

Impact of Equalizer Step Size in Underwater Acoustic Communication Channel

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Abstract: The Underwater Acoustic Channel (UAC) is a time variant channel, and its multipath effects create ISI. This is one of the most important obstacles in the UAC channel which reduces the transmission rate. To remove this obstacle, a proper filter has to be designed in the receiver section. In this article, optimal step size for equalizer is computed and compared the results with the known techniques namely Decision Feedback Equalizer with interleaved division multiple access (DFE IDMA) and Cyclic Prefix - Orthogonal Frequency Division Multiplexing (CP-OFDM) Equalizer. Channels are modeled using ray tracing methods. The various factors considered are ambient noise, attenuation loss, bottom and surface loss. The overall path loss for channels is computed by summing up the attenuation loss, surface and bottom loss. Simulation results evident that for short range UAC channel, the BER in the order of 10^{-2} is achieved using proposed methodology with least E_b/N_0 compared to standard DFE method.

Index Terms: Decision feedback Equalizer, Linear Equalizer, Bit Error Rate, Underwater Acoustic Channel, Cyclic Prefix.

1. Introduction

The UAC channel is a time variant, and its multipath effects create ISI. If the bandwidth of the modulated signal is larger than the message signal, then the modulated signal spreads out in the time domain, ISI is created. This is one of the most important obstacles in the UAC channel which reduces the transmission rate. To remove this obstacle, a proper filter has to be designed in the receiver section. The impulse response of the filter is designed in such a way that, it is inverse to the channel impulse response. So that the ISI effects will cancel out and data is decoded with minimal error rate.

The equalizer plays a vital role in the wireless communication system. The basic types of equalizers are Linear and Decision Feedback Equalizer. The various algorithms applied in the equalizer are Least Mean Square (LMS), Signed Least Mean Square (SLMS), Normalized Least Mean Square (NLMS) and Recursive Least Square (RLS).

There are various error coding techniques are available for Underwater Acoustic Communication (UAC) Channel like turbo code, LDPC. For turbo code, an iterative decoder is applied in the receiver section which will yield minimum BER. The limitation in this it takes long time for better result and design the receiver section is quite complicated. In the case of LDPC code, a greater number of zeros added to the modulated data in order to reduce the effects of ISI. This will increase the data size which requires external storage device for data handling. To combat the data storage issue and to attain the minimum error rate in quick time, an equalizer with optimal step size is proposed in this article. The channel characteristics is analyzed over a range of step size value. An optimal step size is determined from the simulation result, and it is compared with the standard DFE.

The limitation of adaptive equalizer in UAC channel is its ISI effects. This makes the poor error rate in the receiver. Choosing the optimal step size of the receiver is best and tedious procedure in the UAC channel. To solve this issue, in this article, step size of an equalizer is varied from 0 to 1 in step of 0.05 and optimal step size is determined for both short and long-distance channel. Finally, the result of the proposed system is compared with standard Decision Feedback Equalizer (DFE).

2. Related Works

Data detection in UAC channel was done using different ICI equalizers such as MMSE-OFDM [1] and Markov Chain Monte Carlo [2]. For SISO system, Gibbs sample technique and Linear MMSE [3] was applied for the channel estimation and symbol detection. It is focused on the un-coded SISO system of a single carrier. In [4], two iterative receivers termed as multiuser detection and single user detection are tested with large Doppler deviation. The equalizer is combined with the coding technique to analysis the performance of the channel. The author showed that the ESNR is the best tool for the channel analysis rather than input SNR and pilot SNR and they used the OFDM techniques for their evaluation purpose. For multiuser communication in the channel, two different IDMA [5] receiver namely DFE IDMA and rake based IDMA and OFDM [6] was proposed.

