Pre- and Post- Equalization Technique Combining for Wireless Communications

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Abstract— This paper presents OFDM wireless communication system by using different equalization schemes. Performance and complexity are compared between pre-equalization, post-equalization and combined pre- with post- equalization (PPE) schemes. For combining technique, the received symbols are separated to pre- and post- symbols sequence by using the decision constellation splitter (DCS) algorithm. The result has shown performance in term of bit error rate (BER). In practice, channel estimation is not perfect so we also include the impact of imperfect channel estimation on BER performance in this paper.

Keywords— Pre-equalization, Post-equalization, Equalization, Combined pre- and post- equalization, PPE, combining, Decision Constellation Splitter, DCS, low complexity receiver, Imperfect Channel Estimation.

I. INTRODUCTION

The traditional downlink wireless communication from transmitter (Tx) or base station to receiver (Rx) or user equipment (UE) has employed the equalizer in receiver devices which has more complexity, more power consumption and also not be handy by user. The pre-equalization has been applied in order to decrease this complexity. To achieve high data rate of transmission while limited power resource of mobile equipment is a challenge for wireless communication.

In LTE-Advanced (4G), orthogonal frequency division multiplexing (OFDM) modulation which is widely used in many applications and standard such as xDSL, digital video broadcasting (DVB), broadband mobile, IEEE 802.11 and 802.16 standard also supports high data rate requirement to obviate inter-symbol interference (ISI) caused by quasi-static frequency selective-fading channels [1] [2] [3]. Equalization and channel estimation is schemed to improved performance of OFDM and various detection techniques are proposed, including zero-forcing (ZF) equalizer and minimum mean square error (MMSE) equalizer, decision-feedback (DF), maximum a posteriori probability (MAP) [4] [5] [6]. Naturally, there is performance-complexity trade-off among these equalizers. The ZF equalizer is the least complicated and lowest performance while the MMSE equalizer has higher performance and higher complexity.

The ZF equalizer removes all ISI, forces the ISI part of the error to be zero. This is an ideal when the channel is noiseless, but when it is faced to the noisy channel, the ZF equalizer may amplify the noise power greatly. The better balanced linear equalizer is the MMSE equalizer which does not aim at eliminating ISI completely, but instead minimizes the total power of the noise and ISI components at the output [1] [7] [8] [9]. Feedback equalizer sends more processes and increases more complexity of the receiver. The pre-equalization technique in [10] [11] [12] have shown method how to reduce complexity at the receiver.

To achieve high data rate the combination of pre-equalization at transmitter and post-equalization at receiver scheme is applied in wireless communication system [13] [14]. When pre-equalized symbol and equalized symbol from the transmitter have been sent into the same channel and the same time, the mixed complex number of each symbol sequences are difficult to separate by detector at receiver.

Thus, the main contribution of this article is the proposal of pre- and post- equalization (PPE) scheme with decision constellation splitter (DCS) algorithm where separate symbol among pre-equalized symbol and post-equalized symbol by using symbol distance from the received symbol to the reference symbol. The detected symbol that close to the reference symbol is decided to pre-equalized symbol, the other is decided to post-equalized symbol.

In section II, the simulation model of transmission channel is discussed and OFDM descriptions are presented. In section III, the equalization methods and parameters are discussed. In section IV, the complexity measurement is presented. In section V, imperfection channel estimation is discussed for practice and implementation. The bit error rate performance and receiver complexity of the proposed scheme is compared to different conditions and discussed in detail in section VI and VII respectively.

