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BER ENHANCEMENT FOR 1-BIT ADC MIMO-CEM SYSTEM USING SELECTIVE CHANNEL CODING TECHNIQUE

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Abstract- MIMO Constant Envelope Modulation (MIMO-CEM) is presented as a promising alternative candidate for the commonly used MIMO Orthogonal Frequency Division Multiplexing (MIMO-OFDM) system due its fabulous capability in both of power and complexity. This improvement in performance is gained due to using efficient non-linear power amplifier at transmitter and 1-bit Analog to Digital Converter (ADC) sampled at the Intermediate Frequency (IF) in the receiver side. However, despite system's design provides low power consumption and low design complexity, a great reduction in Bit Error Rate (BER) performance is introduced. This was a result of using 1-bit ADC sampled in the IF which caused severe quantization noise. Therefore, a suitable channel coding technique become inevitable to overcome this BER performance degradation. In this proposed, a selective channel coding method is studied for MIMO-CEM system is done to improve high BER problem of the MIMO-CEM system. The evaluation of this study was done over a multipath Rayleigh fading channel with both Minimum Shift Keying (MSK) modulation and Gaussian Minimum Shift Keying (GMSK) modulation. The simulation results show a significant improvement in the BER performance at low values of Signal to Noise Ratio (SNR) when LDPC channel coding is used, while the Convolutional Code (CC) with Viterbi Decoder achieves the best BER performance at high SNR values.

Keywords—1-bit ADC; Constant Envelop Modulation; MIMO; Viterbi Decoder; LDPC Codes

I. INTRODUCTION

One of the chronic drawbacks of the widely used MIMO-OFDM system is the High Peak to Average Power Ratio (PAPR). Hence, an efficient Power Amplifier (PA) like class A or class AB should be used to avoid ODFM signal distortion which make MIMO-OFDM system have a severe power consumption [1]. Moreover that, MIMO-OFDM receiver (RX) uses a high-resolution ADC [2] which increases the computational complexity and the overall power consumption as well [2]. Therefore, two big straggles face the design of massive MIMO branches for OFDM system; the high power consumption and the vast computational complexity [2]. Thus, MIMO-CEM system was introduced as a promising alternative candidate to the MIMO-OFDM system to overcome its drawbacks [2-4]. So, in MIMO-CEM system transmitter, a nonlinear phase modulator (constant envelope modulator) is used while 1-bit ADC operating in the IF frequency is used in the receiver side. Therefore, an efficient PA can be implemented, i.e. class C, in the receiver side instead of the linear class A PA which in commonly used with MIMO-ODFM systems. This modification achieves significant reduction in power consumption comparing to other MIMO-OFDM systems [2-4]. Another advantage is gained by scarifying most of analog stages as Automatic Gain Control (AGC), mixer and analog filters in the receiver side due to using the 1-bit ADC [2-4]. Moreover that, as a result of using the a-bit ADC also, more MIMO branches can be implemented for this MIMO-CEM system than for MIMO-OFDM system [5], [6]. Also, there is another benefit due to system's power and complexity efficiency which reflects on improving spectral efficiency for MIMO-CEM system comparing to MIMO-OFDM system [5], [6]. In spite of all the previous mentioned advantages, MIMO-CEM system suffers from high digital hardware complexity in the receiver side, this is a result of using the 1-bit ADC which causes severe nonlinear quantization noise [2-4]. However, sophisticated Digital Signal Processing (DSP) techniques are required to overcome this drawback [3], [4], [9], [10]. Thus, the practical utilization of MIMO-CEM system still struggles with nonlinear quantization noise caused by the 1-bit ADC [9-11]. Many enhancements were applied for the first version on MIMO-CEM system epically in channel estimation [9], [10], channel equalization [3], [4], and channel coding [12]. Moreover, to neutralize the effect of quantization noise introduce by the 1-bit ADC, a prober channel coding technique should be chosen. The first version of MIMO-CEM system didn't make sufficient study on this obstacle and it was just using a Convolutional Coder (CC) [13] with a Viterbi Decoder [13]. Thus, another deep investigation for the system's BER performance was tested while using the Low-Density Parity Check (LDPC) Codes. It was proven that LDPC codes beat CC with Viterbi decoder in BER performance in high SNR values [2]. Therefore, this proposed makes more enhancement for the BER performance of the MIMO-CEM system by using a selective channel coding method depending on the SNR value at the receiver side in order to achieve the optimum BER performance for MIMO-CEM system. Therefore, the study of the system's BER performance is tested while using both of CC with Viterbi decoder [13] and LDPC codes [12], [14].