In [7], traces of error for the single carrier acoustic channel are analyzed using DFE. The authors proposed a statistical model which includes a parent process and a few daughters' process. PN sequence-based equalizer was designed for the shallow water communication. In this, a least square technique [8] and low order DFE [9] are used for the channel estimation for single carrier spread spectrum sequence. For MIMO acoustic communication, DFE [10, 11], Low Density Parity Code (LDPC) [12], Y shaped antenna was designed for UWB applications [13], Normalized Least Mean Square algorithm [14] and gradient based LMS algorithm [15], Low power SAR ADC for wireless sensor node was designed [16]. The computational complexity is reduced by restricting the length of training pulse less than the number of taps used in the equalizer. In [17], authors proposed an iterative soft-decision feedback equalization (SDFE) algorithm to combat error propagation with Doppler to the carrier frequency in the order of 10^{-4} to 10^{-3} .

The effects of single resampling operation on the UAC channel with different time propagation factors is investigated using Hammersely-Chapman-Robbind Bound [18]. Using diagonalization property of the matrix and conjugate gradient method, Sparse Learning via Iterative Minimization technique [19]. Between source and receiver, sagacious communication link mechanism [20] was developed for underwater wireless sensor network. In [21], comparison of various Error Coding technique in underwater communication is analyzed.

In this paper, the optimal step-size for all these algorithms is calculated by varying the step size from 0 to 1 in step of 0.01 and the corresponding BER are calculated. Using this optimal step-size, the performance of the equalizer in UAC channel is simulated and the results are discussed in terms of Bit Error Rate (BER).

3. Equalizer in UAC

In both LMS and RLS algorithms, a decision device is used to classify the output as 0 or 1. The major requirements of this algorithm are

- Known training signal is used as reference.
- Proper synchronizing between the transmitter and receiver is essential.

Hence LMS and RLS are referred as decision direct equalizer. Few characteristics of DFE are listed below.

- The feedback symbols are free from the noise and computation make simple and easy.
- Compared to decision direct equalizer, the noise enhancement is reduced.
- Recovery time of incorrect decision is short.
- Sensitivity is reduced.

The general block diagram for DFE is shown in Fig.1. It consists of forward and feedback filter in addition to the decision device to combat the effects of ISI.

DFE is a non-linear equalizer which will be useful to study the performance of channel like UAC. The effect of ISI is canceled out using the detection of ISI contribution by the previously detected symbols. To attain a minimum MSE, both the feedback and forward filter coefficients are adjusted simultaneously.

In the detection of a symbol using DFE, training signal are used initially. Once the error signal becomes zero by adjusting the filter coefficients, then the need of the training symbols is not required. Then the feedback filter able to detect and recover the data.

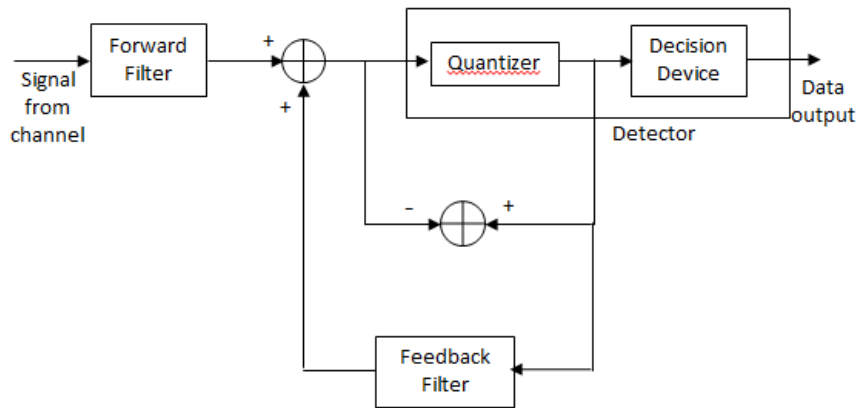


Fig.1. General Block Diagram for DFE

4. Research Methodology

For simulation purpose, two channels with different configurations are modeled and named as channel 1 and 2. Channel 1 has short range of 100 meters, whereas the other one has a range of 1000 meters. In both the channels, the transducers and hydrophone are placed at the depth of 09 and 40 meters respectively. Channels are modeled using ray tracing methods. The various factors considered are ambient noise, attenuation loss, bottom and surface loss. The overall path loss for channels is computed by summing up the attenuation loss, surface and bottom loss and dividing it by the speed of sound. Finally, the impulse response of the channel is computed through the designed channel.

