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Performance of SC-FDMA System with STBC Encoding and TPTS Technique through Rayleigh Fading Channel using BFPFO Algorithm

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Abstract – **Single Carrier- Frequency Division Multiple Access (SC-FDMA) is one of the multiple-access techniques for cellular systems especially when the continuous transmission is required such as in voice or image. It is more efficient than OFDMA. Because of its lower peak-to-average power ratio (PAPR) of SC-FDMA as compared to OFDMA, it is being used in the communication channels. Space-time block codes (STBC) is a coding schemes used to reduce the fading effects in multipath and to increase the strength of the transmitted signal. In this work, an STBC encoded SC-FDMA system is analyzed under Rayleigh fading channel. This work deals with the PAPR and BER reduction in SC-FDMA with STBC 2×1 encoder using a Time-domain Partial Transmit Sequence (TPTS) technique. Bacterial Foraging Phase Factor Optimization (BFPFO) algorithm is used to select the best phase factor for minimum PAPR. This paper also compares various PAPR reduction techniques for SC-FDMA system for PAPR and BER. The results of the original SC-FDMA and STBC encoded SC-FDMA are compared for PAPR and BER.**

Keywords – **Single Carrier-Frequency Division Multiple Access (SC-FDMA), Orthogonal Frequency Division Multiple Access (OFDMA), Partial Transmit Sequence (PTS), Rayleigh Fading channel, Bacterial Foraging Phase Factor Optimization Algorithm (BFPFO).**

I. INTRODUCTION

We can transfer and receive information on the move, anytime and anywhere using Wireless systems. They have opened new dimensions in communications by allowing us to so. Due to interference and fading, these wireless technologies cannot efficiently support high data rates. The data rates can be increased by two methods i.e. either by increasing the transmission bandwidth or by increasing the transmitting power. However, both these parameters (bandwidth and power) are at a premium in wireless systems. Bandwidth of any system is finite and transmitting on higher power adds interference with other systems and reduces the life-time of battery of mobile transmitters.

Moreover, a wireless system is required to accommodate as many users by using "multiple-access" to meet the increasing demands for multimedia applications The multiple access techniques must be able to meet the challenging requirements such as low bit error rate (BER), high output, good robustness, low peak to average power ratio (PAPR), small delays, low complexity, etc.

As cellular applications are affected by fading due to multipath, therefore OFDMA techniques is most commonly used multiple access technique to reduce these effects. *M* orthogonal frequency carriers, each operating at 1/*M* times the bit rate of the information signal are used in OFDMA system to transmit the information. However, OFDMA exhibits high degree of envelope fluctuations leading to high peak-to-average power ratio (PAPR). If the signals have high PAPR then highly linear power amplifiers is required to avoid excessive inter-modulation distortion. To achieve this linearity amplifiers must operate with a large back-off from their peak power. This results in low power efficiency and places a significant burden on portable wireless terminals. Therefore, OFDMA has high transmit peak-to-average power ratio (PAPR), resulting in a lower mean transmit level. Therefore, OFDMA is not suited for the uplink transmission. To obtain this, a new modulation scheme called, Single Carrier FDMA (SC-FDMA) is used. It is also known as discrete Fourier transform (DFT) pre-coded OFDMA, and has been proposed for the uplink in the long term evolution (LTE) standard.

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SC-FDMA is similar to OFDMA except for an added phase called DFT processing. SC-FDMA is ideal in the uplink communication because it has low PAPR value which improves power efficiency and reduces the cost of the power amplifier [4]. The advantage of low peak-to-average power ratio (PAPR) of SC-FDMA makes it a preferred technique for uplink wireless transmission in mobile communication systems.

The increase in fading increases the bit error rate (BER), therefore some kind of channel coding is preferred to boost-up the strength of the transmitted signal and to reduce the fading effects. STBC is one of the channel coding technique in which the number of the transmitted code symbols per time slot is equal to the number of transmit antennas. This achieves diversity gain, coding gain, as well as high spectral efficiency. Space-time coding is used in wireless communication because of its simple decoding algorithm [5]. Here, the data stream to be transmitted is encoded in blocks, and then it is distributed among spaced antennas and across the time. The data of STBC is constructed as a matrix in which its columns represent the number of the transmit antennas and its rows represent the number of the time slots needed to transmit the data. At the receiver, the received signals are first combined and then directed to the maximum likelihood detector where the decision rules are applied [6].

