Enhancement of LMS Convergence Rate with CLS-DFE for 5G Wireless Communication System

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Abstract. WiMAX physical layer implemented Orthogonal Frequency Division Multiple Access (OFDMA) as one of the medium to conduct data transmission. OFDMA suffers from Intersymbol Interference (ISI) which can distort efficiency of the signal transmitted. ISI emerges in the system because of multipath. Basic Cascaded Least Square (CLS) with Decision Feedback Equalizer (DFE) had been proposed in previous research to minimize ISI in wireless communication system. This research will improve CLS performance in terms of convergence. CLS is a cascaded of two adaptive algorithms which are Least Mean Square (LMS) and Recursive Least Square (RLS). Although basic LMS has low complexity than RLS and has been used widely in wireless environment, LMS is suffering in terms of convergence. Updated Normalized Least Mean Square (NLMS) with training rate applied in this research to overcome disadvantage in LMS algorithm. This research justified that training rate is an alternative method to improve CLS-DFE in wireless communication system.

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

1. Introduction
Nowadays technology advancement in mobile communication increased benefits for users who wanted to have higher data speed transmission. The exceptional performance in connecting people make this new emerging technology a demand in society [1]. Multipurpose antenna design has given a lot of advantages especially towards transmitting and receiving multiple data at one time. This merges between multiple inputs multiple output (MIMO) and OFDMA technologies also lead towards better impact in the system. Thus, this research added MIMO smart antenna to intensify performance of its wireless system. For the Metropolitan Area Network (MAN) standard, OFDMA was implemented in the mobility mode of IEEE 802.16 to improve and achieved high speed data rate [2]. ISI in wireless communication system is a well-known problem among researchers. To diminish ISI as much as possible, implementation of equalizer with adaptive algorithm applied in this research to minimize interference. Equalizer could be either linear or non-linear which based on the use of its output. Theoretically, equalizer could effectively diminish ISI in the wireless system and combat time
dispersion occur in channel [3]. This research will improve the efficiency of basic CLS proposed in earlier research [4].

2. Research Development

There were three main parts in wireless communication systems which were transmitter, channel and receiver. CLS-DFE was located at the receiver to minimize error that exist during data transmission. In communication field, adaptive algorithms methods have been proposed to optimize system efficiency. This research considered two basic adaptive algorithms for the equalization technique which were LMS and RLS. Due to its memoryless characteristics, Constant Modulus Algorithm (CMA) which also part of adaptive algorithm was not included in this research because CMA was more compatible for blind equalization technique instead of DFE as mentioned by authors in [5].

DFE was first proposed by Austin in [6]. Low noise amplification behavior is one of the advantage of DFE and also classified as an upgraded of linear equalizer [7]. DFE’s best performance is generally attained with training cycles used to retrieve changes of channel. In [8], the author implemented DFE-based receiver for Orthogonal Frequency Division Multiplexing (OFDM) systems that have channels with long delay spreads. The affected channels due to long delay spreads could be overcome by using design proposed by author. However presence of cyclic prefix (CP) to reduce ISI in the system affect their system efficiency.

LMS and RLS are often used in communication system. LMS is the easiest among adaptive algorithms and commonly used by researchers in their system [9][10]. Besides that, LMS also a popular algorithm due to low complexity compare to other adaptive algorithms [11]. A new LMS adaptive filter with a variable step size to solve convergence rate problem was introduced by Raymond and Edward [12]. The study developed an algorithm to decrease distortion and enhance tracking ability of LMS with constant step size. Although the result show remarkable performance, however the proposed algorithm limited to stationary environment only. Fast convergence in RLS make this algorithm one of the best choice for wireless system but it comes with a disadvantage in terms of computational complexity. The general RLS algorithms’s complexity grows with $N^2$ which N was the number of equalizer coefficients. The number of equalizer coefficients grow linearly with complexity for fast RLS algorithm [7]. RLS is mostly used for convergence speed and recover LMS’s shortcomings.

