d-STC for Dual Polarized MIMO Transmission in the Hybrid Mobile Satellite System

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***Abstract*— Satellite networks has gained substantial research interest, owing to its wide range of capabilities such as lightning speed, vast coverage area, broadcast and multicasting functionalities. In this work, the dynamic Space-Time Coding (d-STC) is adopted for the dual polarized MIMO transmission in the hybrid mobile satellite system. MIMO and OFDM significantly improve the data rate and the efficiency of data transmission respectively. In case of d-STC, two different variants of ST code such as combination of STB and Trellis code and Linear dispersion code are utilised alternately, with respect to a specific time interval. This process boosts up the code and diversity gain. Besides this, this work consumes lesser energy and thus reliable communication is guaranteed.**

Keyword- d-STC, Space Time Code, MIMO, OFDM

I. INTRODUCTION

Satellite networks has gained substantial research interest, owing to its wide range of capabilities such as lightning speed, vast coverage area, broadcast and multicasting functionalities. However, there are several challenges associated with satellite networks and some of them are high complexity, expensiveness and fading with respect to high frequency range. In order to mange these challenges, satellite systems can be clubbed with the terrestrial systems, such that the advantages of both these systems are inherited to the hybrid system. The terrestrial system is economical with high bandwidth.

ITU defines the hybrid of satellite and terrestrial system by the incorporation of satellite and terrestrial components which are interconnected to each other, however they operate independently. This kind of system has separate network management systems and do not operate on the same frequency band. The major advantages of the hybrid of satellite and terrestrial networks are wider area coverage, cost effectiveness and improved quality of service and service availability etc.,

A hybrid broadcasting system consists of satellite and terrestrial components which ensure high quality of service at all time. The satellite signal can offer wider coverage area, whereas the terrestrial signal can ensure continuous service even when the user terminal is out of reach from the satellite signal. Terrestrial components are the antennas for Multi Input Multi Output (MIMO) transmission, so as to ensure path diversity. These components significantly improve the link reliability and multiplexing gain [1-3]. Figure 1 presents all the components employed in the proposed work.

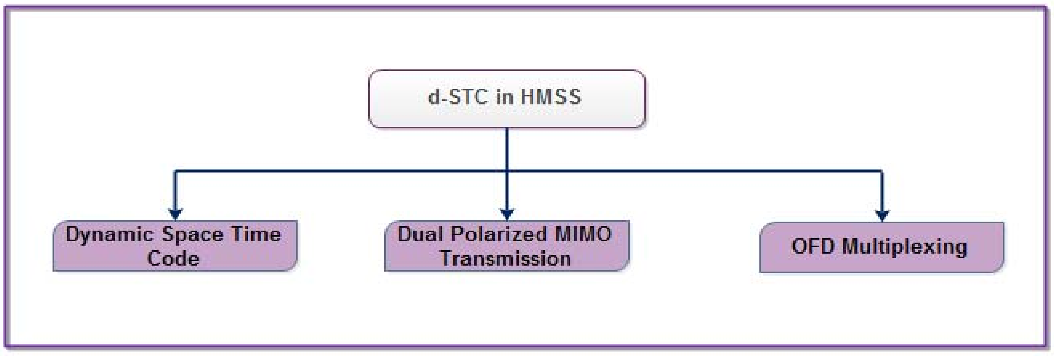

Fig.1. Techniques incorporated in the proposed work

In [4], the MIMO transmission is clubbed with the dual polarization, in order to maximize the polarization diversity and the capacity of the system. When comes to multiplexing, Orthogonal Frequency Division Multiplexing (OFDM) is beneficial with respect to great bandwidth efficiency and fairly robust towards Inter Symbol Interference (ISI).

In this paper, the dynamic Space-Time Coding (d-STC) is adopted for the dual polarization MIMO transmission in the hybrid mobile satellite system. The reason for the employment of d-STC is that the minimal energy requirement for transmission. The d-STC consumes lesser energy by the avoidance of forwarding the erroneous signals. On the other hand, maximum diversity gain is achieved along with reliable transmission. MIMO is incorporated to improve the path diversity. OFDM ensures enhanced bandwidth efficiency and robustness.

