Maximal Ratio Combining using Self Organizing Map in Wireless Channels

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ABSTRACT
The work is related to the use of Self Organizing Map (SOM) which is a type of unsupervised Artificial Neural Network (ANN), as an aid to Maximal Ratio Combining (MRC) in order to improve bit error rate (BER) values of demodulated signals in wireless channels that have both Gaussian and multipath fading characteristics. Among the architectures and algorithms suggested for ANN, the SOM has the special property of effectively creating spatially organised " internal representations" of various features of input signals and their abstractions. The advantage of using the SOM is that it doesn't require any reference signal for training. Modulation technique used in this work is Bipolar Phase Shift Keying (BPSK) in Gaussian and multipath Rayleigh fading channels. The work adopts ANN block as part of a MRC set-up and is tested under SNR variation between -10 to 10 dB in Gaussian and multipath fading channels. The results generated justify the use of SOM neural network block as an aid to the MRC setup.

Keywords
AWGN, Rayleigh, MRC, SOM, MLP

1. INTRODUCTION
Throughout the years, several linear and nonlinear learning structures have been proposed to tackle complex adaptive filtering tasks. These include identification of systems and equalization of communication channels. Major commercial applications of adaptive filters are now available, such as equalizers in highspeed modems and echo-cancelers for long distance telephone and satellite circuits. The equalization task consists of recovering at the receiver the information transmitted through a communication channel subject to several adverse effects, such as noise, intersymbol interference (ISI), co-channel and adjacent channel interference, nonlinear distortions, fading, time-varying characteristics, among others [1]. The equalizer is an adaptive filter available at the receiver that learns how to recover the transmitted signal sequence. It means that the equalizer tries to learn the inverse transfer function of the channel. A linear combiner, also called Finite Impulse Response (FIR) transversal filter in current context, is the basic building block of almost all ANNs and adaptive filters used as equalizers. The adjustable parameters are coefficients (or weights), usually organized into a coefficient vector [2]. Communication through wireless channels suffer from multipath fading. One of the methods available to remove ill-effects of fast fading is diversity techniques. Maximal Ratio Combining (MRC) is a diversity technique, often preferred to mitigate fading effects [7]. The key to the effective design of the MRC is implementation of adaptive structures. Traditionally, adaptive processes of MRC blocks are implemented using Least Mean Squares (LMS)/Recursive Least Squares (RLS) based filter structures. Several works reporting MRC designs using such algorithms are available [5]. The primary limitation of these works is that such systems fail to use transmitter, channel and receiver state information (TCRSI). Artificial Neural Network (ANN) due to its ability to capture knowledge from applied patterns, retain and use it subsequently are capable of using the TCRSI, hence can be optional blocks replacing adaptive filters in MRC design.
This work is related to the design of an MRC scheme assisted by a Self Organising Map (SOM) block so as to investigate the performance of the MRC - ANN assisted equalization combination in Gaussian and multipath fading channels. The work uses Bipolar Phase Shift Keying (BPSK) modulation in Gaussian and Rayleigh fading channels with SNR variation in the range -10 to 10 dB range. The objective is to determine the appropriate combination of MRC and ANN equalisers such that better BER values are obtained for the given modulation technique and the channel types. A few such works are reported in [3][4]. The work considers performance difference in terms of BER rate obtained using MRC-ANN equalizer combination. The aforementioned SOM-based adaptive filters are compared with standard FIR/LMS as well as with powerful Multilayer Perceptron (MLP)-based filters in nonlinear channel equalization and inverse modeling tasks. The obtained results in both tasks indicate that SOM-based filters can consistently outperform powerful MLP-based ones. SOM-based equalisation has the advantage that it does not require supervised training, hence no reference is required. This is useful for real-time systems. Also SOM ANN has advantage that it performs competitive learning among samples showing time-variation as well. Here, we use SOM as an aid to MRC is faded wireless channels. The results derived are compared with that reported in [3]-[6]. Our main goal here is to evaluate the SOM as a feasible tool for nonlinear adaptive filtering. In this work, we considered two ANN topologies widely used in non-linear adaptive filtering: MLP and SOM, based on backpropagation (supervised) and Kohonen (non-supervised) algorithms, respectively. The SOM or Kohonen network is a tool for dimensionality reduction and clustering. The other network (MLP) approximate classification boundaries or otherwise map inputs to outputs [2]. The rest of the paper is organised as below: Section 2 contains the basics of MRC, ANN, SOM and related considerations. Section 3 includes the details of the proposed system model. Experimental results are included in Section 4. The work is concluded by Section 5.