LMS algorithm has its own practical version which is the normalized LMS (NLMS). NLMS implemented one way to optimize preference of varying step size by shifting the value to enable smooth reduction of noise. A few researchers in [13][14][15] used NLMS with DFE in their system but the author’s research focused on computational complexity, mean square error and indoor environment which were different from this research approach. Part 2.1 below will discuss the equation required for the system. This research applied NLMS with training rate during transmission and combined with RLS algorithm. The signal will be processed by DFE to reduce any remaining error or noise.

2.1 Methodology

The general equation for NLMS algorithm can be described below [13],

$$w(k+1) = w(k) + \mu(k) \cdot e(k) \cdot d(k) \tag{1}$$

Which is $\mu(k)$ as a step size assist to classify tap weights revised for next phase, $w(k)$ is the filter coefficient vector and $d(k)$ is filter input vector. The error signal $e(k)$ is the difference between filter input vector $d(k)$ and $d_e(k)$ estimated signal that can be summed up as below;

$$e(k) = d(k) - d_e(k) \tag{2}$$
NLMS formed an adaptive algorithm object solely for DFE to generate an equalizer object. This algorithm also has step size that have value lies between 0 and 1. The general equation of RLS can be written as below;

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

(3)

Which is \( w(k) \) as the filter coefficient vector and \( G(k) \) is gain vector.

CLS has been introduced by researchers in their previous work [4]. Merge of algorithms between NLMS and RLS can be clarified as below;

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

(4)

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

(5)

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

(6)

Total error computed from the equalized output by using training sequence is like below;

\[
\begin{bmatrix}
    y_3 & y_2 & y_1 & a_2 & a_1 \\
    y_4 & y_3 & y_2 & a_3 & a_2 \\
    y_5 & y_4 & y_3 & a_4 & a_3 \\
    y_{10} & y_{10} & y_8 & a_9 & a_8 \\
\end{bmatrix} \begin{bmatrix}
    c_0 \\
    c_1 \\
    c_2 \\
    d_0 \\
    d_1 \\
\end{bmatrix} - \begin{bmatrix}
    a_3 \\
    a_4 \\
    a_5 \\
    a_9 \\
    a_{10} \\
\end{bmatrix}
\]

(7)

Equation above can be finalized as below;

\[ (A^H \cdot A)^{-1} \cdot (A^H \cdot b) \]  

(8)

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

(9)

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

(10)

Which is \( d(k) \) as a desired output, \( u(k) \) is filter input vector, \( y(k) \) is estimated output of NLMS. \( y(k) \) is included in final RLS’s error. The NLMS outcome is being used as an input of RLS. DFE will use CLS final output, \( z_{CLS} \) to minimize interference.
2.2 Receiver Block Diagram

![Equalizer with Wireless Channel](image)

**Figure 1.** Equalizer with Wireless Channel

Figure 1 above shows block diagram of equalizer with wireless channel. Reducing distorted signal that occur during data transmission is a main focused of this research by applying equalization technique. The equalizer worked by implying that the channel was non linear and attempt to construct equalizer filter whose filter coefficients modified in time depending on the channel change. Interference will be diminished as much as possible at each time.

![Block Diagram of DFE](image)

**Figure 2.** Block Diagram of DFE

Figure 2 above illustrate block diagram of DFE as one of adaptive equalizer. Feed-forward (FF) and feed-back (FB) filter are main component in DFE. Value of weights for FF and FB can be adjusted before applying it to operate in symbol rate [16]. Appropriate weighting eliminated previous symbol values for FF output. DFE’s fast-varying channel characteristic required adaptive algorithm to have a fast convergence property [11]. Additive White Gaussian Noise included in channel output $Y_{t}(t)$. Before applying the final value of DFE weight for whole simulation, varying weight rate is required to analyse performance of BER. Training period applied training symbol $I_{k}$ during simulation and $Q_{k}$ as an input of decision device. Equalizer modification was executed as per the error signal $e_{k}$. Equation for $e_{k}$ is stated below [15];

$$e_{k} = i_{k} - Q_{k}$$  \hspace{1cm} (11)

