EFFICIENT DECISION FEEDBACK EQUALIZERS FOR WIRELESS COMMUNICATION USING OPTIMUM FILTER WEIGHTS SELECTION AND NORMALIZED CHANNEL MODEL

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ABSTRACT:

Decision feedback equalizers are widely used non-linear equalizers which are used to reduce the inter symbol interference in the communication systems. Selection of proper weights for forward and feedback filters is very important for the designing of efficient decision feedback equalizers. Performance of the most of existing wireless communication systems degrades under higher PSK (Phase Shift Keying) sizes. But use of higher PSK size is essential to fulfill the demand of high speed broadband wireless communication. In this paper an efficient block based decision feedback equalizer is proposed in a training mode. It is proposed to model the multipath Rayleigh fading channel with normalized channel impulse response (CIR) and measured AWGN (Additive White Gaussian Noise). This significantly improves the performance of wireless communication systems with M-PSK modulation techniques for higher PSK size of 512 and 1024. In addition BER (Bit Error rate) performance of the wireless communication system is evaluated by varying forward and feedback filter weights for RLS (Recursive Least Square) based decision feedback equalizers. Based on the performance evaluation an optimum fuzzy weight selection rule is proposed for providing minimized smooth BER curves.

Keywords: Wireless communication, Decision feedback equalizer, LMS, RLS algorithm, Rayleigh fading channel, Normalized channel impulse response, Filter weights, Bit error rate, M-PSK modulation.

[1] INTRODUCTION

The equalizers are required for wireless communication system because the wireless channel has phase and amplitude dispersion, this result in the interference of the transmitted signals with one another [1, 19]. Decision Feedback Equalizers (DFE) is non-linear adaptive equalizers which uses past detector decision to reduce the fading effect, ISI, and noise for the multipath wireless communication systems. In other sense DFE reduces the distortion in current data pulse which caused due to previous pulses in wireless communication. Rayleigh fading is common phenomenon of communication system [4]. It exists due to reflection, diffraction, and scattering of the transmitted waves from the bulky physical structures such as buildings or mountains as shown in Figure 1. It can be seen from the figure that, Reflection takes place from the smooth surfaces in the wave paths. Diffraction is the change in the wave path due to sharp edges like top of the buildings, and
scattering takes place due to structures like tree and lamp posts. This phenomenon causes the multi path propagation.

In general, DFE commonly used Least Mean Square (LMS) algorithms or Recursive Least Square (RLS) algorithm for filter weights updating in adaptive equalizers. The Least mean square (LMS) equalizers \([3, 11, \text{ and } 16]\) give lower mean square error (MSE) performance. Although the LMS method has a low complexity but when the desired symbols are not correctly known, it does not converge. DFE with Recursive Least Square (RLS) algorithm \([5 \text{ and } 18]\) has better convergence characteristics than the LMS algorithm. But, it has higher computational complexity than LMS algorithm. There are also RLS algorithms that have computational complexities that grow linearly with the number of equalizer coefficients. DFE with RLS weight selection algorithms are efficiently used in wireless communication system.

Figure 1. Reasons of Fading in Multipath wireless channels

\(R\) – Reflection, \(S\) – Scattering, \(D\) - Diffraction

An equalizer performs differently for different working environment therefore, it is required to evaluate and analyze the performance of equalizers over different modulation techniques. Since with the increasing number of wireless users the higher size modulation methods are frequently adopted thus it needs to compare the performance of modulation techniques over fading environment.

The paper proposed an adaptive DFE by automatically adapting the optimum number of forward and backward filter weights. Also the wireless channel is modeled with the normalized channel impulse response to improve the performance of M-PSK modulation. In this paper a comparative analysis of DFE using RLS algorithm is presented for different M-PSK modulations over the Rayleigh fading channels. For comparing the performance various parameters are varied and Bit error rate (BER) is evaluated.

