadrature amplitude modulation (QAM) size and the channel code rate is determined by the Modulation and Coding (MCS) schemes.

At the receiver side, the received signal at the kth subcarrier after the FFT demodulation can be expressed as,

$$y_k = H_k x_k + n_k \qquad \ldots(1)$$

where,

k=1,2,…N_c

y_k = Received signal vector

x_k= Transmitted signal vector

H_k= Channel matrix of size $N_r \times N_t$ whose $(j,i)^{th}$element stands for the channel coefficient between the i^{th} transmit and the j^{th} receive antenna at the k^{th}subcarrier.
N_k= Noise

It is assumed that the channel knowledge H is perfectly known at the receiver in the absence of channel state information at the transmitter.

III LINK ADAPTATION USING MLD

Maximum likelihood (ML) detection calculates the Euclidean distance between the received signal vector and the product of all possible transmitted signal vectors with the given channel H, and finds the one with the minimum distance[12]. Maximum Likelihood Detector (MLD) is considered as the optimum detector that could effectively recover the transmitted signal at the receiver based on the following minimum distance criterion,

$$\tilde{x} = arg_{x_k \in \{x_1, x_2, \ldots, x_N\}} \min \|y - Hx_k\|^2 \ldots(2)$$

where $\tilde{x}$ is the estimated symbol vector.

Using the above criterion, MLD compares the received signal with all possible transmitted signal vector which is modified by channel matrix H and estimates transmit symbol vector x. As per the conditions of the channel the MCS level get varied. Although MLD achieves the best performance and diversity order, it has a limitation of computational complexity in the number of transmit antennas and constellation set size.

IV LINK ADAPTATION USING QRM-MLD

We consider 4×4 MIMO system. In order to avoid complexity the channel matrix H is decomposed into orthogonal matrix Q and upper triangular matrix R which is given as,

$$H=QR \quad \ldots(3)$$

where,

Q is an orthogonal matrix (i.e $Q^T = Q^{-1}$) satisfying the condition $Q^H Q = I$ (I is the identity matrix)

R is upper triangular matrix given by
$$\begin{bmatrix} r_{1,1} & r_{1,2} \ldots r_{1,n} \\ 0 & r_{2,2} \ldots r_{2,n} \\ \vdots & \ddots & \vdots \\ 0 & & r_{n,n} \end{bmatrix}$$

The concept of QRM is based on the classical M-Algorithm that retains only a fixed number of symbol candidates, M, at each detection layer.

For $N_t = N_r = 4$, the equation $y_k = H_k x_k + n_k$ can be expanded as,

$$\|\tilde{y} - Rx\|^2 = \left\| \begin{bmatrix} \tilde{y}_1 \\ \tilde{y}_2 \\ \tilde{y}_3 \\ \tilde{y}_4 \end{bmatrix} - \begin{bmatrix} r_{1,1} & r_{1,2} & r_{1,3} \\ 0 & r_{2,2} & r_{2,3} \\ 0 & 0 & r_{3,3} \\ 0 & 0 & r_{4,3} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} \right\|^2$$

$$= |\tilde{y}_4 - r_{4,4}x_4|^2 + |\tilde{y}_3 - r_{3,3}x_3 - r_{3,4}x_4|^2 + |\tilde{y}_2 - r_{2,2}x_2 - r_{2,3}x_3 - r_{2,4}x_4|^2 + |\tilde{y}_1 - r_{1,1}x_1 - r_{1,2}x_2 - r_{1,3}x_3 - r_{1,4}x_4|^2 \quad \ldots(4)$$

To minimize the metric QRM algorithm keeps only *M* candidates at each detection level and discards the rest. In this paper we have considered M=16.

Detection of the symbols is made as follows:

1. At the first layer metrics are calculated as follows

$$\left\{\tilde{x}_{N_t,c,1}\right\}_{c=1}^{M} = arg \min_{x_{N_t} \in C^M} \| y_{N_t} r_{N_t N_t} (\hat{x}_{tN_t,candidate}) \|^2 \quad \ldots(5)$$

where $\tilde{x}_{N_t,c,1}$ denote one of the M selected symbols and c =1, 2,…,M.

