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MIMO Channel Capacity Improvement Using Space Time Coding

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Abstract

Wireless communication systems play an important role in our life and society. In this paper, the different types of wireless communication systems Single Input-Single Output (SISO), Single Input-Multiple Output (SIMO), Multiple Input-Single Output (MISO), and Multiple Input- Multiple Output (MIMO) were described and compared from capacity and Bit Error Rate (BER) point of view. It was found that the capacity of MIMO communication system is better than other systems. An additional improvement was obtained by using Space Time Coding (STC). Space Time Block Code (STBC) improve the BER of MIMO by (78,6%), and Space Time Trellis Code (STTC) improve the (BER) at the receiver side by (91.37%). Also the use of Artificial Neural Networks (ANN) improve the STTC MIMO communication system by 54.16%. All measurement are done at SNR = 8dB. Using MATLAB version 2013a.

Key words

Channel capacity (C), MIMO, BER, STTC, and ANNs.

تحسين سعة نظام متعدد المداخل متعدد المخارج باستخدام التشفير

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الخلاصة

تلعب الاتصالات اللاسلكية دوراً مهما في جميع مجالات الحياة المختلفة في هذا البحث تم دراسة ومقارنة انواع مختلفة من أنظمة الاتصالات اللاسلكية (SISO, SIMO, MISO, MIMO) من خلال سعة قناة الوسط الناقل للمعلومات وكذا نسبة الخطأ في المعلومات المنقولة . حيث وجد ان سعة نظام متعدد المداخل متعدد المخارج (MIMO) افضل من بقية الانواع وعند استخدام التشفير بكلا نوعيه (STBC) و(STTC) تحسن اداء نظام (MIMO) بنسبة (78,6%) في حالة استخدام (STBC) وبنسبة (91.37%) في حالة استخدام (STTC) . وتم أيضا تقليل نسبة الخطأ (BER) عند استخدام الشبكات العصبية الاصطناعية (ANNs) مع نظام (MIMO STTC) بنسبة (54.16%). جميع هذه القياسات تمت عند (SNR).

1. Introduction

Wireless technology allows to communicate across large distances, such as mobile and satellite communication. In recent years, wireless communication witnessed a large development in order to provide high capacity in transmissions, improve communication reliability and respond to the large demands of the life. Recent applications of the communication systems required high data rates. Some factors limit these requirements such as power and bandwidth limitations. The technology which is able to overcome these limitations and provide high data rates is the use of multiple antennas at the transmitter and at the receiver, such technique is called Multiple Input – Multiple Output (MIMO) [1, 2].

Through propagation mechanisms, such as reflection, diffraction, and scattering, objects in the channel create multiple paths from the transmitter to the receiver. It is collectively refer to these objects as scatters, the paths are of a different length, and thus the signals arrive at the receiver with different amplitudes and phases. In some cases, the multiple signals are added destructively at the receiver, creating points in space where the composite received signal is greatly attenuated. This is referred to as multipath effect, to combat the multipath effect at the receiver, each antenna separated by some distance in space, represents received diversity [1]. In this paper, the capacity of different wireless communication systems it has been described.

2. Types of Wireless Channels

2.1 Single Input- Single Output system (SISO)

For a memory less SISO system, the equation of capacity can be expressed as [2].

$$C_{SISO}=\log_2 (1+SNR\ H^2)\ bps/HZ \qquad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where H represents the channel normalized complex gain matrix and (SNR) is the signal to noise ratio.

2.2 Single input- Multiple Output (SIMO)

The capacity of SIMO system can be expressed as [2].

$$C_{SIMO}= \log_2 (1+SNR\sum_{m=1}^{NR} h_m{}^{2}|) \text{ bps/HZ} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where (h_m) is the impulse response of the channel and (N_R) is the number of received antennas.

2.3 Multiple Input-Single Outputs (MISO)

The capacity of MISO is given as [2].

$$C_{MISO}= \log_2 (1+ \frac{SNR}{NT}\sum_{m=1}^{NT} h_m{}^{2}|) \text{ bps/HZ} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where (N_T) are the number of antennas.

2.4 Multiple Input-Multiple Outputs (MIMO)

The use of multiple antennas at the transmitter and the receiver is an emerging cost-effective technology that offers high data rate wireless communications. The capacity of MIMO system is given as [2]:

$$C_{MIMO} = \log_2 [\det (I+\frac{SNR}{NT} H \mathbf{H}^*)] \text{ bps/HZ} \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where I is an (N_R*N_T) identity matrix, and **H*** is the complex conjugate transpose. The capacity of MIMO system is larger than the capacity of SISO, MISO, and SIMO systems.