The block diagram of equalizer in an UAC channel is illustrated in the Fig.2. The binary data is modulated using BPSK technique and then passed through the channel. The distorted data from the channel is equalized using linear and Decision Feedback Equalizer by four different algorithms viz. Least Mean Square (LMS), Normalized Least Mean Square (NLMS), Signed Least Mean Square (SLMS) and Recursive Least Square (RLS). The equalized data is then demodulated and finally, the BER is calculated. The value of the step-size is considered as a vital parameter in the design process of the equalizer.

To obtain the better BER, an optimal step-size is required. To determine the optimal step-size value the modulated data is passed through the channel with constant E_b/N_0 value of 20 dB. The BER value is obtained by varying the step-size from 0 to 1 in step of 0.01. Fig.3 to Fig.6 shows the BER of the channel 1 and 2 using Linear Equalizer for various algorithms.

It is observed that for channel 1, the minimum BER in the order of the 10^{-2} can be obtained from the step-size 0.75 to 1 and 0.62 to 1 for the LMS and SLMS algorithm respectively. Similarly, for a Normalized LMS (NLMS) and Recursive Least Square Linear Equalizer (RLS), the value ranges from 0.1 to 1 and 0.2 to 1 respectively.

For channel 2, the optimal step-size for LMS and SLMS are less than 0.1 and lies between 0.4 and 0.85. For the NLMS and RLS, the step size values are less than 0.3 and 0.65.

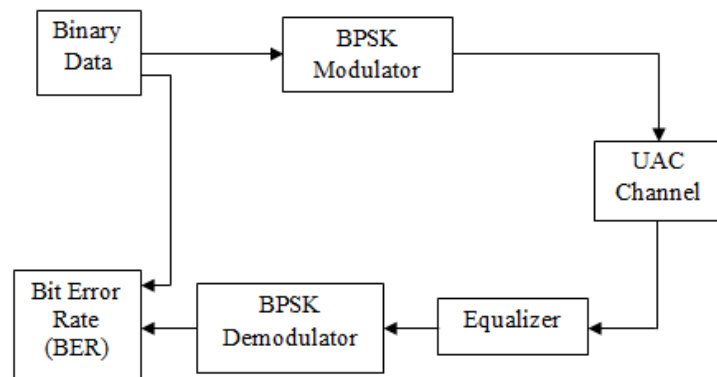


Fig.2. Equalizer Block Diagram in UAC

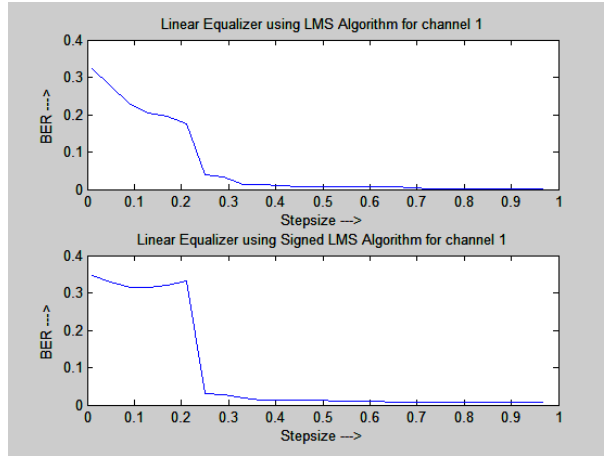


Fig.3. BER versus step-size for channel 1 using linear equalizer of LMS and SLMS algorithm

