In-Sequence Zeros-Ones Patterns Exploiting Approach for Spatial Modulation Performance Enhancement

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Abstract

This paper presents a proposed approach for enhancing both the spectral efficiency of spatial modulation and symbol error rate. The main idea is to exploiting repeated long zeros and ones sequences in the transmitted data, and mapping them into the signal constellation of Three Dimension (3-D) spatial constellation of spatial modulation. The obtained results indicate that the symbol error rate (SER) performance of the proposed algorithm is better as compared to traditional spatial modulation (SM), at a certain number of modulated-symbol selecting bits. The performance enhancement is affirmed by Monte Carlo simulations that show a significant improvement in SER in favor of the proposed approach compared to traditional SM. In addition, the proposed approach provides more improvement of SER performance, especially, when the number of receiving antennas is increased. Furthermore, it provides an improvement of spectral efficiency as compared to traditional spatial modulation.

1. Introduction

In recent days, carbon dioxide emissions are increased, affecting the planet and its population negatively. One reason for this is the evolution of technology and increasing need for burning large amounts of fuel for electricity generation as a consequent. To solve this dilemma, the world has steered research to exploit renewable energy in its various forms; such as solar energy and wind power; and reduce power consumption without

affecting the future requirements of technological development, such as increasing data transfer rates and improving the performance of telecommunication systems, to reach a green world [1]. Multi-Input Multi-Output (MIMO) techniques, e.g., spatial multiplexing (SMX), have been utilized to improve the data rates by transmitting from many antennas, simultaneously [2]. Thus, the spectral efficiency (SE) can be improved at the expense of energy efficiency (EE) [3]. Moreover, the limitations of SMX include the need for a large number of transmitter RF chains, increased receiver complexity and inter-channel interference (ICI) [1].
Spatial Modulation (SM) was presented in [4] to decrease the previously mentioned limitations of SMX by reducing the number of RF chains utilized to one RF chain followed by a fast switching antennas system, moreover, spatial modulation provides a good avoidance of ICI effect; therefore both EE and SE can be enhanced. SM technique concept is established on splitting data to be transmitted into information symbols of length (m) bits. Every information symbol (S) is then mapped into two groups of bits; the first group of bits (S_a^{SM}) of number (m_a^{SM}) bits is bits which define the index of the active antenna (a_t) that will be used for information symbol transmission, out of all the available (N_t^{SM}) transmitter antennas, which constitutes the spatial constellation of spatial modulation technique [1, 5], as given in Eq. (1):

$$m_a^{SM} = log_2\left(N_t^{SM}\right) \tag{1}$$

The second group of bits (S_{mod}^{SM}), given in Eq. (2) [1], determines the data symbol selected from the available signal constellation of cardinality $M-ary$ $(M = 2^{m_{\mathrm{mod}}^{SM}}$), to be transmitted using the selected active antenna.

$$m_{\mathrm{mod}}^{SM} = log_2(M) \quad bits \tag{2}$$

The number of bits per channel use defines the rate of SM transmission (R_{SM}), which is the same as the spectral efficiency of spatial modulation, that is presented in Eq. (3) [4, 5] :

$$R_{SM} = m_a^{SM} + m_{mod}^{SM} \quad bpcu \tag{3}$$

It should be taken into consideration the effect of the number of transmitting antennas and signal constellation cardinality on SE of SM; as they are directly proportioned to SE. The superiority of SM over MIMO has been proved by both laboratory experiments [6,7] and numerical simulations [5,8]. A key limitation of SM is that a large number of antennas needed to increase SE as only one antenna is allowed to be active at every channel realization for transmitting in-sequence information symbols.

