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Enhancement Cascaded Least Square of RLS and NLMS for Wireless Communication System

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ABSTRACT

Orthogonal Frequency Division Multiplexing or known as OFDM has been a prominent digital communication scheme and was introduced in the 4G network. This technique can be described as an exceptional multicarrier instance where the signal data is transmitted using separate subcarriers through a total of the subcarriers at a lower rate. Although OFDM seems perfect for the development of 5G networks and upcoming 6G, this type of digital modulation still suffers from intersymbol interference (ISI). Enhancement Cascaded Least Square (ECLS) which is a sequence of adaptive algorithms has been proposed in this research to overcome ISI that occurs due to multipath propagation. ECLS is a combination of updated Recursive Least Square (URLS) and Normalized Least Mean Square (NLMS). URLS will reduce complexity while NLMS will overcome problem of convergence before being combined to become ECLS. The research outcome will be illustrated in Bit error rate (BER) to analyse lower interference and Mean Square Error (MSE) to analyse convergence. This research justified that ECLS can minimize the existence of interference in wireless communication systems.

1. Introduction

In the 5G era, the surroundings are congested with skyscrapers and high-tech machinery. With this sort of urban climate, the transmitted signals can bounce off trees, houses, vehicles, etc. The signals will continue until the receiver is reached, but the signal will be in various directions considering dispersion throughout transmission. OFDM is a capable multicarrier transmission to overcome fading channels. It is well known that OFDM main advantage is that it can provide better spectral efficiency as stated by Anoh *et al.,* [1]. OFDM obtains spectral efficiency by having very close spacing carriers. The idea of OFDM was to transmit the data using frequency division multiplexing on a parallel modulated subcarrier. Subcarriers of OFDM need to be aligned with each other without overlapping. This was the main factor requiring the subcarrier to have the right frequencies. Carrier spacing must be selected carefully to avoid the symbols interfering with each other. OFDM needs to

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maintain the orthogonality so that the signal is transmitted perfectly over a common channel and leads to no interference. Ravalika and Swetha [2] analysed how the presence of a non-linear adaptive equalizer can affect the performance of OFDM. The final outcome proved that different numbers of antennas with a proper choice of adaptive algorithm can enhance the performance of the system. Babulkar [3] indicated that OFDM can transform a frequency selective fading channel into parallel flat-fading channels by utilising a simple equalization process because neither wired nor wireless communication systems could avoid ISI.

In the wireless field, signals were frequently disrupted by fading and the effect of multipath spreading. ISI's presence in the network resulted in a high probability of errors and degradation of system performance. To overcome ISI in MIMO-OFDM, Bhandari and Jadhav [4] suggested a new hybrid blind channel estimation with independent component analysis. Although the study indicated its effectiveness in diminishing BER, there was no impact in computational complexity or peak average power ratio.

Jadav [5] carried out detailed reviews on ISI, intercarrier interference, and co-channel interference to evaluate thorough research on interference mitigation techniques. In addition, the research also discusses space time block code and channel coding techniques for limiting interference in wireless systems. To preserve orthogonality during transmission, the Cyclic Prefix (CP) was added to the OFDM symbol. The outcomes showed that OFDM can mitigate ISI with the aid of CP. However, it required high processing power and time. Zahoor and Sabraj [6] established a novel approach to reducing ISI in wireless communication by integrating LMS and RLS adaptive equalization. Although the proposed joint method could have been applied to lessen BER and function as an ISI removal solution, it did not perform well in terms of RLS convergence rate.

To boost the efficiency of smart antennas, different step sizes of the LMS and NLMS algorithms were simulated by Qasim and Sallomi [7]. The suggested technique significantly improves system effectiveness in terms of convergence rate and BER. However, an adequate step size must always be considered to avoid instability. To reduce complexity, Djigan [8] compared two different adaptive filters that utilized the RLS algorithm. The first is hybrid, while the second has a diagonalized correlation matrix. Both perform well in terms of minimizing arithmetic complexity. Regardless, it is only applicable to RLS algorithms with quadratic complexity.