The PAPR is calculated for evaluating the amplification efficiency of the power amplifier. It is defined as the ratio of the peak power value to the average power value during signal transmission.

$$PAPR(dB) = 10\log_{10}\frac{max\{|x(t)|^2\}}{E\{|x(t)|^2\}}, \quad (1)$$

Where $E\{.\}$ is the expected value

A high value of PAPR increases the complexity of D/A converter and reduces the efficiency of the power amplifier [7]. Due to high PAPR there are extreme amplitude fluctuations of the transmitted signal, which causes spectral re-growth in the adjacent channels. If the amplifier is modified to avoid distortions, it increases cost, size and power consumption. The Power Amplifier used in wireless system must have large linear range, as the nonlinearity leads to in-band distortion, which increases the bit-error rate, and out-of-band radiation. This causes operating point to go to the saturation region due to the high PAPR.

Many techniques have been proposed to reduce the value of high PAPR. They are divided into two types: receiver-dependent schemes and receiver-independent schemes. Receiver dependent schemes are those which transmit a PAPR reduction signal including additional information. The transmitted signal can be decoded at the receiver side, using this additional information. Tone Reservation (TR), Selective Mapping (SLM) and Partial Transmit Sequence (PTS) are some of the receiver-dependent schemes. However, receiver-independent schemes transmit a PAPR reduction signal without any side information. Some of the receiver-independent schemes are Clipping and Filtering (CAF) and the Peak Windowing (PW) schemes [8].Among all these, PTS is considered to be one of the best techniques to reduce the PAPR[9][10].

To implement PTS there are two main steps. First, divide the original signal into a number of sub-blocks. Second, add the phase rotated sub-blocks to generate a number of signals to pick the one which have smallest PAPR for transmission [4]. In case of broadcasting PTS has always better performance since pre-coding operation has to be done only once. PTS technique does not affect the system performance. However, it increases the complexity significantly [11]. In the PAPR reduction process, PTS requires lots of IFFTs and needs an extensive search over all the combinations of allowed weighting coefficients, which carries a considerable higher computational load [10]. Therefore, there is need of modified version of PTS technique. We have implemented a PAPR reduction technique for STBC 2 ×1 encoded SC-FDMA systems. Partial transmit sequence (PTS) method needs to transmit the side information (SI) to recover the phase factors at the receiver, some methods introduced the carrier of phase factors instead of SI. This method uses the comb type pilots in OFDM systems, which cannot be applicable for SC-FDMA systems in uplink transmissions. Therefore time domain PTS (TPTS) technique is used here.

This research work is carried out to reduce PAPR and BER in STBC encoded SC-FDMA using PTS technique with BFPFO algorithm.

II. SC-FDMA

In this paper SC-FDMA system with 2×1 antennas is presented and shown in Figure 1. At the transmitter the input data symbol, d is modulated using the baseband modulation scheme QPSK. Then the modulated data symbols are grouped into streams of N= [d0, d1,…, dN-1]T data symbols .N-point FFT is applied to transform these data symbols into the frequency domain. Now these N frequency domain samples are mapped into M subcarriers. Figure.1 shows the block-diagram of SC-FDMA transmitter with two transmitting

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antennas and one receiver antenna.SC-FDMA system is presented here with multiple antennas as the coding technique is used for the fading effects,. Therefore, ready-to-transmit signal, x(t) is transmitted through the two transmitting antennas Tx1 and Tx2. At the receiver end, the inverse operations of the schemes presented to generate the ready-to-transmit signal are applied in order to receive the original data symbols.

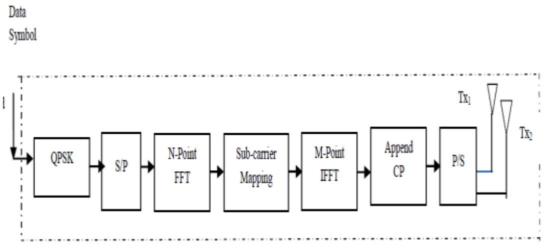

Fig. 1. Original SC-FDMA Transmitter with two antennas

The main advantages of SC-FDMA are listed below:

- Low PAPR.
- Resistant to Multipath fading effects.
- Flexible frequency allocation.

