تحسين نظام STBC- OFDM باستخدام الشفرات التلاصقية لشبكات LTE

Improving of STBC-OFDM systems by Concatenated Codes for LTE Networks

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Abstract:

The objective of designing any wireless network system is to achieve reliable, high data rate and high capacity system. These requirements can be performed by using the most popular technology which is known as Orthogonal Frequency Division Multiplexing (OFDM). In OFDM system, the data is transmitted into some multi carrier which should be orthogonal to each other to overcome interference between them. The combination of OFDM with **S**pace **T**ime **B**lock **C**ode **M**ulti Input **M**ulti **O**utput (STBC –MIMO) has been utilized in many wireless communication systems to enhance system diversity gain and capacity. Since the error correction codes (ECC) are commonly used in the long term evolution (LTE) networks, so to improve the performance of this system a powerful class of ECC is used.

In this paper, two coded systems are proposed, the first system is a serial concatenated convolutional codes (SCCC) which is known as Serial Turbo Code (STC) and the other system is a combination of Parallel Concatenated Convolutional Code (PCCC) as outer encoder with convolutional code as an inner encoder to produce a new code known as Product Turbo Code (PTC), this new code is used to improve the performance of the traditional STBC OFDM system. The STC and PTC are attractive codes used to upgrade the ability of the communication system on error detection and correction, hence improves the coding gain of the proposed schemes. The performance of these systems is also evaluated by varying the number of antennas for three cases

(two transmitters and two receivers), (four transmitters and two receivers) and (four transmitters and four receivers).

Key words: OFDM, STBC, MIMO, STC, PTC, LTE networks, QPSK modulation.

المستخلص:

ان الهدف من تصميم اي شبكة لاسلكية هوالحصول على نظام ذومعدل نقل بيانات سريع وسعة عالية. هذه الاهداف بالامكان تحقيقها من خلال استخدام تقنية شائعة تعرف بمضاعفة تقسيم الترددات المتعامدة (OFDM). في هذا النظام يتم استخدام حاملات متعددة متعامدة مع بعضها من اجل تقليل التداخل بينها. من اجل تحسين فوائد التنوع وسعة الارسال، تم الجمع بين نظام (OFDM) مع رمز زمن الفضاء وقناة متعدد المدخلات متعدد المخرجات (STBC-MIMO) في العديد من انظمة الارسال اللاسلكي. ان استخدام دالة تصحيح الاخطاء في شبكة LTE هو من الامورالمالوفة ولذلك تم تحسين هذه الشفرات واستخدامها مع النظام المقترح.ان التحسين في نسبة الخطا في نظام STBC OFDM تم تحقيقه من خلال استخدام التلاصقية التسلسلية (SCCC) والتي تعرف ايضا (STC) وجمع التلاصقية المتوازية (PCCC) مع شفرة التفافية للحصول على شفرة تعرف (PTC). هذه الشفرات من الشفرات الفعالة والتي تستخدم بتات التصحيح الاضافية من اجل زيادة امكانية النظام على كشف الاخطاء وتصحيحها وبالتالي تحسين الترميز. كما تم تقييم خصائص النظام مع تغيير عدد الهوائيات في جهة الارسال والاستلام.

١. Introduction

One of the most important requirements for wireless communication system is achieving high data rate. This can be accomplished by using orthogonal frequency division multiplexing (OFDM). In OFDM system, the serial data are separated into parallel sub-carriers, which are situated orthogonal to each other. This orthogonality is an important condition to stay away from the multipath problem and interference between these sub-carriers. The generation of the sub-carrier can be implemented by using the Fast Fourier Transform (FFT)[1]. The compensation for Inter Symbol Interference in OFDM system can be achieved by adding a cyclic prefix. This insertion caused degradation in bandwidth efficiency [2].

In many wireless communication systems like IEEE 802.16 (WI-MAX), IEEE 802.11, and LTE networks, to get an improvement in the quality of signal and to increase the data rate a popular arrangement of (MIMO) system with OFDM is considered [3,4,5]. In MIMO systems many antennas are used for both transmitter and receiver, so the combination of MIMO systems with an OFDM offers a system has high resistance to frequency selective fading channel with high data rate and without needing to increase the transmitting power or increasing bandwidth [2, 6]. This combination will be also meeting the requirements for the "upcoming 4G broadband wireless Communication networks"[7].