The remainder of this paper is compartmentalized as follows. The related literature is reviewed in section 2. Section 3 is loaded with the proposed methodology and the performance of the proposed work is evaluated in the section 4. Finally, the concluding remarks are presented in section 5.

II. Review of Literature

This section intends to review several related solutions in the literature and are presented below. In [5], a scheme is presented to improve the coding gain by separating the sub-carriers. This work employs dual polarization MIMO for every component and the Full Rate Full Diversity (FRFD) codes are utilized by the incorporation of Space-Frequency code.

The terrestrial mobile satellite channel specifications are presented in [6], which is then followed by the proposal of a MIMO scheme between the antennas of satellite and terrestrial system. Besides this, a Layered Space-Time Block Code (LSTBC) for NGH broadcasting systems is proposed. The layered approach is followed, so as to focus on the shadowing regions also.

In [7], a novel semi-adaptive beamformer is proposed for a hybrid terrestrial satellite mobile system. A dual form of beamforming is proposed in this work, so as to enable adaptive and non-adaptive processing for co-existence by means of a ground gradient based switch mechanism. The system performance of this work is good.

The potentiality of dual polarization per beam is studied against single polarization per beam for mobile satellite broadcasting systems in [4]. The performance of the system is checked between single polarization SISO and dual polarization MIMO. Several cooperative transmission techniques for hybrid satellite and terrestrial systems are investigated in [8]. Several service scenarios are presented with layered coding methodologies in hybrid satellite system.

The capability of hybrid satellite and terrestrial systems with MIMO transmission are presented in [9]. The performance of the MIMO schemes is compared by carrying out several simulations. In [10], a three stage iterative turbo beamforming algorithm is presented for an OFDM based hybrid terrestrial satellite mobile system. The data subcarriers are exploited as virtual reference signals in the beamforming process.

In [11], certain schemes for dual satellites distributed MIMO scheme are studied with respect to delay tolerance and spectral efficiency. Additionally, MIMO schemes are applied in hybrid satellite-terrestrial system and the outcomes are verified. A new Space-Time Block Code (STBC) is proposed for the distributed 4×2 MIMO systems in [12]. This technique is simulated in Rayleigh channel and the performance of this work is better with minimal decoding complexity.

In [13], the Symbol Error Probability (SEP) performance of hybrid satellite terrestrial cooperative network is investigated. Specifically, the mobile relays that forward the satellite signal to masked mobile destination is considered. This work exploits the Selective Decode and Forward transmission and the relay nodes, which can effectively decode the satellite messages, are picked up to carry out retransmission. The performance of this work is better.

A review of several MIMO based techniques for satellite communications is discussed in [14]. This review focuses on mobile and fixed satellites. In [15], the performance of golden code is evaluated over a dual polarized MIMO-OFDM transmission based hybrid of satellite and terrestrial system.

Motivated by these works, this paper strives to present a system with minimal mean phase error and bit error rate. The proposed work is presented in the forthcoming section.

III. Proposed Methodology

This paper intends to present a dual polarized MIMO-OFDM transmission based integrated satellite and terrestrial networks. The general architecture of integrated satellite and terrestrial networks is depicted in fig. 2.

A. *MIMO-OFDM*

MIMO and OFDM are incorporated into the system, in order to improve the data rate and transmission efficiency. The main purpose of MIMO is to accept multiple inputs and provide multiple outputs, which substantially improves the data rate.

On the other hand, OFDM is a multiplexing scheme that follows the principle of orthogonality for carrying out the conversion between the frequency selective channel and flat fading channels. The information is transmitted simultaneously with the help of multi-carriers through the communication channel. This significantly improves the data rate and efficient bandwidth can also be achieved.

