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MIMO-OFDM System with ZF and MMSE Detection Based On Single RF Using Convolutional Code

Djoko Santoso, I Gede Puja Astawa, Amang Sudarsono

Abstract— **MIMO-OFDM system with detectors Zero Forcing (ZF) and Minimum Mean Square Error (MMSE) is used to eliminate fading and using convolutional code that can help the performance of channel coding in order to work optimally. This coding technique is expected to generate a low BER curves. MIMO-OFDM based on single Radio frequency (RF) has the function to efficiency power consumption. In a previous study discusses the performance of MIMO-OFDM system based on single RF, the result that a single RF antenna symbol rate may change periodically and does not require a high power consumption. Computer simulation results shows that channel estimation in MIMO-OFDM system based on single RF working properly shown by the curve magnitude and phase, showing the performance of MIMO-OFDM system based on single RF with some parameters such as detectors, modulation, convolution code on the curve BER on the SNR.**

Index Terms— **Convolutional Code, MIMO-OFDM, MMSE, Single RF, ZF.**

I. INTRODUCTION

At this time, the development of information technology is increasing, especially in the wireless communication network system or Local Area network (LAN). Wireless LAN (WLAN) has increased significantly, and this is because the number of user requests the system. This development encourages communication network can work easily, fast, efficient and cost-effective. The technique is usually used in a wireless communications network system (LAN) is Multiple Input Multiple Output (MIMO) and Orthogonal Frequency Division Multiplexing (OFDM). For its development, wireless communication systems require large bandwidth, but in real conditions bandwidth is limited. To overcome bandwidth requirements, it can use the method that combines MIMO and OFDM to produce a system with high speed data transfer without expanding bandwidth. But on the other hand, this system has disadvantage that requires a large power consumption in the communication process, then used a single Radio Frequency (RF) antenna which serves to efficiency use of the power consumption.

Single RF located on the receiver to change the symbol rate on a periodic basis and does not require high power consumption [1]. In addition MIMO-OFDM system in this study using convolutional code and uses a detectors ZF and MMSE. This coding technique is needed to get the value of Quality of Services (QOS) that is expected and can result in Bit Error Rate (BER) is low and can work optimally. Meanwhile, ZF and MMSE detectors used to reduce fading that occurs when the transmission process.

On the transmitter using the convolutional code rate (1/2), the use of convolutional code compared with the performance of MIMO-OFDM system without convolutional code that shown on the curve Bit Error Rate (BER) and the modulation technique used 4-QAM and 16-QAM , On the receiver, MIMO technique uses a special technique is required to recover information that has been send. There are used several linear detection technique and applied as detectors MIMO systems, the technique is a minimum mean square error (MMSE), zero forcing (ZF). As well as using the Viterbi algorithm to decode.

II. SINGLE RF ANTENNA IN MIMO OFDM SYSTEM

Single RF antenna or ESPAR antenna (Electrically steerable Parasitic Array Radiator) [6] is a tool that used to transmit and receive radio signals. ESPAR antenna consists of a monopole or dipole element, this antenna has a composition where one active element is surrounded by a variety of passive elements. Figure 1 illustrates the single RF antenna. Single RF in this section is composed of a radiator and parasitic elements terminated with a variable capacitor. Since the radiator and parasitic elements are electromagnetically couple, the output of the single RF antenna is a weighted sum of the received signal the each element.

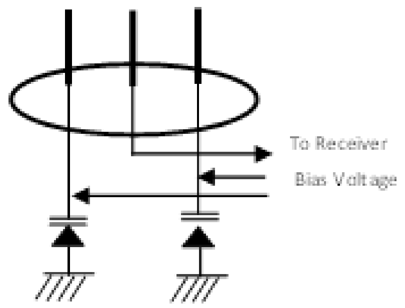

Fig. 1. Single RF antenna Structure [2]

Figure 2 shows the frequency spectrum of the transmitted and received signals. Fig.2(a) is the frequency spectrum of the transmitted signal. Subcarriers are divided into two groups and allocated to the positive and negative sides of the frequency band. The frequency spectrum of the received