The generalized spatial modulation (GSM) algorithm is developed in [9], to reduce the number of antennas at the transmitter; N_t^{GSM}, by allowing u_t antennas to be active at the same time while transmitting a certain information symbol. The number of bits that select the required antennas-combination from available antennas-combinations of GSM; m_a^{GSM}, is as shown in Eq. (4):[9]

$$m_a^{GSM} = \left\lfloor log_2 \binom{N_t^{GSM}}{u_t} \right\rfloor \quad bits \tag{4}$$

where $\lfloor . \rfloor$ is the floor function. Thus, the number of active antennas-combinations (Ψ^{GSM}) of GSM is presented in Eq. (5):[9]

$$\psi_{GSM} = 2^{(m_a^{GSM})} \tag{5}$$

, these combinations obtained from available GSM transmitter antennas (N_t^{GSM}) which is determined as shown in Eq. (6):

$$N_t^{GSM} = \left\lceil \frac{1 + \sqrt{1 + (8 \times 2^{m_a^{GSM}})}}{2} \right\rceil \quad antennas \tag{6}$$

where $\lceil . \rceil$ is the ceil function, and the rate of GSM transmission is as given in Eq. (7):[9]

$$R_{GSM} = m_a^{GSM} + m_{\mathrm{mod}}^{GSM} \qquad bpcu \tag{7}$$

For example, if an information symbol of length $m = 5$ bits, and utilizing a BPSK modulation ($m_{mod} = 1$); the remaining $m - m_{mod} = 4$ bits should select the active antennas combinations. Thus, SM needs $N_t^{SM} = 2^{(m - m_{\mathrm{mod}})} = 2^4 = 16$ antennas; while GSM with $u_t = 2$ active antennas per transmission of this symbol, needs $N_t^{GSM} = 7$ antennas.

Although the reduction in the number of antennas provided by GSM compared to SM, a degradation in performance has been encountered [9].

In [10], it was demonstrated that if the number of active antennas per transmission of a symbol in GSM is configured to be inconstant, the number of transmitter antennas is decreased. In this case, the number of combinations of VGSM antennas can be computed as given in Eq. (8):[10]

$$\psi_{VGSM} = \sum_{n=1}^{N_t^{VGSM}} \binom{N_t^{VGSM}}{u_t} = 2^{N_t^{VGSM}} - 1 \tag{8}$$

that provides a number of antenna selecting bits (m_b^{VGSM}) of VGSM as expressed in Eq. (9):[10]

$$m_a^{VGSM} = log_2(2^{N_t^{VGSM}-1}) = N_t^{VGSM} - 1 \tag{9}$$

thus the number of transmitter antennas for VGSM is as shown in Eq. (10):

$$N_t^{VGSM} = m_a^{VGSM} + 1 \; antennas \tag{10}$$

with rate of transmission(R_{VGSM}) as represented in Eq. (11):[10]

$$R_{VGSM} = log_2(M) + N_t^{VGSM} - 1 \tag{11}$$

For example, $m = 5$ bits, BPSK modulation ($m_{mod} = 1$), and $m_a^{VGSM} = 4$, thus $N_t^{VGSM} = m_a^{VGSM} + 1 = 4 + 1 = 5$ antennas are required at VGSM transmitter. As consequence VGSM is in higher order than SM and GSM in the reduction of the number of antennas, however, there is a degradation in the performance of VGSM as compared to SM and GSM [10].

In [11], it was shown that performing a mid-symbol duration antenna transition (**MAT**), reduce the number of transmitter antennas. In this case, the number of combinations of MAT antennas can be computed as given in Eq. (12):[11]

$$\psi_{MAT} = 2^{m_a^{MAT}} \tag{12}$$

that provides a number of antenna selecting bits (m_a^{MAT}) of MAT as expressed in Eq. (13):

$$m_a^{MAT} = \left\lfloor log_2\left(N_t^{MAT}\right)^2 \right\rfloor \quad \text{bits} \tag{13}$$

thus the number of transmitter antennas for MAT is as shown in Eq. (14):[11]

$$N_t^{MAT} = \left\lceil \sqrt{2^{m_a^{MAT}}} \right\rceil \; \text{antennas} \tag{14}$$

with rate of transmission(R_{MAT}) as represented in Eq. (15):[10]

$$\begin{aligned} R_{MAT} &= m_a^{MAT} + m_{mod} \\ &= \left\lfloor log_2\left(N_t^{MAT}\right)^2 \right\rfloor + log_2(M) \; bpcu \end{aligned} \tag{15}$$