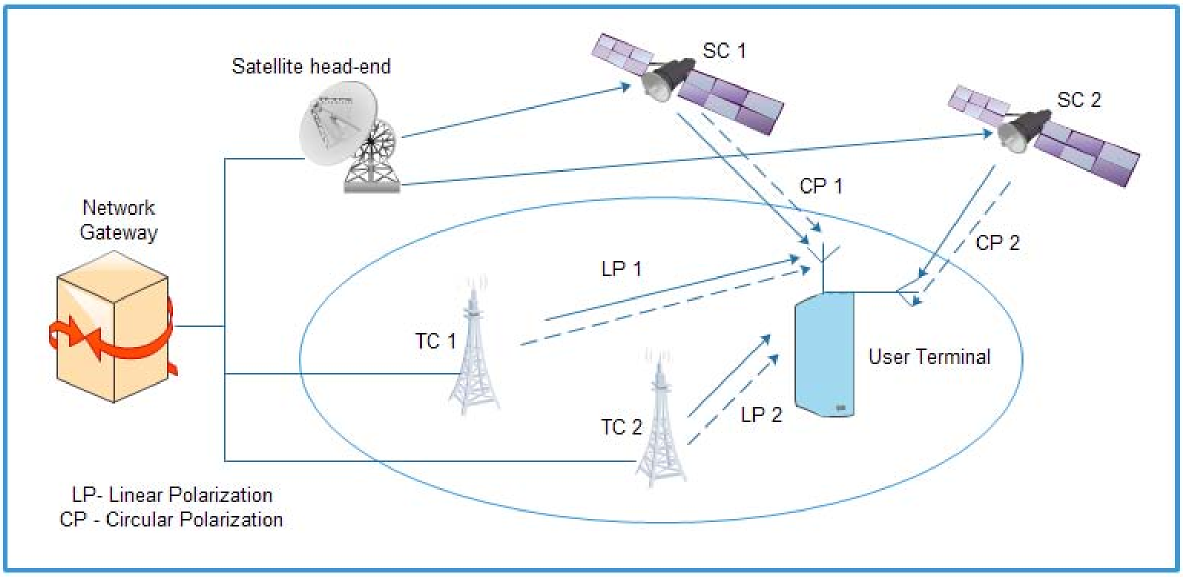

Fig.2. Architecture of integrated satellite and terrestrial networks

The OFDM modulation can be achieved by using IFFT. OFDM utilizes guard interval for eliminating Inter-Symbol Interference (ISI) which may occur because of multi-path fading. This guard interval preserves the signal in such a way that the signals do not interfere with each other and remain perfect.

At the receiving end, a frequency domain equalizer is employed to manage channel distortion that hit the scene because of the sub-carrier. OFDM decomposes the frequency selective channels into narrowband channels and (Inverse Fast Fourier Transform) IFFT has to be carried out.

B. Dynamic Space-Time Code

Dynamic space-time code maps the data with respect to the space and time dimensions with time variance. The transmitter side produces a stream of data and performs carry out space-time code in dynamic fashion.

In this work, the term d-STC refers to the incorporation of two varieties of space-time code. They are the combination of Space Time Block Code and Trellis code and Delay-Tolerant Linear Dispersion Code. These two flavours of Space-Time codes are employed in the proposed work.

Both these Space-Time codes are utilized in an alternative fashion with respect to a time interval. The first flavour of ST code provides coding and diversity gain. On the other hand, the second flavour of ST code provides diversity gain and increased data rate as well. Thus, the proposed work ensures code and diversity gain with maximum data rate.

1) Combination of Space Time Block and Trellis Code: The first flavour of d-ST code is the combination of STB and Trellis code, which guarantees high code and diversity gain. Let the transmission matrix be

$$T(x_1, x_2) = \begin{pmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{pmatrix} \quad (1)$$

The possible 2×2 orthogonal transmission matrices are

$$\begin{pmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{pmatrix} \begin{pmatrix} -x_1 & x_2 \\ x_2^* & x_1^* \end{pmatrix} \begin{pmatrix} x_1 & -x_2 \\ x_2^* & x_1^* \end{pmatrix} \begin{pmatrix} x_1 & x_2 \\ x_2^* & -x_1^* \end{pmatrix} \quad (2)$$
$$\begin{pmatrix} -x_1 & -x_2 \\ x_2^* & -x_1^* \end{pmatrix} \begin{pmatrix} -x_1 & x_2 \\ -x_2^* & -x_1^* \end{pmatrix} \begin{pmatrix} x_1 & -x_2 \\ -x_2^* & -x_1^* \end{pmatrix} \begin{pmatrix} -x_1 & -x_2 \\ -x_2^* & x_1^* \end{pmatrix}$$