Space Time Block Codding (STBC) is a technique has been suggested by Alamouti in 1998 used for MIMO system and it is performed by transmission of multiple copies of data which distributed across the multiple antennas to improve the system diversity [8] .In frequency selective fading channel a good improvement is done when using the STBC OFDM system as compare with the traditional OFDM[9]. The feature of the modulation order on Bit Error Rate (BER) and the effect of antenna selection has been performed in[10]. Forward error correction codes (FEC) are widely used in many of the wireless network applications, especially in LTE network to improve the reliability of the received signals [11-13]. A comparison between block turbo code and convolutional code based OFDM system is achieved [14]. To study the effect of the FCC in MIMO OFDM system and the enhancement of the system capacity by increasing the number of antennas, a simple system has been designed in[15, 12].

In this paper, a combination of STBC in Almouti MIMO OFDM scheme has been improved by utilizing attractive classes of error correction codes which depends on the concatenation of convolutional codes and the iterative decoding algorithm.

The organization of this paper is as follows: section 2 gives an introduction to the traditional OFDM system. Section 3 describes a MIMO system. Section 4 describes the STBC technique. The channel coding technique is explained briefly in section 5. The proposed systems are presented in section 6. BER performances from simulation are presented in section 7. Finally, section 8 gives the conclusions from simulation results.

٢. Principles of MIMO System

The main idea of MIMO system is the usage of multiple antennas at both transmitter and receiver and this leads to increase the spatial dimension. So, multi-dimensional signal processing can be obtained. Any MIMO system is consisted of three parts: the transmitter (TX), the channel (H) and the receiver (RX). If N_t is represented the number of transmit antennas which are placed at the output of the transmitter and N_r is represented the number of receiver antennas which are placed at the input of the receiver, Figure (1) shows the block diagram of the MIMO system[16].

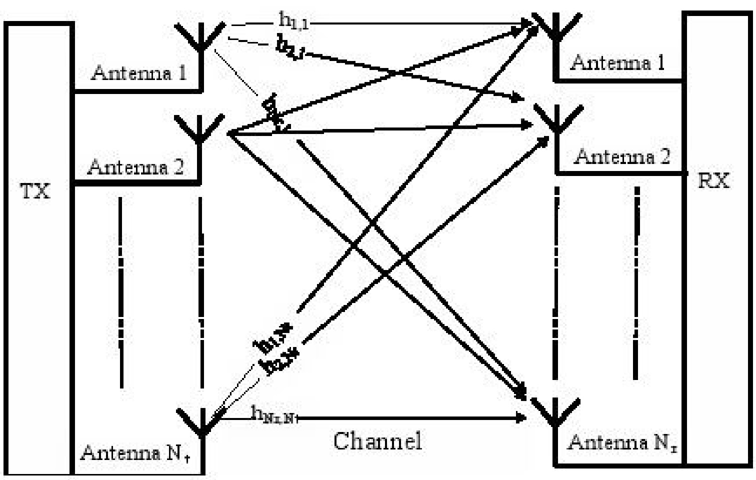


Figure (1): MIMO system block diagram

The functioning of the MIMO system extremely depends on the channel matrix (H). The channel matrix is N_r x N_t matrix which can be described as shown below:

$$H = \begin{pmatrix} h_{١,١} & h_{١,٢} & \cdots & h_{١,Nt} \\ h_{٢,١} & h_{٢,٢} & \cdots & h_{٢,Nt} \\ \vdots & \vdots & \ddots & \vdots \\ h_{Nr,١} & h_{Nr,٢} & \cdots & h_{Nr,Nt} \end{pmatrix} \quad \ldots\ldots\ldots\ldots (١)$$

where, the $h_{i,j}$ represents the phases shift between the transmitter and receiver.

One of the important issues that should be satisfied by MIMO system is that the antennas should be spaced at least $\lambda_c/2$, where λ_c is the wavelength of the carrier frequency. This condition is important to avoid the correlation between the signals [17].

