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NEURAL NETWORK DEMODULATOR FOR QUADRATURE AMPLITUDE MODULATION (QAM)

Ahmed Nasraden Milad
Dept. of Electrical Engineering
Universitas Brawijaya
Malang, Indonesia

M. Aziz M
Dept. of Electrical Engineering
Universitas Brawijaya
Malang, Indonesia

Rahmadwati
Dept. of Electrical Engineering
Universitas Brawijaya
Malang, Indonesia

Artificial neural network (ANN) is one of the most advanced technology fields, which allows machines to learn from examples in a manner similar to the human brain learning. ANNs applied to many scientific fields such as function approximation, data processing, classification, signal processing and much more. The main problem in communication field is the effect of noise into the signal. In this paper an artificial neural network demodulator (ANND) to demodulate quadrature amplitude modulating signal (QAM) is proposed. This project attempts to develop communication systems by developing neural networks and machine learning. This paper will help giving contribution to reduce the bit error rate (BER), optimize the quality of received data, reducing the effect of noise on data communications, optimization of the signal demodulator quality, increasing the quality of communication systems, speed up the process of neural network demodulator, developing the signal recovery and demodulating techniques. The artificial neural network, random data, noise, QAM modulator and demodulator are all simulated by GNU Octave software on this paper.

Key words: demodulation, ANN, communication, QAM, BER, GNU octave simulation.

I. INTRODUCTION

Quadrature Amplitude Modulation (QAM) is one of signal modulation techniques on communication systems, the concept behind QAM is using two carriers, one in-phase and other quadrature, with different amplitude levels for each carrier. Basically QAM is a combination of Amplitude-Shift Keying (ASK) and phase-shift keying (PSK) [1]. In general term, QAM can be defined as the digital modulation format where information is conveyed in the amplitude and phase of a carrier signal. This scheme combines two carrier whose amplitudes are modulated independently with the same frequency and whose phases are shifted by 90 degrees with respect to each other. These carriers are called in-phase carrier (I) and quadrature-phase carrier (Q) [2].

Artificial Neural Network (ANN) or Simulated Neural Network (SNN) or well known as Neural Network is a network from a small processor group unit which modelized based on human neural system attempting to imitate human neural system. ANN is an adaptive system which can change its structure to fix problems based on external or internal information flowing from its network. Artificial Neural Networks (ANNs) is set of interconnected virtual neurons created by a computer programs to work similar to biological neuron. ANNs also known as an information processing paradigm that is inspired by the way biological nervous systems, such as the brain, process the information. The key element of this paradigm is the novel structure of the information processing system. It is composed of a large number of highly interconnected processing elements (neurons) working in unison to solve specific problems. ANNs, similar to human, learn from examples and experiences. An ANN is configured for a specific application, such as function approximation, data processing, robotics, computer numerical control, pattern recognition, classification and signal demodulation, through a learning process [3].

II. QAM AND DEMODULATION

Normally, the expression of QAM signal is expressed by

$$s_n(t) = \sqrt{\frac{2E_s}{T_s}}\left(A_n^I \cos \omega_c t + A_n^Q \sin \omega_c t\right) \qquad (1)$$

Where $s_n(t)$ represented the bandpass signal, E_s is signal energy, A_n^I and A_n^Q indicate I and Q amplitudes, ω_c is known as carrier frequency, and T_s represent the symbol time.

16-state Quadrature Amplitude Modulation (16-QAM) is a QAM with M=16 voltage levels or possible states for the signal, that is, four *I* values and four *Q* values. QAM transmits *k* bits of information during each symbol period, where $k = \log_2 M$ = 4 bits, that is M $= 2^k$, consisting of two bits for *I* and two bits for *Q*. The symbol rate is one fourth of the bit rate, producing a very spectrally efficient transmission [4].

III. ARTIFICIAL NEURAL NETWORK

Typical ANN neuron or computing element (Shown in Figure 1) is basically a comparator that produces an output when the cumulative effect of the input stimuli exceeds a threshold value, a single ANN neuron is illustrated with three inputs and a single output.

