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Set Partitioning to Construct Block Coded Modulation with the Presence of Spatial Modulation in MIMO Systems

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Abstract

In this paper, enhancing the BER performance of multiple-input multiple-output systems (MIMO) is considered by using Block Coded Spatial Modulation (BCSM). It is a combination of Block Coded Modulation (BCM) used set partitioning to formulate the code, and the spatial Modulation (SM) as a transmission technique of MIMO systems. To achieve this, the idea of MIMO communication systems, block coded modulation, set partitioning, multi stage decoding and spatial modulation have been combined. Matrix Laboratory (MATLAB) is used for the simulation and Bit Error Rate (BER) is obtained and verified. The simulation results for the combination of BCM with SM show that there is a significant improvement in BER performance compared to the classical SM techniques. It gives an approximately 5 dB enhancing of BER performance from the use of SM only, and about 3 dB enhancing from the use of coded information bits with SM.

Keywords MIMO, Spatial Modulation, Block Codes, BER, Set partitioning.

استخدام تقنية تقسيم أجزاء الترميز في بناء التضمين الرمزي الكتلي في وجود التضمين المكاني في أنظمة الاتصالات متعددة المداخل والمخارج

ملخص

في هذا البحث ندرس تحسين معامل نسبة الخطأ في أنظمة الاتصالات متعددة المداخل والمخارج وذلك باقتراح تقنية التضمين الرمزي الكتلي المكاني. إن هذه التقنية تعد مزيج من التضمين الرمزي الكتلي باستخدام تقنية تقسيم أجزاء الترميز، وتقنية التضمين المكاني المستخدمة كتقنية نقل للبيانات في أنظمة الاتصالات متعددة المداخل والمخارج. ولتحقيق هذا المزيج، تم الجمع بين مفاهيم تقنية الاتصالات متعددة المداخل والمخارج، والتضمين الرمزي الكتلي، وتقسيم أجزاء الترميز، وفك الترميز متعدد المراحل، والتضمين المكاني. لقد تم استخدام برنامج ماتلاب لعمل المحاكاة لهذا النظام المقترح لتحسين معامل نسبة الخطأ، ولقد أثبتت النتائج التي تم الحصول عليها عند استخدام التضمين الرمزي الكتلي المكاني إلى تحسين كبير في نسبة الخطأ تصل إلى 5 ديسيبل عن تلك التي تم الحصول عليها عند استخدام التضمين المكاني بمفرده، ونسبة تحسين تصل إلى 3 ديسيبل عن تلك التي تم الحصول عليها عند استخدام ترميز البيانات مع التضمين المكاني.

كلمات مفتاحية: أنظمة الاتصالات متعددة المداخل والمخارج، التضمين المكاني، الترميز الكتلي، معامل نسبة الخطأ، تقسيم أجزاء الترميز.

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1. Introduction:

The need for high data rate and high spectral efficiency are the key elements of our modern life. To satisfy these demands; most of research in modern wireless communication systems aims to develop some coding algorithms or new technologies [1]. MIMO system is one of these technologies. The main drawbacks of any MIMO scheme are the increase in the complexity and cost due to Inter–Channel Interference (ICI) caused by coupling multiple symbols in time and space, Inter–Antenna Synchronization (IAS) which represents the baseline assumption for space–time and encoded methods. In addition, multiple Radio Frequency (RF) chains are needed to transmit all the signals simultaneously [2,3]. These issues make the practical implementation of MIMO schemes very difficult, especially in mobile stations because of the economical, energy, and space limits of them. In order to overcome this, Spatial Modulation (SM) is developed recently to use as a transmission technique that uses multiple antennas [4]. The basic idea behind SM is that symbols are chosen from a constellation diagram and a unique transmit antenna number that is chosen from a set of transmit antennas. Spatial modulation is proposed as a new modulation concept for MIMO systems, which aims to reduce the complexity and cost and still guarantee good data rates by [5]:

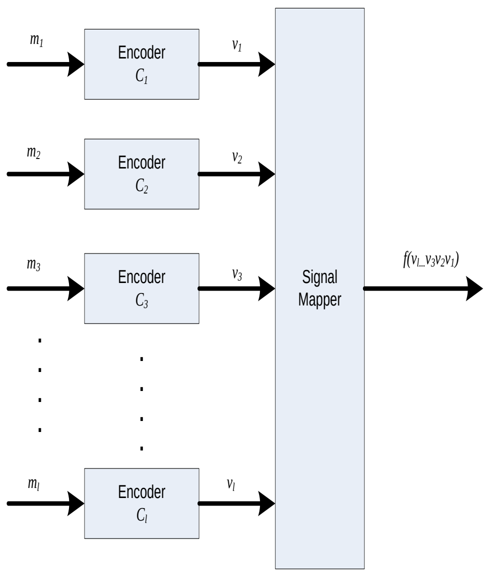
1. One transmit antenna is activated for data transmission at each time instance. This allows SM to avoid the ICI, and to require no synchronization among the transmit antennas. Moreover, SM needs only one RF chain for data transmission. This allows SM to exploit a low–complexity single stream receiver design for optimal Maximum Likelihood (ML) decoding [6].
2. The spatial position of each transmit antenna in the antenna array is used as a source of information which results in a coding mechanism that allows SM to achieve a spatial multiplexing gain with respect to conventional single antenna systems. Accordingly, even though just one antenna is active each time, SM can also achieve high data throughput [7].

Information bits need to be encoded. In this paper; block codes are used with digital modulation to construct Block Coded modulation (BCM). BCM is one of the techniques that combine block codes with the signal sets (modulation constellation) to construct bandwidth-efficient codes [8]. It is designed to achieve large coding gain and high spectral efficiencies with simple decoding process [6]. In order to construct it, multilevel coding process can be used. It is a very powerful technique for constructing bandwidth-efficient modulation codes to enhance the performance for a given channel by providing the flexibility to coordinate the distance parameters of a code [9]. Figure 1(a) shows the process of *l*-level coding where C_1 to C_l indicate number of block codes used, m_1 to m_l are the information bits to be encoded, and $f(v_1 v_2 \ldots v_l)$ is the point in the constellation diagram which contains one element from each code.

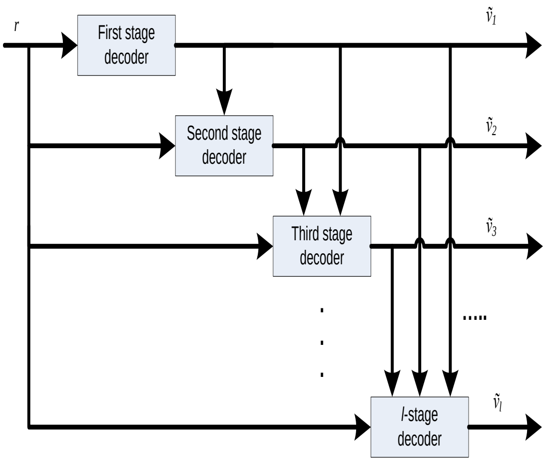
Multi stage decoding is considered as a sup-optimal decoding technique of multilevel codes to achieve an efficient trade-off between error performance and decoding complexity [10]. It can be performed by a maximum likelihood decoder that finds the best input vector in each stage that maximizes the probability of the receiving sequence [11]. This multistage decoding technique allows the receiver to decode the first level code and then use the output decoded sequence in decoding the second level code and so on [12]. In order to perform this technique, a multilevel code should be constructed and entered to the multistage decoder. The component codes are decoded in stages, one at a time, stage by stage from the first $\tilde{v}_1$level component code to the ends as in Figure 1(b) where *r* is the received sequence and $\tilde{v}_l$ are the decoded codes.

In this paper, BCSM is proposed. Set partitioning is based on Ungerboek paper [13,14] on block coded modulation. The BCM and the SM mapper are jointly designed. At the receiver, the ML decoding is used to estimate the antenna index and symbol to decode it by using multi stage decoding.

The organization of the paper is as follows. In Section II, the system model and the new BCSM scheme are introduced. Simulation results and performance comparisons are given in Section III. Finally, Section IV includes the main conclusions of the paper.



(a)



(b)

Figure 1 *(a) The modulator of l-level code, (b) l-level stage decoder*

2. System Model:

The considered BCSM system model is given in Figure 2. The independent and identically distributed binary information sequence u is entered to a separation block to separate the antennas indices bits from the symbol bits. The antenna index bits are not encoded and still as generated. However, symbols bits were encoded by a 3-level BCM coding as shown in Figure 1(a) with rate R = 2/3 whose output sequence v enters the SM mapper. The 3-level BCM codes used in this system are: C_0 is the (8,1,8) repetition code that consists of the all-zero and all-one vectors, C_1 is the (8,7,2) even-parity check code that consists of all the even-weight 8-tuples over GF(2), and C_2 is the (8,8,1) universal code that consists of all the 8-tuples over GF(2). At the receiver, ML decoder is employed to provide an estimation of the antenna index bits and symbol bits. The estimated symbol bits are entered to the 3-stage decoding to provide the decoded ṽ as in Figure 1(b) and then combined to the estimated indices bits to have û output bits.