II. LITERATURE SURVEY

MIMO-CEM was originally introduced by the authors in [1] as a MIMO based PHY layer to enhance the spectral efficiency of wireless backhaul nodes. Wireless backhaul is a type of wireless multihop network in which all nodes (core + relay nodes) are fixed in their positions, and uplink and down link packets are distributed through the network via gateway nodes that are cable-connected to internet [2]. MIMO-CEM was proposed to solve many of the MIMO-Orthogonal Frequency Division Multiplexing problems that withstand the design of high speed power efficient wireless backhaul Access Points (AP) [3] [4]. Due to the multicarrier nature of the OFDM signal; the OFDM signal requires high power consumption linear power amplifier (PA) on the RF transmitter, such as class A or class A/B PAs [5], and high resolution ADC on the receiver side [6]. The authors in [1] stated that the minimum ADC resolution required for QPSK-OFDM systems, which gets the system works well, is 7-bit. These drawbacks prevent OFDM from scalable design when it is extended to MIMO due to hardware complexity. In consequence, high spectral efficiency wireless backhaul nodes can't be designed using MIMO-OFDM. MIMO-CEM was originally designed to overcome these drawbacks of MIMO-OFDM [1]. In MIMO-CEM, constant envelope phase modulation is used on the transmitter side which allows the use of power efficient non-linear PA, such as class C PA. In addition, a low resolution ADC (1-bit in the default operation) can be used on the receiver side. This low resolution ADC operates in the Intermediate Frequency (IF) band. This IF sampling 1-bit ADC eliminates most of the analog stages on

MIMO-CEM receiver, i.e., the Automatic Gain Control (AGC), analog mixer, analog LPF and the anti-aliasing filter, which greatly reduces the receiver complexity. Also, it will overcome the problems of imaging and carrier offset that sometimes arise in case of baseband sampling. Although OFDM has higher spectral efficiency than CEM, this drawback of CEM can be compensated using MIMO. The low complexity CEM system should allow the application of more MIMO branches than OFDM [7] [8]. Although, the digital signal processing computational power will be increased through increasing the MIMO branches of CEM; we can view the concern with optimistic foresight because of the rapid progress on digital circuit evolution [9][10]. Due to the low resolution ADC, MIMO-CEM channel estimation is considered as one of the major problems to withstand its real application. The authors in [3] and [4] have solved the MIMO-CEM channel estimation problem using adaptive filters bank channel estimator. In addition, they proved that Code Division Multiplexing (CDM) preamble is necessary for accurate MIMO-CEM channel estimation. The idea behind their channel estimator is to replicate the received preamble signals in presence of the IF based low resolution ADC. The estimated MIMO channels are determined so as to minimize the error between the actual received preambles and the replicated ones, where an adaptive algorithm is used to minimize this error iteratively. Moreover, because of the low resolution IF sampled ADC, IF based MLSE was proposed as a nonlinear equalization scheme for MIMO-CEM [3] [4]. This equalizer takes into account the severe quantization noise comes from the 1-bit ADC when it equalizes the channel. Due to its IF based design, which requires replication of the whole IF based MIMO-CEM transceiver, the MLSE equalizer is too complicated. This high complexity equalizer prevents the design of high branches MIMO-CEM results in a limited transmission speed MIMO-CEM transceiver. In this proposed, low complexity MIMO-CEM equalizer is proposed. The proposed equalizer is based upon mathematically baseband modeling the nonlinearity inherent in the IF sampled low resolution ADC. Consequently, the ADC quantization noise is approximately estimated. The proposed MIMO-CEM equalization will be done in two steps. In the first step (coarse equalization), number of nominated candidate sequences are chosen from the total available candidates using an MLSE equalizer based upon the approximate baseband model. In the second step, the best candidate sequence among these nominated candidates is evaluated using the accurate IF based MLSE equalizer (fine equalization). Therefore, using the proposed equalizer, the number of equalization processes required by the highly complicated IF equalizer are greatly reduced. Instead, we strongly rely on the low complexity baseband equalizer. The performance of the proposed MIMO-CEM equalizer is evaluated under different channel scenarios and conditions, and compared with the performance of the high complex IF based MLSE equalizer given in [3][4]