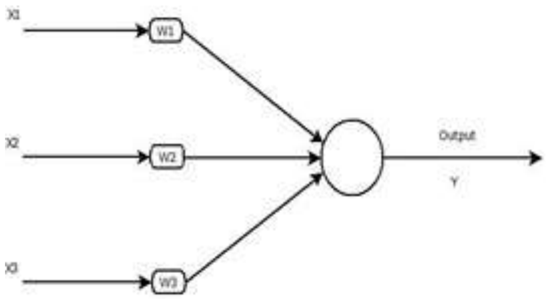

Figure 1. Simple Artificial Neural Network

Each input link *i* (*i* = l, 2, 3) has an associated external input signal or stimulus x_i and a corresponding weight W_j, a sort of filter which is part of the linkage connecting the input to the neuron. The input x_i values can be real (+ or -), binary (0, l), or bipolar (-1, +1). The weights act to either increase (excitatory input) or decrease (inhibitory input) the input signals to the neuron. The weights can also be binary or real-valued, but are usually assumed to be real (positive for excitatory and negative for inhibitory links). The output from the ANN can also be real-valued or binary or bipolar.

The neuron behaves as an activation or mapping function *f* (•) producing an output *y* = *f* (*net*), where *net* is the cumulative input stimuli to the neuron and *f* is typically a linear or nonlinear function of *net*. For example, *net* is often taken as the weighted sum of the inputs.

$$net = \sum_i w_i x_i \quad (2)$$

Where w_i is weights and *xi* the input data.

There are several types of activation functions commonly used in artificial neural networks such as hard limit, linear, tanh, log-sigmoid function and much more. The log-sigmoid transfer function is commonly used in multilayer networks as shown in Figure 2, because this function is differentiable, log-sigmoid transfer function takes the input (which may have any value between plus and minus infinity) and squashes the output into the range 0 to 1, according to the expression:

$$a = \frac{1}{1+e^{-n}} \quad (3)$$

Where *n* is the input of the activation function [5].

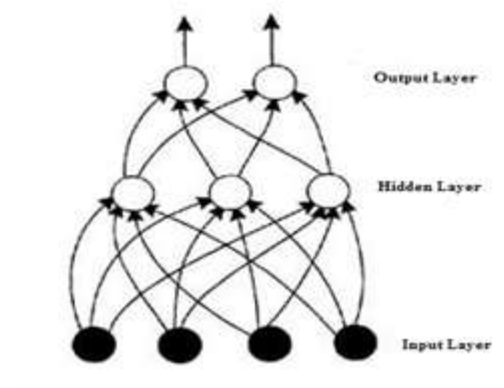

Figure 2. Example of Multilayer Neural Network where of output node is the sum of hidden layer nodes

IV. SUPERVISED LEARNING

Supervised learning methods are methods that attempt to discover the relationship between input attributes (sometimes called independent variables) and a target attribute (sometimes referred to as a dependent variable). The relationship discovered is represented in a structure referred to as a model. Usually models describe and explain phenomena, which are hidden in the dataset and can be used for predicting the value of the target attribute knowing the values of the input attributes. The supervised methods can be implemented in a variety of domains such as marketing, finance and manufacturing.

It is useful to distinguish between two main supervised models: classification models (classifiers) and Regression Models. Regression models map the input space into a real-value domain. For instance, a regression can predict the demand for a certain product given its characteristics. On the other hand, classifiers map the input space into pre-defined classes. For instance, classifiers can be used to classify mortgage consumers as good (fully payback the mortgage on time) and bad (delayed payback). There are many alternatives for representing classifiers, for example, support vector machines, decision trees, probabilistic summaries, algebraic function, etc. Along with regression and probability estimation, classification is one of the most studied models, possibly one with the greatest practical relevance. The potential benefits of progress in classification are immense since the technique has great impact on other areas, both within Data Mining and in its applications [6].

V. DESIGNING AND TRAINING

The artificial neural network demodulator system requires the QAM signal simulator. One of GNU Octave packages is signal processing package. This package include

QAM signal processing functions, the functions which will be used in this system are Generate a Random Binary Data Stream Using default Random Number Generator function, Modulate using 16-QAM, Add White Gaussian Noise (AWGN), Demodulate using 16-QAM, and Compute the System bit error rate (BER).

The supervisor learning dataset consisting of two parts, input data and target data, this data collected from the results of GNU Octave signal processing functions, the signal simulator outputs are binary modulated data, data-in symbols, and transmitted signal for binary coding, the neural network demodulator (NND) will use the signal after adding White Gaussian Noise into the channel in the form of complex numbers as input data and the data before modulating as a target input, the database contains 7 columns, 3 columns for input values collected directly from the signal, because log-sigmoid activation function not support complex numbers, to get the more accuracy three parameters picked from the complex number array, the real part of array elements, the phase angle, in radians, for each element of complex array, and the imaginary part of the elements of array, and 4 columns as desired data for 4 bit.

