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A Forward Error Correcting Scheme by using Concatenated Polar and Convolution Codes with Belief Propagation Decoding in MIMO-FDM Systems

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***Abstract* - *The increasing demand for wireless cellular communication systems has led towards the urgent requirement of communication systems that can fulfill the communication requirements. The Multiple Input Multiple Output Orthogonal Frequency Division Multiplexing (MIMO-OFDM) configuration is considered a promising solution in this field. The MIMO-OFDM systems suffer from various challenges, such as peak average to power consumption and channel estimation. However, these systems suffer from bit error-related issues in massive MIMO and a greater number of antennas in MIMO-OFDM. To overcome this issue, we focused on forwarding error correction mechanisms and presented a concatenation approach to combine the polar code and convolution codes. Further, the performance of polar code is improved by incorporating a belief propagation decoding mechanism. The experimental analysis is carried out on MATLAB simulation tool for coding rate ½ and ¼ for 4x4 antenna configuration. The performance of the proposed approach is compared with varied schemes of detection such as zero-forcing and maximum likelihood detection in the Additive White Gaussian Noise (AWGN) channel. The comparative analysis shows that the proposed approach achieves better performance in terms of Bit Error Rate (BER) and Frame Error Rate (FER) for varied coding rates.*

Keywords: *MIMO, OFDM, FER, BER, LDPC, FEC, BCH, MLD.*

I. INTRODUCTION

During the last decade, wireless communication has noticed an immense growth for real-time infotainment and communication activities. Mobile communication has a paramount role in the current communication paradigm. According to a report presented by Cisco [1], it was estimated that mobile data traffic would increase up to 30.6 Exabytes per month by 2020. Recently, a new report is presented in [2], which shows that mobile data traffic will increase up to 77 Exabytes by 2022, the mobile traffic data will share 20 percent of total IP traffic. This increase in growth will lead to surpass the traffic using 4G and 5G communications. The research community has been motivated to accomplish this task; thus, new communication technologies have been introduced. Currently, the multiple-input-multiple-output (MIMO) has gained huge attraction to facilitate the 4th and 5th generation communication standards [3]. The MIMO systems are adopted in academia and industrial applications. In these systems, the base stations are equipped with massive antennas, which enables the increasing the communication capacity and improving energy efficiency. The MIMO characteristics show that it has channel estimation capacity that is important to improve communication accuracy. Moreover, precoding Peak to AveragePower Ratio (PAPR) reduction is an important characteristic that has a significant role in MIMO.

Nowadays, the OFDM technique is also widely adopted in various communication systems. This scheme is considered a promising technique for wireless access schemes in broadband systems. Moreover, the OFDM systems have a huge capacity, higher data rates, less bandwidth consumption, and power [5]. The combination of MIMO-OFDM systems is a promising solution to improve communication performance. Several techniques have been presented based on the combined model of the MIMO-OFDM system, which shows that OFDM systems suffer from high PAPR [6]. The PAPR and channel estimation techniques are widely studying in this field, and significant performance is also obtained. But these digital communication systems are prone to error due to which the error detection during transmission and correcting those error is one of the most important tasks which can improve the overall QoS of the system. Thus, the error-correcting scheme is highly recommended for recovery to recover the correct data packet.

