A simplified spatial modulation MISO-OFDM scheme

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Article Info

ABSTRACT

Index modulation is one of the promising techniques for future communications systems due to many improvement over the classical orthogonal frequency division multiplexing systems such as single RF chain, increased throughput for the same modulation order, achieved tradeoff between the efficiencies of the power and the spectral, and elimination of inter-channel interference. Many forms of index modulation researches exist where symbols are conveyed in antennas, subcarriers, time slots, and the space-time matrix. Spatial modulation is one member of index modulation family where symbols are conveyed in activating transmit/receive antennas. In this paper, a modification to a standard multiple input single output scheme by integrating spatial modulation using simplified mathematical procedure is achieved. In the transmitter side, data and activation symbols are distributed simultaneously using mathematical module and floor functions. At the receiver, a simplified maximum likelihood detector is used to obtain transmitted pair of symbols. To verify this, MATLAB simulink is used to simulate a downlink system where spatial modulation is applied to a base station. Results for different transmit antenna number and modulation order are obtained in the form of bit error rate versus signal to noise ratio.

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1. INTRODUCTION

Increasing data rate, cell coverage, energy and spectral efficiency in wireless and mobile systems is targeted by manufacturers in the current and future generations referred to as 5G and beyond [1-5]. The customer; on the other hand, is eager for better services either in the crowded or low density cells. Therefore, researches recently proposes new technologies that enhance or even flips the traditional way of implementing communication systems. As an example, exploiting other dimensions such as spatial domain [6-10]. Since the application of OFDM (orthogonal frequency division multiplexing) technique, wireless transceivers perform much better than traditional transceiver systems because of multicarrier over single carrier advances. In traditional OFDM, data from subscribers is represented by subcarriers formed using well known mapping techniques (PSK and QAM). In other words, the only way to transmit data symbols is through OFDM subcarriers. The advances of data transmission in spatial domain enhances data rate by using multiple antennas either in the transmitter (multiple input single output-MISO) or in the receiver (single input multiple output-SIMO) or both (multiple input multiple output-MIMO). Therefore, spatial modulation (SM) is a technique; proposed by [11], suppose to enhance performance by sending more symbols in selecting active antenna (s). The transmitter operating SM divides data symbols into two parts: the first part are symbols

modulated traditionally send using active antennas, while the second part are symbols conveyed in activating those transmit antennas as shown in Figure 1. Convey of information bits in transmit antennas can be seen in MIMO systems operating with subsets of two transmit antennas in each time slot. The latter technique is similar to multiuser MIMO systems where different users are assigned to different transmitter sets and the receiver equipment is composed of single or multiple antennas.
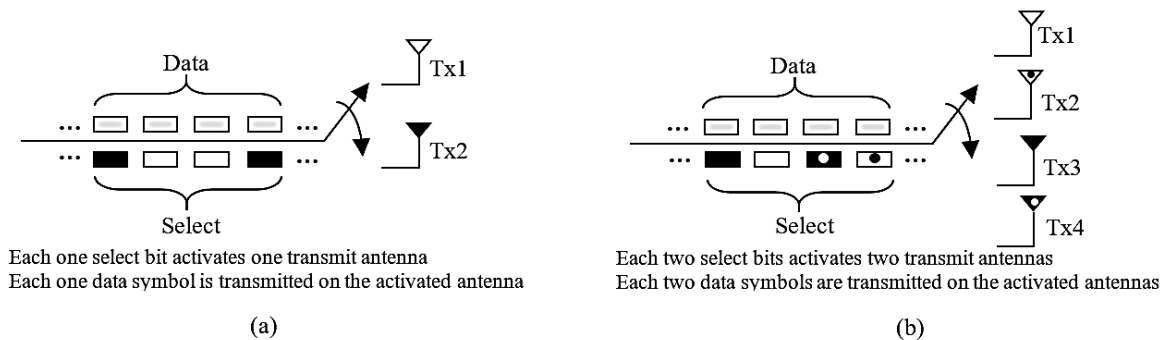

Each one select bit activates one transmit antenna
Each one data symbol is transmitted on the activated antenna

(a)

Each two select bits activates two transmit antennas
Each two data symbols are transmitted on the activated antennas

(b)

Figure 1. Concept of SM where extra symbols are conveyed in select active transmit antenna.
(a) One bit is used to set one active antenna from two transmit antennas
and (b) Two bits are used to set two active antennas from four transmit antennas

