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Performance Analysis of a Time Domain-PTS Technique in STBC Encoded SC-FDMA Systems in the Fading Channel

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Abstract: Single Carrier- Frequency Division Multiple Access (SC-FDMA) is one of the multiple-access and a hybrid modulation method primarily for cellular systems especially when the continuous transmission is required such as in voice or image. Since multipath components exist in wireless channels, fading effects are always present in the received signal leading to degradation of the performance. Space-time block codes (STBC) is one of the useful coding schemes to reduce the fading effects in order to boost-up the strength of the transmitted signal. In this paper, an STBC encoded SC-FDMA system is analysed under fading channels. This research analysis deals with the Peak-to-Average Power Ratio (PAPR) reduction in SC-FDMA with STBC 2×1 encoder. Therefore, this paper employs a time-domain Partial Transmit Sequence (TPTS) technique with Bacterial Foraging Phase Factor Optimization (BFPFO) algorithm. The results of the PAPR and BER performances are compared with the original SC-FDMA and STBC encoded SC-FDMA.

Indexed Terms: Single Carrier-Frequency Division Multiple Access (SC-FDMA), Time domain Partial Transmit Sequence (TPTS), Space-time block codes (STBC), Peak-to-Average Power Ratio (PAPR), Bit Error Rate (BER), Fading channels.

I. INTRODUCTION

The term “multiple-access” of wireless communication can be defined as the phenomena of allowing multiple users to simultaneously share the finite bandwidth with least possible degradation in the performance of the system [1][2][3]. Therefore, Frequency Division Multiple Access (FDMA) was introduced to provide an individual allocation of one or several frequency bands, or channel and it is a traditional multiple-access method for cellular systems [4] [5] [6]. In this method, the available bandwidth is partitioned into a number of frequencies /sub-carriers and disseminated among users with a finite portion of bandwidth for stable usage. The frequencies are allocated only when the user demands are increased. The utilization of LTE (Long Term Evolution project) into wireless communication aims to bring the wireless ecosystem. Thus, a new modulation method called single-carrier frequency-division multiple-access (SC-FDMA) was designed for uplink. It has been implemented as the uplink multiple access scheme in 3GPP Long Term Evolution (LTE), or Evolved UTRA (E-UTRA). These are interesting and trendy spells for the reason that it is exceptional that the communications industry rolls out a new modulation method [7].

The performance of SC-FDMA, in relation to OFDMA has been the focused subject of wireless communication studies. Even though the performance of SC-FDMA is not much better

than OFDM, SC-FDMA's additional advantage of low (Peak-to-Average Power Ratio) PAPR makes it a preferred technique especially for uplink wireless transmission in future mobile communication systems where transmitter power efficiency is of paramount importance [8][9]. On the other hand, fading characteristics of wireless communication also degrades the performance of a wireless system. The fading is caused by multipath components in the wireless channel, the fading occurred mainly due to scattering of electromagnetic waves from surfaces or diffraction over and around buildings [10] [11]. The wave propagating through the wireless channel undergo transmit power dissipation (path loss) and shadowing caused by obstacles on the course from transmitter to receiver which attenuates signal power through absorption, reflection, scattering and diffraction.
To reduce the fading effects in a wireless channel, many transmission schemes have been proposed in the literature [12] [13] [14] [15], which utilizes the MIMO channel in different ways, e.g. spatial multiplexing, space-time coding or beamforming etc. Space-time coding (STC)is a promising method; where the number of the transmitted code symbols per timeslot is equal to the number of transmit antennas. These code symbols are generated by the space-time encoder in an effective manner that diversity gain, coding gain, as well as high spectral efficiency are achieved. Space-time coding treasures its application in cellular communications as well as in wireless communication and local area networks. There are various coding methods as space-time trellis codes (STTC), space-time block codes (STBC), space-time turbo trellis codes and layered space-time (LST) codes. Meanwhile, STBC is an efficient transmit diversity scheme to conflict detrimental effects caused by wireless fading channels because of its simple decoding algorithm realizing full diversity at a receiver [16]. Alamouti code is a sophisticated and inspiring STBC method for a two-transmit antenna system [17]. Performances of the STBC method is analyzed in many literatures, which can be found in [18] [19].

However, importance of the PAPR in FDMA/OFDMA system has been studied; many researchers [20] [21] [22] have failed to minimize the PAPR of SC-FDMA system while achieves the good performances such as Bit Error Rate (BER) and Diversity with the use of STBC schemes. In this paper, we propose a PAPR reduction technique for STBC 2×1 Encoded SC-FDMA systems. As the traditional Partial Transmit Sequence (PTS) methods are in need 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 [23]. But this method has used the comb type pilots in OFDM systems, which is not applicable for SC-FDMA systems in uplink transmissions [24]. Therefore, we propose a Time-domain PTS (TPTS) technique with Bacterial Foraging Phase Factor Optimization (BFPFO) algorithm for reduction of PAPR in STBC 2×1 Encoded SC-FDMA systems, without the transmission of SI. As the proposed system is for uplink transmission, TPTS technique utilizes the multi-domain signal processing and the random characteristic of time-domain signal. Alamouti code is employed in the phase of STBC encoding. Simulation results compares the performances of the proposed TPTS technique for 2×1 SC-FDMA and STBC 2×1 Encoded SC-FDMA with original 2×1 SC-FDMA systems.

Furthermore, this paper is structured as follows: In Section II, we present some of the related works of the PAPR reduction methods and time-domain PAPR techniques in SC-FDMA systems. This section also analyzes the influences of the Coding techniques into the SC-FDMA systems. Section III illustrates and explains the functionalities of the SC-FDMA and STBC encoded STBC systems. Section IV explains the detailed procedure of the proposed TPTS for STBC 2×1 Encoded SC-FDMA system. This section also explains the phase factor optimization through the proposed Bacterial Foraging Phase Factor Optimization (BFPFO) algorithm with the flow chart. In Section V, PAPR and BER performances of the proposed TPTS method are analyzed by the graphical representations and finally, this paper is concluded in Section VI.

