

Performance Evaluation of Channel Equalization for nonlinear Channels using ANFIS

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Abstract— recently, more attentions are paid on the quality of the data transmission and the speed of the digital communication systems. Limitations can face the rate of data transmission over the communication channel because of the effect of the linear and nonlinear distortion. Different equalization techniques are applied to alleviate these effects.

In this paper, an equalizer based on the Adaptive Neuro-Fuzzy Inference System (ANFIS) is proposed for digital channel equalizer. For the performance evaluation, the proposed equalizer is compared with other classical equalizer. The experimental work demonstrates the significant improvement of the performance using ANFIS equalizer over the Radial Basis Function and Least Mean Square equalizers.

Index Terms— ANFIS, Channel equalizer, digital communication, inter-symbols interference.

I. INTRODUCTION

In a digital communication channels the two principal causes of distortion are Inter Symbol Interference (ISI) and the additive noise. The transmitted signal passes through the channel before reaching the receiver, or in other words the transmit signal convolves with the channel. This convolution bring distortion in the transmit signal. Therefore, the transmission of digital signals through the communication channel suffers from noise and inter-symbol interference (ISI). The process of recovery of a signal convolved with the impulse response of a communication channel, or a recording medium is known as equalization. To recover the original transmitted signals, channel equalization is used at the receiver.

The main goal of the channel equalizers are based on finding the inverse of the channel and compensating the channel's influence using inverse filter technique. Traditionally, the linear filter (finite-duration impulse response (FIR)) is a commonly used equalizer. These linear equalizers have poor performance especially when the signals are transmitted across nonlinear channels. For that reason, the nonlinear equalizers instead of the linear ones are used to achieve efficient and robust transmission over nonlinear channels.

In many practical cases the channel cannot be inverted which may have various reasons. Hence there exists no equalizer for non-invertible channels. It has been an area of research that has attracted many researchers during the last two decays; number of papers and technical reports has been published with different solution techniques.

Neural networks are extensively applied for the equalization of high nonlinear distortions and rapidly varying signals. The most popular neural networks are Radial basis function (RBF) [3,5] and Multi-layer perceptron (MLP) [1]. The MLP equalizer requires long training time. In contrast, the RBF equalizer has simple structure and requires less training time. However, it usually requires a large number of centers, which increase the complexity of computation. Another effective way to achieve reliable data communication system and to improve the quality of transmission is the use of fuzzy technology.

Recently, soft-computing techniques such as hybridization between Fuzzy logic and Neural Networks have been applied successfully to the nonlinear distortion problems. The hybridization technique has many features that make it a particularly appealing and promising approach. The main features of such hybridization are:

- Neural networks, which model the low-level structure of the human brain, can learn from experience and easily adapt to changing environments.
- Fuzzy systems, which reproduce the approximate reasoning process of the human mind by representing knowledge via linguistic if-then rules, allow for precise output inference starting from imprecise input.

This work will investigate a new channel equalizer based on adaptive neuro-fuzzy inference system, i.e., an adaptive fuzzy inference system whose parameters are adapted using neural network learning algorithms. The performance of the proposed equalizer will be evaluated in terms of bit-error rate (BER) for different noise powers in the channel.

This paper is organized as follows. In Section II we describe the adaptive channel equalization. In Section III the ANFIS architecture is introduced. Experimental results are presented in Section IV along with a comparative performance analysis involving other traditional technique. Finally, Section V provides some concluding remarks.

II. ADAPTIVE CHANNEL EQUALIZATION

The two principal causes of distortion in a digital communication channels are Inter Symbol Interference (ISI) and the additive noise. The ISI can be characterized by a Finite Impulse Response (FIR). The noise can be internal to the system or external to the system. Hence at the receiver the distortion must be compensated in order to reconstruct the transmitted symbols. The equalization process must be adaptive because it is very difficult to predict the effect of the changing environment. The mechanism of the adaptation includes two phases. Firstly the equalizer needs to be trained with some known samples in the presence of some desired response (Supervised Learning). After training the weights and various parameters associated with the equalizer structure are determined. These two processes are frequently implemented to keep the equalizer adaptive. A typical digital communication system with adaptive equalizer is shown in Fig. 1.

