Reliable of High Data Rate Using Spatial Multiplexing and Convolution Code

Dr. Mahmood F. Mosleh
Electrical& Electronic Technical Engineering College/Baghdad.
E-mail: drmahfa@yahoo.com
Dr. Raad H
College of Engineering, University of Mustansiriyah /Baghdad.
Eman A. Farhan
College of Engineering ,University of Mustansiriyah /Baghdad.

Received on:1/10/2014 & Accepted on:2/42015

Abstract

Spatial Multiplexing (SM) can be achieved higher transmission rate without allocating higher bandwidth or increasing transmit power, so it is wildly used recently to serve the extremely demand of mobile communications. But multipath fading is major bottleneck in increasing the data rate and reliability of transfer of information over wireless channel. SM suffers from significant degradation in term of Bit Error Rate (BER) in such environments. In this research it has been tested a SM system with three types of detection. The first results show the Maximum Likelihood (ML) is the better one, but the complexity is increased dramatically with increasing of data rate or the level modulation order in addition of delay time. On the other hand, Zero Forcing (ZF) is very simple related to ML and it suitable for real time communications, but the problem is the Bit Error Rate (BER) is very high related to the performance of ML. So that this research proposed to adopt ZF decoder, and to support its performance, Convolutional Codes (CC) is added to this system to overcome this problem. The results show the proposed scheme gives a gain of about 10 dB of Signal to Noise Ratio (SNR) at BER of 10^{-4} for code rate of ½ of CC. To reduce the redundancy informations of CC, 2/3 code rate is proposed instead of ½. The results illustrates such system gives significant gain at high SNR, but the problem is the BER in increased up to system with code at low SNR. Also the results confirm that this problem decreases with high number of antennas. So that MIMO system is suitable for high data rate.

Keywords: MIMO, Zero Forcing, Channel codes.

بيانات بمعدل عالي وموثوقة باستخدام نظام متعدد المكانية مع المشفر الالتفافي

الخلاصة:

في هذا البحث تم اختبار نظام متعدد الادخال متعدد الاخراج (MIMO) باستخدام ثلاثة انواع من الكواشف. النتائج الاولية بينت ان افضل اداء يكون مع الكاشف القريب الاكبر (ML) لكن التعقيد يزداد في هذا النوع من بشكل واضح مع زيادة مستوى التضمين او زيادة سرعة البيانات. من ناحية اخرى فان الكاشف نوع الدفع الصفري (ZF) هو ابسط في التركيب قياسا الى ML كما انه مناسب لظروف الزمن الحقيقي في الاتصالات لكن مشكلته يعاني من نسبة خطأ(BER) عالية. لذلك اعتمد البحث هذا النوع من الكاشف واقترح اضافة مشفر من النوع الالتفافي (CC) لمعالجة هذه المشكلة. النتائج اوضحت بان التركيب المقترح حصل على ربح بحدود 10dB من نسبة الاشارة الى الضوضاء (SNR) عند $BER=10^{-4}$ عند معدل تشفير1/2. ولغرض تقليل

https://doi.org/10.30684/etj.33.5A.14
2412-0758/University of Technology-Iraq, Baghdad, Iraq
This is an open access article under the CC BY 4.0 license http://creativecommons.org/licenses/by/4.0

البيانات الخاصة بالمشفر تم اقتراح معدل تشفير 2/3 بدلا من ½. النتائج بينت ان هذا التركيب يعطي ربح واضح عند SNR العالية لكن المشكلة هو زيادة معدل الخطأ عند SNR الواطئة. لكن النتائج بينت ان هذه المشكلة تقل مع زيادة عدد الهوائيات. لذلك فان نظام MIMO مناسب للبيانات العالية.
الكلمات المرشدة : متعدد المداخل والمخارج, الكاشف الصفري, ترميز القناة

INTRODUCTION

Multiple-input multiple-output (MIMO) channels are an abstract and general way to model many different communication systems of diverse physical nature. In particular, wireless MIMO channels have been attracting a great interest in the last decade, since they provide significant improvements in terms of spectral efficiency and reliability with respect to single-input single output (SISO) channels [1]. MIMO schemes are typical for the purposes of maximizing data rate, or diversity gain. A maximum data rate is achieved by a spatial multiplexing method by which a single user's data stream is split into multiple sub streams and transmits them in parallel using an array of transmit antennas over the same frequency band [2]. MIMO system also used to support other technique to increase reliability or data rate. The authors in [3] proposed blind detection method for Multiple Input Multiple Output-Space Time Coded (MIMO-STC) wireless systems based on Independent Component Analysis (ICA). Another technique used in [4] to increase the throughput by applying MIMO system with Orthogonal Frequency Division Multiple Access (OFDMA) by allocating the users, transmission power and information bits across the utilized sub-channels.