A possible set of present Space Time Block code items are widened by means of rotation, but the orthogonality is maintained. All the eight possible transmission matrices are utilised in this system. A set partitioning operation is performed for efficient naming of the trellis, at last. The outcome of the trellis is mapped to the transmitting antennas. This model proves better performance with maximum code and diversity gain.

2) Linear Dispersion Code: In this type of code, the transmitter forwards the data streams in linear fashion over space and time. This code maximizes the data rate and diversity gain. This can be given by the following formula.

$$x = x\left(a_1 = p_1 + kq_1, \dots, a_J = p_J + kq_J\right) = \sum_{j=1}^{J}(p_J P_J + k\, q_J Q_J) \quad (3)$$

In the above equation, $a_J = p_J + kq_J$ is a signal which is selected from the Phase Shift Keying (PSK) or QPSK. P_J and Q_J are complex spreading matrices. The J signals are transmitted in T continuous time instances. The systematic diagram for the proposed work is depicted in figure 3.

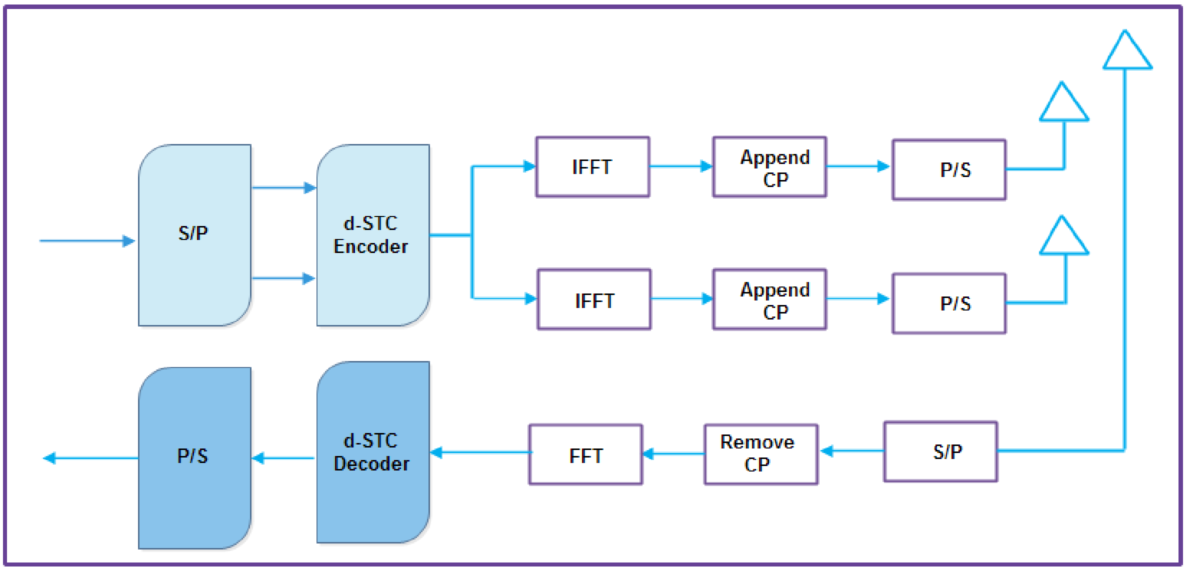

Fig.3. Systematic flow diagram

3) Transmitter: The transmitter utilises a dual polarized antenna, so as to forward the OFDM signal with n number of sub-carriers on each polarization. The transmitter end is responsible for dividing frames, serial to parallel conversion, modulation, IFFT bins, IFFT, cyclic prefix extension and parallel to serial conversion. The overall flow of the system is presented in figure 3.