Djoko Santoso, Department of Electrical Engineering, Politeknik Elektronika Negeri Surabaya, Indonesia
I Gede Puja Astawa, Department of Electrical Engineering, Politeknik Elektronika Negeri Surabaya, Indonesia
Amang Sudarsono, Department of Electrical Engineering, Politeknik Elektronika Negeri Surabaya, Indonesia

signal at the output of the phase shifting element is illustrated in Fig.2(b), whose frequency is a positive frequency shifted for subcarrier frequency spacing. The received signal is composed of the shifted and the non-shifted signal components as shown in Fig.2(c), the overall number of efficient subcarriers are N+2, where N is the number of subcarriers.

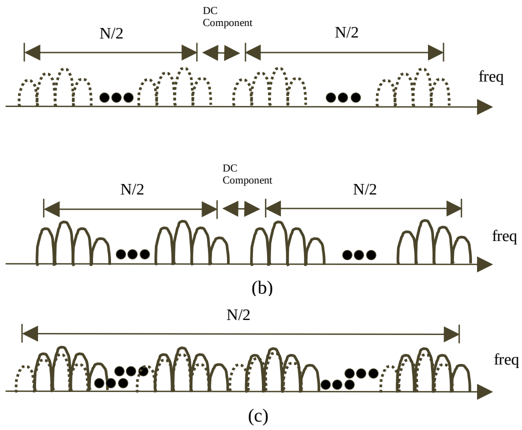

Fig. 2. The frequency spectrum of transmitted and received signals. (a) in the transmitter, (b) In the phase shifting element of receiver (c) in the combiner of receiver [3]

Now, let $v_d(t)$ and $v_p(t)$ be the received signals corresponding to the phase non-shifting and the phase shifting elements, respectively. In tthis scheme the phase shifting is controlled by the oscillator whose frequency is the same as the subcarrier spacing of the OFDM signals. Then the output of the RF signal processing is given by

$$v(t) = a v_d(t) + \beta e^{\frac{j2\pi t}{T_s}} v_t(t) \quad (1)$$

where T_s is a FFT (Fast Fourier Transform) window period of the OFDM signal, while α and β are weighting factors for the phase non-shifting element and the phase shifting element. At the receiver, a specific type of equalization to reduce the ICI (Inter Channel Interference) generated by the proposed scheme. In the following I derive the channel estimation algorithm for the proposed RF signal processing based diversity receiver. The received signal is applied to the FFT processor followed by the frequency-domain equalizer.

Assume that the transmitted symbol vector in the frequency-domain is

$$x = [x_{0,} x_{1,} \dots, x_{N-1}]^T \quad (2)$$

where x_k is the data symbol of the k-th subcarrier. The transmitted symbol vector is divided into two parts, and zeros are padded to adjust the vector size to FFT window. The modified transmitted vector is given by

$$\hat{x} = \left[0 \left| x_0 x_1 \dots x_{\frac{N}{2}-1} \right| x_{NFFT-N-1} | x_{\frac{N}{2}} \cdots x_{N-1}\right]^T \quad (3)$$

Where N_{FFT} is the FFT window size. The data symbol in the time-domain is given by

$$v = F^{-1}\hat{x}, \quad (4)$$

where F is the Fourier transformation matrix that is, the k-th column l-th raw element of F is $e^{\frac{2\pi kl}{N_{FFT}}}$. The transmitted symbol v is the propogated though the multipath fading channel. The received signal component at the i-th element is given by

$$q_i = C_i v \quad (5)$$

where C_i, is the channel impulse response matrix corresponding to the i-th element. The received signal at the input of the baseband demodulation block is given by

$$\begin{aligned} r &= q_i + D_{qi+1} + Z_T \\ &= (c_i + D_{c2})y + Z_T \\ &= (C_1 + DC_2)F^{-1}X + Z_T \end{aligned} \quad (6)$$