Spatial Multiplexing (SM) offers a linear increase in the transmission rate (or capacity) for the same bandwidth and with no additional power expenditure. It is only possible in MIMO channels [1, 5].

Error control is an important feature for compensating transmission impairments such as interference and multipath fading which cause high bit error rates in the received data [6]. Codes are used to improve the reliability of data transmitted over communication channels susceptible to noise. Coding techniques create code words by adding redundant information to the user information vectors.

One of the most important of error control is the Convolutional Codes (CC) which takes advantage of the relativity between code types, so they have better error correction performance and are used widely. Unlike the block code, convolutional code is not memory less devices. CC is the most reliable method for transmitting or retrieving the error free data [7].

Spatial multiplexing can provide a higher capacity but in contrast it degreases the Signal to Noise Ratio (SNR). Spatial Diversity improves the signal quality and achieves a higher signal-to noise ratio at the receiver-side. Especially in extensive network areas, SM is pushed to its limits. The larger the network environment is, the higher the signal strength has to be. To solve this problem it can be use a channel codes to support the BER of SM with maintaining the high throughput. In this paper it has been proposed a simple convolutional code combined with SM. Therefore we attempt to reduce the complexity by using a simple case for such code.

Spatial multiplexing (SM)

SM transmits independent parallel data streams through multiple antennas at both transmitter and receiver, as shown in Fig. 1 [8].

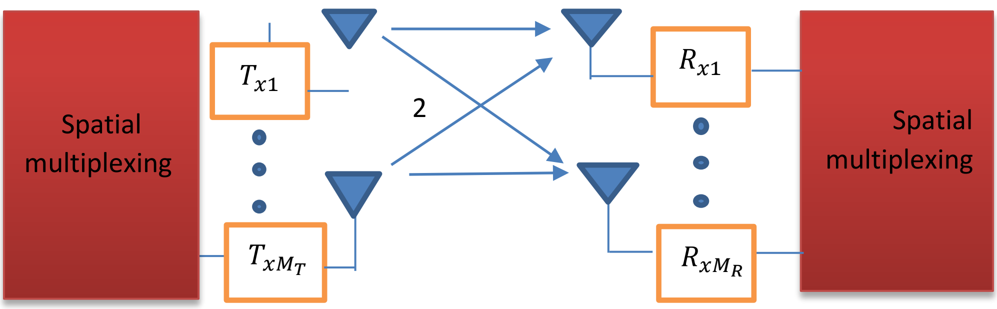


Figure (1): spatial multiplexing for MIMO system

The general concept of SM can be understood using MIMO antenna configuration. In SM, a high data rate signal is divided into multiple low rate data streams and each stream is transmitted from a different transmitting antenna [9]. Consider a flat-fading MIMO channel with M_T transmit antennas, M_R receive antennas and $M_R \geq M_T$. This channel is part of a SM system where the mth data symbol (or layer) d_m is directly transmitted on the mth transmit antenna. At a given time instant, this leads to the well-known baseband model

$$r = Hd + w, \qquad \text{.... (1)}$$

With the transmit vector is $d = (\, d_1 d_2 \ldots\ldots..\, d_{M_T}\,)^T$, the matrix H is $M_R \times M_T$ Channel, the received vector is $r = (r_1\, r_{2\_\_\_}\, r_{M_R})^T$, and the noise vector is $w = \left(w_1 \ldots\ldots..\, w_{M_R}\right)^T$ [10].

Detection techniques for SM

Linear Detection Techniques

The idea behind linear detection techniques is to linearly filter received signals using filter matrices; this category includes Zero-Forcing (ZF) and Minimum Mean Square Error (MMSE) techniques. Although linear detection schemes are easy to implement, they lead to high degradation in the achieved diversity order and error performance due to the linear filtering [5].

(ZF) technique is the simplest MIMO detection technique. Where filtering matrix is constructed using the ZF performance based criterion. The drawback of ZF scheme is the susceptible noise enhancement and loss of diversity order due to linear filtering. ZF can be implemented by using the inverse of the channel matrix H to produce the result of ZF detection y_{ZF} [5]. For the (ZF) detection, G is given by the pseudo-inverse of H [10],

$$G = H^{\#} = (H^H H)^{-1} H^H \qquad \text{... (2)}$$

The result of ZF detection is

$$y_{ZF} = H^{\#} r = (H^H H)^{-1} H^H r \qquad \text{... (3)}$$

The noise enhancement effect plaguing the ZF detector can be reduced by using the MMSE detector:-

The MMSE detector is given by

$$G = (H^H H + \sigma^2{}_w I)^{-1} H^H \quad \text{.... (4)}$$

Where

$(\sigma^2{}_w)$ is the noise term with $N_0/2$ spectral for impulse response of channel.
Which is the G minimizing the mean-square error $E\{\|Gr - d\|^2\}$
Thus, the result of MMSE detection is

$$y_{MMSE} = (H^H H + \sigma^2{}_w I)^{-1} H^H r \quad \text{.... (5)}$$

MMSE possess the desirable property of not enhancing noise as much as ZF. Furthermore, its bit error rate (BER) performance is better than ZF [11].

