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Spatial Permutation Modulation for MIMO-OFDM Systems

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ABSTRACT: Spatial Modulation (SM) is a recently developed low-complexity Multiple-Input Multiple-Output scheme. In any given symbol interval, SM selects only one antenna from multiple available antennas for transmission. In this, a block of information bits is mapped into two information carrying units: first unit selects the antenna index from a set of transmit antennas and second unit selects a symbol from the constellation. This will increase the spectral efficiency and decrease the complexity at the receiver. Spatial Permutation Modulation (SPM) is a variant of SM which extends SM in to time co-ordinate. SPM exploits the transmit diversity to enhance error rate performance. This new transmission technique modulates data bits to a permutation vector and activates the transmit antenna at successive time instants. In the proposed system, SPM MIMO is integrated with OFDM system which enhance the spectral efficiency of the system. Similar to SM, SPM MIMO-OFDM also maps a block of information bits in to two information carrying units: first units selects a unique permutation vector from a permutation set and second unit selects symbol from the constellation sets. This system model also increases the data rate of transmission with minimum bit error rate.

KEYWORDS: MIMO, OFDM, SM, SPM

I. INTRODUCTION

The need for high data rate and high spectral efficiency are the key requirements for wireless communication systems. Multiple antennas in wireless systems offer a practical way to extend next-generation communication systems. This concept leads to the evolution of Multiple-input multiple output (MIMO) technology with improved data rate and diversity. However, regardless of the use of spatial multiplexing, diversity, or smart antenna system, the main draw-back of any MIMO system is an increase in complexity and cost. This is primarily due to the following reasons: Inter-Channel Interference (ICI), which is introduced by superimposing independent information sequences to be transmitted by multiple transmit antenna, the complexity of the system due to multiple antennas and requirement of multiple Radio Frequency (RF) chains, which are needed to transmit all the signals simultaneously and are, in general, expensive. However, because of the benefits of MIMO system it must be a clear research goal to develop new approaches for multiple antenna transmission in order to mitigate the practical limitations while retaining the key advantages.

Spatial Modulation (SM) has been proposed as a new MIMO transmission scheme, which aims at reducing the complexity and cost of multiple antenna system without deteriorating the end-to-end system performance and still guaranteeing good data rates. More specifically, low complexity system design and high spectral efficiency are simultaneously achieved by adopting spatial modulation.

In SM, one transmit antenna is activated at a time instance for data transmission. This allows SM to entirely avoid the ICI, to require no synchronization among the transmit antenna. So SM requires only one RF chain for data transmission resulting in huge saving of circuit complexity and power consumption with respect to conventional MIMO schemes where the multiple-antenna are used to simultaneously transmit multiple data streams.

The spatial position of each transmit-antenna in the antenna-array is used as a source of information. This is obtained by establishing a one-to-one mapping between each antenna index and a block of information bits to be transmitted, which results in a coding mechanism that can be called transmit-antenna index coded modulation. This allows SM to achieve a spatial multiplexing gain with respect to conventional single-antenna systems since part of the information is implicitly conveyed by the position of the transmit antenna. Accordingly, even though just one antenna is active, SM can also achieve high data throughput[1].

There are some limitations for SM. As only one antenna is active at a time, the spectral efficiency of SM is reduced as the number of transmitting antenna is increased. Data rate can be increased only in logarithmic scale, rather than linear, in SM-MIMO. This limits SM to attain high spectral efficiency as number of antenna increase beyond a limit. Accurate knowledge of CSI is required at receiver to retrieve the message transmitted. Design problems of SM-MIMO

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in frequency selective fading channels still exist. Frequency selective fading cannot be avoided in 5G networks due to the high transmission rate[3].

Spatial permutation modulation was recently proposed to extend the conventional SM into the time coordinate. A sequence of activated transmit antennas during a codeword interval, called permutation array (PA), is transmitted in the SPM system. The main difference of SPM from SM is that the SPM transmits a set of antenna indices according to the PA during several time instants. The SPM utilizes more antennas for several time instants and has more transmit diversity than the SM system. Therefore, the SPM has superior BER performance to the SM. Moreover, the SPM also uses single antenna at a time instant and therefore, SPM strikes a good balance among the spectral efficiency, energy efficiency, computational complexity, and reliability[2].