٣. Space Time Block Code (STBC)

In STBC system, the transmitter transmits several copies of a data through a number of antennas to improve the reliability of the received data[18]. A STBC is usually described by a matrix. In this matrix, each row corresponds a time slot and each column corresponds to the antenna that's transmitted over time. For Alamouti – STBC, two transmitters transmit the data symbol at the same time as shown below [8]:

$$\begin{bmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{bmatrix} \quad \ldots\ldots\ldots (2)$$

To explain the function of STBC two cases have been considered:

١. The simple case for two transmitters (T_{x1},T_{x2}) and one receiver (R_x) at period t, (s_1) is the transmitted signal from the antenna (T_{x1}) and (s_2) is the transmitted signal from antenna (T_{x2}) simultaneously. At the period t+T, the antenna (T_{x1}) transmits ($-s_2^*$) and antenna (T_{x2}) transmits (s_1^*). So, the received signal as a vector at time t, and t+T can be explained as follows[20]:

$$y = \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{bmatrix} \begin{bmatrix} h_1 \\ h_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \quad \ldots\ldots\ldots\ldots (3)$$

where h_1 and h_2 are channel vector which represent channel responses for antenna (T_{x1}) and antenna (T_{x2}), also n_1 and n_2 represent the noise vector at times t and t +T. So, the received signal (y_1 and y_2) can be written as:

$$y_1 = h_1 s_1 + h_2 s_2 + n_1 \quad \ldots\ldots\ldots\ldots (4)$$

$$y_2 = -h_1 s_2^* + h_2 s_1^* + n_2 \quad \ldots\ldots\ldots\ldots\ldots (5)$$

Then, the two signals can be estimated from equations 6 and 7 as follows:

$$\tilde{s}_1 = h_1^* y_1 + h_2 y_2^* \qquad \text{.......... (6)}$$

By substitution of y_1 and y_2 in equations (4 and 5) the equation (6) will be written as follows:

$$\tilde{s}_1 = (|h_1|^2 + |h_2|^2) s_1 + h_1^* n_1 + h_2 n_2^* \qquad \text{.......... (7)}$$

Likewise, the signal s_2 will be extracted and written as follows:

$$\tilde{s}_2 = h_2^* y_1 - h_1 y_2^*$$

$$\tilde{s}_2 = (|h_1|^2 + |h_2|^2) s_2 + h_2^* n_1 - h_1 n_2^* \qquad \text{......... (8)}$$

Finally, the maximum likelihood transmitted symbols is estimated by passing the resultant signals to the maximum likelihood detector.

٢. For two transmitters (T_{x1}, T_{x2}) and two receivers(R_{x1}, R_{x2}), the received signals will be as follows:

$$\left.\begin{aligned} y_{11} &= h_{11} s_1 + h_{12} s_2 + n_{11} \\ y_{12} &= -h_{11} s_2^* + h_{12} s_1^* + n_{12} \end{aligned}\right\} For\ Rx_1 \qquad \text{.......... (9)}$$

$$\left.\begin{aligned} y_{21} &= h_{21} s_1 + h_{22} s_2 + n_{21} \\ y_{22} &= -h_{21} s_2^* + h_{22} s_1^* + n_{22} \end{aligned}\right\} For\ Rx_2 \qquad \text{......... (10)}$$

The transmitted signals s_1 and s_2 will be recovered by combining the received signals y_{11}, y_{12}, y_{21}, and y_{22} as follows:

$$\begin{aligned} \tilde{s}_1 &= h_{11}^* y_{11} + h_{12} y_{12}^* + h_{21}^* y_{21} + h_{22} y_{22}^* \\ \tilde{s}_2 &= h_{12}^* y_{11} - h_{11} y_{12}^* + h_{22}^* y_{21} - h_{21} y_{22}^* \end{aligned} \qquad \text{....... (11)}$$