II. SIMULATION MODEL

This paper has simulated by using Rayleigh fading channel model and the multiple antenna system. The multiple transmits and receives antenna can be realized in the form of $M \times N$ channel matrix. The basic multiple input multiple output (MIMO) system shows in Fig. 1. Generally, output symbol y has shown in (1).

$$y = Hx + n \tag{1}$$

Refer to (1), x represents the input data, n represents noise with a variance and H represents the channel gain of the antenna between transmitter and receiver. H can be written in form of matrix (2), whereas N is the number of transmitter antenna, M is the number of receiver antenna. The simple MIMO 4x4 model is selected as parameter in our simulation.

$$H = \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1N} \\ h_{21} & h_{22} & \cdots & h_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ h_{M1} & h_{M2} & \cdots & h_{MN} \end{bmatrix} \quad (2)$$

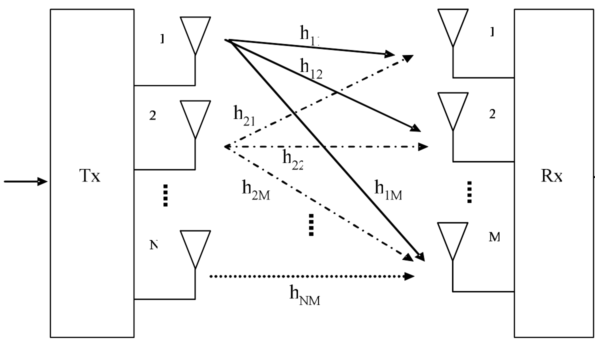

Figure 1. Typical MIMO system

This paper considered OFDM scheme to maintain high data rate transmission. The simple OFDM is selected for our simulation, showed in Fig. 2. The OFDM scheme without forward error correction (FEC) and interleaving process reduces complexity, small size of receiver and easy to implement. The impacts of the larger FFT are not only power consumption and the size of the RAMs, but also include the multipliers and control logic. The complexity increase in logic and the memory increase are linear with the FFT size [15]. FFT 512 is selected for our simulation.

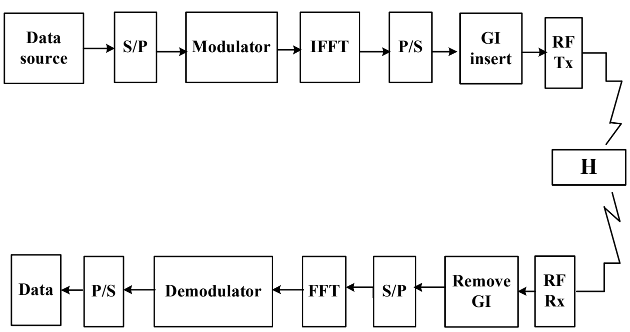

Figure 2. Basic OFDM block diagram

High order modulation increases a level of noise sensitivity that causes high bit error rate for detection at the receiver. The errors can be decreased by using lower modulation order [16]. QPSK scheme is selected for our simulation because of low receiver's complexity and reasonable noise immunity.

III. POST-, PRE- AND PPE EQUALIZATION

A. Equalization

An equalizer or post-equalizer is designed to compensate the effect of channel. Linear signal detection method treats all transmitted signals as interferences except for the desired stream from the target transmit antenna. Therefore, interference signals from other transmit antennas are minimized throughout detecting the desired signal from the target transmit antenna. To facilitate the detection of desired signals from each antenna, the effect of the channel is inverted by a weight matrix. The standard linear detection methods include the ZF and MMSE technique. The equalization block diagram shown in the Fig. 3, weight processing is proceeded at the receiver-side.

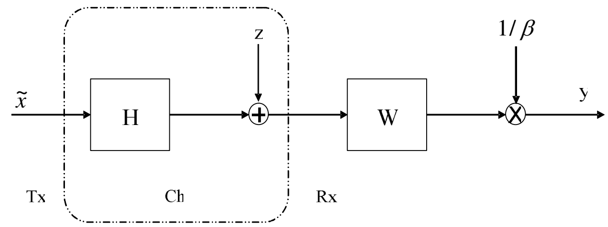

Figure 3. Equalization block diagram

Zero-forcing is simple linear and easy to implement, but low performance also. Weight matrix (W), constant to meet the total transmitted power constant after Pre-equalization (β), the received signals (y) are given as (3), (4), (5), respectively [17].

$$W_{ZF} = \beta \hat{H}^{-1} \quad (3)$$

$$\beta = \sqrt{\frac{N_T}{Tr(\hat{H}^{-1}(\hat{H}^{-1})^H)}} \quad (4)$$

$$y = \frac{1}{\beta} W_{ZF}\left(\hat{H}\tilde{x} + z\right) \quad (5)$$

Where, $\tilde{x}$ is the bit input, let $\hat{H}$ denote the estimate of channel H, z is channel noise, N_T is numbered of transmitter antenna. Normally, simulation channel estimation is perfect ($\hat{H} = H$), channel noise is Additive white Gaussian noise (AWGN).