The data rate and spectral efficiency of SPM MIMO can be enhanced by combining SPM MIMO system with OFDM as high data rate stream is converted in to a number of small data rate streams and transmitted simultaneously through different subcarriers. The proposed system also provides better BER performance compared to SM-MIMO and SPM-MIMO.

II. SM-MIMO SYSTEM MODEL

The basic idea of SM is to map a block of information bits into two information carrying units: a symbol that was chosen from a constellation diagram and a unique transmit antenna number that was chosen from a set of transmit antennas. Figure 2.1 shows the basic block diagram of SM. Compared to the conventional MIMO system, SM uses only one active antenna at a time to avoid Inter Channel Interference (ICI). Let N_T be the number of transmit antennas and N_R be the number of receive antennas. Let M be the size of Signal Constellations. The length n of information block will be:

$$n = \log_2 N_T + \log_2 M \qquad \text{eq. (1)}$$

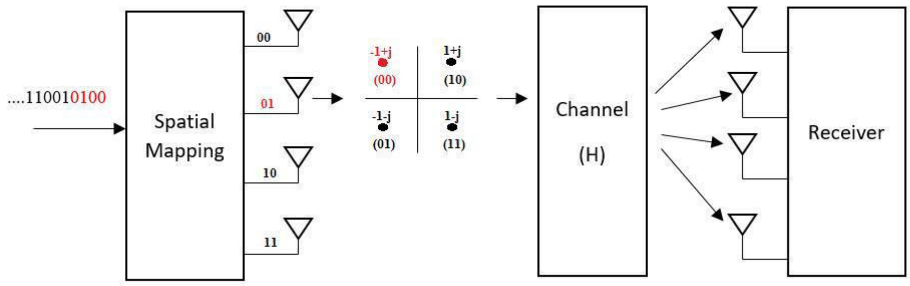

Figure 2.1: Basic block diagram of SM with 4-QAM modulation for 4 transmitters and 4 receivers [2]

These information bits with length n are divided into $\log_2 N_T$ bits for mapping into set of antenna combinations, and log2M bits for mapping into signal constellations. As shown in Figure 2.1, a stream of information data is selected as blocks containing four bits. These four vectors are considered as two fields. From the stream of information, first selected the block 0100 in which first two bits 01 maps to antenna through which the data is sent. Since the system shown is of 4x4 MIMO, the number of bits to map spatial constellation will be $\log_2 4 = 2$ bits. The remaining bits of 0100 (i.e., 00) is mapped into signal constellation. In SM, the block of bit stream is mapped to two constellations, and we get a three dimensional constellation diagram .

Since only one antenna is active at a time, the transmission matrix, s(k) will have only one non zero element. The symbols are transmitted through the MIMO channel and is added with Additive White Gaussian Noise (AWGN), n(k). The received matrix will be:

$$Y(k) = H(k) * s(k) + n(k) \qquad \text{eq. (2)}$$

where H(k) is the channel state information (CSI) and * represents the convolution operation. The received signal Y(k) contains both antenna constellation point and signal constellation point and are retrieved back by various receiver algorithms. In ideal case, the estimated g(k) will be same as s(k). Thus the antenna number P of the transmitted antenna is given by the index of g(k) in matrix whose absolute value is maximum in presence of AWGN as:

$$P = \text{argmax}(|g_i(k)|) \qquad \text{eq. (3)}$$

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The symbol at that instant is found using Maximum Likelihood Detection. Maximum likelihood detection selects the symbol in the codebook which have the minimum distance with the received noisy symbol. The three dimensional constellation of SM is given in Figure. 2.2.

Compared to the conventional MIMO system, SM using only one active antenna at a time to avoid ICI. Complexity of receiver is far reduced in SM-MIMO by using only one active antenna at a time and the complex receiver design for overcoming the ICI problems is not required. The data rate is increased in SM due to the mapping of data into spatial domain and thus helps in increase in spectral efficiency.

