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An Efficient DM OFDM-IM Transmission Using Antenna Subset Spatial Modulation

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ABSTRACT: Index modulated DM OFDM is recently proposed, which is spectrally as well as energy efficient technique. In DM OFDM-IM spectral efficiency is improved by utilizing all the subcarriers for information transmission. The subcarriers are divided into several subblocks, in each subblocks there are two distinguishable signal constellations used to modulate these subcarriers. Each block of information bits is divided into two information carrying units: a unique subcarrier index number that determines the subcarrier activation pattern and symbols that was chosen from the two constellation sets. In this, antenna subset spatial modulation is applied to the DM OFDM MIMO system. Antenna subset spatial modulation maps a block of information bits to three information carrying units: A unique antenna subset number that was chosen from a set of antenna subsets, a unique transmit antenna number that was chosen from a set of transmit antennas and symbols that was chosen from the constellation sets. This will further increase the data rate of transmission with minimum bit error rate.

KEYWORDS: DM OFDM-IM, MIMO, SM

I. INTRODUCTION

Multicarrier transmission has become an attractive technique in many wireless standards to meet the increasing demand for uninterrupted access to the information with high quality, higher data rate communication systems. Orthogonal frequency division multiplexing (OFDM) is a pervasive multicarrier digital communications technique due to its numerous benefits such as capability of providing high-rate data transmission by splitting the serial data into many low-rate parallel data streams. It can also effectively combat the inter symbol interference caused by a dispersive channel. Therefore, OFDM has been applied in many broadband wireless standards, such as the third-generation partnership project (3GPP), 802.16 WiMAX, 802.11a/g Wi-Fi, HIPERLAN/2 standard and Long-Term Evolution (LTE) [1].

In 5G networks, the explosive growth in the mobile data services and the popularization of smart devices leads to the requirements for high spectral and energy efficiency. Index modulation (IM) uses an effective way to transmit the information for future generation wireless networks as they offer hardware simplicity, apart from being spectral and energy efficient[2]. IM, in which the indices of the building blocks of the considered communications systems are used to convey additional information bits in the form of transmitting entities like radio frequency mirrors, antennas, LEDs, subcarriers etc. apart from M-ary signal constellation symbols.

Spatial modulation (SM) is a multi-input multiple-output (MIMO) technique. In this, additional information bits are conveyed as a unique transmit antenna number. 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.

IM was introduced into multicarrier OFDM systems as an index modulated OFDM (OFDM-IM) [2]-[3]. In this, additional bits are conveyed by transmitting subcarrier activation pattern. This improves the spectral efficiency and energy efficiency of OFDM systems. The main disadvantage of index modulated OFDM is that a portion of subcarriers is deactivated and unused during the transmission and results in the decrease of the overall spectral efficiency.

Dual mode OFDM with index modulation (DM OFDM-IM)[4]-[5] is a recently developed multicarrier technique. This system utilizes all the subcarriers for transmitting information by make use of two sets of disjoint constellation sets. This enhances the spectral efficiency of OFDM systems. The basic idea of DM OFDM-IM is to map a block of information bits into two information carrying units: a set of symbols that was chosen from two constellation sets and unique subcarrier indices.

The data rate of DM OFDM-IM can be enhanced by implementing MIMO DM OFDM-IM. There are some limitations for MIMO DM OFDM-IM. The main problem in MIMO DM OFDM-IM systems is the receiver complexity

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as number of antenna increases and also the effect of inter channel interference (ICI) due to the simultaneous transfer of data from multiple antennas[6]. Accurate knowledge of CSI is required at receiver to retrieve the message transmitted. Design problems of DM OFDM in frequency selective fading channels still exist. Frequency selective fading cannot be avoided in 5G networks due to the high transmission rate. In this paper data rate of DM OFDM-IM is enhanced by transmitting index modulated DM OFDM by antenna subset spatial modulation.