This paper focused MMSE equalization, showed better performance than ZF. Weight matrix of MMSE equalization and the received signal are given (6), (7), respectively.

$$W_{MMSE} = \beta \times \hat{H}^H \left(\hat{H}\hat{H}^H + \frac{\sigma_z^2}{\sigma_x^2} I \right)^{-1} \quad (6)$$

$$y_e = \frac{1}{\beta_e} W_{e,MMSE}\left(\hat{H}\tilde{x} + z\right) \quad (7)$$

Where, σ_z^2 is noise variance, σ_x^2 is input variance [7].

B. Pre-equalization

The pre-equalization scheme on the transmitter-side outperforms the receiver-side equalization. It is attributed to the fact that the receiver-side equalization suffers from noise enhancement in the course of equalization. In view of the complexity, this scheme is provided low complexity at receiver. Fig. 4 shows pre-equalization with MMSE, the received signal is given by (8) [17].

$$y_p = \frac{1}{\beta_p}\left(\hat{H}W_{p,MMSE}\tilde{x} + z\right) \quad (8)$$

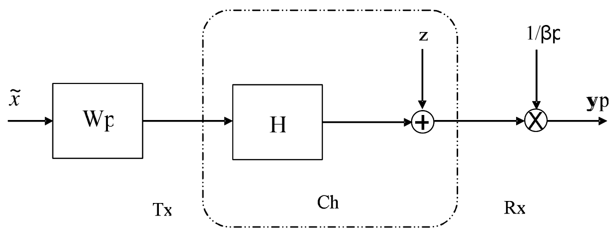

Figure 4. Pre-equalization block diagram

C. Combined pre- and post- equalization (PPE)

In the scenario that complexity is unlimited, or system BER is seriously, we may use combined pre- and post- equalization as shown in Fig. 5. The input data are copied to two parts, one multiplied by pre- weight (*Wp*) before transmitted into channel, other transmitted directly into the same channel and same time. At the channel H, the signals are mixed and suffered by noise. The mixed signals are detected and separated to two parts by DCS algorithm. Each pair of symbol from two sequences is compared with reference symbol, calculated symbol distance from received to reference symbol as (9), (10). In the areas of mathematics, symbol distance is magnitude of vector or the length of vector from the received symbol to the reference symbol on constellation diagram. The detected symbol that has smaller symbol distance or smaller magnitude is decided to pre-equalized symbol, the other symbol is decided to post-equalized symbol. The reference symbol depend on modulation type or constellation diagram. Example, there are four points of reference symbols in QPSK; 1+i, 1-i, -1+i, -1-i.

$$d\,1 = \left|\, ref\ symb - received\ symb\,1 \,\right| \quad (9)$$

$$d\,2 = \left|\, ref\ symb - received\ symb\,2 \,\right| \quad (10)$$

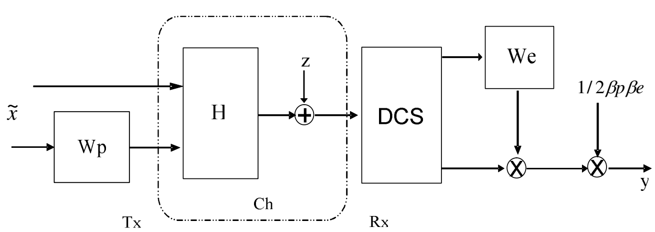

Figure 5. Combined pre- and post- equalization (PPE)