Recently, Forward Error Correction (FEC) scheme is adopted in these communication systems to deal with data transmission errors. Generally, the FEC is a technique that is used to improve the channel capacity by adding the redundant bits in the original data in such a way that the original data can be recovered at the receiver despite the error during transmission. This process of adding the redundant data is useful for the receiver to detect and correct the error bits where it discards the need for data re-transmission and handshaking process between transmitter and receiver antennas. In noisy channels where multiple retransmissions are needed, the FEC scheme helps to reduce the retransmission and offers error-free data to the receiver. The FEC techniques are also helpful in the scenario where there is no feedback available between transmitter and receiver. The encoding process in these systems can be categorized into two main categories, which include systematic coding and non-systematic coding. The systematic coding is identified if the portion of output data resembles the input data, whereas non-systematic coding is identified if the output data is shuffled from the original form using interleaver, which enables the uniform distribution of errors [7, 8]. Further, the FEC techniques can be divided into two main classes as block-based error-correcting codes and convolution-based error correction codes. The block-based schemes include turbo codes, hamming codes, Bose-Chaudhuri-Hocquenghem (BCH) codes, and Reed-Solomon codes, whereas the convolution-based schemes include Low-density parity-check code and Viterbi codes [9]. The convolution codes are helpful in obtaining optimal decoding, whereas the block-based codes are used to obtain the optimal efficiency. Several techniques have been presented based on these coding schemes such as Agarwal et al. [10] studied the performance of MIMO systems with concatenated FEC, which includes Low-Density Parity Check (LDPC) with convolution codes, Turbo codes with convolution codes, and Reed-Solomon Code (RSC) with convolution codes. Based on this concatenation approach, Agarwal et al. [11] presented a combined scheme using polar code and convolution codes with relaying scheme [12]. However, these techniques suffer from the issue of degrading the output of decoding, which is an unavoidable event after increasing the decoding iterations [13]. Moreover, it also affects the detection process. Several existing schemes fail to achieve the multipath diversity for high data rate applications. Moreover, the existing schemes suffer from computational complexity issues.

In this work, we focus on both aspects and preset a combined scheme by considering the polar codes with convolutional codes. We develop a concatenated model by using a polar and CC scheme. The decoding issues of polar codes after concatenation are mitigated with the help of belief propagation decoding.

The rest of the article is divided into the following sections, and section II presents the brief literature review about the existing scheme of FEC, section III presents the proposed solution by combining polar code with convolutional codes, section IV describes the comparative analysis, and section V presents the concluding remarks about this scheme.

II. LITERATURE SURVEY

In this section, we focus on studying the existing techniques in this field of forwarding error correction in MIMO-OFDM systems.

Yavasoglu et al. [9] suggested that uncoded OFDM systems are not enough to deal with several issues in communication hence incorporating channel coding is an important task that can improve communication performance. In this article, the authors considered Bose Chaudhuri Hocquenghem (BCH) and convolution codes and presented an amalgamation of BCH and CC OFDM systems. The combination of these two codes a significant improvement in the performance.

Shubhi et al. [13] reported that the 3GPP and LTE standards use forward error correction schemes to provide better QoS and throughput. However, the turbo decoding schemes provide satisfactory performance for a general MIMO-OFDM architecture, but it fails to handle the overloaded MIMO systems. To overcome this issue, a joint turbo decoding scheme is developed where rather than computing the soft information separately for each combination of bits, this calculation is performed for all streams. Further, a super-trellis diagram is also applied to combine all trellis diagrams.

Jalali et al. [14] introduced a combined joint detection and decoding receiver module for MIMO systems. This technique uses the polar codes and transforms the constraints from Galois field to the real field. Now, the joint linear programming optimization problem is designed, which considers the transformed constraints deal with the issue of channel state information, co-channel interference, additive noises, and pilot contamination-related issues. Wang et al. [15] considered the code constraints for MIMO systems, and a Semi-definite relaxation (SDR) detector is presented for maximum likelihood performance. This integration of SDR and MIMO constraints deals with the timing complexity. The joint-SDR utilizes the FEC information in SDR for the detection process. However, this scheme is only suitable for the short-to-medium length FEC codes.

Watanabe et al. [16] studied the performance of polar coded MIMO-OFDM systems under frequency selective channels. The polar codes are capable of dealing with successive cancellations with a likelihood ratio. Since the computational complexity of polar code is less than the LDPC, hence it consumes comparatively less power to meet the demand of 5G systems. Choudhary et al. [17] studied the optical FEC codes while considering the Reed-Solomon and LDPC codes. This comparative study shows that the LDPC outperforms in terms of BER, complexity, and delay.

