Design and Implementation of Distributed Space-Frequency to Achieve Cooperative Diversity in Wireless Relay Networks

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Abstract

Recently, there has been much interest in modulation techniques that can help in achieving transmit diversity motivated by the increased capacity of multiple-input multiple- output (MIMO) channel. To achieve transmit diversity the transmitter needs to be equipped with multiple antennas. The antennas should be well separated to have uncorrelated fading among the different antennas. This results in higher diversity orders and higher coding gains. However, achieving transmit diversity for mobile units requires cooperative diversity. In this context, the space-time codes (STC) for spread spectrum CDMA systems have received great interest in recent times. The schemes presented in this paper ensure that the limitations of conventional correlation receivers are overcome. The effect of the space-time code distribution on the space-time code that achieves full diversity with maximum coding gain over MIMO channels is studied in this paper. In most of the analogous works surveyed so far, it is observed, that, there has been very little focus on the study of systems that exhibit diversity of all the three forms namely: source coding diversity, channel coding diversity and user cooperation diversity. However, in this paper, all these three forms of diversity are uniformly considered and the proposed schemes are studied for their robustness and performance. It is shown, that, the proposed space-time coded communication scheme is both bandwidth and power efficient. To analyze the proposed scheme fully, communication over fading channels is considered. The maximum-likelihood decision metric is used to decode the original information in the presence of channel estimation errors. A study of the performance of the proposed STC system in the presence of slowly changing Rayleigh channels is also presented.

Keywords: Multipath fading, Communication systems, Distributed Space-time codes, Wireless relay networks, Signal Processing, Multinode Cooperative communication, multiple sensor detection systems

1. Introduction

Cooperative diversity can provide a new dimension over which higher diversity orders can be achieved. In this research work, the design of efficient schemes and protocols that can facilitate several terminals to cooperate via forwarding each other's data is proposed. The proposed schemes can increase the system reliability by achieving spatial cooperative diversity. The focus of this research work is to identify and devise schemes that can help to tackle the problem of how to achieve and where to exploit diversity in cooperative networks.

A spread-spectrum scheme typically consists of the following signal transmission and reception stages.

1. A pseudo-random code that is different for each channel and each successive connection.
2. The information data which modulates the pseudo-random code (i.e. the data is "spread").
3. The resulting signal that modulates a carrier.
4. The modulated carrier is amplified and broadcast.
5. The carrier is received and amplified.
6. The received signal is mixed with a local carrier to recover the spread digital signal.

7. The receiver acquires the received code and phase locks its own code to it.

8. The received signal is correlated with the generated code, extracting the information data.

The design of Distributed Space Time Code (DSTC) can mitigate the relay nodes synchronization errors. However, most of the previous works on cooperative transmission assume perfect synchronization between the relay nodes. This implies that the relays' timings, carrier frequencies, and propagation delays are identical. But, perfect synchronization is difficult to achieve among randomly located relay nodes. The process of acquiring the timing information of the transmitted spread spectrum signal is essential to the implementation of any form of spread spectrum technique. In figures 1 and 2, the importance of phase synchronization between the transmitted signal (assuming no noise case) and the locally generated carrier (PN code) is illustrated. The de-spreader output for case (i) equals the data input, whereas, for case (ii) the de-spreader output is another random sequence. This is due to the reason that, perfect phase synchronization is achieved only in case (i).

Rapid growth in mobile computing and other wireless multimedia services is inspiring many research and development activities on high-speed wireless communication systems. Main challenges in this area include the development of efficient coding and modulation signal processing techniques to improve the quality and spectral efficiency of wireless systems. The recently emerged space-time coding and signal processing techniques for wireless communication systems employing multiple transmit and receive antennas offer a powerful paradigm for meeting these challenges. This chapter provides an overview on the recent use of space-time coding and signal processing techniques for multiple-input multiple-output (MIMO) communication systems. A review of the information theoretic results on the capacities of wireless systems employing multiple transmit and receive antennas is presented. Coding and signal processing techniques for wireless systems employing multiple transmit and receive antennas are also briefly touched upon.