For example, $m = 5$ bits, BPSK modulation ($m_{mod} = 1$), and $m_a^{MAT} = 4$, thus $N_t^{MAT} = \left\lceil \sqrt{2^{m_a^{MAT}}} \right\rceil = \left\lceil \sqrt{2^4} \right\rceil = 4$ antennas are required at MAT transmitter. Therefore, MAT is the best in reducing the number of required transmitter antennas for the same spectral efficiency with a significant performance enhancement. It should be noted that all above-mentioned techniques GSM, VGSM, and MAT have the same spectral efficiency sub-optimality as SM [1].

The contribution of this paper is using the Zeros-Ones EXploiting proposed approach (ZOEX) that is constructed on exploiting repeated long zeros and ones sequences in transmitted data, and mapping them into the signal constellation of the 3-D spatial constellation, [1], of spatial modulation. The main advantage of this approach is that it provides a significant improvement in the spectral efficiency compared to SM. Furthermore, the proposed approach improves the SER performance compared to SM.

The organization of the rest of the paper is as follows. The system model is presented in section II. Section III discusses Monte Carlo simulation results. Finally, the conclusion is reported in section IV, followed by the relevant references.

2. SYSTEM MODEL

The proposed approach (ZOEX) introduces an algorithm for enhancing the spectral efficiency, moreover improving the SER performance, rather than SM, through exploiting repeated long zeros and ones sequences in transmitted data, and mapping them into the signal constellation of the 3-D spatial constellation of spatial modulation.

The procedure of the proposed approach is starting with computing the required number of transmitting antennas ($N_t^{proposed}$) from the available number of antennas selection bits ($m_a^{proposed}$), according to Eq. (16):

$$N_t^{proposed} = m_a^{proposed} \; bits \tag{16}$$

as well as, antennas combinations for information symbols transmissions can be obtained from Eq. (17):

$$\psi_{antenna}^{proposed} = 2^{m_a^{proposed}} \tag{17}$$

in addition to the number of available (M) QAM symbols in the signal constellation of the proposed approach, which is the same as SM signal constellation, as given in Eq. (18):

$$M = 2^{m_{\mathrm{mod}}^{proposed}} \qquad (18)$$

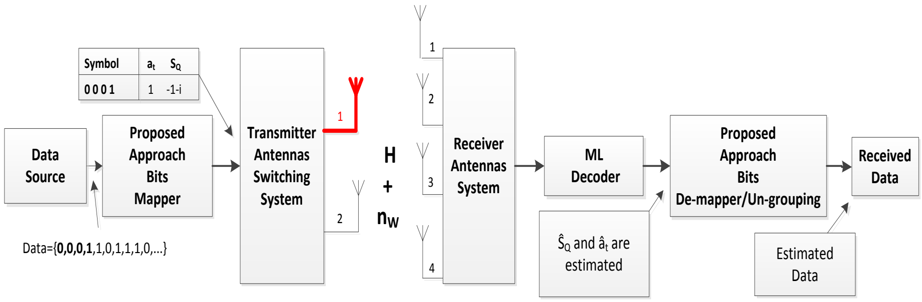

Fig. 1: Proposed ZOEX approach system model with 4 bits symbol transmission presented.

The block diagram for the proposed ZOEX approach is depicted in Fig. 1. The transmission and reception processes of the proposed approach are presented in the following steps:

1- Data is flowing from the source, then the proposed ZOEX approach bits mapper starts to define the first bit (S_a), which determines the index of active transmitting antenna (a_t) for the present information symbol transmission.