Non Linear Detection Techniques

Maximum Likelihood Detection (ML) is one of the important aspects for nonlinear detection for SM. The ML detector is given by

$$\hat{d}_{ML} = arg \min_{d \in M^{M_T}} \{\|r - Hd\|^2\} \quad \text{..... (6)}$$

Here, M^{M_T}or 2^{bM_T} (b is the number of bits per symbol) denotes the set of all possible transmitted data vectors d [10]. ML detector is optimal but computational complexity as given in (6) is extremely high; the optimal ML detection scheme needs to examine all M^{M_T}or 2^{bM_T} symbol combinations. The problem can be solved by enumerating over all possible d and finding the one that causes the minimum value as in (6). Therefore, the computational complexity increases exponentially with constellation size M and the number of transmitters M_T [11].

The convolutional codes (CC)

Convolutional codes were first introduced by Elias in 1955 as an alternative to block codes. To ensure high reliability, however, CC tends to occupy a large bandwidth. This is due to the fact that convolutional codes add redundancy to each transmitted bit, producing a code rate of smaller than 1. The larger number of redundancy bits added to each transmitted bit, the stronger the protection given to the said bit against transmission errors. One way to reduce the occupied bandwidth is by using punctured CC [12].

Convolutional Encoder

A convolutional encoder is a linear finite-state machine with *l* binary input, *n* outputs and an *m*-stage shift register, where *m* is the memory of the encoder sees Fig. 2. Such a finite state encoder has 2^m possible states. The *constraint length K* of the CC is defined as *K*=*m*+1. In comparison to block codes, CC encode the input data bits continuously rather than in blocks A code rate *r* =*l*/*n* code can also be produced by puncturing [13].

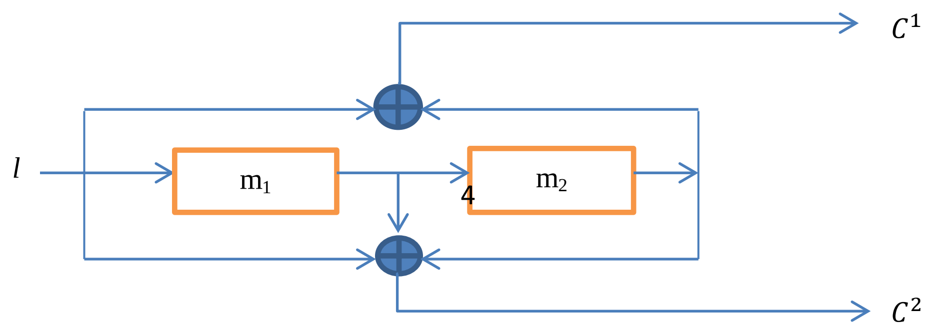


Figure (2): Convolutional Encoder

One form of describing a convolutional code *C* conv (*L*, *n*, *K*) is by means of a vector description of the connections that the finite state sequential machines (FSSMs) has, which are directly described by the vector representation of the generator polynomials $\boldsymbol{g}^{(1)}$ and $\boldsymbol{g}^{(2)}$ that correspond to the upper and lower branches of the FSSM of Fig. 2, respectively. In this description, a ‘1’ means that there is connection, and a ‘0’ means that the corresponding register is not connected [14].

$$\boldsymbol{g}^{(1)} = (101) \quad \text{.... (7)}$$

$$\boldsymbol{g}^{(2)} = (111) \quad \text{.... (8)}$$

Convolutional Decoder

Viterbi algorithm is a well-known maximum-likelihood algorithm for decoding of CC and is an optimal (in a maximum-likelihood sense) algorithm for decoding of a CC using trellis. It is applied to the trellis of a convolutional code whose properties are conveniently used to implement this algorithm. The decoding procedure consists of calculating the cumulative distance between the received sequence at an instant t_i at a given state of the trellis, and each of all the code sequences that arrive at that state at that instant t_i [14]. An exhaustive search maximum-likelihood decoder would calculate the likelihood of the received data for code symbol sequences on all paths through the trellis. The path with the largest likelihood would then be selected, and the information bits corresponding to that path would form the decoder output. Unfortunately, the number of paths for an *L* bit information sequence is 2^L; thus this exhaustive search decoding quickly becomes impractical as *L* increases. With Viterbi decoding, it is possible to greatly reduce the effort required for maximum likelihood decoding by taking advantage of the special structure of the code trellis. It is clear that the trellis assumes a fixed periodic structure after trellis depth *K* is reached [13].