The proposed work considers the antenna array used by the space-time code to comprise of antennas of several geographically separated base stations (i.e. multiple antennas) and hence is more practical. In the first phase of this paper, the performance of an existing DS-CDMA scheme is studied in the presence of channel noise and interference. In the second phase, a block-coded Space-time coding scheme is designed and using a maximum likelihood decision metric at the receiver the decoding is achieved. Block space-time-codes are considered to reduce algorithmic complexity. A slow fading Rayleigh channel noise is considered in the simulation study. A major beneficiary of this paper could be in the field of wireless sensor networks. The concepts presented shall assist in using some of the relay nodes instead of some of the sensor nodes that are less-informative to the fusion center. These relay nodes can relay the information for the other more informative sensor nodes. Allowing some relay nodes to forward the measurements of the more-informative sensors will increase the reliability of these measurements at the expense of sending fewer measurements to the fusion center. This will create a tradeoff between the number of measurements sent to the fusion center and the reliability of the more-informative measurements.

2. Two Antenna System

If two transmit antennas are spread out geographically, the Rayleigh fading becomes uncorrelated spatially because there is enough separation between the transmit antennas. Furthermore, it can be assumed that the fading is temporally quasi-static in the sense that, there is no correlation between two consecutive channel gains.

Since the mobile station has different distances from each transmit antenna on the downlink, the mean received signal power at the mobile station is not the same for all paths. One can normalize the distance between the mobile station and the nearest base station to unity such that all the other distances are greater than unity.

Consider the simple case where there are two base stations as shown in figure 3. The normalized distances are found using

$$d_{1,n} = \frac{d_1}{d_r}$$

$$d_{2,n} = \frac{d_2}{d_r}$$

where d_r is the reference distance, which is the distance from the mobile station to the closest base station, and $d_{1,n}$ and $d_{2,n}$ are the normalized distances. Suppose $d_1 < d_2$ and thus $d_r = d_1$, so we can normalize $d_{1,n}$ to be 1 and $d_{2,n}$ is d_2/d_r. The received signal power is inversely proportional to the distance, so the mean SNR at each receiver becomes

$$\Gamma_1 = (E_S / N_0) \quad (d_{1,n})^{-n}$$

$$\Gamma_2 = (E_S / N_0) \quad (d_{2,n})^{-n}$$

where n is the path loss exponent. For free space, n = 2, and for perfect ground reflection, n = 4. However, field tests have shown that the path loss exponent is in practice in the range $2 \le n \le 4$. Thus, n=3 was chosen in this work during simulation. This can be extended to a typical edge-excited cellular system with 3 transmit antennas located on the edges of the cell.

If the transmit antennas are placed in the same location, then the fading is highly correlated spatially, and the simulated system performance is not satisfactory even with block STC.

3. Two-Branch Transmit Diversity With One Receiver

shows the base-band representation of the new two-branch transmit diversity scheme. The scheme uses two transmit antennas and one receive antenna and may be defined by the following three functions:

The encoding and transmission sequence of information symbols at the transmitter;

The combining scheme at the receiver;

The decision rule for maximum likelihood detection.

At a given symbol period, two signals are simultaneously transmitted from the two antennas. The signal transmitted from the antenna zero is denoted by $\mathbf{s_0}$ and from antenna one by $\mathbf{s_1}$. During the next symbol period signal ($-s_1^*$) is transmitted from antenna zero, and signal s_0^* is transmitted from antenna one where * is the complex conjugate operation.

The encoding is done in space and time (space-time coding). The encoding, however, can also be done in space and frequency. Instead of two adjacent symbol periods, two adjacent carriers may be used (space-frequency coding).

The channel at time t can be modeled by a complex multiplicative distortion $h_0(t)$ for transmit antenna zero and $h_1(t)$ for transmit antenna one. Assuming that fading is constant across two consecutive symbols, the values of $h_i(t)$ can be written as,

$$h_0(t) = h_0(t + T) = h_0 = \alpha_0 e^{j\theta 0}$$

$$h_1(t) = h_1(t + T) = h_1 = \alpha_1 e^{j\theta 1}$$

where T is the symbol duration. The received signals can then be expressed as

$$r_0 = r(t) \quad = \quad h_0 s_0 + h_1 s_1 + n_0$$

$$r_1 = r(t+T) \quad = \quad {}^*h_0 s_1{}^* + h_1 s_0 + n_1$$

where r_0 and r_1 are the received signals at time t and t + T and n_0 and n_1 are complex random variables representing receiver noise and interference.

