Interference Reduction Using MMSE-DFE Equalizer with One-Third ICI-SC STFBC for MIMO-OFDMA System

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***Abstract*—Orthogonal frequency division multiple access (OFDMA) allows simultaneous low data rate transmission for several users. However, as one symbol interferes with subsequent symbol, it will produce a phenomenon called intersymbol interference (ISI) which has similar effect as noise and thus making the communication less reliable. Besides that, Doppler spread due to channel time-variation destroys the orthogonality in OFDMA system and degrade the system performance with intercarrier interference (ICI). In order to solve this issue, minimum mean square error-decision feedback equalizer (MMSE-DFE) with one-third (ICI-SC) subcarrier mapping method using space-time-frequency block codes (STFBC) is proposed. The objective is to minimize both ISI and ICI effects by evaluating pairwise error probability (PEP) and bit error rate (BER) performances. From the simulation results, MMSE-DFE with one-third ICI-SC technique shows the best result for MIMO-OFDMA system with 25% improvement of PEP and 4.8% improvement of BER.**

***Index Terms*—Intersymbol Interference (ISI); Intercarrier Interference (ICI); Pairwise Error Probability (PEP); Minimum Mean Square Error-Decision Feedback Equalizer (MMSE-DFE.**

I. INTRODUCTION

Nowadays, high demand for wireless communication systems has increasing rapidly to fulfill the need of mobile users all around the world. This is due to higher bit rates for mobile integrated service, digital video and high quality audio and other services. Research and development on wireless communication system need to be improved all the time to provide better data transmission from service provider and reception to the end user. Currently, one of the noticeable example in this research is orthogonal frequency division multiple access (OFDMA) [1]. OFDMA is widely used for downlink of the 3GPP Long-Tem Evolution (LTE), IEEE 802.16 WiMAX, and also IEEE 802.22 Wireless Regional Area Networks (WRAN).

In order to promote simplicity, high performance and multipath diversity to enhance data rates and link reliability to OFDMA system, more than one antenna at both transmitter and receiver of wireless system (MIMO technology) is applied. This combination is called MIMO-OFDMA technology which can optimize data speed and minimize error. Three basic diversity orders in MIMO technology are space diversity, time diversity and frequency diversity techniques. To increase diversity order of the system in MIMO channels, the coding symbols are distributed in different time slots and frequencies [2]. From the previous research, combination of the three diversity techniques which is space-time-frequency block codes (STFBC) can achieve maximum diversity gain in end-to-end MIMO-OFDMA wireless system [3].

However, the implementation of MIMO-OFDMA system has several drawbacks. Synchronization error such as carrier frequency offset (CFO) and phase noise (PN) will destroy the orthogonality among subcarriers [4]. CFO rises when Doppler shifts in the channel which causes frequency difference between transmitter and receiver oscillators. This can cause reduction of signal amplitude and system performance will be degraded by inter-carrier interference (ICI) which introduces thermal noise. Accordingly, one-third ICI-SC subcarrier mapping scheme is adapted into the system to diminish ICI. The symbol to be transmitted will be mapped in a phase shift of Π/2 with '+' and '-' countersign onto the subcarrier mapping technique either adjacent or non-adjacent subcarriers [5].

Other than that, since the data are sent in radio space, the channel exhibits multipath fading phenomenon at the receiver side produces inter-symbol interference (ISI) and it increases the bit error rate [6]. Two popular methods to overcome the effect of ISI are guard interval insertion of transmitting symbol and adopting equalizer at the receiver. In this paper, equalization technique will be emphasized. There are two types of equalizer which are linear and non-linear. The equalizer is called linear when there is no feedback path adapts to the equalizer for example zero forcing (ZF) and minimum mean square error (MMSE). Otherwise, non-linear equalizer is used when the signal is fed back to change the subsequent outputs of the equalizer such as decision feedback equalizer (DFE) and Maximum Likelihood sequence estimator (MLSE). In order to optimize on ISI reduction, this paper proposed a combination of linear and non-linear equalizer (MMSE-DFE) as it is fairly simple and does not suffer from noise enhancement.

In this paper, one-third ICI-SC subcarrier mapping scheme and MMSE-DFE equalization techniques using STFBC are proposed to reduce the effect of ICI and ISI as it is simple and easy to implement. The previous research [7] has shown that, combination of both techniques with full diversity will greatly improved PEP and BER system performance. The idea of one-third ICI-SC subcarrier mapping is proposed to get the optimum distance between subcarriers and repeated subcarriers as the frequency gain is difficult to obtain. Besides that, MMSE-DFE equalization technique is applied to reduce ISI and compensate the interference during transmission at the receiver.

