ICIC Express Letters
Volume **10**, Number **2**, February **2016**
ICIC International ©2016 ISSN 1881-803X
pp. 385–390

LOW-COMPLEXITY DETECTION METHOD BASED ON SYMBOL VECTORS FOR DIFFERENTIAL SPATIAL MODULATION SYSTEM

Xiaoping Jin[1,2], Sijie Wen[1], Youming Li[2,*] and Zhengquan Li[1]

[1]Department of Information Engineering
China Jiliang University
No. 258, Xueyuan Street, Xiasha Higher Education District, Hangzhou 310018, P. R. China
{ jxp1023; 10a0303117 }@cjlu.edu.cn; wsj973507837@163.com

[2]Institute of Communication Technology
Ningbo University
No. 818, Fenghua Road, Jiangbei District, Ningbo 315211, P. R. China
*Corresponding author: liyouming@nbu.edu.cn

Received August 2015; accepted November 2015

Abstract. *In order to reduce the complexity of maximum likelihood (ML) detection in differential spatial modulation (DSM) system, a low-complexity differential spatial modulation (LC-DSM) detection method is proposed in this paper. The algorithm utilizes the bit-padding concept at transmitter and divides the received signal matrix into signal vectors at receiver. The simulation results show that LC-DSM algorithm achieves more than 90% complexity reduction compared with DSM-ML proposed by Bian et al. and 50% compared with the algorithm proposed by Xiao et al. respectively. Meanwhile, it can obtain the same bit error rate (BER) performance as the algorithm proposed by Xiao et al. while signal noise ratio (SNR) is at medium and high region.*
Keywords: Maximum likelihood detection, DSM, Low-complexity detection method, Bit-padding, Wireless communication

1. **Introduction.** As a special MIMO (Multiple Input Multiple Output) transmit scheme, spatial modulation (SM) [1] can avoid inter-channel interference (ICI) and inter-antenna synchronization (IAS). However, in high mobility scenarios, where the fading channel changes rapidly compared with the symbol transmission rate, it is very difficult and costly to obtain accurate Channel State Information (CSI) and the performance loss will become serious without CSI. For this reason, differential modulation for space-time shift keying (DSTSK) [2,3] was proposed. However, DSTSK needs to search exhaustively the linear dispersion matrix and can only transmit one constellation symbol at a time. Differential spatial modulation (DSM) [4,5] solves these two problems by constructing multiple-symbol matrix, but the complexity of the detection method increases correspondingly. Then a low-complexity detector was proposed in [6]. It utilizes HL-ML algorithm [7] to obtain the antenna indexes and the transmitted symbols. Although the algorithm performs well and its complexity is independent of the size of constellation, the complexity is still high, especially in the cases of larger number transmitting antennas. This paper presents a low complexity differential detection algorithm. It utilizes the concept called bit-padding at transmitter and divides the received signal matrix into signal vectors which can make LC-ML detection algorithm [8] more easily to be applied. Moreover, the computational complexity of the proposed algorithm is further reduced by shrinking the channel matrix at receiver, while the performance remains almost the same as DSM-ML and algorithm in [6] at medium and high SNR region.

The rest of the paper is organized as follows. In Section 2, we introduce the DSM system model and its ML-optimal detection criterion. In Section 3, we present the LC-DSM algorithm for DSM systems under M-PSK modulation. Section 4 compares the performance of the proposed algorithm with other two kinds of algorithms in terms of simulation results, and gives computational analysis. Section 5 ends up the paper with conclusions.

2. **System Model.** Consider an $N_r \times N_t$ differential spatial modulation system with M-PSK modulation. The differential transmission process is as follows.

Step 1: map $\lfloor \log_2^{N_t!} \rfloor + N_t \log_2^M$ ($\lfloor \bullet \rfloor$ means rounding a real number toward negative infinity, and M is the size of constellation) bits into an $N_t \times N_t$ matrix X (there is one and only one non-zero entry in any row and any column of X, which means that only one antenna remains active at each time slot).