Benaissa et al. [18] focused on power line communication and reported that this technique is vulnerable to Gaussian noise. Hence, to overcome this issue, the authors developed a hybrid coding scheme for the MIMO-OFDM system. The hybrid coding is an amalgamation of convolution codes and quasi cyclic-low density parity check codes (QC-LDPC). The proposed hybrid coding scheme is then followed by an orthogonal space-time block code (OSTBC) which deals with the heavy impulsive noise. Later, the asymmetric α-stable model is also implemented to handle the PLC noise and mitigate the issue of overestimation of performance. Thaher et al. [19] focused on improving the performance of wireless communication systems by considering the concatenation of STBC with FECand presented BCH concatenation with STBC to obtain the better coding gain.

Deepa et al. [20] reported that the fifth-generation communication systems are developed to satisfy the requirement of ultra-large transmission rate, seamless connectivity, and improving mobile broadband services. Thus, MIMO, Cyclic prefix-based OFDM, and forward error correction-based schemes are widely adopted in 4G, 5G, and LTE communication systems. However, the existing cyclic prefix-based scheme suffers from several drawbacks such as appropriate synchronization, higher out of bound leakage, and limited CP length. Currently, researchers have suggested to apply filtered OFDM on existing CP-OFDM, which can handle and operate in a 5G air interface. To further improve the performance, the authors suggested incorporating an error-correcting scheme and presented a polar coded filtered OFDM system.

Koike-Akino et al. [21] reported that currently, the forward error correction techniques are touching the Shannon limit, which increases the spectral efficiency of wireless communication. To improve the overall performance of 5G communication, low-latency and low-power decoding schemes are highly desirable. To accomplish this objective, the authors introduced turbo product code which comprises multiple polar codes. This combination improves the parallel decoding resulting in improved throughput and minimized latency.

Wei et al. [22] developed an orthogonal circulant matrix transform with the help of an adaptive frame-level FEC scheme for a visible laser light communication system. The adaptive FEC scheme uses Reed-Solomon codes where no extra bit is incorporated for generating the adaptive message. However, the training sequence uses extra bits, which are used for better synchronization and channel estimation. This helps to perform RS coding in a frame-by-frame manner by using the last codeword error rate.

These studies reported that the combination of forwarding error-correcting schemes with decoding techniques could improve the performance significantly. However, the existing scheme suffers from complexity and throughput performance. To overcome these issues, we present a novel scheme as mentioned in the proposed section.

III. PROPOSED MODEL

This section presents the proposed solution to improve the performance of the MIMO-OFDM system by incorporating a channel coding scheme. We further present a concatenation approach for channel coding where we consider polar codes and convolution codes. The complete model is divided into multiple sections where. The first section presents the introduction to polar codes, and the next section presents the description of convolution codes. Further, we present a combined model by combining the polar codes and convolution code. The further performance of this combined model is improved by incorporating the belief propagation decoding and puncturing scheme.

A. Polar Codes

Polar code has become an important part of information theory. It is known as the error-correcting code, which follows the block-based error-correcting coding strategy. The polar code is constructed by performing the recursive concatenation of a short kernel code which allows transforming the physical channel into virtual channels. As the number of recursions increases, the virtual channel starts to become polarized, which has two characteristics as either high reliability or low reliability. From this reliability information, the most reliable channel is selected to allocate the data bits. Initially, Erdal Arikan introduced the concept of polar codes in 2009 [23]. These codes achieved the reliable capacity for various channels and their data encoding - decoding complexity is reported as of order $O(N \log N)$ Where N a code length. This less complexity and better spectral efficiency of polar codes have uplifted its use in digital communication.

