**Performance Evaluation of CLS-DFE for MIMO OFDMA System**

Siti Maisurah Sulong, Azlina Idris, and Suzi Seroja Sarnin

Abstract—Orthogonal frequency division multiple access (OFDMA) is a multiuser of digital modulation technique used to increase wireless transmission rate. Signal efficiency is distorted due to Inter symbol interference (ISI) that occurs due to the multipath propagation. Cascaded Least Square (CLS) with Decision Feedback Equalizer (DFE) had been used in this research in order to mitigate ISI in OFDMA system. CLS is combination of two adaptive algorithms which are Least Mean Square (LMS) and Recursive Least Square (RLS). This research also justified that combination of space time frequency block code (STFBC) with multiple input multiple output (MIMO) antenna enable to minimize ISI. The simulation results show the improvement of bit error rate (BER) performance after reducing ISI and also prove that STFBC was able to achieve maximum diversity order in the MIMO OFDMA system.

Index Terms—Least mean square (LMS), recursive least square (RLS), cascaded least square (CLS), decision feedback equalizer (DFE).

I. INTRODUCTION

A combination of multiple input multiple output (MIMO) is an innovation for antenna technology to significantly increase transmission capacity. Nowadays, MIMO is using together with Orthogonal Frequency Division Multiple Access (OFDMA) as a latest technique that combines frequency division multiple access (FDMA) with Orthogonal Frequency Division Multiplexing (OFDM) by subdividing the bandwidth into multiple frequency sub-carriers as stated in [1]. OFDMA has been introduced in the IEEE 802.16 wireless for Metropolitan Area Network (MAN) standard to improve transmission rate in wireless communication system. This technique will assign different groups of carriers to different user.

OFDMA need to maintain their orthogonality between each other to avoid signal loss due to the multipath propagation occur during transmission [2]. Each signal that reach receiver are propagating through different paths and the signal will have different delay time. That reason can still affect system performance even though OFDMA can handle multipath interference at the receiver. Besides that, multipath also can can cause inter symbol interference (ISI) in the wireless system.

Previous researchers [3] stated that, ISI is major problem to achieve high speed data transmission because it will attenuate signal in the channel. This physical environment causes some symbols to be spread beyond their given time interval. Due to that reason, it can interfere with the following transmitted symbols. Adaptive algorithm will be used with decision feedback equalizer (DFE) to overcome ISI problem. DFE is much better compare to linear equalizer because it has lower noise enhancement while processing the received signal. Cyclic prefix (CP) as a guard interval will be added to help DFE remove interference as long as the CP at least equal or larger than channel delay spread. Transmitted symbol that is in linear convolution form change to circular convolution form and ISI will completely eliminated from the system [4].

In order to improve more on wireless communication performance, space time frequency (STF) code had been introduced to distribute the element of the orthogonal design both in time and frequency. STF are promising for achieving high bandwidth efficiency, latency and low overhead. Before STF is used, space time (ST) code is the first technique that realize the advantage of diversity of multiple antennas [5] but the performance of ST will degrade in fast time-varying channel. After that, space frequency (SF) has been proposed by replacing time domain with frequency domain but system performance degrade in heavily selective channels. Previously, we can see that ST and SF cannot achieve maximum diversity but after a few years, there are improvement of performance. They can be used in MIMO system with a few changes that need to be considered but the performance is still not as good as STF [6].

Based on the information above, LMS and RLS will be tested in this project with DFE to reduce ISI. LMS is one of the most widely used adaptive algorithms due to its robustness and simplicity while RLS is also one of adaptive algorithm commonly used due to its fast convergence. This research will prove that combination of both algorithms with equalizer have better performance in MIMO OFDMA. It makes the differences with previous work by [7] and [8] because so far there is no exact research relate to the combination of two adaptive algorithms with equalizer using space time frequency block coding technique for MIMO OFDMA.

II. METHODOLOGY

To study the performance of MIMO OFDMA, a full system shown in Fig. 1 below.