II. DM OFDM-IM

In DM OFDM-IM, a block of information bits is split into two units and are used for the subsequent mapping: Constellation mapping and subcarrier index mapping. The name dual mode indicates that there are two constellations used to map the incoming bits into symbols. These constellation pairs ought to be distinguishable and will have a completely different average power. So at receiver, detection and demodulation are often easily achieved. In DM OFDM-IM, all the subcarriers are actively modulated using these two constellations, which is not possible in OFDM-IM. This helps to increase the spectral efficiency of the system.

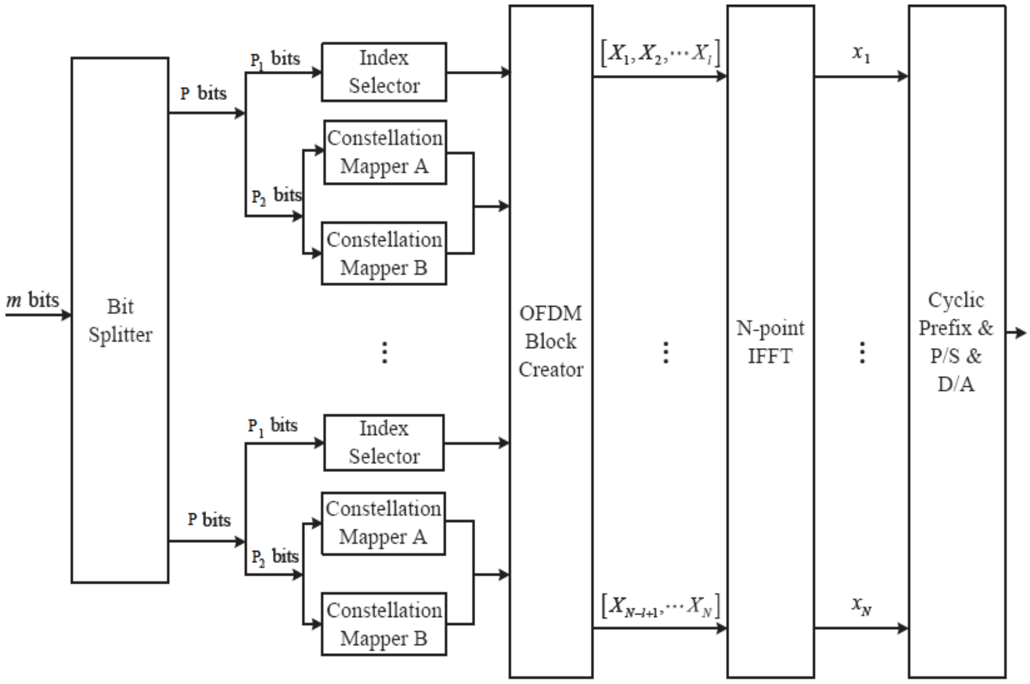

Figure 1: System model of the DM-OFDM transmitter [4]

Figure 1 shows the block diagram of DM OFDM-IM. Bit splitter divides the m incoming bits into g groups, each containing p bits and p = m/g. Each group of p data bits is fed into an index selector and two different constellation mappers for generating an OFDM subblock of length l = N/g, where N is the size of inverse fast Fourier transform (IFFT). In each block, the p incoming bits are further divided into $p_1$and p_2. The first p_1 its referred as index bits, are used by the index selector to divide the indices of each subblock into two index subsets, denoted as I_A and I_B. The remaining p_2 bits are fed to the mappers A and B having the constellation sets of μ_A and μ_B associated with the sizes of M_A and M_B, respectively, where $M_A \cap M_B = \varphi$.

Using these two mappers, the subcarriers corresponding to I_A and I_B are modulated with the help of the index selector. Note that index selector solely determines the indices of subcarriers modulated by mapper A, i.e., I_A. With the knowledge of I_A, the indices of the subcarriers modulated by μ_B are often determined. Assume that, k out of l subcarriers in each subblock is modulated by M_A-ary constellation and remaining l-k subcarriers are modulated by M_B-ary constellation. Then size of each subblock is given by

$$p = p_1 + p_2 \qquad \text{(Equation 1)}$$

where,

$$p_1 = \left\lfloor \log_2 \left(\frac{l!}{(l-k)!k!} \right) \right\rfloor \qquad \text{(Equation 2)}$$

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$$p_2 = k\log_2(M_A) + (l-k)\log_2(M_B) \quad \text{(Equation 3)}$$

and $\lfloor\,\rfloor$ denotes the integer floor operator.