2. BACKGROUND PRINCIPLES
The following section provide a brief description about the constituent components as given below:

2.1 MRC

It represents a theoretically optimal combiner over fading channels as a diversity scheme in a communication system. Theoretically, multiple copies of the same information signal are combined so as to maximise the instantaneous SNR at the output. Out of several diversity techniques, MRC is preferred due to the fact that it maximizes the correct reception and reduces inter-symbol interference (ISI) [5]. Figure 1 shows a MRC block.

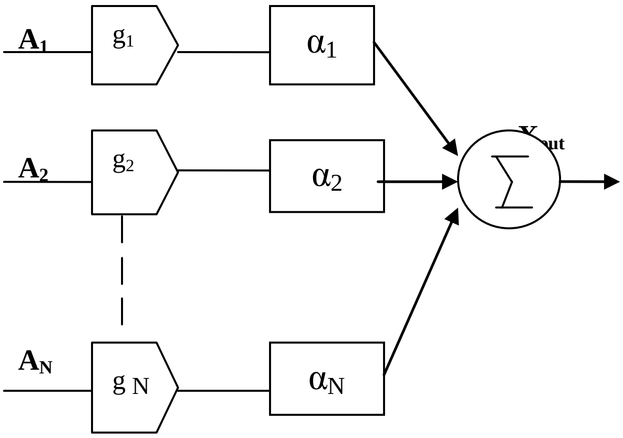

Fig. 1 MRC Block

2.2 MLP

It is an ANN which is a feedforward structure with one or more layers between input and output layer. Feedforward means that data flows in one direction from input to output layer (forward). The back propagation algorithm is the principle procedure for training MLPs. MLP consist of units arranged in layers. Each layer is composed of nodes and in the fully connected network considered here each node connects to every node in subsequent layers [8]. Figure 2 shows a typical three layer MLP.

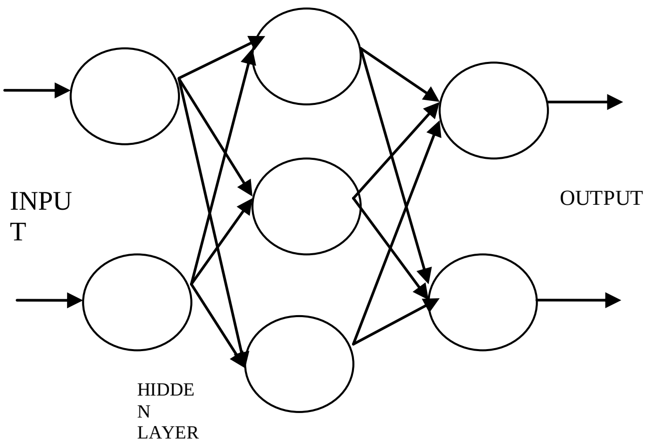

Fig. 2 Typical three layer multilayer perceptron neural network

2.3 SOM

A SOM is a type of ANN that is trained using unsupervised learning to produce a low-dimensional (typically two dimensional), discretized representation of the input space of the training samples, called a map. SOMs are different from MLPs in the sense that they use a neighbourhood function to preserve the topological properties of the input space. Like most ANNs, SOMs operate in two modes: training and mapping. Training builds the map using input examples. It is a competitive process, also called vector quantization [8]. Figure 3 shows a Self Organising Map.

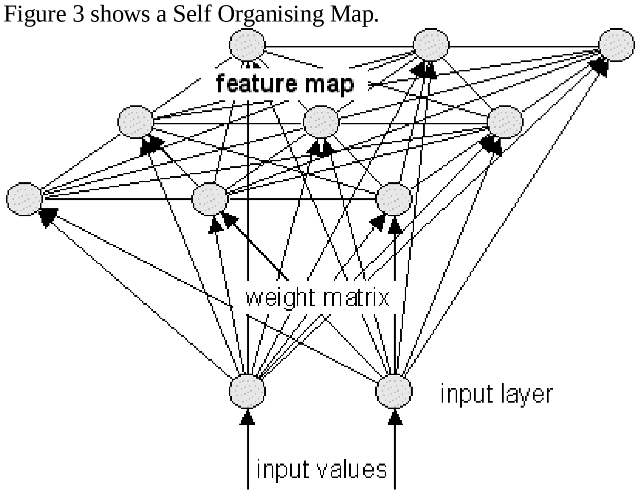

Fig. 3 A Self Organising Map

2.4 Working of SOM

SOM adapts specifically to various input signal patterns or classes of patterns through an unsupervised learning process [8]. The SOM is a topology based ANN that re-organizes depending upon the re-grouping of neurons as per the closeness to the applied pattern. The topology has a coordinate system which changes depending upon the Euclidean distance the input pattern has with the connectionist weight value linking the neurons of the topological map. The basic process for the working of SOM:

a) Initialize each nodes weights.
b) Choose a random vector from training data and present it to the SOM.
c) Every node is examined to find the Best Matching Unit (BMU).
d) The radius of the neighborhood around the BMU is calculated. The size of the neighborhood decreases with each iteration.
e) Each node in the BMUs neighborhood has its weights adjusted to become more like the BMU. Nodes closest to the BMU are altered more than the nodes furthest away in the neighborhood.
f) Repeat from step b for enough iterations for convergence.

3. PROPOSED SOM-AIDED MRC

MRC is an essential process used to fight multipath fading. One of the basic considerations of MRC design is the configuration of the equaliser. Traditionally, statistical equalisers are preferred for such applications but ANNs have also been preferred due to their ability to use TRCSI and related prior knowledge [9][10]. ANNs like MLPs are often used due to their simplicity of configuration. But due to some of its limitations such as the system is time consuming for supervised training and its inability to track time-varying channels, SOM-based equalisers are preferred. Further, SOM is fast and requires no reference during training and guarantees convergence. The experimental work carried out can be summarized by the block diagram shown in Figure 4.

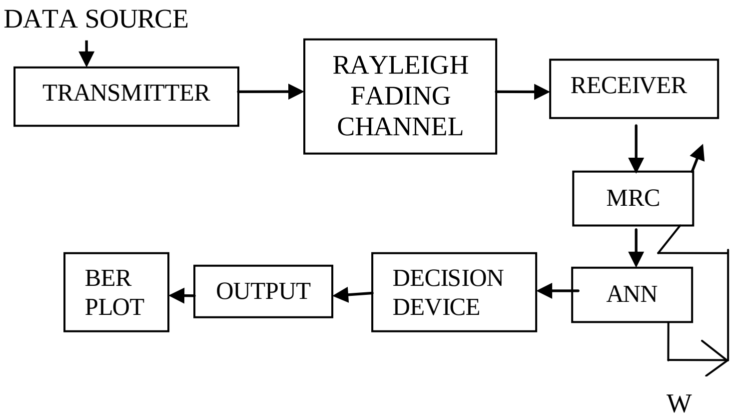

Fig. 4 Block Diagram of ANN assisted MRC

Initially, the data obtained in binary form are modulated using BPSK modulation and then passed through a Rayleigh fading channel. The Rayleigh faded channel is simulated using the parameters shown in Table 1.

At the receiver end, more than one copy of the signal is received due to the multipath fading that takes place in the fading channel. After the receiver block, there is a combiner block (MRC), where the signals from all the branches are weighted according to their SNR, cophased and summed. MRC produces an output SNR equal to the sum of individual SNRs. A fixed threshold SNR is set. The updating process of the weights of the MRC system is linked to the SOM in such a way that the process continues adaptively till the SNR crosses the fixed value. The SOM-based equaliser designed for the application, for a single MRC branch, is shown in Figure 6. Here, two SOM blocks represent the ANN block in Figure 5 shown within the dotted lines.

Table 1. Parameters used for simulating channel using Clarke-Gans model

Sl Num	Parameter	Value
1	Freq., f_c	900MHz
2	ω_c	$2\pi f_c$
3	Mobile Speed, V	3 kmph
4	No. Of paths	8
5	Wavelength,λ	$3*10^8/f_c$
6	Doppler shift, f_m	V/λ
7	Sampling Freq,f_s	$8*f_m$
8	No. Of Samples, N	10^3 to 10^6
9	Paths	16
10	Sampling Period,T_s	$1/f_s$