Initially, the polar codes were designed only to deal with the code lengths that are 2^nWhere n is an integer [23], this type of polar code is known as the mother polar codes (MPC). The polar mother code is represented as $(\mathcal{N}_m, \mathcal{K}_m)$ for code of $\mathcal{N}_m = 2^n$ Length where $\mathcal{K}$ denotes the dimension of MPC. The polar code can be represented in a transformation matrix by applying the Kronecker product on the kernel as $\mathcal{T}_{\mathcal{N}_m} = \mathcal{T}_2^{\otimes n}$ where $\mathcal{T}_2$ is a kernel matrix which is represented as $\mathcal{T}_2 = \begin{bmatrix} 1 & 0 \\ 1 & 1 \end{bmatrix}$ and a frozen set as $\mathcal{F} \subseteq \{1, \ldots, \mathcal{N}_m\}$ which is of size $\mathcal{N}_m - \mathcal{K}_m$. The frozen set is designed in such a way that it can reduce the error probability under successive cancellation decoding. The frozen set is designed by considering the $\mathcal{N}_m - \mathcal{K}_m$ Position bits with the lowest reliabilities. Several methods are present to compute the reliability information of these bits, such as evolution under Gaussian approximation, mean value tracking, variance, mutual information, and Batthacharyya parameter analysis of the Gaussian L-densities as mentioned in [24].

B. Polar code encoding

During the encoding process, the information bits are transformed into encoded codewords. Let us consider that we have information bits as $u \in \mathbb{F}_2^{\mathcal{K}_m}$ which need to be encoded into codewords as $x \in \mathbb{F}_2^{\mathcal{N}_m}$. The encoding is defined in the form of vector as $v \in \mathbb{F}_2^{\mathcal{N}_m}$ such that $v_{\mathbb{I}} = u$ and $v_{\mathcal{F}} = 0$, which are sub-vectors of v defined by $\mathbb{I}$ and $\mathcal{F}$, respectively. The codeword can be computed as $x = v.\mathcal{T}_{\mathcal{N}_m}$. in [23], the encoding was defined with the help of bit-reversal permutation of length $\mathcal{N}_m$ as $B_{\mathcal{N}_m}.\mathcal{T}_{\mathcal{N}_m}$. The bit reversal permutation is a process where we index the sequence of numbers from 0 to $\mathcal{N}_m - 1$ and then reverse this indexing sequence with its binary representation of each number. In some polar code construction mechanisms, the cyclic redundancy check of the length N_{CRC} Is also included. In this case, the length of the actual information word u' is denoted as $\mathcal{K}_m' = \mathcal{K}_m - N_{CRC}$. With the help of this, the information word vector is defined as $u = [u' u_{CRC}]$. Generally, the polar codes use a generation matrix $\mathcal{M}_{\mathbb{N}}$ for $\mathbb{N}$ number of channels. This generation process is defined as:

$$\mathcal{M}_{\mathbb{N}} = \mathrm{B}_{\mathbb{N}}\mathcal{T}^{\otimes n} = \mathrm{P}_{\mathbb{N}}\left(I_2 \otimes \mathrm{B}_{\mathbb{N}/2}\right)\mathcal{T}^{\otimes n} \qquad (1)$$

Where $\mathrm{B}_{\mathbb{N}}$ is the bit reversal, $\mathrm{P}_{\mathbb{N}}$ is the permutation operation, $\otimes$ Kronecker product of matrix I. $\mathrm{B}_{\mathbb{N}}$ is given as $\mathrm{P}_{\mathbb{N}}\left(I_2 \otimes \mathrm{B}_{\mathbb{N}/2}\right)$. The total bit generation is given as:

$$g_1^{\mathbb{N}} = \mathrm{a}_1^{\mathbb{N}}\mathrm{M}_{\mathbb{N}} \qquad (2)$$

where $\mathrm{a}_1^{\mathbb{N}}$ represents the information bits. These bits are further divided into two parts as active and inactive bits. The active bits are transmitted through the ideal channel, whereas the inactive part of bits is transmitted through the noisy channel.