System model

The system used in this research for simulation is shown in Figure 3. The source used here is Bernoulli Generator block which generates random binary numbers using a Bernoulli distribution. The Bernoulli distribution with parameter p produces zero with probability p and one with probability 1-p. The Probability of a zero parameter specifies p, and can be any real number between zero and one.

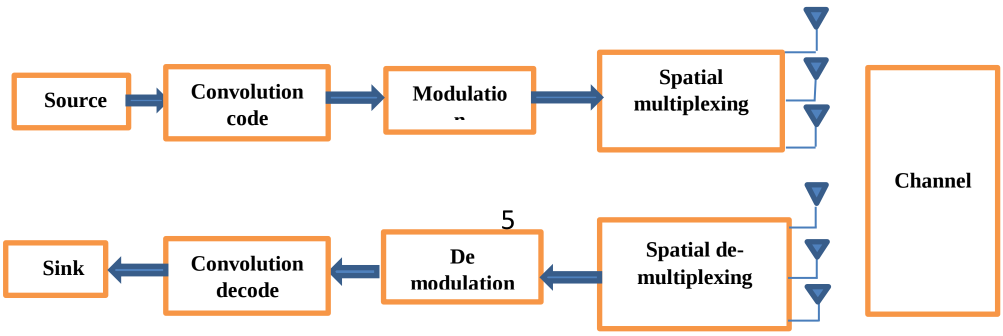


Figure (3): system model

The Convolutional Encoder block encodes the data from the Bernoulli Binary Generator; The Convolutional Encoder block encodes a sequence of binary input vectors to produce a sequence of binary output vectors. This block can process multiple symbols at a time. The constraint length is 7, and code generator polynomials of 171 and 133 (in octal numbers).

The Modulator used the phase shift keying (PSK) type to modulate the output of convolutional code with various mode orders, the order used here is Binary PSK (BPSK), Quadrature PSK (QPSK), 8PSK and 16PSK). The output is a baseband representation of the modulated signal.

The spatial multiplexing schemes is subdivide the data into independent sub-streams, one for each transmit antenna employed. The number of transmitted and received antennas used here are (2x2, 3x3 and 4x4). Such SM employs flat fading over independent transmit- receive links. We assume perfect channel knowledge with no feedback to the transmitter, i.e., an open-loop spatial multiplexing system.

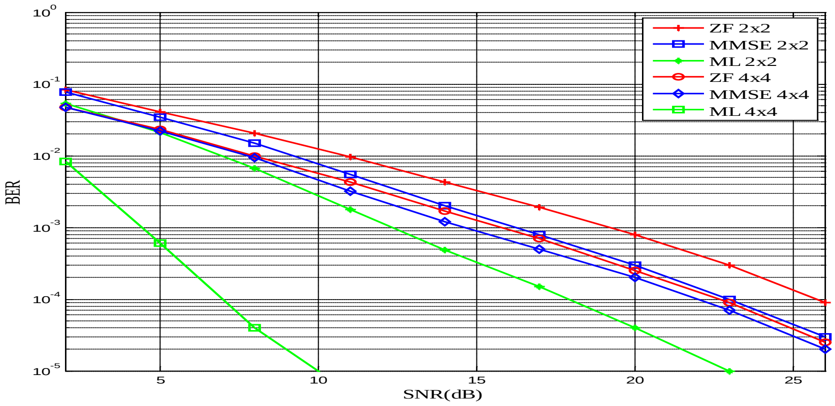
Detection techniques for SM used Linear Detection Techniques such as the minimum mean square error (MMSE) and Zero-Forcing (ZF) techniques, Non Linear Detection techniques such as Maximum Likelihood Detection (ML).

Then Demodulate modulated data by using PSK Demodulator Baseband, and decode convolutionally encoded data using Viterbi algorithm. The Viterbi Decoder block decodes input symbols to produce binary output symbols. This block can process several symbols at a time for faster performance. The Viterbi Decoder used here is Hard Decision Decoding. Then the symbols received to the sink.

Simulation result

All simulations in this research are applied using Matlab package version R2013a. The first test is to evaluate the performance of SM system in term of BER with various detection schems ZF, MMSE and ML. Fig. 4 is the result of modulation oreder of 2 that means QPSK is used, for 2x2 and 4x4 antennas formation to show the performance of each types of detection.

It very clear that the ML is outperform other type while zero forcing is the worst case. On the other hand the amount of gain between 4x4 and 2x2 for ML is the largest while it is the lowest for ZF. Also the test hold the same previous system but with higher level of modulation order 16PSK. Fig. 5 illustrats the performance of three types of detection.



