Channel Equalisation Using Multilayer Perceptron Structure

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Abstract: This paper investigates the application of artificial neural network structures to the problem of nonlinear channel equalization. The difficulties caused by channel distortions such as inter symbol interference (ISI) and nonlinearities can be overcome by equalizers employing neural networks. We present a structure of a nonlinear equalizer with decision feedback using multilayer perceptron (MLP DFE) which is trained by means of the back propagation algorithm. We compare its performance with a conventional decision feedback equaliser (DFE). Simulation results show that the performances of the MLP DFE surpass significantly the classical DFE in term of signal equalised and the steady state mean square error (MSE) attainable. The conventional DFE perform poorly on the nonlinear channel whereas the MLP DFE provide more advanced solution for the nonlinear equalisation problem, the consistency in performance is observed in nonlinear channels.

Key words: Channel equalization, multilayer perceptron, decision feedback equaliser, performances.

INTRODUCTION

In modern digital communications systems there is an ever increasing need for high speed data transmission rate over the variety of limited bandwidth channels, which by their nature distort the digital signal. The effect of this distortion is to cause the transmitted symbol to persist beyond the time interval allocated for its transmission, thus causing subsequent symbols to interfere. This symbol interference (ISI) can also arise in multipath propagation. The transmitted signal is also subject of other impairment such as nonlinear distortion and noise. At the receiver, an equalizer is used to mitigate these effects and restore the transmitted symbols [QUR 85] [PWE 01][GIB 89][MUL 96] [SAN 02][IBN 00][ZER 01][FEN 03][CHO 05][HAY 94]. Due to the variety and time varying nature of some channels, adaptive equalisation techniques need to be implemented. The aim of the equaliser is to reconstruct the corrupted data sequence from a set of received symbols by creating an inverse model of the transmission channel. Nonlinear equalisers are superior to linear ones in situation where the channel distortion is too severe.

The decision feedback equaliser DFE is considered as a powerful alternative to the linear transversal equaliser LTE; it has been demonstrated that the DFE performs significantly better than the LTE of equivalent complexity [QUR 85]. Although the DFE capacities, it can only cope with very moderate nonlinear distortion [SAN 02]. When the channel is nonlinear, a nonlinear equaliser is required to eliminate the ISI. More recently, artificial neural networks have been investigated in the area of digital communications [IBN 00][CHO 05]. The neural networks have several properties which make them very attractive for channel equalisation, these properties are: adaptive processing, universal approximation, learning and generalisation capacities.

In this paper, nonlinear channel equalisation by means of multilayer perceptron will be considered. We present a study of the MLP DFE and we exhibit its capacities to equalise nonlinear channels. We compare and evaluate the performance of the MLP DFE against the conventional DFE in term of the equalised signal and the steady state MSE reached for the considered non channel.
1. Decision Feedback Equalizer

The DFE is widely used in situations where the ISI is very large, the basic structure of the DFE is depicted in Fig.1.

The structure of the decision feedback equalizer consists of two filters a transversal feed-forward filter (FFF) and a feedback filter (FBF). The input to the FFF is the sequence of the received symbols whereas the FBF in the feedback path has, as input, the output of the decision device (the hard symbol estimates). The DFE is built on the principle that once a transmitted symbol has been estimated, the ISI contribution of that symbol to future received symbols can be exactly removed by feedback filter [QUR 85].

The channel is modelled by a finite impulse filter (FIR); the observed sequence at the input of the equaliser can be determined by a convolution as following:

\[ r_k = \sum_{i=0}^{N-1} h_i x_{k-i} + n_k \]  

(1)

Equivalently the equation above can be rewritten in matrix vector notation for greater clarity as:

\[ r_k = H x_k + n_k \]  

(2)

Where \( r_k \) is the noisy observed vector, \( x_k \) is the input vector to the channel, \( n_k \) is the vector of noise samples and \( H \) is the matrix convolution of the channel, of dimension MX (N+M-1), expressed as:

\[
H = 
\begin{bmatrix}
0 & 0 & \cdots & h_1 & h_2 & \cdots & h_{N-M+1} \\
\vdots & \ddots & \ddots & \vdots & \ddots & \ddots & \vdots \\
0 & \cdots & 0 & 0 & h_1 & h_2 & \cdots & h_{N-M+1} \\
\end{bmatrix}
\]  

(3)

The DFE is characterised by the coefficients of the feed forward filter \( C = [c_1, c_2, \ldots, c_{M-1}] \) and those of the feedback filter \( b = [b_1, b_2, \ldots, b_{M-1}] \), thus the equalised signal is expressed as:

\[ z_k = C^\top y_k - b^\top \hat{x}_k \]  

(4)