3. MIMO channel capacity

The channel capacity plays a central part in the design and analysis of multi-input multi-output (MIMO) communication systems. Studying the capacity of the MIMO channel system involves considering two cases related to the knowledge of the Channel State Information (CSI) at the transmitter.

3.1 No Channel State Information at the Transmitter

MIMO transmit techniques that do not require channel knowledge at the transmitter may be broadly classified into two categories: those designed to increase the transmission rate and those designed to increase relia MIMO transmission applies vector modulation $X= [x_1 \quad x_2 \; \ldots\ldots\ldots\ldots \; x_{NT}]$, by transmitting an independent symbol from each channel, the received signal reliability [3].

$$\vec{Y} = \vec{X}\,\mathrm{H} + \vec{N} \qquad \ldots\ldots\ldots\ldots\ (5)$$

Where $\vec{X}$ is the transmitted vector and $\vec{N}$ is the noise vector. When the channel is unknown to the transmitter, the vector **X** is statistically independent. This means that, the signals are independent and the power is equally divided among the transmit antennas.

3.2 Channel State Information at the Transmitter

When the transmitter has perfect knowledge of the channel, the water filling method is used to optimize the transmitted signal power scheme. The water filling algorithm state the total transmitted power is divided in such a way so that the greater portion of power goes to the channels with higher gain and small portion of power goes to the channels with smaller gains [2]. In practice, CSI is obtained by training, estimation, or feedback.

4. Space Time Coding (STC)

Both capacity and spectral efficiency for MIMO channels depend principally on the correlation between the transmitting and receiving antenna elements. Highly correlated sub-channels tend to provide similar capacity and spectral efficiency as a SISO channel; therefore, it would be necessary to ensure minimum correlation between antenna elements in order to deploy a MIMO system. The correlation between the antenna elements is firstly influenced by the surrounding environment and secondly by the transceiver hardware design [4]. In order to fully exploit the potential of MIMO channels, Space-Time Coding (STC) techniques were developed by relying on transmit diversity and receive diversity, STC provides a coding gain in addition to the spatial diversity gain **[5].**

4.1 Space Time Block Code (STBC)

The transmit diversity technique (two transmit antennas and one received antenna), proposed by Alamouti in 1998 **[6],** was the first Space Time Block Code (STBC). **Figure (1)** shows the block diagram of the Alamouti space-time encoder, as **[6].**

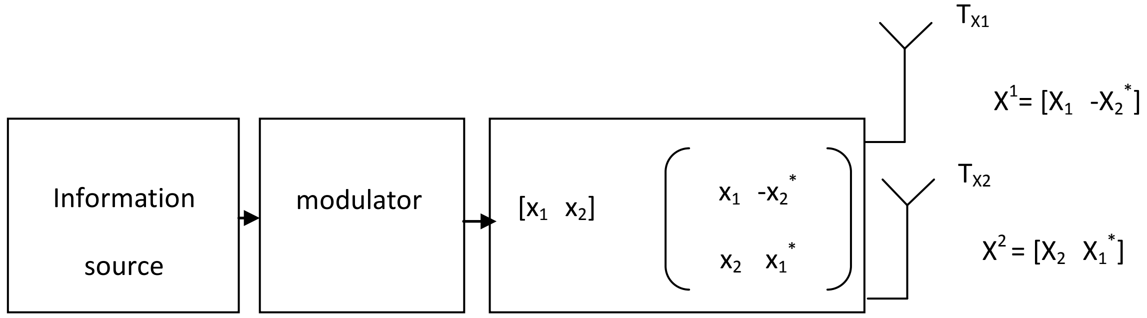


Fig 1 Alamouti space-time encoder

The space–time encoding mapping of Alamouti's two-branch transmits can be represented by the coding matrix:

$$X=\begin{pmatrix} X_1 & -X_2^* \\ X_2 & X_1^* \end{pmatrix} \quad \ldots\ldots\ldots\ldots\ldots (6)$$

The rate of (STBC) is defined as the ratio between the number of symbols the encoder takes as its input and the number of space-time coded symbols transmitted from each antenna. It can be expressed as **[5].**

$R = k/p$ …………… (7)

Where (k) is the number of symbols that the encoder takes as its input in each encoding operation is and (p) is The number of transmission periods required to transmit the space-time coded symbols through the multiple transmit antennas. The spectral efficiency of the space-time block code is given as **[5].**

$\eta = r_b/B = r_s mR/r_s = (k\times m)/p$ bits/s/Hz …………… (8)

Where r_b and r_s are the bit and symbol rate, respectively, and B is the bandwidth. In order to achieve the full transmit diversity of the N_T, the transmission matrix X is constructed based on orthogonal designs so that:

$$X \cdot X^H = c\,(|X_1|^2 + |X_2|^2 + \cdots + |X_k|^2) I_{nT} \qquad \ldots\ldots\ldots\ldots\ldots (9)$$

Where c is a constant, X^H is the Hermitian of X and I_{NT} is an $N_T \times N_T$ identity matrix [6].