In the rest of paper after introduction section \([2]\) discusses brief literature review of the existing work followed by the various channel degradation modeling of fading channel in section \([3]\). The block diagram of proposed communication system along with proposed channel normalization is explained in the section \([4]\). The DFE equalizer is described in the section \([5]\). The results of performance evaluation are given in the section \([6]\) followed by the conclusion in section \([\_\_\_\_\_\_\_\_\_]\).

The equalizers are widely used by the researchers for reducing the channel distortions. The equalizers are broadly classified as linear and non-linear equalizers. The most commonly used linear equalizer from the performance and complexity point of view is the LMS algorithm [9, 13]. The linear equalizers are computationally easy to implement but inefficient when the desired symbols are incorrect such as under the noisy channel. Therefore, nonlinear equalizers are stretched in the literatures. The most popular nonlinear equalizers are decision feedback equalizer (DFE) [1, 3]. Decision feedback equalizer was first designed by M. E. Austin [19] in 1967. The DFE can be implemented using LMS or RLS weight adoption algorithms. S. C. Lin [1] (2009) have presented the performance analysis of decision-feedback equalization for cellular mobile radio with co-channel interference and fading. The mainly the author evaluated the pulse waveform, modulation and fading of the signal of interest, as well as the CCI. Quadrature-amplitude modulation (QAM) signaling in frequency selective and quasi-static channels is considered.

Jaymin et al. [11] presented a comparative analysis of the various linear equalizers Viz. MLSE, LMS and RLS adaptive non-linear equalization algorithms over the wireless communication channel. Each of these algorithms is tested for the BPSK, 4PSK and 16QAM modulation techniques. Budihal et al. [3] have presented a performance comparison of adaptive Turbo decision feedback equalizer using RLS and LMS algorithms. They have shown that DFE with RLS has an improvement of 0.7 dB at BER of 10^-4 over DFE with LMS algorithm. Kumar et al. [4] have designed a chip level decision feedback equalizer using zero-forcing and MMSE criterion for W-CDMA application.

Alireza et al. [2] have used the LMS algorithm for analysis of proposed blind linear equalization, for an efficient un-coded transmission over a frequency selective Rayleigh fading channel. Yamazaki et al. [5] have presented a performance evaluation of the decision feedback equalizer using adaptive error propagation filters for achieving the faster convergence rate. Method was designed for minimum phase (MP) channel model. Yu Gong et al. [6] have proposed a MMSE equalizer which jointly adopts the tap length and decision delay for improving the performance. But method was computationally complex. Fu Shaozhong et al. [12] have updated the length of LMS equalizer for using exponential function. Method reduces the average number of iterations and thus converges faster than standard LMS algorithm. Garima Malik et al. [14] have given a brief overview of the RLS and LMS adaptive equalizers. They have concluded that bandwidth efficient communication is possible by compensating the time varying channel distortions using equalizers. Yuan et al. [17] have reviewed the various design techniques for decision feedback equalization of giga-bit-per-second data links.

But the performance of DFE with adaptive filter weights and normalized channel have not been evaluated for M-PSK modulation techniques over the fading channels. Also it is needed to evaluate the performance of DFE equalizers with different number of filter weights over the fading channel. These are the prime goals of this paper.

[3] CHANNEL DEGRADATION AND CHANNEL MODEL

The wireless radio channels are usually affected by the multipath reflections of the transmitted signal and attenuate the transmitted power, called fading. There are many types
of fading channels. Rayleigh fading channel is most commonly used. Rayleigh fading channel is a statistical model which assumes that the power of a signal faded as per the Rayleigh distribution. The Rayleigh fading models are further classified as Flat or Frequency selective fading channels as mentioned in our previous paper [20]. In Flat fading all channels vary simultaneously. On the other hand Frequency selective fading is time varying fading [18]. The fading channel is modeled with a linear and time-varying Channel Impulse Response (CIR) denoted by the function $h(t, \tau)$.

$$r(t) = h(t, \tau) \ast s(t)$$  \hspace{1cm} (1)

In discrete time the channel is modeled as impulse response of the channel filter for $n^{th}$ samples;

$$r(n) = \sum_{i=0}^{N} C_i s(n-i)$$  \hspace{1cm} (2)

Where, $s(n)$ is the input signal, 
$r(n)$ is the output signal, and 
$C_i$ is the filter coefficients.