The data to be transmitted is divided into frames and then converted from serial to parallel fashion. This is followed by the process of modulation and IFFT bins required are computed. IFFT is then performed and the data is transformed per symbol at a time. The time-domain samples of a symbol are transmitted. The cyclic prefix is then appended to avoid distortion.

4) Representation of Channel: A standard block fading scheme is denoted by 2×2 channel matrix. Let the satellite and terrestrial repeater for a dual polarized transmission be T_s and T_t. The channel matrix T_m of a Rician MIMO channel is given by

$$T_m = \sqrt{\frac{L_m}{(L_m+1)}}\, Los_m + \sqrt{\frac{1}{(L_m+1)}}\, \widehat{T_m} \; ; m = s, t \quad (4)$$

In the above equation, Los_m is the constant line of sight matrix, $\widehat{T_m}$ is the non line of sight factor and L_m is the Rician factor of the channel.

$$\widehat{T_m} = [A_m^{gd}]^{d/2}\, T_{u,m} [A_m^{bd}]^{1/2} \; ; m = s, t \quad (5)$$

A_m^{gd} and A_m^{bd} are technically same. Mostly, the satellite and terrestrial transmission experience a reflective delay of s seconds, to reach the user terminal. It is guessed that the satellite communication reaches the user terminal initially, without losing the generality. The channel matrix takes the form of the following.

$$T(s) = \sqrt{\partial_o T_o}\, \Delta(s) + T_w \Delta(s - s_0) \quad (6)$$

In (6), is the generalized delta function and ∂_o is the power imbalance between the satellite and terrestrial components.

5) Receiver End: The OFDM receiver handles the transmitted and the received signals by means of sub-carriers. The receiver end performs the all the operations as that of the transmitter but in vice versa. The receiver end initially performs the operation such as dividing frames, serial to parallel conversion and removal of cyclic prefix. This step is then followed by carrying out Fast Fourier Transform, allocating FFT bins, demodulation and parallel to serial conversion. Finally, inverse mapping is done to obtain the data being transmitted.

C. Case Study

In this section, the overall process of the work is explained. This work is simulated with the help of Matlab. Initially the lena image is passed as input for transmission, by providing the IFFT size, number of carriers, type of modulation, amplitude and Signal-to-Noise ratio. The IFFT size is set as 2048, the number of carriers is chosen as 1009 and the modulation can either be QPSK or PSK. The amplitude is passed as 9 dB and the Signal-to-Noise ratio is given as 12 dB. All the aforementioned parameters can be varied with respect to the user's wish.

This process is then followed by symbol mapping and the transmitter takes the control of the system by dividing the frames, serial to parallel conversion, modulation and IFFT bins. The OFDM carriers on IFFT bins of the passed input image is presented in figure 4 and the phase of the OFDM modulated data is represented by figure 5.