Figure(4): SM of 4x4 and 2x2 with modulation order =2

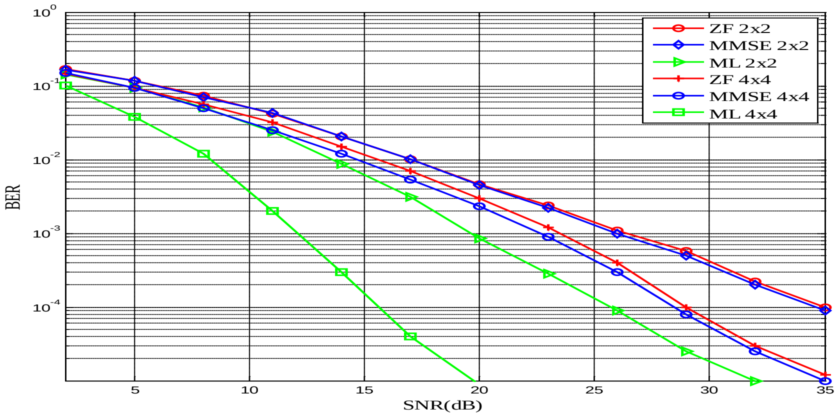


Figure (5): SM of 4x4 and 2x2 with modulation order =4

The ML is better performance, it needs 15 dB to achieve 10^{-4} BER, while only 7 dB for QPSK of 4x4 antennas. MMSE and ZF also suffer from high BER in the high level of mode order. On the other hand the problem of ML that, it is suffer from high complexity and delay time specially at high modulation order, so that to design a reliable system with suitable complexity the ML is unfavorable for real time and high data rate.

This research attempt to adress such problem by suggest to adopt ZF detection instead of ML for its simplicity and without delay time. But ZF also suffers from BER degradation as it is seen fro previous results. To support its performance, simple scheme of CC will be added to the system to treat the week BER of ZF. The following simulation is applied to the proposed system model shown in Fig. 3. Befor going ahead in details of analysing the results of such case study, it is necessary to compare the performance of ML and ZF with CC. Fig. 6, 7 and 8 are illustrate such comparison.

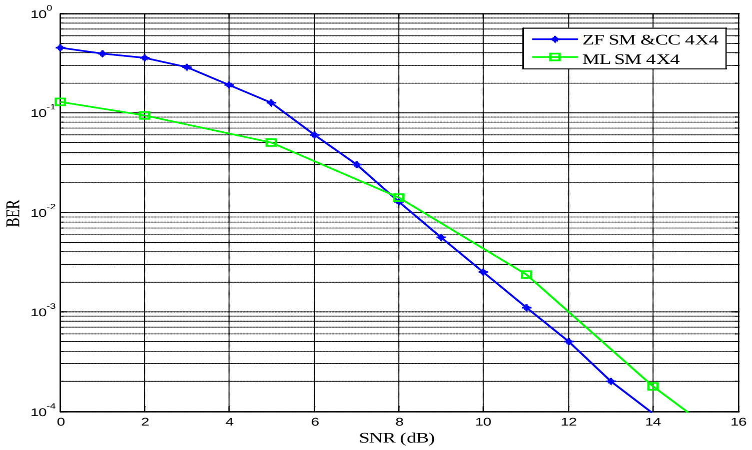


Figure 6: Comparison of ZF with CC and ML for 4x4 scheme

It is clear that significant improvement in the performance of ZF with CC, but as it is known redundance information will added to the origin bits which caused degredation in the speed of data rate because of such redundancy, so that the user must be tradeoff between complexity and data rate. However it can be reduce such degredation by increasing the code rate of CC as we will see later.