III. PROPOSED SYSTEM

MIMO CONSTANT ENVELOP MODULATION (CEM) SYSTEM

Nowadays, one of the most chronic challenge of communication system is the Power Consumption [1]. Figure 1 shows a standard power consumption for a micro-cellular radio access base station [1]. As shown in Fig. 1, the PA alone absorbs about 50% - 80% from the total consumed power by the base station. Furthermore, only from 5% to 15% of the power is consumed by the signal processing equipment. Therefore, the MIMO-CEM system was designed as an alternative candidate to replace the currently used MIMOOFDM system which used in the IEEE 802.11n standard particularly for wireless backhaul network applications [3], [10]. This system was implemented to enhance the power efficiency of the PA at the TX side and to reduce the analog hardware complexity in the RX side. As, the constant envelop Phase Modulation (PM) was used in the MIMO-CEM TX side and an IF-sampler 1-bit ADC was used in the MIMIO-CEM RX side [2]. Thus, a nonlinear PAs such as Class C or Class D can be used at RX this however, will introduce significant improve of the MIMO-CEM power consumption compared to the conventionally MIMO-OFDM system. In general, Fig. 2 shows a 2×2 MIMO-CEM system structure. Where, the input data is encoded using channel encoder and interleaved to improve the BER performance of the MIMO-CEM system particularly with the existence of the 1-bit ADC. Then, the encoded data is split to number of streams equal to the number of transmitted MIMO antennas. Furthermore, the Constant Envelop Phase Modulation

(PM) is applied to each stream of data using a differential encoder followed by MSK/GMSK frequency modulation to produce the constant envelop signal at the transmitter side. At the receiver side, Band Path Filter (BPF) operates in the IF band is used to enhance the SNR of received signal. After that, the signal is transformed to digital signal by using 1-bit ADC sampled at the IF frequency. Moreover, a down converter is used to convert the received filtered IF-band signal to Baseband (BB) signal (IF to BB). Due to the channel effect a MLSE equalized [3], [4] is applied to this BB signal to decode the received signal. Finally, a de-interleaver is applied along with a proper channel decoder as an error correction code to correct the remaining errors after the MLSE operation.

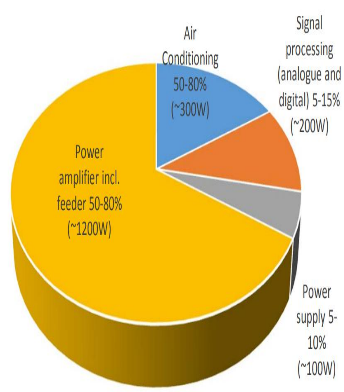

Fig. 1. Standard power consumption for a micro-cellular radio access base station

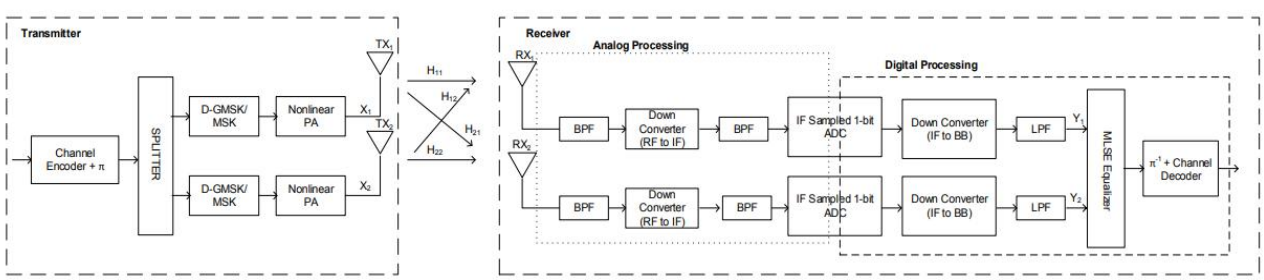

Fig. 2. The MIMO-CEM 2×2 transceiver system

CONVOLUTIONAL CODER WITH VITERBI DECODER: A Convolutional Coder (CC) is considered one of Forward Error Correction (FEC) codes which introduced by Peter Elias in 1955 [13]. CC generates parity check symbols by using the sliding application of the Boolean polynomial function to a data stream. This sliding nature of the convolutional codes simplify the decoding process using trellis. Thus, the convolutional codes can be maximum likelihood soft decision decoded with reasonable complexity. This was discovered by Andrew Viterbi in 1967 and it was called "The Viterbi Algorithm" [13]. The idea of the Viterbi algorithm is to find the most likely sequence in of hidden states; which is called: the Viterbi Path; that results in a sequence of observed events, especially in the context of Markov information sources and hidden Markov models [13].

