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A HOPFIELD NEURAL NETWORK BASED MIMO SYSTEM

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Abstract
In this paper, we present a MIMO (Multiple Input Multiple Output) communication system that uses the Alamouti algorithm for transmission with an appended Hopfield Encoder at the transmitter and Hopfield Decoder at the receiver. The Hopfield Encoders and Decoders are a part of the Hopfield Neural Network that can be used as an associative memory. At the transmitter, the symbols to be transmitted are first separated into blocks of length say k. These blocks are then elongated in size to a length l = (2k/0.15). These blocks of data each of length l are then encoded using the Alamouti algorithm and transmitted over a Rayleigh fading channel. At the receiver, the received blocks are sent to a Hopfield network which acts as an associative memory and tries to retrieve one of the possible transmitted symbols. After retrieval, the original data symbols are decoded. It was observed that the performance of the system was enhanced by use of the Hopfield network compared to Alamouti system without Hopfield neural network.

Keywords:
MIMO, Alamouti Algorithm, Hopfield Neural Network

1. INTRODUCTION

With the advent of high data rate next generation wireless systems, the need for a very low error rate in wireless systems has increased. The systems are also required to operate in diverse environments. To make the wireless systems comparable to optic cables, fibers etc., in their performance, the effect of time varying multipath fading has to be reduced.

The Alamouti algorithm makes use of transmit and receive diversity to achieve an improvement in the error rate over multipath fading. In this paper, the performance of the transmission using multiple antennas has been increased by using the Hopfield Neural Network [1]. The Hopfield neural network acts like an associative memory. It is trained to store a set of patterns and to remember the same when noisy or incorrect versions of the patterns are fed to it.

This paper has been organized as follows. In section 2 Almouti Algorithm reviewed and in section 3 Hopfield neural network description is given. The proposed communication system is presented in 4. In sections 5, 6 we presented the Matlab simulations and issues of the proposed system and finally the paper is concluded in section 7.

2. THE ALAMOUTI ALGORITHM

The communication system under the Alamouti algorithm contains 2 transmitter and 1 receiver antenna is shown in [2], [7] .The channels between the transmitter antennas 1 and 2 and the receiver antenna are represented by h_0 and h_1 respectively. The channel coefficients can be expressed as,

$$\begin{aligned} h_0 &= \alpha_0 \exp(j\theta_0) \\ h_1 &= \alpha_1 \exp(j\theta_1) \end{aligned} \tag{1}$$

Let the signals transmitted be given by s_0 and s_1 Noise and interference are added at the receivers. Therefore, the received signals at the receivers are given by,

$$\begin{aligned} r_0 &= h_0 s_0 + h_1 s_1 + n_0 \\ r_1 &= -h_0 s_1^* + h_1^* s_0 + n_1 \end{aligned} \tag{2}$$

Here, n_0 and n_1 represent the noise and interference where s_0^* and s_1^* are the conjugate of the transmitted signals. At the combiner, the following scheme is used,

$$\begin{aligned} \tilde{s}_0 &= h_0^* r_0 + h_1 r_1^* \\ \tilde{s}_1 &= -h_0 r_1^* + h_1^* r_0 \end{aligned} \tag{3}$$

These combined signals are then sent to the maximum likelihood receiver where the following rule is employed: choose s_i iff

$$d^2(\tilde{s}_0, s_i) \le d^2(\tilde{s}_0, s_k) \text{ for all } i \ne k \tag{4}$$

3. HOPFIELD NEURAL NETWORK

The Hopfield Network [1], [8] consists of N interconnected neurons which update their weights continuously and independently of the other neurons. All neurons are both input and output neurons. The activation values are binary. The activation values are chosen to be +1 and −1 instead of 1 and 0. A sample Hopfield network consisting of 4 input and output neurons is shown in Fig.1. The path between the i^{th} and the j^{th} neuron is denoted by w_{ij}. The weight matrix is given by,

$$W = \frac{1}{N}\sum_{\mu=1}^{N} \xi_\mu \xi_\mu^T - MI \tag{5}$$

Here ξ_μ represent the patterns that the network must be trained to remember. It is an N-dimensional column vector. The diagonal elements of w are zero. During retrieval, we assume a noisy version of a pattern Y is fed into the network. Then the output of the network is given by,

$$y = \text{sgn}(WY) \tag{6}$$

Here "sgn" represents the signum function. The above operation is repeated till the output vector Y becomes stable. The above network cannot store an infinite number of patterns.