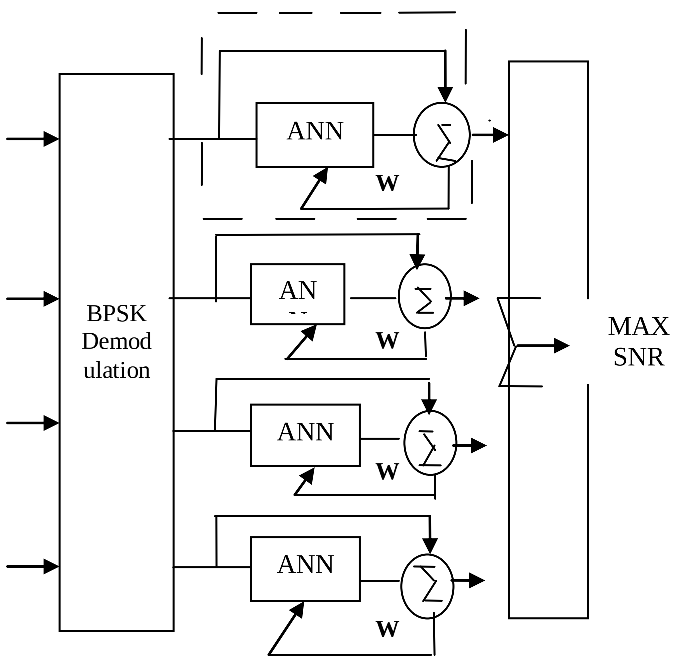

Fig. 5 Proposed model of ANN assisted MRC

The received signal consists of contributions from significant (S) and non-significant (NS) channel coefficients. The SOM-based equaliser is designed to deal with these two situations. The SOM is a classifier which when trained with an appropriate topology (here we used a 1-D form) for some numbers of sessions, creates clusters from input samples during testing using the best match principle. In another form, with different number of training sessions, the SOM can also create another cluster of samples that do not fall under the best match criteria of the previous case. This is the guiding principle behind the design.

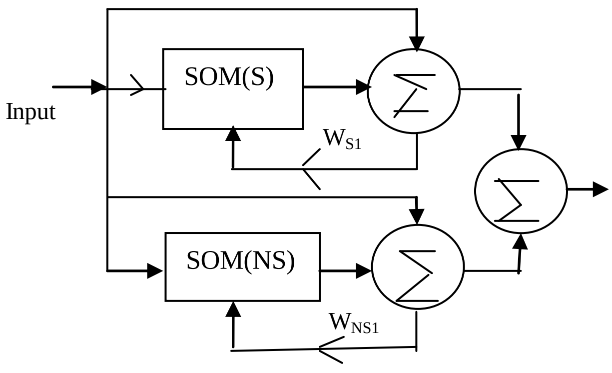

Fig. 6 Representation of ANN by two SOM Blocks

We have used two SOM units for the design of the equaliser. The first unit called SOM(S) classifies the patterns due to the contributions from the significant channel coefficients while the second unit called SOM(NS)[Fig. 6] deals with the contributions of non-significant or co-channel interference (CCI) channel coefficients. Both these blocks trained for different number of sessions work together as an effective and fast equaliser for each MRC branch. During a cycle, first the training part is completed. The SOM units for significant and non-significant channel coefficients are trained for different training sessions. The four branch MRC considered for the work thus is configured to provide the most suitable SNR for the receiver. And finally the BER plot is obtained.

4. EXPERIMENTAL RESULTS

The proposed system model is depicted in Figure 5. The signal at the receiver is captured by several diversity branches and passed on to the demodulation block. Before demodulation and reconstruction, there is a SOM block which is combined with the MRC to make improvement in the SNR of the received signal. The detailed working of the block has already been described in Section 3. The SOM is trained using the Batch Unsupervised Weight/Bias training algorithm and is provided a mean square error (MSE) convergence goal of 10^{-3}. The ANN takes a maximum of 200 iterations for severe fading to reach this goal for about data set of size 10^4. If data size is reduced and the fading is not severe this training complexity is considerably less and in some cases it takes only around 10% of this value. Four path Rayleigh channel is generated using the considerations described in Section 3 and as summarized in Table 1. After the channels are generated the modulated signals are convolved to provide the transmission effect. At the receiver end, the MRC process is carried out with four branch configurations. The MRC branches have the SOM blocks each constituted by special units as shown in Figure 6. The four branch configuration provides better results but at the cost of greater computational constraints. The updating process of the weights of the MRC system is linked to the ANN in a way that the process continues adaptively till the SNR crosses the fixed threshold value. Weight adjustment is performed until a steady state of global ordering of the weight vectors has been achieved. In this case, we say that the map has converged. The resulting map also preserves the topology of the input samples in the sense that adjacent patterns are mapped into adjacent regions on the map. Due to this topology-preserving property, the SOM is able to cluster input information and spatial relationships of the data on the map. Experiments are carried out with and without the ANN block. Results are derived from the set-up for SNR ranges between -10 and 10 dB. Figure 7 shows a BER plot generated for SNR ranges between -10 and 10 dB with four branch MRC for a Rayleigh multipath fading channel. The presence of the ANN block using MLP improves the BER values further as depicted by Figure 8 reported in [3]. Figure 9 shows the MRC plot with four branches and SOM, which shows further improvement in the BER values. Here, we see that the BER values have improved by 27% to 50% when we used SOM neural network. Figure 10 shows the comparison plot of ANN assisted equalisation using SOM and MLPs. We see that the SOM-based equalizers performed better than or as good as the MLP-based equalizers. Another advantage of SOM-based equalizers over MLP-based ones, useful for real-world implementations, is that they can be easily implemented in hardware.