The differences between OFDMA and SC-FDMA are given below as:

OFDMA	**SC-FDMA**
Parallel transmission	Series transmission
Multi-carrier	Single-carrier
High PAPR	Low PAPR

III. STBC

To decrease the fading effects using diversity, the most promising schemes is space-time block coding (STBC). In STBC the number of the transmitted code symbols per time slot is equal to the number of transmit antennas as shown in Figure 2. The three advantages of STBC are simple decoding algorithm, low error probability, and maximum information rate.

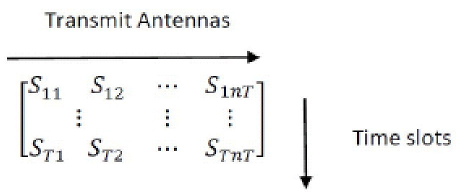

Fig. 2. Representation of space-time block codes (STBC).

Here Sij = modulated symbol which is to be transmitted from antenna "j" in time slot "i".

T= time slots, nT= transmit antennas and nR = receive antennas.

IV. SC-FDMA WITH TPTS TECHNIQUE

To lessen the PAPR of the transmitted signals, PTS method is broadly recognized as the efficient technique. It produces many signals by applying phase factor rotation in every sub-block. Moreover with increasing sub-blocks and phase factor's combinations, computational high complexity of the PTS increases [32]. A time-domain PTS (TPTS) method is implemented in this paper. Figure 3 shows the block representation of the TPTS method for the SC-FDMA system.

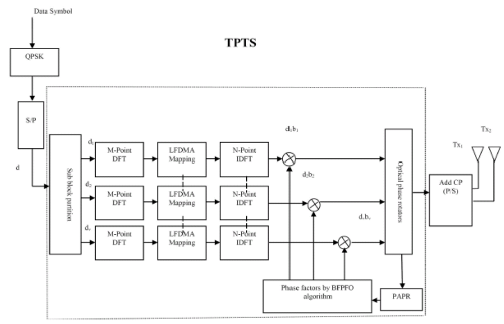

Fig. 3. Representation of SC-FDMA with TPTS.

$$d = \sum_{v=1}^{V} d_v. \quad (2)$$

After the sub-block partition, M-point DFT is applied to every sub-block d_v and these resulting frequency-domain signals are mapped into sub-carriers. Now every sub-block is applied with N-point IDFT to transform into time-domain, and multiplied by the optimized phase factor combinations:

$$b_v \in \{e^{j2\pi(w-1)/W},\ w = 1, 2, \ldots, W\}. \quad (3)$$

After multiplying the phase factors with sub-blocks separately, the transmitting SC-FDMA signal is given by following equation:

$$x(t) = \sum_{v=1}^{V} b_v F_N^{-1} D F_M d_v, \quad (4)$$

Where F_N^{-1} represents the N-point IDFT matrix, D is the subcarrier mapping transform matrix and FM represents the M-point DFT matrix. When the number of sub-blocks (V) and phase factor (W) is increased, the searching complexity of the best phase factor is also increased. For phase factor optimization, our proposed research presents the bacterial foraging phase factor optimization

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(BFPFO) algorithm. Hence, the transmitting signal x(t) is nominated from the one with the lowest PAPR rotated by the best phase factors of BFO:

$$\overline{x(t)} = \arg\min\{PAPR(x(t))\}. \tag{5}$$

V. BFPFO

The Bacterial Foraging Optimization (BFO) algorithm was introduced by E.coli few years ago, which was focused for the numerical optimization and for solving many engineering domain problems [29]. In BFO algorithm, the food foraging strategy of the bacterium is used as the basic concept of searching. The bacterium switches their moving actions (tumbles and swim) to search the positions of the best food among the predefined boundary. Tumble is one unit random walk in any direction, which is taken by the bacterium when they are failed to search the best foods in one swim step. During a swim step of the bacterium, they are free to take any number of tumble steps to complete their single chemo taxis steps. Meanwhile, they reproduce the bacterium with the best food positions by the reproduction and elimination-dispersal steps, which converges the searching ability.