The number M of N-dimensional patterns that can be stored is given by the critical limit α_c [1],

$$\alpha_c = \frac{M}{N} \tag{7}$$

For efficient retrieval of the stored patterns, they have to be orthogonal to each other. If the above critical limit is not adhered to, the retrieved pattern may not match any of the stored patterns.

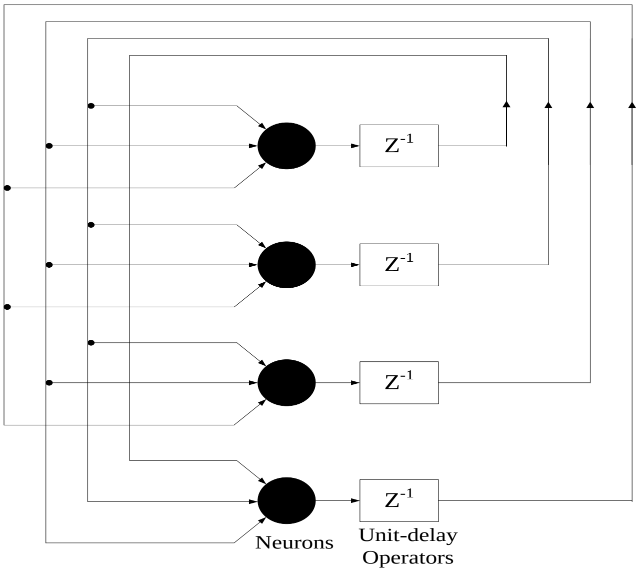

Fig.1. The Hopfield Neural Network with 4 neurons that act as both input and output nodes

4. PROPOSED COMMUNICATION SYSTEM

The communication system with a Hopfield Network appended to the Almouti decoder is illustrated in Fig.2.

4.1 SEGMENTING BLOCK

In the Segmenting block, the incoming continuous stream of data is segmented into blocks of length *k* each. Since the Hopfield network works only with binary data, care must be taken to ensure that the incoming stream of data is binary in nature.

4.2 SIGNAL ENCODING BLOCK

In this block, the length of each block is increased from *k* to $l=2k/0.15$. The orthogonality requirement must also be adhered to while increasing the size of the blocks of data. Then, the data is encoded using the Alamouti algorithm [2]-[7] and then sent to the modulator and transmitted over a multipath fading channel.

4.3 DECODER

The received data from the demodulator is decoded using the Alamouti algorithm and the Maximum Likelihood (ML) Detection scheme [2].

4.4 HOPFIELD NETWORK

The received data is sent to the Hopfield network in blocks of length *l* each. The network (which was initially trained to retrieve the stored patterns) iterates the incoming blocks until a stable output pattern is obtained. Once a stable pattern is obtained, the extra data that was added in the Signal encoding block is removed. The detailed procedure of the system is presented in Appendix.

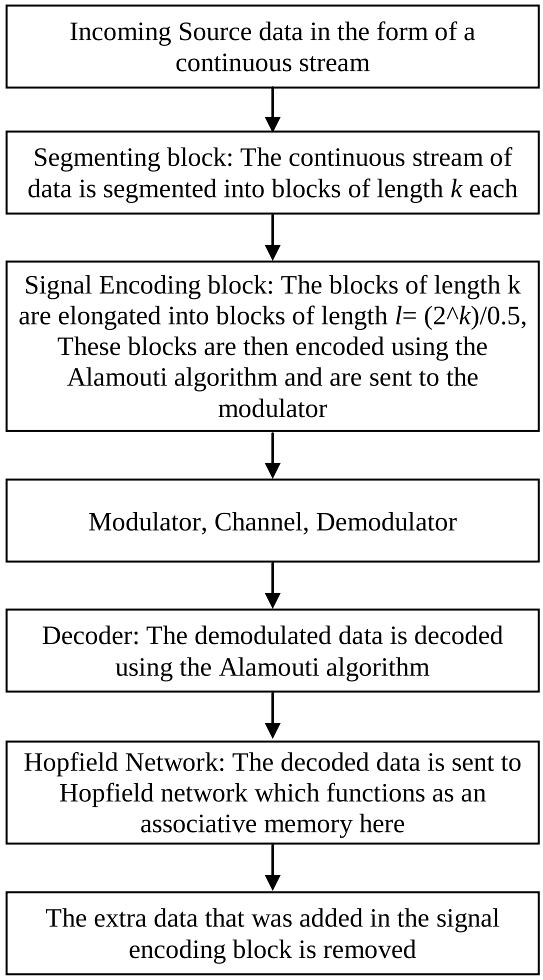

Fig.2. Block Diagram of a MIMO system with the Hopfield Network appended to the Decoder

5. RESULTS

The above communication system was simulated using Matlab and the results are shown in Fig.3. The simulation was also carried out for pattern lengths that did not adhere to the critical limit of 7. It can be seen that the Bit Error Rate (BER) reduces as the length of the pattern increases from 8 bits to 32 bits.