II. RELATED WORKS

Cristina Ciochina.et al [25], have investigated the performance of Single Carrier Space Time Block Coding (SC-STBC) on SC-FDMA systems. As per their adaptation of SC-FDMA from the possible air interface environment, the other transmits antenna diversity techniques such as STBC and SFBC were incompatible either with the system constraints or with the low envelope variations of SC-FDMA. Zhongding Lei.et al [26], have proposed a class of quasi-orthogonal space-time block codes (Q-STBC) for systems with 2 antennas and 3 time slots. Their proposed codes have achieved the rate one and full diversity with lower complexity maximum likelihood detection. Their design is taken into consideration of the signal power fluctuation and which has minimized the potential PAPR in the transmitted signals. Moreover, they proposed a transmission scheme to realm the good PAPR property of SC-FDMA and iterative decoding algorithms to simplify the receiver complexity.

The authors of [27] have proposed the Boolean Particle Swarm intelligence Optimization (BPSO) to optimize the phase factors of PTS technique. Using this BPSO-PTS technique, they have reduced the PAPR of the STBC encoded MIMO-OFDM. The BER performance of the proposed method was also increased when PTS was applied independently on both the transmitting antennas. Ahmad Mohammad et.al have proposed a time-domain SLM (selective mapping) [28] technique to reduce the PAPR of the SC-FDMA systems. Since Localized Frequency Division Multiple Access (LFDMA) produces higher throughput, their SLM technique was applied into it. Li Wang et.al have proposed the time-domain PAPR reduction technique using PTS [24] for the SC-FDMA systems. This TPTS technique has reduced the PAPR noticeably than the other techniques. These two time-domain reduction techniques have not transmitted any SI to the receivers.

Pochun Yen and Hlaing Minn have proposed a PAPR reduction technique [29] for the carrier aggregated systems by considering both the OFDMA and SC-FDMA. Their proposed method called Multi-symbol selective mapping (MSSLM) has reduced the complexity and removed the signaling overhead. To make the processing requirement easy, they have introduced Partial group selection. Cesar A.et al [30] have derived and implemented a novel pulse shaping filter satisfying the Nyquist-I criterion to reduce the PAPR over a SC-FDMA scheme. The new filter has reduced the PAPR, while maintaining the same excess bandwidth and the zero inter symbol interference condition. The novel filter was designed with a parameter β to minimize PAPR, which was independent from the roll-off factor α. The minimum PAPR of the SC-FDMA scheme was linked to the value given to the parameter β for a specific roll-off factor α.

III. SC-FDMA AND PARTIAL TRANSMIT SEQUENCE

Single Carrier-Frequency Division Multiple Access (SC-FDMA)

This paper considers a SC-FDMA system with 2×1 antennas (M_t transmitting antennas and M_r receiving antennas).At the transmitter the input data symbol, d is modulated using the baseband modulation scheme QPSK based on the channel conditions. Then the modulated data symbols are grouped into streams of $N=[d_0, d_{1,\dots,} d_{N-1}]^T$ data symbols and N-point FFT is applied to

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transform into the frequency domain. These N frequency domain samples are mapped into M subcarriers, where space allocation types can be classified into three types. They are localized FDMA (LFDMA), distributed FDMA (DFDMA), and interleaved FDMA (IFDMA).In the LFDMA mode, the modulated frequency domain symbols are allocated to M adjacent subcarriers. In the DFDMA mode, the symbols are equally spaced across the entire channel bandwidth [31]. Figure.1 shows that the allocation scheme of LFDMA for the data symbols X_n where n=0, 1,…N-1 and M subcarriers, where n = 0, 1, … M-1 and terminal Q = M/N. In the LFDMA mode, the X_n modulation symbols are allocated to the subcarriers as follows: $Y_0 = X_0$, $Y_1 = X_2$ and $Y_{M-1} = X_{N-1}$.After LFDMA subcarrier mapping, M-point IFFT is performed to transform the mapped signal into time domain. At the transmission antenna end, these time-domain signals are ready to transmit when parallel to serial conversion has been applied.

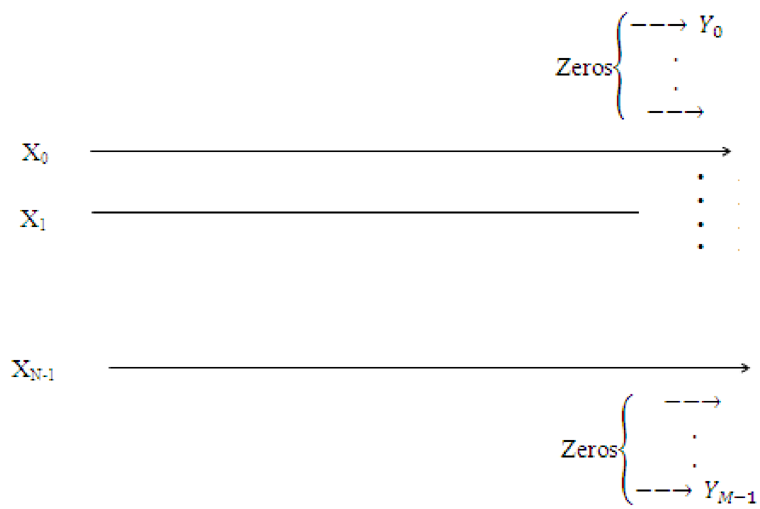

Figure.1. Localized FDMA (LFDMA) Subcarrier Mapping

Figure.2. shows that the block-diagram of SC-FDMA transmitter with two transmitting antennas and one receiver antenna. As this paper focus the coding technique used for the fading effects, SC-FDMA system is presented with multiple antennas. Therefore, ready-to-transmit signal, x(t) is transmitted through the two transmitting antennas T_{x1} andT_{x2}. 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.