Where, $N$ is known as the filter order; an $N$th-order filter has $(N + 1)$ terms on the right-hand side; these are commonly referred to as taps.

[4] PROPOSED METHOD

The proposed method uses DFE equalizers in a training mode operation. The block diagram of the proposed wireless communication system is shown in Figure 2 below. The sequence of input digital bit streams is first modulated using M-PSK modulation techniques and then passed through the pulse shaping filters. Use of the Nyquist Pulse shaping filters efficiently minimizes the inter symbol interference (ISI) induced by the channel. Proposed method uses the square root raised cosine filters for pulse shaping the input.

**Figure 1. Block diagram of proposed wireless communication system**

The equalized signals are demodulated to reconstruct the desired bit sequences. The channel is modelled as Rayleigh flat fading channel. The channel impulse response is normalized using the maximum response value. Then linear equalizers are implemented at the receiver to reduce the channel distortions.
Channel Normalization and noise addition

In this paper it is proposed to use the normalized channel impulse response with respect to maximum absolute response value as;

\[ Mx = \max(\{ |r(n)| \}) \]  

(3)

\[ r_{\text{norm}}(n) = \frac{r(n)}{Mx} \]  

(4)

The normalized impulse response is added with the additive white Gaussian noise \((v(n))\) the noisy channel response is given as;

\[ \text{Chan} = r_{\text{norm}}(n) + v(n) \]  

(5)

The one main advantage of using the normalized channel impulse response is that it controls the problem of error propagation in the DFE’s.


An adaptive equalizer is a filter that automatically adapts to time-varying properties of the wireless channel [16]. In this paper the equalizer is designed in a training mode. The better performance of block based DFE is achieved by using training period which is used for initial acquisition of channel. The training period requires a training sequence this reduces the transmission bit rate. Thus in this paper the Tail and Train sequences are once randomly generated and it is assumed to be known at the receiver end. The same Train sequence is appended with different pay load data in each block of transmission. In this method, the training sequence between the transmitter and receiver is sent before the actual payload data transmission starts. This updated the equalizer coefficients values closest to the optimal ones. But, sometimes the re-transmission of the Train sequence is required due to change in the channel.

A decision feedback equalizer (DFE) is basically a non-linear equalizer which uses previous detector decision to reduce the ISI from pulses that are currently being demodulated. Figure 3 shows simplified block diagram of a DFE where the forward filter and the feedback filter are linear FIR filters. The nonlinearity of the DFE may be observed from the nonlinearity of the detector which provides an input to the feedback filter.

![Decision Feedback Equalizer using FIR filters](image)

**Figure 2. Decision Feedback Equalizer using FIR filters**

The basic idea of a DFE [19] is that if the previous symbols are known, then ISI caused due to these symbols is eliminated exactly at the output of the forward FIR filter by subtracting past symbol values with suitable RLS weighting algorithm. As an hypothetical way various experiments are performed with different filter weights and BER curves are evaluated. The
number of forward and feedback weights can be adjusted simultaneously to fulfill a criterion such as minimizing the BER. Based on experimental analysis following adaption rules are defined for selection of optimism number of forward and feedback filter weights selection.

\[
\begin{align*}
\text{if SNR} & \leq 8 \text{ then } n_{\text{FwdWeights}} = 2 \\
\text{if SNR} & \geq 8 \&\& \leq 12 \text{ then } n_{\text{FwdWeights}} = 4 \\
\text{if SNR} & \geq 12 \&\& \leq 16 \text{ then } n_{\text{FwdWeights}} = 6 \\
\text{if SNR} & \geq 16 \&\& \leq 20 \text{ then } n_{\text{FwdWeights}} = 8
\end{align*}
\]

The proposed DFE structure is particularly useful for equalization of system with higher order M-PSK modulation or for channels with severe amplitude distortion.