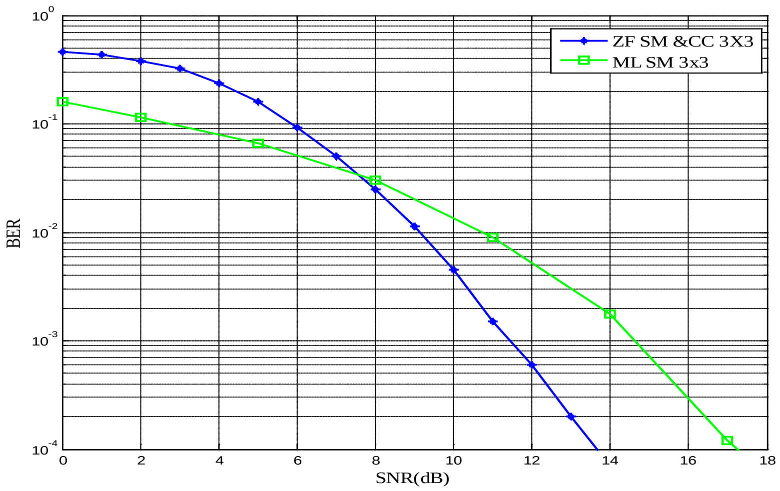


Figure (7): Comparison of ZF with CC and ML for 3x3 scheme

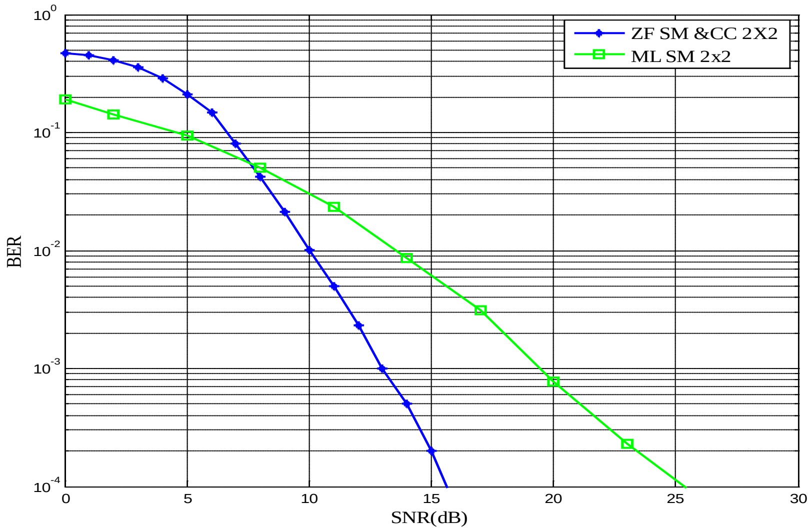


Figure (8): Comparison of ZF with CC and ML for 2x2 scheme

Now the simulation is done for ZF with and without CC. Fig. 9 shows the results of using ZF decoder.

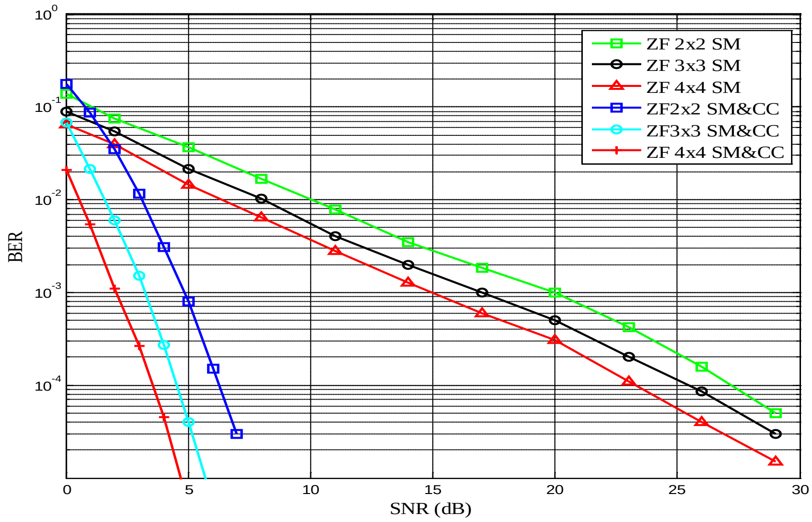


Figure (9): ZF decoder with mode order =1 and various antenna schemes

The mode order here is equal to 1 or BPSK modulation, in this case the 10^{-4} BER can be achieved at 4dB of SNR for 4x4 scheme as illustrates the red curve and code gain is exceed 10 dB which make such system is optimum for very low SNR. If the mode order is increase up to 2 or QPSK is used, the BER of 10^{-4} is increase to 6 dB while reducing the code gain as shown in Fig. 10.

The following steps are repeated for the same system with mode order 3 and 4 or 8PSK and 16PSK respectively, which means increasing the data rate. As shown in Fig. 11 and 12 the system is still robust for high data rate. For 4x4 antennas scheme the 10^{-4} BER can achieved at 8 and 11.5 dB of SNR for 3 and 4 mode orders respectively.