C. Polar code decoding

Initially, polar codes use the successive cancellation (SC) decoding mechanism to decode the data. The SC decoder is a simple yet efficient technique that provides faster decoding; however, it suffers from decoding errors [25]. To overcome this issue, an improved model of successive cancellation list (SCL) decoder is developed to improve the performance in terms of Block Error Rate (BLER). The transmitter module encodes the data $a_1^{\mathbb{N}}$ and generates a data vector $g_1^{\mathbb{N}}$ which is transmitted through the polarized channel $C^{\mathbb{N}}$. During the decoding process, the decoder generated the estimated value $\hat{a}_1^{\mathbb{N}}$by using vector A, inactive bit a_{A^c} and code word $z_1^{\mathbb{N}}$. Because the decoder is allowed only to transmit $\hat{a}_{A^c} = a_{A^c}$ Through the fixed inactive bit. During the decoding scheme, the decode computes a_{A^c} and also determines the value of data bit a_A. With the help of successive cancellation decoding, we obtain the estimated value $\hat{a}_1^{\mathbb{N}}$ given as:

$$\hat{\mathrm{a}}_{\mathrm{i}} \triangleq \begin{cases} \mathrm{a}_{\mathrm{i}}, & if\ i \in \mathrm{A}^{\mathrm{c}} \\ \mathrm{D}_{\mathrm{i}}\left(z_1^{\mathbb{N}}, \hat{a}_1^{i-1}\right), & if \in A \end{cases} \qquad (3)$$

Where D denotes the decision function given as

$$D_i\left(z_1^{\mathbb{N}}, \hat{a}_1^{i-1}\right) = \begin{cases} 0, & if \quad \dfrac{C_{(i)}^N\left(z_1^N, \hat{a}_1^{i-1}|0\right)}{C_{(i)}^N\left(z_1^N, \hat{a}_1^{i-1}|1\right)} \\ 1, & \qquad else \end{cases} \qquad (4)$$

Where these conditions 1 and 0 denote the polarization level of channels. However, computational complexity is a challenging task. To deal with this issue, we present a belief propagation decoding scheme.

D. Belief propagation decoding

In this section, we present the belief propagation coding to mitigate the complexity issue of polar code. The BP decoding is obtained by processing the factor graph of any polar code $\mathcal{P}(\mathcal{N}, \mathcal{K})$ where factor graph depends on the polarization matrixG_N. Here, we consider a factor graph which is composed of n number of stages which are given as $n = \log N$ and total nodes are given as $(n+1)N$. Each stage is equipped with $\frac{N}{2}$ processing elements. For each stage and node, two types of LLRs are evaluated for each stage of the factor graph, which are called left to right $R_{i,j}^{(t)}$and right to left $L_{i,j}^{(t)}$ Message. Let us consider a BPSK modulation to map the $x \in \{0,1\}^N$ to $s \in \{+1,-1\}^N$. The left to the right message is denoted as:

$$R_{1,j}^{(0)} = \begin{cases} 0, & if\ j \in A \\ +\infty, & if\ j \in A^c \end{cases} \qquad (5)$$

Similarly, the LLR (Log-likelihood) for polar codes can be computed as:

$$L_{n+1,j}^{(0)} = \ln \frac{\Pr\left(x_j = +1 \middle| r_j\right)}{\Pr\left(x_j = -1 \middle| r_j\right)} \qquad (6)$$

Where x_j denotes the modulated and r_j Denotes the received codewords. These values of LLRs are updated and propagated iteratively based on specific rules. These rules can be defined as:

$$\begin{cases} L_{i,j}^{(t)} = g\left(L_{n+1,j}^{(t-1)}, L_{i+1,j+\frac{\mathbb{N}}{2^i}}^{(t-1)} + R_{1,j+\frac{\mathbb{N}}{2^i}}^{(t)}\right) \\ L_{i,j+n/2^i}^{(t)} = g\left(L_{n+1,j}^{(t-1)}, R_{i,j}^{(t)}\right) + L_{i+1,j+N/2^i}^{(t-1)} \\ R_{i+1,j}^{(t)} = g\left(R_{i,j}^{(t)}, L_{i+1,j+N/2^i}^{(t-1)} + L_{i,j+N/2^i}^{(t)}\right) \\ R_{i+1,j+N/2^i}^{(t)} = \mathrm{g}\left(R_{i,j}^{(t)}, L_{i+1,j}^{(t-1)}\right) + R_{i,j+N/2^i}^{(t)} \end{cases} \quad (7)$$