Based on these characteristics of the bacterium, phase factor optimization for the PAPR reduction is implemented. The BFO algorithm is used to optimize the best phase factor b_v from W^{V-1} combinations for V sub-blocks presented in the TPTS technique of SC-FDMA and STBC encoded SC-FDMA systems. The number of sub-blocks are V and allowed phase factor is W. The BFPFO algorithm is used to minimize the fitness function PAPR P(bi) in order to get the best ready-to-transmit signal.

VI. STBC ENCODED SC-FDMA WITH TPTS TECHNIQUE

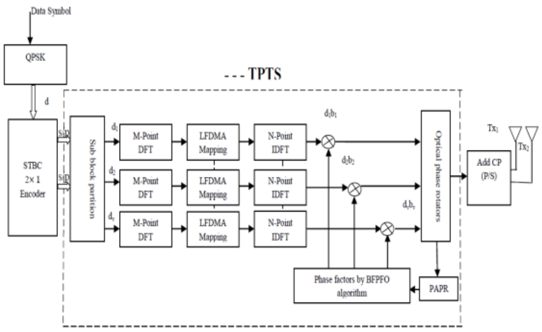

Fig. 4. Representation of STBC encoded SC-FDMA with TPTS.

Figure 4. Represents the STBC encoded SC-FDMA with TPTS technique to describes about the functionalities of the STBC scheme on the SC-FDMA systems and BFO algorithm, which is used in the TPTS technique to reduce the PAPR value as well as BER.

VII. RESULTS AND ANALYSIS

In this section we analyze the performance of TPTS method for PAPR and BER in the SC-FDMA system when STBC encoding is used**.**

Figure.5. shows the CCDF of the PAPR for original SC-FDMA system. PAPR of 8.4 dB is obtained at CCDF of 10^{-4}.

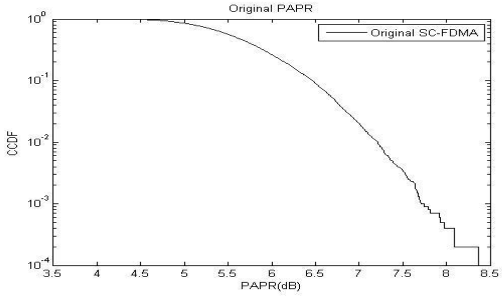

Fig. 5. PAPR Performance of the original SC-FDMA

Figure.6. shows the CCDF of the PAPR for SC-FDMA system with TPTS technique.

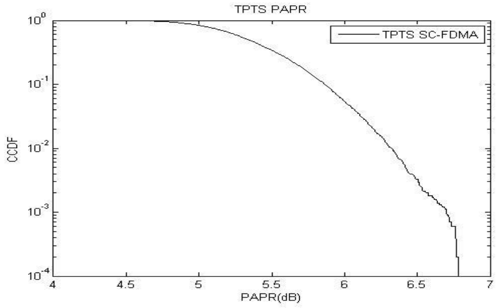

Fig. 6. PAPR Performance of TPTS based SC-FDMA

PAPR of 6.8 dB at CCDF of 10^{-4} shows that a reduction in PAPR is obtained when TPTS is used with SC-FDMA. Figure.7. shows the CCDF of the PAPR for STBC encoded SC-FDMA system with TPTS technique. Obviously, STBC encoded SC-FDMA system with the TPTS technique provide a better PAPR reduction performance.

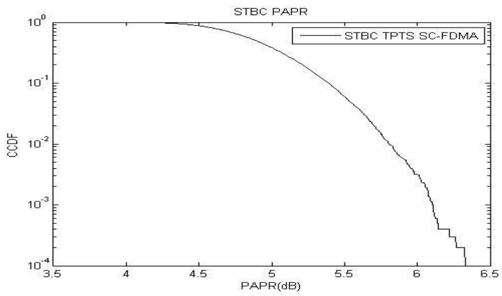

Fig. 7. PAPR of the STBC encoded TPTS based SC-FDMA

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In Figures.8, 9, and 10 the BER performance for all the three systems has been shown. It is observed that for a constant SNR the BER decreases as we use TPTS with SC- FDMA and it further reduces when we apply STBC with TPTS and SC-FDMA.