4.The Combining Scheme

The combiner shown in figure 4 builds the following two combined signals that are sent to the maximum likelihood detector:

$$\widetilde{So}=h_o{}^*r_o+h_1r_1{}^*$$

$$\widetilde{S1}=h_o{}^*r_o-h_1r_1{}^*$$

It is important to note that this combining scheme is different from MRRC. the combiner output is expressed as

$$\widetilde{So}=(\alpha_o{}^2+\alpha_1{}^2)s_o+h_o{}^*n_o+h_1n_1{}^*$$

$$\widetilde{So}=(\alpha_o{}^2-\alpha_1{}^2)s_1-h_o{}^*n_1+h_1n_o{}^*$$

4.1 The Maximum Likelihood Decision Rule

These combined signals are then sent to the maximum likelihood detector which, for each of the signals s_0 and s_1, uses the decision rule for BPSK signals.

The combined signals are equivalent to that obtained from two-branch MRRC. The only difference is the presence of phase rotations on the noise components which do not degrade the effective SNR. Therefore, the resulting diversity order from the new two-branch transmit diversity scheme with one receiver is equal to that of two-branch MRRC.

5. The Proposed Algorithm

Maximum likelihood decoding of any space-time block can be achieved using only linear processing at the receiver. The maximum likelihood decision amounts to minimizing the decision metric

$$\sum_{j=1}^{m}(|r_1{}^j-\alpha_{1,j}\ s_1-\alpha_{2,j}\ s_2|^2+|r_2{}^j-\alpha_{1,j}\ s_2\alpha_{2,j}s_1{}^*\ |^2)$$

over all possible values of s_1 and s_2. Note that due to the quasi-static nature of the channel, the path gains are constant over two transmissions. The minimizing values are the receiver estimates of s_1 and s_2, respectively. When the above metric is expanded and the terms that are independent of the code words are deleted then the above minimization is equivalent to minimizing.

$$\sum_{j=1}^{m}\ [r_1^j\ \propto_{1,j}^*\ s_1^*+(r_1^j)^*\ \propto_{1,j}^*\ \ s_1+r_1^j\ \propto_{2,j}^*\ s_2^*+(r_1^j)^*\ \propto_{2,j}^*\ \ s_2-\ r_2^j\ \propto_{1,j}^*\ s_2$$

$$-(r_2^j)^*\ \propto_{1,j}^*\ s_2^*+r_2^j\ \propto_{2,j}^*\ s_1+(r_2^j)^*\ \propto_{2,j}^*\ s_1^*]+(|s_1|^2+|s_2|^2)\sum_{j=1}^{m}\sum_{i=1}^{2}|\propto_{i,j}|^2$$

The above metric decomposes into two parts, one of which

$$-\sum_{j=1}^{m}[r_1^j\ \propto_{1,j}^*\ s_1^*+(r_1^j)^*\ \propto_{1,j}^*\ s_1+r_2^j\ \propto_{2,j}^*\ s_1\ +(r_2^j)^*\ \propto_{2,j}^*\ s_1^*\ ]+|s_1|^2\ \sum_{j=1}^{m}\sum_{i=1}^{2}|\alpha_{i,j}|^2$$

$$-\sum_{j=1}^{m}[(r_1^j)^*\ \propto_{2,j}^*\ s_2-(r_2^j)^*\ \propto_{1,j}^*\ s_2^*]-r_2^j\ \propto_{2,j}^*\ s_2+(r_2^j)^*\ \propto_{2,j}^*\ s_2^*+|s_2|^2\sum_{j=1}^{m}\ \sum_{i=1}^{2}|\propto_{i,j}|^2$$

is only a function of s_2. Thus the minimization is equivalent to minimizing these two parts separately. This in turn is equivalent to minimizing the decision matrix