In order to achieve the best system performance in wireless communications, one-third ICI-SC subcarrier mapping combined with different types of equalizer such as linear equalizer (LE), decision feedback equalizer (DFE), maximum likelihood sequential equalizer (MLSE) and proposed MMSE-DFE equalizer are simulated. By using this technique, it is expected that the interference for the whole system can be reduced and as a result, PEP and BER could be lessen due to reducing number of ISI and ICI and maximum diversity order with an efficient bandwidth can be achieved [5].

II. System Model

The MIMO-OFDMA transmitter and receiver architecture is proposed according to one-third ICI-SC subcarrier mapping scheme as shown in Figure 1. The system is simulated using MATLAB software programming.

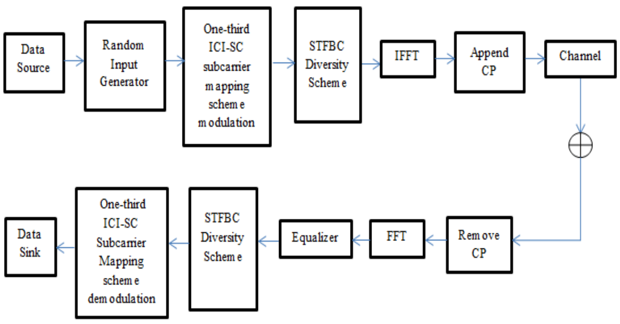

Figure 1: One-third ICI-SC subcarrier mapping scheme with STFBC of MIMO-OFDMA model

The data source at the transmitter produces random data input. The random data will undergo 64-QAM modulation technique and map into one-third subcarrier mapping scheme with full diversity technique. Later on, cyclic prefix (CP) will be inserted before the data is being transmitted through the antennas into the channel (air). At the receiver, CP will be removed before the equalization technique takes place. During equalization technique, different types of equalizer are simulated to investigate the effectiveness of the equalizer to reduce ISI. Last but not least, the symbol is demodulated before it sinks to the end user. The system parameters used in this wireless communication system is Mobile WiMAX standards as shown in Table 1 with OFDMA technology is applied at both transmitter and receiver.

The MIMO-OFDMA received signal vector at the receiver with k_{th} subcarriers which has been divided into segments respectively can be shown as follows:

$$Y_n(k) = \sum_{m=1}^{M} X_m(k)H_{m,n}(k)S_{m,n}(0) + z_n(k) \qquad (1)$$

where:

$Y_n(k)$: Received signal at the receiver
$X_m(k)$: Transmitted signal
$H_{m,n}(k)$: Channel impulse response
$S_{m,n}(0)$: Desired k_{th} carrier component
$z_n(k)$: Complex Gaussian thermal noise

Table 1
Mobile WiMAX System Parameter

System Bandwidth (MHz)	Sampling Frequency (MHz)	FFT Size	Subcarrier Spacing (kHz)	OFDM Symbol Duration (μs)	Useful Symbol Time (μs)	Cyclic Prefix (μs)
1.25	1.4	128				
2.5	2.8	256				
5	5.6	512	10.94	102.86	91.43	11.43
10	11.2	1024				
20	22.4	2048				

The basic STFBC mapping code word from [7] can be expressed in matrix form as:

$$X_m = \begin{bmatrix} X_1(0) & \cdots\cdots & X_2(0) \\ X_1(0) & \cdots\cdots & -X_2(0) \\ \vdots & \cdots\cdots & \vdots \\ X_1(N-1) & \cdots\cdots & X_2(N-1) \\ X_1(N-1) & \cdots\cdots & X_2(N-1) \end{bmatrix} \qquad (2)$$