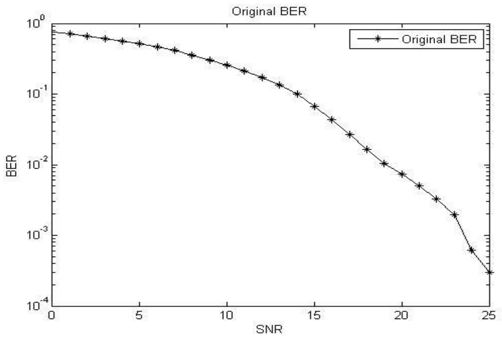

Fig. 8. BER Performance of the Original SC-FDMA

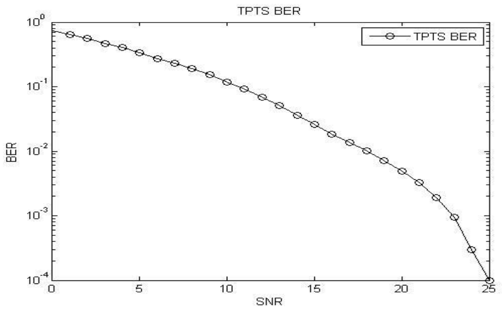

Fig. 9. BER Performance of the TPTS based SC-FDMA

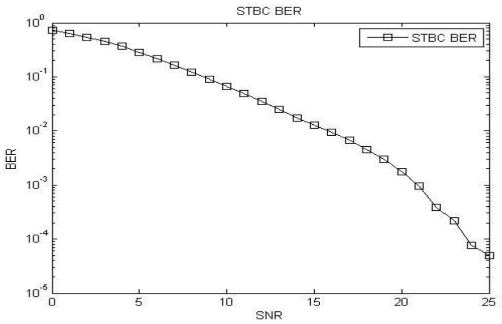

Fig. 10. BER Performance of the STBC encoded TPTS based SC-FDMA

It is observed that PAPR is further reduced when number of sub-block and phase factor increased to V=4 and V=8, which is shown in figure.11, figure.12 and figure.13 respectively. TPTS method with BFPFO algorithm offers the reduction of 0.8 dB at V&W = 4 and 1.65 dB at V&W = 8. When the number of sub-block is increased, PAPR of the TPTS method is decreased.

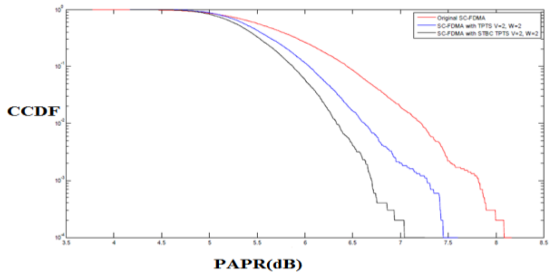

Fig. 11. PAPR Performance of the TPTS SC-FDMA, STBC Encoded TPTS SC-FDMA with Original SC-FDMA for V=2 and W=2

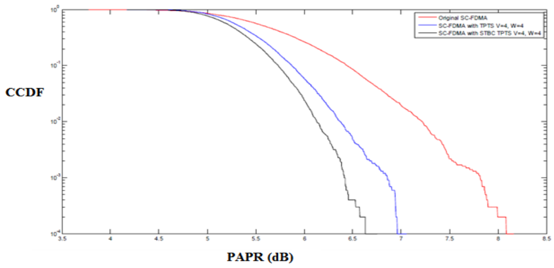

Fig. 12. PAPR Performance of the TPTS SC-FDMA, STBC Encoded TPTS SC-FDMA with Original SC-FDMA for V=4 and W=4

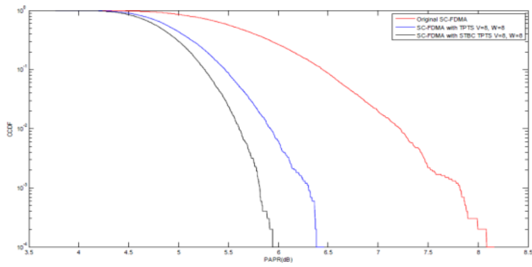

Fig.13. PAPR Performance of the TPTS SC-FDMA, STBC Encoded TPTS SC-FDMA with Original SC-FDMA for V=8 and W=8

VIII. COMPARISON WITH OTHER METHODS

In this section, comparison is made between TPTS based STBC encoded SC-FDMA method with BFPFO algorithm and other methods employed for reducing the PAPR in the SC-FDMA system. The parameters used for this comparison are listed in Table 1.