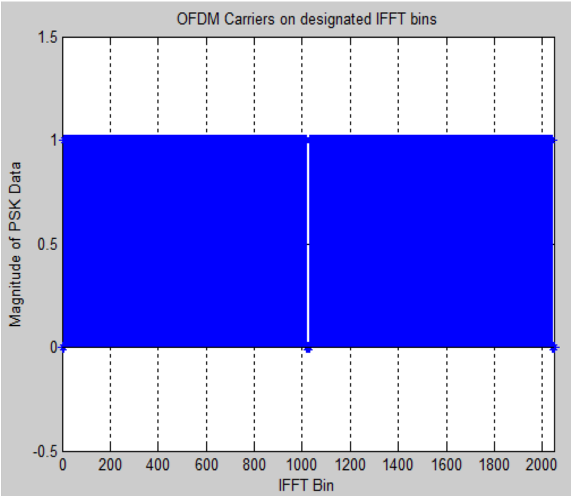

Fig.4. OFDM carriers on IFFT bins

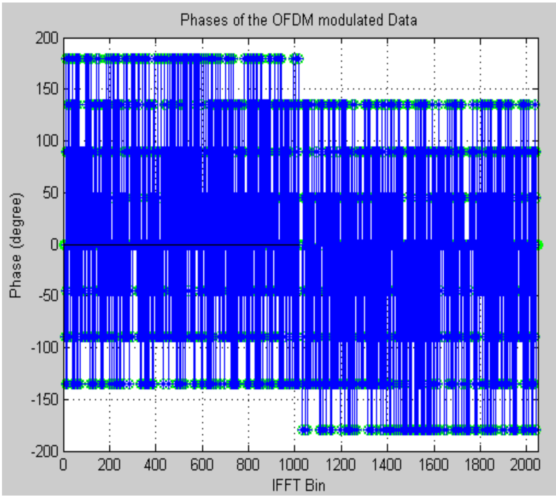

Fig.5. Phases of OFDM modulated data

The system visualises the IFFT by providing a OFDM time signal of a symbol per carrier, which is represented in figure 6 and the samples of OFDM time signals are presented in figure 7.

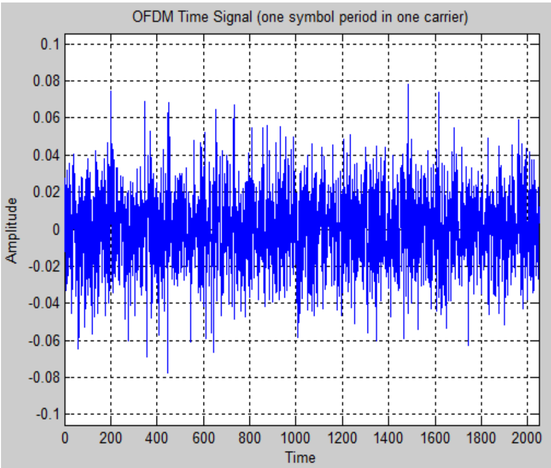

Fig.6. OFDM time signal

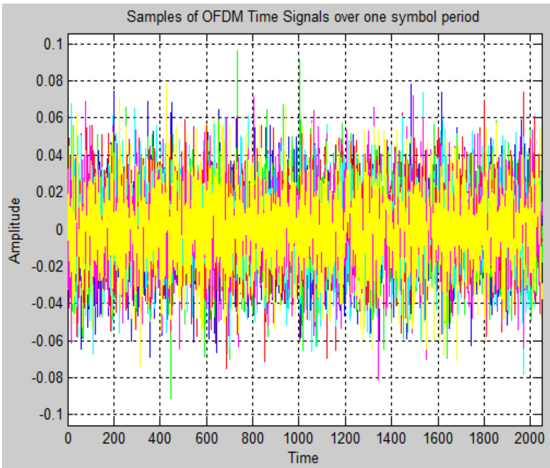

Fig.7. Samples of OFDM time signal

This step is followed by the addition of cyclic prefix and then the process of parallel to serial is carried out and finally, the frames are cascaded. This step is moved on further by the incorporation of communication channel, so as to transmit the data to the receiver.

The receiver performs division of frames, serial to parallel conversion, removal of cyclic prefix and carrying out FFT. While performing FFT, the magnitude of the received OFDM spectrum is provided in figure 8 and the received OFDM spectrum is depicted in figure 9.

