# BER Analysis Of IEEE802.11n MIMO System Using MMSE And ZF Detectors

Ye Lwin Oo, Su Su Yi Mon, Hla Myo Tun

**Abstract:** With the increasing demand of higher data rate for telecommunication, the IEEE802.11n standard was constituted in 2009. The most important character of the standard is MIMO-OFDM, which not only improves the throughput but also the spectrum efficiency and channel capacity. And in wireless communication, the role of MIMO detectors plays an important part to remove inter-symbol interference (ISI) caused by multipath fading channel. In this paper the BER performance of IEEE 802.11n for 3x2, 4x2 and 4x3 antennas are compared using MMSE and ZF detectors in Matlab Simulink.

**Keywords:** BER, Detector, MIMO-OFDM, Simulink.

## I. Introduction

WLAN is a wireless broadband technology that utilizes radio frequency (RF) to transmit and receive data through air interface. It is basically used to substitute wired Ethernet as well as in public hot spot wireless network because of its high data rates [1].The first WLAN standard is IEEE 802.11 WLAN which operates in 2.4 GHz frequency spectrum with data rate up to 2 mbps. Now, IEEE 802.11 WLAN has a variety of standards such as 802.11a, 802.11n, 802.11b and 802.11g, with operating frequency Spectrum of 5 GHz and 2.5GHz with data rate up to 54 mbps, 140 mbps, 11 mbps and 54 mbps respectively [2,3,4 ]. EEE 802.11n uses MIMO techniques to increase the throughput significantly compared to the previous IEEE 802.11 standard sets.[5]MIMO is an important part of the IEEE802.11n standard and is also widely used in today's wireless communication. By using multiple antennas at the transmitter and the receiver, both the throughput and the range of the reception can be improved. MIMO can also provide better capacity and potential of improved reliability compared to single antenna channels. And the combination of MIMO and OFDM is a very effectual way to achieve high efficiency spectral wideband systems. Multipath propagation can lead to fading problems. Components with the same phase will be added constructively, while components with opposite phase will be added destructively. For MIMO, Generally there are two ways to solve the problem, Spatial Diversity and Spatial Multiplexing. Spatial Diversity is the idea that, in case the antennas are spaced apart enough, the fading problem will occur independently. By always selecting the antenna with the best channel, the probability of a poor reception is dramatically reduced. The communication will be more stable, but the data rate can't be increased so much this way. In this case, Spatial Diversity is usually used in lower signal to noise ratio situations.



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To get a redundant signal, space- time code can be used. Spatial multiplexing, on the contrary, increases the data rate but do not make the transmission system more robust. The radio channels in wireless communications systems are usually multipath fading channels, which can cause inter-symbol interference (ISI) in the received signal. To remove ISI from the signal, a strong equalizer which requires knowledge on the channel impulse response (CIR) is required.[6]

## II. MIMO Detection

MIMO detection refers to the process of determining the transmitted data symbols, sent using SDM, from the received signal vector.[7] In this part, transmitted streams will be separated and channel equalization will be done.The reception of MIMO OFDM needs to be implemented individually. There are three main methods to realize MIMO detection: Minimum Mean Square Error (MMSE) linear detector. Here, MMSE and ZF detectors are used. For MIMO detection, basic form of a memoryless MIMO system is

$$r = Ha + n \qquad (1)$$

where

r = the N-dimensional receive signal vector,
H = the N x M matrix of channel estimates
n = a complex additive white Gaussian noise vector

### A. Minimum Mean Square Error (MMSE) Detector

A MMSE estimator is a method in which it minimizes the Mean square error (MSE), which is a universal measure of estimator quality[8]. The most important characteristic of MMSE equalizer is that it does not usually eliminate ISI totally but instead of minimizes the total power of the noise And ISI components in the output.

For MMSE linear detector, if the additional constraint CH =I is ignored, C is able to minimized as

$$MSE=E[\|S'-S\|^2] \qquad (2)$$

$$S'=W^H R \qquad (3)$$

Where S' = estimated signal
S = transmitted signal
R = received signal

Assuming signal from each antenna are independent and noise from each path are independent.

$$E[SS^H]=I \qquad (4)$$

$$E[SN^H]=0 \qquad (5)$$

$E[NN^H]=\sigma^2 I$ (6)

Here $\sigma^2$ is noise variance

$\frac{\partial MSE}{\partial W}=\frac{\partial}{\partial W}E[(S-W^H R)^H(S-W^H R)$ (7)