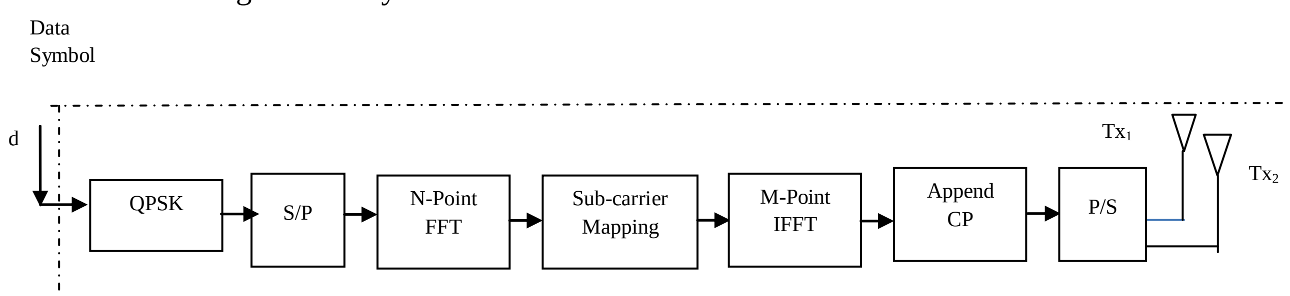

Figure.2. Block Diagram of original SC-FDMA Transmitter with two antennas

The PAPR of the transmitted signal x(t)is defined as the ratio of the square of the peak power magnitude and the average power of the signal, namely

$$\mathrm{PAPR(dB)} = 10\log_{10}\frac{\max\{|x(t)|^2\}}{E\{|x(t)|^2\}}, \text{ where } E\{.\} \text{ is the expected value} \quad (1)$$

SC-FDMA with TPTS Technique

To reduce the PAPR of the transmitted signals, many techniques have been proposed in past literature. Among them, PTS technique is widely accepted as the efficient technique than the other techniques. It produces multiple candidate signals by applying phase factor rotation in every sub-block meanwhile with the increasing of sub-blocks and phase factor's combinations, computational high complexity of the PTS increases. Nevertheless, many of the traditional PTS methods disregard the time-domain spreading property of SC-FDMA signal accordingly, which causes the degradation to the PAPR performance [24]. Therefore, a time-domain PTS (TPTS) method is proposed in this paper. Figure.3 shows that the functionalities of the TPTS technique for the SC-FDMA system, which is also considered as the multiple antenna systems as discussed in figure.2. The traditional PTS [27] [32] [33] [34] and time-domain PTS [24] techniques for PAPR reduction can be studied briefly from the past literatures. Different from the blocks of SC-FDMA in figure.2, d input data symbols are partitioned into V disjoint sub-blocks as follows,

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

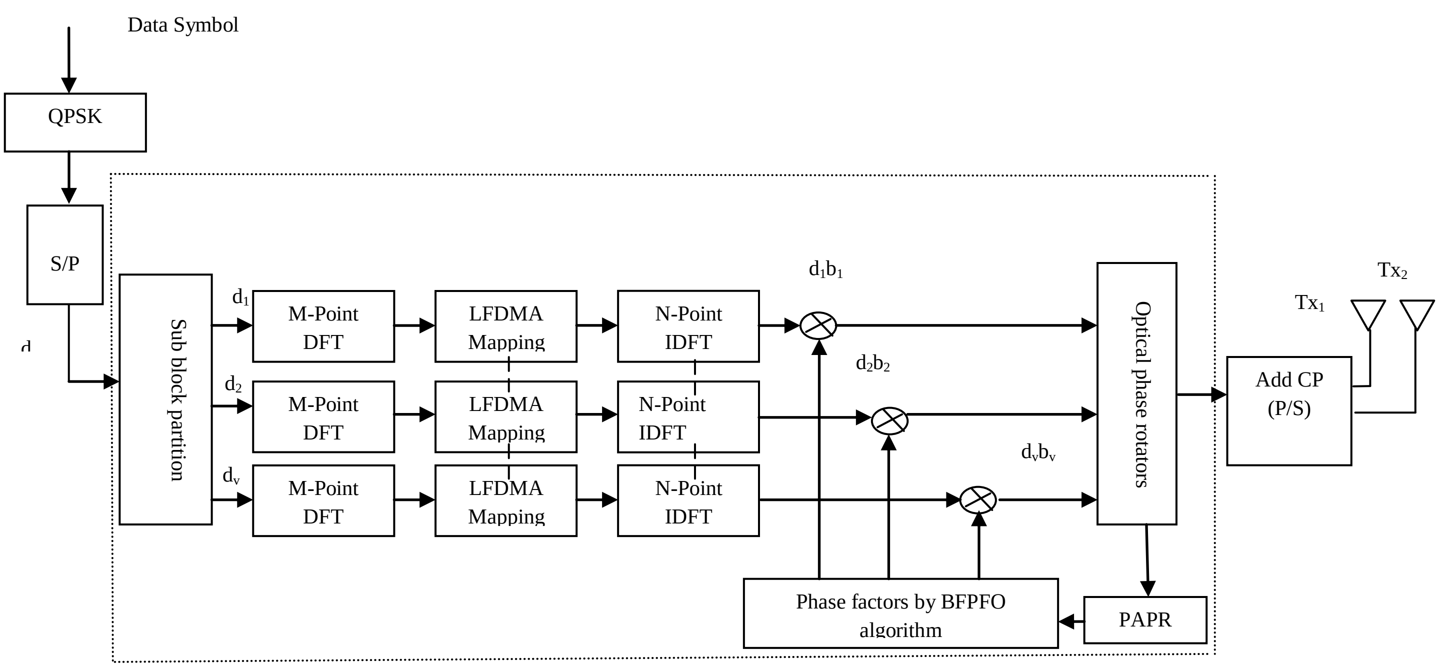

Figure.3. Block Diagram of SC-FDMA Transmitter with TPTS technique

After the sub-block partition, M-point DFT is applied to every sub-blocks, d_v and these resulting frequency-domain signals are mapped into LFDMA sub-carriers. Each sub-block is transformed into time-domain by applying the N-point IDFT, and multiplied by the optimized phase factor combinations.

