Abstract

In this paper we have present performance analysis of different equalization techniques such as minimum mean–squared error (MMSE), Least mean square (LMS), Recursive Least Square (RLS) linear equalizers and MMSE-Decision Feedback equalizer (DFE), LMS-DFE, RLS-DFE non-linear equalizers in different channel conditions, in order to achieve optimal equalizer. In our simulation model we have consider quaternary phase–shift keying (QPSK) modulation scheme under Additive White Gaussian Noise (AWGN), lognormal and Rician channel condition. The analysis of Linear and Non-linear equalization in different channels are performed and as an outcome we can conclude that standard Decision Feedback Equalization (DFE-Non linear Equalizer) methods are clearly outperformed the Linear equalizer by means of the Bit Error Rate (BER) performance. We use the MATLAB to show that the DFE provide better performance in low SNR region with respect to that of linear equalizer over AWGN, Rician and log-normal channels.

Introduction

The ultimate goal of digital communication [1] [2] is the reliable transmission of information at the highest possible data rates. High speed data transmission over communication channels is subject to inter symbol interference (ISI) [3] and noise. The information transmitted suffers amplitude attenuation and phase variation which is caused by multipath fading and signal shadowing effects of the environment. These channel impairments are commonly described by three fading [4] phenomena which are Rayleigh fading, Rician fading and Log-normal fading which characterizes signal propagation in different environments. The inter symbol interference is usually the result of the restricted bandwidth allocated to the channel and the presence of multipath distortion in the medium through which the information is transmitted.

Equalization is a very popular technique often employed to mitigate the effects of ISI in wireless communication. Its purpose is to reverse the effects that the channel has on the transmitted signal, with the aim of reproducing the original signal at the receiver end. Many techniques have since been developed, both linear and non-linear, and used in different applications and transmission mediums.

Linear equalization i.e. MMSE, LMS, RLS [5] and Non-Linear i.e. DFE are the major attempts in this direction. Non-linear equalization is needed when the channel distortion is too severe for the linear equalizer to mitigate the channel impairments.

Channel equalizers are either linear [6] or non-linear. Non-linear equalization is needed when the channel distortion is too severe for the linear equalizer to mitigate the channel impairments. A linear equalizer minimizes the error between the received symbol and the transmitted symbol without enhancing the noise. Although linear equalizer performs better, but its performance is not enough for channels with severe ISI. An obvious choice for channels with severe ISI is a non-linear equalizer.

A classical DFE receiver ‘learns’ the ISI, using linear equalizer [7] [8] algorithm, to update the forward and backward filter coefficients. The Decision Feedback Equalizer (DFE), which is a non-linear structure, is known to show superior performance when employed in channels that exhibit amplitude distortion Decision feedback equalizers (DFE’s) [9] can be used to combat the distortion of communication channels [10] [11] because of their many advantages—even with severe and noisy channels, they can reach pretty good steady-state performance .Since the channels are unknown, the DFE must be implemented in an adaptive way.

The reason for choosing DFE over linear equalizer is that the latter’s performance in channel that exhibit nulls is not effective. Noise enhancement in these regions and long impulse response are a problem. The basic reason for this problem is that in linear filtering, the desired signal and noise are processed together, causing noise enhancement problem.
System Model

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Consider the digital data sequence x(k) consisting of independent and equi-probable binary symbols, which is passed through a noiseless linear channel with finite impulse response h=[h0 h1 h2 ....... hN-1]T [12][13] The output of the channel is

\[ r(k) = y(k) + n(k) \]

(2)

The channel estimation problem is in a supervised manner and can be stated as follows: given the sequence of observations \( r(k) \) and the respective channel input sequence \( x(k) \), the task is to find an estimate of the true channel tap weights vector \( h \).

\[ h=[h0 h1 h2 ....... hN-1]T \]

(3)

Here, we assume that the length of the channel impulse response is known, so that vector \( h \) has the same size as vector \( h \). The channel estimation filter performs the convolution of the channel input sequence \( x(k) \) with the estimate \( h \) to produce an estimate \( y(k) \) of the channel output, i.e.,

\[ y(k) = h^T x_{ch}(k) \]

(1)

The estimation error is given by

\[ e(k) = r(k) - y(k) = r(k) - \sum_{i=0}^{N-1} h_i x(k - i) \]

(5)

and is used to drive the update algorithm of the channel estimation filter.

Decision Feedback Equalizer (DFE)

The Decision Feedback Equalizer (DFE) [14][15] consists of Feed forward Filters, Feedback Filters, and Decision Devices. Both the Feed forward and the Feedback Filters are usually realized as transversal finite impulse response (FIR) filters.