Many research articles address spatial modulation in terms of new technique, performance enhancement, modification, and generalization for MIMO-OFDM systems (refer to [6, 12-14] for a survey on SM theoretical analysis, receiver design, and other important issues). The work in this paper is closely related to the following research papers in terms of using OFDM and single or multiple transmit antenna activation. Luna-Rivera et al [15] do their work on the design of constellation in SM. They concludes that transmitting the same data symbol from more than one antenna at a time enhances spectral efficiency but, on the other hand, it degrades the bit error rate (BER) performance. Lin et al [16] worked on generalized SM systems with ML (maximum liklehood) detector. They proposed a method to lower complexity in the detector design by splitting the received symbols into two vectors index and symbol. Simulation results show that the proposed schemes significantly outperform other existing methods while the detection complexity remains low. Zhang et al [17] propose low complexity algorithms for SM detection by rearranging the detection order of ML with respect to channel and received signal. They prove that BER performance is better than normal MML (M-algorithm ML) but comparable complexity. Acar et al [18] concentrate their work on estimating channel state information and how they use interpolation in SM-OFDM. The results show low estimation complexity with least squares (LS) and low pass interpolation technique. Kumaravelu et al [19] propose an 8X8 MIMO design with SM. They use adaptive mapping for antenna selection with ML scheme. They claimed; using encoding, that their proposed scheme is a good candidate for IMT-2020 as well as IEEE802.11ax based handheld devices with improved performance under line of sight channel. In this paper, it is assumed that the transmitter is composed of multiple antennas selectively activated in each transmission time slot. The system uses OFDM as the main subcarrier modulation technique. The rest of the paper is organized as follows: Section 2, demonstrates the proposed system model of MISO-OFDM-SM. Section 3 presents the results and section 4 concludes the work in this paper.

2. MISO-OFDM-SM SYSTEM MODEL

This section present a proposed model for implementing SM in the transmitter of a typical baseband OFDM system. To understand the latter one, Figure 2 shows a typical OFDM baseband tranciever system without coding [20, 21]. According to literature, source data symbols are modulated using M-QAM (such as 4-QAM), paralleled, and the frequency domain output stream is fed to the IFFT block where pilot symbols are inserted to enable receiver channel state information (CSI) estimation. Typically, zero padding stage enables forming required FFT size. Therefore, an OFDM symbol is formed from data symbols (subcarriers), pilot symbols, and zero pad symbols. Part of a time domain OFDM symbol (a tail) is replicated to the head of that symbol to prevent intersymbol interference (Cyclic Prefix). At receiver side, CP is removed from time domain signal, a reverse operation FFT takes place to transform back into frequency domain and pilot symbols are extracted and compared to locally generated replicas to obtain the CSI. The previous operation is referred to

as channel estimation and it is vital in performing symbol detection. Equilization compensates for subcarriers change and ML detection [22] decides for transmitted symbols. Finally, the total number of bits conveyed in this operation is $\log_2 M$, where M the constellation order of the M-QAM demapper (demodulator). Modifying the system shown in Figure 2 for SM requires adding extra OFDM and antenna blocks as shown in Figure 3. Since SM conveys extra bits in activating transmitters that is, if N_T is number of transmit antenas then a maximum of $\log_2 N_T$ bits are conveyed in this operation. Therefore, total number of transmitted bits become:

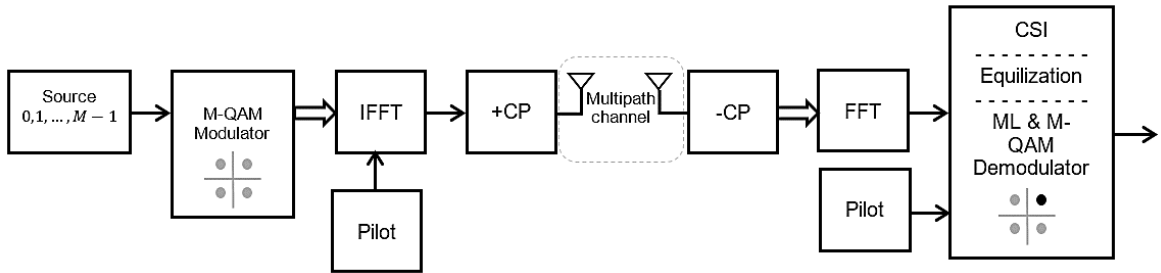$$Transmitted\ bits = \log_2 M + \log_2 N_T = \log_2(M \cdot N_T) \tag{1}$$