Where z_T is the thermal noise component in the time-domain, and D = diag{d_0, d_1, d_2, … d_{N-1}} is a diagonal matrix, whose k-th diagonal element is d_k according to (1), d_k is given by

$$d_k = ee^{j\frac{2\pi k}{N_{FFT}}} \quad (7)$$

The received signal is applied to the FFT. The output of the `FFT is then given by

$$\hat{u} = Fr = (\hat{H}_1 + \hat{G}\hat{H}_2)\hat{x} + \hat{z} \quad (8)$$

Where z = F z_T is the thermal noise component in the frequency-domain. And

$$\hat{H}_1 = FC_iF^{-1} \quad (9)$$

Is a diagonal matrix (i = 1,2), whose diagonal elements represent the frequency response [3].

$$\hat{G} = FDF^{-1} \quad (10)$$

A. *Channel Estimation*

Channel estimation is one of the error-correcting function to generate channel estimation information. Channel estimation works by inserting pilot at transmitted data, there are two kinds of the pilot insertion block-type pilot and comb-type pilot [8],[9]. The aim of the MMSE estimation is to get a better estimation. Let the pilot symbol and its cyclic shifted one be P_1 and P_2 respectively. The received signal u_i calculated at the i-th RF signal processing in the frequency-domain is given by

$$u_i = P_1 h_{i,1}^{ns} + GP_1 h_{i,1}^{s} + P_2 h_{i,2}^{ns} + GP_2 h_{i,2}^{2} + z \quad (11)$$

where $h_{i,1}^{ns}$ and $h_{i,1}^{s}$ are the channel response between the i-th receiver antenna element and l-th transmitter antenna element for the phase non-shifting element (ns) and the phase shifting element (s), respectively, by using R = $E[u_i u_i^H]$ dan $B_i = E[u\, h^H]$ for auto-correlation matrix formed by

$$R = P_1 R_h P_1^H + G P_1 R_h P_1^H G^h + P_2 R_h P_2^H + G P_2 R_h P_2^H + \delta_z^2 I \quad (12)$$

And cross-correlation is given by

$$B_i^{ns} = P_i R_h$$
$$B_i^{s} = G P_i R_h \quad (13)$$

where i = 1,2. B_i^{ns} and B_i^{s} are a cross-correlation matrix in i-th receiver antenna element for the phase non-shifting element (ns) and the phase shifting element (s). The channel response is finaly estimated by

$$h_i = W_i^H u \quad (14)$$

where

$$W_i = R^{-1} B_i \quad (15)$$

Is the weight matrix in terms of the minimum mean square error (MMSE) criterion, where R^{-1} is the inverse matrix of R.

B. *Equalizer Zero Forcing and MMSE*

In this section describe of equalizer type in MIMO system. In the following we assume zero forcing (ZF) and MMSE equalizer. Zero forcing equalizer is the equalizer that combines the channel response with equalizer response to force the output to produce the level of "0". Then estimated channel response[7] is given by

$$W_{zf} = (H^H H)^{-1} H^H r \quad (16)$$

Although zero forcing equalizer can eliminate ISI well, but the equalizer didn't give a good performance in the communication system because zero forcing ignored the noise in the system. Another equalizer that ignored noise is MMSE equalizer. MMSE equalizer is the development of zero forcing equalizer. MMSE equalizer may reduce the effect of ISI and overcome interference in the channel so that error becomes less. The MMSE equalizer is given by

$$W_{mmse} = (\alpha I_{Nt} + H^H H)^{-1} H^H r \quad (17)$$

Where α denotes the variance of the noise and I denotes the identity matrix. The advantage of MMSE equalizer against zero forcing equalizer is to reduce the enhancement. It is noted that the MMSE in equation (17) reaches ZF when α = 0.