Khan *et al.,* [9] developed a modified RLS algorithm for interference cancellation to optimize the data rate performance of wireless systems. The proposed algorithm outperforms the previous classical RLS algorithm remarkably. Nevertheless, the algorithm was not focused on complexity. Meanwhile, Mohammad *et al.,* [10] proposed improving the LMS adaptive noise canceller using a polyphase digital filter bank. Despite using the Discrete Fourier Transform, the system generates excellent outcomes. Akkad *et al.,* [11] introduced the use of parallel RLMS and Kalman RLMS in adaptive beamforming. RLMS is a hybrid algorithm that incorporates the capabilities of RLS and LMS. The final result proves that RLMS surpasses RLS and LMS in terms of convergence.

Reddy *et al.,* [12] proposed a hybrid filter to outperform adaptive algorithms, including LMS, NLMS, and RLS. The combination filter highlighted three distinct parameters: speed, power, and area. It was constructed by combining a five-tap filter and cascaded core filters. The research fulfilled all of the objectives, and yet the design still requires improvement to achieve greater efficiency in terms of power consumption. Karthickmanoj *et al.,* [13] evaluated six different filtering techniques. The study also included RLS and LMS. The overall outcome illustrates that RLS has a relatively high BER compared to LMS. The authors state that, despite RLS's complexity, it significantly improves LMS in aspects of SNR performance. LMS and RLS variants have exhibited great performance, and the combination of these two algorithms can yield better results.

Mainly, this research proposes combining training NLMS with updated RLS (URLS), which simplifies complexity, stability and convergence. Section 2 will discuss the proposed method and equations. All research outcomes will be evaluated in terms of MSE and BER for Section 3. Section 4 encloses the research's conclusion.

2. Methodology

Section 2 will go into greater detail about the LMS and RLS algorithm research. Other than that, related equations, block diagrams, and system parameters to implement for this study are included in this section too.

Researchers frequently utilised LMS and RLS at the receiver to minimise ISI. However, both algorithms have limitations, including slow convergence for LMS and high computational complexity for RLS. As mentioned by Claser and Nascimento [14], integrating LMS and RLS algorithms can lead to significantly improved tracking performance. The study developed a convex combination of various algorithms, resulting in a lower level of computational complexity. Although it covered a non-stationary condition, the research did not include multicarrier modulation. Dash *et al.,* [15] proposed various approaches to improve the convergence rate, including the use of a modified proportionate affine projection algorithm. Although their suggested technique enhances the performance of LMS, has a low misadjustment error and acceptable complexity, the method was not derived for the OFDM system.

Recently, Akkad *et al.,* [16] presented a novel LMS structure to intensify LMS convergence. Although the results improved convergence speed when compared to previous methods, the environment only simulated different assigned Signal to Noise Ratios (SNR). Chitikena and Rani [17] identified how various adaptive algorithms, notably LMS-based techniques, can improve the performance of an OFDM system. Aside from that, the authors outlined the advantages and disadvantages of each algorithm. For smart antenna, a combination of several algorithms, including RLS, LMS, and sample matrix inversion, was implemented to improve beamforming as mentioned by Dunggineni *et al.,* [18]. Niu and Chen [19] proposed a new variable step size for the LMS approach based on the gradient of the filter coefficient. The findings indicate that the proposed method has greater convergence and robustness. However, the step size value cannot be too large since it can influence system stability.

Arezki *et al.,* [20] developed an innovative algorithm that surpasses the classical adaptive algorithm in complexity and convergence but is unable to manage a massive number of filters. The simulation findings indicate that RLS and NLMS have good complexity and a faster convergence rate, but their performance degrades in the fast-varying channel. To boost filter performance, Claser and Nascimento [21] identified and discussed potential combinations of adaptive algorithms that could achieve tracking performance comparable to the optimal results acquired by the Kalman Filter. Both findings from Patra and Nayak [22] and Ismail *et al.,* [23], studied adaptive algorithms for adaptive beamforming in smart antennas.

An earlier design of cascading least squares (CLS) was proposed by Sulong *et al.,* [24] by justifying that the method can reduce bit error rate, whereas Sulong *et al.,* [25] introduced a combination of URLS and basic LMS. URLS applied matrix inversion to minimise the complexity of the system. Instead of traditional LMS and RLS, this study used training NLMS and URLS. There is no exact research that applies the sequence of training rate NLMS with low complexity RLS in the OFDM system at the moment. For RLS, it became URLS using matrix inversion. For LMS, it went from basic LMS to NLMS and then training NLMS.