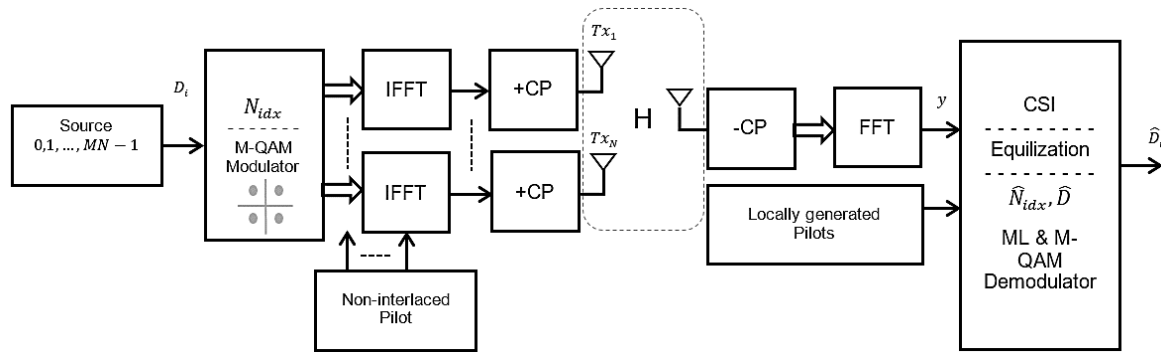Figure 2. Typical baseband OFDM tranceiver

Figure 3. MISO-OFDM-SM block diagram

As an example, using two transmit antennas and 4-QAM, a total of $\log_2 4 + \log_2 2 = 2 + 1 = 3\ bits$ are transmitted in one transmit period result in enhancement of 50% over the traditional single antenna while the same modulation order is preserved. The receiver; due to a fact that one (or a set of) transmit antenna (s) are active in one transmit period, will try to detect the received bits. The complexity of achieving this detection (or prediction) depeds on many factors related to the detection method itself, channel behavior, constellation order, channel estimation accuracy, and number of bits conveyed in selecting transmit antennas (as the number of spatial bits increase, complexity increases [23, 24]).

In Figure 3, Data bits are grouped into $\log_2(M \cdot N_T)$ bits where the least significant $\log_2 N_T$ used to activate antennas and the rest of the grouped bits i.e. $\log_2 M$ are used as subcarriers modulated symbols. M-QAM modulator receives the latter bits and convert them to specified mapped symbols and N_T streams are produced. A simple rule is introduced here for calculating the pair (N_{idx}, D_{idx}) where N_{idx} is transmit antenna index, D_i is data symbol before SM, and D_{idx} is the transmitted (after SM) symbol:

$$\{N_{idx}, D_{idx}\} = \begin{cases} D_i \bmod N_T + 1 & Selecting\ antenna\ index \\ floor(D_i / N_T) & Transmitting\ symbol \end{cases} \tag{2}$$

The receiver; equipped with a single antenna, receives a summed symbol from a flat faded channel $\boldsymbol{H}$ in the form given by:

$$y = \sqrt{p}\boldsymbol{H}\boldsymbol{x} + n$$
$$\boldsymbol{H} = [h_{11} \quad h_{12} \quad \cdots \quad h_{1N_T}]$$
$$\boldsymbol{x} = [x_1 \quad x_2 \quad \cdots \quad x_{N_T}]^T$$
(3)

In (3), p is the average signal to noise ratio measured at the receiver input and n is an additive white Gaussian noise power. Part of the received symbols are known to the receiver side (pilot symbols) used to estimate the channel coefficients, therefore it is assumed; for simplicity, that channel estimation is performed using direct LS (least squares). The estimated channel coefficients are used to equalize the received symbols and ML detector jointly estimates the transmitted symbol and the antenna index using the following decision rules:

$$\hat{S}_{idx} = \min_{i=1,2,...,N_T M-1} \left(\left| Y - \hat{h} Z_i \right|^2 \right)$$
(4)

$$\hat{D} = \boldsymbol{Z}[(\hat{S}_{idx} - 1) mod M + 1]$$
(5)

$$\widehat{N}_{idx} = ceil\left(\frac{\hat{S}_{idx}}{M}\right)$$
(6)

Where:

$Y = Received\ symbol,\ \hat{D} = detected\ symbol,\ \widehat{N}_{idx} = detected\ antenna\ index$
$\hat{h}\ is\ the\ estimate\ of\ h$
$\boldsymbol{Z} = [Z_1 \quad Z_2 \quad \cdots \quad Z_{M-1}] = mapped\ set\ of\ all\ possible\ transmitted\ symbols$
$\hat{S}_{idx}\ index\ of\ minimum\ value\ in\ a\ vector\ of\ N_T M \times 1$

In (4), the operator min selects the minimum value from a vector formed by subtracting received symbol from all possible transmitted symbols. In (5) and (6) give simplified mathematical equations to find the data symbol and the antenna number transmitted from. This will be explained later on using example. Table 1 illustrates the use of (1) and (2) for different values of M and N_T.

Table 1. Proposed spatial mapping according to (1) and (2)

	$N_T = 2^1$	$N_T = 2^2$	$N_T = 2^3$	$N_T = 2^4$
$M = 2^1$	$D_i = 0,1,2,3$ $0,2\ on\ ANT_1,$ $1,3\ on\ ANT_2$	N/A	N/A	N/A
$M = 2^2$	$D_i = 0,1,...,7$ $0,2,4,6\ on\ ANT_1,$ $1,3,5,7\ on\ ANT_2$	$D_i = 0,1,...,15$ $0,4,8,12\ on\ ANT_1$ $1,5,9,13\ on\ ANT_2$ $2,6,10,14\ on\ ANT_3$ $3,7,11,15\ on\ ANT_4$	N/A	N/A
$M = 2^3$	$D_i = 0,1,...,15$ $0,2,4,...,14\ on\ ANT_1$ $1,3,5,...,15\ on\ ANT_2$	$D_i = 0,1,...,31$ $0,4,8,...,28\ on\ ANT_1$ $1,5,9,...,29\ on\ ANT_2$ $2,6,10,...,30\ on\ ANT_3$ $3,7,11,...,31\ on\ ANT_4$	$D_i = 0,1,...,63$ $0,8,16,...,56\ on\ ANT_1$ $1,9,17,...,57\ on\ ANT_2$ $\vdots$ $7,15,23,...,63\ on\ ANT_8$	N/A
$M = 2^4$	$D_i = 0,1,2,...,31$ $0,2,4,...,14\ on\ ANT_1$ $1,3,5,...,15\ on\ ANT_2$	$D_i = 0,1,...,63$ $0,4,8,...,60\ on\ ANT_1$ $1,5,9,...,61\ on\ ANT_2$ $2,6,10,...,62\ on\ ANT_3$ $3,7,11,...,63\ on\ ANT_4$	$D_i = 0,1,...,127$ $0,8,16,...,120\ on\ ANT_1$ $1,9,17,...,121\ on\ ANT_2$ $\vdots$ $7,15,23,...,127\ on\ ANT_8$	$D_i = 0,1,...,255$ $0,16,32...,240\ on\ ANT_1$ $1,17,33,...,241\ on\ ANT_2$ $\vdots$ $31,47,63...,255\ on\ ANT_{16}$
$M = 2^j$	$D_i = 0,1,..,2^{j+1}-1$ $D_{idx} = floor(D_i/2)$ $N_{idx} = D_i mod 2 + 1$	$D_i = 0,1,..,2^{j+2}-1$ $D_{idx} = floor(D_i/4)$ $N_{idx} = D_i mod 4 + 1$	$D_i = 0,1,..,2^{j+3}-1$ $D_{idx} = floor(D_i/8)$ $N_{idx} = D_i mod 8 + 1$	$D_i = 0,1,..,2^{j+4}-1$ $D_{idx} = floor(D_i/16)$ $N_{idx} = D_i mod 16 + 1$

3. IMPLEMENTATION AND RESULTS

To obtain performance in terms of BER versus Signal to noise ratio (SNR), MATLAB SIMULINK is used to build a baseband transceiver as shown in Figure 4. The design parameters for OFDM part follows the IEEE802.16 standard listed in Table 2 [25]. For the pilot symbols, binary phase shift keying (BPSK) is used to modulate orthogonal generated code using Hadamard code. The use of Hadamard is advantageous in activating more than one transmit antennas at a time in case it is required. In Figure 4, total bits are 6 ($M = 16$ and $N_T = 4$) which creates $360 \times 6 = 2160$ bits generated using Bernolli binary generator and converted into symbols using