The matrix of one-third ICI-SC subcarrier mapping from [8] with full diversity (STFBC) code word has the form of:

$$\begin{bmatrix} x_1(0) & \cdots\ \cdots & x_2(0) \\ -x_1(\frac{N}{6}) & \cdots\ \cdots & -x_2(\frac{N}{6}) \\ x_1(\frac{N}{36}) & \cdots\ \cdots & x_2(\frac{N}{36}) \\ -x_1(\frac{N}{6}-1) & \cdots\ \cdots & -x_2(\frac{N}{6}-1) \\ \cdots & \cdots\ \cdots & \cdots \\ & \cdots\ \cdots & \\ x_1(\frac{N}{6}+1) & \cdots\ \cdots & x_2(\frac{N}{6}+1) \\ & \cdots\ \cdots & \\ -x_1(\frac{N}{3}) & \cdots\ \cdots & -x_2(\frac{N}{3}) \\ \vdots & \cdots\ \cdots & \vdots \\ & \cdots\ \cdots & \\ x_1(\frac{N}{3}+1) & \cdots\ \cdots & x_2(\frac{N}{3}+1) \\ & \cdots\ \cdots & \\ -x_1(\frac{N}{2}) & \cdots\ \cdots & -x_2(\frac{N}{2}) \\ & \cdots\ \cdots & \\ x_1(\frac{N}{2}) & \cdots\ \cdots & x_2(\frac{N}{2}) \\ & \cdots\ \cdots & \\ -x_1(\frac{N}{3}+1) & & -x_2(\frac{N}{3}+1) \end{bmatrix} \qquad (3)$$

In this paper, one-third method will be evaluated using PEP performance. The ICI coefficient is:

$$S_{m,n}(k) = \frac{\sin\left(\pi(k+\varepsilon_{m,n})\right)}{K\sin\left(\frac{\pi}{K}(k+\varepsilon_{m,n})\right)} \exp\left[j\pi\left(1-\frac{1}{K}\right)(k+\varepsilon_{m,n})\right] \qquad (4)$$

Note that the $S_{m,n}$ is a constant with respect to subcarrier index, $k = 0$, where $\varepsilon_{m,n}$ is normalized frequency offset (NFO).

$$S_{m,n}(0) = \frac{\sin(\pi\varepsilon_{m,n})}{K\sin\left(\frac{\pi}{K}\varepsilon_{m,n}\right)} . \exp(j\pi\left(1-\frac{1}{K}\right)\varepsilon_{m,n}) \qquad (5)$$

It is very important to get the lowest PEP value to have lower noise and interference in the system. If the value of $\varepsilon_{m,n}$ in Equation (4) increases, ISI and ICI will also increase.

Therefore, to produce better system performance, the best equalization technique will produce lowest PEP value with highest SNR performance [8].

III. Design Criteria of PEP

A. Pair-wise Error Probability (PEP)

Probability error of transmitted signal corresponding to distorted version received signal is called pairwise error probability. It is because of the probability exists with a pair of signal vectors in a signal constellation.

$$P(D \to \overline{\mathrm{D}}) \le \ell \binom{2\Gamma N - 1}{\Gamma N} \left(\prod_{i=1}^{\Gamma} \lambda_i \right)^{-N} \quad \xi^{-\Gamma N} \ell \qquad (6)$$

where:

- D : Transmit codeword
- $\overline{D}$: Decoded codeword with error
- λ : Loss
- Π : Product criterion
- λ_i : Non-zero Eigen value
- N : Number of subcarriers
- Γ : Rank $(\Delta \mathrm{D}.\mathrm{R})$

From Equation (6), it is shows that the probability to detect the received signals vector or symbol containing error when another transmit symbol is coming. $\mathrm{P}(\mathrm{D} \to \overline{\mathrm{D}})$ is the possibility of decoded symbol containing error or faulty.

B. Space Time Frequency Block Coding (STFBC) Schemes

A space time frequency scheme is shown in Figure 2. It is a combination of ST and SF code used to transmit multiple copies of data stream across a number of antennas. In this simulation, the MIMO system is having two antennas at the transmitter and receiver. STF diversity is beneficial since it can allow many similar symbols to be transmitted through the multiple antennas at different time and frequency. Therefore, a maximum diversity order can be seized by using this spatial multiplexing and diversity technique. Table 2 is the example of coding in STFBC method as suggested in [6].

Table 2
Coding in STFBC Method

Antenna and Time Slot Frequency	Ant 1 (T1)	Ant 2 (T2)
f1	X_k	X_{k+1}
f2	$-X_{k+1}$	$X_k{}^*$

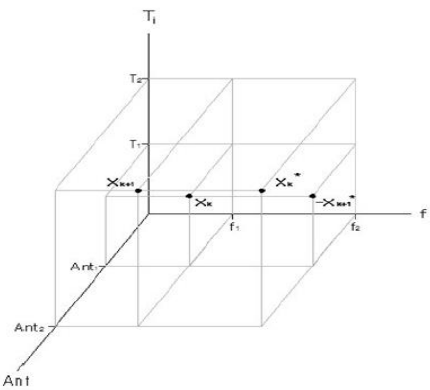

Figure 2: STFBC scheme

C. Decision Feedback Equalizer (DFE)

Once an information symbol has been is detected and decided, the ISI that it induces on future symbols can be estimated and subtracted out before detection of subsequent symbols. It is used when the channel distortion is too severe. Figure 3 shows the structure of DFE equalizer.