2.1 Proposed Method

The transmitted OFDM symbol determined by Inverse Fast Fourier Transform (IFFT) and FFT is described as,

$$X[k] = FFT\,\{x[n]\} = \sum_{n=0}^{N-1} x[n]e^{-j\frac{2\pi nk}{N}}, \quad 0 \leq k \ \leq N-1; \tag{1}$$

$$x[n] = IFFT\,\{X[k]\} = \frac{1}{N}\sum_{k=0}^{N-1} X[k]e^{-j\frac{2\pi nk}{N}}, \quad 0 \leq n \ \leq N-1 \tag{2}$$

X[k] denoted the transmitted data symbols,, *N* represented the number of FFT size and *x[n]* was OFDM symbol number at discrete time *n*. The subcarriers were orthogonal if it did not overlap with one another. The common OFDM symbol in the time domain can be written as;

$$x = [x_1, x_2, \ldots\ldots x_L] \tag{3}$$

and upon implementation of CP;

$$x_{CP} = [\ x_{L-V}, x_{L-V+1} \ldots\ldots x_0\ x_1 \ldots\ldots x_{L-1}] \tag{4}$$

L is the symbol length while V is the period of CP. Duration of CP is within the symbol period range of one-fourth to one-thirty seconds [26]. Total length of the transmitted symbol was;

$$T_{total} = T_{cp} + T_s \tag{5}$$

Which *Tcp* was the period of CP and *Ts* was the duration of the usable symbol. The period must be longer than CIR so ISI can be omitted but it still occurs in band fading. The first step, the desired output signal *d(n)* for NLMS can be defined as;

$$d_{NLMS}(n) = w^T(n)\, y_{NLMS}(n) \tag{6}$$

Which w^T is a weight transpose and *y(n)* is NLMS estimated output. Error calculated derivations;

$$e_{NLMS} = d_{NLMS}(n) - y_{NLMS}(n) \tag{7}$$

NLMS algorithm adjusts filter tap weights to ensure the minimization of e_{NLMS}. The error $e_{NLMS}(n)$ is determined by applying the training rate as a guideline;

$$(A^H \cdot A)^{-1} \cdot (A^H \cdot b) \tag{8}$$

NLMS output will be used when calculating error for URLS;

$$e_{URLS} = d_{URLS}(n) - w_{URLS}(n-1)\, y_{NLMS}(n) \tag{9}$$

Matrix inversion of A,B,C and D can be done using simplified method below;

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} \cdot \begin{bmatrix} E & F \\ G & H \end{bmatrix} = \begin{bmatrix} A \cdot E + B \cdot G & A \cdot F + B \cdot H \\ C \cdot E + D \cdot G & C \cdot F + D \cdot H \end{bmatrix} = \begin{bmatrix} I & 0 \\ 0 & I \end{bmatrix} \tag{10}$$

M=ABCD is 2x2 matrix. While Invertible matrix made of blocks ABCD is written as identical structure M^{-1} = EFGH. The inverse of M is M^{-1} only when M x M^{-1} = M^{-1} x M = I. Both A and D is assumed to be invertible;

$$\begin{bmatrix} E & F \\ G & H \end{bmatrix} \cdot \begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} E \cdot A + F \cdot C & E \cdot B + F \cdot D \\ G \cdot A + H \cdot C & G \cdot B + H \cdot D \end{bmatrix} = \begin{bmatrix} I & 0 \\ 0 & I \end{bmatrix} \tag{11}$$

Both Eq. (12) and Eq. (13) will break into eight matrix forms. And from that, two products will be constructed from it. The equation can be simplified as;

$$E = (A - B \cdot D^{-1} \cdot C)^{-1} \tag{12}$$

$$H = (D - C \cdot A^{-1} \cdot B)^{-1} \tag{13}$$

The final total of error is;

$$e_T = O_{desired}(n) - P_{ECLS}(n) \tag{14}$$

which $O_{desired}(n)$ is updated RLS output and P_{ECLS} is final output of ECLS.

