Reduction of Time Complexity for CLS-DFE MIMO-OFDMA System

S M Sulong 1, A Idris, N M Salih, D M Ali

Wireless Communication Technology Group, Faculty of Electrical Engineering UiTM Shah Alam, 40000 Shah Alam Selangor

sitimaisurah91@gmail.com

Abstract. OFDMA is a multiuser of digital modulation technique used to increase wireless transmission rate. As one of promising technique, OFDMA still suffer from a few types of interference especially ISI. ISI is an interference that occurs due to the multipath propagation and can distort signal efficiency. Upgraded 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). Although RLS is one of the best adaptive algorithm but it still suffer from high complexity. Wireless system should use algorithm that ran quickly and used available computing resources efficiently. Running time of an algorithm need to be considered in order to reduce cost when being implemented to hardware. Due to that reason, inverse matrix method is implemented for RLS instead of using basic RLS in order to overcome disadvantage of time complexity in RLS. For equalization technique, DFE as a non-linear equalizer is used because of its performance which is not enhancing noise during simulation. The combination of CLS with DFE can minimize ISI better compare to conventional LMS and RLS alone. This research also justified that combination of CLS-DFE OFDMA with MIMO antenna enable to mitigate ISI too.

Keywords- Inter Symbol Interference (ISI), Decision Feedback Equalizer (DFE), Cascaded Least Square (CLS), Least Mean Square (LMS), Recursive Least Square (RLS), Complexity

1. Introduction

Over the last few decades, the world has witnessed the sudden shift in mobile communication technology and reaped a lot of benefits from it. The invention of multipurpose antenna in transmitting and receiving multiple data at once has created a lot of advantages in wireless transmission technology and somehow the merges between two technologies also bring a greater impact towards the system. Multiple input multiple output (MIMO) can be categorized as the advanced technology in transmitting the data signal and can be diversified into different spaces (antenna), time and frequency or in other words the signal can be sent simultaneously for a different user [1]. Wireless technology introduces multiple access techniques that provide communications services to multiple users in a single-bands. OFDMA is a multiuser of digital modulation technique that had been introduced in order
to improve wireless performance due to the multipath propagation which can cause ISI [2]. Based on the previous research [3], ISI will attenuate a signal waveform in the channel.

To eliminate ISI and the noise as much as possible, equalizer become one of the main method to overcome this problem in this research. Different equalization adaptive algorithm can be applied with decision feedback equalizer (DFE) to overcome interference. In addition, equalizer can boost up wireless performance by combining with any adaptive algorithm. Performance of equalizer with adaptive algorithms will be explained more in part 2 below. This research will enhance performance of conventional CLS proposed by previous research in [4].

2. CLS-DFE In The Receiver

Adaptive algorithms have been introduced in communication field to maximize efficiency of communication system. There are three main adaptive algorithms which are LMS, RLS and CMA. LMS basic algorithm which was proposed by Windrow and Hoff is widely used in signal processing and adaptive technology while RLS algorithm known as an algorithm with good convergence speed that calculates inverse matrix with iteration method. CMA is also another approach to reduce BER but this algorithm work most effectively when used with blind equalizer or also known as one of linear equalizer. LMS is one of the most widely used adaptive algorithms due to its robustness and simplicity while RLS is one of adaptive algorithm commonly used due to its fast convergence.

DFE was first proposed by Austin in [5]. It was an adaptive equalizer that used previous detector decisions to eliminate ISI on pulses that are currently being modulated. If previously detected symbols were known, ISI from these symbols could be cancelled out by having suitable weighting to subtracts past symbols values [6]. The connection between DFE and adaptive algorithm; it was proposed to calculate the time varying for DFE to equalize time-varying frequency-selective fading channels.

LMS and RLS were widely used in communication system. This was because LMS simplicity and cheap production attract researchers to apply it in the system. RLS was chosen among other algorithm because of its faster convergence rate and tracking ability as stated by authors in [7]. Although RLS was helpful and could solve problems but at the expense of increased complexity of O(L^2) which L is the finite impulse filter length. Complexity of algorithm explains how much the number of operations was affected as the input get larger. This research will proof reduction of time complexity by measuring running time of system using time elapsed indicator in Matlab.