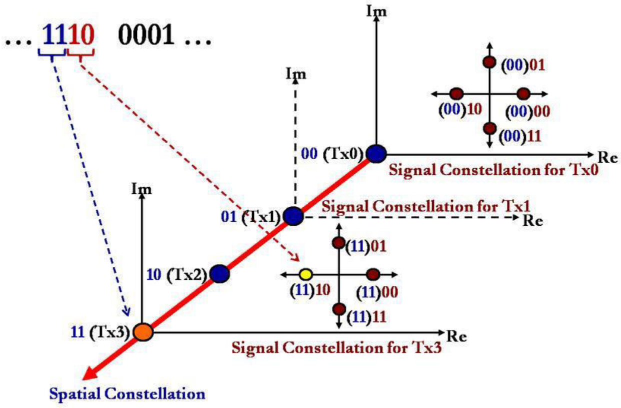

Figure. 2.2:Three dimensional constellation of SM [7]

The circuit complexity is reduced at transmitter because only one radio frequency chain is needed for transmission at an instant. The main power consumption in base station is at the power amplifier section at the transmitter which increases with number of RF chains. Thus in SM-MIMO systems this power consumption is reduced to a great extent. SM can help in designing efficient unbalanced MIMO channels where the number of receiver antenna is less than number of Transmitting antennas used.

There are some limitations for SM. As only one antenna is active at a time, the spectral efficiency of SM is reduced as the number of transmitting antenna is increased. Data rate can be increased only in logarithmic scale, rather than linear, in SM-MIMO. This limits SM to attain high spectral efficiency as number of antenna increase beyond a limit. Accurate knowledge of CSI is required at receiver to retrieve the message transmitted. Design problems of SM-MIMO in frequency selective fading channels still exist. Frequency selective fading cannot be avoided in 5G networks due to the high transmission rate.

III. SPM-MIMO YSYTEM MODEL

SPM disperses the spatial symbol in the time coordinate by using the permutation vector that indicates the active transmit antennas at successive time instants. Take a toy example using two transmit antennas and two time instants. In addition to the bits conveyed by the QAM symbols, the SPM transmitter modulates another bit with a permutation set $[1; 2]^T$; $[2; 1]^T$, where $(:)^T$ denotes the transpose operation. For bit '0', the permutation vector $[1; 2]^T$ is selected, and then the first and second transmit antennas are activated at the first and second time instants, respectively. Similarly, when $[2;1]^T$ is selected to represent bit '1', the second and first transmit antennas are successively activated at the first and second time instants. SPM can be interpreted as a general case of SM, since the active transmit antenna index in SM is generalized to the permutation vector in SPM.

Define $\tilde{c}_{N_t,T}$ as a set of N_T permutations of T, i.e., different ordered arrangements of a T element subset of an N_T set. To characterize the permutation set, we define the Hamming distance matrix **D** whose the $(i; j)$th entry $d_{i;j}$ represents the Hamming distance between the ith and jth permutation vectors.The minimum Hamming distance of a permutation set is determined by the smallest off-diagonal component in the matrix D, i.e.,

$$d_{min} = \min_{i,j;i\neq j} d_{ij} \qquad \text{eq. (4)}$$

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To modulate the bits by the permutation vectors, we denote $C_{N_t,T}(k, d_{\min}) \subseteq \tilde{c}_{N_t,T}$ which selects k permutation vectors with the minimum Hamming distance $d_{\min}$ from $\tilde{c}_{N_t,T}$. The SPM spatial symbol is thus generated by choosing a specific permutation vector in $C_{N_t,T}(k, d_{\min})$ according to the data bits.

Figure 3.1 lists different permutation sets. Permutation set selection is based on distance reduced mapping where there is at least one permutation vector pair whose hamming distance is less than that of the encoded binary data bits resulting in highest k but smallest d_{min}. Similar to the SM spatial symbol conveying $\log_2 N_t$ bits, the number of modulated bits of the SPM spatial symbol is logarithmically proportional to the size of the adopted permutation, i.e., $\log_2 k$. The more permutation vectors are included in $C_{N_t,T}(k, d_{\min})$, the more bits can be modulated at the expense of decreased Hamming distance.