2.2 System Parameter

The parameters used to execute the process of this wireless communication system are shown in Table 1. Two antennas are used at the transmitter and two at the receiver. RLS employs a 0.9 forgetting factor, whereas NLMS employs a 0.001 step size. Note that in this research, size of FFT is equal to number of subcarriers.

Table 1
System parameter [27]

Parameter	Values
Type of Channel	COST 207 Typical Urban
Type of Modulation	64-QAM
Number of Subcarriers	2048
Number of multipath	6
Length of CP	144

2.3 System Block Diagram

Figure 1 shows the OFDM system block diagram applied for this research. There are three main parts in a wireless communication system: the transmitter, channel, and receiver. At the transmitter, the S/P converter will convert the data input from series to parallel. Then the IFFT will convert the signal from frequency domain to time domain. Before entering the channel, CP must be inserted, and it must be longer than the channel's maximum spread. The channel part was multipath and noise. COST 207 TU (Typical Urban) applied at the channel. ECLS, which was a combination of training NLMS and URLS, was located at the receiver part after FFT. FFT will convert time domain back to frequency domain. ECLS will refine the signal more by reducing interference and enhancing the performance of the system.

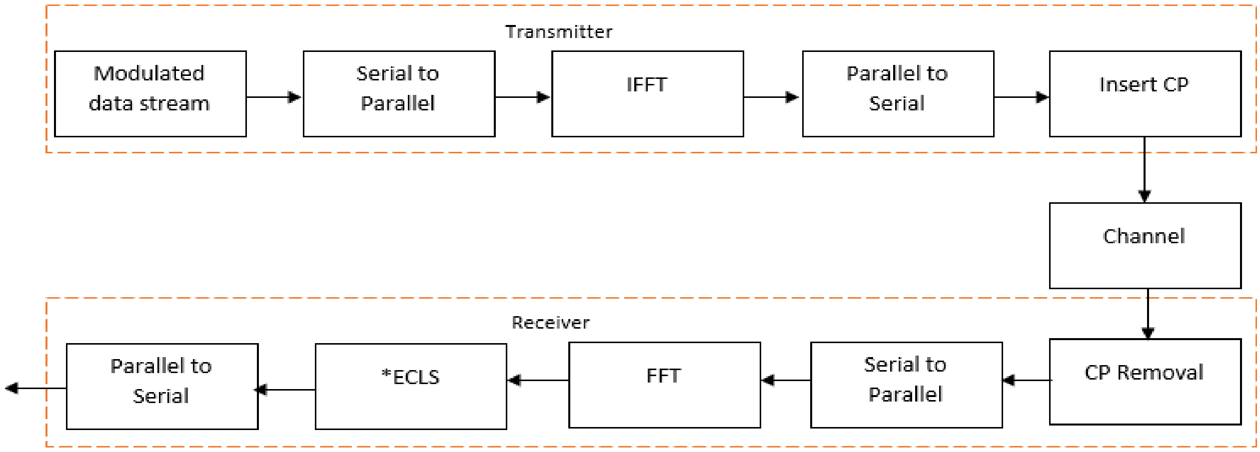

Fig. 1. System Block Diagram (*indicate research contribution)

2.4 System Flowchart

Figure 2 depicts the system's simulation process after initialization. For the default settings, as seen in Table 2, the input is set to '1'. Once the user desires to attempt some other value without adjusting the default, users enter '0'. When the loop is initiated, the symbols are derived at random. Data in information is also random and serial. Since OFDM data is transmitted in parallel, it ought to be transformed from serial to parallel. Following that, modulation will prevail, employing the Quadrature Amplitude Modulation (QAM) technique based on the OFDM parameter. To inhibit symbol overlapping, CP is assigned to the transmitter. Before the signal reaches the receiver, the simulation will encounter channel fading. Rayleigh fading is employed to replicate the real world. The system now includes Additive White Gaussian Noise (AWGN). At the receiver, CP is omitted and the ECLS algorithm is introduced. After equalizing the signal, it will demodulate prior to actually evaluating the BER and MSE.