[5.1] FILTER ARCHITECTURE

Working of an adaptive filter is shown in the Figure 4 below. The coefficients of the filters are called as weights and are the one of prime controlling parameter of the equalizer algorithm.

The filters output is calculated as:

\[
y(n) = \sum_{k=0}^{M-1} u(n-k)w_k^*(n)
\]

The error signal is calculated as:

\[
e(n) = d(n) - y(n)
\]

Where,  
- \(w\): weight vector or coefficients  
- \(u\): Input vector  
- \(e\): error signal

In order to minimize the error signal, the weights can be updated using either LMS or RLS algorithms. In this paper DFE is designed using RLS algorithm.

[5.2] RLS EQUALIZERS

The RLS based DFE are widely used [5, 14 and 18] and are based on adaptive filter algorithm which recursively finds the filter coefficients and minimize the weighted linear least squares cost function associated to the input signals. Structure of the RLS algorithm is shown in Figure 4. RLS algorithm uses covariance matrix updating formula [14], which is used for automatic adjustment corresponding to the estimation error. The initial inverse correlation matrix Delta is given as:

\[
\text{Delta} = \delta^{-1} I
\]
Where, \( \Delta \) is the inverse correlation matrix and \( \lambda \) is regularization parameter which is positive constant for high SNR and negative for the low SNR value. For any time instance \( n=1, 2, 3 \ldots \)

\[
x(n) = \Delta u(n-k)
\]

\[
G(n) = \frac{x(n)}{\lambda + u^T(n) \cdot x(n)}
\]

Where, \( \lambda \) = Forget Factor;
The updated value of inverse correlation matrix is given as:

\[
\Delta = \frac{1}{\lambda} \cdot (\Delta - G(n) \cdot u^T(n) \cdot \Delta)
\]

The updated weights are calculated as:

\[
w_k(n+1) = w_k(n) + G(n) \cdot e^*(n)
\]

[6] EXPERIMENTAL RESULTS

In this paper an efficient DFE is proposed which is capable of adopting the filter weights for generating the smoother Bit error rate (BER) responses. The BER of the proposed DFE is conspired for various M-PSK modulation techniques by varying the PSK size.

[6.1] SIMULATION PARAMETERS

The experiments and simulation of communication system is performed on the MATLAB software. The various input parameters used for the simulation are given in the Table 1. The BER performance of the different M-PSK with \( M = 4, 16, 256, 512 \) and 1024 are evaluated.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>NbitspSk</td>
<td>2-10</td>
<td>Bits per PSK Symbol</td>
</tr>
<tr>
<td>Ts</td>
<td>1e-6</td>
<td>Sampling time</td>
</tr>
<tr>
<td>M</td>
<td>4 – 1024</td>
<td>Size of Modulation</td>
</tr>
<tr>
<td>NTap</td>
<td>4</td>
<td>Length of equalizer</td>
</tr>
<tr>
<td>xPayload</td>
<td>randi(1,400)</td>
<td>Number of data bits per block</td>
</tr>
<tr>
<td>xTrain</td>
<td>randi(1,100)</td>
<td>Training data</td>
</tr>
<tr>
<td>xTail</td>
<td>randi(1,20)</td>
<td>Tail sequence</td>
</tr>
<tr>
<td>nBlock</td>
<td>50</td>
<td>Number of data blocks</td>
</tr>
<tr>
<td>E2No</td>
<td>0 to 20</td>
<td>Range of SNR</td>
</tr>
<tr>
<td>Fd</td>
<td>30 Hz</td>
<td>Doppler Shift</td>
</tr>
<tr>
<td>Chan</td>
<td>Channel</td>
<td>Rayleigh fading channel</td>
</tr>
<tr>
<td>osffilt</td>
<td>4</td>
<td>Over sampling factor</td>
</tr>
<tr>
<td>D</td>
<td>1e-6[0 4 8 12]</td>
<td>Multipath Delay vector</td>
</tr>
<tr>
<td>G</td>
<td>[0 3 6 9]dB</td>
<td>Multipath Gain vector</td>
</tr>
<tr>
<td>nBlocks</td>
<td>50</td>
<td>Number of blocks</td>
</tr>
<tr>
<td>Step</td>
<td>0.1</td>
<td>LMS Step size</td>
</tr>
<tr>
<td>Forgot</td>
<td>0.9</td>
<td>RLS Forgot Factor</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>nFwdWeights</th>
<th>2, 4, 6, or 8</th>
<th>Numbers of Forward filter weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>FbkWeights</td>
<td>2</td>
<td>Numbers of Feedback filter weights</td>
</tr>
</tbody>
</table>