III. Single RF Antenna with Coding in MIMO OFDM System

In this section we present about MIMO-OFDM system with ZF and MMSE detection based on single RF using convolutional code. The transmitter and receiver block diagrams of the proposed shown in Fig.3 and Fig.4

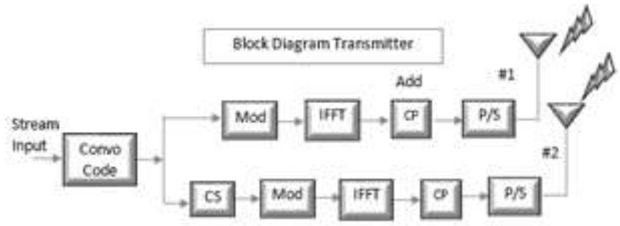

Fig. 3. Block diagram transmitter of MIMO-OFDM system based on Single RF

At the transmitter in Fig.3 we use convolutional code. Convolutional code is the non-blok code or sequential code that has fuction to channel coding process. At the receiver in Fig.4, we use two single RF antenna for receiving the signal and Viterbi algorithm. The received signals are then applied to the corresponding FFT processor followed by channel estimator and MIMO decode. The output of the MIMO-OFDM decoder is then applied to the demapper to demodulate the symbol then Viterbi algorithm is a decoding method

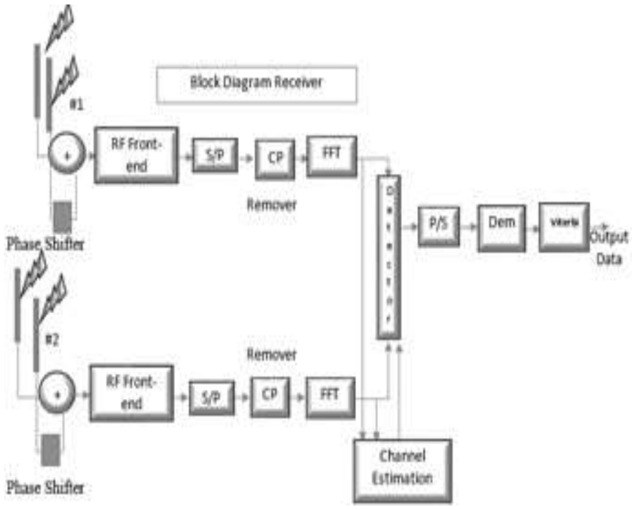

Fig. 4. Block diagram receiver of MIMO-OFDM system based on single RF

A. *Conventional code*

In the transmitter, stream input encoded by convolutional code. In the following we use convolutional code rate ½. Convolutional code is one part of the coding techniques that can help the working channel coding in order to work optimally. Convolutional codes are commonly specified by three parameters (n,k,m). n is the number of output bits, k is the number of input bits, m is the number of memory registers. The quantity k/n called the code rate is a measure of the efficiency of the code. Commonly k and n parameters range from 1 to 8 from 2 to 10 and the code rate 1/8 to 7/8 except for deep space applications where code rates as log as 1/100 or even longer have been employed. Often the manufacturers of convolutional code chips specify the code by parameters (n,k,L). the quality L is called the constraint length of the code and is defined by[4],[5].

Constraint Length, L = k (m-1) (18)

The constraint length L represents the number of bits in the encoder memory that affect the generation of the n output bits. The constraint length L is also referred to by the capital letter K, which can be confusing with the lower case k, which represents the number of input bits. Code convolution structure rate ½ shown in Fig.5.

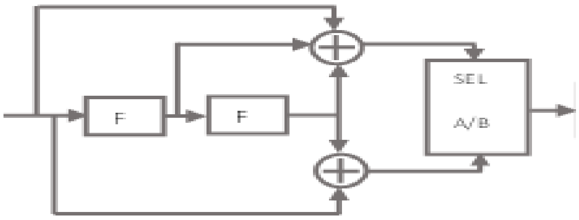

Fig.5. Code convolution structure rate ½ [4]

At the convolutional code in Fig.5. has (2,1,2) structure, It's mean that n (output) = 2, k (input) = 1, and m (memory) = 2. Convolutional code has three ways to signal analyze there are consist of state diagram, tree diagram and trellis diagram. State diagram for (2,1,2) code shown in Fig.6. Each circle represents a state. At any one time, the encoder resides in one of these states. The lines to and from it show state transitions that are possible as bits arrive. Only two event can happen at each time, arrival of 1 bit or arrival of 0 bit. Each of these two events allows the encoder to jump into a different state.