bit to integer converter. For the purpose of demonstrating application of SM to an OFDM system, the following example assumes low FFT size for illustration purposes. Example: A MISO-OFDM-SM with the following parameters: 4-QAM $(M = 4), N_T = 2, FFT\ size = 16, D = 11\ symbols, pilot\ symbols = 2,\ and\ 3\ symbols\ for\ zero\ pading$, $SNR = 15\ dB$. The Table 3 show possible symbol mappings and antenna index according to (2).
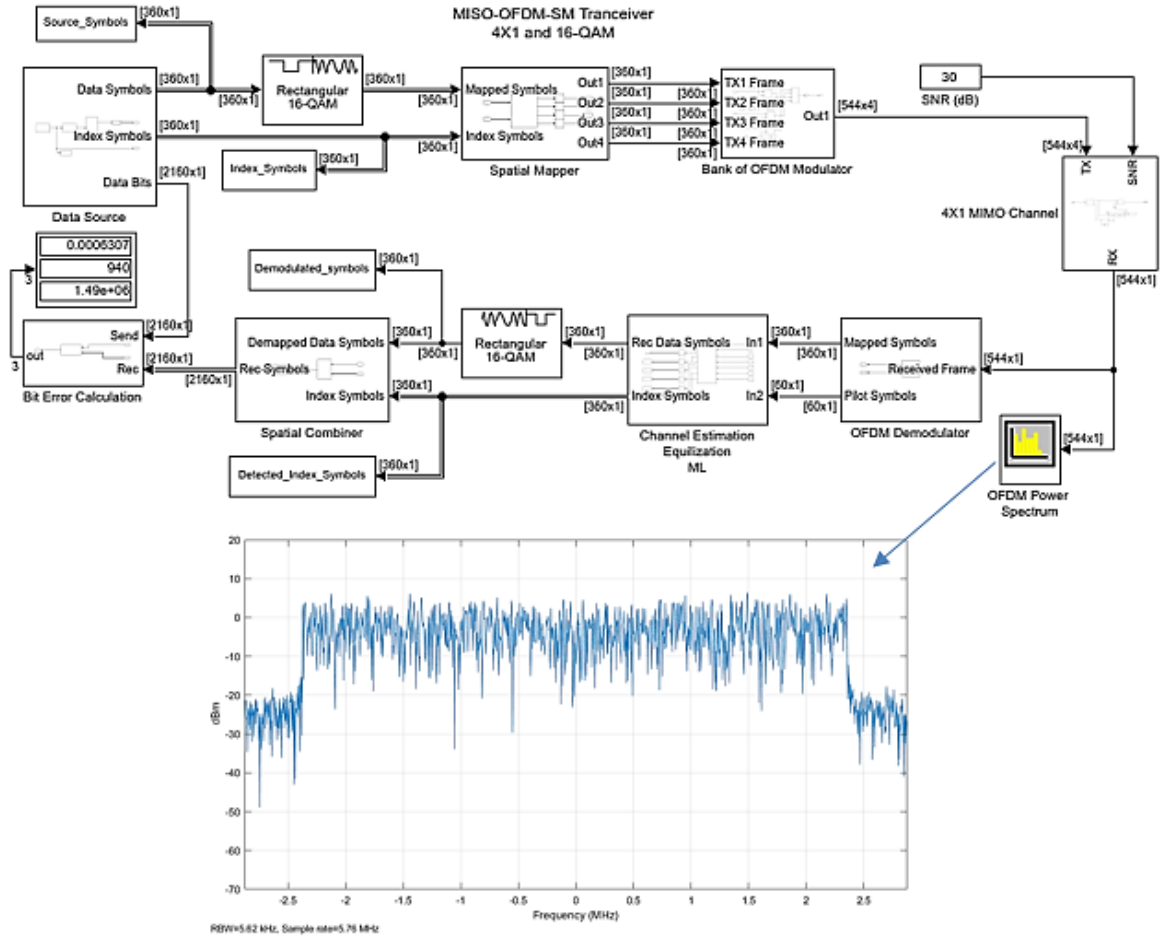

Figure 4. MATLAB SIMULINK of proposed MISO-OFDM-SM with 4X1 16-QAM showing the frequency spectrum of the received time domain signal