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

After multiply the phase factors with sub-blocks individually, the transmitting SC-FDMA signal is defined as

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

where F_N^{-1} represents the N-point IDFT matrix, D is the subcarrier mapping transform matrix and F_M represents the M-point DFT matrix. The allowed phase factor combinations W is selected through the different values of π of equation.4. When the number of sub-blocks V and phase factor W is increased, the searching complexity of the best phase factor is also increased. To optimize the best phase factor, this paper presents the Bacterial Foraging Phase Factor Optimization (BFPFO) algorithm, which will be discussed in Section IV. Therefore, the transmitting signal x(t) is selected from the one with the lowest PAPR which are rotated by the best phase factors of BFO.

$$\overline{x(t)} = \text{argmin}\{PAPR(x(t)\} \quad (5)$$

IV. PAPR REDUCTION METHOD FOR STBC ENCODED SD-FDMA

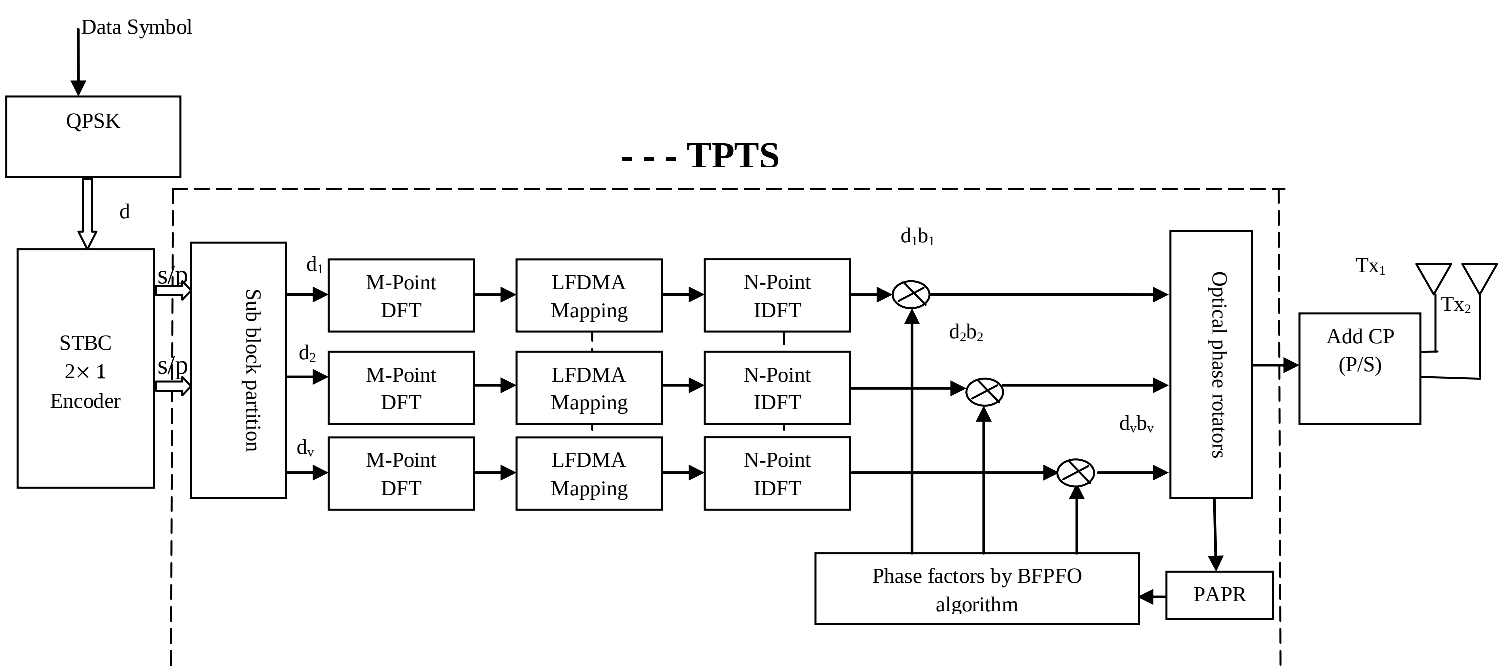

Figure.4. Block Diagram of 2×1 STBC Encoded SC-FDMA Transmitter with TPTS technique

This section 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.

Figure.4. shows the block diagram of the 2×1 STBC encoded SC-FDMA system with the TPTS technique.

STBC Encoded SC-FDMA with TPTS Technique

As mentioned in introduction, coding schemes are one of the best solutions to reduce the fading effects of the transmitted signals. Transmit diversity for SC-FDMA signals can be implement in several ways [25]. In this paper, SC-FDMA signals are combined with the Alamouti precoding scheme, as it is one of the STBC encoding techniques. To apply this precoding scheme, there are three constraints makes a lot of attention. They are

- Precoding should better be applied on pairs of frequency components $(s_k)^i, (s_m)^j$ which practices similar channel realizations in order to obtain optimum performance with a simple maximum ratio combiner.
- Precoding should not degrade the PAPR performance of SC-FDMA signals, whatsoever the number of sub-carriers allocated to a terminal.
- Precoding should be well-matched with practical system restrictions such as frame length.

Table.1. STBC Precoding components on k-th subcarrier

On k-th subcarrier	Time 2j	Time 2j+1
Tx1	$(s_k)^{T\times1,(2j)} = s_k^{(2j)}$	$(s_k)^{T\times1,(2j+1)} = -\left(s_k^{(2j+1)}\right)^*$
Tx2	$(s_k)^{T\times2,(2j)} = s_k^{(2j+1)}$	$(s_k)^{T\times2,(2j+1)} = \left(s_k^{(2j)}\right)^*$

In this paper, precoding involves a pair of frequency components $(s_k)^i, (s_m)^j$ to be sent onto two antennas, Tx1 and Tx2 over two consecutive time intervals, 2j and 2j+1. Table.1. shows that the Alamouti precoding technique performed on the k-th frequency components $s_k^{(2j)}$of DFT output vector s^{2j} at time 2j and s^{2+1j} at time 2^{j+1}. Hence, the precoded components are mapped onto two consecutive SC-FDMA blocks for each subcarrier, and the frequency configuration of the signal from one block to another is not changed. Because complex conjugation and/or sign changes do not affect any degradation in the low PAPR feature, the signals sent on the two transmit antennas are both single-carrier signals. Alamouti precoding techniques can be applied to the time components of SC-FDMA signals on before DFT transformation. However, the TPTS technique used in the SC-FDMA system is also applied into this 2×1 STBC encoded SC-FDMA in order to ensure the PAPR property of the SC-FDMA systems. Moreover, the channel performances improved by using the STBC encoding as well as the PAPR features.