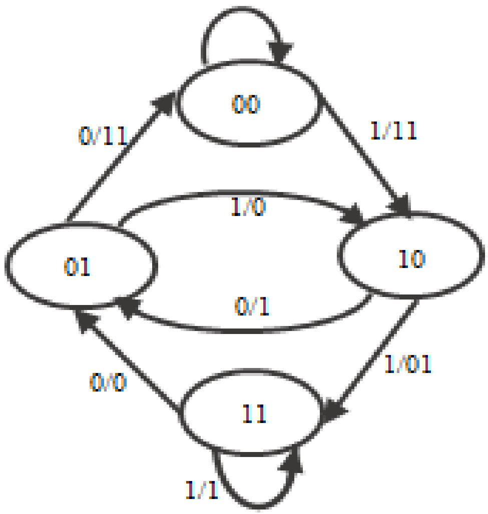

Fig.6. State diagram rate ½ [4]

The second way is tree diagram. The three diagram attempts to show the passage of time as we go deeper into the tree branches. It is somewhat better than a state diagram but still not offered approach for representing convolutional codes. Fig.7 shows the tree diagram for the code (2,1,2).

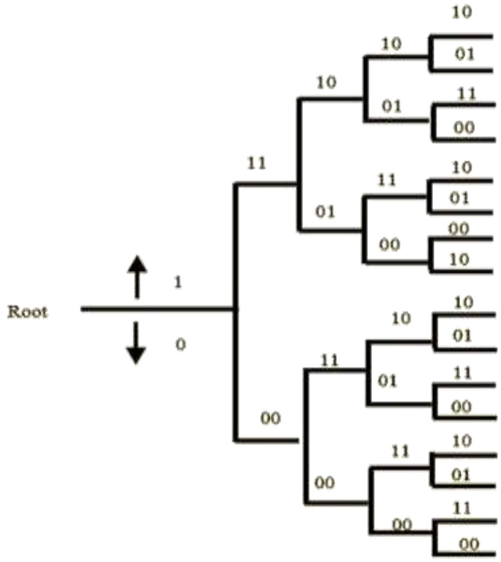

Fig.7. Tree Diagram rate ½ [4]

And the third way is trellis diagram, trellis diagram are messy but generally preferred over booth tree and the state diagrams because they represent linear time sequencing of events. The x-axis is discrete time and all possible states are shown on the y-axis. We move horizontally through the trellis with the passage of time. Each transition means new bits have arrived.

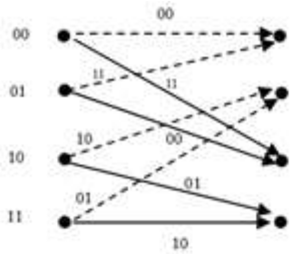

Fig.8. Trellis Diagram rate ½ [4]

B. Viterbi Algorithm

In the receiver, the data decoded by viterbi algorithm. Viterbi decoding is the best known implementation of the maximum likely-hood decoding. Here we narrow the options systematically at each time tick. The principal used to reduce the choices in this

1. The error occur infrequently. The probability of error is small.

2. The probability of two error in a row is much smaller than a single error, that is the errors are distributed randomly.

The Viterbi decoder examines an entire received sequence of a given length. The decoder computes a metric for each path and makes a decision based on this metric. All paths are followed until two paths converge on one node. Then the path with the higher metric is kept and the one with lower metric is discarded. The paths selected are called the survivors.

For an N bit sequence, total numbers of possible received sequences are 2^N of these only 2^{kt} are valid. The

Viterbi algorithm applies the maximum-likelihood principles to limit the comparison to 2 to the power of *kL* surviving paths instead of checking all paths. The most common metric used is the hamming distance metric. This is just the dot product between the received code-word and the allowable code-word [4].

IV. Simulation and Discussions

A. System Parameter

The transmitted symbols belong to a QAM (Quadrature Amplitude Modulation) constellation (4-QAM and 16-QAM) and are obtained from the information bits. In this simulation we use pilot sequence of high throughput long training Field (HTLTF) based on IEEE 802.11n for frequency in 20 MHz. The total number of subcarriers are 56 and complete of simulation parameter is shown in Table 1. The multipath fading channel is generated by Rayleigh fading channel.