Step 2: compute the transmitted block S_t as follows: $S_t = S_{t-1}X_t$ (X_t is the symbol matrix X transmitted at time t).

Step 3: the receive signal Y_t is expressed as

$$Y_t = H_t S_t + N_t, \tag{1}$$

where Y_t, H_t, N_t represent $N_r \times N_t$ receive matrix, channel matrix, additive white Gaussian noise with zero-mean and variance σ^2 at time t respectively.

Step 4: according to [5], the optimal maximum-likelihood (ML) differential detector can be derived as

$$\hat{X}_t = \underset{\forall X \in \Theta}{\arg\min} \left\| Y_t - Y_{t-1}X \right\|_F^2, \tag{2}$$

where Θ is the set of $N_t!M^{N_t}$ symbol matrices X.

3. **Detection Algorithm.** Since the complexity of ML detection increases linearly with the number of transmit and receive antennas, and exponentially with the order of constellation, the complexity of DSM with large-scale antennas is daunting. Considering this problem, by using detective structure of ML, we take Y_{t-1} as channel matrix H_t. From (1), we get

$$\left(\hat{l}_i, \hat{s}_i\right) = \underset{\substack{\forall i \in 1:N_t,\ \forall l \in 1 \sim N_t \\ \forall S \in Q}}{\arg\min} \left\| Y_{t|i} - h_{t|l}s \right\|_F^2, \tag{3}$$

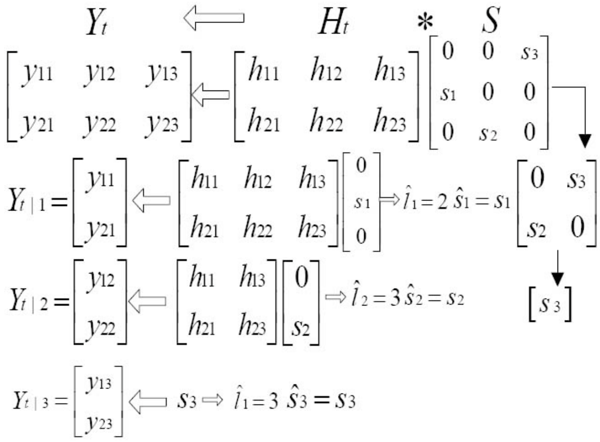
where $\hat{l}_i$, $\hat{s}_i$ are the activated antenna and transmitted symbol respectively, $h_{t|l}$ is the lth column of H_t and it represents the corresponding channel matrix when the lth transmit antenna is activated at time t, and Q is the set of constellation symbols.

The LC-DSM algorithm divides Y_t into N_t signal vectors and utilizes them one by one to recover the transmitted signal. During detection process, we firstly take out the first column of Y_t as $Y_{t|1}$, and then Formula (3) can be deduced as

$$\left(\hat{l}_1, \hat{s}_1\right) = \underset{\substack{\forall l \in 1 \sim N_t \\ \forall S \in Q}}{\arg\min} \left\| Y_{t|1} - h_{t|l}s \right\|_F^2. \tag{4}$$

From (4), the candidate symbols for searching are no longer a matrix but a symbol vector, so we transform the matrix-searching in ML algorithm into vector-searching in coherent detection algorithm. By using the low-complexity detection algorithm in [8], we obtain the activated antenna $\hat{l}_1$ and the transmitted symbol $\hat{s}_1$. The transmitted symbol matrix satisfies the requirement that the transmitted antennas will be used only one time at a transmitter matrix as in [8], so the channel vector corresponding to $\hat{l}_1$ will not participate in the next searching process. On the basis of this characteristic, we delete the $\hat{l}_1$ column from channel matrix H_t and obtain an $N_r \times N_{t-1}$ channel matrix. According to the same method, we take out the second column of Y_t and obtain activated antenna $\hat{l}_2$ and the transmitted symbol $\hat{s}_2$, and then shrink channel matrix H_t. The process is repeated until all activated antennas and transmitted symbols are detected.