It was possible to get decision error either due to impulse response of false equalizer or period at the initial filter [7].
2.3 Wireless Communication System Parameter

Table 1. Parameter for Wireless Communication System

| Parameter          | Values                                      |
|--------------------|---------------------------------------------|
| Channel Type       | COST 207 Typical Urban (TU)                 |
| Number of Multipath| 6                                           |
| Multipath Delays   | 0 0.2e-6 0.5e-6 1.6e-6 2.3e-6 5.0e-6        |
| Path Gains         | 1.122 1.259 1.156 1.059 1.038 1.023         |
| Doppler Frequency  | 200 Hz                                      |

Table 2. Parameter for Algorithms

| Algorithm | Parameter | Value                  |
|-----------|-----------|------------------------|
| LMS       | Step Size | 0.001                  |
|           |           | (0.01 ≤ μ ≤ 0.001      |
| NLMS      | Training Rate | 0-2000               |
| RLS       | Forget factor | 0.9                  |
|           |           | (0.01 ≤ λ ≤ 0.9       |
| DFE       | Weight system | 7[17]               |

Table 2 above summarized the parameter for algorithms used to finalize simulation of CLS-DFE. Analyses for step size used increment of 0.001 while forget factor increment was 0.01.

3. Results and Discussion

Figure 3. Performance of BER for LMS Algorithm
Table 3. Percentage of Improvement between LMS Tracking and Training

| BER Value | SNR (db) | SNR (db) | Percentage of Improvement |
|-----------|----------|----------|--------------------------|
| Training  | 13.74    | 13.98    | 1.72%                    |
| Tracking  |          |          |                          |

Figure 3 above illustrates tracking and training technique that usually applied for previous work by researchers to upgrade LMS efficiency. Compared to tracking LMS, training LMS has better development with 1.72%. Previous researcher used less value of training rate for DFE contrast to CLS-DFE simulation which applied 0 until 2000 [18]. Although time constraint will be affected due to large sample, however this method can help to balance process of algorithms. From equation (1), \( d(k) \) is the desired signal while \( e(k) \) from equation (2) is error signal. \( d(k) \) is a process that applicable at the beginning of the training period while \( e(k) \) present as a directed decision mostly during corresponding phase. Tracking is convenient for LMS track capabilities compare to convergence rate of LMS. As stated by researchers in [19], LMS is more applicable with training method due to its simpler behavior. The system required to get the rapid startup for NLMS during conjunction with RLS. This is to determine that reduction of time complexity for the system will have minimum processing time.

Figure 4 above compared performance between basic LMS, training LMS and NLMS. As expected, training NLMS has 3.78% improvement compare to basic LMS. NLMS which has better convergence speed is popular among researchers. High sensitivity towards their own scaling input become major disadvantage of the basic LMS algorithm. Analysing step size value that can preserve the algorithm’s reliability will become complicated. In order to have the best outcome, large large training rate will be permitted. NLMS is an alternative to overcome problem of LMS by normalising with the power of the input [20]. LMS and NLMS training behave almost the same. Equation (1) prove the only difference
between both algorithms. Coefficient that has been updated for next cycles is based on the reference input signal vector.

4. Conclusions
As a conclusion, enhancement of convergence rate in CLS-DFE for wireless communication system can be seen when percentage of improvement for training NLMS is 3.78% better than basic method while training LMS has only 1.89% improvement. The percentage improvement might not be huge but still it still can be improve in the future. All the results were analyzed based on performance of bit error rate (BER). For upcoming research, the outcome can be analyse using performance of mean square error (MSE). Basic CLS algorithm with serial number CRLY00007358 was already copyrighted.

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