A 4x4 MIMO-OFDM System with MRC in a Rayleigh Multipath Channel for WLAN

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Abstract: This paper evaluates a 4x4 MIMO-OFDM system using transmit diversity with MRC at the receive end for WLAN applications. We compare different MIMO detection algorithms with different modulation schemes. The combined MIMO-OFDM using the combined MMSE-SIC method for the IEEE 802.11a/n standards is then implemented and the performances are given.

1 Introduction

The term 'MIMO' is used to describe systems that employ the use of multiple antennas at both transmitter and the receiver so as to improve performance by achieving higher bit error rates. It is one of the major developments in the third generation wireless communication system and is internationally researched [1-8]. The signals are transmitted in multiple paths and therefore introduce spatial diversity on the data stream in the channel. It is unlikely that all the paths would encounter severe fading at the same time which allows the MIMO scheme to improve the signal liability in a natural wireless environment.

MIMO systems [3] have become attractive trends for broadband wireless communications such as wireless LAN (IEEE 802.11n), WCDMA and WiMAX (IEEE 802.16); this is partly due to the significant increase in data throughput and link range without the need to either increase the transmit power or the system bandwidth [8].

In this paper, we investigate a 4x4 MIMO system using different modulation techniques. A brief explanation of the different system components is given. This MIMO system is then combined with an OFDM signal based partially on the parameters set in the IEEE 802.11a and 802.11n standards. The results obtained using MATLAB to simulate N bits in a Rayleigh multipath environment were discussed.

2 MIMO System and MIMO Detection

2.1 System Description

Figure 1 shows a typical MIMO system. To evaluate the MIMO system, a linear representation of its associated signals is required. Assuming a system comprising N transmit and M receive antennas where x_n represents the transmitted signal, h_{mn} is the relevant entry in the channel matrix, H and v_n is the noise with a variance of σ^2, the received signal y_m is represented as follows:

$$y_m = \sum_{n=1}^{N} h_{mn} x_n + v_n \qquad \mathrm{m} = 1,2,...\mathrm{M} \tag{1}$$

The multiple transmit and receive antennas create channel coefficients [7] that can be realised in the form of an M x N channel matrix shown below.

$$H = \begin{bmatrix} h_{11} & h_{12} & \dots & h_{1N} \\ h_{21} & h_{22} & \dots & h_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ h_{M1} & h_{M2} & \dots & h_{MN} \end{bmatrix} \tag{2}$$

Therefore, at any given time, t, the received signal can be expressed in the matrix format as shown below.

$$y(t) = Hx(t) + n(t) \tag{3}$$

where y(t), x(t) and n(t) are the vectors of y_m, x_n and v_n, respectively.

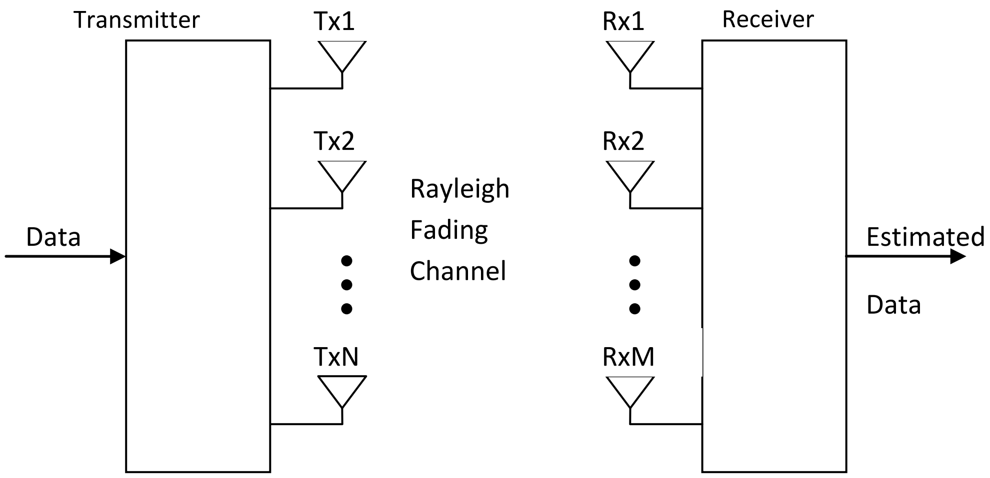


Figure 1: A typical MIMO system

2.2 Minimum Mean Squared Error, MMSE Detector

This is an algorithm which performs better than the standard ZF detector [3] under noisy conditions. Although it does not fully eliminate ISI like the ZF algorithm; it substantially reduces the total noise power experienced at the receiver [4].