4.2 Space Time Trellis Code (STTC)

STTC can offer a substantial coding gain, spectral efficiency, and diversity improvement on flat fading channels. The main idea behind coding is to use structured redundancy to reduce the effects of noise **[6, 7].** The STTC combines the spatial diversity and time diversity in order to combat efficiently the signal fading **[6, 7]**. The encoder of Space Trellis Code (STTC) maps binary data for modulation symbols **[5].** The data to be transmitted are encoded by a space-time encoder. At each instant t, a block of (m) binary information symbols which is denoted as [6]. is fed into the space-time encoder. The space-time encoder maps the block of (m) binary input data into M_T modulation symbols from a signal set of $M = 2^m$ points. The coded data are applied to a serial-to-parallel (S/P) converter to produce a sequence of M_T parallel symbols, arranged as an M_T ~~x~~1 column vector **[6].**

$$s_t = (s_t^1, s_t^2, \ldots, s_t^{MT})^T \ldots\ldots\ldots\ldots\ldots \textbf{(10)}$$

where $()^T$ is the transpose of a matrix. The M_T parallel outputs are simultaneously transmitted from all the M_T antennas, whereby symbol sets, the spectral efficiency of the system is **[6].**

$$\eta = \frac{rb}{B} \qquad \ldots\ldots\ldots\ldots\ (11)$$

Where r_b is the data rate and B is the channel bandwidth. The multiple antennas at both the transmitter and receiver create a MIMO channel. It is assumed that, there is flat fading between each transmit and receive antenna and it is also assumed that, the channel is memory less. In the encoder of the STTC ,(m)binary input sequences (c^1, c^2 …. , c^m) is fed into the encoder, which consists of (m) feed forward shift registers, The k-th input sequence $c^k = (c^k{}_0, c^k{}_1, c^k{}_2, \ldots$ ckt , . . .), k = 1, 2, . . .m, is passed to the k-th shift register and multiplied by an encoder coefficient set. The multiplier outputs from all shift registers are added modulo M, giving the encoder output x = (x^1, x^2, . . . , x^{nT}). The space-time trellis coded M-PSK can achieve a bandwidth efficiency of m bits/s/Hz, The total memory order of the encoder, denoted by ν, is given by [5].

$$V = \sum_{k=1}^{m} v_k \qquad \text{...............} (12)$$

Where ν_k, k = 1, 2. . . m, is the memory order for the k-th encoder branch. The value of νk for M-PSK constellations is determined as [5].

$$v_k = \frac{v+k-1}{\log 2M} \qquad \text{.................} (13)$$

In the system that used, a simple space-time trellis coded QPSK with two transmit antennas, the encoder consists of two feed forward shift registers. The encoder structure for the scheme with memory order of v and two transmit antennas was shown in Figure (2). Two binary input streams c^1 = ($c_0{}^1$, $c_1{}^1$, . . . $c_t{}^1$, . . .) and c^2 = ($c^2{}_0$, $c^2{}_1$, . . . , $c^2{}_t$, . . .) are fed into the upper and lower encoder registers. The memory orders of the upper and lower encoder registers are v_1 and v_2, respectively, where $v = v_1 + v_2$. The added outputs $x^1{}_t$ and $x^2{}_t$ are pointing from a QPSK constellation. They are transmitted simultaneously through the first and second antennas, respectively. The trellis consists of (2^v = 4) states, represented by state nodes. The input binary sequence to the upper shift register can be represented as **[6]:**

$$C^1 (D) = C^1{}_0 + C^1{}_1 D + C^1{}_2 D^2 + C^1{}_3 D^3 + \ldots\ldots\ldots\ldots\ldots (14)$$

Similarly, the binary input sequence to the lower shift register can be written as:

$$C^2 (D) = C^2{}_0 + C^2{}_1 D + C^2{}_2 D^2 + C^2{}_3 D^3 + \ldots\ldots\ldots\ldots\ldots (15)$$

Where $C^k{}_j$,j = 0,1,2,3,……, k = 1,2, are binary symbols 0, 1. The feed forward generator polynomial for the upper encoder and transmit antenna i, where i = 1, 2, can be written as:

$$G^1{}_i (D) = g^1{}_{0,i} + g^1{}_{1,i} D + \ldots\ldots\ldots\ldots\ldots + g^1{}_{v1,i} D^{v1} \text{ ....} (16)$$

where $g^1{}_{j,i}$, j = 0, 1, . . . , v_1 are non-binary coefficients that can take values 0, 1, 2, 3 for QPSK modulation and ν1 is the memory order of the upper encoder. Similarly, the feed forward generator polynomial for the lower encoder and transmit antenna i, where i = 1, 2, can be written as:

$G^2_i\ (D) = g^2_{0,i} + g^2_{1,i}\ D + \ldots\ldots\ldots\ldots\ldots + g^2_{v1,i}\ D^{v1}$ .... (17)

Where $g^2_{j,i}$, j = 1, 2, . . . , v_2, are non-binary coefficients that can take values 0, 1, 2,3 for QPSK modulation and v_2 is the memory order of the lower encoder. The encoded symbol sequence transmitted from antenna i is given as:

$X^i\ (D) = C^1(D)\ G^1_i\ (D) + C^2_1\ (D)\ G^2_i\ (D)\ \text{Mod}\ 4$ .... (18)

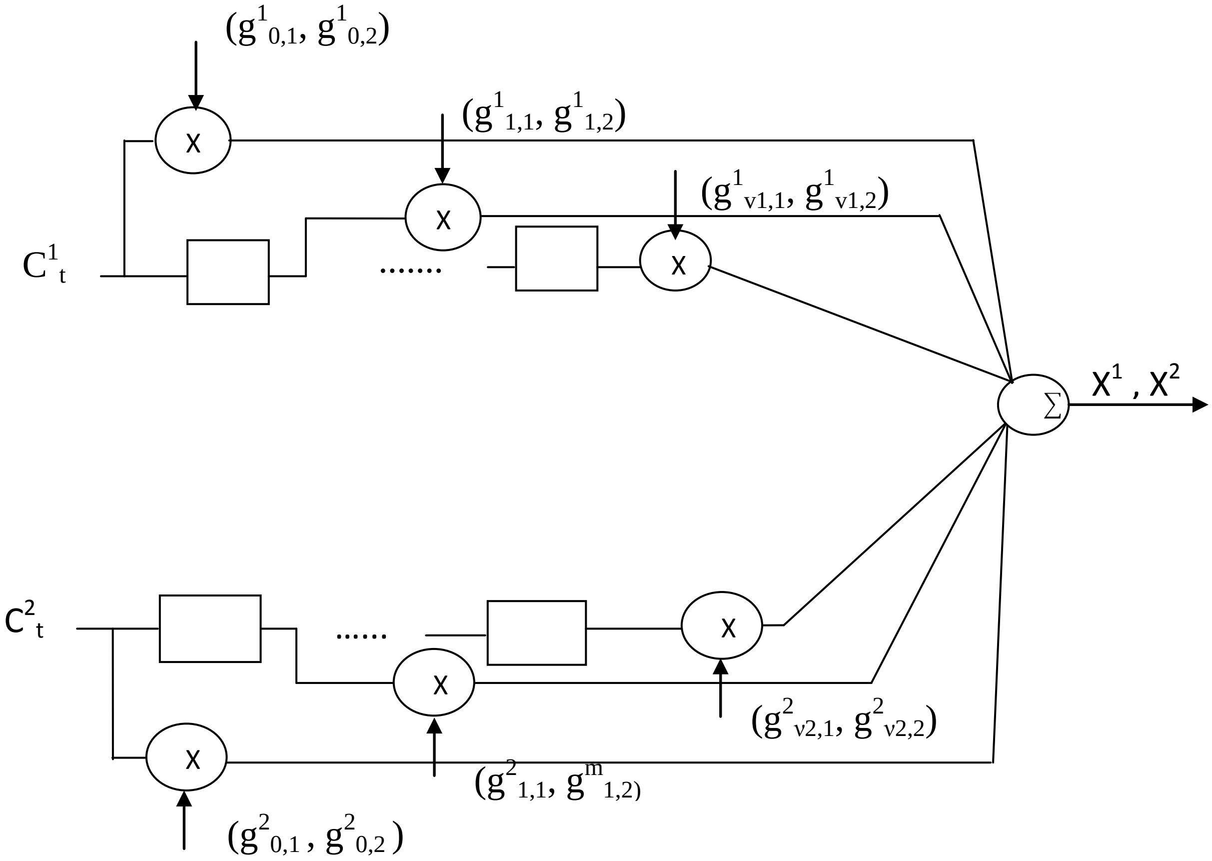


Fig 2 STTC encoder for two transmit antennas

The encoder takes m = 2 bits as its input at each time. There are $2^m = 4$ branches leaving from each state corresponding to four different input patterns. Each branch is labeled by $c^1_t\ c^2_t\ /x^1_t\ x^2_t$, where ($c^1_t$ and c^2_t) are a pair of encoder input bits, and x^1_t and x^2_t represent two coded QPSK symbols transmitted through antennas (1 and 2) respectively. The row listed next to a state node in the Figure (3) indicates the branch labels for transitions from that state corresponding to the encoder inputs 00, 01, 10, and 11, respectively [5].