Bacterial Foraging Phase Factor Optimization Algorithm (BFPFO):

Bacterial Foraging Optimization (BFO) algorithm has been introduced by E.coli in recent years, which was mainly focused for the numerical optimization and many engineering domain problems [35]. In BFO algorithm, the basic concept of searching method adopts the food foraging strategy of the bacterium. 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 chemotaxis 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 the aforementioned characteristics of the bacterium, phase factor optimization for the PAPR reduction is implemented. This paper proposes BFO algorithm 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. V is the number of sub-blocks and W is the allowed phase factor, where b_v is varied based on the changes of W and V as shown below.

$$\begin{cases} \text{If W and V} = 2\,, \text{b} = \;+1, -1 \\ \text{If W and V} = 4, \text{b} = +1, -1, +\text{j}, -\text{j} \\ \text{If W and V} = 8, \text{b} = 1, 0.7071 \;+\; 0.7071\text{j}, \text{j}, -0.7071 \;+\; 0.7071\text{j}, \\ -1, -1, -0.7071 \;-\; 0.7071\text{j}, -\text{j}, 0.7071 \;-\; 0.7071\text{j} \end{cases} \tag{6}$$

In the proposed BFPFO algorithm, the food source i.e., the predefined boundary for the bacterium is equivalent to phase factor.

$$\text{b} \;= \{\text{b}_{\text{i}1}, \text{b}_{\text{i}2}, \dots, \text{b}_{\text{i}W^{V-1}}\}, \text{i} = 1,2, \dots, W^{V-1}. \tag{7}$$

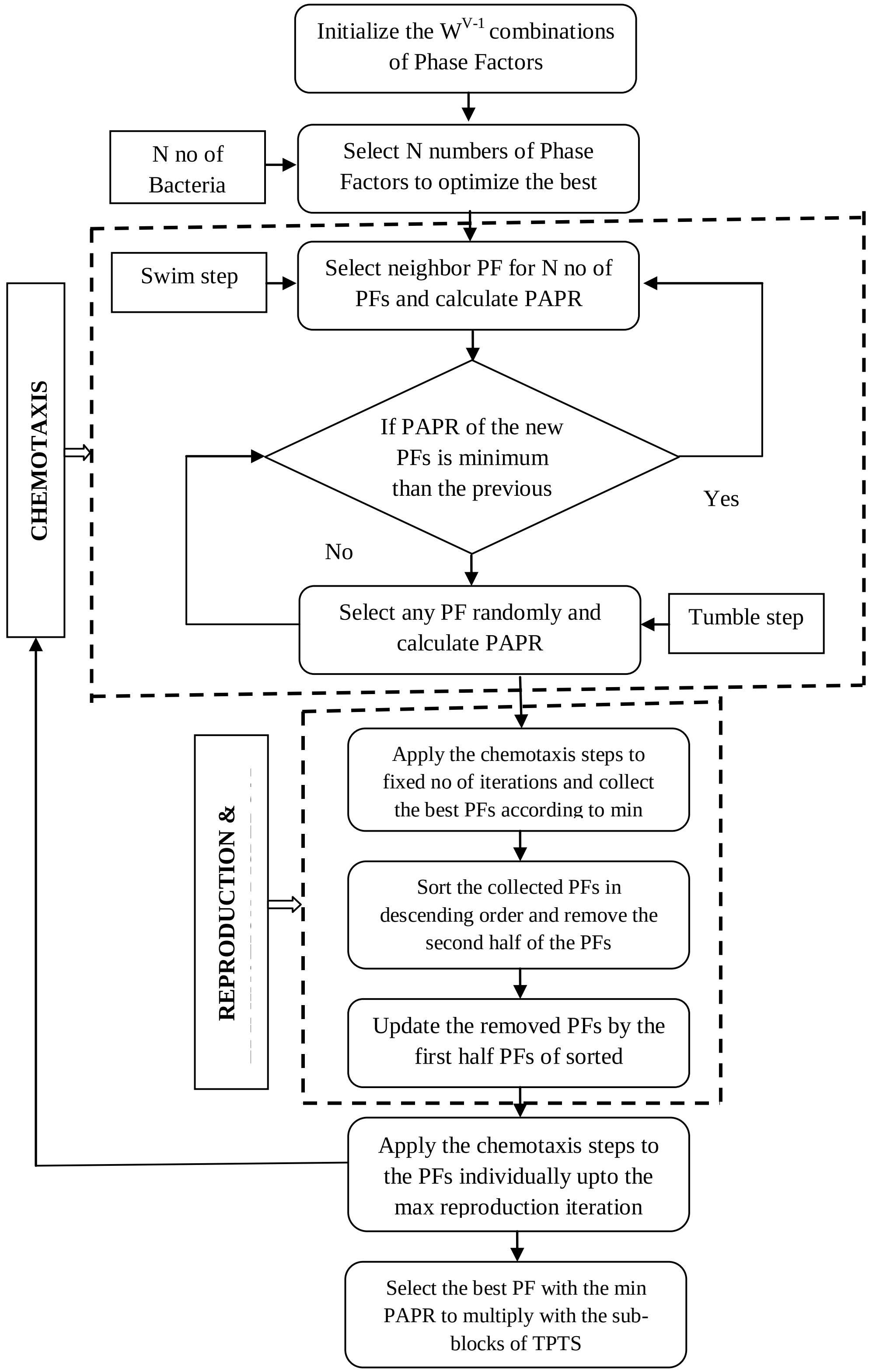

Figure.5. Flow Chart of the proposed BFPFO algorithm for PAPR Reduction in STBC encoded SC-FDMA system

The objective function of the BFPFO algorithm is minimization of the fitness function PAPR $P(b_i)$ in order to get the best ready-to-transmit signal as shown in equation.5., $\overline{x(t)} = \mathrm{argmin}\{PAPR(x(t)\}$ where, b_i is optimized through the steps of the proposed algorithm. The flow of the BFPFO algorithm is depicted in figure.5.