$=E[R^H(S-W^H R)]-E[(S-W^H R)^H R]$

$=2E[R^H W^H R]-2E[R^H S]$

$\frac{\partial MSE}{\partial W}=2E[(HS+S)^H W^H(HS+N)]$ (8) $-2E[(HS+N)^H S]$

$=2H^H HW^H R(SS^H)+2W^H E(NN^H)-2H^H E(SS^H)$

$=2(H^H H+\sigma^2 I)W^H-2H^H$

Let the equation above be equal to zero, then

$W^H=(H^H H+\sigma^2 I)^{-1}H^{-1}$(9)

In that case C can be written either

$C=H^H(HH^H+N_0 I)^{-1}$ (10)

or

$C=(H^H H+N_0 I)^{-1}H^H$ (11)

In the formula above, $N_0$ means noise power, which can be measured by using the received signal. That kind of method can decrease the error caused by noise and the same spectrum signal interference, without increasing noise.

### B. Zero-forcing Detector

The zero-forcing liner detector selects the liner detector matrix C in order to eliminate interference completely. [9] Assuming that the columns of H are linearly independent, CH = Iwill always exist. If the channel has the same number of inputs as outputs, H is a square matrix and the ZF linear detector has a unique solution:$C = H^{-1}$. [7] In the other case, for the situation that the channel consists more outputs than inputs, which means there are more RX antennas than TX antennas, there will be an infinite number of solutions for CH = I. Then C is chosen in the situation that itcan minimize $MSE = E[||Cr - a||^2$. The form of ZF linear detector is

$C=(H^H H)^{-1}H^H$(12)

$C=H^{-1}$(13)

when H is invertible.

A drawback with the ZF linear detector is that it focuses solely on interference cancellation. [7] In this process, it can also remove signal energy that projects onto the interference subspace, even when the interference is significantly lower than the desired signal. [7].

## III. System Model

The simulation is done according to the parameters from Table 2 set by IEEE802.11n standard.

***Table I***

*Parameters of IEEE802.11n(PHY)[5]*

| Parameters | Specification |
|---|---|
| Modulation Type | 64QAM |
| Channel Model | AWGN |
| Coding Technique | Convolutional Code |
| No. of transmitter x No. of receiver | 3x2 , 4x2 and 4x3 |
| FFT Length | 64 points IFFT, 56 subcarriers(52 data subcarriers and 4 pilot subcarriers) |
| Cyclic Prefix Length | 16 |
| Detector | Minimum Mean Square Error Detector (MMSE) and Zero Forcing (ZF) detector |
| Bandwidth | 20 MHz |

At the transmitter side, data is generated with a random integer generator. This data is passed through convolutional encoder and parsed into two spatial streams. These streams are modulated and coded with STBC encoders.The outputs of STBC encoders are given to OFDM modulators and then passed through AWGN channel. At the receiver side, cyclic prefix is first removed then OFDM decoder is used to decode the data .Finally using channel impulse response from estimation the most possible and efficient combination is chosen by STBC combiner and MMSE (or) ZF detector. The Simulink model of MIMO detection is shown in Figure 1.

### A. MIMO Detection Model

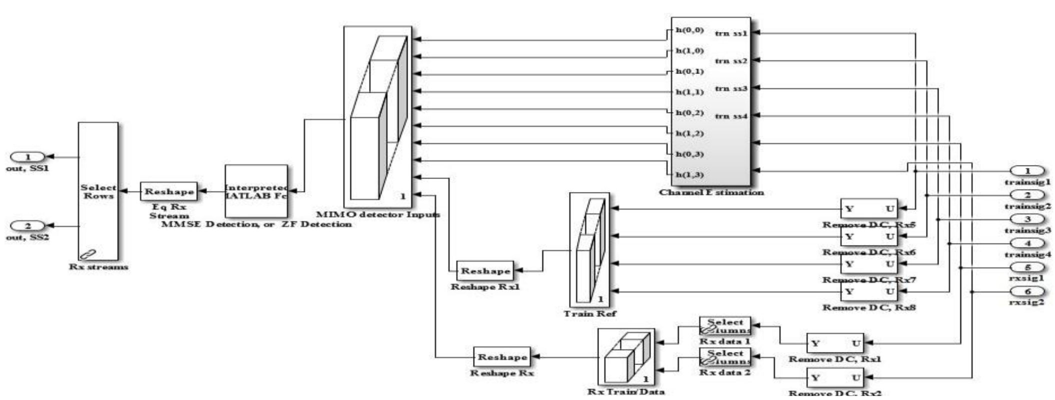


***Figure 1:*** *MIMO Detection Simulink model*

A whole MIMO detection model used in the Simulink simulation part is shown. The key point of the model is the channel estimation. In the model remove DC means removing the DC component of the matrix. Select training data is to choose the training data from the received signal. By using channel matrices obtained from channel estimation , and received training data and signal , ZF or MMSE detection is done to give to outputs as SS1 and SS2.