LOW DENISTY PARITY CHECK (LDPC) CODES: Low Density Parity Check (LDPC) codes belong to FEC codes family which was introduced by Gallager in 1963 [14]. LDPC codes were derelict until 1996 when it was rediscovered by Mackay [14]. LDPC codes become a robust error correction codes that grant transmission of data rate near to Shannon's limit. Also, many standards are using LDPC codes as 10G BaseT Ethernet and Digital Video Broadcasting Satellite Second Generation (DVB-S2). Wi-Fi 802.11 standard also uses LDPC codes in the High Throughput (HT) specification as an optional part of 802.11n and 802.11ac standards. Low density parity check codes are linear block codes obtained from spares bipartite graphs. The generator matrix G and the spares parity check matrix H are considered the crux of the LDPC codes.

The decoding process of LDPC codes are differ from other block codes as Maximum Likelihood (ML) decoding algorithms are commonly used to decoded traditional block codes. So, the code world length is designed shortly with special mathematical constraint to simplify the decoding process. Furthermore, LDPC codes use iterative algorithm during the decoding process via a graphical notation of their parity check matrix. Therefore, the parity check matrix's characteristics control the design of LDPC codes. Message passing algorithms are decoding algorithms which are used in decoding LDPC codes [14]. The decoding process can be illustrated using Tanner graph. As a message pass through edges of

Tanner graph, with every node of the Tanner graph works separately and isolated, so only edges connected to the message have access to information contained in it. Message passing algorithms are called iterative decoding algorithms also as each message goes forward and backward between the bit and the check nodes during a certain number of iterations until the required result is accomplished or the process is stopped after certain number of iterations. Different decoding algorithms can be classified either per the operation performed or per the type of message passed through check nodes. In the bit-flipping decoding algorithm, the message is a binary data but in the belief propagation decoding algorithm, the message is probability information which show an accuracy level about the actual value of the codeword bits. When using the loglikelihood ratio to represent this probability values, and uses this value for calculations at bit and check nodes using sum and product operations, the belief propagation method then is called sum-product decoding algorithm. Soft LDPC decoding operation uses both reliability and parity information during the decoding process. This reliability information requires generation of more bits at each node in the Tanner graph. Check nodes perform both reliability and parity update together. Therefore, in case of other incoming messages, its reliability is merged to calculate reliability for each outgoing message. In fact, log-likelihood ratios can be used to denote this reliability information for each message. Also, MAP decoding algorithm which is introduced by Bahl et. al uses the same update technique including the hyperbolic tangent function. In case of hard decision decoding algorithm, the same updating scenario for both the message and the decoded bits is performed as in the soft decoding algorithm. The major different is in calculating reliability values of received bits and message as they are considered scaling values of their associated weighting function.

IV. SIMULATION RESULTS

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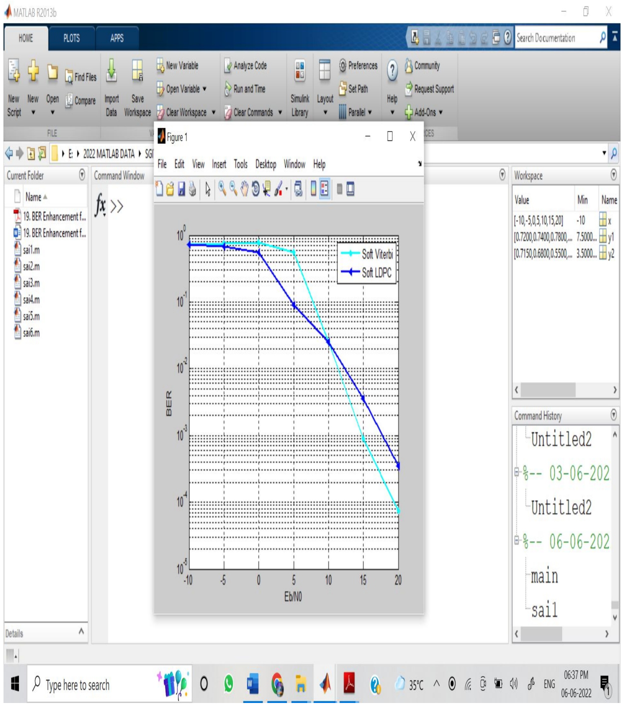