٤. CHANNEL CODING IN STBC OFDM SYSTEM

In STBC-OFDM system, error correction codes represent the most powerful technique that has been used to improve the reliability of any proposed system[12, 15]. This technique can be implemented by adding parity or check bits to information bits to enable the proposed system to overcome errors which happen due to the channel impairment. The convolutional codes are a subclass from error correction codes. It is defined by CC (n, k, L), where n is the output bits from encoder at each time unit, k is the input bits to the encoder and L represents the constraint length which means memory depth of the CC. To improve BER performance of the proposed system the serial turbo code STC and product turbo code PTC have been suggested where concatenations between two CC with a pseudo-random inter-leaver are employed. For STC system, the concatenation is between (2,1,7) CC of rate 1/2, d_{free}=10, generator vectors in octal form are (133,171) and (3,2,3) CC of rate 2/3, d_{free} =5 generator vector in octal form are (27,75,72). So the overall rate will be 1/3. The encoder is adding before the mapping process and the decoder at the receiver side is after the de-mapping. The PTC is a new proposed scheme has a high error correction capability if it is compared with the traditional TC. The PTC can be achieved by utilizing parallel concatenated convolutional codes PCCC of two CC each of rate 1/2 as outer encoder combines with CC of rate 2/3 as inner encoder and inter-leaver between the two codes to eliminate the effect of burst errors. For every OFDM symbols, the interleaving is performed separately. The parity bits and the data bits are punctured to the required rate by omitting specific bits. A puncturing technique means the changing of the code rate to another higher rate so a PTC of rate 1/3 can be obtained from the proposed system. The complexity of decoder algorithm for TC used in this work is not high compared with that required to decode the two CCs separately. The essential idea of the decoding procedure depends on a maximum likelihood a posteriori prob. (LOG MAP) algorithm and iterative decoding. The structure of STC decoder is consisting of two soft inputs soft output (SISO) decoders depend on this algorithm, inter-leaver and de-inter-leaver, while the structure of PTC is consisting of three SISO decoders. More details about this decoding algorithm can be explained in [20, 21, 22]. Figure (2) shows the structure of STC and PCCC decoders which represents the outer decoder for the second proposed system.