2.1. CLS-DFE Algorithms

The basic equation for LMS algorithm can be written as [8]

\[ w(k+1) = w(k) + \mu \cdot e(k) \cdot d(k) \]  \hspace{1cm} (1)

While \( \mu \) was the step size, \( w(k) \) was filter coefficient vector and \( d(k) \) was filter input vector. The error signal \( e(k) \) was the difference between filter input vector \( d(k) \) and \( d_{e}(k) \) estimated signal which can be summarised as below

\[ e(k) = d(k) - d_{e}(k) \]  \hspace{1cm} (2)

For RLS, basic equation can be written as

\[ w(k+1) = w(k) + e(k) \cdot G(k) \]  \hspace{1cm} (3)

While \( w(k) \) was the filter coefficient vector and \( G(k) \) was gain vector, it could be defined as
\( G(k) = \frac{P(k) \cdot R(k)}{\lambda + R^T \cdot P(k) \cdot R(k)} \)  

(4)

\( \lambda \) was a forgetting factor with its value \( 0 < \lambda < 1 \). Faster convergence rate could be achieved when \( \lambda \) had smaller value but it must not be too small because it might make algorithm became unstable. \( P(k) \) was an inverse matrix of input signal while \( R(k) \) was filter input vector for RLS. The general RLS algorithm’s complexity growth is growing with coefficients number \( N^2 \). Due to that reason, RLS will use matrix inversion to overcome time complexity in the algorithm that can be simplified as:

\[
\begin{bmatrix}
A & B \\
C & D
\end{bmatrix}^{-1} = 
\begin{bmatrix}
E & F \\
G & H
\end{bmatrix}
\]

(5)

\[(A - B \cdot D^{-1} \cdot C^{-1}) = A^{-1} + A^{-1} \cdot B \cdot (D - C \cdot A^{-1} \cdot B)^{-1} \cdot C \cdot A^{-1}\]

(6)

CLS is new method proposed by author in [4]. The algorithm which was combination of LMS and RLS can be summarized as below:

\[ e_{LMS} = d(k) - w_{LMS}(k)u(k) \]

(7)

\[ y_k = w_{LMS}(k)u(k) \]

(8)

\[ e_{RLS} = d(k) - w_{RLS}(k-1)y(k) \]

(9)

\[ z_{CLS} = w_{LMS}(k)u(k)w_{RLS}(k-1) \]

(10)

\[ e_{TOTAL} = d(k) - z_{CLS}(k) \]

(11)

Which \( d(k) \) is desired output, \( u(k) \) is filter input vector, \( y(k) \) is estimated output of LMS. Error for RLS will include \( y(k) \) in it. Output of LMS will be used with input RLS as a combination. \( z_{CLS} \) is final output for CLS before included in DFE operation.

2.2. MIMO OFDMA Block Diagram
Figure 1 shows OFDMA transceiver block diagram use in this research. Transmitter first converts input data from a serial stream to parallel sets using serial to parallel (S/P) converter. Modulator will modulate corresponding subcarrier. OFDMA modulation is generated using inverse fast furious transform (IFFT). It will convert frequency domain data set into samples of corresponding time domain. IFFT will generate sample waveform with orthogonal frequency components. Parallel to serial (P/S) converter creates OFDMA signal by outputting time domain samples. Cyclic prefix as a guard interval inserted to extend the transmitted signal beyond the nominal symbol period to create a cyclically extended guard interval so inter symbol interference (ISI) can be completely eliminated as long as cyclic prefix is longer than maximum spread of the channel [9]. Length of CP usually is a quarter of IFFT size. Channel of this system put multipath and AWGN to match with real environment performance. At the receiver, combination of adaptive algorithm LMS and RLS will be applied to DFE in order to equalize and minimizing the interference.

2.3. Simulation Parameter

Table 1. OFDMA-PHY based on IEEE 8022.16 Mobile WiMAX Parameter [2]

| Parameter          | Values    |
|--------------------|-----------|
| Modulation         | QPSK      |
| FFT size           | 1024      |
| Number of Subcarrier | 128      |
| Subcarrier Spacing (kHz) | 10.94  |
| Cyclic Prefix      | 256       |

Channel type choose for this research is COST 207 Typical Urban (TU) because this channel parameter function like real environment. Besides that, TU is more compatible because this research focusing on non-stationary environment. 6 multipath had been considered in this simulation to get the best optimize performance [10]. The multipath delays are [0 0.2e-6 0.5e-6 1.6e-6 2.3e-6 5.0e-6] while
the path gains are [1.122 1.259 1.156 1.059 1.038 1.023] [11]. This simulation use maximum Doppler frequency of 200 Hz [12].