Table 1 Simulation Parameters

	Parameters	Value
Transmitter	Pilot sequence Encoding Type of Modulation Number of Subcarrier Size of FFT/IFFT Antenna dimension Guard Interval ratio	HTLTF for 20 MHz Convolutional Code QAM 56 64 2x2 1/4
Channel	Rayleigh fading	Two-rays
Receiver	Channel estimation Equalization Decoding	MMSE ZF and MMSE Viterbi

B. Performance Assessments

This section we show output our scheme simulation for a 2x2 MIMO OFDM based on single RF. The results of the simulation MIMO-OFDM system using zero forcing and MMSE equalizer shown in Fig.9.

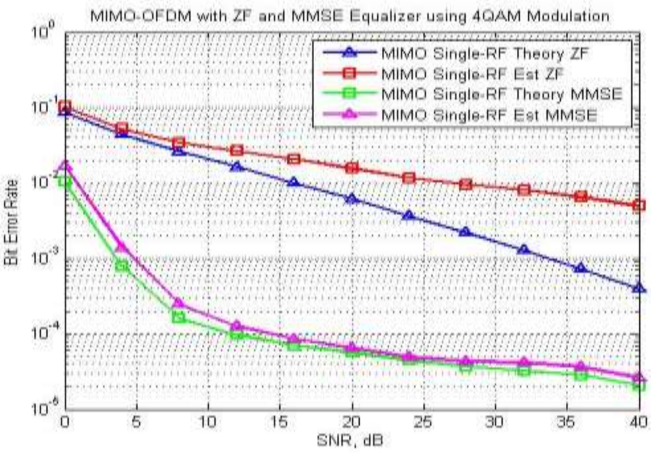

Fig. 9. BER performance of MIMO-OFDM system with ZF and MMSE equalizer using 4-QAM modulation

The performance are compare ZF and MMSE equalizer using 4-QAM modulation MIMO-OFDM system based on single RF in theory and estimation. In Fig.9 we compare performance bit error rate for ZF and MMSE equalizer. MIMO-OFDM system using ZF equalizer in theory yields results better than ZF estimation and ZF equalizer theory can reach voice communication standard 10^{-3} gives diversity gain of ≈ 33 dB. MIMO-OFDM system using MMSE equalizer in theory and estimation can reach voice communication standard 10^{-3}, MMSE theory gives diversity gain of ≈ 4 dB and 5 dB for MMSE estimation. So the performance of MMSE equalizer yields results better than ZF equalizer in MIMO-OFDM system based on single RF.

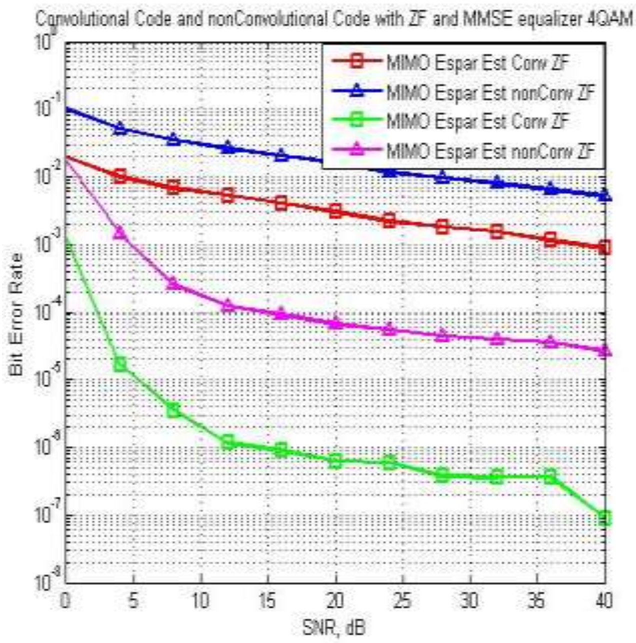

Fig. 10 BER performance of MIMO-OFDM system with and without convolutional code using ZF and MMSE equalizer 4-QAM modulation