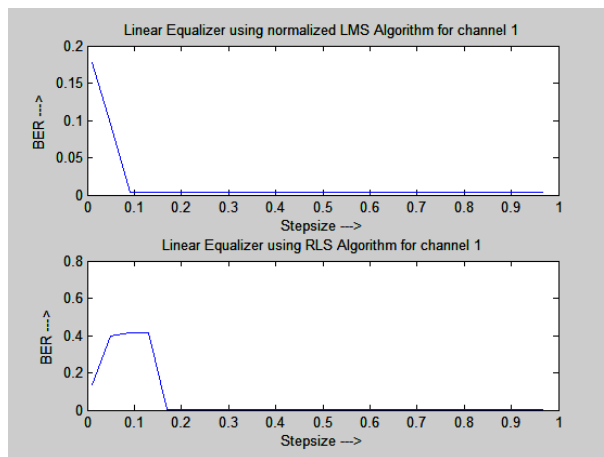


Fig.4. BER versus step-size for channel 1 using linear equalizer of NLMS and RLS algorithm

From figure 3 and 4, the minimum BER for channel 1 for different algorithm can be determined and listed in Table 1. In the same way, for channel 2 the minimum BER can be obtained from Figure 5 and 6. Referring the Table 1, the optimal step-size is determined by taking average of values and listed in Table 2. For example, the minimum BER for LMS algorithm can be attained when the step size ranges from 0.75 to 1. The mean value for LMS is 0.875 and it is considered as the optimum step size for the algorithm. In the same way the optimal step size for other algorithms is determined and listed in the table2.

Table 1. Optimal Step-size using Decision Feedback Equalizer

Channel	Step-size range for minimum BER			
	LMS	Signed LMS	Norm LMS	RLS
I	0.75 to 1	0.62 to 1	0.1 to 1	0.2 to 1
II	< 0.1	0.4 to 0.85	< 0.3	< 0.65

Table 2. Optimal Step-size using Linear Equalizer

Channel	Step-size range for minimum BER			
	LMS	Signed LMS	Norm LMS	RLS
I	0.875	0.81	0.55	0.60
II	0.05	0.625	0.15	0.325

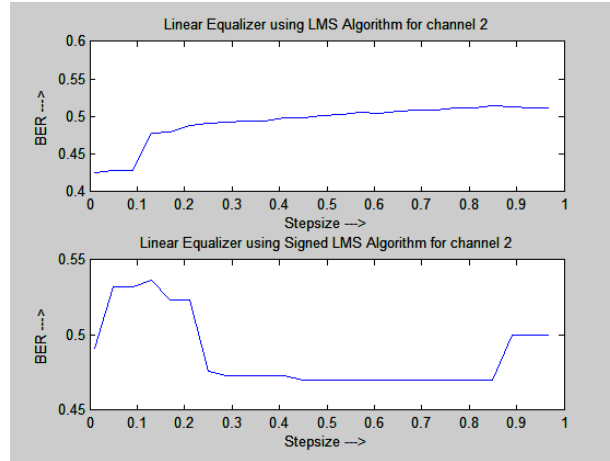


Fig.5. BER versus step-size for channel 2 using linear equalizer of LMS and SLMS algorithm

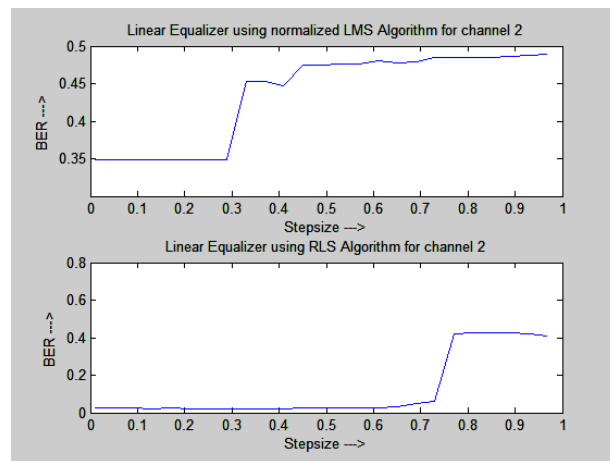


Fig.6. BER versus step-size for channel 2 using linear equalizer of NLMS and RLS algorithm

The average step-size value using the linear equalizer for both the channel 1 and 2 is fixed and the BER is determined by varying the E_b/N_0 value from 0 to 40 and it is shown in the Fig. 7 and 8.