$$|(\sum_{j=1}^{m}(\bar{r}_1^j\ \propto_{1,j}^*-(r_2^j)^*\propto_{2,j})]-s_1|^2+(-1+\sum_{j=1}^{m}\ \sum_{i=1}^{2}|\propto_{i,j}|^2\ )\ |s_1|^2$$

for detecting s_1 and the decision metric

$$\left| \left(\sum_{j=1}^{m} (r_1^j \propto_{2,j}^* - (r_2^j)^* \propto_{1,j}) \right] - s_2 \right|^2 + \left(-1 + \sum_{j=1}^{m} \sum_{i=1}^{2} |\propto_{i,j}|^2 \right) |s_1|^2$$

for detecting s_2.

This is a simple decoding scheme and there is no performance sacrifice for achieving it.

6. DS-CDMA Implementation

The proposed DS-CDMA scheme is shown in figure 5. The user data from the cell network is modulated using a pseudo-random code. In order to protect signal, the code used is pseudo-random. It appears random, but is actually deterministic, so that the receiver can reconstruct the code for synchronous detection. This pseudo-random code is called pseudo-noise (PN). The digital data is directly coded at a much higher frequency. The authenticated receiver knows how to generate the same code, and correlates the received signal with that code to extract the data.

The Monte- Carlo simulation model used to study the performance of the proposed scheme is shown in figure 6. Different strengths of interference (represented as A in the plot) are considered and the probability of error is obtained for varying values of signal to noise ratio.

The performance curves Monte-Carlo simulation model used for the simulation study of the proposed scheme are shown in figure 7.

7. Space-Time Codes For Cooperative Diversity

Space-time coding of CDMA signals offer increased bandwidth and bit rate [10]. A linear block code is employed in this work. The generator matrix (for the block codes) chosen for the two user data is

genmat1= [1 0 0 1 1 0;0 1 0 0 1 1;0 0 1 1 0 1] and

genmat2= [1 0 0 0 1 1;0 1 0 1 0 1;0 0 1 1 1 0].

The results obtained by using the proposed algorithms are discussed in this section. Figure 8 to 12 show the transmitted two user data, received data with noise, the demodulated and de-spread data for the case of two transmit antenna and one receive antenna. Similarly figure 8 and 9 shows the probability of detection of error obtained versus signal to noise ratio for a two-sensor network over wireless fading channels.

The performance curve i.e. Probability of error Vs SNR plot is shown in figure 13. The curve shows a significant improvement with very less Probability of error even at low SNRs.

8. Conclusion

The primary objective of present day's mobile technologies is to enhance the data rate on multi-path fading channels. A convincing solution introduced in this research work to achieve this is the use of multiple antennas in transmission. This thesis report new design schemes for transmitters and receivers of coded modulations over multiple antenna channels. The objective is to achieve near Shannon capacity performance over ergodic channels and near outage probability performance over block fading channels. Iterative joint detection and decoding are applied in the aim of achieving near maximum likelihood performance. Whenever the wireless channel does not experience a large amount of coupled delay and angle spread the algorithms proposed in this work can assist in producing a good improvement in performance with less complex topology. It has been shown in this thesis that coding across both spatial and temporal domains together achieves a diversity order equal to the product of the number of transmit and receive antennas.

The proposed work is the development of architecture for secure communication in mobile wireless networks. The problem of deploying relay nodes in sensor networks is well considered in this work. A system consisting of a set of sensor nodes communicating to a fusion center, where decisions are made, is considered. As some sensor nodes provide "less-informative" measurements to the fusion center, effective means of assigning the system resources allocated for these sensors to relay nodes to forward the measurements of the other "more-informative" sensor nodes is considered in this thesis. This introduces a new tradeoff in the system design between the number of measurements sent to the fusion center and the reliability of the more-informative measurements, which is enhanced by deploying more relay nodes in the network.