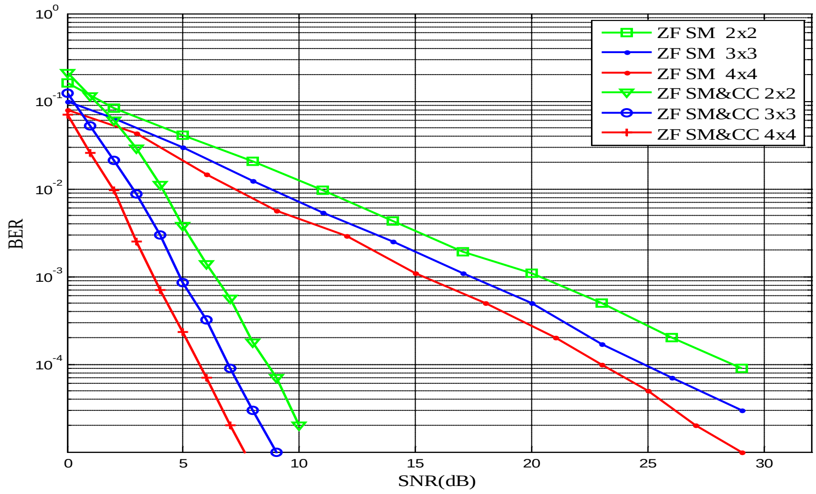


Figure (10): ZF decoder with mode order =2 and various antenna schemes

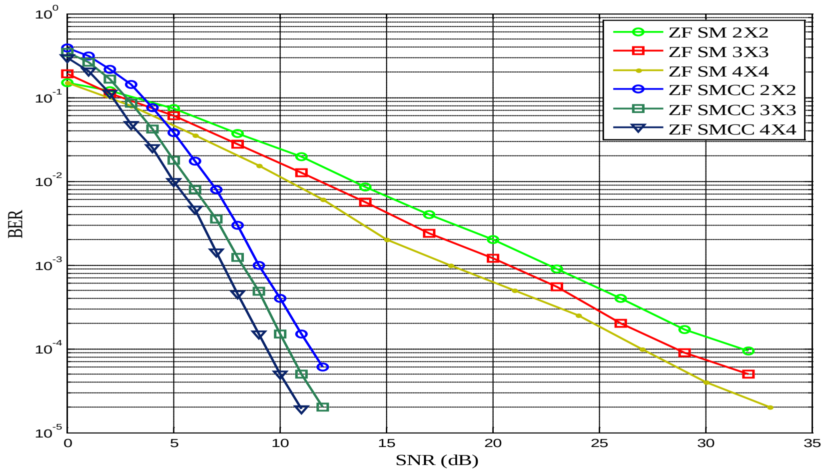


Figure (11): ZF decoder with mode order =3 and various antenna schemes

Note that although the performance is improved using CC with ZF decoder, but the BER increases at low SNR, this phenominon seems clear whenever the mode order is increase as shown in Fig. 12 for 16PSK, not that the BER becomes larger than in the case of ZF witout code, this is the drawback of such system or the payment versus the profit of previous gain.

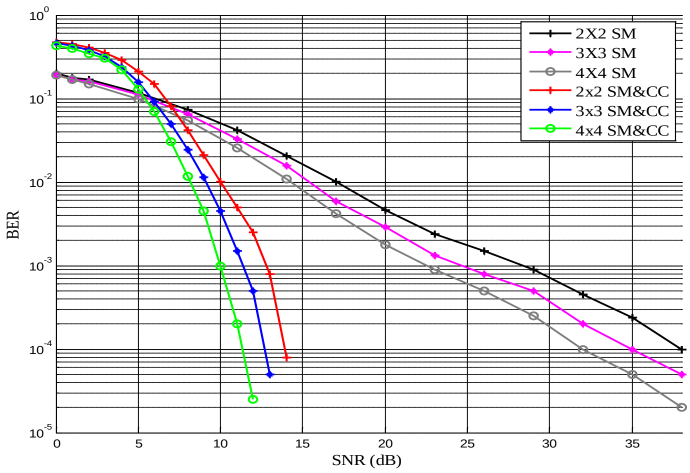


Figure 12: ZF decoder with mode order =4 and various antenna schemes

It must pointed out here that code rate of CC used in all previous simulations was 1/2, that means the information bits is doubled with redundancy which reduces the data speed to half but the gain was to reduce the SNR significantly.

To reduce the redundancy information added by CC, it can be increase the data rate of such code. It has been tested this idea for our system, Fig. 13 shows the results which clear that the code gain is reduced significantly.

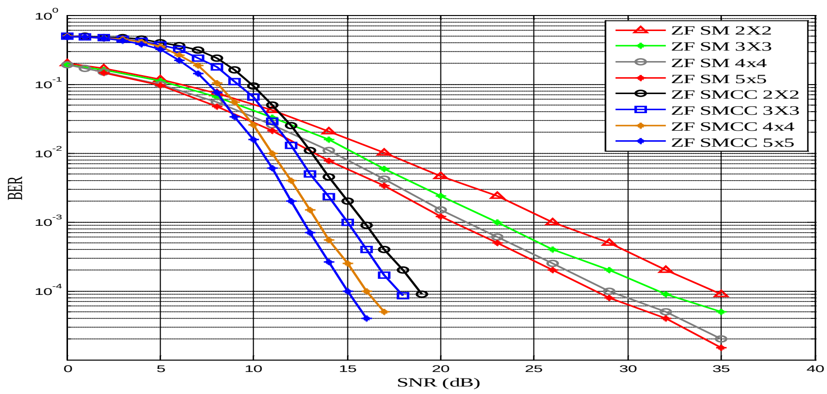


Figure (13): SM with CC of 2/3 code rate

In addition the previous phenominon becomes worst because the error is more than previuos case. As it is clear from Fig. 13 befor 10 dB of SNR the error with CC is more than error without code which make such code constitute a burden on the system. But it can reduce the effect of such phenominon by increas the number of antennas, as shown in Fig.13 the effect is reduced significantly for 5x5 antennas. Hence the importance of the use of MIMO system to increase the speed data rate with suitable reliability so that this research is adopt such technique because it is efficient without more spectrum and complexity.