T	K	$d_{\min}$	$C_{4,T}(K, d_{\min})$
2	4	2	$[1,3]^\top, [2,4]^\top, [3,1]^\top, [4,2]^\top$
3	2	3	$[1,2,3]^\top, [2,3,4]^\top, [3,4,1]^\top, [4,1,2]^\top$
	16	1	$[1,2,3]^\top, [1,3,2]^\top, [1,4,2]^\top, [1,4,3]^\top, [2,1,3]^\top, [2,1,4]^\top, [2,3,4]^\top, [2,4,1]^\top, [3,1,4]^\top, [3,2,1]^\top, [3,2,4]^\top, [3,4,1]^\top, [4,1,2]^\top, [4,2,3]^\top, [4,3,1]^\top, [4,3,2]^\top$
4	4	4	$[1,2,3,4]^\top, [2,3,4,1]^\top, [3,4,1,2]^\top, [4,1,2,3]^\top$
	8	3	$[1,2,3,4]^\top, [1,3,4,2]^\top, [1,4,2,3]^\top, [2,3,1,4]^\top, [2,4,3,1]^\top, [2,1,4,3]^\top, [3,2,4,1]^\top, [4,1,3,2]^\top$
	16	2	$[1,2,3,4]^\top, [1,2,4,3]^\top, [1,3,2,4]^\top, [1,3,4,2]^\top, [1,4,2,3]^\top, [1,4,3,2]^\top, [2,1,3,4]^\top, [2,1,4,3]^\top, [2,3,1,4]^\top, [2,3,4,1]^\top, [3,1,2,4]^\top, [3,1,4,2]^\top, [3,2,1,4]^\top, [3,2,4,1]^\top, [3,4,1,2]^\top, [3,4,2,1]^\top$

Figure 3.1: Examples of permutation sets with various K and d_{min} [1]

Therefore, one can flexibly adjust the parameters k and d_{min} to achieve the desired balance between the error rate performance and throughput. Note that when the transmitter is equipped with more antennas, the number of usable permutation vectors increases. The design of permutation set can be formulated as an optimization which selects k permutation vectors out of all $N_t!/(N_t-T)!$ candidates to maximize the minimum Hamming distance, where (:)! is the factorial operation.

For the SPM transmission, $C_{N_t,T}(k, d_{\min})$ is pre-determined and available at both the transmitter and receiver. SPM modulates log_2k bits to a permutation vector $p = [p_1,.., p_T] \in C_{N_t,T}(k, d_{\min})$ such that the p_t th transmit antenna is activated at the t-th time instant. The received symbol vector y_t is given by :

$$y_t = h_{p_t} s + n_t \qquad \text{eq. (5)}$$

where h_{p_t} is the p_t th column of the channel matrix H, s is the symbol transmitted and n_t is the noise. By cascading y_t at different time instants $t=1,...,T$ into a received matrix $Y = [y_1; ::::; y_T]$, the SPM transmission model takes the form of :

$$Y = H(p)S + V \qquad \text{eq. (6)}$$

where $H(p) = [h_{p_1}, ..., h_{p_T}]$ represents the permuted channel matrix , $V = [n_1, ..., n_T]$ is the noise matrix and S is the set of symbols.

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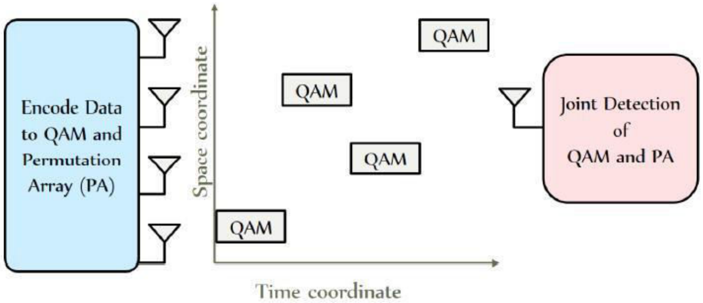

Figure 3.2: The illustration of SPM transmission with (N_t;N_r;T) = (4;1;4), i.e., the same QAM symbol is repetitively transmitted at four time instants. The permutation vector p = [1; 3; 2; 4] is used for modulation. [1]

As mentioned previously, the trade-off between the error rate and the throughput of the spatial symbol can be adjusted by changing the permutation set $C_{N_t,T}(k,d_{\min})$ Likewise, we can design the value of M to balance the error rate and the throughput of the QAM symbol. For the SPM detection, the ML criterion that delivers the optimal solution (s^*, p^*) can be implemented by exhaustively searching the space with $k\chi^M$ elements:

$$(s^*, p^*) = \text{argmin} \sum_{t=1}^{T} \| y_t\_h_{p_t} s \|^2 ; s \in \chi^M \quad ; p \in C_{N_t,T}(k,d_{\min}) \qquad \text{eq. (7)}$$

which is similar to the SM detection. Consequently, the low-complexity techniques invented for the SM can be extended for the efficient SPM detection.