$$\begin{aligned} \bar{y}_{MMSE} &= (H^H H + (\sigma_n^2 / \sigma_s^2) I)^{-1} H^H y \\ \bar{y}_{MMSE} &= (H^+ + (\sigma_n^2 / \sigma_s^2) I)^{-1} H^H y \end{aligned} \tag{4}$$

where σ_n and σ_s represent the noise power and received signal power respectively and I represents an identity matrix. It should be noted that when $\sigma_s >> \sigma_n$, the MMSE estimate equates the ZF estimate.

2.3 Ordered Successive Interference Cancellation

This is a form of non-linear equalization and is the detection algorithm utilised in this paper. The major impairment in MIMO systems is Co-Antenna Interference, CAI. This impairment is readily avoided using the OSIC algorithm [6]. This algorithm recursively detects the incoming sub-streams i.e. layers. It would initially detect the strongest layer; i.e. sub-stream with the highest SNR, and then subtracts it from the original received signal to properly eliminate the CAI. This process repeats for subsequent layers; detected on a basis of their signal strength; until all the available sub-streams / layers have been detected and subtracted from the original received signal [8].

SIC systems need initial estimates to perform efficiently. These initial estimates are obtained from the output of the MMSE detector. It can behave in two manners. Firstly, it can subtract the soft information from received signal, which leads to little or non-existent error propagation but acquires an accumulating noise effect for weak users. Secondly, it can subtract hard information from the received signal leading to little or no noise accumulation but possible error propagation. Successive interference cancellation could be done in a circular manner to improve the performance at the expense of low convergence and thus high complexity. MAI is reduced and near/far problem increased. Cancelling the strongest signal has the most benefit and is the most reliable cancellation [5]. Therefore being the most reliable cancellation, the SIC algorithm would mainly suffer from error propagation. It also requires channel estimate at the receiver [5]. Pre-filtering for general SIC systems normally adopt either a ZF or an MMSE detector [6].

3 MIMO OFDM System and Implementation of IEEE 802.11 Standards

Orthogonal Frequency Division Multiplexing (OFDM) is one of the most popular modulation schemes available due to its significant advantages over other schemes such as BPSK, QPSK and n-QAM. It is used in wireless LAN standards like 802.11a/g/n, HIPERLAN/2, Digital Video Broadcasting standard (DVBT). The latest draft of the new IEEE 802.11n standard proposes high improvements on older standards with respect to the increased throughput experienced in the physical layer (PHY); with data rates up to 600 Mbps [8]. This is achieved through the combination of OFDM with MIMO techniques.

An understanding of how to interpret the standards is required to fully understand the increased throughput in the proposed newer drafts of each 802.11 standard. As an example, the IEEE 802.11a standard is shown in Table 1 and examined further.

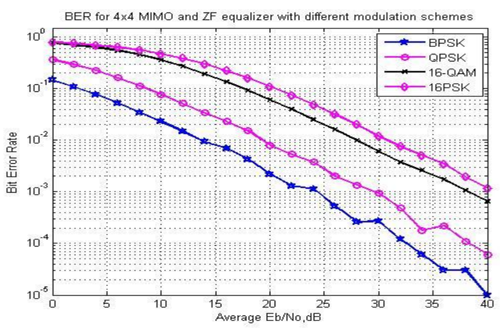
Parameter	**Value**
FFT Size	64
Used Sub-Carriers	52
Cyclic Prefix	n/4
Subcarrier spacing	312.5kHz
Index of used sub-carriers	{-26 to -1, +1 to +26}
Data symbol	3.2us