[6.2] BER ANALYSIS

In the paper the channel is modelled with normalized Channel Impulse Response (CIR). The Figure 5 compares the BER performance of the DFE with RLS algorithm and normalized CIR for QPSK modulation. It is found that using the normalized CIR improves the performance of DFE equalizers significantly. It is found that equalizers without normalization can achieve minimum BER order of $10^{-2}$, while DFE with normalized CIR can achieve minimum BER order of $10^{-5}$ as in Figure 5.

![Figure 5: BER for DFE with different Feedback weights for multipath frequency selective fading channel](image)

[6.3] SELECTION OF OPTIMUM NUMBER OF FILTER WEIGHTS

The DFE is designed using the forward and feedback filters. The performance of the DFE equalizer varies with the number of the filter weights. Thus in orders to find the optimum number of filter weights various experiments are performed in this paper.

![Figure 5: BER for DFE with different Feedback weights for multipath frequency selective fading channel](image)
In the first experiment the number of Feedback filter weights of DFE is varied from 2-8 keeping the forward weight of 8 and BER is plotted in the Figure 6. It can be observed that the number of feedback weights must be minimum (equal to 2) for better BER performance. Increasing the number of feedback filter weights of DFE may significantly degrades the BER performance of the communication system.

![Figure 6: BER comparisons for DFE with different Forward weights for multipath frequency selective fading channel](image)

As an another experiment in Figure 7 BER is plotted by keeping number of Feedback filter weights constant to 2 and the forward weight is varied from 2-8. Experiment is performed for 20 times and average is shown in Figure 7. It is observed that the smoothness of BER curve varies as the SNR and number of forward filter weights increases. Therefore in this paper based on this experimental analysis the number of forward filter weights are increased as per the equations (6-9). Here the number of forward filter weights is increased by factor 2 between the increased SNR values divisible by 4.

![Figure 7: BER for DFE with adaptive fuzzy Forward and Feedback weights for frequency selective channel with normalized channel impulse response](image)
The performance evaluation of the proposed adaptive optimal number of forward filter weights selection method with normalized CIR for the QPSK modulation is presented in the Figure 8. Figure shows that the proposed method gives smoother BER curves for even higher PSK sizes and achieved the BER performance of the order of $10^{-5}$.

The BER performance of the proposed DFE system with normalized CIR is compared for the increasing PSK sizes as shown in the Figure 9. It is observed that DFE performs approximately similar for all PSK sizes. It can be also observed that proposed method performs better for even PSK size of up to 512 and 1024.

[7] CONCLUSION

In this paper the performance of DFE equalizers with RLS algorithm are compared for different M-PSK modulations. In order to improve the BER performance of the PSK modulation, channel is modeled with normalized channel impulse response. Normalizing the channel impulse response is capable of reducing the inter symbol interference. DFE is designed by adapting the number of forward and feedback filters weights. It is found that proposed method improves the performance of the PSK modulations at the higher size of 512 and 1024 significantly. It is found that the proposed DFE-RLS equalizer gives better performance in terms of minimum BER of the order of $10^{-5}$. A new weight adoption rule is defined based on the various performed experiments. These are useful where channel parameter does not vary frequently. But the complexity increases linearly with the increasing tap weights based on the increasing SNR.

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REFERENCES


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