The aforementioned discussion shows that SM can be considered as a special case of SPM with T=1 whose permutation vector reduces to a scalar. Compared with SM, SPM inherits its low-complexity advantages with better error rate performance, especially in the cases of few receive antennas or spatially-correlated channel.

IV. SPM MIMO-OFDM SYSTEM MODEL

In SM-MIMO and SPM-MIMO as only one antenna is active at a time only a symbol can be transmitted through the antenna which limits the data rate of the system. As only one antenna is active at a time, the spectral efficiency is reduced as number of transmitting antenna is increased. In the proposed system, OFDM directly extends to MIMO channels with IFFT/FFT and cyclic prefix operation being performed at each transmitter and receiver ends. OFDM transmits data simultaneously on multiple carrier which are orthogonal to each other. Thus a high data rate stream is converted in to a number of small data rate streams and transmitted simultaneously on different subcarriers. The main advantage of the proposed system over the current system is that it can improve the spectral efficiency and data rate as the SPM-MIMO is integrated with OFDM system. Figure 4.1 shows the transmitter section for the proposed system.

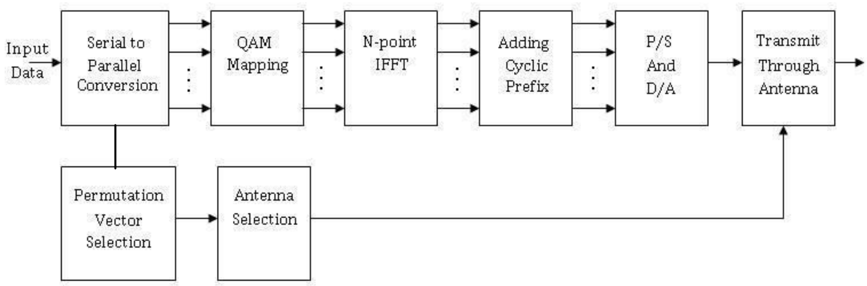

Figure 4.1: SPM MIMO-OFDM Transmitter

In the proposed system, a permutation set is considered first, i.e., a set of all different ordered arrangements of a T element of an N_t set. The permutation set consists of k permutation vectors with the minimum hamming distance. The incoming serial bits are first converted into parallel blocks of *'n'* bits. From each block of bits, the first p bits are used to select the permutation vector, from the permutation set where $p = log_2 k$ bits and the remaining $(n - p)$ bits are mapped into symbols where $(n - p) = log_2 M$, M is the size of constellation.

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Data bits	Permutation Vector
00	[1;3;2;4]
01	[2;3;4;1]
10	[3;4;1;2]
11	[4;1;2;3]

Consider an example with k=4, mapping table for selecting the permutation vector is given in the above table. Considering the mapping table, if the first unit of the parallel blocks are 00, permutation vector p = [1 3 2 4] is selected. Then the same QAM symbols are transmitted through the first, third, second, and fourth transmit antennas at successive four time instants.

In SPM MIMO, if 4-QAM modulation is considered, 2 bits are selected for transmitting through a single antenna and another 2 bits for permutation vector selection with
d_{min} = 4. So a total of 4 bits are selected as a block. If this concept is applied to OFDM system which uses 8 point IFFT, the data rate can be increased. A single transmitter can transmit 16 bits if 4-QAM and 8-point IFFT is used . Thus the length of the block will be 18. Then cyclic prefix is added which act as a guard band between successive symbols to overcome Inter Symbol Interference and it helps the system to operate reliably. Figure 4.2 shows the receiver section for the proposed system.

Since only one antenna is active at a time, the transmission matrix will have only one non-zero value. Here the system have four transmitters and one receiver, thus the channel matrix will have a dimension 4x1. Let X be the transmission matrix, H be the channel matrix, then the received matrix is given by:

$$Y = HX + AWGN\ noise \qquad \text{eq. (8)}$$

For retrieving the permutation vector, the received matrix is multiplied with the Hermitian conjugate of the channel matrix. From the resulting matrix we can find the antenna index. The same procedure is carried out for the remaining three time instants to obtain the permutation vector. The cyclic prefix are then removed from the symbols. Then FFT operation is performed to convert the time domain signal into frequency domain. The transmitted symbols are estimated with the help of Maximum Likelihood Detection technique.

