Performance Enhancement through Reduced Complexity Channel Estimation Algorithm for 4G OFDM Systems

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Summary

The channel estimation algorithms play a vital role in third generation (3G) communication systems to support efficient spectrum utilization. The transition from 3G to 4G systems is to provide high data rate, error free low complexity system with efficient adaptive techniques. A noisy Channel estimation and feedback error introduces imperfect Channel State Information (CSI). This paper introduces a modified optimum SNR threshold set using Levenberg Marquardt (LM) algorithm and is used in selecting the modulation scheme and it improves the average spectral efficiencies.

Key words:
OSTBC, Bit error rate, Spectral Efficiency, Moment generating function.

1. Introduction

Increasing market expectations for 4G mobile radio systems show a great demand for the wider range of services spanning from voice to high rate data services required for supporting mobile multimedia communications [1-3]. OFDM may be combined with antenna arrays at the transmitter and receiver to increase the diversity gain and enhance the system capacity over frequency selective channels, resulting in Multi-Input Multi-Output Orthogonal Frequency Division Multiplexing (MIMO-OFDM) configuration used in a lot of applications [4-7].

Link adaptation scheme enhances the spectral efficiency of a communication system by adapting the modulation scheme and coding rate depending on the CSI. For a coherent detection, channel estimations are necessary particularly in MIMO-OFDM systems. The accuracy of channel estimation directly affects the performance of MIMO-OFDM systems [8-11]. At the receiver, channel estimator estimates the channel state information (CSI), which is feedback to the transmitter [12]. That is, if the channel quality is good then more bits can be transmitted and if the channel quality is bad, fewer bits can be transmitted. In comparison to fixed modulation order scheme, the adaptive modulation scheme can achieve higher data rate.

Practically, the noisy channel estimation error and feedback delay when passing CSI from receiver to transmitter may cause the imperfect CSI [13]. The accuracy of the modulation order depends on feedback delay, which can be controlled by using efficient coding techniques. On the other hand, noisy channel estimation error cannot be eliminated may cause random interference in the detection. Although reasonable work is done in the literature under perfect-CSI-based adaptive transmissions developed for both SISO [14] and MIMO-OFDM wireless systems [15] over slow fading. Also, orthogonal space-time coding research efforts put toward the imperfect CSI to be available at the transmitter.

The design issues and the effects of the multipath induced channel quality fluctuations on the performance will be addressed and the investigation is performed to improve the performance through the link adaptation of OSTBC MIMO-OFDM.The channel coefficients (CSI) can be updated using the Expectation Maximization Decision Directed iterative channel estimation (EMDDIS) scheme. The paper proposed a set of optimal SNR thresholds over the whole SNR region to tolerate estimation errors by using Levenberg Marquardt (LM) algorithm.

The structure of the paper is organized below. Section II describes the system model. Section III describes analysis of SNR optimum thresholds and section IV presents simulation model and the performance analysis of various approaches to link adaptation. Section V presents the conclusion.

2. System Model

An adaptive OSTBC MIMO OFDM system architecture is shown in the figure (1) with Nt transmits antennas and Nr receiving antennas is considered to analyze the performance of the system. The information bit stream is mapped into data symbols using M-QAM modulation technique followed by orthogonal space-time block code of data symbols is sent through serial to parallel S/P converter to generate the complex vector. This will be passed through IFFT block to generate OFDM time

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domain signal. The serially converted data transmitted over NT transmitting antennas in terms of OFDM blocks. Each OFDM block consists of NC subcarriers.

At the receiver, the channel coefficients can be updated using the proposed Expectation Maximization Decision Directed iterative channel estimation (EMDDIS) scheme. The interference due to imperfect CSI is treated as white noise. In this paper, the impact of channel estimation errors on the overall performance of adaptive modulation in OSTBC systems is addressed.

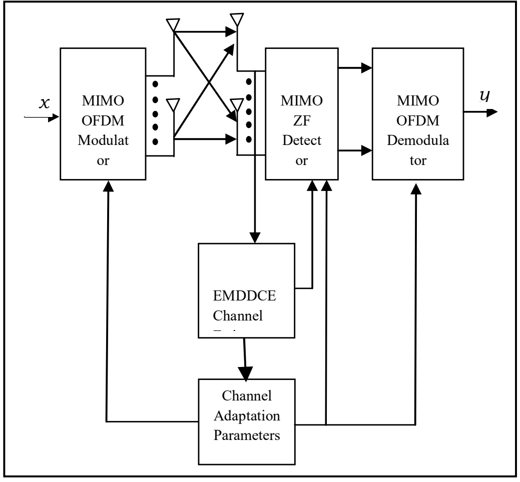

Fig. 1. Block diagram for adaptive MIMO-OFDM with EMDDCE estimator

Let $\hat{H}$ denote the estimated channel, it can be modelled as

$$\hat{H} = H + \Xi \tag{1}$$

Where

Ξ is the estimation noise, $\mathcal{N}(0, \sigma_e^2)$

H is the actual channel,

$$H = \eta\hat{H} + \sqrt{1-\eta}W$$

W is i.i.d. Gaussian noise, $\mathcal{N}(0,1)$

$\eta = \frac{1}{1+\sigma_e^2}; \eta = 1$, for perfect CSI.