The second database is used by Neural Network Data Filter (NNDF) for learning mode. This database contains 8 columns, 4 columns for input values collected directly from NND output and 4 columns as desired data collected for QAM simulator (data before modulating). The neural network demodulator include 3 layers, with 3 nodes for input layer, hidden layer 16 nodes, and the output layer 4 nodes, the neural network data filter also have 3 layers, but with 4 nodes in input layer, one node for each bit, 16 nodes in the hidden layer, and 4 nodes for the output layer as shown in Figure 3.

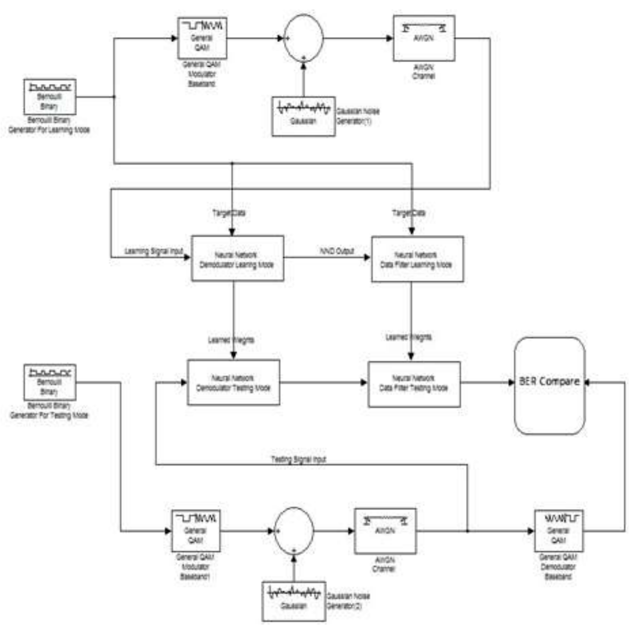

Figure 3. Project diagram shows the learning and testing scheme of NND and compare results with standard QAM demodulator outputs

A back propagation algorithm with delta rule and log-sigmoid transfer function is presented to train the ANN demodulator. There are details of the simulation experiment I the following text.

Basic parameters of the training signal in NND and NNF:

Number of epochs: 1500

Phase Offset of 16-QAM Modulated signal: 0

E_b/N_0 (The ratio of bit energy to noise power spectral density) for learning mode: 7 dB

Eta-NND (Learning Rate for NND binary coding): 0.0009

Eta-NNF (Learning Rate for NNF binary coding): 0.0007

Figure 3-4 show learning curve of ANN demodulator and ANN data filter.

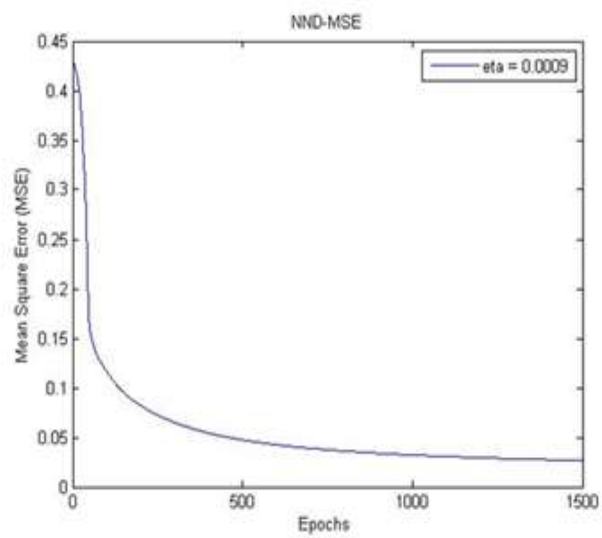

Figure 4. Learning curve of ANN Demodulator shows the mean square error over 1500 epochs with 0.0009 ANN Demodulator learning rate

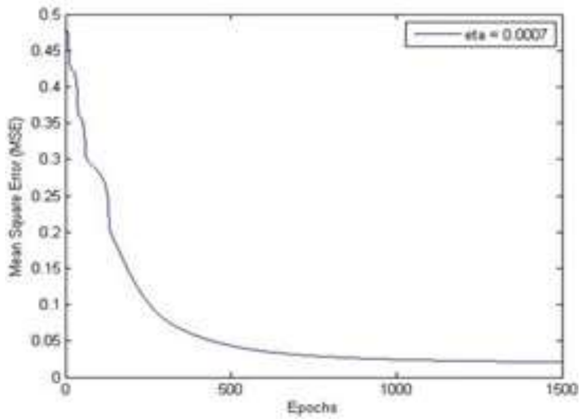

Figure 5. Learning curve of ANN data filter shows the mean square error over 1500 epochs with 0.0007 ANN data filter learning rate