Table 2. Shows PAPR comparison on the basis of STBC encoding scheme. PAPR of 5.9 dB is obtained using SC-FDMA with STBC and TPTS compared to PAPR of 7.2 dB [5] and 8 dB [14] obtained when STBC alone is applied with SC-FDMA. In each case QPSK modulation was used.

Table 3. Shows the variation of PAPR under Rayleigh fading conditions. Superiority of TPTS with STBC is again brought out showing a PAPR of 5.9 dB which is the least of the other two.

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Table 4. Shows BER comparison for different fading channels. TPTS technique with STBC coding gives the best results.

IX. CONCLUSION

STBC technique has been implemented in the SC-FDMA signals to avoid the effects caused by the fading characteristics. A time-domain PTS (TPTS) method to reduce the PAPR in the STBC encoded SC-FDMA system is presented. In TPTS method, phase factor optimization has been used to select the transmitted signal with the best phase factors as well as to reduce the search complexity of traditional PTS method. Bacterial Foraging Phase Factor Optimization (BFPFO) algorithm is presented to optimize the best phase factor from the W^{V-1} combinations. The results have been presented to evaluate the performances of these methods in terms of PAPR and BER. With the use of the BFPFO-TPTS algorithm, STBC encoded SC-FDMA system offers reduction in PAPR and BER compared to other methods. This work has also reviewed different PAPR reduction techniques for SC-FDMA system. In this work the efficiency of the other methods has also been compared and reviewed with the results of this technique. The comparison based on the different fading channel has also been presented. BER performance has also been compared in this work. From the results, it is evident that the technique of TPTS with BFPFO algorithm in STBC encoded SC-FDMA had achieved a better PAPR and BER performance as compared to other schemes.

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TABLE 1. Parameters used for comparison

Technique	Fading channel	Modulation scheme	Number of transmitter antennas	Number of receiver antennas	Number of subcarriers	STBC Encoded
TPTS based STBC encoded SC-FDMA with BFPFO [30]	Rayleigh	QPSK	2	1	600	Yes
SC-FDMA QO-SFBC [15]	Pedestrian	QPSK	4	2	512	No
SC-FDMA STBC [14]	Rayleigh	QPSK	2	1	512	Yes
SC-FDMA STBC [5]	Pedestrian	QPSK	2	2	600	Yes
Amplitude pre-distortion scheme [17]	Rayleigh	16-QAM	1	1	1024	No
PC-CES technique [7]	AWGN	16-QAM	2	2	512	No

TABLE 2. PAPR comparison in STBC encoding

Technique	Modulation scheme	No. of Tx. antennas	No. of Rx. antennas	Number of subcarriers	CCDF	PAPR (dB)
SC-FDMA STBC [14]	QPSK	2	1	512	10^{-4}	8
SC-FDMA STBC [5]	QPSK	2	2	600	10^{-4}	7.2
TPTS based STBC encoded SC-FDMA with BFPFO [30]	QPSK	2	1	600	10^{-4}	5.9

TABLE 3. PAPR comparison under Rayleigh fading channel

Technique	Fading Channel	CCDF	PAPR (dB)
SC-FDMA STBC [14]	Rayleigh	10^{-4}	8
Amplitude pre-distortion scheme [17]	Rayleigh	10^{-4}	7.0
TPTS based STBC encoded SC-FDMA with BFPFO [30]	Rayleigh	10^{-4}	5.9

TABLE 4. PAPR comparison under different fading channel

Technique	Fading Channel	SNR	BER
SC-FDMA QO-SFBC [15]	Pedestrian	5 dB	0.15
PC-CES technique [7]	AWGN channel	5 dB	0.8
TPTS based STBC encoded SC-FDMA with BFPFO [30]	Rayleigh	5 dB	0.1