Table 1: IEEE 802.11a standard

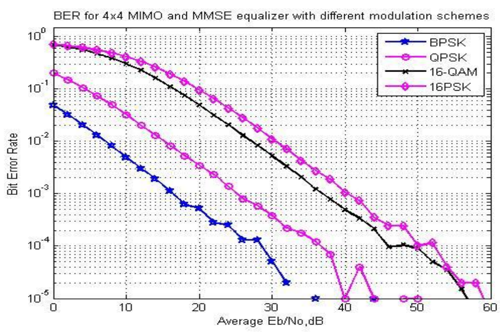
From Table 1, it is noted that the total number of subcarriers is 64 with a sampling frequency of 20MHz. In the 802.11n standard, operation at 40MHz is supported. Only 52 of these are used in the IEEE 802.11a standard but 56 are used in the 802.11n standard; these are the sub-carriers used to transmit the actual data sequence. With the symbol duration at 3.2μs, therefore the total spacing between sub-carriers is $\Delta f = {}^{1}\!/_{T}\, kHz = \pm 312.5 kHz$. A total of 16 samples are required, therefore 0.8μs is the duration of the cyclic prefix leading to total symbol duration of 4μs.

4 Simulation Results

We first studied the performance and comparison of different modulation schemes (BPSK, QPSK, 16PSK and 16QAM) and different detection methods (ZF and MMSE) for 4x4 MIMO with MRC. The results of this study are presented in Figure 2.



(a)

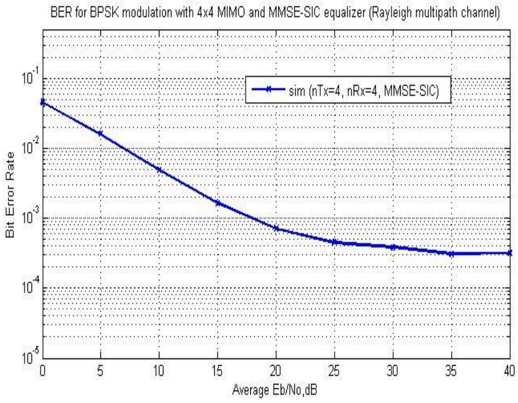


(b)

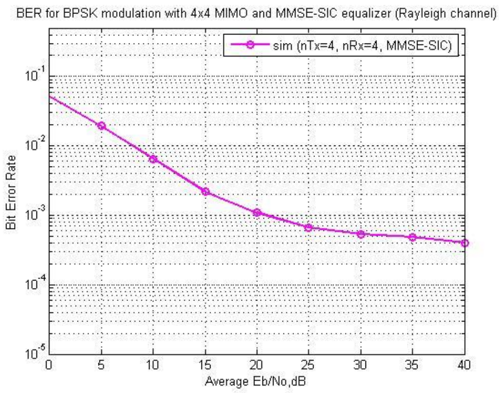
Figure 2: Comparison of different modulation schemes for 4x4 MIMO with MRC: (a) ZF and (b) MMSE

A MIMO-OFDM combination using MRC at the receive end was then investigated in a Rayleigh multipath environment. We try to achieve maximum gain by sending copies of the same OFDM through a 4x4 MIMO System. This is also called transmit diversity in OFDM systems. Maximum Ratio Combining was then used to boost the received estimated signal. Different configurations of the parameters in the 802.11a and 802.11n standards were investigated to examine the effect on the received BER values.

A data signal with N = 10^5 was modulated using OFDM for a 4x4 MIMO System. The received signal was then passed through a MRC stage to boost the performance. This data signal was investigated using OFDM partially based on the 802.11a/n standards and the results for 802.11a and 802.11n are shown in Figure 3(a) and (b) respectively. The cyclic prefix adds redundancy to the system so therefore, an account of this occurrence has been accounted for in the form of wasted energy.



(a)



(b)

Figure 3: BER values for 4x4 MIMO-OFDM with MMSE/SIC/MRC: (a) IEEE 80211a and (b) IEEE8011n

5 Conclusions

The choice of modulation scheme depends on the scenario with respect to the factors of transmission required. For instance, 16PSK and 16QAM transmit more symbols than QPSK and BPSK. The 4x4 MIMO System was investigated with receiver architecture based on ZF and MMSE receiver. As expected, due to increasing the total number of transmitted symbols per second, there would be an increase in the total number of errors and therefore the need to operate at a higher SNR values. The combination of OFDM with MIMO shows a form of flooring in the curve which signifies the need for additional coding to fully utilise the OFDM scheme. This flooring is a result of both inter-subcarrier and inter-antenna interference.

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