At the receiver, post- equalized symbol sequence is multiplied by post- weight (*We*). The last output symbol is the average of complex number from both pre- and post- equalized symbol sequences as (11).

$$y = \frac{W_{e,MMSE}\left(\hat{H}\tilde{x} + z\right) + \left(\hat{H}W_{p,MMSE}\,\tilde{x} + z\right)}{2\beta_e\beta_p} \quad (11)$$

IV. COMPLEXITY

Normal complexity measurement by using big-O represents computation complexity [18] [19] [20]. This paper considers only Rx complexity by using computational complexity of arithmetic operations TABLE I [19] to calculate and compare the complexity at the receiver-side. As we known this computational complexity is how many times of multiplication (M) and addition (A) process.

TABLE I. COMPUTATIONAL COMPLEXITY OF ARITHMETIC OPERATIONS[19]

Operation	Inputs		Output	Complexity
	#real	**#complex**		
Complex multiplication	0	2	Complex	4M+2A
Complex multiply by real	1	1	Complex	2M
Square root	1	0	Real	M
Complex power	0	1	Real	2M+A
Real division	2	0	Real	M
Complex division	0	2	Complex	8M+3A
Complex divide by real	1	1	Complex	2M

V. IMPERFECT CHANNEL ESTIMATION

Pre-equalization needs channel estimation process to predict channel gain or channel information. Normally simulation used perfect channel estimation ($\hat{H} = H$).

In practice, we do not know channel information and channel is not perfect, so that channel estimate gets the error. Imperfect channel estimation depends on variance channel estimation error (σ_ε^2). The acceptable error will be specific to maintain system performance. Let $\hat{H}$ denote the estimated channel, it can be a model as,

$$\hat{H} = H + E \quad (12)$$

Where, E is the estimation noise with independent complex Gaussian entries, $[E]_{ij} \sim CN(0,\sigma_\varepsilon^2)$. We denote E as channel estimation error from actual channel. Channel estimation is perfect when the channel estimation error variance $\sigma_\varepsilon^2 = 0$. Let H denote the actual channel matrix, the original channel can be rewritten as (13),

$$H = \eta\hat{H} + \sqrt{1-\eta}\;G_w \quad (13)$$

where $\eta = \frac{1}{1+\sigma_\varepsilon^2}$, G_w is independent and identically distributed Gaussian white noise [20], $[G_w]_{ij} \sim CN(0,1)$, G_w denote the random complex normal distribution, C means complex domain, and N indicates the normal distribution with mean zero and variance 1.

Normally, imperfect channel state information is incurred at two places, at channel estimation and feedback part. Noisy channel estimation can cause random interference in the detection which cannot be eliminated. Feedback introduces delay as well as errors when passing information from the receiver to the transmitter [21] [22].

VI. Simulation Results

To review the effectiveness of the proposed combining technique with proposed decision algorithm (DCS), we set simulation parameters as Rayleigh fading channel model with MIMO 4x4, QPSK modulation, cyclic prefix 25% and FFT 512.

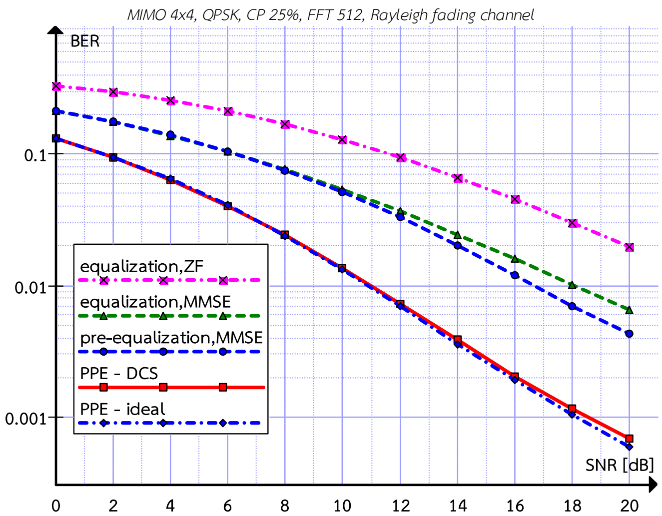

Figure 6. ZF-Equalization, MMSE-Equalization, Pre-equalization-MMSE, Combined pre- and post- equalization performance comparison