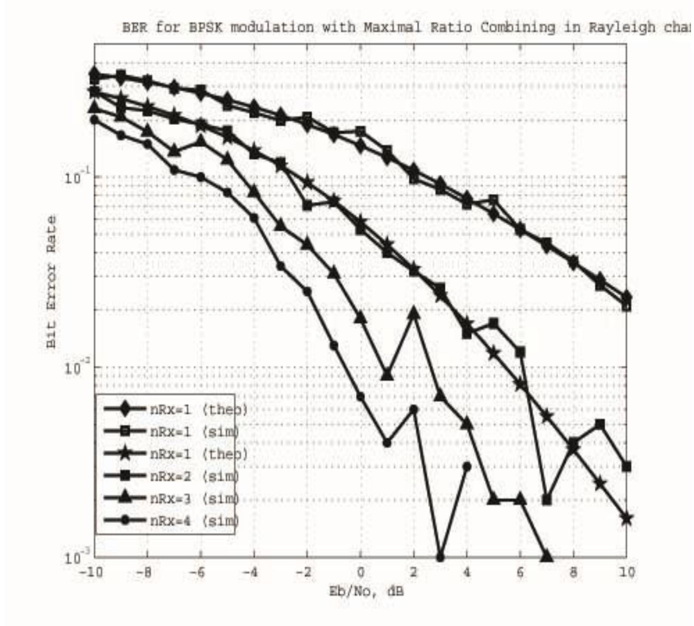

Fig. 7 MRC plot with four branches

From the plot, we see that at 9 dB there is an improvement in the BER values by 5.68% after using MLP-assisted equalisation whereas after using SOM-assisted equalisation, the BER values improved further by 27.44%. At 10 dB, there is an improvement in the BER values by 35% and 50% after using MLP and SOM- assisted equalisations respectively. So from the results we see that as the SNR increases, there is a significant improvement in the BER values with the use of SOM- assisted equalisation as compared to MLP-assisted equalisation. The comparative results of BER values for different methods is given below in Table 2. Table 3 shows the percentage gain obtained in BER values using MLP and SOM assisted equalisation. The use of the SOM block with the MRC system is thus justified.