2- Thereafter, the proposed ZOEX approach bits mapper checks if the first-next bit in the data sequence is the same as antenna selecting bit, then the ZOEX mapper maps the second-next bit in the data sequence and so on. Until the ZOEX mapper finds that the i^{th}-next bit in the data sequence is not the same as the antennas selecting bits. Thereafter, the ZEOX mapper takes these mapped bits in sequence as an information symbol ($S_{\mathrm{mod}}^{proposed}$) of length ($i+1$).

3- The first bit, in this ZOEX information symbol of ($i+1$) bits length defines antenna selecting bit, and the length of the rest (i) bits determines the binary index ($S_{Q-index}^{proposed}$) of modulated data symbol (s_Q) from available (M) QAM symbols in proposed approach signal constellation, which transmitted by this active antenna (a_t). It should be noted that the length of the binary index

($S_{Q-index}^{proposed}$) equals to the length of $M-QAM$ selecting bits (m_{mod}^{SM}) for SM, as $M=2^{m_{\text{mod}}^{SM}}$.

4- As a result of the proposed ZOEX approach mapping process, the rate of transmission is computed according to the variable-length mapped information symbols from the data sequence, from the following Eq. (19):

$$R_{proposed}=\frac{\sum_{i=1}^{M}(i+1)}{M}\quad bpcu \tag{19}$$

5- These grouped bits of the information symbol is then mapped according to the proposed ZOEX approach look-up table, each row in this look-up table defines a certain information symbol, which is defined by its length and antenna index. An example of the proposed approach look-up table is outlined in Table 1, for m=4, $m_{a}^{proposed}$=1, $m_{\text{mod}}^{proposed}$=3 and the rate of transmission is $R_{proposed}=\frac{2+3+4+5+6+7+8+9}{8}=5.5\ bpcu$.

6- Thereafter, transmitter antennas switching system selects the indexed (a_t) antenna, which is utilized to transmit the ZOEX mapper output; information symbol (S_Q), over MIMO wireless channel, H, of dimensions $N_r x N_t^{proposed}$.

7- At the receiver with (N_r) receiving antennas, a signal (y) is detected with all available antennas, which is defined by the following Eq. (20):

$$y=h_{a_t}S_Q+n \tag{20}$$

, as (n) is a (N_r) length channel noise vector , (h_{a_t}) selects only one column of (H) according to the antenna (a_t), and (S_Q) is the selected QAM symbol referring to $S_{Q-index}^{proposed}$ bits.

8- Maximum-Likelihood decoder is used at the receiver to search for an estimation for transmitting antenna index ($\hat{a}_t$), in addition to an estimation of transmitted QAM symbol ($\hat{S}_Q$), as shown in Eq. (21):[9, 12]

$$[\hat{a}_t,\hat{S}_Q]=\underset{(a_x,s_x)^{proposed}}{arg}\ min\sum_{n=1}^{N_r}|y-h_{a_x}s_x|^2 \tag{21}$$

where a_x is the available antennas indices at the transmitter ($a_x \in \left[1 : N_t^{proposed}\right]$), s_x is the available QAM Symbols in the signal constellation ($s_x \in M$), and h_{a_x} is the selected column of H according to a_x.

9- Proposed ZOEX de-mapping process utilizes $\hat{S_Q}$, and $\hat{a}_t$ values to define an estimation of the transmitted information symbol $\hat{s}$, according to the proposed ZOEX approach mapping table.

10- Thereafter, the un-grouping process provides an estimated form of the transmitted data.

An one instance example of information symbol (S) transmission of [0 0 0 1] bits is represented in Fig. 1, where $m = 4$, 8-QPSK modulation is utilized, $M = 8$, $m_{\mathrm{mod}}^{proposed} = \log_2 M = \log_2 8 = 3$ bits, $m_a^{proposed} = m - m_{\mathrm{mod}} = 4 - 1 = 3$ bits, $N_t^{proposed} = 2^{m_a^{proposed}} = 2^1 = 2$ antennas, $S_a = [0]$, $S_{QAM}^{proposed} =$ [001], $i = 3$, $S_{Q-index}^{proposed}$ =[010], and S_Q =-1-i .