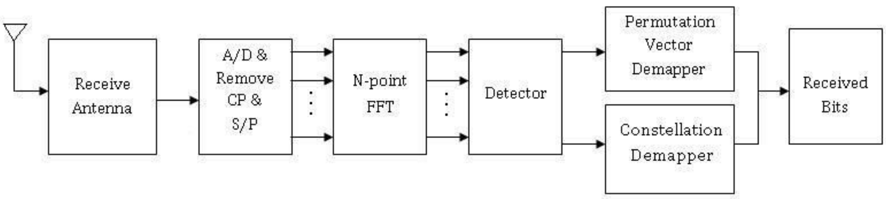

Figure 4.2: Receiver of proposed system

V. SIMULATION RESULTS

The performance of conventional SPM MIMO is compared with proposed SPM MIMO-OFDM system. In the case of SPM MIMO, same symbol is transmitted at successive time instants. For 16-QAM and dmin=2, 8 bit blocks are considered. In that 4 bits are used for permutation vector selection and next 4 bits are mapped into 16-QAM constellation.

In the case of proposed system, a stream of symbols are transmitted at successive time instants. Here 8-point IFFT is used. So for 16-QAM and d_{min}=2, 36 bit blocks are considered where 4 bits are used for permutation vector selection and remaining 32 bits mapped 16-QAM constellation. So there will be 8 symbols generated. Figure 5.1 shows the Bit Error Ratio vs SNR comparison of SPM MIMO and proposed SPM MIMO-OFDM system.

By analysing figure 5.1, its clear that for a given SNR, the Bit Error Ratio is minimum for the proposed SPM MIMO-OFDM system compared to SPM MIMO. Also proposed system has more data rate than the conventional system.

The proposed system is implemented using 4-QAM and 16-QAM for d_{min}=2 and d_{min}=4. The BER performance of proposed system with 4-QAM is better than that of proposed system with 16-QAM, This is shown in figure 5.2. This is because, in 4-QAM, the constellation points are in four quadrants. But in the case of 16-QAM, each quadrant contains four constellation points. Thus while performing Maximum Likelihood detection, the error probability will be higher for 16-QAM.

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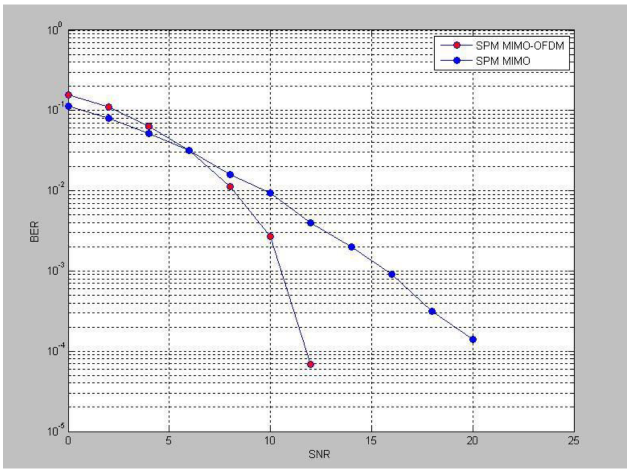

Fig 5.1:BERvsSNR comparison of SPM MIMO & SPM MIMO-OFDM

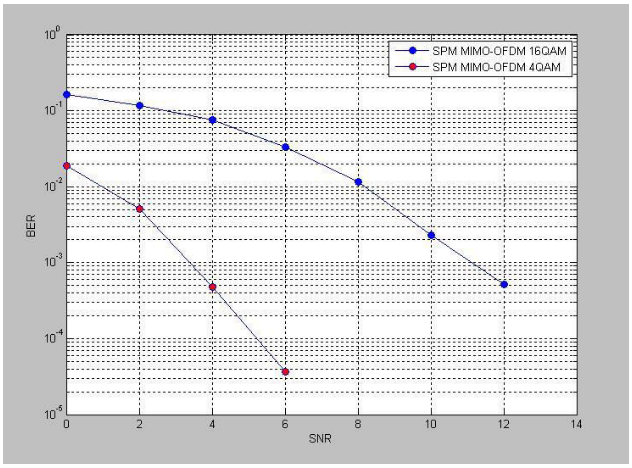

Figure 5.1: BER vs SNR comparison of SPM MIMO-OFDM using 4- QAM and 16-QAM

VI. CONCLUSION

The need for compression of data, to be sent through the channel, to its maximum possible means with minimum or negligible error is one of the main criteria of communication system design so as to get higher data rate and maximum spectral efficiency. In spatial modulation, a block of information bits is mapped to two information carrying units: a unique transmit antenna number that was chosen from a set of transmit antennas and a symbol that was chosen from a constellation diagram. In any given symbol interval, SM selects only one antenna from multiple available antennas for transmission. This will increase the data rate of the MIMO systems. Since one antenna is active at a time, the probability of error will be high.