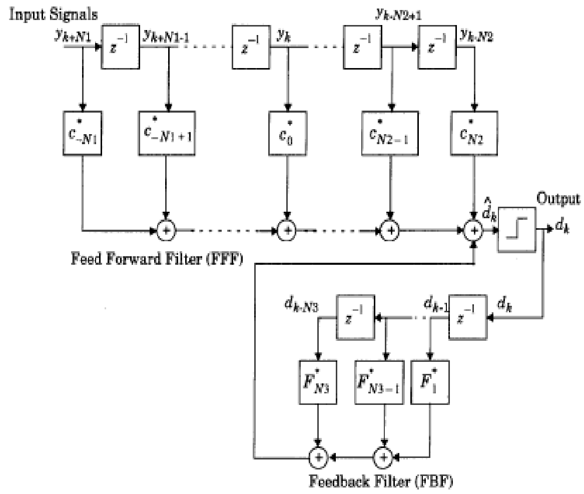

Figure 3: DFE structure

D. Maximum Likelihood Sequence Equalizer (MLSE)

MLSE tests all possible data sequences (rather than decoding each decoding each received symbol by itself) and chooses the data sequence with the maximum probability as the output. It usually has a large computational requirement. MLSE requires knowledge of the channel characteristics and statistical distribution of the noise corrupting the signal. Figure 4 shows the MLSE structure in a system.

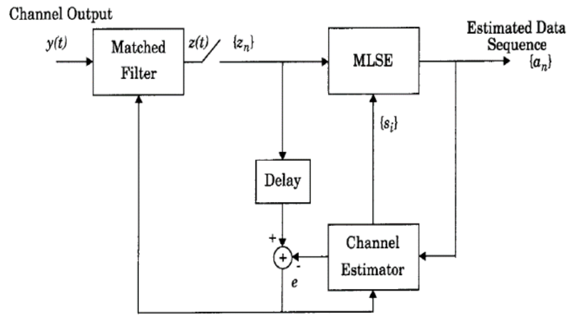

Figure 4: MLSE structure with adaptive matched filter

E. Minimum Mean Squared Error – Decision Feedback Equalizer (MMSE-DFE)

The MMSE-DFE jointly optimizes the settings of both the feedforward filter and the feedback filter to minimize the mean squared error (MSE). The MMSE criterion ensures on optimum trade-off between residual ISI and noise enhancement. Figure 5 shows MMSE-DFE system structure.

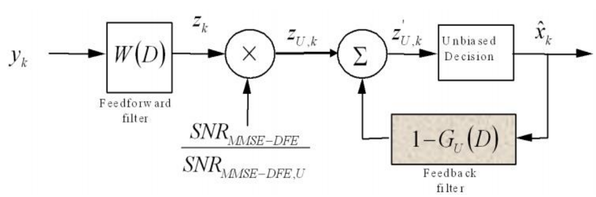

Figure 5: MMSE-DFE system structure

IV. RESULT AND DISCUSSION

By using MATLAB software programming, the proposed equalization technique with one-third ICI-SC using STFBC design methods are simulated with system parameter in Table 3. The system uses 72 subcarriers for STF block codes design method for different equalization techniques such as DFE, MLSE, MMSE-DFE, LE and without equalizer. The results of each technique are compared to analyze the best system performance.

Table 3
Simulation Parameters

Parameters	Values
IFFT size	128
Mapping scheme	64-QAM
No of OFDMA symbols	100
Bits per OFDMA symbols	N*log2(M)
Number of carriers	72
Channel	Multipath Rayleigh Fading
Frequency offset	0.05

Figure 6 shows the simulation results of PEP performance by using different types of equalization technique using one-third ICI-SC with STFBC in MIMO-OFDMA system. In this paper, the simulation using 5% frequency offset is performed. PEP for MMSE-DFE outperformed others with lowest PEP value at PEP = $5X10^{-5}$, followed by MLSE, DFE, LE and without equalizer. Theoretically, PEP value will decrease when Eb/No increases. This proves that PEP is inversely proportional to the noise spectral density. Throughout this experiment, with higher Eb/No, less PEP value indicates that the system becomes more efficient as the decoded coded with error is reduced. For overall results, it can be seen clearly that the proposed MMSE-DFE technique offers optimal value of PEP with maximum frequency diversity with compared to other existing equalization technique. As a result, both ISI and ICI effects can be reduced by using a system with one-third ICI-SC subcarrier mapping scheme with STFBC and using suitable equalizer at the receiver end.