After the mapping, symbols of g different DM OFDM subblocks are concatenated. The symbols are then converted into time domain using inverse FFT (IFFT) operation. After performing IFFT, cyclic prefix is added to these symbols. Use of cyclic prefix is a key component of enabling the OFDM signal to operate reliably. The cyclic prefix acts as a buffer region or guard interval to safeguard the OFDM signals from inter symbol interference. The resultant signals are then fed into a parallel-to-serial converter (P/S) and a digital-to-analog converter (D/A) and transmitted through Rayleigh channel.

At the receiver, received signal is multiplied with the complex conjugate of the channel matrix followed by removal of cyclic prefix. After, N -point FFT operation is performed on the resultant noise contaminated signal to yield the frequency-domain (FD) received signal. The symbols are then demapped into bits using a low complexity Maximum likelihood detector. Low complexity ML detection finds the symbol in the constellations having minimum distance with the incoming symbol and convert into its binary equivalent. The corresponding index bits are recovered.

III. PROPOSED SYSTEM

The data rate of DM OFDM-IM can be enhanced by implementing MIMO DM OFDM-IM. But the main problem associated with a MIMO system is receiver complexity as the number of antenna increases and additionally Inter Channel Interference (ICI) affects the performance of the MIMO system.

In the proposed system, index modulated DM OFDM symbols are transmitted using antenna subset spatial modulation system. Figure 2 shows the transmitter section of the proposed system. Here, a block of information bits is split into four units and are used for the following mapping: Constellation mapping, antenna index mapping, antenna subset index mapping and subcarrier index mapping The concept of antenna subset SM can be explained using figure 3.

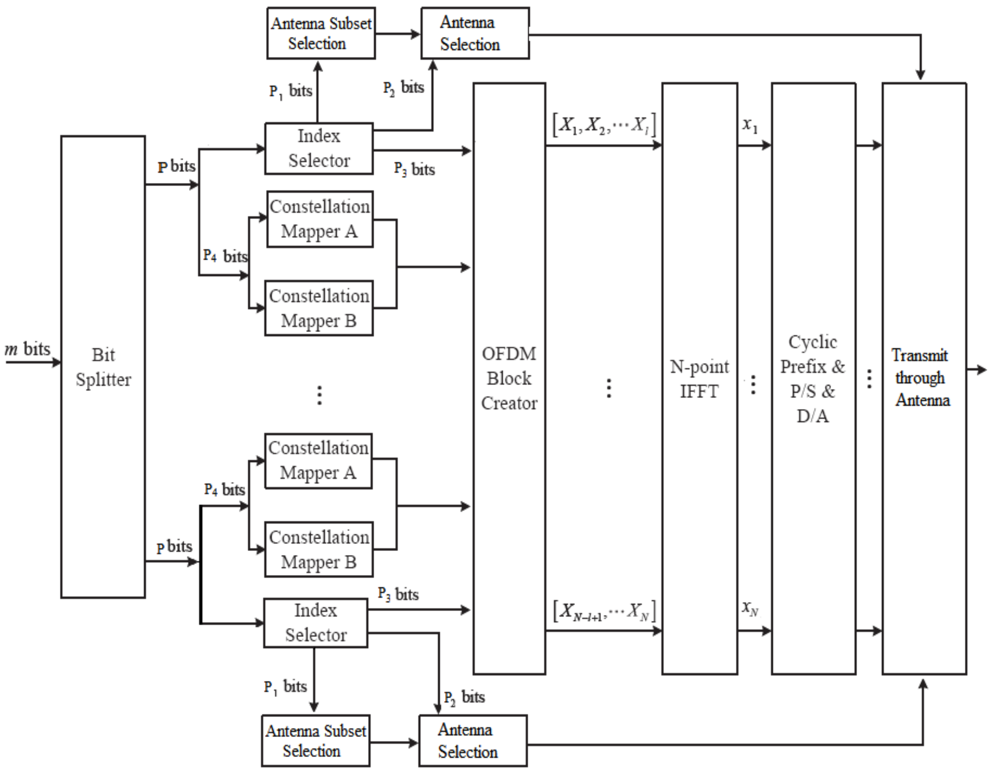

Figure 2: Transmitter section of the proposed system

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Number of transmitting antenna N_T= 16 is divided into 4 subsets, each having 4 antennas. Let N_S denote the number of antenna subsets. From equation 1, we block the information bits with block length