The approach divides the network into clusters and implements a decentralized certification authority. Decentralization is achieved using threshold cryptography and a network secret that is distributed over a number of nodes. While this basic idea has been proposed earlier partially, its application on clustered network is a novelty of the work. The work address issues of authorization, access control and a multilevel security model and helps to adapt to the complexity of mobile end systems. It also effectively counteracts the denial of service (DoS) threats and hence, can prolong the life time and improve robustness of wireless sensor network. To check the validity of algorithms proposed in this thesis, different test inputs are given and the results are analyzed. The algorithm was validated with uniform distribution of nodes and also random distributions like Gaussian, Poisson, Rayleigh and Exponential. Studies related to energy spent in transmission and reception to discover the given topology using the proposed algorithm is done along with throughput fluctuations. Results obtained show that the schemes proposed in this work, result in significant dependability improvement for a wireless sensor network.

The proposed work shall enable a wireless sensor network to consume extremely low power, operate in high volumetric densities and be dispensable. It is ideally suited to most of the applications that share similar features such as difficult to access because of geographical location where the network has been deployed, the large scale of deployment, high mobility and prone to failure. It also ensures that the wireless sensor network be autonomous and operate unattended, be adaptive to the environment and choose an optimal number of communicating sensing nodes since too many sensors can generate bottlenecks in the communication infrastructure when they all compete for bandwidth.

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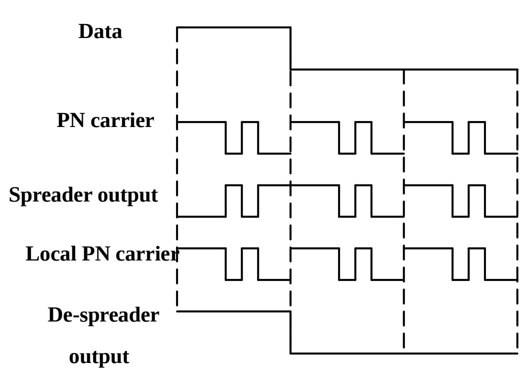


Fig 1 : Phase synchronization is perfect

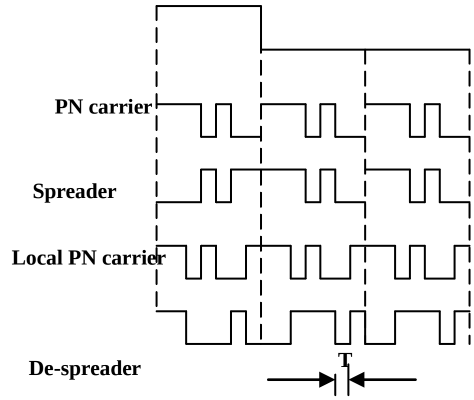


Fig 2 : Phase error due to one bit offset

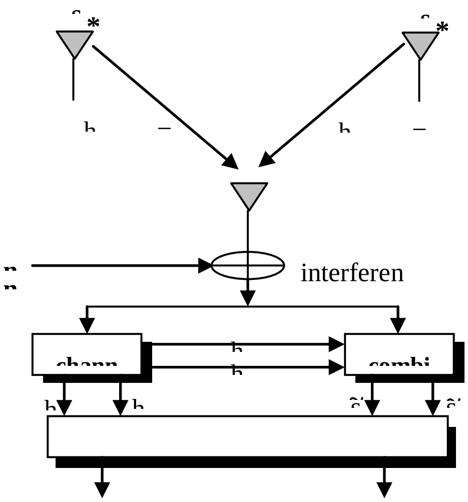
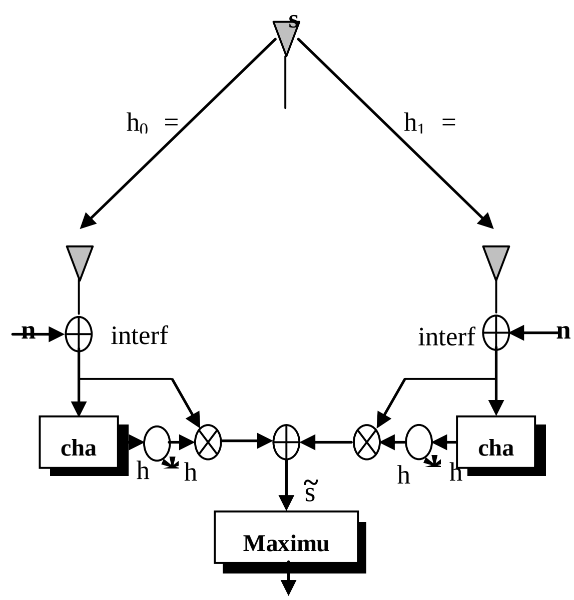