Table 1 PROPOSED ZOEX APPROACH LOOK-UP TABLE EXAMPLE

S	S_a	$S_{QAM}^{proposed}$	$S_{Q-index}^{proposed}$	S_Q	a_t
01	0	1	000	-3-i	1
001	0	01	001	-3+i	1
0001	0	001	010	-1-i	1
00001	0	0001	011	-1+i	1
000001	0	00001	100	+1-i	1
0000001	0	000001	101	+1+i	1
00000001	0	0000001	110	+3-i	1
000000001	0	00000001	111	+3+i	1
10	1	0	000	-3-i	2
110	1	10	001	-3+i	2
1110	1	110	010	-1-i	2
11110	1	1110	011	-1+i	2
111110	1	11110	100	+1-i	2
1111110	1	111110	101	+1+i	2
11111110	1	1111110	110	+3-i	2
111111110	1	11111110	111	+3+i	2

3. SIMULATION RESULTS

Monte Carlo simulations [13] of 10^{6} channel realizations for the proposed ZOEX approach were performed, to verify that the proposed ZOEX approach provides more improvement of SER performance, compared to SM. Monte Carlo simulations are executed by system parameters outlined in Table 2.

Figure 3 illustrates the SER Vs. SNR for the proposed ZOEX approach and SM, over a MIMO Rayleigh flat fading wireless channel with AWGN of zero-mean and unit variance, where $m = 4$, $N_r = 2$ & 4, $N_t^{proposed} = 2$ and $N_t^{SM} = 2$, using 8-QPSK modulation. As depicted in Fig. 3, the obtained simulation results of the proposed ZOEX approach conclude that the SER performance is better as compared to SM. The improvement in SER performance using the proposed ZOEX approach as compared to SM is presented numerically in Table 3 and displayed graphically by bar chart in Fig. 4.

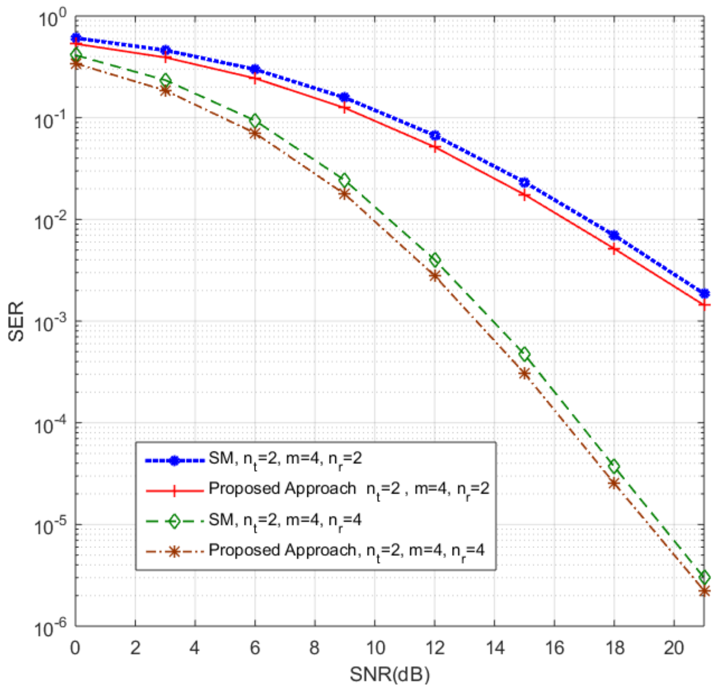

Fig. 3 SER vs. SNR for proposed ZOEX approach and SM.

TABLE 2 MONTE CARLO SIMULATIONS SYSTEM PARAMETERS FOR PROPOSED ZOEX APPROACH[1].