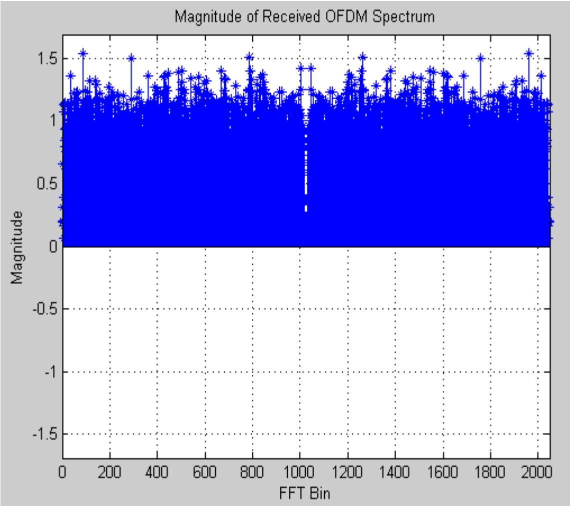

Fig.8. Magnitude of OFDM spectrum

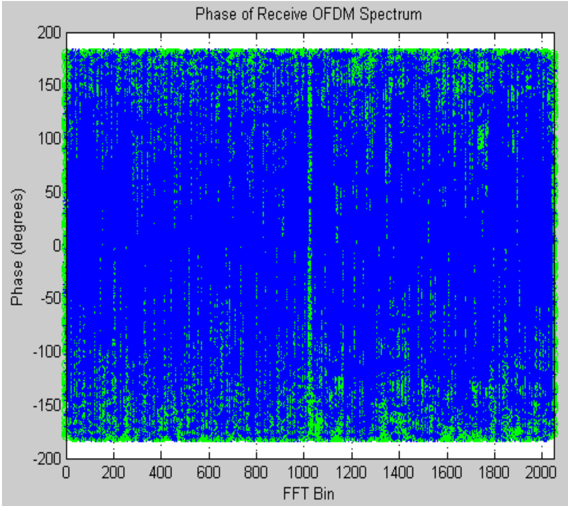

Fig.9. Phase of OFDM spectrum

The phases of received OFDM spectrum with respect to FFT bins are presented in fig.10.

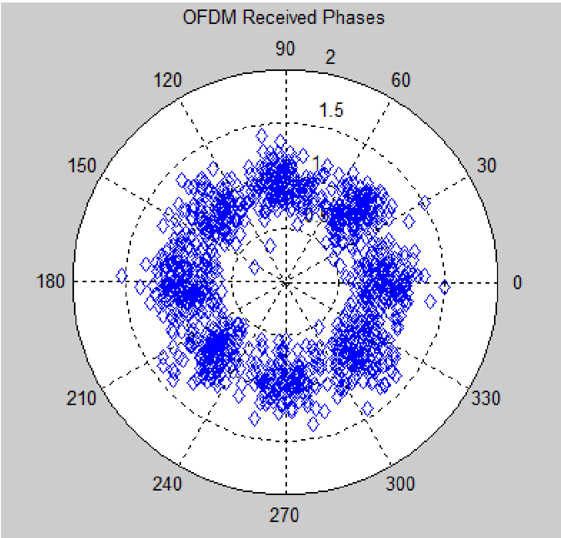

Fig.10. OFDM Phases in FFT

Fig.11. Transmitted data

Fig.12. Received data

This step is followed by the process of demodulation, parallel to serial conversion and frame cascading. Finally, the process of inverse mapping is performed to obtain the transmitted data. The transmitted and the received data is presented in fig.11 and fig.12 respectively. The SNR is passed as 12 dB in the system and so the quality of the image.

IV. PERFORMANCE ANALYSIS

The proposed work is compared with the existing works such as Space-Time code, Golden code [16], Layered Space Time lock Code LSTBC [6] in terms of average phase error, bit error rate, transmitter peak RMS ratio.

Bit Error Rate (BER) is the number of bit errors per unit time. This can the number of bit errors to the total number of bits transmitted, within a period of time. The BER is calculated by eqn.7. The performance of the proposed work is provided in figures 13-15 respectively. The transmitter peak RMS Ratio is calculated by the following formula.

$$BER = \frac{No.of\ errors}{Total\ no.of\ bits\ sent} \tag{7}$$

$$Average\ phase\ error\ =\ 1/M * \sum_{i=1}^{M} original\ signal - received\ signal \tag{8}$$

$$Transmitter\ Peak\ RMS\ =\ 20 * log10\left(\frac{original\ signal - received\ signal}{std(original\ signal - received\ signal)}\right) \tag{9}$$