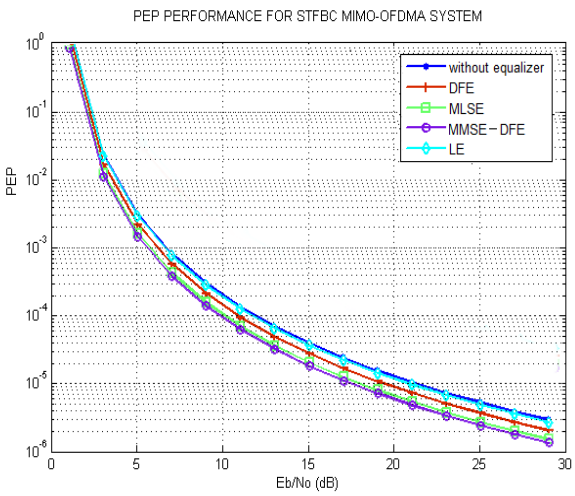

Figure 6: PEP performance of different equalization technique with One-third ICI-SC STFBC

Table 4
Simulation Result of Different Equalization Technique at Eb/No = 20 dB

Parameters	Values
Without equalizer	$9.5X10^{-4}$
LE	$9.6X10^{-4}$
DFE	$2X10^{-5}$
MLSE	$4X10^{-5}$
MMSE-DFE	$5X10^{-5}$

In order to support the PEP results and the theory assumption, further investigation of BER results is obtained. Figure 7 shows the BER results of one-third ICI-SC subcarrier mapping scheme with different types of equalizer. It shows that BER performance of without equalizer is 10.2 dB followed by LE 9.8 dB, DFE 8.7 dB, MLSE 8.4 dB and MMSE-DFE is 8 dB. MMSE-DFE technique has the best BER performance compared to other equalization techniques as it produces lowest BER value. This is because MMSE-DFE technique produces less interference in the system, as it effectively reducing the ICI and ISI with maximum diversity order in MIMO-OFDMA system architecture.

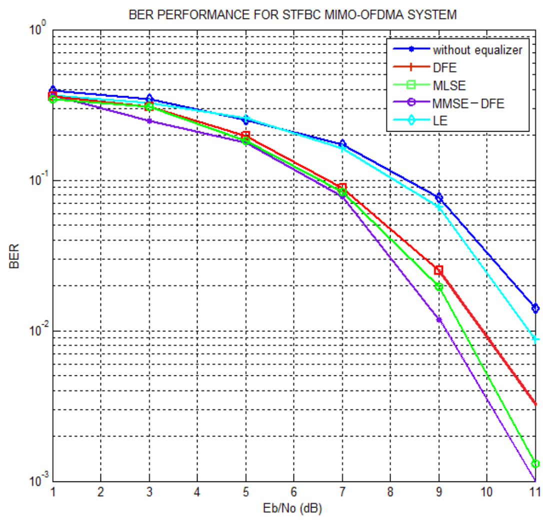

Figure 7: BER performance of different equalization techniques with one-third ICI-SC STFBC

Table 5
Simulation Result of Different Methods with nfo 5% at BER = $3x10^{-2}$

Equalization Techniques	Eb/No (dB)
Without equalizer	10.2
LE	9.8
DFE	8.7
MLSE	8.4
MMSE-DFE	8.0

V. CONCLUSION

In conclusion, MMSE-DFE equalization technique contributes the best PEP and BER performances compared to other equalization techniques. It can effectively reduces interference (ICI and ISI) performance of one-third ICI-SC subcarrier mapping method with STFBC MIMO-OFDMA due to synchronization error. To sum up, MMSE-DFE equalization technique achieves maximum frequency diversity with optimal distance, a higher SNR, with less noise and coding complexity which makes it suitable to be implemented in the system. In future, the equalization techniques can be performed and compared by using various adaptive equalizer and turbo equalizer.

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