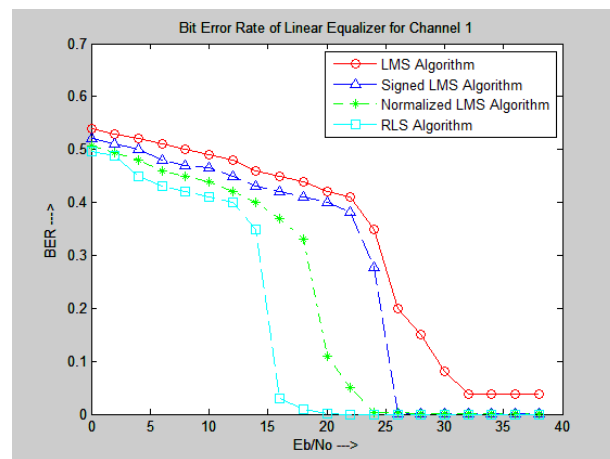


Fig.7. BER of UAC channel 1 using optimal step-size of linear equalizer

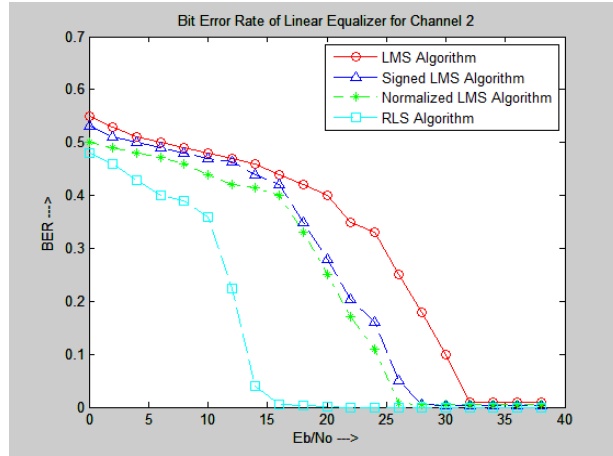


Fig.8. BER of UAC channel 2 using optimal step-size of linear equalizer

Similar to the linear equalizer of the channel, the optimal step-size for DFE is also determined. Fig. 9 to Fig. 12 shows the BER of the channel 1 and 2 using DFE with the constant E_b/N_0 value of 20 dB. It shows the error rate of the channel 1 for step-size ranging from 0 to 1. The minimum BER in the order of the 10^{-2} can be obtained for the step-size 0.2 to 1 and 0.45 to 1 for the LMS and SLMS algorithm. For a Normalized LMS (NLMS) and Recursive Least Square Linear Equalizer (RLS) the value ranges from 0.72 to 1 and 0.01 to 1. For the channel 2, the optimal step-size for LMS and SLMS ranges from 0.35 to 1 and from 0.65 to 1. For the NLMS and RLS any values range from 0.6 to 1 and from 0.45 to 1 respectively.

The step-size range to obtain the minimum BER from the Fig.9 to 12 is consolidated and listed in Table 3. Using this table, the optimal step-size is determined by taking average of values and listed in Table 4. The average step-size value using DFE for both the channels is fixed and the BER is evaluated by varying the E_b/N_0 value from 0 to 40 and it is shown in the Fig.13 and Fig.14.

Table 3. Step-size range using Decision Feedback Equalizer

Channel	Optimal step-size range			
	LMS	Signed LMS	Norm LMS	RLS
I	0.2 to 1	0.45 to 1	0.72 to 1	0.01 to 1
II	0.35 to 1	0.65 to 1	0.6 to 1	0.45 to 1

Table 4. Optimal step-size using Decision Feedback Equalizer

Channel	Optimal step-size range			
	LMS	Signed LMS	Norm LMS	RLS
I	0.6	0.725	0.86	0.505
II	0.675	0.825	0.8	0.725