$\hat{H}$ can be employed using Maximal Ratio Combining diversity technique (MRC) to determine the effective SNR of the transmitted signal from multipath delayed replicas by sum of weighted individual paths, and the decision statistic can be written as:

$$\hat{x} = \frac{\eta\|H\|^2}{R} x_i + \underbrace{I(x) + \hat{Z}}_{\hat{n}} \tag{2}$$

Then the effective SNR is given by,

$$\hat{\gamma} = \frac{u.\gamma_0 \cdot \|H\|^2}{R.N_t} \tag{3}$$

Where u = the degradation factor due to channel estimation noise.

3. Analysis of SNR Threshold

Consider discrete adaptive coded MIMO-OFDM system with a finite set of modulation orders (integers) i.e., M_k = {0, 2, 4, 16,}. The discrete adaptive modulation scheme divides the whole SNR region into number of fading regions (K + 1). Each fading region is associated with a modulation order [Tk, Tk+1). Proposed SNR threshold set has to fulfil either instantaneous BER (I-BER) constraint or average BER (A-BER) constraint. The instantaneous BER defines the error probability of every transmission subject to the target BER. The average BER defines the average error probability after a sufficient number of transmissions. The error probability (Pb) of QAM modulation for coherent detection with Gray bit mapping is given as,

$$P_b \cong 0.2 \exp\left[\frac{-1.5\gamma_i}{M_k - 1}\right] \tag{4}$$

With a predefined BER, the SNR thresholds can be easily found from (1) for every constellation size.

$$T_k = \frac{M_k - 1}{1.5} \ln\left(\frac{1}{5BER_t}\right) \tag{5}$$

Using the effective SNR threshold equation (5), the closed-form expression for the average spectral efficiency derived based on the discrete modulation orders are as follows:

$$SE_{avg} = \eta = \sum_{i=0}^{N-1} K_i \int_{\gamma_i}^{\gamma_i+1} p(\gamma) d\gamma \tag{6}$$

By using moment generating function (MGF), the probability distribution function (pdf) of the effective SNR can be derived either classified into non- repeated roots case or repeated roots case.

The pdf of the effective SNR using MGF can be calculates as,

$$M_{\hat{\gamma}}(s) = \prod_{i=1}^{N_t} \prod_{j=1}^{N_r} \frac{1}{1 - \hat{\alpha}_{i,j} s} \tag{7}$$

Where $\hat{\alpha}_{i,j}$ is the newly estimated effective SNR employed in choosing the fading region with the associated modulation order.

$$\alpha_{i,j} = \frac{\gamma_0 \lambda_{r,i} \lambda_{t,j}}{R.N_t} \tag{8}$$

Where, λ is the correlation factor at the receiver and the transmitter, R is the coding rate for OSTBC. Under the perfect channel estimation is, $\hat{\alpha}_{i,j}$ reduces to original $\alpha_{i,j}$ otherwise, the pdf of effective SNR can be updated as,

$$P_{\hat{\gamma}}(\hat{\gamma}) = \sum_{m=1}^{N_d} \sum_{l=1}^{N_s(m)} \frac{\hat{\varphi}_{m,l}\,\hat{\gamma}^{l-1}}{\Gamma(l)\hat{\alpha}_m{}^{l}} \exp\left(-\frac{\hat{\gamma}}{\hat{\alpha}_m}\right) \tag{9}$$

And

$$\hat{SE} = R \sum_{k=1}^{K} \sum_{m=1}^{N_d} \sum_{l=1}^{N_s} \frac{\hat{\varphi}_{m,l}}{\Gamma(l)} \Delta d_k \Gamma_u\left(l, \frac{T_k}{\hat{\alpha}_m}\right) \tag{10}$$

The equations (9) and (10) can be used to evaluate the pdf of SNR and average spectral efficiencies. Based on the SNR threshold set (5), the LM algorithm finds a particular set of SNR thresholds that approach the target BER and hence improve the average spectral efficiency.

4. Simulation Results

The whole wireless channel transmission bandwidth is 800 kHz, and it is divided into 64 subcarriers. To make subcarriers orthogonal to each other, symbol period is selected to be 80 microseconds. An additional 20 microseconds CP (N_{CP}=16) is utilized to give protection from ISI and ICI because of wireless channel delay spread. Therefore, total OFDM block length is *Ts* 100 microseconds and sub channel symbol rate is 10 kbaud. Consider spatial correlation is constants under Rayleigh fading channel at both transmitter and receiver are 0.5.