Spatial Permutation Modulation improves the error rate performance of the system compared to SM-MIMO. In SPM the copy of same symbol is transmitted at successive time instants depending on a permutation vector which sequentially selects the transmit antennas to transmit data.

The data rate and spectral efficiency of SPM MIMO can be further improved by integrating SPM MIMO with OFDM system. The OFDM directly extends to MIMO channels with IFFT/FFT and CP operation being performed at each transmitter and receiver ends. Simulation results shows that the proposed system provides better Bit Error Rate performance compared to SM-MIMO and SPM-MIMO.

REFERENCES

1. Jhih Wei Shih, I Wei Lai, “Spatial Permutation Modulation for Multiple Input Multiple Output Systems”, IEEE Access Journal, published on May 4, 2019.
2. Raed Y. Mesleh, Harald Haas, Sinan Sinanovi C, Chang Wook Ahn, Sangboh Yun , “Spatial Modulation”, IEEE Transactions on Vehicular Technology, VOL. 57, NO. 4, JULY 2008.
3. Pilitha Chandran K, Narayanan P.P, Dr.C.D.Suriyakala, “Spatial Modulation – A High Efficient Technique for MIMO Communication”, IOSR Journal of Electronics and Communication Engineering (IOSR-JECE) e-ISSN: 2278-2834, p- ISSN: 2278-8735. PP 80-86
4. Marco Di Renzo, Harald Haas, “Bit Error Probability of SM-MIMO Over Generalized Fading Channels”, IEEE Transactions on Vehicular Technology, Vol. 61, NO. 3, March 2012..
5. Jinlin Fu, Chunping Hou, Wei Xiangy, Lei Yan, Yonghong Hou ”Generalized Spatial Modulation with Multiple Active Transmit Antennas”, In Proc. 2010 Signals, Syst. Comput., pp. 1498-1502.
6. Yue Xiao, Lixia Xiao, Lilin Dan, Xia Lei, “Spatial Modulation for 5G MIMO Communications, Proceedings of the 19th International Conference on Digital Signal Processing, August 2014.
7. Marco Di Renzo, Harald Haas, Ali Ghrayeb, Shinya Sugiura, Lajos Hanzo, Spatial Modulation for Generalized MIMO: Challenges, Opportunities, and Implementation, Proceedings of the IEEE, Vol. 102, No.1, January 2014.
8. Rahul Saxena, Prof. Rupesh Dubey, Prof. Poonam Lilhare, Transmit-Diversity for Spatial Modulation (SM) and Space-Time Block Codes - A Review ,ISSN: 2278 7798 International Journal of Science, Engineering and Technology Research (IJSETR) Volume 2, No 6, June 2013.

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|| Volume 9, Issue 3, March 2021 ||

| DOI: 10.15680/IJIRCCE.2021.0903008 |

9. Ping Yang, Marco Di Renzo, Yue Xiao, Shaoqian Li, and Lajos Hanzo, Design Guidelines for Spatial Modulation , IEEE Communications Surveys and Tutorials.
10. Yong Soo Cho, Jaekwon Kim, Chung G. Kang, "MIMO-OFDM Wireless Communications with Matlab", John Wiley & Sons Pte Ltd.
11. Simon Haykin "Communication system", Fourth edition,Wiley publication.
12. R. Mesleh, H. Haas, Chang Wook Ahn, Sangboh Yun, Spatial Modulation - A New Low Complexity Spectral Efficiency Enhancing Technique, IEEE Transactions on Vehicular Technology, vol.57, no.4, July 2008.
13. Ali Afana, Hadi M. Aggoune, Salama Ikki, Quadrature Spatial Modulation, IEEE Transactions on Vehicular Technology.
14. Sudharsan Ganesan, Raed Mesleh, Harald Haas, "On the Performance of Spatial Modulation OFDM", IEEE, May, 2007.
15. Shubhangi R. Chaudhary, Madhavi Pradeep Thombre, "BER Performance Analysis of MIMO-OFDM System Using Different Equalization Techniques", IEEE - ICACCCT, 2014.