2. The best *M* candidates are retained for the next detection layer. The metric values are ordered from lowest to the largest and only the no. of M symbol which has the smallest metric are retained for the next level. For j^{th} layer the metrics are calculated as follows:

$$arg \min_{x_j \in C^M} \left\| y_j - \{ r_{j,j}\, \hat{x}_{tj,candidate} + \sum_{l=j+1}^{N_t} r_{j,l}\, \hat{x}_{tl,candidate} \} \right\|^2$$

Fig.2 illustrates the flowchart of QRM algorithm. Decomposition of the channel matrix is performed and the received signal vector is pre multiplied by Q^H. The branch metrics are calculated and the resulting $M\delta$ branches are sorted based on their accumulative metrics. The *M* branches with the smallest accumulative metrics are retained for the next detection layer. This strategy is repeated down to the last detection layer, i.e., j =1. At the last step the *x* with the smallest overall metric is chosen as the ML decision.

Thereafter link adaptation is performed which deals with choosing the most suitable modulation and coding schemes appropriate to the current channel conditions. If SNR is high then higher order modulation schemes like 64 QAM can be used. For poor SNR lower order modulation like QPSK can be used. For a given modulation scheme, an appropriate code rate is chosen depending on the channel quality. The better the channel quality, the higher the code rate. Table I illustrates the different MCS level we have chosen.

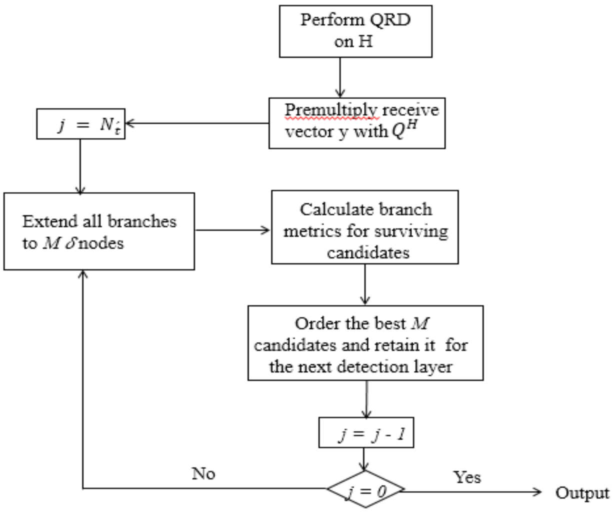


Fig.2 Flowchart of QRM

Table-I
Different MCS levels

SNR(dB)	MODULATION LEVEL	CODE RATE
11	QPSK	1/2
15	4 QAM	1/2
19	16 QAM	3/4
25	64 QAM	5/6

V SIMULATION RESULTS

In our simulation, we consider a 4×4 MIMO-OFDM system. The simulation parameters taken are indicated in table II. The different modulation schemes taken are depicted in table I. For a particular value of SNR the modulation schemes and code rate gets varied.

Table- II
Simulation Parameters

PARAMETERS	DESCRIPTION
No. of transmit antenna(Nt)	4
No. of receive antenna(Nr)	4
Modulation scheme	Adaptive
Channel coding	Convolutional encoder
Channel estimation	Perfect
Interleave	Random interleaver
Signal detection	QRM-MLD

Fig 3 illustrates the BER performance of QRM-MLD and compares with MLD for QPSK modulation. For lower SNR values QPSK modulation is chosen with a code rate of ½. For SNR value of 12 dB the bit error rate of MLD and QRM-MLD are 10^{-2} and 10^{-3} respectively. QRM-MLD performs superior to MLD. The complexity limitation of MLD can be reduced as the number of decompositions increase.