The summarized of proposed results is listed in table 1

Table (1): Summarized of proposed results

No. of antennas / Mode order	SNR for 10^{-3} BER					
	2x2		3x3		4x4	
	ZF without code	ZF with code	ZF without code	ZF with code	ZF without code	ZF with code
BPSK	20dB	5dB	17dB	3dB	15dB	2dB
QPSK	21dB	6dB	17.5dB	5dB	15.5dB	4dB
8QPSK	23dB	9dB	21dB	8dB	18dB	7.2dB
16QPSK	29dB	13dB	25dB	11dB	22.5dB	10 dB

The mode order which is motioned in such research is referred to the capacity of system, that are the data rate in QPSK is doubled as in BPSK, 8QPSK is three times of data over BPSK and four times in 16QPSK. The results confirm that the capacity improved the system four times with only 10 dB to achieve 10^{-3} BER using CC with 4x4 antennas.

Conclusions

The first testing of SM without additional codes is to evaluate the performance of such system with ZF, MMSE and ML decoders. The results show that ML is better than MMSE and ZF in the term of BER. The gain of ML reaches 10 and 8 dB related to MMSE and ZF respectively. But as it known ML is unacceptable for high order of modulation because of the complexity is increased linearity with mode order, in addition to the delay time. After adding CC as a proposed system shown in Fig.3, the results confirm that more than 10 dB gained by adding such code, and it can be increase mode order to reach 16PSK to achieve 10^{-4} BER at low SNR about 12 dB, to overcome the redundancy information caused by CC. Also it can be reduced such redundancy be increasing the code rate to 2/3 instead of ½. But in this case it must be increase the number of antennas to more than 4x4, which illustrates the importance of MIMO system that adopted in this research.

References

[1].Luis Garcia Ordonez, "Performance limits of spatial multiplexing MIMO systems", Ph.D. Thesis, Technical University of Catalonia, 2009.

[2].In-Ho Lee "SER performance of enhanced spatial multiplexing codes with ZF/MRC receiver in time-varying rayleigh fading channel " *The Scientific World Journal,* 2014.

[3].Dr. Wafaa Mohammed, R. Shakir AL-Dahan " Blind detection method of MIMO – space time coded wireless systems based on ICA" Eng. & Tech. Journal , Vol.32,Part (A), No.4, 2014

[4].Dr. Salah Awad Aliesawi, "Suboptimal resource allocation for MIMO-OFDMA systems" Eng. & Tech. Journal , Vol.32,Part (A), No.2, 2014

[5].Auda M. Elshokry, "Complexity and performance evaluation of detection schemes for spatial multiplexing MIMO systems", Master Thesis, the Islamic University- Gaza, 2010

[6].Mei Yen, Cheong "Block error correction codes and convolution codes", *available at the website of:*

http://www.comlab.hut.fi/opetus/333/2004slides/topic18.pdf
[7].Ripple Dhingra and Danvir Mandal, "Convolutional code optimization for various constraint lengths using PSO", International Journal of Electronics and Communication Engineering, Volume 5, Number 2, 2012.
[8].H. Jafarkhani: “Space-time coding theory and practice”, Cambridge, 2000.
[9].Mohinder Jankiraman, "Space-time codes and MIMO systems", British Library Cataloguing in Publication Data, 2004.
[10].Dominik Seethaler, Harold Artes and Franz Hlawatsch, "Detection techniques for MIMO spatial multiplexing systems", Elektrotechnik und Informationstechnik (e&i), vol. 122, no. 3, March 2005.
[11].Adnan Ahmed Khan1, Sajid Bashir, Muhammad Naeem, Syed Ismail Shah and Xiaodong Li, "Symbol detection in spatial multiplexing system using particle swarm optimization meta-heuristics", International Journal of Communication Systems, 2008
[12].Aditya Kumar, Pratibha Tripathi and Amrita, "Performance evolution of MIMO-OFDM system with efficient coding", International Journal Of Engineering Research & Management Technology, March- Volume-1, 2014.
[13].Shu Lin and Daniel J. Costello, Jr. "Error control coding", 2nd ed. Upper Saddle River, New Jersey, Prentice Hall, 2004.
[14].Jorge Castineira Moreira and Patrick Guy Farrell, "Essentials of error-control coding", John Wiley & Sons Ltd, 2006.