Here we present an example to illustrate the algorithm. Assume differential spatial modulation system with QPSK (Quadrature Phase Shift Keying) modulation and $N_t = 3$, $N_r = 2$. A diagram of detection procedure is depicted as follows:



Firstly, we take out the first column of Y_t as $Y_{t|1}$, use it to recover the activated antenna $\hat{l}_1 = 2$ and the transmitted symbol $\hat{s}_2 = s_2$, and then delete the $\hat{l}_1$ column of H_t and H_t shrinks to a 2×2 matrix. Secondly, we take out the second column of Y_t as $Y_{t|2}$, and obtain $\hat{l}_1 = 3$, $\hat{s}_2 = s_2$. Repeat this step until all activated transmit antennas and symbols are detected. During detecting, LC-DSM algorithm utilizes the advantage that the complexity of LC-ML [8] algorithm is independent of M. Moreover, because of the shrinkage of H_t, the algorithm avoids multiplying the candidate symbols by unrelated channel vector, which can further reduce the complexity. However, owing to the detected antenna index should be found essentially in the preset activated antenna matrix [6], the elements in $\hat{l}_i$ $(i = 1, \ldots, N_t)$ obtained at receiver must be different from each other. This may cause some performance loss in low SNR region if the previous elements in $\hat{l}_i$ $(i = 1, \ldots, N_t)$ are detected in error.

A phenomenon needs to be explained here. When $N_t \geq 3$, $N_t!$ may not be an integer power of two. According to the rule of DSM, there are only $2^{\lfloor \log_2^{N_t!} \rfloor}$ kinds of antenna activation schemes, but actually it can be $N_t!$ due to the order of the matrix. This leads to an overflow phenomenon in LC-ML algorithm. Assuming $N_t = 4$, Table 1 gives the antenna activation schemes from 15th to 24th of DSM-ML and LC-DSM algorithm, where the combination of numbers (for example 3-2-1-4) indicates the activation order of all transmitting antennas.

As shown in Table 1, there are 8 more antenna activation schemes in LC-DSM than in DSM-ML. So we might obtain a scheme that cannot be inversely mapped to the right bit information. To solve this problem, we adopt the concept of bit-padding in [9] here and

Table 1. Antenna activation scheme from 15th to 24th of DSM-ML and LC-DSM algorithm

	15	16	17	18	19	20	21	22	23	24
DSM-ML $N_t = 4$	3 2 1 4	3 2 4 1	∼	∼	∼	∼	∼	∼	∼	∼
LC-DSM $N_t! = 4$	3 2 1 4	3 2 4 1	3 4 1 2	3 4 2 1	4 1 2 3	4 1 3 2	4 2 1 3	4 2 3 1	4 3 1 2	4 3 2 1

switch the mapping method from directly using transmit antenna N_t in MIMO system to select transmit antenna based on the N_t! kinds of symbol matrices in DSM system.

4. Simulation Results and Analysis.

4.1. Simulation results. Figure 1 compares the BER (bit error rate) performance with LC-DSM algorithm, DSM-ML algorithm and the algorithm proposed in [6]. We target a spectral efficiency of 2.5 bit/s/Hz and use QPSK modulation in frequency-flat block Rayleigh fading channel.