Here, $g(x,y)$ denotes the box plus operator, which is expressed as:

$$g(x,y) \triangleq \ln \frac{1+e^{x+y}}{e^x + e^y} \quad (8)$$

Once the belief propagation decoding achieves the maximum number of iterations, the LLR is used to estimate the information bit $\hat{u}_j$ and transmitted codeword $\hat{x}_j$. The LLR of u ad x is denoted as Λ_j^u and Λ_j^x, respectively. The Λ_j^u is given as $L_{1,j}^{(T)} + R_{1,j}^{(T)}$ and Λ_j^x is expressed as $\Lambda_j^x = L_{n+1,j}^{(T)} + R_{n+1,j}^{(T)}$. Based on this, the updated decision function can be expressed as:

$$\hat{u}_j = \begin{cases} 0, if\ \ \Lambda_j^u > 0 \\ 1, otherwise \end{cases}$$

E. Concatenation of polar codes with Convolution codes

Further, we concatenate the polar codes with the convolution coding scheme. The output of the polar encoder is processed through the convolutional encoder. The generated output is used as a transmitter module. This output is transmitted through a channel and received by the receiver. The data of polar code and convolution code is combined through a concatenation mechanism. Below given figure below shows the concatenation scheme to improve the performance of forwarding error correction.

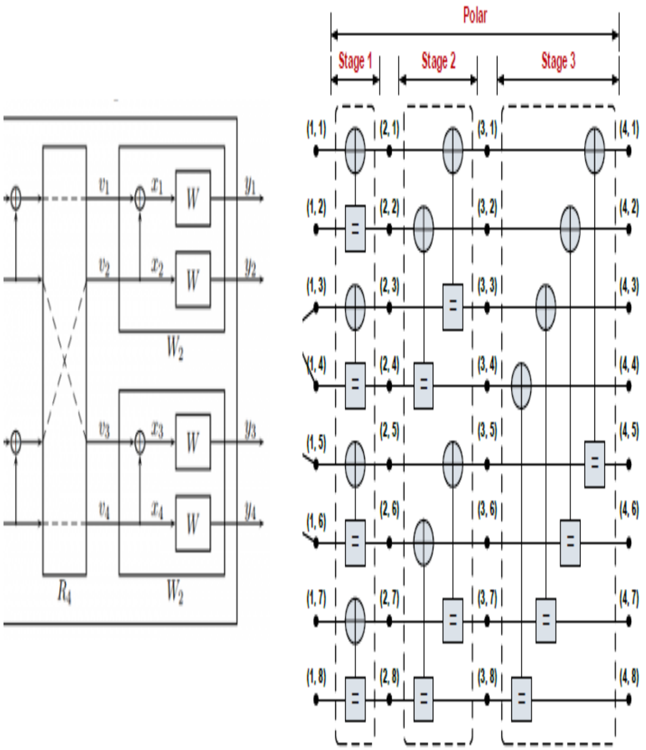

Fig.1. Convolution Codes and Polar Code

IV. RESULTS AND DISCUSSION

In this section, we presented the experimental analysis of the proposed scheme and compared the performance of the proposed approach with existing schemes. The complete experimental study is carried out using the MATLAB simulation tool. For this experiment, we have considered a 4x4 MIMO-OFDM antenna system with different coding rates as $R = \frac{1}{2}, \frac{1}{4}$. Initially, we obtained the performance for QPSK modulation and compared the performance with the existing technique as mentioned in [26]. Below given table 1 below shows the complete simulation parameters used in this research.

Table 1. Simulation Parameters

Parameters	Considered Value
Transmission technique	OFDM
Modulation	BPSK, QPSK, 16-QAM, 64-QAM
FFT size	64
Total carriers	64

Coding rate	½ and ¼
Number of the transmitter antenna	2,4
Number of receiver antenna	2,4
MIMO Detection scheme	ZF and MLD
Channels	AWGN

Moreover, we measured the performance for different modulation schemes and different channels. First, we measured the performance for varied SNR and compared the outcome with a zero-forcing detector-enabled polar coded OFDM system. This study is carried out for a 4x4 antenna configuration. Below given figure 2 shows the comparative analysis for this experiment.