A full system shown in Fig. 1 is separated into three main parts; Transmitter, channel and receiver. This system use 2-Tx and 2-Rx antennas. A random data stream is generated and modulator will modulate corresponding subcarrier. OFDMA modulation is generated using inverse fast fourier
transform (IFFT). It will convert frequency domain data into time domain signal while maintaining the orthogonality of subcarriers. STF implementation consists of two encoders for both diversities. Cyclic prefix will act as a guard interval to help DFE operations. From that inter symbol interference (ISI) can be completely eliminated as long as cyclic prefix is longer than maximum spread of the channel.

This paper is focusing on nonlinear equalizer which is DFE. This equalizer has better performance compare to Linear Equalizer because DFE remove ISI from tails of previously received symbols. Feedback filter (FBF) will eliminate ISI using previous receiver decision while at feed-forward filter (FFF), ICI cancellation occurs on the transmitted symbol. For further research, \( F(z) \) and \( D(z) \) can be optimized according to any suitable criterion such as Zero Forcing or Minimum Mean Square Error. DFE perform with lower computational complexity and comparable to the behaviour of optimum demodulator. Suitable weighting is required to remove previous symbol values. Slicer will eliminate the noise before feedback to make sure no additional noise enhancement [10]. Error signal, \( e(k) \) equation can be written as

\[
e(k) = I(k) - Q(k)
\]  

(1)

where \( I(k) \) is a decision for decision–directed mode and \( Q(k) \) is the decision device input. Updated equation for FFF is;

\[
F(k + 1) = F(k) + \mu y[k] e[k]
\]  

(2)

While updated equation for FBF is;

\[
D(k + 1) = D(k) + \mu z[k] e[k]
\]  

(3)

With \( y(k) \) as an input at feed forward filter while \( z(k) \) is input at feedback filter.

The channel response for this equalizer can be written as

\[
C(z)_{DFE} = cz^{-n_o}/H(z)
\]  

(4)

While \( n_o \) is the delay introduce due to the filter operations and \( c \) is a constant gain.

B. Cascaded Least Square

CLS is a combination of 2 adaptive algorithms that will help DFE to perform well for MIMO OFDMA System. Least Mean Square (LMS) LMS is well known among adaptive algorithm due to its simplicity and low complexity but LMS is not good in terms of convergence speed. In addition, it will not converge if the desired symbols are not correct. The only parameter to be adjusted is the adaptation step size but for this research, only 1 value of step size will be used in the system. The LMS basic equation can be written as stated by [11];

\[
w(k + 1) = w(k) + \mu e(k) d(k)
\]  

(5)

While \( \mu \) is the step size, \( w(k) \) is filter coefficient vector and \( d(k) \) is filter input vector. During each sample period, filter tap weights will be adjusted. Recursive Least Square (RLS) perform better in term of convergence speed compare to LMS. RLS is formalized as below

\[
w(k + 1) = w(k) + e(k) G(k)
\]  

(6)

Which \( e(k) \) is error signal and \( G(k) \) is gain vector that can be written as;
\[ G(k) = P(k)R(k) \div [\lambda + R^2P(k)R(k)] \]  \hspace{1cm} (7)

\( P(k) \) is an inverse matrix of input signal while \( \lambda \) is forgetting factor that must not be too small in order to avoid algorithm become unstable. Suitable value is between 0 and 1.

**Proposed Algorithm**

This research proposed the signal to enter LMS before entering RLS and equalize by DFE. This is because LMS is simple and easy to perform compare to RLS even though RLS has better performance in terms of convergence speed. The equation can be described as below;

\[
\begin{align*}
    e_{LMS} &= d(n) - w_{LMS}(n)u(n) \\
    y_n &= w_{LMS}(n)u(n) \\
    e_{RLS} &= d(n) - w_{RLS}(n-1)y(n) \\
    z_{CLS} &= w_{LMS}(n)u(n)w_{RLS}(n-1) \\
    e_{TOTAL} &= d(n) - z_{CLS}(n)
\end{align*}
\]

\hspace{1cm} (8)

Which \( d(n) \) is desired output, \( u(n) \) is filter input vector, \( y(n) \) is estimated output of LMS. Error for RLS will include \( y(n) \) in it. \( z_{CLS} \) is final output for CLS before included in DFE operation.