Fig. 3. The BER performances of MIMO-CEM without (W/O) coding and with (W) convolutional encoder using soft Viterbi decoding

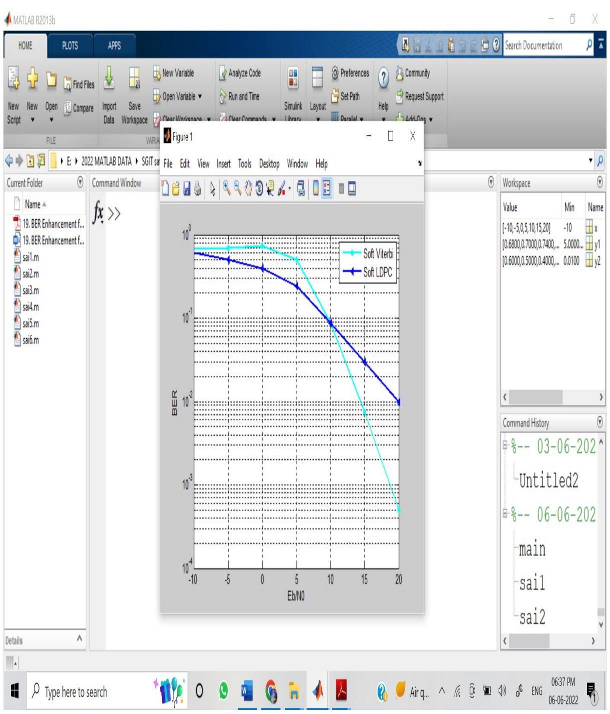

Fig. 4. BER performances of studied and original SISO-CEM system using GMSK modulation with BT = 1.0