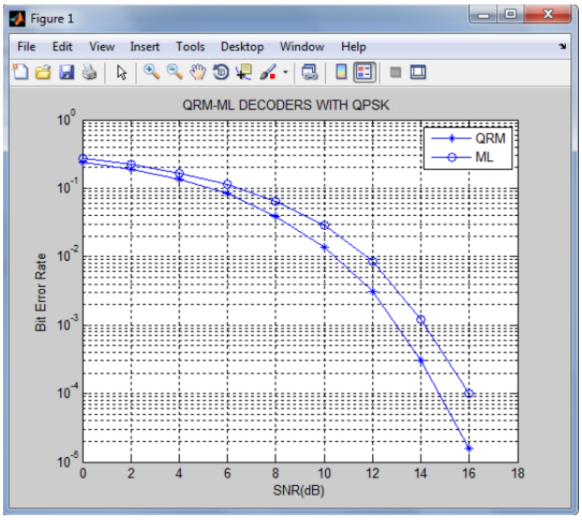


Fig.3 Performance comparison of ML and QRM ML receivers under QPSK modulation

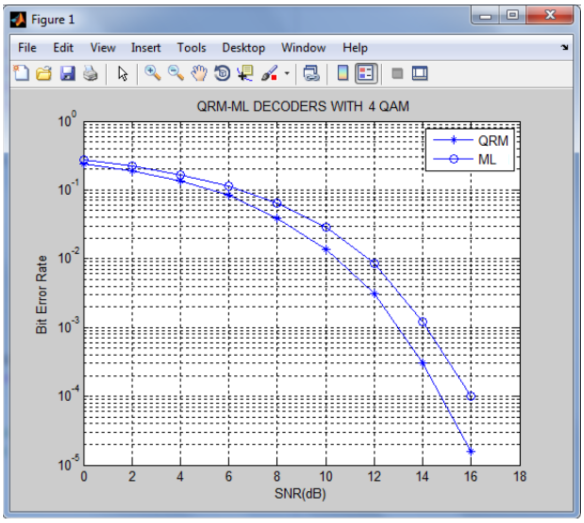


Fig.4 Performance comparison of ML and QRM ML receivers under 4 QAM modulation

Fig.4 illustrates the BER performance of ML and QRM ML receivers under 4 QAM. BER performance is better in QRM-MLD compared to MLD.

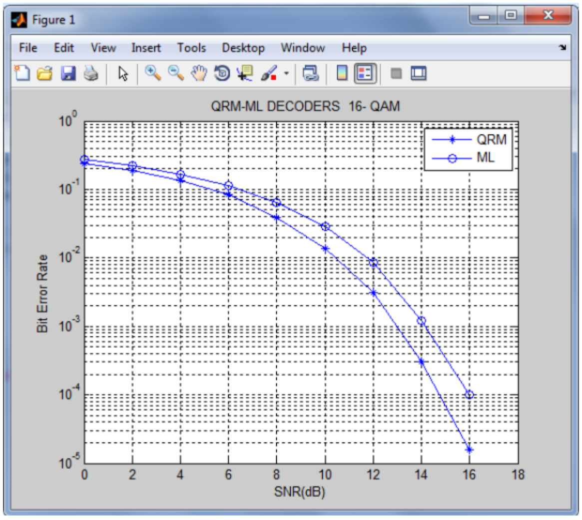


Fig.5 Performance comparison of ML and QRM ML receivers under 16 QAM modulation

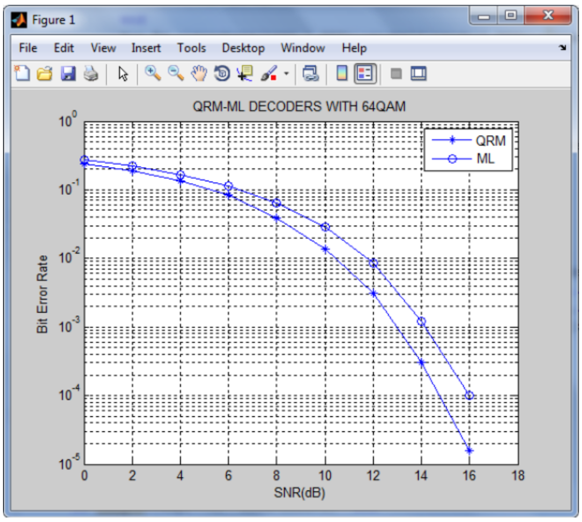


Fig.6 Performance comparison of ML and QRM ML receivers under 64 QAM modulation

Fig.5 illustrates the BER performance of QRM-MLD and compares with MLD for 16 QAM modulation. For SNR value of 19 dB 16 QAM modulation is chosen with a code rate of 3/4. The performance shows that QRM MLD provides BER of 10^{-4} and MLD provides 10^{-3} for SNR of 12 dB which shows QRM-MLD results in better performance.

Fig.6 depicts the performance comparison of ML and QRM ML receivers under 64 QAM modulation. Even for higher modulation levels QRM-MLD out performs MLD. The MCS levels can be easily chosen at each transmission as per the conditions of the channel. Therefore, we can conclude that the proposed link performance estimation technique for MIMO systems is quite superior with less complexity.

VI CONCLUSION

In this paper we have proposed link adaptation techniques for MIMO-OFDM systems with QRM-ML receiver for low complexity and the link level performance are estimated. The performance has been analyzed for ACMs with QRM and it is been compared with MLD and it is found that the performance of QRM overtakes ML which is shown in the simulation results.

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