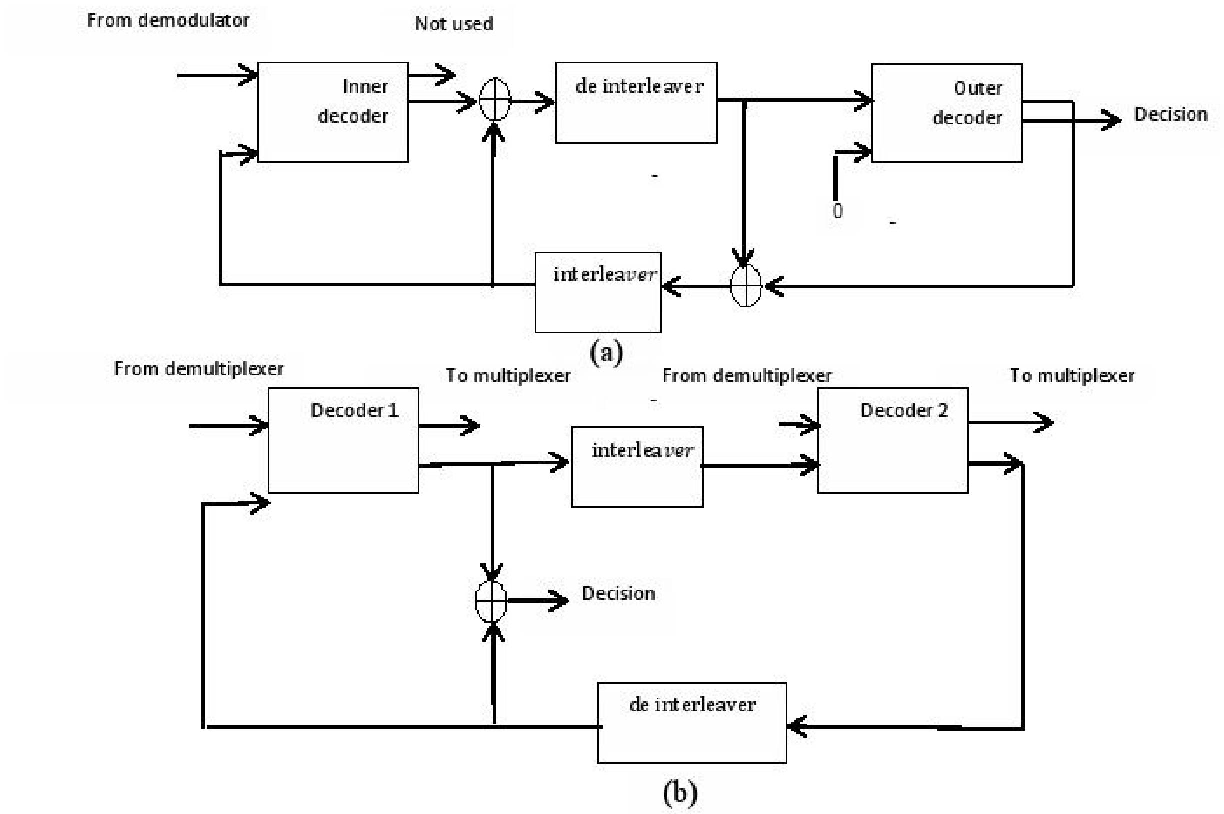


Figure (2): Block diagram for iterative decoding (a) STC decoder (b) outer decoder of PTC system.

٥. Proposed STBC- OFDM Coded System

The performance of the proposed STC and PTC systems are evaluated for three cases (2T, 2R), (4T, 2R) and (4T, 4R). Figure (3) shows the first case, where the transceiver for two transmitters and two receivers (2T, 2R) only. The data stream is encoded by STC or PTC then modulated by QPSK modulation to be mapped to a sequence of symbols then converted from serial to parallel. These symbols are passed through the STBC stage. According to this encoding the signal copy is transmitted from another antenna at another time. Next, pilot carriers are inserted to enable the system for compensating the channel impact. After that, IFFT is applied to the signal so the subcarriers have been orthogonal to each other. To eliminate the effect of ISI, a cyclic prefix is added then the data is converted from parallel to serial to be transmitted through the wireless channel. As explained in section (4), at time t the antenna (T_{x1}) transmits (s_1) and antenna (T_{x2}) transmits (s_2), while at the next period at (t+T) antenna (T_{x1}) transmits (-s2*) and antenna (T_{x2}) transmits (s1*).

After transmission over the wireless channel, the receiver received y_{11} and y_{21} at time t and y_{12} and y_{22} at time t+T as shown in equation (11) and (12). The next steps are the reverse steps to the transmitter side , after the conversion from serial to parallel, the CP is removed and transform the signal from time to frequency by passing through the FFT. A good estimation values can be obtained from STBC combiner with channel estimation. The received signals have been combined as shown in equation (13) to resolve (s_1) and (s_2).