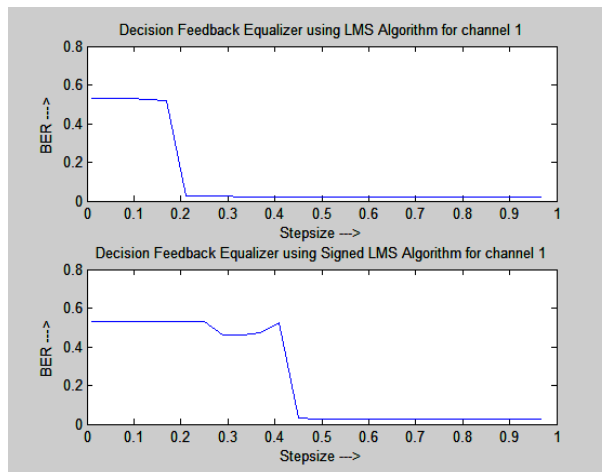


Fig.9. BER versus step-size for channel 1 using DFE of LMS and SLMS algorithm

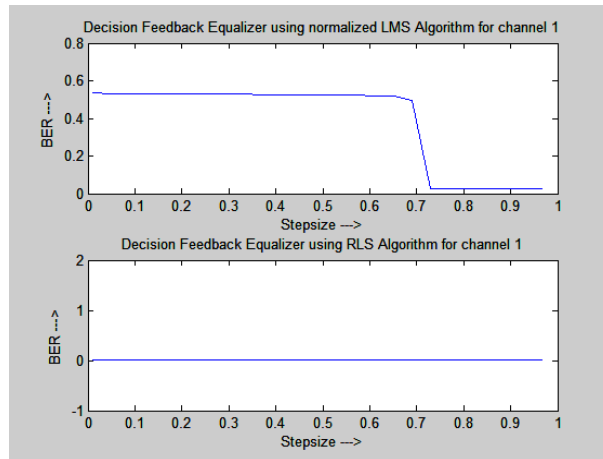


Fig.10. BER versus step-size for channel 1 using DFE of NLMS and RLS algorithm

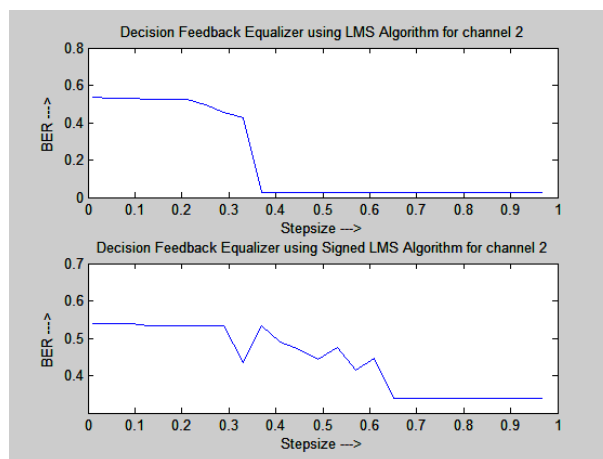


Fig.11. BER versus step-size for channel 2 using DFE of LMS and SLMS algorithm

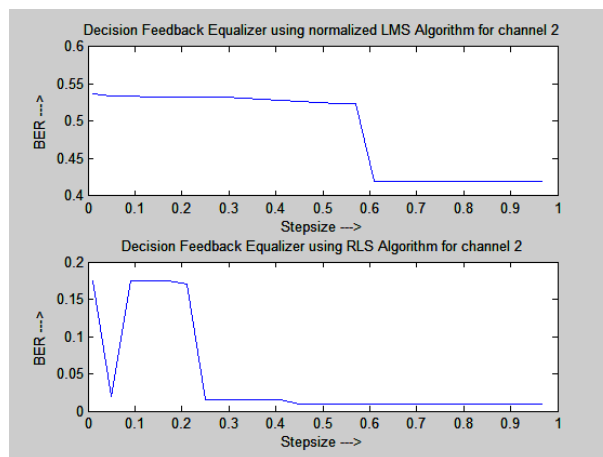


Fig.12. BER versus step-size for channel 2 using DFE of NLMS and RLS algorithm

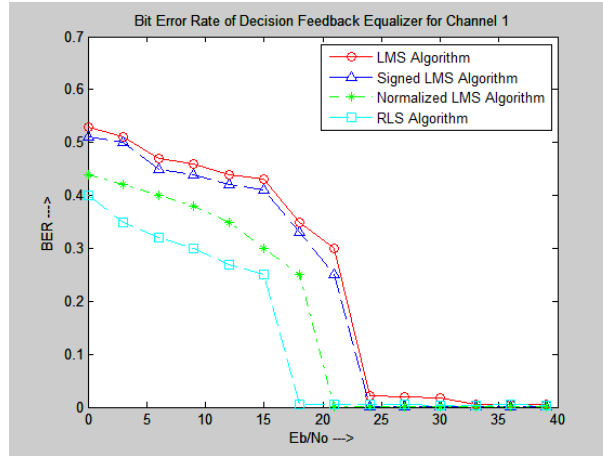


Fig.13. BER of UAC channel 1 using optimal step-size of DFE

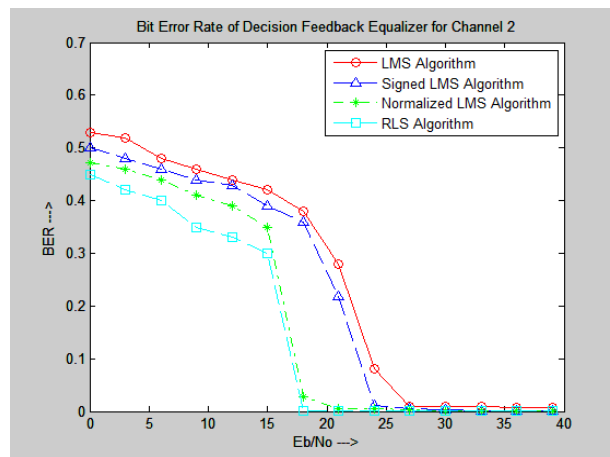


Fig.14. BER of UAC channel 2 using optimal step-size of DFE

5. Conclusions

Choosing step size of an equalizer in the UAC was a challenge task for the researchers. In this article, an optimal step size of an equalizer is attained for both short and long-distance underwater communication. The step size of an equalizer is varied from 0 to 1 with an increment of 0.01 and optimal value is attained for least BER. The optimal step-size for the linear and DFE equalizer was estimated, and it lies between the value of 0.5 and 0.87 for the LMS, SLMS NLMS and RLS algorithm. Using this step-size, binary data is allowed to pass through the channel and its performance is analyzed in detail. The BER in the order of 10^{-2} is achieved using the optimal step-size for the UAC channel using both linear and DFE equalizer. It is evident from the result that the RLS algorithm gives better BER and waterfall curve than the LMS algorithm.