3. Results and Discussion

Figure 2. Comparison of OFDM and OFDMA Performance for MIMO

| BER Value  | SNR (db) OFDM | SNR (db) OFDMA | Percentage of improvement |
|------------|---------------|----------------|--------------------------|
| $1 \times 10^{-2}$ | 17.28         | 14.12          | 18.28%                   |

Table 2. Percentage of Improvement between OFDM and OFDMA

Figure 2 shows the comparison of BER between MIMO-OFDM and MIMO-OFDMA. OFDMA prove to have lower BER compare to OFDM with 18.28% improvement. This is because OFDM can only allow one user on the channel at one time compare to OFDMA that allow multiple access on the same channel. Subchannel process can be described as a distribution of subcarriers among users in OFDMA at the same time within a same channel. Due to this reason, single user did not need to occupy all the subcarriers at any given time because subset of subcarrier will be assigned to particular user. This allows users to be assigned dynamically to low interference channel and avoid certain part of fading in the system. In OFDMA, both time and frequency resources are used to separate the multiple user signals. OFDMA employs multiple closely spaced subcarriers but the subcarriers are divided into groups of subcarriers named a subchannel. Since OFDMA is a multiple access scheme, the data for the various users is contained within a symbol.
Figure 3 above show simulation of method that usually use for RLS algorithm in communication system. Fixed RLS is a normal and basic algorithm. Variable method in RLS is applied for its forgetting factor while for inverse RLS it is related to inverse matrix. Inverse RLS has 2.32% improvement while compared to basic RLS and prove as a best method for RLS algorithm compare to variable method. Inverse RLS elapsed time is 72 seconds with 10.2% improvement while variable RLS has 84 seconds. In RLS algorithm, the equalization error sequence is considered to be a deterministic process. Because of that reason, variable forgetting factor can enhance error in the estimation due to effects of input noise and channel dynamics. Besides that, forgetting factor in equation (4) cannot have value larger than 1 which inappropriate for simulation RLS because theoretically, value of forget factor is only between 0 and 1. Based on equation (5), inverse matrix in RLS algorithm is calculated with an iterative method. Performance of the system depends on the efficiency of formulation of the inverse matrix in the RLS algorithm.

4. Conclusions
As a conclusion, reduction of time complexity by measuring running time algorithm for CLS-DFE MIMO OFDMA can be seen when percentage of improvement for inverse method is 2.32% better than basic method and 10.2% improvement compare to variable method. The time elapsed decrease to 72 seconds only. The percentage improvement might not be that big but still there is more room for improvement in the future. CLS method had been copyrighted with serial number CRLY00007358.

Acknowledgments
The authors acknowledge Faculty Electrical Engineering UiTM Shah Alam for the lab facilities and financial supports by UiTM GIP (064/2018) grant. Special thanks to members of Wireless Communication Technology Group for all the ideas and moral support to finish this research.
References

[1] B. L. B.Siva Kumar Reddy, “Adaptive Modulation and Coding in COFDM for WiMAX Using LMS Channel Estimator,” in Advances in Communication and Control Systems, 2013, pp. 23–29.

[2] W. ForumTM, “Mobile WiMAX–Part 1: A Technical Overview and Performance Evaluation,” WiMAX Forum CERTIFIED, vol. 2.8. p. 15, 2006.

[3] J. Cheol Seo, T.-H. Kim, and J.-K. Kang, “A high-speed adaptive linear equalizer with ISI level detection using periodic training pattern,” International SoC Design Conference. pp. 419–422, Nov-2012.

[4] S. M. Sulong, A. Idris, and S. S. Sarmin, “Performance Evaluation of CLS-DFE for MIMO OFDMA System,” J. Adv. Comput. Networks, vol. 4, no. 2, pp. 2–5, 2016.

[5] M. Austin, Decision-feedback equalization for digital communication over dispersive channels. 1967.

[6] Z. Tian, “Mitigating Error Propagation in Decision-Feedback Equalization for Multiuser CDMA,” IEEE Transactions on Communications, vol. 52, no. 4. pp. 525–529, Apr-2004.

[7] M. Rana, “Performance comparison of LMS and RLS channel estimation algorithms for 4G MIMO OFDM systems,” Proceedings of International Conference on Computer and Information Technology, no. Iccit. pp. 22–24, 2011.

[8] P. Sivakumar, K. . Rajesh, and M. Rajaram, “A new normalized block LMS based adaptive decision feedback equalizer for wireless communications,” IEEE Advances in Engineering, Science and Management, no. l. pp. 116–120, 2012.

[9] M. N. Seyman and N. Taspinar, “MIMO-OFDM Channel Estimation Using ANFIS,” Signal Technology, vol. 4, no. 4. pp. 75–78, 2012.

[10] W. Su, Z. Safar, M. Olfat, and K. Liu, “Obtaining full-diversity space-frequency codes from space-time codes via mapping,” IEEE Transaction on Signal Processing, vol. 51, no. 11. pp. 2905–2916, 2003.

[11] G. L. Stuber, “Principle of Mobile Communication (2nd Edition).” Springer, p. 688, 2000.

[12] S. Soon, P. Jin, J. Hwang, and C. K. Baik, “A Spreading MIMO-OFDM Transmission Scheme for Wireless Mobile Environment,” International Conference on Computational Science and Its Applications. pp. 236–242, 2006.