Table 2. System parameters for simulation of MISO-OFDM-SM

Parameter	Value	Parameter	Value
Channel bandwidth	5 MHz	Subcarrier frequency spacing	11.25 kHz
Sampling frequency	5.76 MHz	Useful symbol time	88.889 us
FFT size	512	Guard time (1/8)	11.11 us
Number of data subcarriers	360	OFDM symbol duration	100 us
Number of pilot subcarriers	60	Digital Modulation	4-, 8-, and 16-QAM

Table 3. Spatial mapping of 3 bits using 4-QAM and two transmit antennas

Data bits	Data symbols	D_{idx}	Modulated symbol	N_{idx}
000	0	0	$-0.7071 + 0.7071i$	1
001	1	0	$-0.7071 + 0.7071i$	2
010	2	1	$-0.7071 - 0.7071i$	1
011	3	1	$-0.7071 - 0.7071i$	2
100	4	2	$+0.7071 + 0.7071i$	1
101	5	2	$+0.7071 + 0.7071i$	2
110	6	3	$+0.7071 - 0.7071i$	1
111	7	3	$+0.7071 - 0.7071i$	2

Assuming that a data frame is generated: $Dataframe = [5 \quad 2 \quad 6 \quad 0 \quad 4 \quad 6 \quad 3 \quad 0 \quad 6 \quad 4 \quad 7]$

$D_{idx} = [2 \quad 1 \quad 3 \quad 0 \quad 2 \quad 3 \quad 1 \quad 0 \quad 3 \quad 2 \quad 3]$ *and* $N_{idx} = [2 \quad 1 \quad 1 \quad 1 \quad 1 \quad 1 \quad 2 \quad 1 \quad 1 \quad 1 \quad 2]$

Frame $1: [0 \quad 1 \quad 3 \quad 0 \quad 2 \quad 3 \quad 0 \quad 0 \quad 3 \quad 2 \quad 0] \rightarrow$

modulated frame $1 = [\mathbf{0} \; -0.7071 - 0.7071\text{i} \; 0.7071 - 0.7071\text{i} \; -0.7071 + 0.7071\text{i} \; 0.7071 + 0.7071\text{i} \; 0.7071 - 0.7071\text{i} \; \mathbf{0} \; -0.7071 + 0.7071\text{i} \; 0.7071 - 0.7071\text{i} \; 0.7071 + 0.7071\text{i} \; \mathbf{0}]$

Frame $2: [2, 0, 0, 0, 0, 0, 1, 0, 0, 0, 3] \rightarrow$

modulated Frame $2 = [0.7071 + 0.7071\text{i} \; \mathbf{0 \; 0 \; 0 \; 0 \; 0} \; -0.7071 - 0.7071\text{i} \; \mathbf{0 \; 0 \; 0} \; 0.7071 - 0.7071\text{i}]$

pilot for frame $1: [1 \; 1]$ *and pilot for frame* $2: [1 \; -1]$

$h = [0.6391 + 0.1991i \; 1.3546 - 0.7361i]$

On the receiver side, the received data frame is (single antenna):

Received frame $\mathbf{Y}$
$= [1.3539 + 0.6591\text{i} \; -0.3667 - 0.5401\text{i} \; 0.5478 - 0.2099\text{i} \; -0.3400 + 0.3209\text{i} \; 0.4844 + 0.6090\text{i} \; 0.8106 - 0.1779\text{i} \; -1.6373 - 0.4004\text{i} \; -0.6716 + 0.4227\text{i} \; 0.6243 - 0.2995\text{i} \; 0.3468 + 0.5703\text{i} \; 0.3065 - 1.5442\text{i}]$

Received pilot symbols $= [2.0086 - 0.6737\text{i} \; -0.6207 + 0.7692\text{i}]$

$\hat{h} = [0.6940 + 0.0477\text{i} \; 1.3147 - 0.7214\text{i}]$

Original set of symbols: $\mathbf{Z}$
$= [-0.7071 + 0.7071i \; -0.7071 - 0.7071i \; 0.7071 + 0.7071i \; 0.7071 - 0.7071i]$

$\hat{h}_1 \cdot \mathbf{Z} = [-0.5245 + 0.4570i \; -0.4570 - 0.5245i \; 0.4570 + 0.5245i \; 0.5245 - 0.4570i]$

$\hat{h}_2 \cdot \mathbf{Z} = [-0.4195 + 1.4397i \; -1.4397 - 0.4195i \; 1.4397 + 0.4195i \; 0.4195 - 1.4397i]$