Assume that, the input sequence is C = (10, 01, 11, 00, 01 . . .), The output sequence, generated by the space-time trellis encoder, is given by X = (02, 21, 13, 30, 01, . . .). The transmitted signal sequences from the two transmit antennas are:

X1 = (0, 2, 1, 3, 0 . . .), and X2 = (2, 1, 3, 0, 1 . . .)

Note that, this example is actually a delay diversity scheme since the signal sequence transmitted from the first antenna is a delayed version of the signal sequence from the second antenna **[5].**

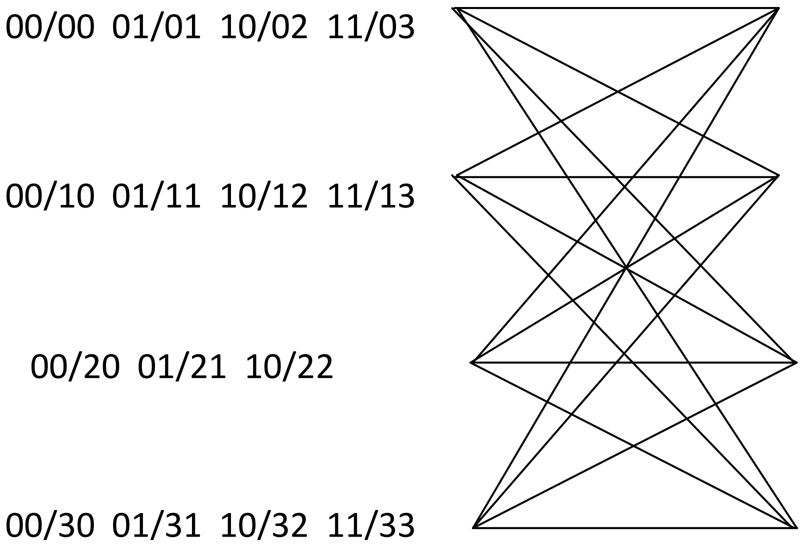


Fig 3 Trellis structure for a 4-state space-time coded QPSK with two antennas

5. Artificial Neural Networks (ANNs)

Artificial neural networks are massively parallel computing systems consisting of an extremely large number of simple processors with many interconnections **[8].**

5.1 Back Propagation Algorithm

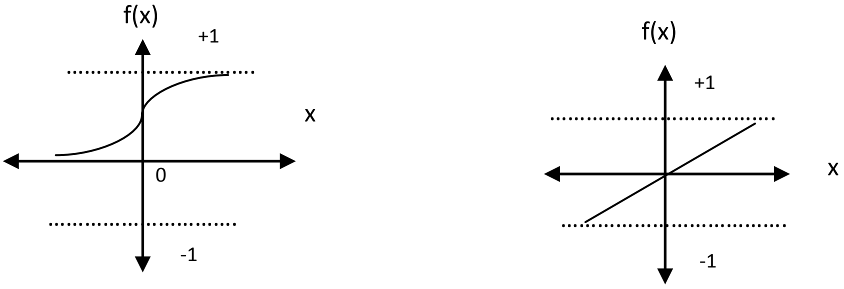
The back propagation algorithm is used in layered feed-forward ANNs. This means that the artificial neurons are organized in layers, and their signals “forward”, and then the errors are propagated backwards. The network receives inputs by neurons in the input layer, and the output of the network is given by the neurons on an output layer. There may be one or more intermediate hidden layer **[8].**

5.2 Activation function

The function that is applied by a neuron to convert its input activations to an output is known as an activation function, it is called (squashing function). Many of these functions are **[9].**

1. Linear transfer function.
2. Symmetric (hard limit transfer function).
3. Stalinlin transfer function.
4. Tan- sigmoid transfer function.
5. Radial basis function.
6. Log-sigmoid transfer function).