Parameter	**Symbol**	**SM**	**Proposed ZOEX Approach**
On channel transmitted Symbol length	m	4	
Data length	$m \times 10^6$	4*10^6	
No. of antenna selection bits per symbol	m_a	1	
No. of data bits	m_{mod}	3	variable
No. of QAM binary index bits	$m_{Q-index}^{proposed}$	-	3
Modulated symbols number	M	8 for 8-QPSK	
Channel	H	MIMO Rayleigh flat fading wireless channel	
Noise	n_W	AWGN of zero-mean and unit variance	
No. of transmitting antennas	N_t	2	
No. of receiving antennas	N_r	Simulation Iterated for 2 and 4	

TABLE 3 PROPOSED ZOEX APPROACH SER PERFORMANCE IMPROVEMENTS

SNR (dB)	**Proposed ZOEX Approach Improvement Parentage (%)**	
	$\mathbf{N_r = 2}$	$\mathbf{N_r = 4}$
0	12.21	17.26
3	15.05	20.84
6	18.25	24.75
9	20.75	26.95
12	23.02	30.47
15	24.62	34.88
18	26.04	31.43
21	22.81	25.38

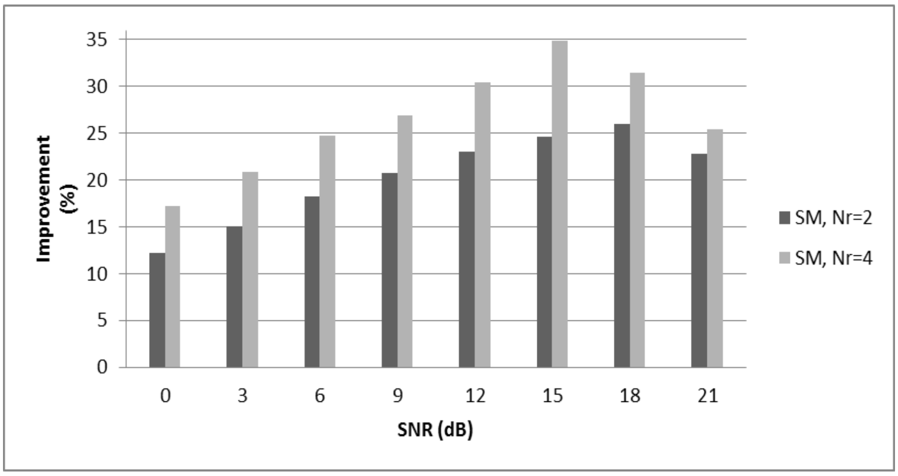

Fig. 4 The Bar chart of the proposed ZOEX approach SER performance improvements.

At a specific value of SNR (dB), e.g. 12 dB, SER values for the proposed ZOEX approach and SM are 0.051602 and 0.06704, respectively, at $N_r = 2$. For $N_r = 4$, SER values for the proposed ZOEX approach and SM are 0.0027899, 0.004013 respectively. By utilizing this sample of data of SER as an example, improvement percentage of the proposed ZOEX approach compared to SM can be calculated by the following Eq. (15):

$$\left(\frac{BER_{proposed} - BER_{SM}}{BER_{SM}} \right) \times 100\% \tag{22}$$

The proposed ZOEX approach shows an improvement of SER performance, at N_r=2 compared to SM, by 23.02 %. In addition, at N_r=4, the improvement percentage, at SNR of 12 dB, is 30.47%. Moreover, when N_r is increased from 2 to 4, SER value of the proposed ZOEX approach changes from 0.051602 to 0.0027899, that introduces self SER performance improvement of the proposed ZOEX approach by 94.59 %.

Enhancing Spectral Efficiency is the main objective of the proposed ZOEX approach. It should be noted that the link spectral efficiency of a digital communication system is the net bitrate (useful information rate excluding error-correcting codes) or maximum throughput divided by the bandwidth in hertz of a communication channel or a data link, is measured in (bit/s/Hz). Alternatively, the spectral efficiency may be measured in bit/symbol, which is equivalent to bits per channel use (bpcu)[14]. Therefore, the spectral efficiency has the same value of the rate of SM or the rate of the proposed ZOEX approach.