Then: $\hat{h}\mathbf{Z} = [-0.5245 + 0.4570i \; -0.4570 - 0.5245i \; 0.4570 + 0.5245i \; 0.5245 - 0.4570i \; -0.4195 + 1.4397i \; -1.4397 - 0.4195i \; 1.4397 + 0.4195i \; 0.4195 - 1.4397i]$

Applying Equation 4 *for the first received symbol* $(1.3539 + 0.6591\text{i})$ *yields*:

$[3.5690; 4.6800; 0.8226; 1.9335; 3.7542; 8.9676; \mathbf{0.0648}; 5.2781]$

with minimum value of 0.0648 *located at position* 7
$\rightarrow$ *from Eqs.* 5 *and* 6, *the index pair of values are*:

$\widehat{D} = \mathbf{Z}\big[(\hat{S}_{idx} - 1)modM + 1\big] = \mathbf{Z}[6mod4 + 1] = \mathbf{Z}[3] = 0.7071 + 0.7071i$

$\widehat{N}_{idx} = ceil\left(\dfrac{\hat{S}_{idx}}{M}\right) = ceil\left(\dfrac{7}{4}\right) = ceil(1.75) = 2$

From Table 2 *above, the row corresponding to antenna index* 2 *and modulated symbol* $0.7071 + 0.7071 i$ *gives data symbol* 5 *which concludes recovery of transmitted symbol successfully.*

Figure 5 shows BER versus SNR for various number of transmit antennas and modulation order using simulation parameters presented in Table 1. As modulation order increases, the separation between modulated symbols gets closer which in turn makes the process of distinguishing them harder and needs more enhanced methods.
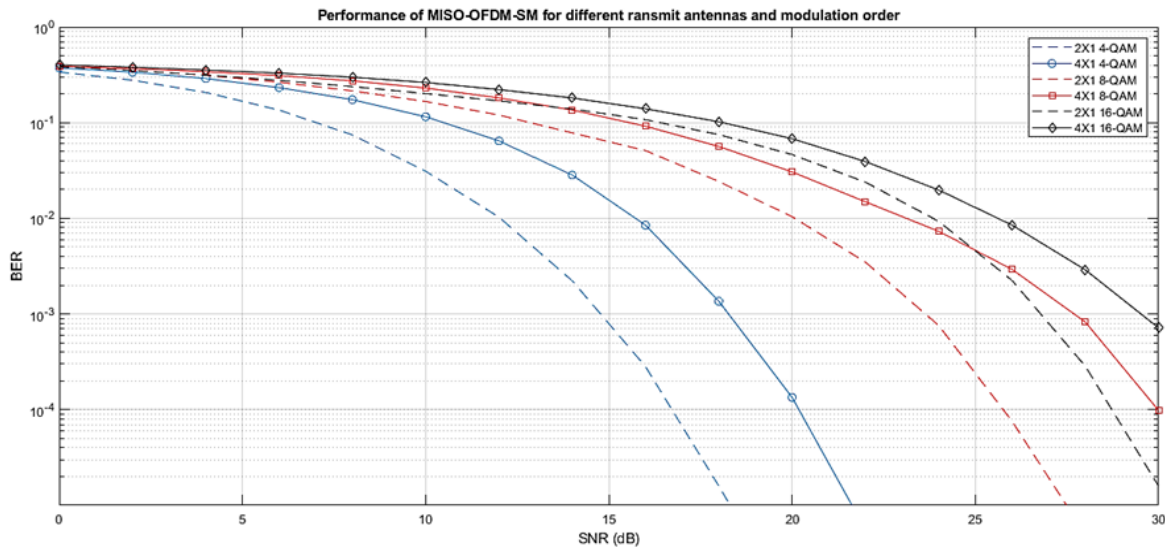
Figure 5. Performance evaluation of BER versus SNR for MISO-OFDM-SM system
with different transmit antennas an modulation order

4.   CONCLUSION

In this paper, a simplified spatial modulation based OFDM is presented and simulated using MATLAB SIMULINK. The proposed system; MISO-OFDM-SM is equipped with multiple transmit/single receive antennas in which simple mathematical functions are used for assigning modulated simples to active tranmit antennas. The proposed system assumes a receiver with maximum likelihood detector that discriminates and detects both modulated and spatial symbols. It has been proven that the proposed method achieves the required task and further ease receiver decision process. Furthermore, multiple input single output representing a base station downlink is targeted in this work where the mobile client is equipped with single antenna.

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