The transfer functions that used in the Proposed Design are shown in **figure (4)**



Log-sigmoid transfer function

Linear transfer function

Fig 4 ANN transfer functions

By adjusting the weights of an artificial neuron, the output can be obtained for specific inputs. The summing block is directly connected with the input vector ($x_1,x_2,$ …….x_n) from out side of the neuron. There is a weight ($w_{1,1},w_{1,2},$ …..$w_{1,m}$) on each connection (path) between each input and the In addition, a bias (b) whose input value is 1 is also associated with the neuron. The basic model of an artificial neuron is shown in **Figure (5)** as **[8].**

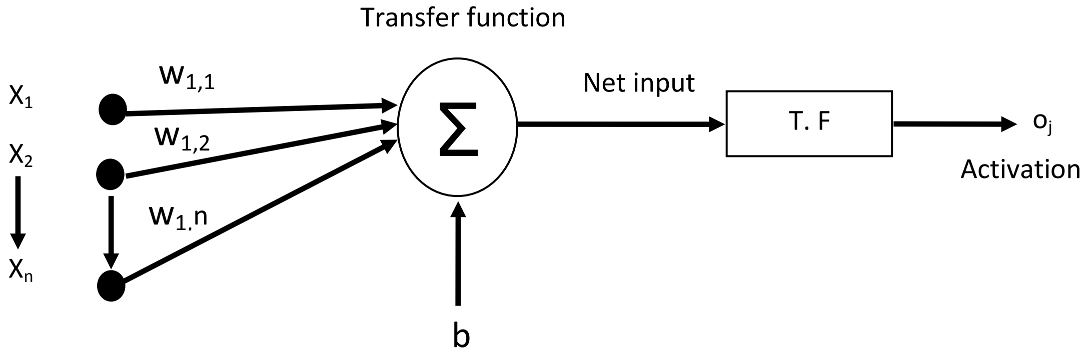


Fig 5 Artificial Neuron

The following relation describes the transfer function of the basic neuron model **[8].**

$$N = w_{1,1}x_1 + w_{1,2}x_2 + \cdots + w_{1,n}x_n + b$$

where *n* = number of elements in input vector , this expression can be written in matrix form:

$N = W. X+ b$

where the matrix W for the single neuron case has only one row. The neuron output can be written as:

$O_j = f\ (w.x +b)$

6. Proposed Design of STTC with ANN

The block diagram of proposed ANN is shown in **figure (6),** after the signal demodulated at the receiver the it fed in to ANN to obtained the output final received signal, and obtained the smallest BER between the target data and received signal.

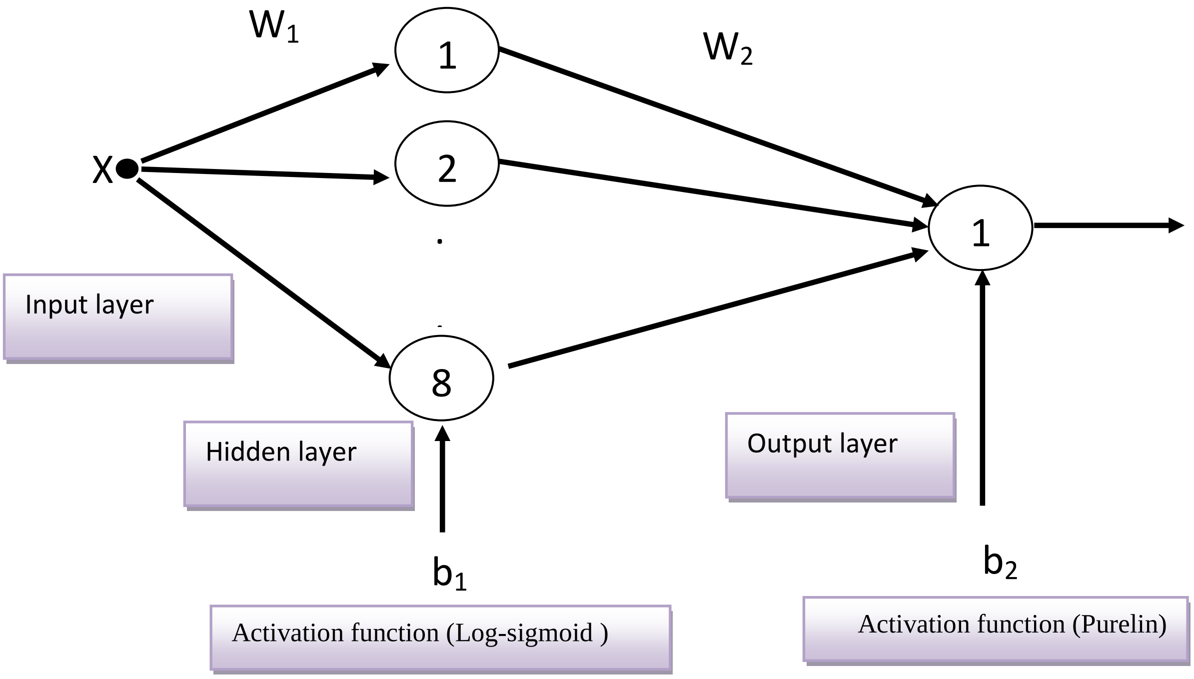


Fig 6 Proposed architecture of ANN

7. Simulation Results

Figure (7) shows the capacity of SISO, SIMO, MISO, and MIMO versus SNR.