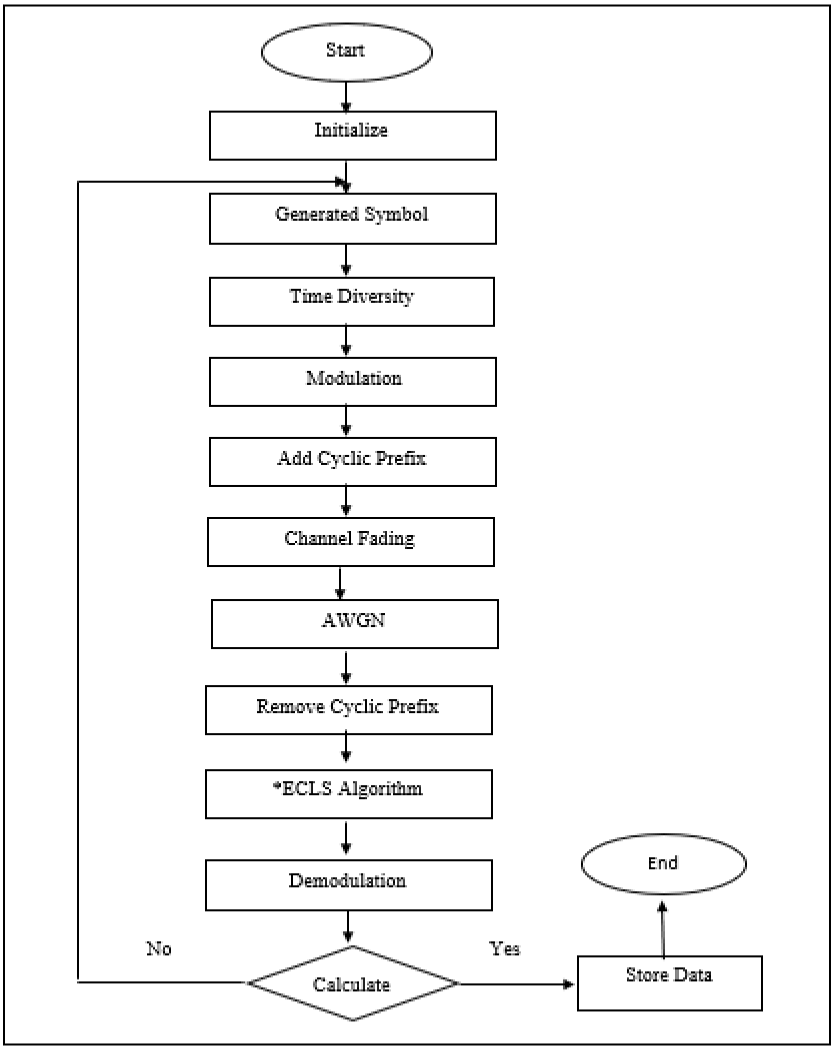

Fig. 2. System Flowchart (*indicate research contribution)

3. Results

This section will elaborate more on the outcomes of the research based on the BER and Mean Square Error (MSE) results.

3.1 Performance of BER for OFDM System

Figure 3 exhibits the output of BER for the OFDM system, which includes inverse RLS or URLS, training NLMS, CLS and ECLS. According to Table 2, training NLMS results in a 68.35% improvement over the inverse RLS. Although the inverse RLS has good results in terms of convergence speed, it cannot exceed the reliability of the training NLMS algorithm, which is well balanced in both terms. With the aid of the training rate, the performance of NLMS is developing. For iteration, NLMS takes 3N+1 contrasted to the 3N (N+3)/2 needed for RLS for each N tap input vector. The training NLMS execution time is 2.5 seconds. In comparison to the executed time for inverse RLS, which is 6.2 seconds. With a 59.67% difference in improvement, it indicates that training NLMS algorithm is less complex than the RLS algorithm. For CLS and ECLS, the result definitely shows an improvement, with ECLS having 62.95% better performance than CLS. Previous CLS only used basic LMS and RLS to optimise the system. The LMS disadvantage of slow convergence can be overcome with ECLS by using the NLMS algorithm with a training rate of 1000, as shown in Eq. (9). Though NLMS is useful for improving convergence rate, choosing a step size value for adaptation is also critical for achieving both a good convergence rate and a low mean square error. RLS which suffers from high complexity, uses matrix inversion in Eq. (12) and Eq. (13) to minimize the weakness. RLS calculated the inverse matrix with an iterative method due to its advantage in convergence speed and tracking ability.