The proposed method result is compared with the standard Decision Feedback Equalizer (DFE). Table 5 and 6 shows the comparison for the channel 1 (short distance) and 2 (long distance) communication. It is evident from the result that the proposed method gives the least BER for minimal Eb/No value. When compared with CP OFDM equalizer system, proposed system yields on par result. The finding of the article is that rather than designing the new error code techniques with complex receiver section like LDPC or CP OFDM, researchers can apply on the optimization technique in the existing methodology.

Table 5. BER comparison of proposed Equalizer technique with other techniques (Channel 1)

UAC Channel		Channel 1		
		DFE	CP OFDM Equalizer	Proposed Equalizer
Eb/No	1	0.428	0.282	0.577
	5	0.311	0.171	0.424
	10	0.195	0.042	0.139
	15	0.030	0.004	0.028
	18	0.012	0.008	0.004
	20	0.004	0.002	0
	22	0.004	0	0
	24	0.002	0	0

Table 6. BER comparison of proposed Equalizer technique with other techniques (Channel 2)

UAC Channel		Channel 2		
		DFE	CP OFDM Equalizer	Proposed Equalizer
Eb/No	1	0.690	0.397	0.717
	5	0.624	0.351	0.567
	10	0.440	0.169	0.377
	15	0.163	0.038	0.159
	18	0.054	0.012	0.076
	20	0.026	0.008	0.028
	22	0.010	0.008	0.012
	24	0.002	0	0

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