VI. RESULT AND DISCUSSION

Table 1 summarizes the results of experiments. The shortcuts of table header row are neural networks (ANNs), number epochs (Epochs), signal phase offset of 16-QAM modulator (SP), learning rate of neural network demodulator (eta NND), learning rate of neural network filter (eta NNF), the ratio of bit energy to noise power spectral density for learning mode (L db), (T db) for testing mode, number of testing data by bits (T bits), number of errors on general 16-QAM demodulator (16Q DM), the number of errors from neural network demodulator system output (NN DM) and 2NN are neural network demodulator (NND) and neural network filter (NNF).

Table 1. Description of 16 Experiments.

No	ANNs	Epochs	SP	eta NND	eta NNF	L db	T db	T bits	16Q DM	NN DM
1	2NN	1.5k	0	9e-4	7e-4	7	3	1k	304	298
2	2NN	1.5k	1	9e-4	7e-4	7	3	1k	377	259
3	2NN	1.5k	2	9e-4	7e-4	7	3	1k	558	249
4	2NN	1.5k	3	9e-4	7e-4	7	3	1k	753	253
5	2NN	1.5k	3	9e-4	7e-4	7	10	1k	902	79
6	2NN	1.5k	2	9e-4	7e-4	7	10	1k	585	82
7	2NN	1.5k	1	9e-4	7e-4	7	10	1k	375	87
8	2NN	1.5k	0	9e-4	7e-4	7	10	1k	86	92
9	2NN	1.5k	0	9e-4	7e-4	7	7	1k	162	161
10	NNF	200	0	Null	0.2	5	5	300	83	75
11	NNF	200	0	Null	0.6	5	5	300	83	76
12	NNF	200	1	Null	0.2	7	10	300	111	54
13	NND	1k	0	0.05	Null	5	3	300	67	70
14	NND	1k	0	0.05	Null	5	1	300	80	75
15	NND	1k	1	0.05	Null	5	3	300	118	32
16	2NN	1k	0	1.5e-4	1.5e-4	5	3	300	52	45

From the experiments results, there are some characteristic features of ANNs demodulator system:

(1) The NND (Neural Network Demodulator) system can increases the quality of QAM demodulating data by 3-70% than standard QAM demodulators depending to the learning epochs, size of learning data, learning rate, the density of noise into channel on learning mode and the signal phase offset.

(2) In the testing stage, whenever the noise increases into AWGN channel, the NND gives more accuracy than standard QAM demodulator.

(3) The learning rate is depended to the learning time (number of epochs), type of input data and its relation to the desired output. So eta (Learning Rate) is different between neural network demodulator and data filter neural network.

(4) The NND can be applied to demodulate any signal modulating method without changes in main system structure.

(5) The NNF (Neural Network Filter) can be connected to standard QAM modulator to reduce the errors from 2% to 50%, depended to learning parameters and signal phase offset.

(6) When the signal phase offset increases the number of errors in NND reduced and the BER of standard QAM demodulator increases.

(7) The testing part of the system is stand-alone software which can be used (after one time of learning) to any QAM channel without process the learning stage again, which increases the speed of neural network demodulating up to 70%.

(8) The relationship between size of learning database and learning rate is inverse relationship.

CONCLUSION

This paper propose to use ANN as a demodulator for QAM signal due to its high ability to classify the regions and ability to learn the behavior of the signal when exposed to any distortion as a result of interference or noise, creating independent database can be used for any other application or other neural network structure, using independent databases will make the demodulation process faster and more flexible. In this paper we explained the QAM modulating techniques and described the structure of neural network demodulator and neural network data filter, The ANN demodulator is used to demodulate 16-QAM signal. Actually, ANN demodulator can be all-purpose system for modulated signal. It can demodulate different modulation methods like ASK signal, PSK signal, etc. Last section presented the neural networks performance, description of the results and some characteristic features of neural network demodulator and data filter neural network. To conclude this paper, future research options are given. Using a non-linear functions to separate the classes will increases the accuracy of classification especially when using noisy channels, the non-linear data classification techniques should be carried out. The difference of cost between traditional signal demodulators and neural network demodulator should investigated to reduce the cost of communication systems.

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