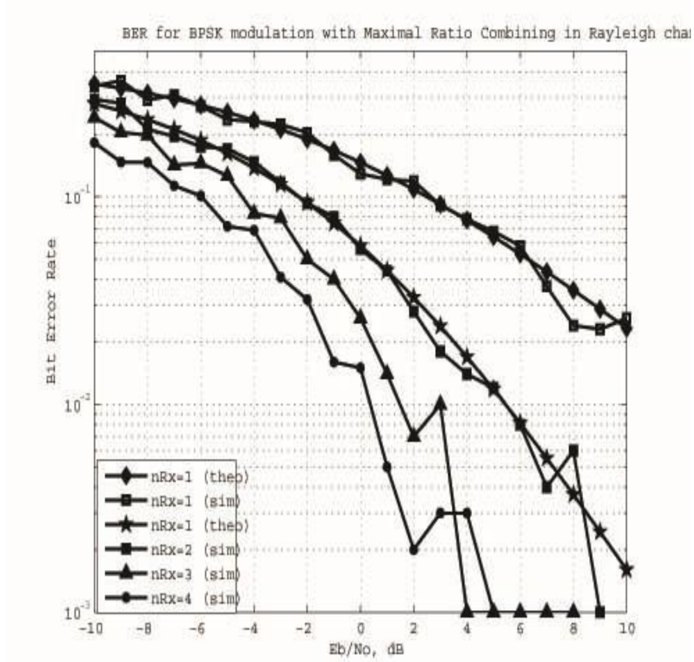

Fig. 8 MRC plot with four branches and MLP-equalization

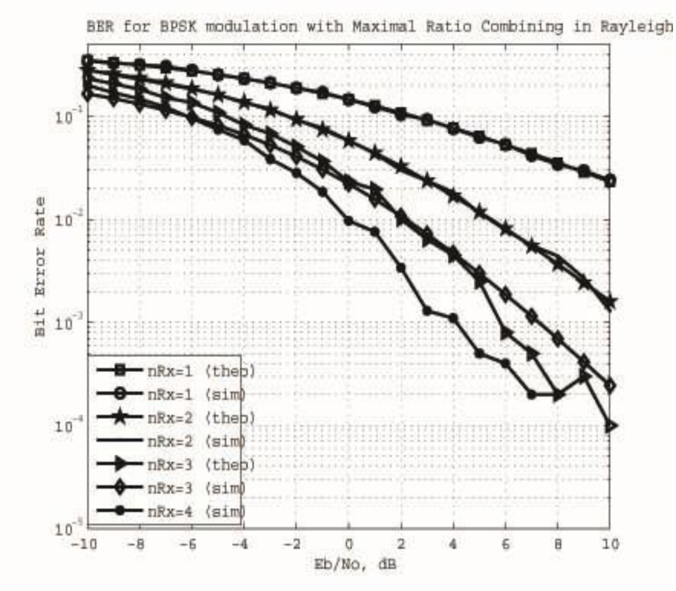

Fig. 9 MRC plot using four branches and SOM-equalisation

Table 2. Comparative Depiction of BER values for conventional MRC, MRC assisted by LMS filter [5] and proposed method

SNR(dB)	BER using conventional MRC	BER with Adaptive Filter	BER with MLP	BER with SOM
7	0.001148	0.0012	0.00099	0.0007
9	0.0004135	0.00052	0.00039	0.0003
10	0.0002	0.00022	0.00013	0.0001

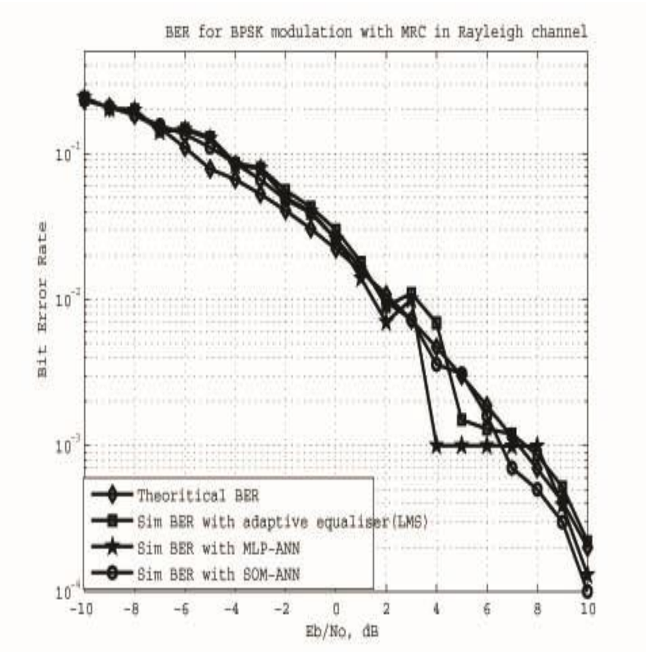

Fig.10 BER plot using SOM and MLP assisted equalisation

TABLE 3. PERCENTAGE GAIN IN BER WITH USE OF MLP AND SOM

SNR (dB)	With MLP	With SOM
9	5.68%	27.44%
10	35%	50%

5. CONCLUSION

This work is an attempt to investigate the effect of combined use of MRC and SOM-equalization in multi-path fading channel. At the receiver end, after the MRC stage, when an SOM equalizer is placed and linked to adaptively update the connecting weights of the MRC system, the BER improves considerably in fading channels. The performances of SOM-based adaptive filters on this real-world application are better than the MLP-based filters. This can be explained in part due to the fact that the types of nonlinearity are not necessarily of sigmoidal type, and thus the SOM-based filters fairly demonstrated their better performances with respect to MLP-based ones.The obtained results indicate that the proposed SOM-based adaptive equalizers perform better than the standard linear ones and compare favorably with MLP-based equalizers. The improvement is noticeable despite a SNR range of around -10 to 10dB. The work on an extended scale is applicable to mobile and wireless communication transmitting data through multipath fading channels.

6. REFERENCES

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