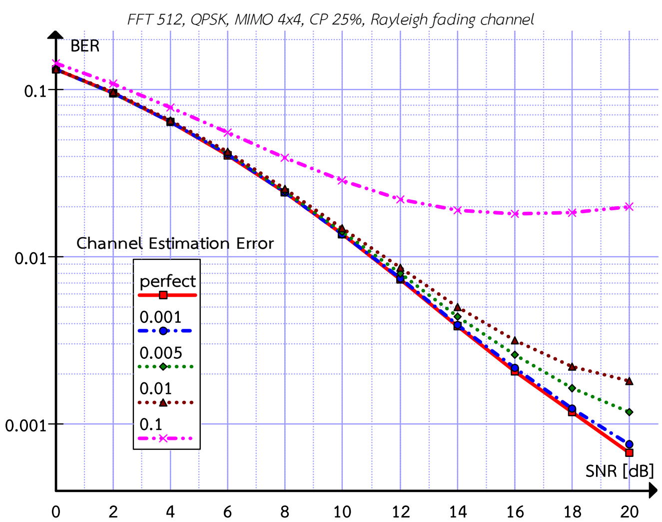

Figure 7. PPE-DCS under imperfect channel estimation

Fig. 6 shows plot of bit error rate versus SNR for ZF-equalization, MMSE-equalization, pre-equalization with MMSE, PPE with DCS algorithm and ideal PPE (with perfect DCS algorithm). It is observed at BER level of 10^{-2} SNR about 11 dB can be achieved by using the proposed method, but it must attained SNR over 16 dB by using pre-equalization with MMSE. That means pre-equalization requires transmitting power more than three times of transmitting power by using proposed method. In the noise facing scenario, the proposed method shows that it is outstandingly noise immunity which is observed at 18 dB NSR, pre-equalization get bit error rate around 1/100, meanwhile proposed method get bit error rate around 1/1000.

Fig. 7 shows the result of imperfect channel estimation simulation. The channel estimation error variance effects to performance. The perfect channel is estimation, $\sigma_{\varepsilon}^{2} = 0$. The result shows lack performance when channel estimates are error increase ($\sigma_{\varepsilon}^{2} > 0.01$).

Consider pre-equalization scheme (8), the operation of $\left(\hat{H}W_{p,MMSE}\tilde{x}+z\right)$ is operated over the transmitter side, so the receiver complexity calculation is not included this operation. The operation at receiver is only a real number multiplied by matrix 4x512. Refer to TABLE I, the computational complexity of pre-equalization equals 4,096M. In the same way calculation, the computational complexity of PPE scheme in (12) equals 4144A+4162M.

Consider (9) and (10), the symbol distances are calculated and compared by DCS. There are absolute, square root and addition operations in DCS. Thus, computational complexity of DCS algorithm equals 2050A+6M. The TABLE II shows all computational complexity comparison.

TABLE II. Rx complexity comparison (512FFT,QPSK,MIMO 4x4)

Scheme	Addition	Multiplication
Equalization	48	4,160
Pre-equalization	0	4,096
PPE – ideal	4,144	4,162
PPE - DCS	6,194	4,168

VII. Conclusion

This paper proposes combining method of pre- and post-equalization (PPE) with decision constellation splitter (DCS) algorithm to improve the system performance for OFDM wireless communications. The DCS algorithm has proposed for detect and separate the mixed signals by calculates and compares symbol distance with the reference symbol. From the result, the proposed method can be achieved the higher performance in term of bit error rate compared to other methods. In the other words, the method shows out performance in term of higher noise immunity.

Acknowledgment

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Future Work

Adaptive PPE with DCS for noise immunity wireless communication systems under imperfect channel estimation.

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