$$n = log_2 N_S + log_2 N_T + p \text{ bits.} \qquad \text{(Equation 4)}$$

Consider that the block of information consists of n bits. The block of information is divided into four information carrying units. The first k bits are mapped into the antenna subset index. The next l bits are mapped into the antenna index and the next $p_1$bits are mapped into the subcarrier index. The remaining n-k-l-p_1 bits are mapped by two sets of constellation points as in conventional DM OFDM-IM.

In the proposed system, 16 transmitting antennas and one receiving antenna are considered for the simulation. A stream of information bits is divided into subblocks each having length of 14 bits. Here, a simple example is given to have an insight on the proposed system. Let the first block is 00101010111000. The block of bits is divided into three sets of index units and data unit. Each sets of index units having a length of two bits. The first unit consists of the bits 00. The antenna subset, through which transmission should be done, is selected based on this first block. Since the first unit is 00, we select antenna subset 1 for transmission.

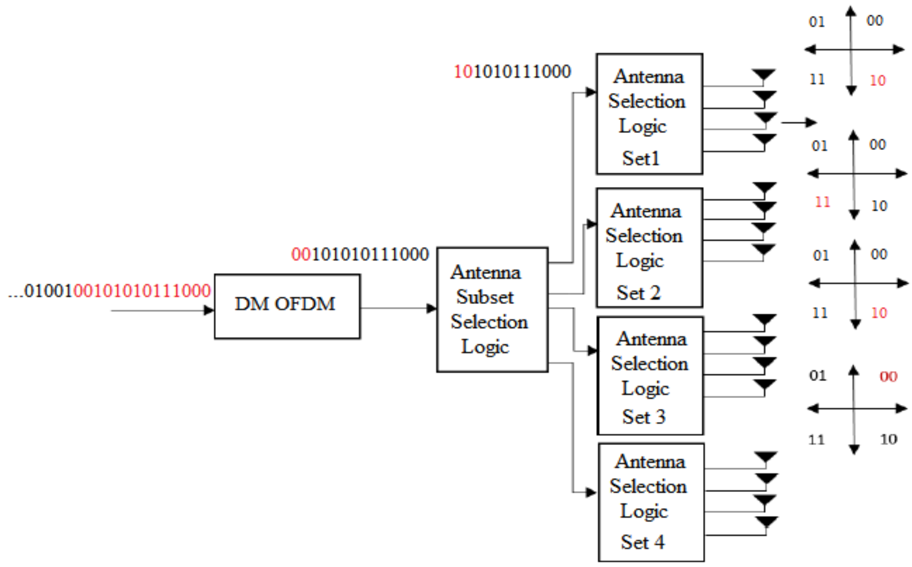

Figure 3: Block diagram of antenna subset SM

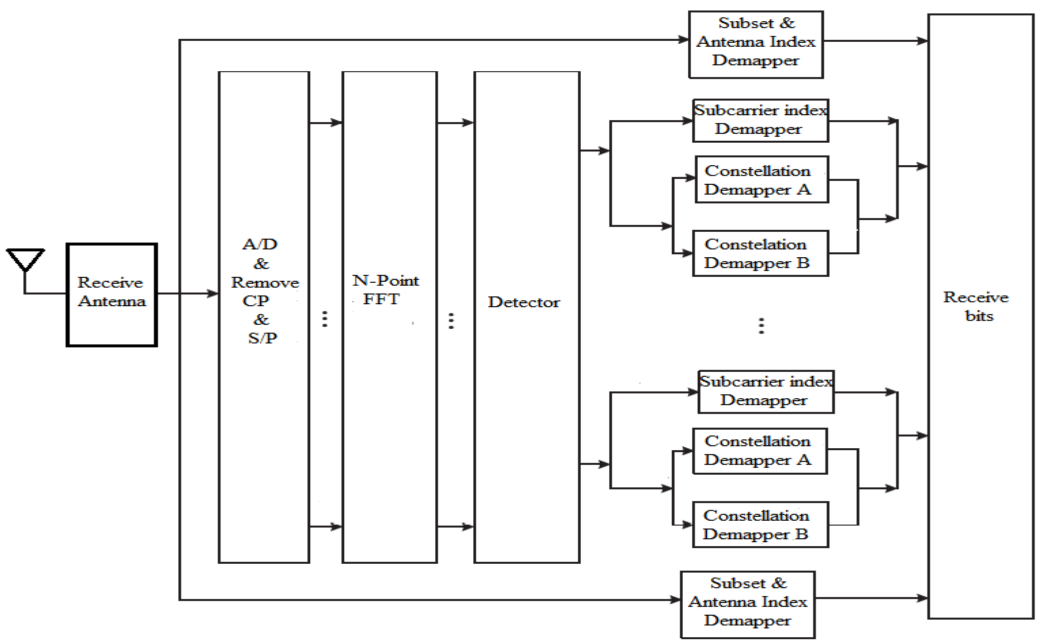

Figure 4: Receiver section of the proposed system

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Now let us consider the next unit. It contains the bits 10. This unit is used for antenna number mapping. The information will be transmitted through the selected antenna. Here we select the third antenna from the first antenna subset for transmitting the information. The third unit is used for subcarrier index mapping and remaining unit will be mapped into symbols in the constellation diagram. In [4], look-up table for subcarrier index mapping is explained.

Since only one antenna is active at a time, the transmission matrix will have only one non-zero value. Here the system is 16x1 MIMO, thus the channel matrix will have a dimension 16 x1. Let X be the transmission matrix, H be the channel matrix, then the received matrix will be:

$$Y = HX + awgn \qquad \text{(Equation 5)}$$

For decoding the antenna subset index, we multiply the received matrix with the Hermitian conjugate of the channel matrix corresponding to each antenna subset. From the resulting matrix we can find the antenna index also. The transmitted symbols are estimated using low complexity Maximum Likelihood detection technique. From the recovered symbol pattern, subcarrier index bits can be retrieved also.

IV. SIMULATION RESULTS

The performance of conventional DM OFDM-IM system and proposed DM OFDM-IM system with antenna subset spatial modulation is compared under the AWGN and the frequency-selective Rayleigh fading channel conditions. Consider conventional DM OFDM-IM system where 4-QAM constellations are utilized for simulation and shown in figure 5. Let the number of subcarriers N=17920 is divided into 4480 subblocks, and each block has 4 subcarriers. The length of cyclic prefix is 2240. Thus, a total of $p_1 + p_2 = 2 + 8 = 10$ information bits are transmitted per DM OFDM subblock, where 2 bits are used to determine subcarrier indices and the remaining 8 bits are mapped by dual mode 4-QAM constellations. The spectral efficiency of this DM-OFDM system is equal to 2.22 bits/s/Hz.

In the case of proposed system, $p_1 + p_2 + p_3 + p_4 = 2 + 2 + 2 + 8 = 14$ information bits are transmitted per subblock. Here, the first 2 bits are used to select antenna subset, the next 2 bits are used for antenna selection from the selected antenna subset, the next 2 bits are utilized by subcarrier index selector and remaining 8 bits are mapped to obtain 4 QAM symbols. For simulation purpose, antenna subset SM with 16x1 MIMO is considered. The total 16 antennas are divided into 4 subsets, each contains 4 antennas. The number of total subcarriers N is set to 12800 and is divided into 4 subcarriers of 3200 sub blocks. The cyclic prefix length is 3200 and the spectral efficiency of the proposed system is equal to 2.8 bits/s/Hz.