**B.Channel Estimation Model**

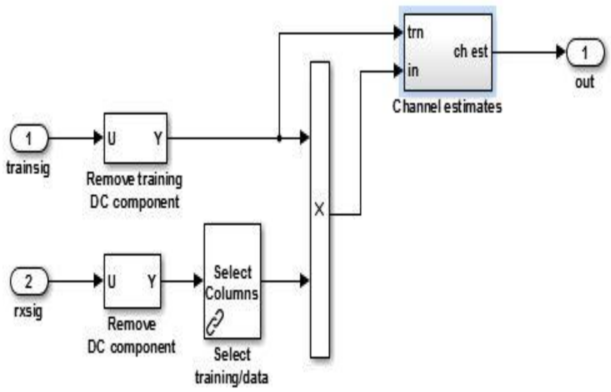


***Figure 2:*** *Channel Estimation Model*

After removing DC components from the training signal and the received signal,and selecting the training part form the received signal, channel estimation is done as follows: The receive sequence can be represented in matrix as

$R_k = H_k (S_k P) + N_k$(14)

To obtain a least squares estimation of the MIMO channel, it can be written as

$$R_kW = H_k (S_k P) W + N_kW \quad (15)$$
$$= H_k + N_k W$$

where

$W= U_H (UU^H)^{-1}$ (16)

$U = S_k P$ (17)

Since

$S_k = 1/ -1$

$W = S_k P^H (P P^H)^{-1}$ (18)

In the equations above, Sk. P is the transmitted training sequence and $R_k$ is the received sequence for sub-carrier k, $N_k$ is noise and $H_k$ is MIMO channel

**C. Bit Error Rate (BER) and Signal To Noise Ratio (SNR)**

The bit error rate (BER) is defined as therate at which errors occur in a transmission system during a studied time interval. BER is a unitless quantity, often expressed as a percentage or 10 to the negative power.

The definition of BER can be translated into a simpleformula:

$$\text{BER}= \frac{\text{number of errors}}{\text{total number of bits sent}} \quad (19)$$

The SNR is the ratio of the received signal power over the noise power in the frequency range of the process. SNR is inversely related to BERSNR is anindicator usually measures the clarity of the signal in acircuit or a wired/wireless transmission channel andmeasure in decibel (dB). The SNR is the ratio betweenthe wanted signal and the unwanted background noise.

$$\text{SNR}= \frac{P_{signal}}{P_{noise}} \quad (20)$$

SNR formula in terms of BER:

$$\text{BER}= \frac{1}{\text{SNR}} \quad (21)$$

**D. Number of Antennas**

The number of simultaneous data streams is limited by the minimum number of antennas on both sides of the link. However, the individual radios further limit the number of spatial streams that may carry data. The a x b : c notation helps identify what a givenradio is capable of. The first number (a) is the maximum number of transmit antennas or TX RF chains that can be used by the radio. The second number (b) is the maximum number of receive antennas or RX RF chains that can be used by the radio. The third number (c) is the maximum number of data spatial streams the radio can use. For example, a radio that can transmit on two antennas and receive on three, but can only send or receive two data streams would be 2 x 3 : 2. The 802.11n allows up to 4 x 4 : 4 [1] . In my system, 3 x 2 : 2 , 4 x 2 : 2 and 4 x 3: 3 configurations are used .