A shorthand comparison study for the proposed ZEOX approach main objective proof is performed by taking several values of QAM Symbol Selecting bits number (m_{mod}), thereafter, computing values of data rates of SM and the proposed ZOEX approach from aforementioned equations (3), and (19), respectively. This short hand study shows that increasing number of QAM Symbol Selecting bits number (m_{mod}), improves Spectral Efficiency, e.g., for $m_{\text{mod}} = 4\ bits$, $R_{SM} = 5\ bpcu$ and $R_{proposed} = 9.5$ bpcu. Thus, the proposed ZOEX approach Spectral Efficiency improvement percentage is 90%, as outlined in TABLE 4 and presented graphically by bar chart in Fig. 5.

TABLE 4 PROPOSED ZOEX APPROACH SPECTRAL EFFECIENCY IMPROVEMENTS

No. of QAM Symbol Selecting bits m_{mod}	**SM Spectral Efficiency** R_{SM} $(bpcu)$	**Proposed ZOEX Approach Spectral Efficiency** $R_{proposed}$ $(bpcu)$	**Proposed ZOEX Approach SE Improvements (%)**
2	3	3.5	16.66
3	4	5.5	37.5
4	5	9.5	90
5	6	17.5	191.67
6	7	33.5	378.5

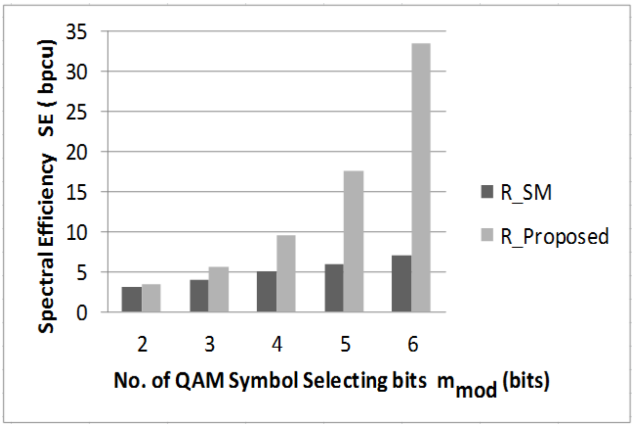

Fig. 5 The Bar chart of the SE of proposed ZOEX approach and SM vs No. of QAM Symbol Selecting bits.

4. CONCOLUSION

This paper presented a proposed approach to improve the Spectral Efficiency of spatial modulation and enhance the SER performance of SM. Exploiting repeated Zeros-Ones sequences in the data sequence is the basis for the proposed ZOEX approach. The Symbol Error Rate (SER) performance of the proposed algorithm is better than SM. The performance enhancement is proved by Monte Carlo simulations that show a significant improvement in SER in favor of the proposed ZOEX approach by about 26% as compared to SM. When the number of receiving antennas is doubled, the achieved improvement of SER performance is nearly 94.59 %, for same system configuration. In addition, a comparison study between SM and the proposed ZOEX approach is established by calculating the spectral efficiency for both techniques at different values of modulated data selecting bits. Results show that there is an improvement in Spectral Efficiency, for the same number of modulated data selecting bits, by 90% as compared to SM.

References

[1] M. Di Renzo, H. Haas, A. Ghrayeb, S. Sugiura, and L. Hanzo, "spatial modulation for Generalized MIMO: challenges, opportunities, and implementation," *Proc. IEEE Proceedings of the IEEE,* vol. 102, pp. 56-103, 2014.

[2] J. Mietzner, R. Schober, L. Lampe, W. H. Gerstacker, and P. A. Hoeher, "Multiple-antenna techniques for wireless communications-a comprehensive literature survey," *IEEE communications surveys & tutorials,* vol. 11, 2009.