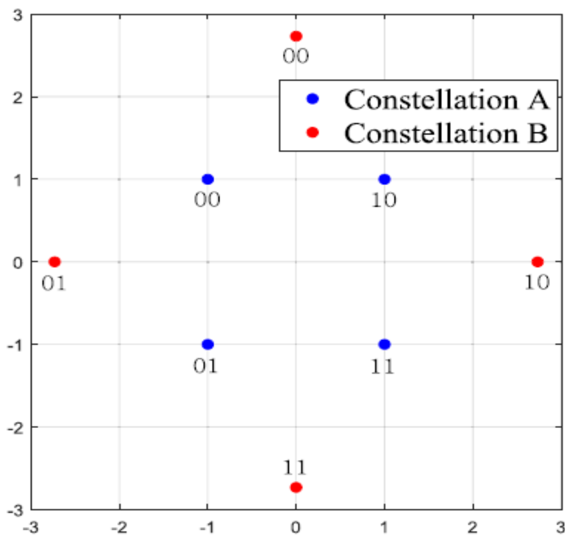

Figure 5: DM-OFDM constellation design for μ_A and μ_B with M = 4

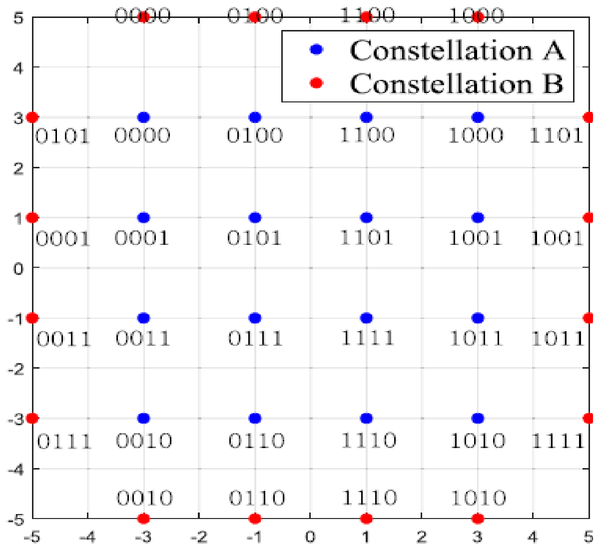

Figure 6: DM-OFDM constellation design for $\bar{\mu}_A$ and $\bar{\mu}_B$ with M =16

Figure 7 shows the Bit Error Ratio vs SNR graph of conventional DM OFDM-IM system and the proposed system utilising 4-QAM constellation. By analyzing this graph, it is clear that for a given SNR, the bit error ratio is minimum for the proposed DM OFDM-IM system with antenna subset SM compared to the conventional DM OFDM-IM system without antenna subset SM. Also, the proposed system has more spectral efficiency than the conventional system.

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Both the conventional and proposed systems are implemented using 16-QAM constellation. The 16-QAM constellation pair is shown in figure6. In the conventional DM OFDM-IM system, a total of $p_1 + p_2 = 2 + 16 = 18$ information bits are transmitted per DM OFDM subblock. In the proposed system, $p_1 + p_2 + p_3 + p_4 = 2 + 2 + 2 + 16 = 22$ information bits are transmitted per subblock. The total number of subcarriers in conventional and proposed systems are 14080 and 12800 respectively. The cyclic prefix length is 1760 in conventional system and is 3200 in the proposed system. The spectral efficiency of conventional system is 4 bits/s/Hz, while that in the case of proposed system is 4.4 bits/s/Hz.

Figure 8 shows the Bit Error Ratio vs SNR graph of conventional DM OFDM -IM system and the proposed system utilizing 16-QAM constellation. Comparing both the figures 6 and 7, we can see that the BER performance of the proposed system with 4-QAM is better than that of the proposed system with 16-QAM. This is because, in 4-QAM, the constellation points are in four different quadrants. But in 16-QAM, each quadrant contains four constellation points. Thus, while performing maximum likelihood detection, the error probability will be higher for 16-QAM.

Considering the spectral efficiency performance, the proposed system with 16-QAM is better than the proposed system with 4-QAM. This is because, a single 16-QAM symbol conveys more information bits than a single 4-QAM symbol.