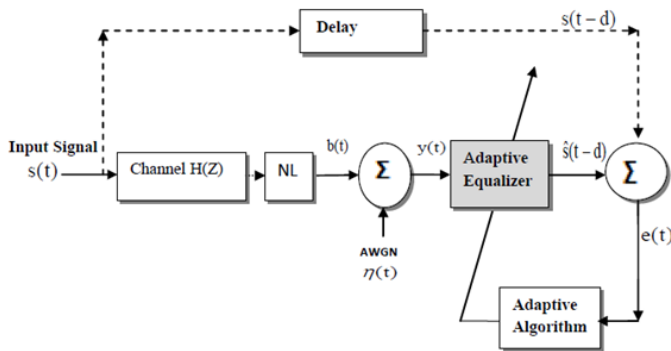


Fig.1, Digital transmission system with equalizer

The transmitted symbols are given as $s(t)$ for discrete time instant. They are then passed into the channel model which may be linear or nonlinear. $\eta(t)$ represents Additive White Gaussian Noise (AWGN). $y(t)$ is the received data and $\hat{s}(t-d)$ is an estimate of the transmitted data. d is called the decision delay.

The channel is usually modeled by a FIR filter with the following transfer function:

$$H(z) = \sum_{i=0}^{n_h-1} h_i z^{-i} \quad (1)$$

where h_i is the channel impulse response.

III. THE ANFIS ARCHITECTURE

The structure of Adaptive Neuro-Fuzzy Inference System (ANFIS) is given in fig. 2.

For simplicity, we assume that the fuzzy inference system under consideration has two inputs x and y and one output f . Suppose that the rule base contains two fuzzy if-then rules of Takagi and Sugeno's type [4]:

Rule1

If x is A_1 and y is B_1 , then $f_1 = p_1x + q_1y + r_1$.

Rule2

If x is A_2 and y is B_2 , then $f_2 = p_2x + q_2y + r_2$.

where p_i, q_i, r_i are the parameters set of node i . These are referred to as Sugeno consequent parameters [4].

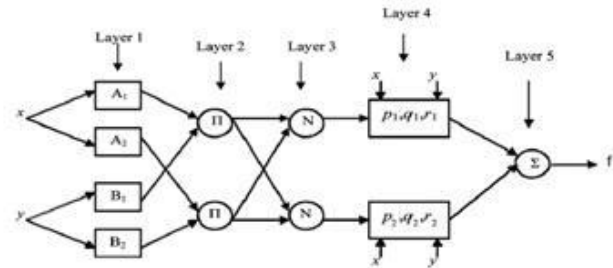


Fig. 2, An ANFIS architecture

The circular nodes represent nodes that are fixed whereas the square nodes are nodes that have parameters to be learnt.

Layer 1

The output of each node is:

$$\begin{aligned} O_{1,i} &= \mu_{A_i}(x) & \text{for } i=1,2 \\ O_{1,i} &= \mu_{B_{i-2}}(y) & \text{for } i=3,4 \end{aligned} \quad (2)$$

So, the $O_{1,i}(x)$ is essentially the membership grade for x and y .

Typically, the membership function for a fuzzy set can be any parameterized membership function, such as triangle, trapezoidal, Gaussian, or generalized Bell function, but for illustration purposes we will use the bell shaped function given by

$$\mu_A(x) = \frac{1}{1 + \left| \frac{x-c_i}{a_i} \right|^{2b_i}} \quad (3)$$

where a_i, b_i, c_i are parameters to be learnt. These are the premise parameters.

Layer 2

The output is the product of all the incoming signals

$$O_{2,i} = w_i = \mu_{A_i}(x)\mu_{B_i}(y), \quad i=1,2 \quad (4)$$

Each node output represents the firing strength of a rule.

Layer 3

The i^{th} node calculates the ratio of the i^{th} rule's firing strength to the sum of all rules' firing strengths

$$O_{3,i} = \bar{w}_i = \frac{w_i}{w_1+w_2} \quad (5)$$

Outputs are called normalized firing strengths.