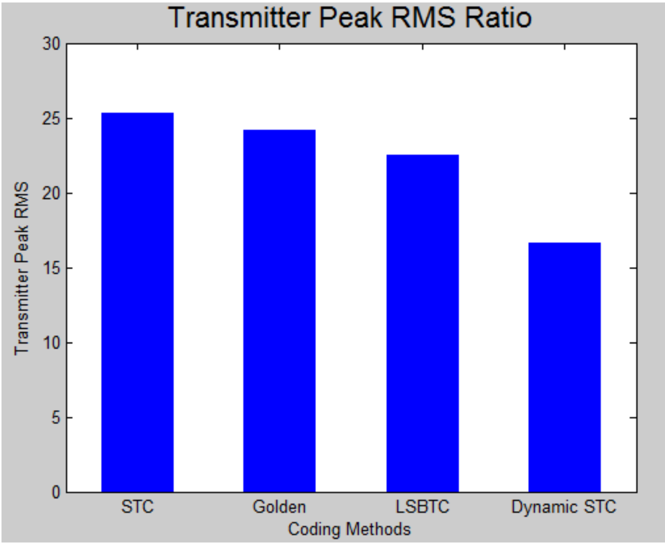

Fig.13. Transmitter Peak RMS Ratio

The reduced transmitter peak RMS ratio shows that this work preserves the energy of the system along with improved communication range and data throughput.

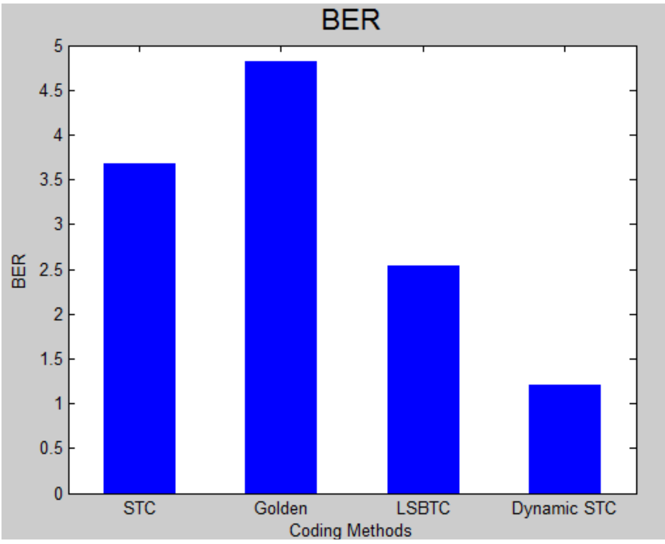

Fig.14. Bit Error Rate analysis

The above graph makes it evident that the BER of the proposed work is minimal, when compared to all the other techniques.

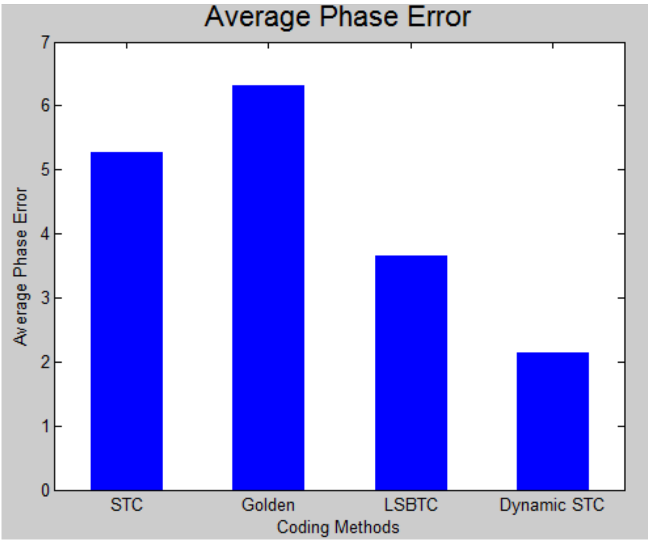

Fig.15. Average Phase Error analysis

From the experimental results, it is proved that the proposed work comes across the least error rate and is shown in the graphs. Thus, the proposed work attains good code and diversity gain and conserves the energy of the system.

V. CONCLUSION

This paper presents a dynamic Space-Time Coding (d-STC) based dual polarized MIMO transmission in the hybrid mobile satellite system. Two different flavours of Space Time Code such as combination of STB and Trellis code and Linear dispersion code are employed alternately, with respect to time. Thus, this is named as dynamic STC. By incorporating d-STC, the system ensures maximum code gain, diversity gain and data rate. As an added advantage, this work conserves energy of the system also. In future, the frequency code can also be taken into account.

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