V. RESULTS AND ANALYSIS

In this section, we analyze the performances of the proposed TPTS method with BFPFO algorithm for reduction of PAPR in the SC-FDMA system. The simulation parameters used for the results section are shown in table.2. Moreover, we present the comparison graphs for the original SC-FDMA without any reduction technique and with the TPTS technique in order to evaluate the performance of the STBC encoded SC-FDMA system. The simulation was done using the MATLAB R2012a tool with 10^4 number of input data symbols.

Table.2. Simulation Parameters

Simulation parameters	Type/value
Number of subcarriers	600
Number of sub-blocks (V)	2, 4, 8
Number of antennas	2×1
Modulation Scheme	QPSK
Subcarrier mapping Scheme	LFDMA
Phase Factor (W)	2, 4, 8
System bandwidth	10MHz

Figure.6. shows the complementary cumulative distribution functions (CCDF) of the PAPR for original SC-FDMA system and the PAPR obtained by the TPTS method in SC-FDMA system, the proposed TPTS technique based on the BFPFO algorithm for the STBC encoded SC-FDMA system respectively. With the number of sub-block is V=2, thus there are allowed phase factor combination is W=2 for the TPTS method. When the PAPR of the SC-FDMA is compared with the other original SC-FDMA system, the TPTS method offers 0.7 dB of PAPR reduction at CCDF = 10^{-4}. Meanwhile, the proposed BFPFO algorithm of the STBC encoded SC-FDMA is compared with the original SC-FDMA and TPTS of the SC-FDMA systems respectively. It offers the high reduction of 1.05 dB and 0.35 dB PAPR than the original and TPTS applied SC-FDMA systems respectively. Obviously, STBC encoded SC-FDMA system with the TPTS and BFPFO techniques provide a better PAPR reduction performance.

The variation of number sub-block V=2 to V=4 and V=8 brings the high PAPR reduction, which is shown in figure.7 and figure.8 respectively. TPTS method with BFPFO algorithm offers the reduction of 0.8 dB and 1.65 dB PAPR than the original SC-FDMA system at V&W = 4 and V&W = 8 respectively. When the number of sub-block is increased, PAPR of the TPTS method is decreased noticeably; however, the computational complexity and space complexity is considerable with increasing number of V and W. But the STBC encoded SC-FDMA signals with the proposed TPTS and BFPFO algorithm offers the reduction 0.3 dB and 0.4 dB PAPR than these methods achieved in SC-FDMA signals. Figure.9 and figure.10 shows the individual performances of the proposed method with different number of V and W and it compares the PAPR with the original SC-FDMA system.

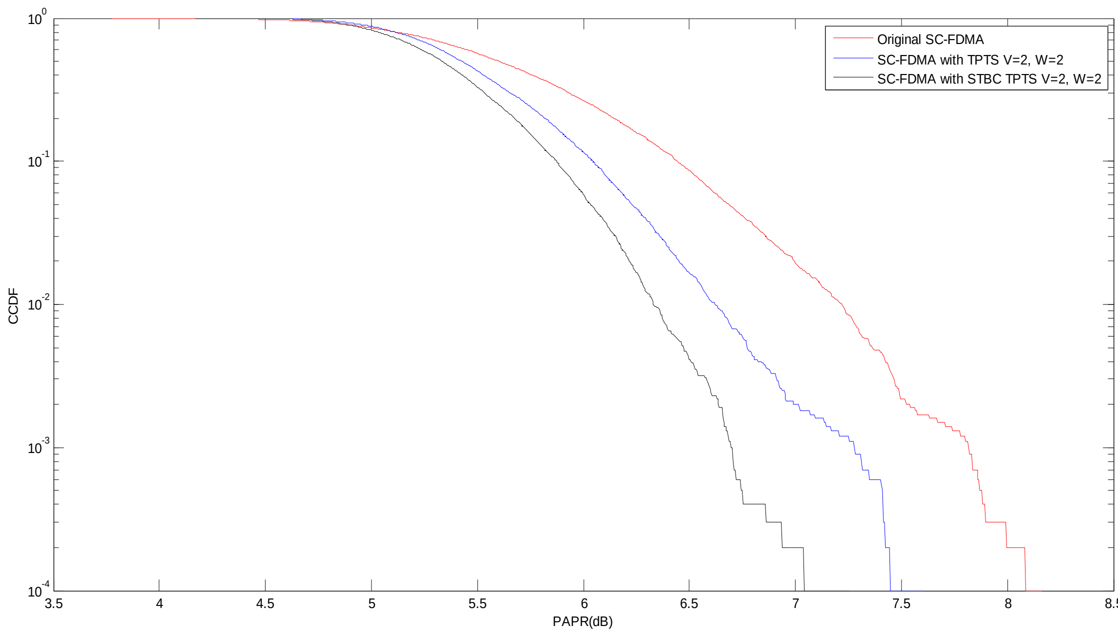

Figure.6. PAPR Performance of the proposed TPTS method V=2 and W=2 for SC-FDMA and STBC Encoded SC-FDMA with Original SC-FDMA