The MIMO channel, over which the spatially modulated symbols are transmitted, is characterized by an $N_t\times N_r$ matrix H, whose entries are independent and identically distributed (i.i.d.) complex Gaussian random variables with zero means and unit variances. H remains constant during the transmission of a frame (antenna index and symbol like $x = [0,0,s,0]$) and takes independent values from one frame to another, and is perfectly known at the receiver, but it is not known at the transmitter. The transmitted signal is corrupted by an N_r-dimensional additive complex Gaussian noise vector with (i.i.d.) complex Gaussian random variables with zero means and unit variances.

The system has four transmit antennas (N_t = 4) and a single receive antenna (N_r =1). Consider the overall rate of the 3-level BCM code is 2/3 which leads to a 2 bits/s/Hz for BCM and 2 bits for choosing the transmission antenna at each time. That is, the overall spectral efficiency of this BCSM system is 4 bits/s/Hz. At each coding step, the first two coded bits determine the active transmit antenna over which the 8-PSK symbol determined by the last three BCM coded bits.

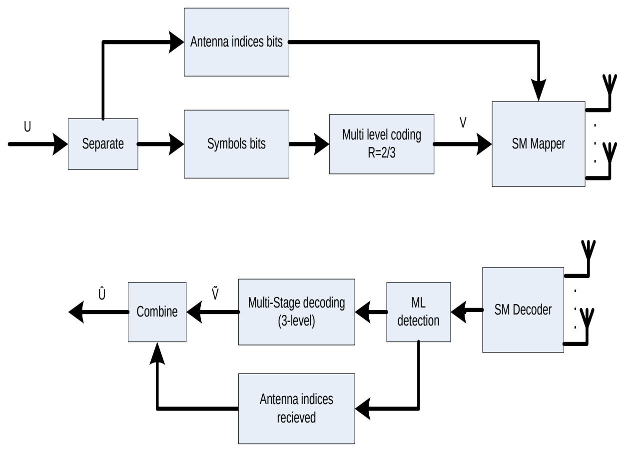


Figure 2 *BCSM system model*

The received signal vector, Y, is given by:

$$Y = \sqrt{\frac{\rho}{\mu}}XH + N, \quad (1)$$

where X is the $1\times N_t$ BCSM transmission matrix, transmitted over channel uses, and μ is a normalization factor to ensure that ρ is the average SNR for each receive antenna. An ML decoder should make an exhaustive search over all possible MN_t transmission matrices, and decides in favor of the matrix that minimizes m' in the equation 2 which represents the estimated antenna index and symbol.

$$m' = arg \min_{x\,\epsilon\,all\,possible} \left\| y - \sqrt{\frac{\rho}{\mu}}\,x(i,t)h(i,t) \right\|^2, \quad (2)$$

The estimated 3 bits of symbol r from equation 2 entered a 3-stage decoding process to estimate a decoded vector at each stage by using equations from 3 to 5.

For the first stage decoding, the minimum squared Euclidean distance (MSE) $d_E^2[r_i, Q(v_{1i})]$ ($Q(.)$ is the symbol's location on the constellation diagram) between r and v_{1i} is calculated and defined as:

$$d_E^2(r, v_1) = \sum_{i=1}^{n} d_E^2[r_i, Q(v_{1i})], \quad (3)$$

For every codeword $v_1 \in C_1$, the distance $d_E^2(r, v_1)$ is calculated, and r is decoded into the codeword $\tilde{V}_1 = (\tilde{V}_{11}, \tilde{V}_{12}, \ldots\ldots, \tilde{V}_{1n})$ for which $d_E^2(r, \tilde{V}_1)$ is minimum.