**C. Space Time Frequency**

TABLE I: SPACE TIME FREQUENCY BLOCK CODE USING 2 TRANSMIT ANTENNAS AT DIFFERENT FREQUENCY AND TIME

<table>
<thead>
<tr>
<th>Space Time Frequency</th>
<th>Time 1</th>
<th>Time 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antenna 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency 1</td>
<td>( X_n )</td>
<td>( X_{n+1} )</td>
</tr>
<tr>
<td>Frequency 2</td>
<td>- ( X_{n+1} )</td>
<td>( X_n )</td>
</tr>
</tbody>
</table>

Based on the Table I above, first symbol \( X_n \) from antenna 1 will be transmitted during time slot 1 and frequency slot 1 followed by \( X_{n+1} \) as a second symbol. This type of diversity will distribute element of the orthogonal design in both time and frequency. STF implementation consists of two encoders for both diversities. It will separate spatial and frequency diversity by mapping the information symbols to antenna. Four channels are involved in every time slot whose channel impulse response follows Rayleigh distribution [12]. The received signal will produce

\[ Y = Hx + n \]  \hspace{1cm} (13)

With \( H \) is for channel influence, \( x \) represent signal to be transmitted and \( n \) is additive white Gaussian noise. Input signal \( x \) that has interference \( n \) is convolved by \( H \) in order to produce \( Y \).

**III. SIMULATION RESULTS**

**A. Simulation Parameter**

Based on the Table II, the simulation parameter is referring to IEEE 802.16 protocol. Table III above shows value use to simulate the algorithm and equalizer. The value may change if we want to get more result but need to aware of equalizer stability. Interference is not completely removed from the designated system if the equalizer is unstable.

**B. Diversity Technique**

Fig. 3 shows comparison between STF, ST and SF in this system. Diversity gain can be obtained by transmitting signal through spatial, time slot and frequency diversities. As stated in Table I, the signal used all types of diversities and STF proved its efficiency in Fig. 4. ST combiner can be applied after inverse operation of serial to parallel converter at the transmitter but there will be a problem since symbol duration channel will change during the transmission. Performance of ST will degrade in fast time-varying channel. For SF, the performance will degrade in heavily frequency selective channels. SF can be used with low frequency-selectivity in order to make subcarrier spacing very narrow. Due to both ST and SF suffer with their own disadvantage STF had been used in order to relax the requirements for constant channel coefficients in both dimensions. It is proved that STF perform better compare to ST with improvement 28.07%. For SF, STF is still much better with 16.3% of improvement. Table IV below indicates BER for the diversity.
The authors wish to thank members of Wireless Communication Technology Group, Faculty Electrical Engineering UiTM Shah Alam, Selangor, Malaysia for the guidance and support during the support.

REFERENCES


Siti Maisurah Sulong received her B.Eng. (Hon.) degree in communication from Universiti Teknologi MARA (UiTM), Shah Alam in 2014. She currently pursues her M.Sc. degree (electrical) in UiTM. Her research interests include wireless telecommunication, OFDMA for the WiMax, adaptive algorithm, equalizers and diversity scheme.

Azlina Idris received her B.Eng. (Hon.) degree from Leeds Metropolitan University and M.Sc. degree from Universiti Teknologi Malaysia. She completed her PhD degree in Universiti Malaya and now holds position as a senior lecturer in UiTM Shah Alam. Besides that, she is also the coordinator for student employability. Her research interests include pair wise error probability in OFDM, diversity scheme, wireless interference and equalizers.

Suzei Seroja Sarnin received her B.Eng. (Hon) degree from Universiti Teknologi Malaysia (UTM), Malaysia in 1999 and M.Sc. (microelectronics), degree from Universiti Kebangsaan Malaysia (UKM), Malaysia in 2006 respectively. She currently pursues her PhD degree in UiTM. Her research interests include channel estimation, coding algorithm for CDMA and WCDMA, mobile telecommunication, synchronization algorithm in OFDM for the Wimax technology application.