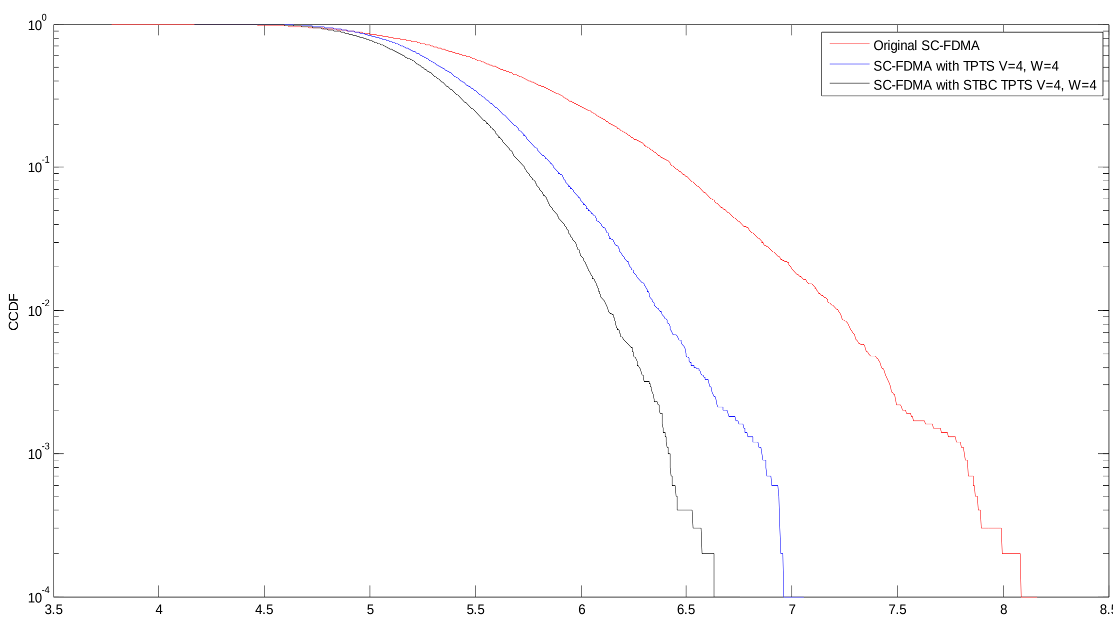

Figure.7. PAPR Performance of the proposed TPTS method V=4 and W=4 for SC-FDMA and STBC Encoded SC-FDMA with Original SC-FDMA

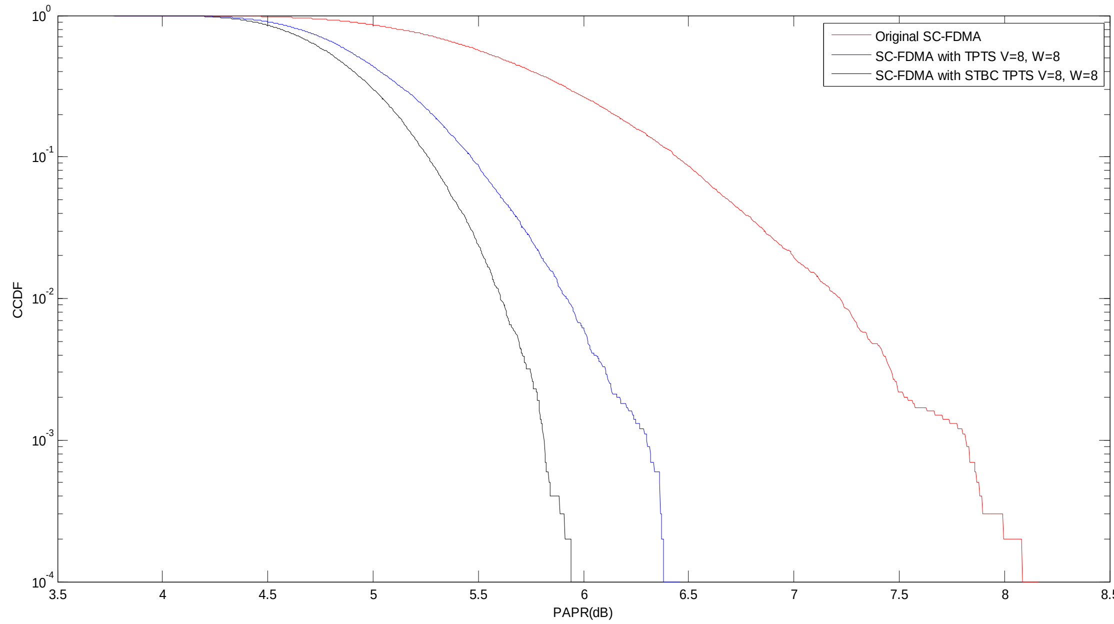

Figure.8. PAPR Performance of the proposed TPTS method V=8 and W=8 for SC-FDMA and STBC Encoded SC-FDMA with Original SC-FDMA

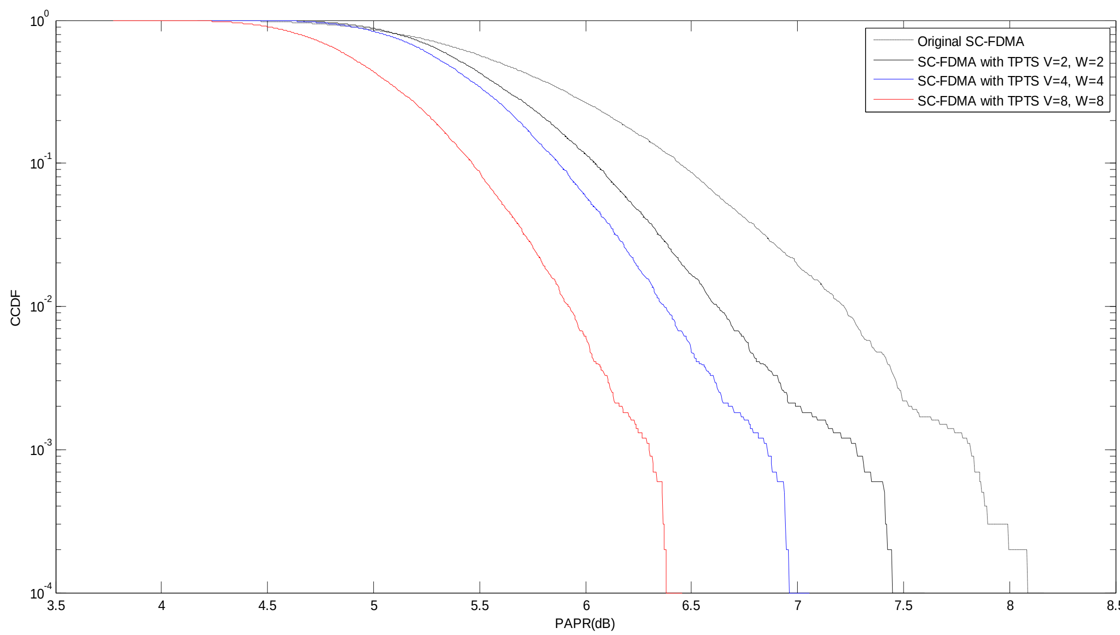

Figure.9. PAPR Performance of the proposed TPTS method for SC-FDMA with different number of V and W