Fig 3 The new two-branch transmit diversity scheme with one receiver



Two-branch MRRCV The Proposed Algorithm

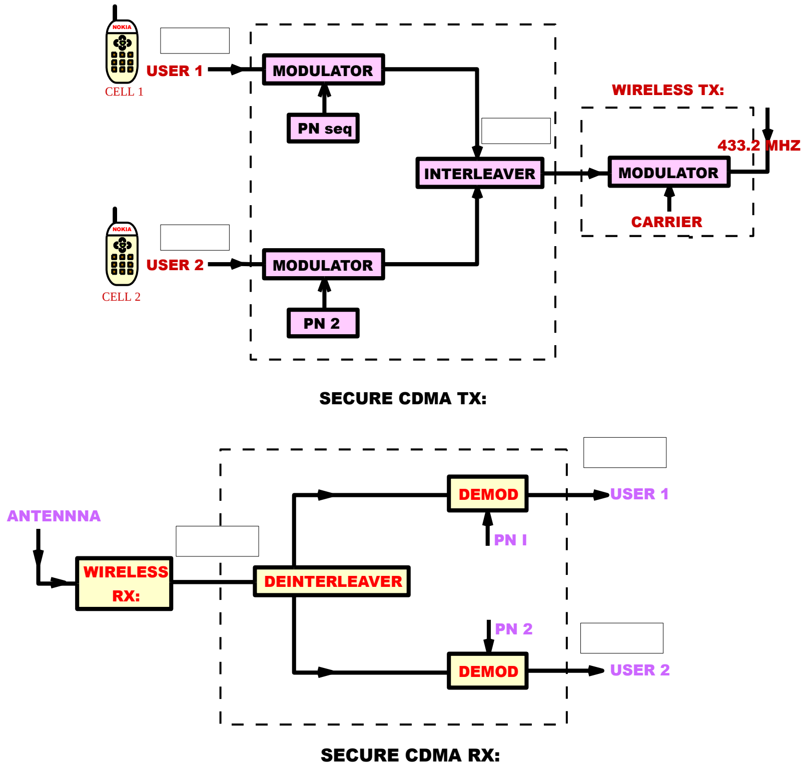


Fig 5 : Proposed real-time implementation of the CDMA Tx: and Rx

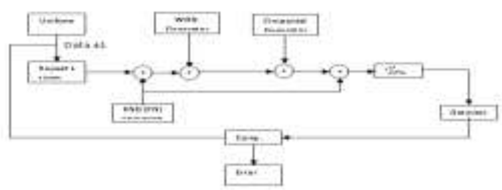


Fig 6 : Monte-Carlo simulation model used for the simulation study of the proposed scheme