## IV. SIMULATION RESULTS

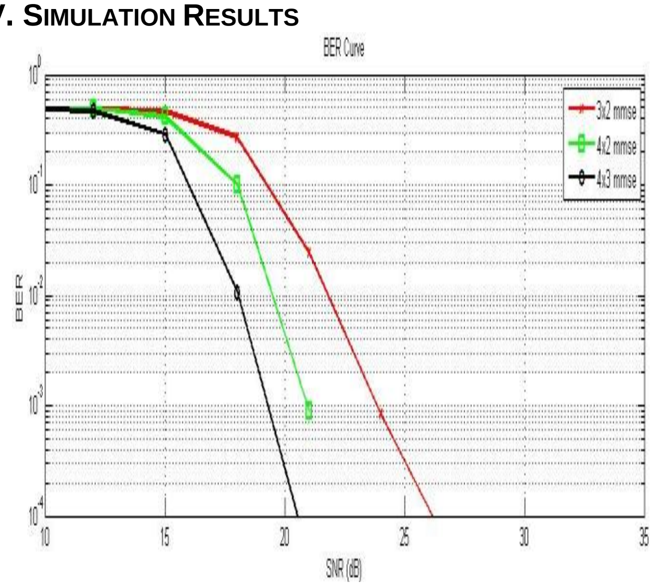


***Figure 3:*** *BER plot for IEEE 802.11n with Minimum Mean Square Error equalization*

Figure 3 shows BER results of IEEE 802.11n system using 64QAM and MMSE equalization for 3x2, 4x2 and 4x3 antennas. It is observed that the system of 4x3 has better BER than the systems of 4x2 and 3x2.

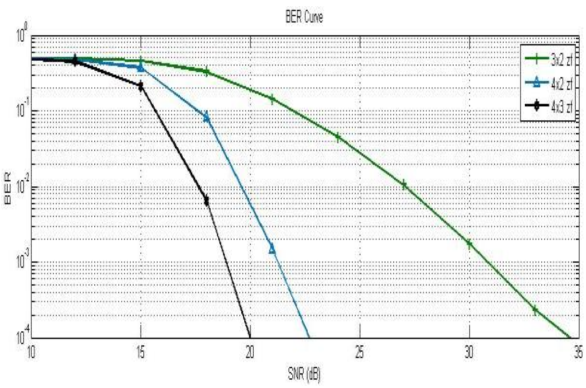


***Figure 4 :*** *BER plot for IEEE 802.11n with Zero Forcing equalization*

Figure 4 shows BER results of IEEE 802.11n system using 64QAM and ZF equalization for 3x2, 4x2 and 4x3 antennas. It can be seen that the system of 4x3 has better BER than the systems of 4x2 and 3x2 and BER of 4x3 system is better than 4x2. Comparing two equalization schemes, at 0.001 BER point, Zero Forcing equalization results in around 1dB improvement for 4x3 antenna system. For 4x2 system, ZF equalization gives BER of 0.001 at about 21.5dB of SNR while MMSE detection gives BER of 0.001 at about 21dB of SNR. For 4x3 system, MMSE detection results in around 7dB improvement at BER of 0.001. So MMSE equalizer can give better BER than ZF equalizer.

***TABLE II***

*SNR VS BER VALUES FOR IEEE802.11N UNDER TWO ANTENNA CONFIGURATIONS*

| Equalizer | No: of antennas | BER | SNR(dB) |
|---|---|---|---|
| MMSE | 3x2 | $10^{-3}$ | 23.8 |
| | 4x2 | $10^{-3}$ | 21 |
| | 4x3 | $10^{-3}$ | 19.2 |
| ZF | 3x2 | $10^{-3}$ | 30.8 |
| | 4x2 | $10^{-3}$ | 21.2 |
| | 4x3 | $10^{-3}$ | 19 |

Table II shows the values of SNR corresponding to BER of $10^{-3}$for IEEE802.11n system of 3x2, 4x2 and 4x3 antenna configurations using MMSE and ZF equalizers.

## V. CONCLUSIONS

Equalization techniques are very important in the design of high data rate wireless systems. They can combat for inter symbol interference even in mobile fading channel with high efficiency. This paper provides bit error rate (BER) comparisons of IEEE802.11n system for 3x2 , 4x2 and 4x3 antenna configurations using zero forcing (ZF) and minimum mean square error (MMSE) detectors. Zero Forcing equalizer performs well only in theoretical assumptions that are when noise is zero. Its performance degrades in mobile fading environment. Minimum Mean Square Error (MMSE) equalizer uses LMS (Least Mean Square) as criterion to compensate ISI. BER of $10^{-3}$ is acceptable for wireless communication system. According to table 2, for 3x2 antenna system, using MMSE detector requires only 23.8 dB of SNR to get BER of $10^{-3}$ while using ZF detector requires 30.8 dB. Using MMSE detector needs 21 dB of SNR and ZF detection needs 0.2 dB more than MMSE detection for 4x2 system. For 4x3 system, at BER $10^{-3}$ point, the required SNR for MMSE detection systemis 19.2 and 19 for ZF detection. So by observing the simulation results,it can be concluded that MMSE detector can give better BER than ZF detector.

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