[3] J. Xu and L. Qiu, "Energy efficiency optimization for MIMO broadcast channels," *IEEE Transactions on Wireless Communications,* vol. 12, pp. 690-701, 2013.

[4] R. Y. Mesleh, H. Haas, S. Sinanovic, C. W. Ahn, and S. Yun, "Spatial modulation," *IEEE Transactions on Vehicular Technology,* vol. 57, pp. 2228-2241, 2008.

[5] M. Di Renzo, H. Haas, and P. M. Grant, "Spatial modulation for multiple-antenna wireless systems: A survey," *IEEE Communications Magazine,* vol. 49, 2011.

[6] N. Serafimovski, A. Younis, R. Mesleh, P. Chambers, M. Di Renzo, C.-X. Wang, *et al.*, "Practical implementation of spatial modulation," *IEEE Transactions on Vehicular Technology,* vol. 62, pp. 4511-4523, 2013.

[7] A. Stavridis, S. Sinanovic, M. Di Renzo, and H. Haas, "Energy evaluation of spatial modulation at a multi-antenna base station," in *Vehicular Technology Conference (VTC Fall), 2013 IEEE 78th*, 2013, pp. 1-5.

[8] M. Di Renzo and H. Haas, "Bit error probability of SM-MIMO over generalized fading channels," *IEEE Transactions on Vehicular Technology,* vol. 61, pp. 1124-1144, 2012.

[9] A. Younis, N. Serafimovski, R. Mesleh, and H. Haas, "Generalised spatial modulation," in *Signals, Systems and Computers (ASILOMAR), 2010 Conference Record of the Forty Fourth Asilomar Conference on*, 2010, pp. 1498-1502.

[10] A. Younis, "Spatial modulation: theory to practice," *Ph.D. dissertation, University of Edinburgh*, 2014.

[11] M. Arafa, M. Elwekeil, and M. Dessouky, "Mid-Symbol duration antenna transition approach for performance enhancement of spatial modulation," *Electronics Letters*, 2018.

[12] Y. S. Cho, J. Kim, W. Y. Yang, and C. G. Kang, *MIMO-OFDM wireless communications with MATLAB*: John Wiley & Sons, 2010.

[13] T. S. Rappaport, *Prentice hall communications engineering and emerging technologies series*: Prentice Hall PTR, 1998.

[14] S. Benedetto and E. Biglieri, *Principles of digital transmission: with wireless applications*: Springer Science & Business Media, 1999.

الملخص باللغة العربية

يقدم هذا البحث مقترحًا لتعزيز كل من الكفاءة الطيفية ومعدل أخطاء الرموز للتعديل الحيزي. الفكرة الرئيسية هي استغلال الأصفار والوحدان الطويلة المتتالية والمتكررة في البيانات المنقولة ، وإدراجها داخل كوكبة الإشارة التي هي جزء من الكوكبة الحيزية الثلاثية الأبعاد للتعديل الحيزي. وتشير النتائج التي تم الحصول عليها إلى أن أداء معدل الخطأ للرمز (SER) للخوارزمية المقترحة أفضل بالمقارنة بالتعديل الحيزي التقليدي (SM) ، عند استخدام نفس العدد من البتات التي تختار الرموز المعدلة. تم التأكيد على تحسين الأداء من خلال محاكاة مونت كارلو التي تظهر تحسنا كبيرا في أداء معدل الخطأ للرمز (SER) لصالح النهج المقترح مقارنة بالتعديل الحيزي التقليدي. بالإضافة إلى ذلك ، يوفر النهج المقترح تحسينًا أكبر لأداء معدل الخطأ للرمز (SER) ، خاصة عند زيادة عدد هوائيات الاستقبال. وعلاوة على ذلك ، فإنه يعمل على تحسين الكفاءة الطيفية مقارنة بالتعديل الحيزي التقليدي.