When transmitting a symbol, the best we can wish is that the equalized output, \( y_k \) at time \( k \), is a time delayed version of the transmitted symbol, in other words \( y_k = x_{k-d} \), where \( d \) is the delay parameter. The coefficients of the DFE can be trained together to minimise the mean square error (MSE) cost function between the sequence equalised \( z_k \) and the wanted sequence \( x_{k-d} \) as follows:

\[ J_{\text{mse}} = \frac{1}{2} E \left\{ |e_k|^2 \right\} = \frac{1}{2} E \left\{ |z_k - x_{k-d}|^2 \right\} \]  

(5)

This cost function is minimal when its gradient with respect to the equaliser parameters is equal to zero:

\[
\frac{\partial J_{\text{mse}}}{\partial (C,b)} = \left( \frac{\partial J}{\partial c_0}, \ldots, \frac{\partial J}{\partial c_{M-1}}, \frac{\partial J}{\partial b_1}, \ldots, \frac{\partial J}{\partial b_{M-1}} \right) = 0
\]  

(6)

The iterative method by means of LMS algorithm is used to determine the optimum solution. The coefficients of the equaliser are updating as follows:

\[
C_{k+1} = C_k - \mu r_k e_k  \\
b_{k+1} = b_k + \mu \hat{x}_k e_k
\]  

(7)

\( \mu \) is the step size, its choice must be a compromise between convergence speed and fine equalizer settings. To further enhance the capacities of the DFE, neural networks have been incorporated to its basic structure.

2. Multilayer perceptron based equaliser

Neural network based equalisers have been privileged in the nonlinear equalisation area [PWE 01] [IBN 00] because of their nonlinear processing capacities. Especially the multilayer perceptron is the most popular neural network because of its attractive properties [PWE 01][GIB 89][ZER 01]. Its basic element, the artificial neuron, is composed of a linear combiner and an activation function. The neuron receives inputs from other neurons processors. The linear combiner output is the weighted sum of the inputs plus a bias term. The activation function which can be linear or nonlinear (identity, sigmoid, tangent hyperbolic, etc.), gives then the neuron output:

\[
y = \sum_{j=1}^{N} W_{j} x_{j} + b,
\]

(8)

\[ X = f(y) \]

\( f(\cdot) \) is the activation function, the most commonly used is of the sigmoid type [HAY 94], defined by:

\[
f(y) = \frac{1 - e^{-y}}{1 + e^{-y}}
\]  

(9)

Where \( f(y) \in [\text{-}1, 1] \ \forall \ y \in \mathbb{R} \) (the set of real number), \( x_{j} \) is the \( j^{th} \) input value of the neuron, \( W_{j} \) the corresponding synaptic weight, and \( b \) the bias term.
A multilayer perceptron is composed of neurons connected to each other. The input information is processed from the input layer to the output layer. The network inputs are the inputs of the first layer. The outputs of the neurons in one layer form the inputs to the next layer. The network outputs are the outputs of the output layer. The hidden layers have the ability of performing complex, nonlinear mappings between the input and output layer. The MLP can have several of these hidden layers [HAY 94].

The multilayer perceptron based decision feedback equaliser MLP DFE is realised by connecting the outputs of time delay lines TDL with the input layer of the MLP. The output layer of the MLP is the output of the equaliser, the error signal is used for adjusting weights network into there optimum values by means of the back propagation algorithm.

\[ v_k = u_k + 0.2u_k^2 - 0.1u_k^3 \]  \hspace{1cm} (10)

Where \( u_k \) is the output of the linear part of the channel, \( v_k \) is the nonlinear channel output. Such non linearity arises from saturation phenomena of the amplifiers [SAN 02].

Fig. 4 shows the performance of the equalizers through the equalised signal under SNR of 20 dB. Part (a) shows the transmitted signal, (b) illustrates the received signal which is completely distorted by channel and additive noise. The equalised signal by the classical DFE is depicted in part (c) which still presents some residual distortion. The equalised signal by the MLP DFE is illustrated in part (d), the improvement in the equalised signal quality for the MLP DFE is pretty obvious. Fig. 5 illustrates the learning curves of the equalisers for the nonlinear channel. The steady state MSE reached by the DFE became worse under nonlinear effect of the channel, it is about -9dB. Whereas the steady state MSE of the MLP DFE decreases a little bit, its about -26 dB.

4. Conclusion

We presented the multilayer perceptron based decision feedback equaliser (MLP DFE) which is characterised by its capacity to equalise linear and nonlinear channels and its immunity against noise impairment. The DFE performs poorly; the MSE level is greater than the noise level for the considered channel. However the MLP DFE shows good performances; the attainable steady state MSE level is lower than the noise in nonlinear channel. Nonlinear channel equalisation by means of multilayer perceptron offers a more advanced solution to the equalisation problem.
Figure 4. Equalized signal for a nonlinear channel. (a) the transmitted signal. (b) the received signal. (c) DFE equalized signal. (d) MLP DFE equalized signal.

Figure 5. Learning curves of the equalisers for the nonlinear channel.

REFERENCES