The decoding process is continued, so for the second stage decoding, the decoded information $\tilde{V}_1$ is passed to the second stage, then $d_E^2[r_i, Q(\tilde{V}_{1i}v_{2i})]$ is calculated by:

$$d_E^2(r, \tilde{V}_1 v_2) = \sum_{i=1}^{n} d_E^2[r_i, Q(\tilde{V}_{1i}v_{2i})] \;, \quad (4)$$

Then r is decoded into the codeword $\tilde{V}_2$ for which $d_E^2(r, \tilde{V}_1\tilde{V}_2)$ is minimum.

The last stage of the 3-level 8-PSK modulation is the third stage decoding, where the decoded information at the first and second stages is made available to the third one. For every codeword $v_3 \in C_3$, the distance $d_E^2[r_i, Q(\tilde{V}_{1i}\tilde{V}_{2i}v_{3i})]$ is calculated by:

$$d_E^2(r, \tilde{V}_1\tilde{V}_2 v_3) = \sum_{i=1}^{n} d_E^2[r_i, Q(\tilde{V}_{1i}\tilde{V}_{2i}v_{3i})], \quad (5)$$

Then r is decoded into the codeword $\tilde{V}_3$ for which $d_E^2(r, \tilde{V}_1\tilde{V}_2\tilde{V}_3)$ is minimum. This completes the entire decoding process and $\{\tilde{V}_1\tilde{V}_2\tilde{V}_3\}$ forms the decoded set $\hat{u}$.

3. Simulation results and performance comparisons:

In Figure 3, the simulation results for the system model are obtained and compared to the case of using SM only as a transmission technique without any linear coding of the information bits. It is also compared to the case of using linear code RM(1,3) as a coding of the information bits because this code corrects one errors only and has a rate of 1/2. As seen from this Figure, BCSM schemes offer a significant improvement in BER performance compared to the classical SM techniques.

It gives an approximately 5 dB enhancing of BER performance over the use of SM only, and about 3 dB enhancing over the coded information bits. This is because the combination of BCM and SM properties of enhancing BER performance as mentioned in introduction.

To validate the concept for any number of transmit-antennas, the system is repeated by the same process using Q-PSK as symbol modulation transmitted at one of the8 transmit-antennas used, and compared the result with those obtained when using 4 transmit-antennas. The result as in Figure 4 shows an enhancing of BER performance by 1 dB.

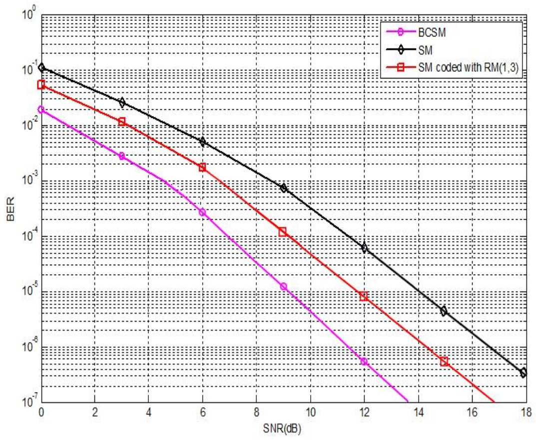


Figure 3 *BCSM simulation result*

4. Conclusion:

SM in general gives an enhancement in the BER performance of MIMO systems, it gives an improving due to the properties of eliminating ICI and IAS and the use of only one RF in each transmission time. In addition, Figures 3 and 4 show that using set partitioning to construct BCM as a coding with SM gives a coding gain enhancement in MIMO systems. Figure 4 shows that increasing number of transmit antenna will enhance the BER performance but with a complex construction in the transmitter due to a large number of transmit antennas used. There is several possible future works, one of them is to modify the method of BCSM to let the antenna indices play a role of detection some errors-received symbols in BCSM according to know the exact transmit antenna used. It can also use the same approach of constructing BCSM to construct trellis coded modulation transmitted via a spatial modulation technique.

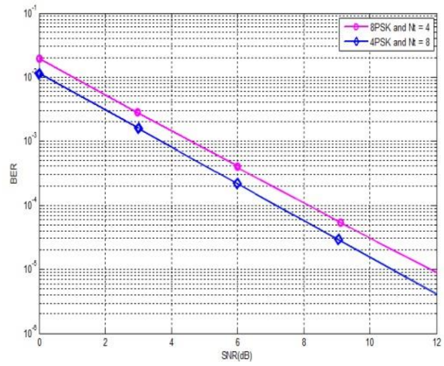


Figure 4 *BCSM comparison between 8-PSK with 4Tx and QPSK with 8Tx*

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