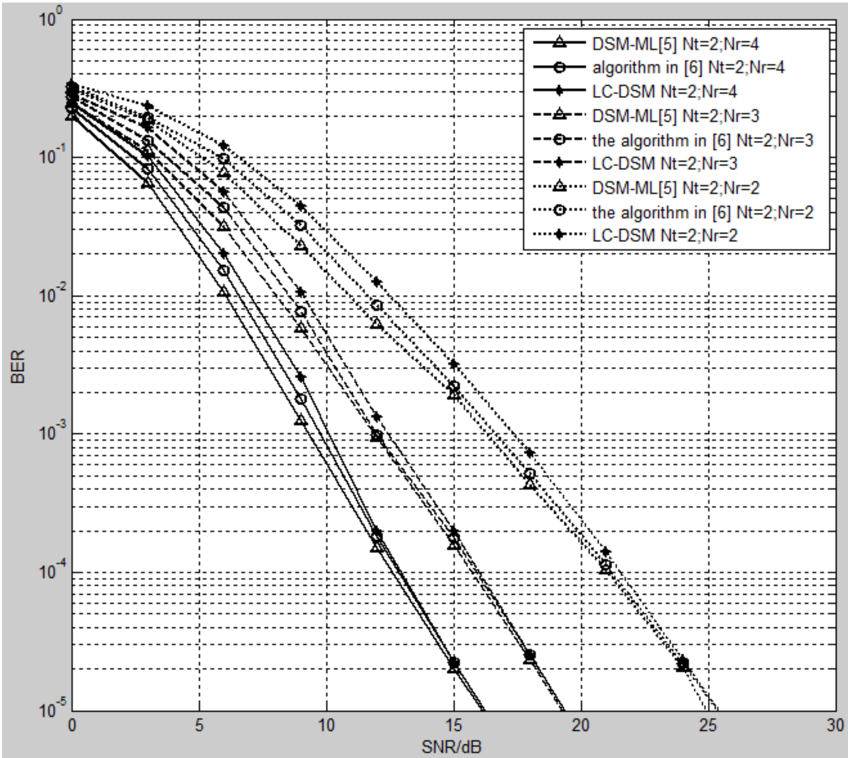


FIGURE 1. BER performance against $N_t = 2$, $N_r = 2, 3, 4$

It can be observed from Figure 1 that under the same spectral efficiency conditions, the LC-DSM has approximately 0.3dB and 0.2dB performance loss compared with DSM-ML and the algorithm in [6] at the SNR region less than 8dB respectively, but has almost no performance loss at the SNR region greater than 12dB. The performance of the algorithms increases with the number of receive antennas under the same number of transmit antennas.

4.2. Complexity analysis. In this subsection, we analyze the complexity of LC-DSM detector by using the number of real-valued multiplications needed in the algorithms. We give the computational complexity of LC-DSM detector as follows.

1) The computational complexity of LC-DSM detector: Employing the complexity analysis method in [8], the algorithm needs $(6N_r + 9)\, N_t$ real-valued multiplications for $Y_{t|1}$ to recover the activated antenna and the transmitted symbol. In the case of $Y_{t|2}$, because there is no need to repeatedly compute $\left\|h_{t|l}\right\|_2^2$ as in [8], we need $(4N_r + 9)\,(N_t - 1)$ real-valued multiplications for $Y_{t|2}$. Analogously we need $(4N_r + 9)$ real-valued multiplications for $Y_{t|N_t}$. Thus, the computational complexity of LC-DSM is

$$C_{LC\text{-}DSM} = 2N_rN_t^2 + \frac{9}{2}N_t^2 + 4N_rN_t + \frac{9}{2}N_t. \quad (5)$$

From (5), it is obvious that the complexity of the algorithm is independent of the size of constellation.

2) The computational complexity of the algorithm proposed in [6] can be expressed as Formula (6) at medium and high SNR regions.

$$C = (4N_rN_t + 11)N_t + (4N_r + 11)N_t(N_t - 1). \tag{6}$$

Figure 2 shows a comparison among DSM-ML in [5], the algorithm in [6] and LC-DSM in this paper. We can see that the algorithm in [6] achieves more than 90% complexity reduction over the DSM-ML algorithm and the LC-DSM algorithm has even lower complexity than [6]. Figure 3 gives a detailed comparison between LC-DSM algorithm and the algorithm in [6].