A decision feedback equalizer makes use of previous decisions in attempting to estimate the current symbol. Any tailing ISI caused by a previous symbol is reconstructed and then subtracted. The DFE is inherently a non-linear device, but by assuming that all the previous decisions were correct, a linear analysis can be made. There are different variations of DFEs. The choice of which type of DFE to use depends on the allowable computational complexity and required performance. The input to the feedback filter is the decision of the previous symbol (from the decision device). [16]

Derivation of Decision Feedback Equalizer

Consider the development, where \( b_k \) and \( w_k \) are the feedback and feed forward filter coefficients derived in minimum-mean-square-sense, by making the error orthogonal to the received sequence[17]. In Equation 6 represents the received signal as, \( y(t) \), the channel-input data symbols as, \( x_k \), and the channel-impulse response as, \( h(t) \) where \( n(t) \) is additive-white Gaussian noise and \( T \) is the symbol duration [18]

\[ Y(t) = \sum (x m h(t - mt) + n(t)) \]

(6)

\[ Y_k = \sum (x_k h m + n_k) \]

(7)

The equalizer output error is expressed as

\[ e_k = b^* x_{k,k} - v - w^* y_k + N_{f-1,k} \]

(8)

Where \( v \) is expressed as channel memory

The \( \mathbf{w}^* \) feed forward filter taps are expressed as

\[ \mathbf{w}^*=[w^*-(N_{f-1})w^*-(N_{f-2})………w_0] \]

(9)

For a decision delay of \( \Delta \), the corresponding MMSE is expressed as

\[ E(| e_k |^2) = E((x_{k-\Delta} - w Y_k + b x_{(k-1-\Delta)})(x_{k-\Delta} - w Y_k + b x_{(k-1-\Delta)})) \]

(10)
where b is the vector of the coefficients for the feedback FIR filter and xk – Δ 1 is the vector of the data symbols in the feedback path. [19]

Applying the orthogonal principle by making the error orthogonal to the output we get

$$E(e_k Y_k^*) = 0 \quad (11)$$

The optimum error sequence is uncorrelated with the observed data. This simplifies to Equation 11, which gives the relation between the DFE feedback and feed forward filter coefficients

$$B^* R_{xy} = w^* R_{yy} \quad (12)$$

The FIR MMSE-DFE autocorrelation matrix is expressed as

$$R_{yy} = (E(Y_{(k+N_f-1,k)}^* Y_{(k+N_f-1,k)})) = s_x H H^* + R_{nn} \quad (13)$$

Where Rnn = N0INf and where N0 is the noise power, and where I is an identity matrix, the input-output cross-correlation matrix, where Sx is the signal power as expressed

$$R_{xy} = E[X_{(k,k-v)}^* Y_{(k+N_f-1,k)}] = s_x [O_{(v+1)(N_f-1)}] H^* \quad (14)$$

The mean-square error is expressed in

$$R_{ss} - R_{sy} R_{yy}^{-1} R_{ys} = s_x [O_{(v+1)}] H^* [(1/SNR) I_{N_f-1} - H] [0; I_{v+1}] \quad (15)$$

The matrix inversion lemma is given by

$$H^* (HH^* + (1/SNR) I_{N_f-1})^{-1} H = (HH^* + (1/SNR) I_{N_f-1})^{-1} H^* H \quad (16)$$

Simplifying Equation 16 by using the matrix inversion lemma results in

$$R_{ss} - R_{sy} R_{yy}^{-1} R_{ys} = s_x [O_{(v+1)}] [H^* + (1/SNR) I_{N_f-1}] [0; I_{v+1}] = \frac{N_s [O_{(v+1)}] (HH^* + (1/SNR) I_{N_f-1})^{-1} [0; I_{v+1}] - R_{sy} R_{yy}^{-1} R_{ys}}{N_s} \quad (17)$$

The middle term in the right-hand side of Equation 17, is defined as a Cholesky factorization, where LDL is the Lower-Diagonal-Upper[20].

$$R_{ss}^{-1} + H^* R_{nn}^{-1} H = (R_{ss} - R_{sy} R_{yy}^{-1} R_{ys})^{-1} = \frac{1}{(1/SNR) I_{N_f-1} + H^* H = LDL^*} \quad (18)$$

Where L is a lower-triangular monic matrix, D is a diagonal matrix. L is a monic matrix, its columns constitute a basis for the (Nf+v) dimensional vector space. When the feedback coefficients are located, the solution expressed gives the optimal setting for w, the feed forward coefficient i.e.

$$w^*_{opt} = b^*_{opt} R_{xy} R_{yy}^{-1} \quad (19)$$

Simulation Results

Figure 1 represent BER Vs SNR curves in different channel condition with different receiver equalization techniques. As in figure 1, in AWGN channel condition the communication system provide better performance whereas in Rician – Lognormal channel condition it is the worst one. And also MMSE based equalizer provides better performance with respect to that of LMS based equalizer.

Results for Linear Equalizer in Different Channel Condition

![Figure 1. Linear Equalizer in Different Channel Condition](image-url)
Results for Non-Linear Equalizer in Different Channel Condition

Figure 2 represent BER Vs SNR curves in different channel condition with different receiver equalization techniques. Figure 2, shows that performance of communication system in AWGN channel is better than that of the Rician –Lognormal channel which is the one of the worst channel condition. And it also depicts that performance of MMSE based equalizer shows better result than that of LMS based equalizer.

![Figure 2. Non Linear Equalizer in Different Channel Condition](image)

Conclusion

This paper deals with the details performance analysis of Non-linear equalizer and linear equalizer in different channel condition. As it is emerge from the above simulation results, the performance of Non-linear equalizer is better than linear equalizer in different channel condition. From the perspective of equalizer, MMSE, RLS and LMS based receiver system have been considered and analyzed. MMSE based equalizer shows less data error with respect to that of LMS and RLS based equalizer both in case of linear and Non-linear receiver. Therefore, from the perspective of today’s communication system and dense channel condition, Non-linear equalizer is the best solution to achieve the goal of next generation communication system.

References


[18] www.freescale.com-Free Scale Semiconductor DFE