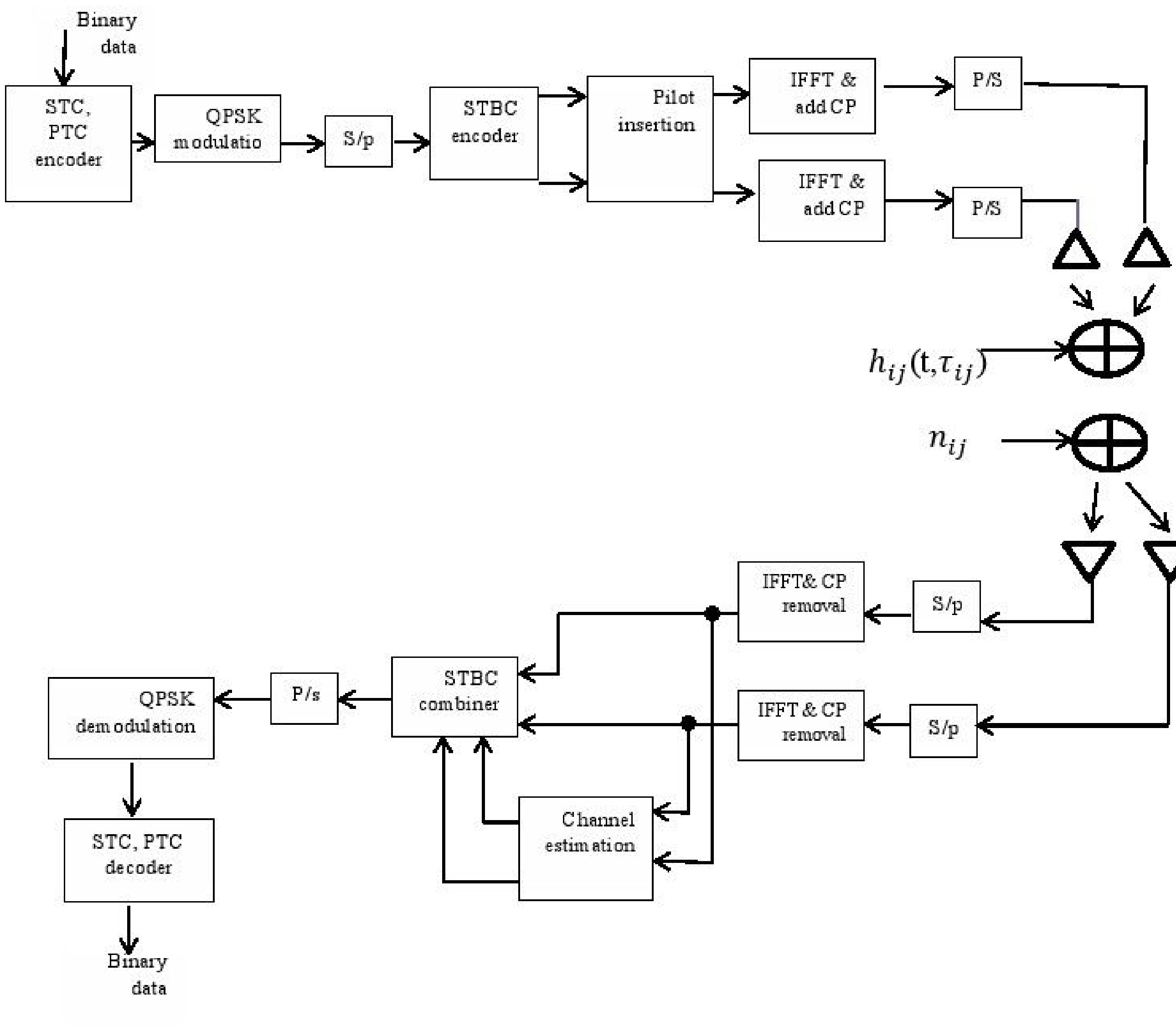


Figure (3): STBC OFDM coded system transceiver

٦. Simulation Results

In this simulation, the same rate for the two types of Turbo codes has been taken to obtain a fair comparison. The STC and PTC parameters are explained in section 4. The simulation is done also for (3, 1, 7) CC with rate 1/3, generator polynomial [133,145,175] and d_{free}=15 to show the coding gain that obtained from the proposed systems and the error correction capability of STC and PTC. The performance of the proposed scheme is evaluated for different number of transmitting and receiving antennas. The performance is tested in terms of BER of the received data with E_b/N_0. The simulation results are obtained using Matlab, the performance of the proposed scheme is tested for three iterations and with parameters presented in table (1):

Table (1): Simulation parameters

System Parameter	Parameter Value
Modulation	QPSK
Number of subcarriers	52
Number of data subcarriers	48
Length of Cyclic prefix	16
Number of pilot subcarrier	4
FFT/IFFT length	64
Convolutional coding	rate1/3
STC	rate1/3,1/2
PTC	rate1/3,1/2

Figure (4) shows that the BER performance of the proposed systems vs. CC for 4Tx and 2Rx with a code rate =1/3. From this figure, it is clear that the performance of the proposed coded systems is much better than the system coded by CC, also the coding gain is about 7dB for PTC about 4 dB for the system with STC when BER≈ $١٠^{-٤}$, the system which is coded by PTC needs SNR ≈ -0.25 dB, while the system coded by STC needs about 3dB to get the same BER. The CC of rate 1/3 requires 7dB to obtain the same BER.