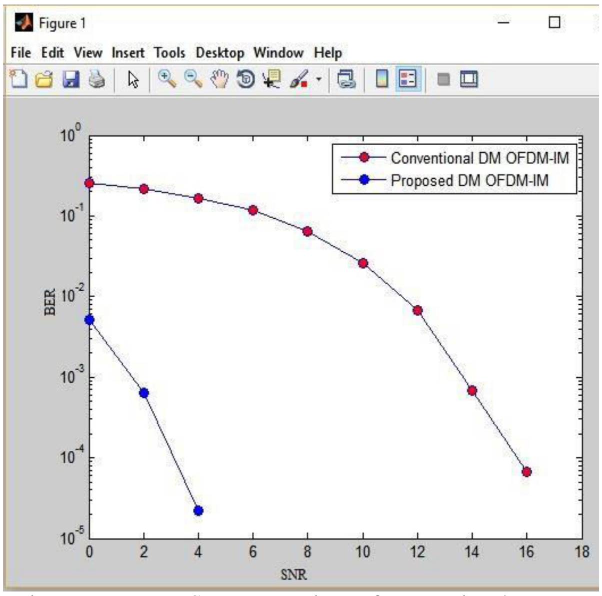

Figure 7: BER vs SNR comparison of conventional system and proposed system using 4-QAM constellation

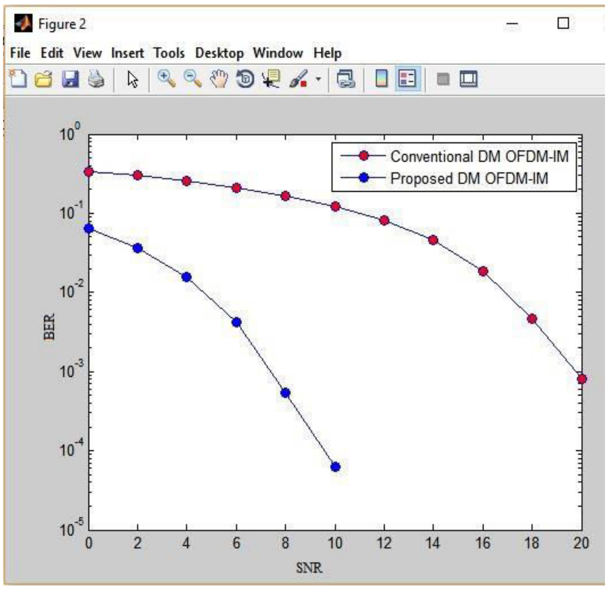

Figure 8: BER vs SNR comparison of conventional system and proposed system using 4-QAM constellation

The calculation complexity of receiver in conventional DM OFDM-IM and proposed system is in terms of the number of multiplication operations shown in table I, where η is the spectral efficiency. Despite the large computational complexity, the performance of the proposed system can be compromised with high energy efficiency and spectral efficiency.

	DM OFDM-IM	Proposed System
Computational Complexity	$o(6\eta(M_A + M_B))$	$o(6(\eta(M_A + M_B) + 2^{\eta}))$

Table 1: Comparison of computational complexities in conventional system and proposed system

V. CONCLUSION

The demand for uninterrupted access of high speed data leads to design a communication system with maximum spectral efficiency and minimum or negligible error. In DM OFDM-IM, a block of information bits is mapped to two information carrying units: a unique subcarrier index number which determines the subcarrier activation pattern and

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symbols chosen from two constellation sets. The system utilizes all the subcarriers to carry information which are not possible in existing OFDM-IM. This will increase the data rate OFDM systems.

The data rate of the DM OFDM system can be further increased by transmitting DM OFDM symbols using antenna subset spatial modulation. In the proposed system, the information bits are conveyed not only by the constellation symbols and subcarrier indices, but also by a unique antenna subset number that was chosen from a set of antenna subsets, and a unique transmit antenna number that was chosen from a set of transmit antennas. In any given symbol interval, antenna subset SM selects one antenna from the selected subset containing multiple antennas for transmission. This will increase the data rate of the MIMO systems.

In the proposed system, the information bits conveying subcarrier indices, antenna subset number and antenna number are not directly transmitting. Hence the system is also energy efficient. More data can be transmitted so that the data rate will be greater than that of the conventional DM OFDM-IM.

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