When the channel is known at the transmitter, the capacity of a MIMO system will increase, as compared with the case when the channel is known only at the receiver, as shown in **Figure (8).** The capacity of MIMO with Alamouti STBC is illustrated in **Figure (9**) which shows how the capacity of full code rate Alamouti (2*1) STC is smaller than or equal to the capacity of MIMO system.

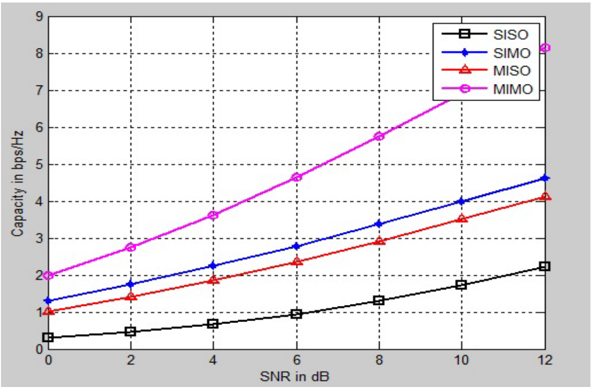


Fig 7 Comparison of Capacity for (SISO, MISO, SIMO, MIMO)

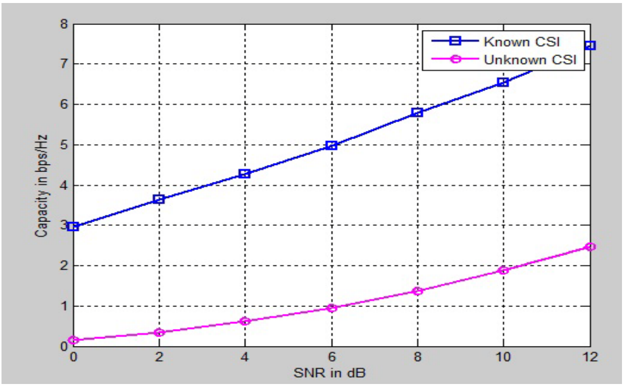


Fig8 MIMO capacity versus SNR for CSI known

and unknown at the MIMO transmitter

In addition, **Fig (10)** shows the throughput of MIMO with and without STBC and STTC techniques where

$$\text{Throughput} = \frac{\text{No. of correct packets}}{\text{Total transmitted packets}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ (4.8)$$