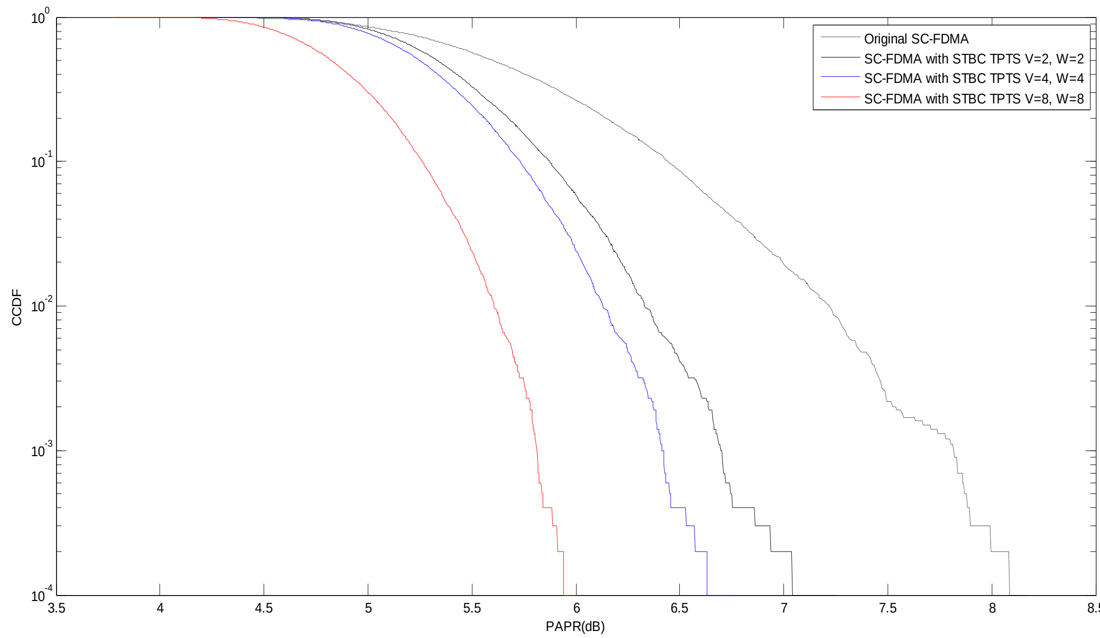

Figure.10. PAPR Performance of the proposed TPTS method for STBC Encoded SC-FDMA with different number of V and W

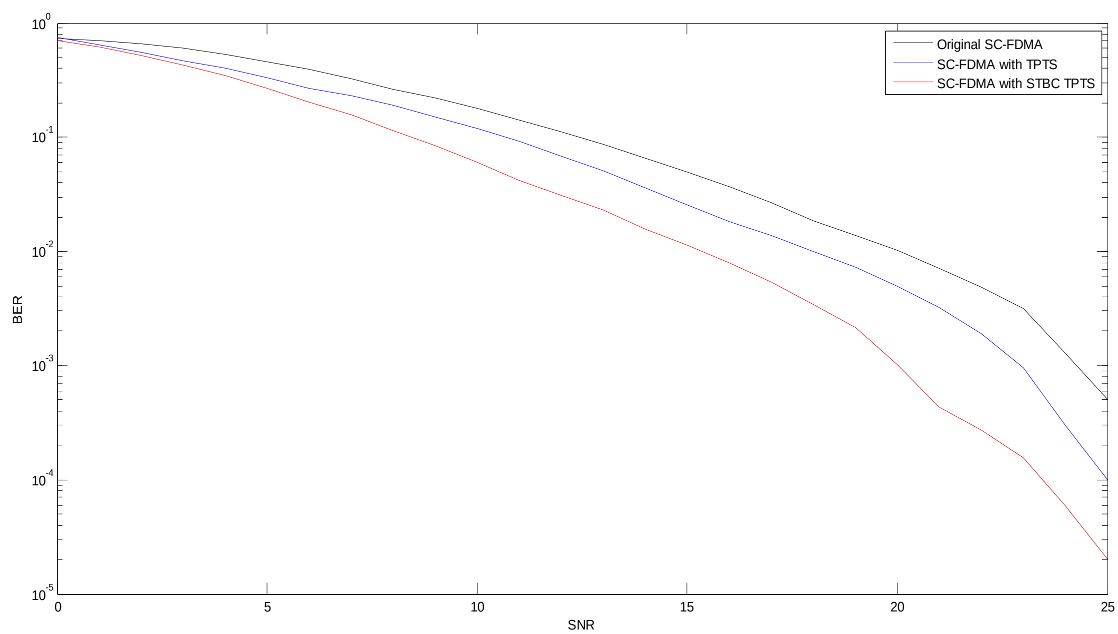

Figure.11. BER Performance of the proposed TPTS method for STBC Encoded SC-FDMA and SC-FDMA with Original SC-FDMA

Figure.6 demonstrates the BER performance comparison of the proposed BFPFO-TPTS algorithm for the SC-FDMA and STBC encoded SC-FDMA systems with the original SC-FDMA system. The proposed STBC encoded SC-FDMA signal with the proposed PAPR reduction method can achieve the BER performance compared with the other methods. With also the benefit of PAPR reduction by the proposed TPTS, the proposed scheme has better BER performance than the original SC-FDMA signals.

VI. CONCLUSION

In this paper, Alamouti STBC precoding technique was implemented in the SC-FDMA signals in order to avoid the effects caused by the fading characteristics. The PAPR performance of the STBC encoded SC-FDMA system is not yet ensured in the past literatures. Thus, we presented a time-domain PTS (TPTS) method to reduce the PAPR in the STBC encoded SC-FDMA system. In TPTS method, phase factor optimization was required to offer the transmitted signal with the best phase factors as well as to reduce the search complexity of traditional PTS method. Therefore, we also presented the Bacterial Foraging Phase Factor Optimization (BFPFO) algorithm to optimize the best phase factor from the W^{V-1} combinations. Simulation results were presented to evaluate the performances of the proposed methods in terms of PAPR and BER. With the use of the proposed BFPFO-TPTS algorithm, STBC encoded SC-FDMA system offers high reduction of PAPR than the other methods. Moreover, BER performance of the proposed method was achieved obviously. Thus, from the understanding from the simulation results that the precoding techniques are not only offers the better BER performance meanwhile they can offer the better reduction of PAPR in multiple antenna systems.

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