The performance are compare ZF and MMSE equalizer with and without convolutional code using 4-QAM modulation MIMO-OFDM system based on single RF. In Fig.10 compare performance bit error rate with and without convolutional code. MIMO-OFDM system with ZF equalizer using convolutional code yields results better than MIMO-OFDM system without convolutional code and ZF equalizer using convolutional code can reach voice communication standard 10^{-3} gives diversity gain in ≈ 38 dB. Then MIMO-OFDM system with MMSE equalizer using convolutional code yields better than MIMO-OFDM system without convolutional code, but both of them can reach voice communication standard 10^{-3}, MMSE equalizer using convolutional code gives diversity gain in 0dB can reach 10^{-3} then MMSE equalizer without convolutional code gives diversity gain in 5dB can reach 10^{-3}.

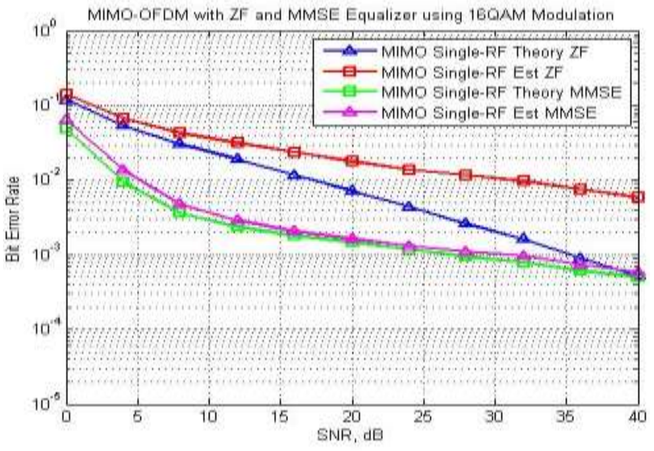

Fig.11. BER performance of MIMO-OFDM system with ZF and MMSE equalizer using 16-QAM modulation

The performance are compare ZF and MMSE equalizer using 16-QAM modulation MIMO-OFDM system based on single RF in theory and estimation. In Fig.11 we compare performance bit error rate for ZF and MMSE equalizer. MIMO-OFDM system using ZF equalizer in theory yields results better than ZF estimation and ZF equalizer theory can reach voice communication standard 10^{-3} gives diversity gain of ≈ 35 dB. MIMO-OFDM system using MMSE equalizer in theory and estimation can reach voice communication standard 10^{-3}, MMSE theory gives diversity gain of ≈ 27dB and31 dB for MMSE estimation. So the performance of MMSE equalizer yields results better than ZF equalizer in MIMO-OFDM system based on single RF.

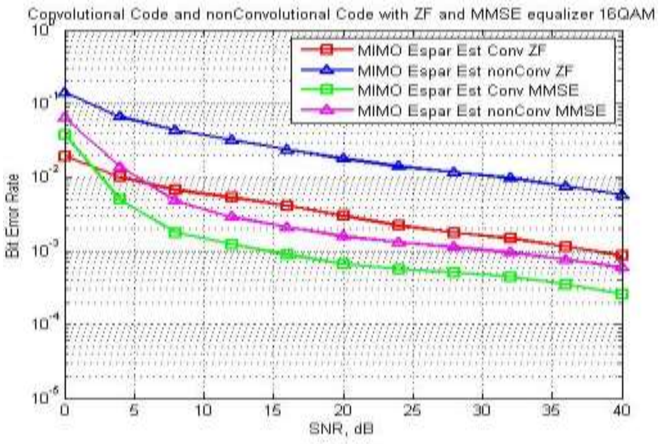

Fig.12. BER performance of MIMO-OFDM system with and without convolutional code using ZF and MMSE equalizer 16-modulation

The performance are compare ZF and MMSE equalizer with and without convolutional code using 16-QAM modulation MIMO-OFDM system based on single RF. In Fig.12 compare performance bit error rate with and without convolutional code. MIMO-OFDM system with ZF equalizer using convolutional code yields results better than MIMO-OFDM system without convolutional code and ZF equalizer using convolutional code can reach voice communication standard 10^{-3} gives diversity gain in ≈ 37 dB. Then MIMO-OFDM system with MMSE equalizer using convolutional code yields better than MIMO-OFDM system without convolutional code, but both of them can reach voice communication standard 10^{-3}, MMSE equalizer using convolutional code gives diversity gain in 14dB can reach 10^{-3} then MMSE equalizer without convolutional code gives diversity gain in 30dB can reach 10^{-3}.