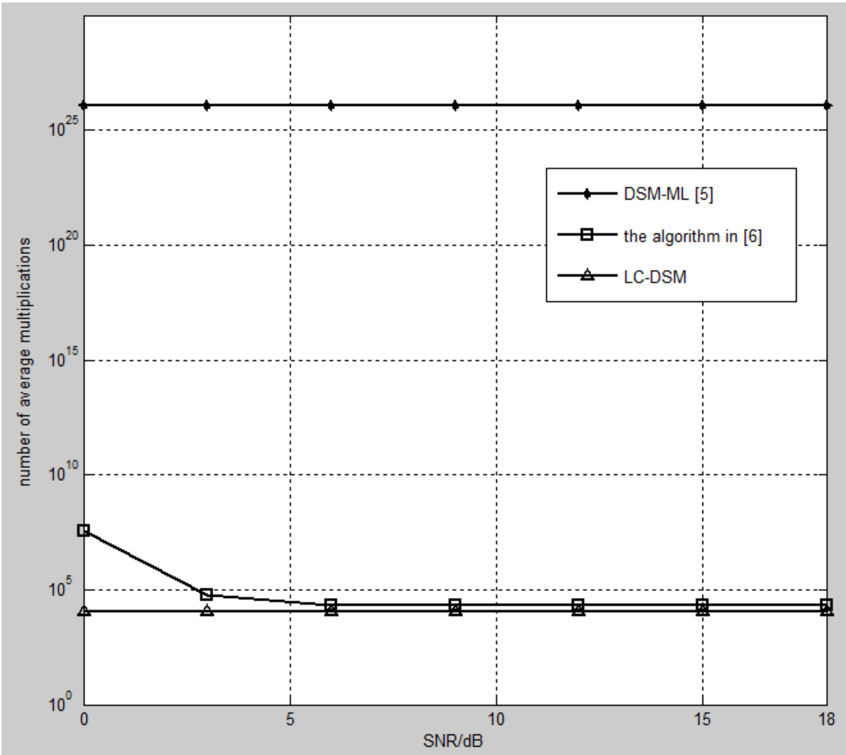


Figure 2. Comparison of the computational complexity among three kinds of algorithms aided QPSK at $N_t = 16$, $N_r = 16$

As can be seen from Figure 3, the computational complexity of LC-DSM algorithm has an at least 50% reduction compared with the algorithm in [6] when $N_r = 16$. Meanwhile, as the number of transmit antennas grows, the difference becomes more considerable. In the case of $N_t = 14$, as the number of receive antenna grows, the complexity difference becomes bigger than 50%.

5. **Conclusions.** In this letter, a novel LC-DSM detection method is proposed for differential spatial modulation system. By transforming the equation structure of DSM-ML algorithm, the LC-DSM detection can perform on the basis of the traditional searching method of spatial modulation system. Simulation results show that LC-DSM algorithm greatly reduces the computational complexity compared with the algorithm in [6], while keeps the same performance in medium and high SNR regions. As its complexity is independent of modulation order, the algorithm is more suitable to large-scale MIMO systems. Our future work will be focused on applying the integration of ASVD algorithm [10] and sphere-decoding [11] into the proposed scheme.