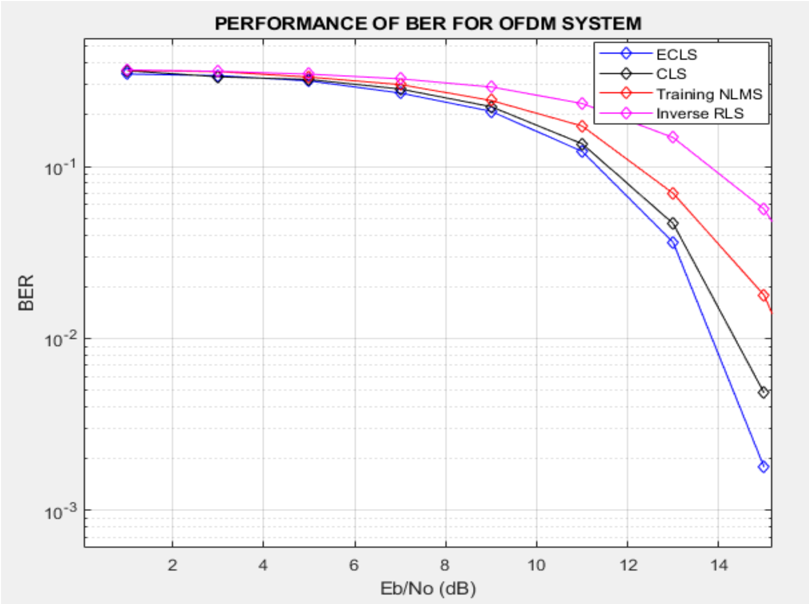

Fig. 3. Performance of BER for OFDM System

Table 2
Percentage Improvement of BER for OFDM System

		10^{-3}			
		Inverse RLS	Training NLMS	CLS	ECLS
SNR	15dB	56.43	17.86	4.821	1.786
(%)			68.35	73	62.95

3.2 Performance of MSE for Convergence Rate

Figure 4 above depicts the learning curve for various kinds of training techniques to distinguish the convergence benefit, which is crucial. The training rate can range from 0 to 2000. 1000 can be used to evaluate the centre point of the training rate for MSE. Referring to Table 3, as predicted, training NLMS came out with the greatest result of 62.88% enhancement accompanied by LMS training. Basic LMS was typically seen in channel equalization due to its simple design and robustness. However, the major obstacle that needs to be faced is the speed of convergence. The achievement of the LMS and NLMS algorithms was influenced by the step size. If the step size is too high, the convergence speed becomes faster but the filtering is not accurate. If the step size is smaller, the filter produces a slow response. Therefore, it is important to select an appropriate value of step size for a particular system to achieve an optimum result.