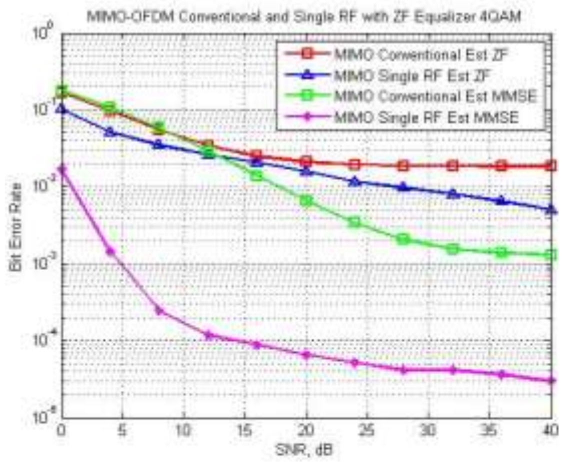

Fig.13. BER performance of MIMO-OFDM single RF and MIMO-OFDM conventional using ZF and MMSE equalizer in 4-QAM modulation

The performance are compare of MIMO-OFDM single RF and MIMO-OFDM conventional using ZF and MMSE equalizer in 4-QAM modulation shown in Fig.13, we compare performance bit error rate for ZF and MMSE equalizer in single RF and conventional MIMO-OFDM system. MIMO-OFDM system based on single RF using ZF equalizer yields results better than MIMO-OFDM system conventional. So the performance of ZF and MMSE equalizer in MIMO-OFDM single RF yields results better than ZF and MMSE equalizer in MIMO-OFDM conventional.

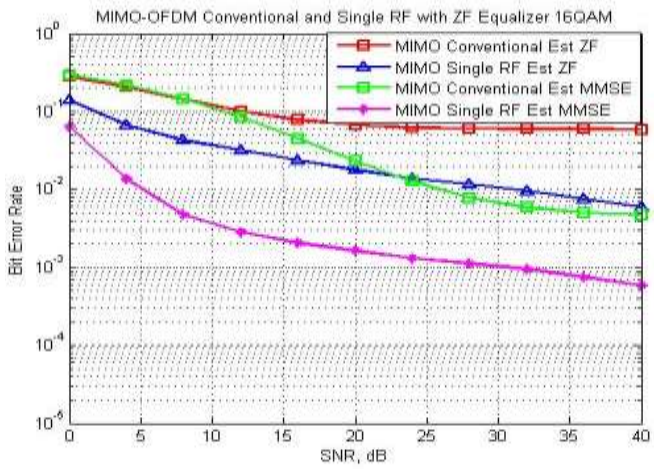

Fig.14. BER performance of MIMO-OFDM single RF and MIMO-OFDM conventional using ZF and MMSE equalizer in 16-QAM modulation

The performance are compare of MIMO-OFDM single RF and MIMO-OFDM conventional using ZF and MMSE equalizer in 16-QAM modulation shown in Fig.14. MIMO-OFDM system based on single RF using ZF equalizer yields results better than MIMO-OFDM system conventional. So the performance of ZF and MMSE equalizer in MIMO-OFDM single RF yields results better than ZF and MMSE equalizer in MIMO-OFDM conventional.

V. Conclusions

This work has shown that MIMO-OFDM system based on single RF in several parameters, there are channel coding, modulation, equalizer, channel estimation. It is achieve that performance MIMO-OFDM single RF using MMSE detection is recommended for this system in channel Rayleigh fading.

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