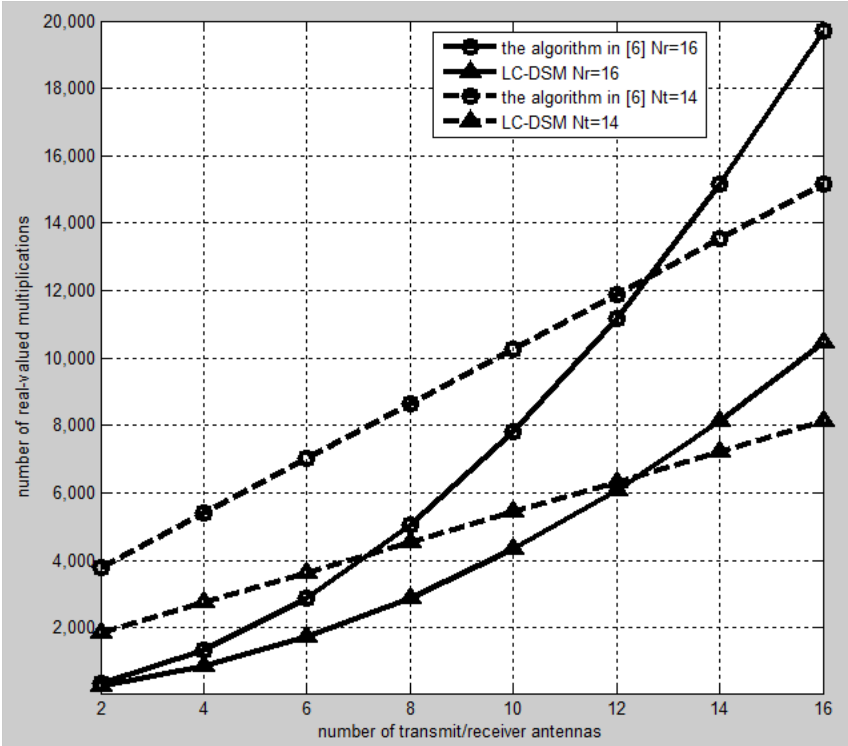


FIGURE 3. Comparison of the computational complexity between LC-DSM algorithm and the algorithm in [6] against $N_r = 16$ and $N_t = 14$

Acknowledgment. This work was supported by the National Science Foundation of China (61571108&61571250). The project of Education Department of Zhejiang Province (Y201432108) and the Open Fund for the Information and Communication Engineering Key-Key Discipline of Zhejiang Province, Ningbo University (xkx11414).

REFERENCES

[1] J. Jeganathan, A. Ghrayeb and L. Szczecinski, Spatial modulation modulation: Optimal detection and performance analysis, *IEEE Communications Letters*, vol.12, no.8, pp.545-547, 2008.
[2] C. Xu, S. Sugiura and S. X. Ng, Reduced-complexity noncoherently detected differential space-time shift keying, *IEEE Signal Processing Letters*, vol.18, no.3, pp.153-156, 2011.
[3] N. Ishikawa and S. Sugiura, Unified differential spatial modulation, *IEEE Wireless Communications Letters*, vol.3, no.4, pp.337-340, 2014.
[4] Y. Bian, M. Wen and X. Cheng, A differential scheme for spatial modulation, *IEEE Global Communications Conference*, pp.3925-3930, 2013.
[5] Y. Bian, X. Cheng and M. Wen, Differential spatial modulation, *IEEE Trans. Vehicular Technology*, vol.64, no.7, pp.3262-3268, 2014.
[6] L. Xiao, P. Yang, X. Lei and Y. Xiao, A low-complexity detection scheme for differential spatial modulation, *IEEE Communications Letters*, vol.19, no.9, pp.1516-1519, 2015.
[7] R. Rajashekar, K. V. S. Hari and L. Hanzo, Reduced-complexity ML detection and capacity-optimized training for spatial modulation systems, *IEEE Trans. Communications*, vol.62, no.1, pp.112-125, 2014.
[8] H. Men and M. Jin, A low-complexity ML detection algorithm for spatial modulation systems with MPSK constellation, *IEEE Communications Letters*, vol.18, no.8, pp.1375-1378, 2014.
[9] Y. Yang and S. Aissa, Bit-padding information guided channel hopping, *IEEE Communications Letters*, vol.15, no.2, pp.163-165, 2014.
[10] W. Zhang and Q. Yin, Adaptive signal vector based detection for spatial modulation, *IEEE Communications Letters*, vol.18, no.11, pp.2059-2062, 2014.
[11] A. Younis, S. Sinanovic and M. D. Renzo, Generalised sphere decoding for spatial modulation, *IEEE Trans. Communications*, vol.62, no.7, pp.2805-2815, 2013.