Layer 4

The output of each node is

$$O_{4,i} = \bar{w}_i f_i = \bar{w}_i (p_i x + q_i y + r_i) \quad (6)$$

Layer 5

There is a single node here that computes the overall output

$$O_{5,i} = \sum_i \bar{w}_i f_i = \frac{\sum_i w_i f_i}{\sum_i w_i} \quad (7)$$

IV. EXPERIMENTAL WORK

The Simulations were conducted in order to illustrate the comparison in performance between the traditional LMS linear, RBF, and ANFIS nonlinear equalizers structures. In this simulation transmitted signal $s(t)$ was considered as a random sequence of symbols chosen from $\{-1, +1\}$ with equal probabilities as shown in Fig. 3. This signal is transmitted through a channel that has transfer function given by $b(t)=s(t)+0.3s^2(t)-0.1s^3(t)$, and corrupted by additive noise $\eta(t)$. Noise was assumed as a Gaussian. The corrupted signal is shown in Fig. 4.

For the ANFIS based equalizer, a type-3 TSK FIS with Gaussian membership functions was considered. The following function is used to determine the amount of noise that is added to the transmitted signal

$$SNR = 20 \log_{10}(\sigma_r/\sigma_e) \quad (8)$$

Where, σ_r is a standard deviations of the signal, and σ_e is a standard deviations of the noise.

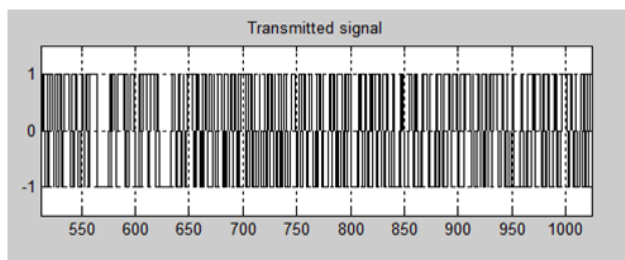


Fig. 3, Transmitting signal $s(t)$.

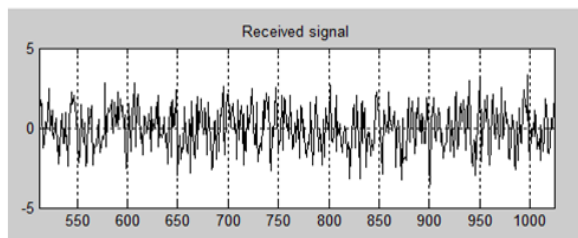


Fig. 4, Channel output $y(t)$.

The simulation results for ANFIS-15 (with one input and 5 membership functions), the traditional linear LMS equalizer with 5 weights and 0.01 step size and the RBF with 6 neurons are shown in Figure 5.

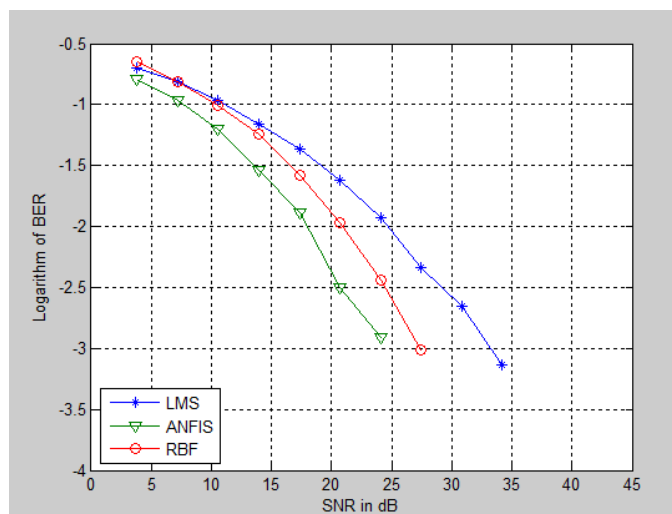


Fig. 5, simulation results for LMS ,RBF and ANFIS-15 based Equalizers.

From Figure 5, it is obvious that the nonlinear structure outperform the linear structure when both are undergoing the same condition of channel distortion.

V. CONCLUSION

In this paper, equalization problem of transmitted signal that is corrupted by AWGN channel is investigated using tradition linear LMS equalizer structure and non linear structure equalizer based on ANFIS and RBF. The performance criteria used for the performance comparisons between the two structures is the BER. The experimental work demonstrates that combining Neural Networks with fuzzy logic has the potential for significant performance improvements especially in severely distortion. Particularly, ANFIS technique can be applied to the equalization problem for achieving better performance than any other conventional or neural network techniques. However, further investigation to determine the optimal parameters of the proposed architecture is still needed with a comprehensive experimental work.

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