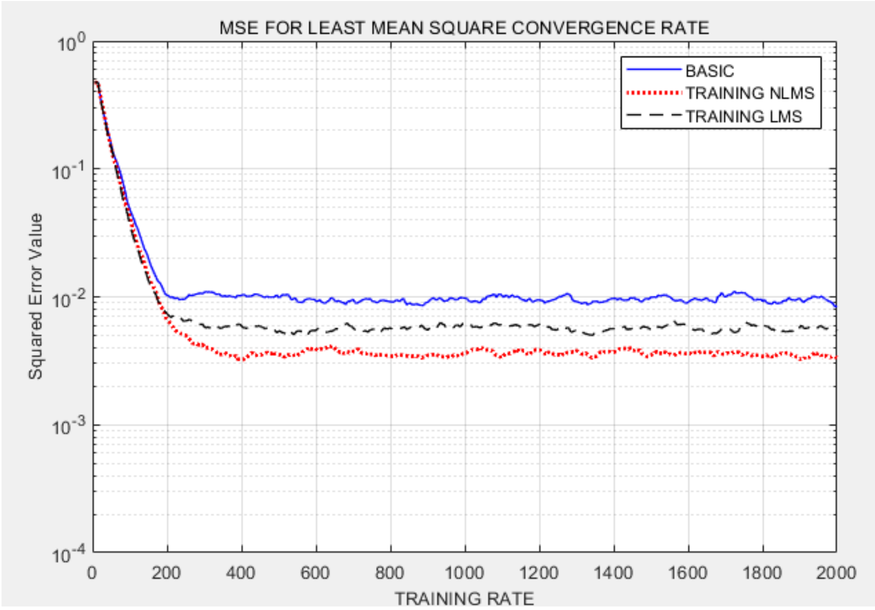

Fig. 4. Comparison of MSE for Convergence NLMS Training Rate

Table 3
Performance of MSE between Different Types of Training

Training rate	Basic	Training LMS	Training NLMS	(%) Training LMS	(%) Training NLMS
1000	0.0097	0.0062	0.0036	36.08%	62.88%

3.3 Performance of MSE for OFDM System

Figure 5 exhibits a performance analysis of the MSE for the CLS to see a consistent learning curve for convergence. ECLS has an increase of 31.57% over common CLS. As compared to the result in Figure 3, as shown in Table 4, the MSE value for this evaluation is significantly smaller, which indicates how ECLS can also have a massive influence on OFDM after reducing the ISI in the network. Given by Eq. (14), the actual error is calculated after generalising the 2000 sample training rate for NLMS to Eq. (8) in an attempt to transform the output of the conjunction with URLS. The inverse matrix procedure is performed via URLS that have fast convergence speeds. Throughout the adaptive system, the algorithm error from Eq. (7) is optimized since training NLMS adjusted the filter tap weights, and the result is then used to compute the error using Eq. (9).

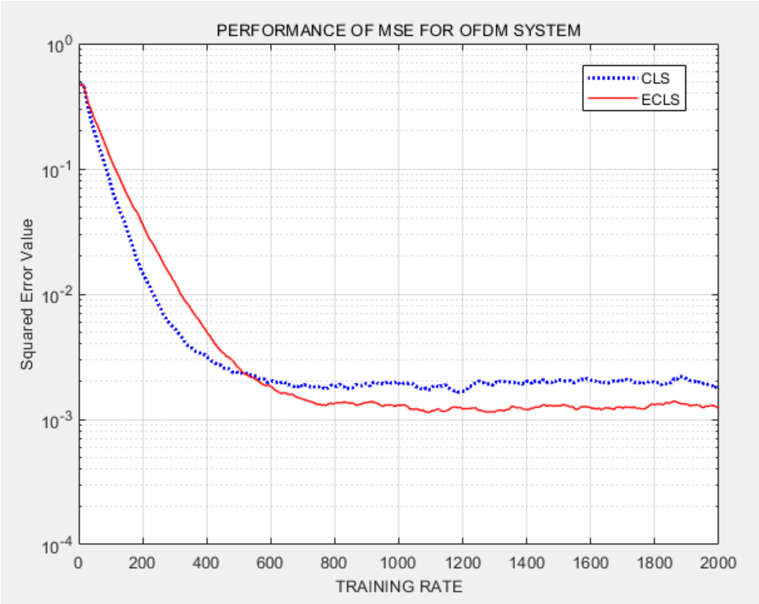

Fig. 5. Comparison of MSE between CLS and ECLS

Table 4
Performance of MSE for OFDM System

Training rate	CLS	ECLS	(%)	
			CLS	ECLS
1000	0.0019	0.0013	-	31.57%

4. Conclusions

Simulation results show that ECLS can improve the performance of the OFDM system and outperform CLS. The reliability of training NLMS with the aid of URLS helps OFDM diminish ISI in the system. The ECLS algorithm is well balanced in terms of convergence speed and complexity. The difference may not be huge, however, there is a possibility for advancement. For future studies, in terms of design, this system may use space time or space frequency block code at the transmitter and receiver. Adding an equalizer at the receiver part will also help the efficiency of the system. For algorithms, the values of forgetting factor and step size can be thoroughly examined to determine the best value. Other than that, the study of ECLS for another multicarrier modulation technique, especially to combat the next generation, will be pursued.

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