6. ISSUES

The bandwidth required increases with the required performance. However, there is an appreciable performance enhancement over a normal MIMO system when the bandwidth used is 8 times or 16 times the bandwidth requirement of a SISO (Single Input Single Output) system. Since the Hopfield Network deals with only binary data, the incoming data also should be binary in nature. Therefore, the data has to be real and cannot be complex. The number of iterations of the network is lesser if the data is in the form of ′ +1′ and ′ −1′ rather than ′ 0′ and ′1′.

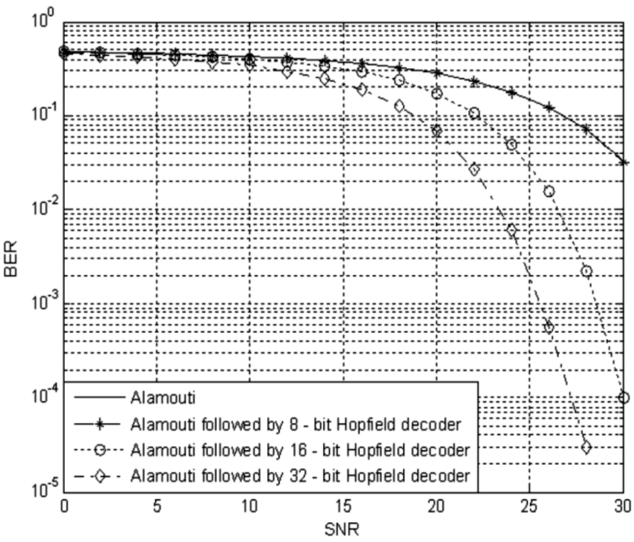

Fig.3. Performance comparison between the Alamouti algorithm and the proposed algorithm

7. CONCLUSIONS

In this paper we have made use of the Hopfield neural network to improve the performance of MIMO systems that employ the Alamouti algorithm. This has enabled a reduction in the SNR (Signal to Noise ratio) of 8dB for the same BER.

APPENDIX

Assume that the Alamouti algorithm for 2 transmitter antennas and 1 receiver antenna is being employed. The incoming data stream is first segmented into blocks of length 2. There can be 4 different symbols of binary data namely, (-1,-1), (-1,1), (1,-1) and (1,1). Since 4 different blocks of data can be possibly be transmitted, these blocks are elongated to (4/0.15) = 26.667 bits or 32 bits (to the nearest power of 2). Consider 4 orthogonal 32-bit patterns (vectors) as shown below,

A = [1 1 1 -1 -1 -1 1 1 -1 -1 1 1 -1 1 1 -1 1 -1 -1 1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 1]’

B = [1 1 -1 1 1 1 1 1 -1 -1 -1 -1 1 -1 1 -1 1 -1 1 -1 1 1 -1 -1 -1 -1 1 1 1 1 -1 1]’;

C = [1 1 -1 1 -1 -1 -1 -1 -1 -1 -1 -1 -1 1 -1 1 -1 1 -1 1 1 1 -1 -1 1 1 -1 -1 1 1 -1 1]’;

D = [1 1 -1 1 -1 -1 -1 -1 1 1 1 1 1 -1 1 -1 1 -1 1 -1 -1 -1 1 1 1 1 -1 -1 1 1 -1 1]’;

It is observed that the 20th and the 21st elements of each of these vectors form four different possible sets of data. Therefore, the four 2-bit patterns are mapped into one of these four vectors A, B, C or D. Thus the bandwidth has been increased by 16 times here.

This new stream is transmitted using the Alamouti algorithm. At the receiver, the same algorithm and the ML detection scheme is used. The estimated 32-bit vectors are then passed through a Hopfield network for further error correction. The Hopfield network here has 32 neurons and the weights of the interconnections are generated using 5. After the network outputs a stable vector (pattern), the 32-bit pattern is mapped back to the 2-bit data and thus the data is completely decoded. As the pattern length is reduced, the memory capacity gets reduced and this is reflected in the relatively lower BER values for 8-bit and 16-bit patterns.

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