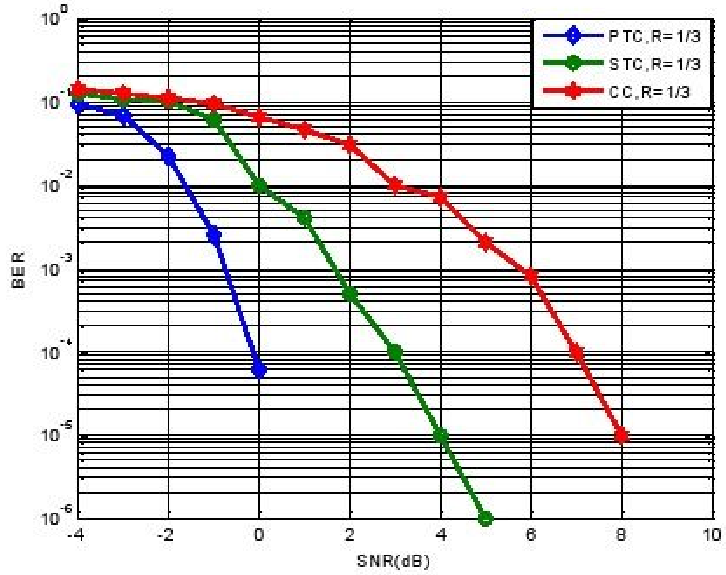


Figure (4): BER performance of 4Tx and 2Rx STBC-OFDM system with variable FEC codes.

Figure (5) shows the features of the proposed systems in case of 2Tx and 2Rx for the same code rate. From this figure, the system that coded by PTC requires 4dB to reach BER≈$١٠^{-٤}$, while the STC system reaches to BER≈$١٠^{-٤}$ at SNR≈7dB. The CC coded system requires 10dB to obtain the same BER.

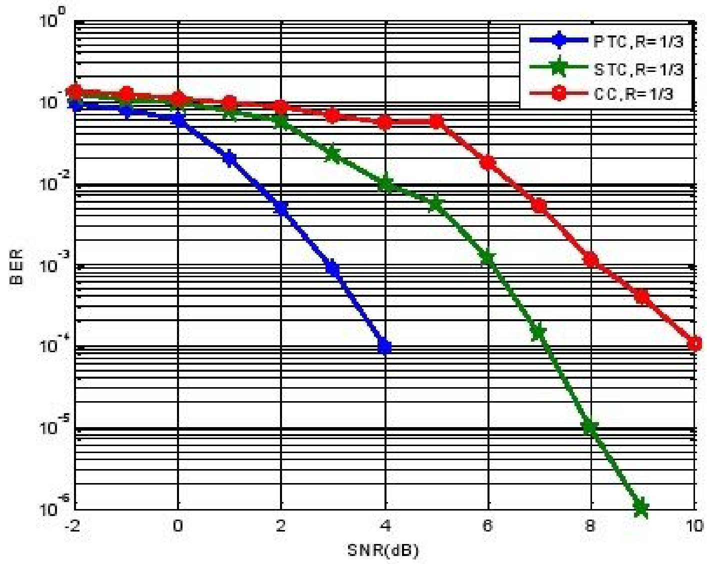


Figure (5): BER performance of 2Tx and 2Rx STBC-OFDM system with variable FEC code.

Figure (6) shows the performance of 4Tx and 4Rx STBC OFDM system coded by PTC, STC and CC. From the previous cases, the behavior of PTC is better than the other two systems. The PTC system needs SNR ≈ -1.5dB to reach BER≈ $١٠^{-٤}$ while the STC system requires 1dBto get the same BER. On the other hand, the CC system needs 4dB to reach $١٠^{-٤}$ BER. From above results, it can be deduced that the coding gain is about 5.5 dB for PTC system and 3 dB for STC system.