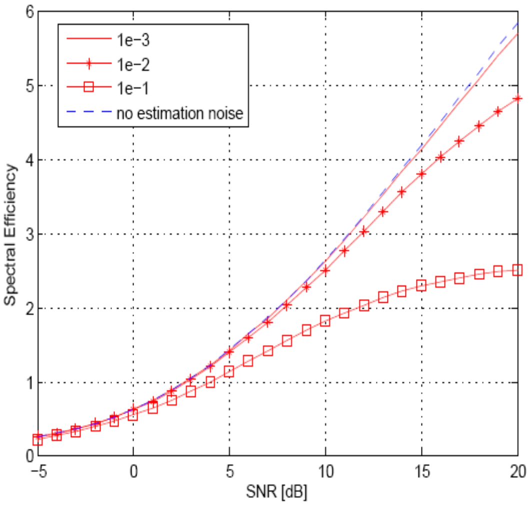

Fig. 2. Spectral efficiency versus SNR of OSTBC with imperfect CSI

From simulation results, the degradation of spectral efficiency is more serious in high SNR region and becomes substantial as the estimation noise power exceeds 10^{-2}. From figure (2), it is observed that the interference increases as SNR increaseswith or without consideration of estimation noise. Theoretical SNR thresholds can be computed, by fixing the BER at a threshold level. Table. 1 shows BER_t from 10^{-2} to 10^{-5}.

Table. 1: Theoretical SNR thresholds

BER$_t$	**BPSK**	**QPSK**	**16QAM**	**64QAM**
10^{-2}	4.3dB	7.3dB	13.9dB	19.6dB
10^{-3}	***6.8dB***	***9.8dB***	***16.5dB***	***22.6dB***
10^{-4}	8.4dB	11.4dB	18.2dB	24.3dB
10^{-5}	9.6dB	12.6dB	19.4dB	25.6dB

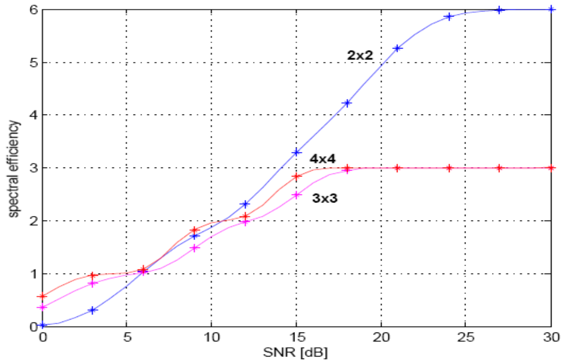

Fig. 3. Average spectral efficiencies of adaptive OSTBC in Nr × Nt with constsnt correlation coefficients $\rho_{tx} = \rho_{rx} = 0.5$.

From figure (3), the average spectral efficiencies of adaptive MIMO-OFDM OSTBC system under Nt = Nr = 2, 3, 4 are derived. It is observed that, under Nt = 3 and 4, the maximal achievable rates are only half of that achieved by 2X2 Alamouti code due to half-rate orthogonal codes (code rate =1/2) .

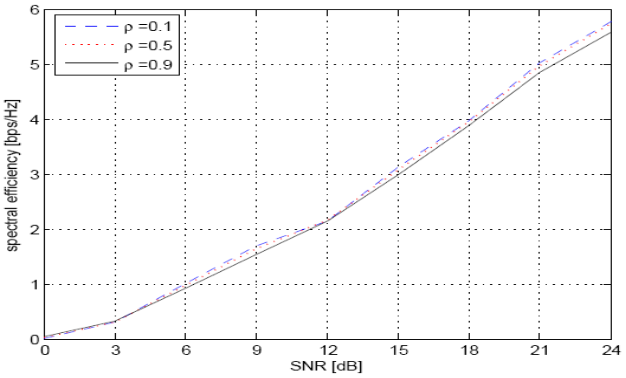

Fig. 4. Average spectral efficiencies of OSTBC in 2 × 2 under different correlation coefficients ρ_{tx} = 0.1, 0.5, 0.9, ρ_{rx} = 0.

From figure 4, the impact of spatial correlation on the average spectral efficiency is observed. It is noticed that OSTBC is more robust to the variation of the spatial correlation due to which it experiences only small variation as the correlation changes.

4. Conclusion

The errors in channel estimation process deteriorate the average spectral efficiency due to the un-removable interference. The interference increases as SNR increases. By letting the ratio between the interference to noise power as low, the actual BER approaches the target BER. By using target BER as 10^{-3} and estimation noise powers are 10^{-3}, 10^{-2} and 10^{-1}, it is observed that if the estimation noise power is dominant factor, the resultant BER is higher than the target BER as SNR increases otherwise if the interference becomes the dominating factor, the actual BERs diverge from the target level. The optimal SNR thresholds and closed-form expression for the average spectral efficiency are derived to evaluate the performance. The average spectral efficiency is dominated by the channel gain, which experiences only small variation as the correlation changes and the OSTBC scheme is more robust to the variation of the spatial correlation.. The p.d.f. of the effective SNR can be derived by using moment generating function (MGF). The average spectral efficiencies that can be achieved by using OSTBC when Nt = Nr = 2, 3, 4. The maximal achievable rates of 3X3, 4X4 are only half of that achieved by 2X2 Alamouti code.

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