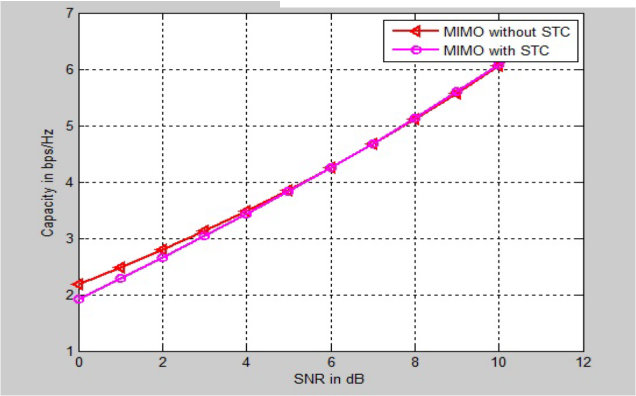


Fig 9 Capacity of 2*2 MIMO with and without STBC versus SNR

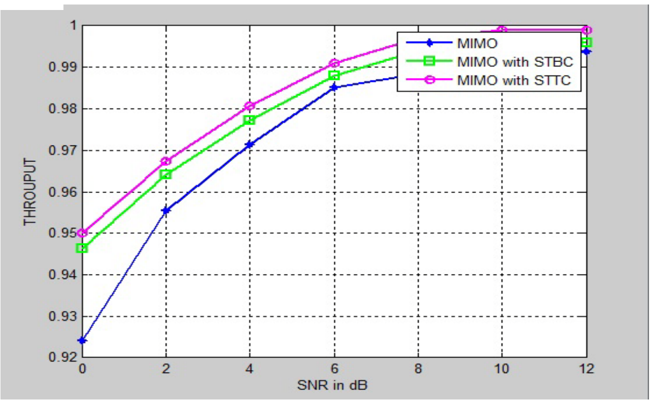


Fig 10Throughput f 2*2 MIMO with and without STC versus SNR

Figure (11) shows the BER of (SISO, SIMO, MISO and MIMO) systems

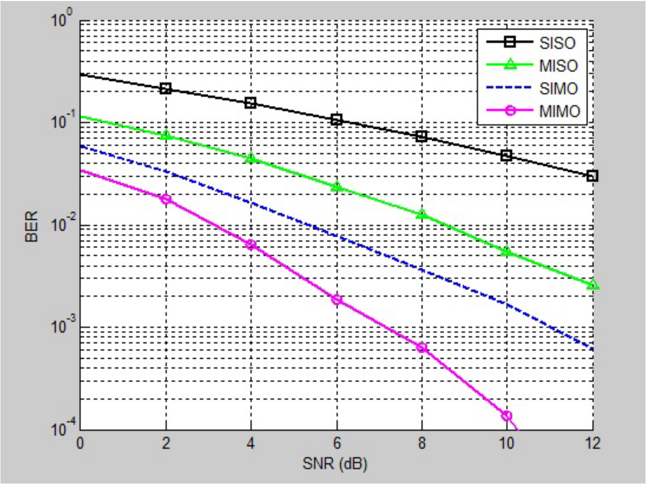


Fig 11 BER versus SNR for SISO, MISO, SIMO, and MIMO systems

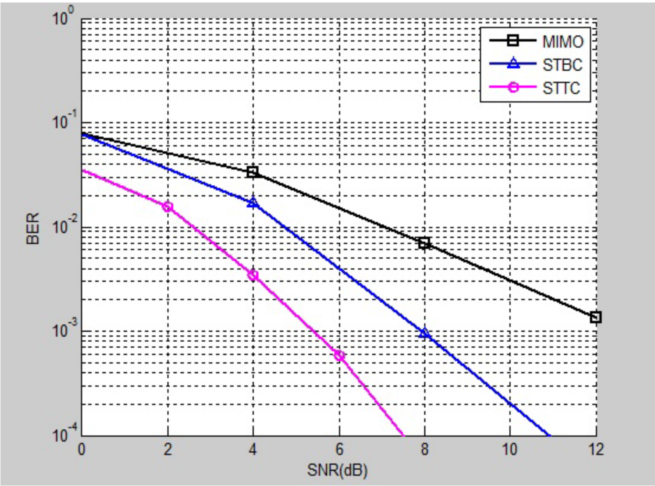


Fig 12BER versus SNR for 2*2 MIMO with and without STC

versus SNR. **Figure (12)** shows The BER of MIMO without STC, MIMO with STBC technique, and MIMO with STTC, it was seen that the BER for MIMO could be decreased by using with STBC and farther decreased using STTC.

Figure (13) shows The BER of STTC without neural network and STTC with neural network. It was seen that the neural network decrease the BER by 54.16%.

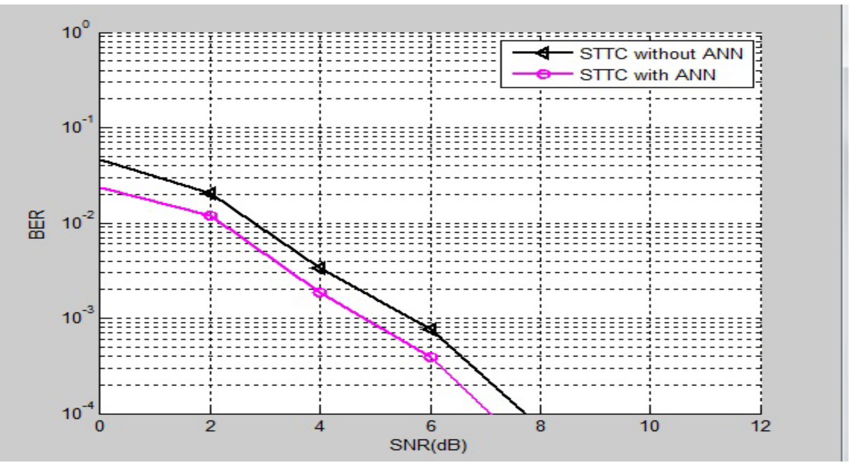


Fig 16 BER versus SNR for STTC with and without ANN

8. Conclusion:

The capacity of MIMO system can be increased if the channel state information is known at the transmitter, and assigned extra power at the transmitter by allocating the power according to the water filling algorithms to all the channels. BER decreases from 0.0355 to 0.006373 at (8dB) SNR by using multiple antennas at the transmitter and receiver, as compared with SISO communication system, which means that the improvement by using MIMO technique is (82.05%). It is found that, minimum BER can be obtained by using STTC with MIMO, as compared with uncoded MIMO, and MIMO with STBC. The BER at (8dB) SNR for MIMO system and is 0.006373, for MIMO with STBC is 0.001364, and for MIMO with STTC is 0.00055; therefore, the performance of MIMO system is improved by using STTC by (91.37%). The use of artificial neural network leads to BER improvement, so that BER is decreases from 0.00072 for estimated STTC MIMO system to 0.00033 for STTC MIMO system with ANN, therefore the improvement of this case is 54.16%.

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