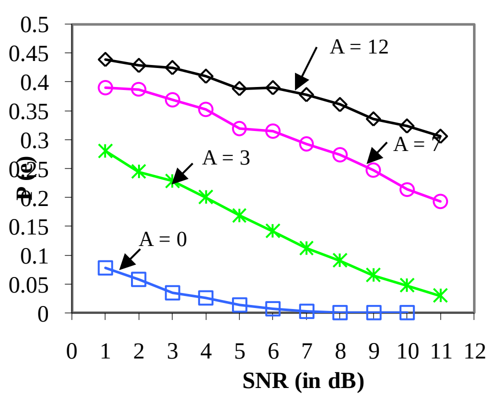


Fig7 : Performance graph for the Proposed CDMA

OBSERVATION PLOTS

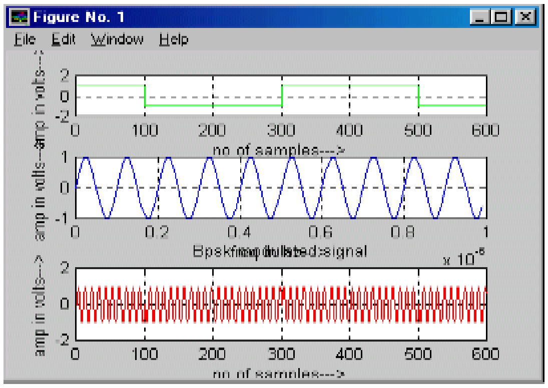


Fig 8 BPSK modulated data of user 1 generated by antenna 1

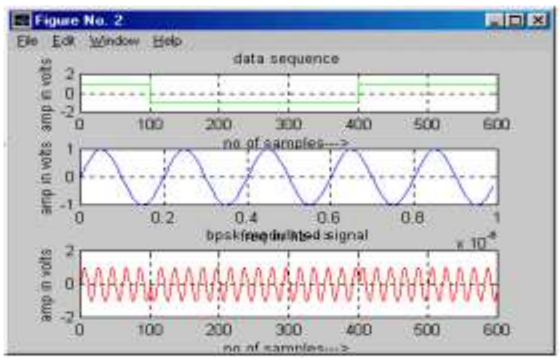


Fig 9 BPSK modulated data of user 2 generated by antenna 2

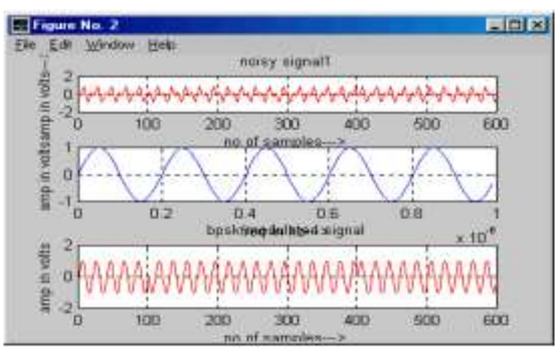


Fig 10 Space-time coded received signal with noise (obtained with 2 transmit and 1 receive antenna)

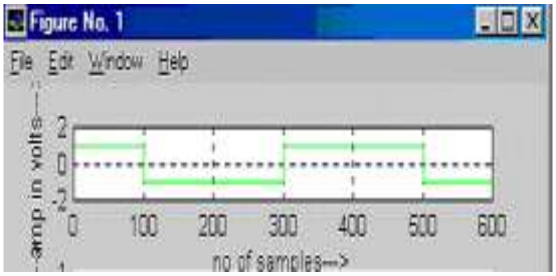


Fig 11 Demodulated data 1

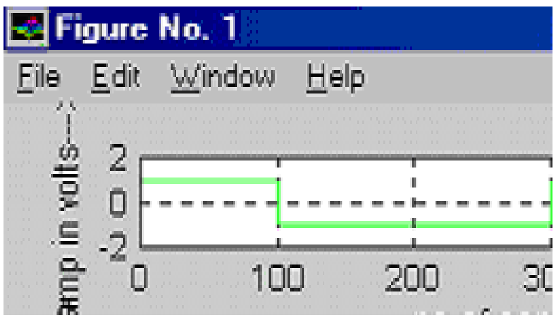


Fig 12 demodulated data2

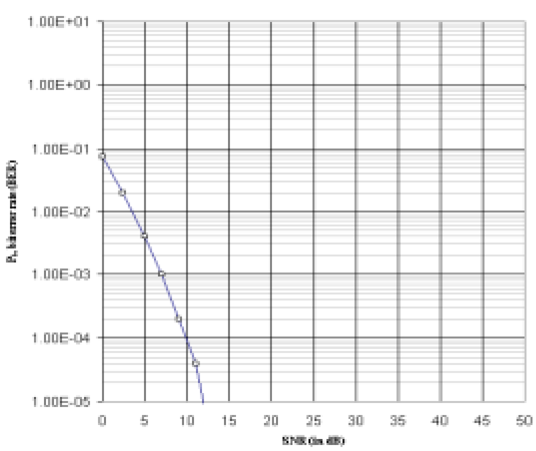


Fig 13. Performance graph for the proposed Scheme