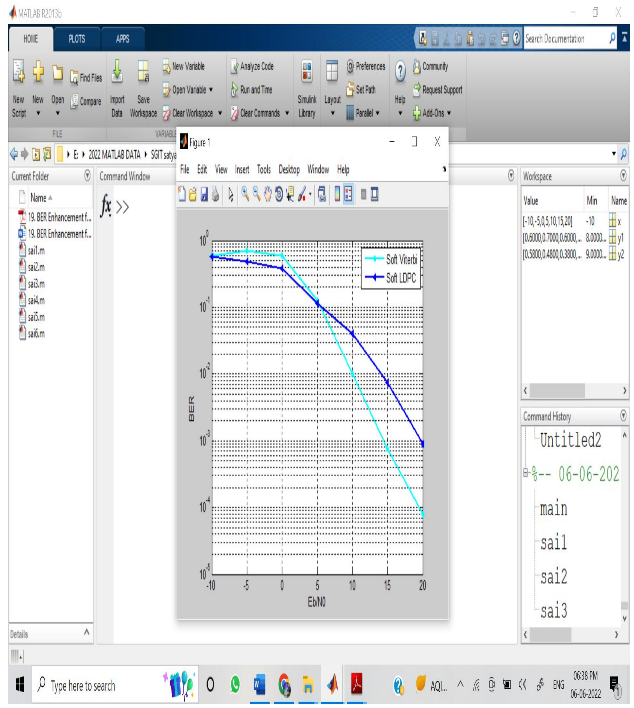

Fig. 5. BER performances SISO-CEM system using GMSK modulation with BT = 0.3

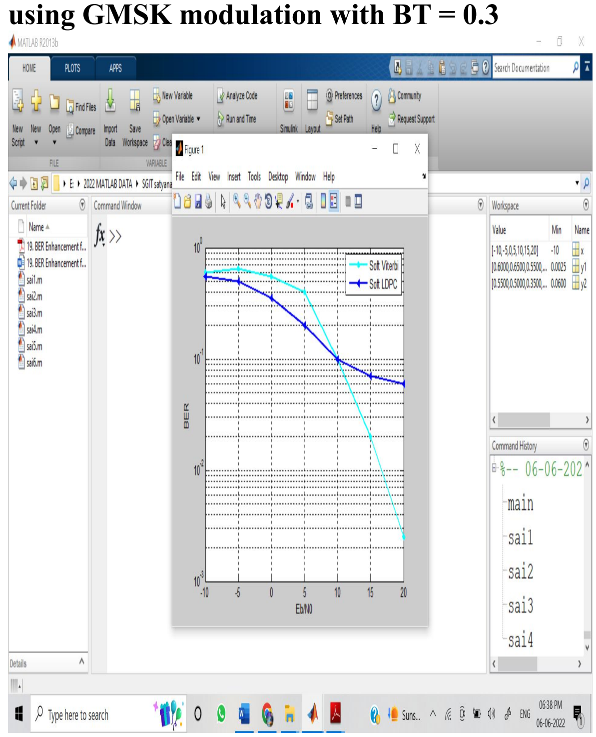

Fig. 6. BER performances SISO-CEM system using GMSK modulation with BT = 0.3

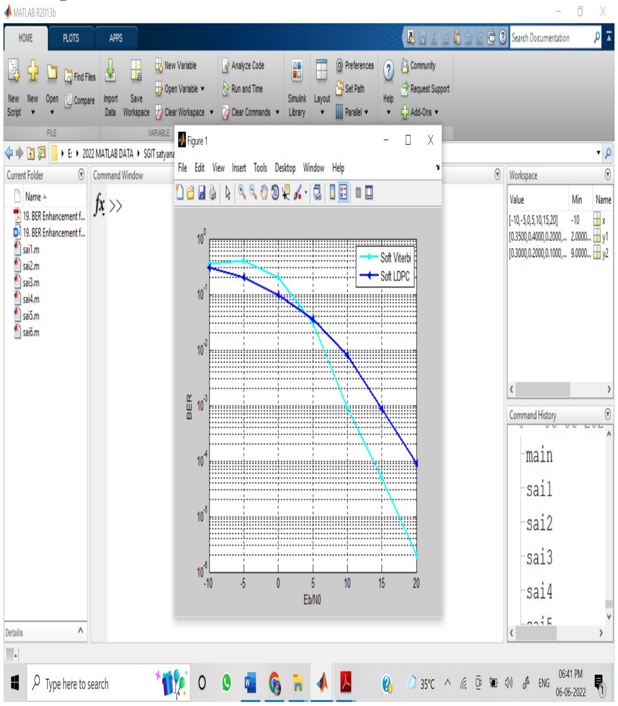

Fig. 7. BER performances of SISO-CEM system using MSK modulation

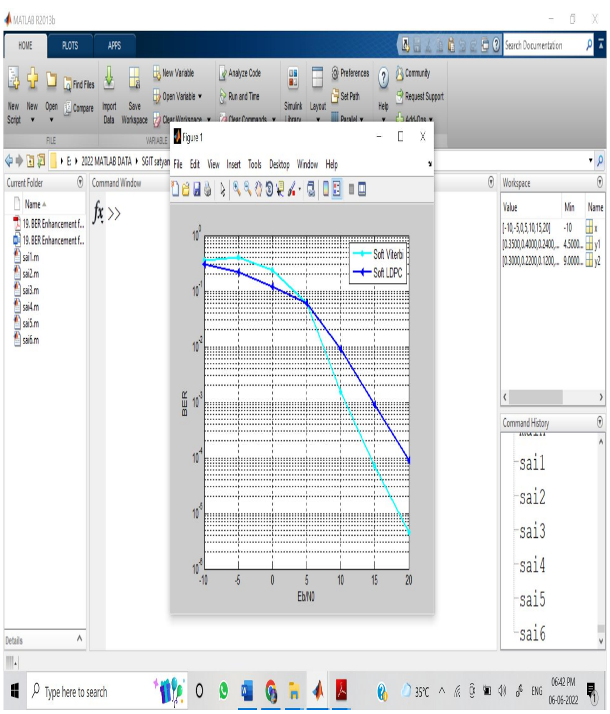

Fig. 8. BER performances of MIMO-CEM system using GMSK modulation with BT = 1.0

V. CONCLUSION

In this project, the BER performance of the SISO/MIMOCEM system was studied with different channel coding techniques as soft LDPC and the convolutional coder with soft Viterbi decoder which was used with the conventional SISO/MIMO-CEM. According to the results, the SISO/MIMO-CEM with soft LDPC and BCH coding techniques gives the best BER performance at low SNR values, while the SISO/MIMO-CEM with soft Viterbi gives the best BER performance at high SNR values. The overall SISO/MIMOCEM system BER performance can be improved by using an adaptive SNR based channel coding technique that selects the suitable channel coding technique (i.e. soft LDPC or convolutional coder with soft Viterbi decoder) depending on the received signal SNR to achieve the optimum coding gain to relax the SISO/MIMO-CEM drawback caused by using of the 1-bit ADC at RX side. The performance of the soft LDPC decoder can be improved using larger codeword length but this will increase the overall system complexity, so a tradeoff study between system complexity and BER performance has to be done

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