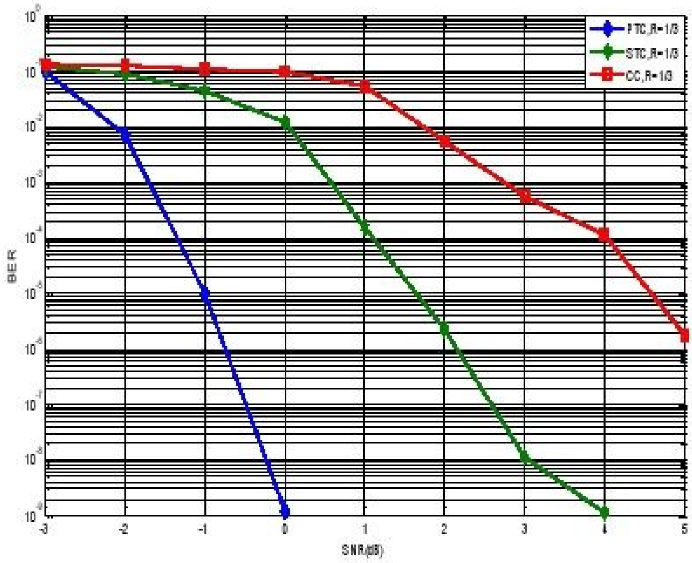


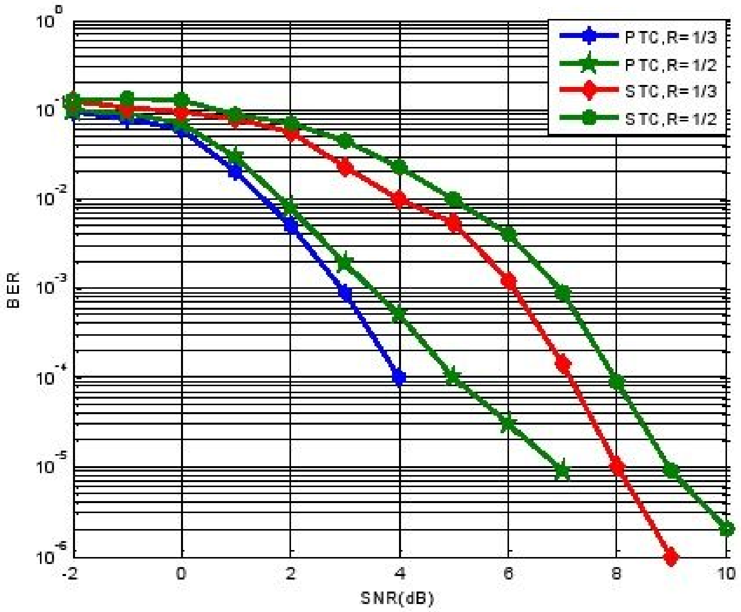
Figure (6): BER performance of 4Tx and 4Rx STBC-OFDM system with variable FEC code.

Table (2) summarizes the improvement of the proposed system, it is obvious that the performance of the system is improved when the number of the receiving antennas are increasing. And this is because the diversity gain enhance with the increasing of receiving antennas. Also, it is noticed that better BER performance is obtained from the STBC-OFDM based PTC system. Also, this table shows that the required SNR to obtain BER $\approx$ ١٠$^{-٤}$ for each coded system.

Table2: Simulation results

Coded STBC OFDM systems	4Tx and 2Rx	2Tx and 2Rx	4Tx and 4Rx
PTC system	-0.25dB	4dB	-1.5dB
STC system	3dB	7dB	1dB
CC system	7dB	10dB	4dB

In this simulation, the performances of the proposed system are examined with different code rate (1/3, 1/2) and with 2Tx and 2Rx for both systems. As shown in Figure (7), it is clear that the PTC and STC systems of rate 1/3 need less SNR than the same systems with rate 1/2 to reach the same BER value. For example, if BER is taken approximate equal to ١٠$^{-٤}$, then the systems with code rate =1/3 provides coding gain about ١dB.



Figure(7): performance of coded STBC OFDM with 2Tx and 2Rx.

٧. Conclusion

In this paper, two types of TC are proposed, STC and a new class known as PTC. The traditional STBC OFDM system with the suggested tubo codes is examed, and from the simulation results, an improvement in BER performances of the proposed systems can be achieved where the STBC OFDM systems coded by PTC and STC give better BER at lower SNR than that coded by CC. Also another evaluation depends on the number of antennas at the transmitter and receiver was done, it is clear that when the number of receiving antennas increases the diversity gain also improves and enhancement on BER values was achieved.

The effect of code rate for the proposed coded STBC-OFDM systems is also tested and found that the proposed systems with rate 1/3 give better BER than the system with a higher rate for the same iteration and decoding technique.

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