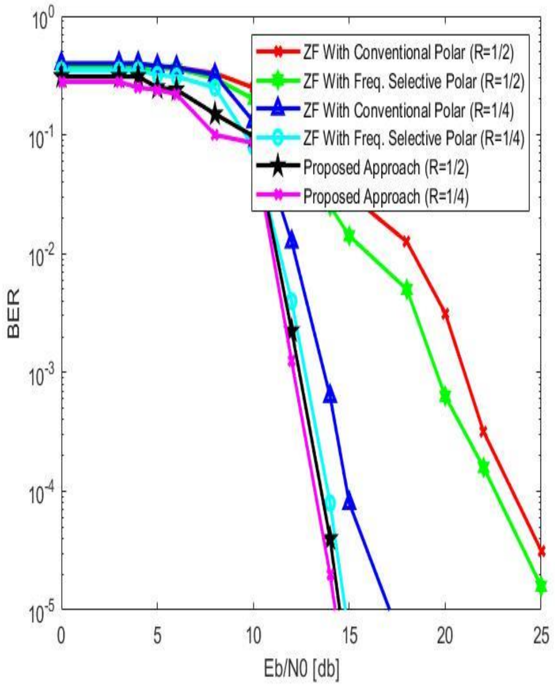

Fig.2. Comparative Analysis for 4x4 Antenna System with Zero Forcing Detector

In this figure, we have compared the performance of the proposed polar code system with an existing zero-forcing detector with conventional polar code, zero-forcing detector with selective polar code for varied code rates as ½ and ¼ . The comparative analysis shows that the performance of conventional polar codes is improved by applying a frequency-selective scheme for ½ coding rate. However, the BER performance is not satisfactory when it is considered for large-scale or massive MIMO scenarios. Hence, the proposed approach shows the significant decay in the bit error rate of the system. The average performance is obtained as 0.1936, 0.1724, 0.1660, 0.1438, 0.1190, and 0.1040 by using ZF with conventional polar code with ½ coding rate, ZF with conventional polar code with ¼ coding rate, frequency selective polar code with ½ coding rate, frequency selective polar codes with ¼ coding rate, proposed hybrid polar code with ½ coding rate and proposed hybrid polar code with ¼ coding rate. From this analysis, we show that the error rate of the proposed approach with coding rate ½ is decreased by 38.5331 % and 28.31 % when compared with ZF with conventional polar code with ½ coding rate and frequency selective polar code with ½ coding rate. Similarly, the error rate is reduced by 39.67% and 27.677% when compared with ZF with conventional polar code with ¼ coding rate and frequency selective polar code with 1/4 coding rate.

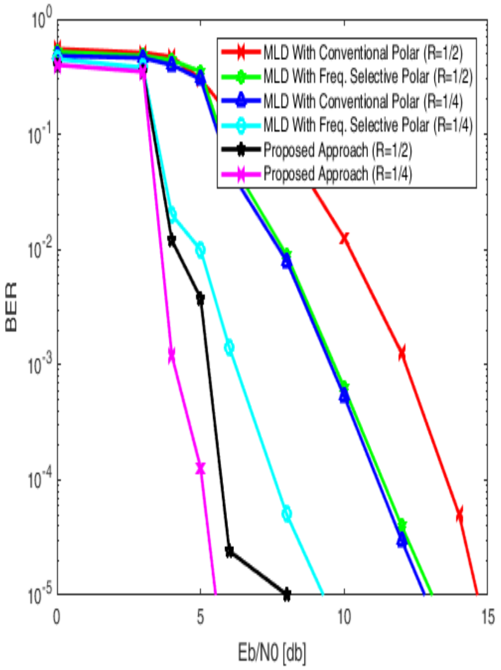

Fig.3. Comparative Performance by using MLD Detection Scheme.

Similarly, we have measured the performance for the maximum likelihood detection scheme and compared the performance with the proposed polar coding scheme. The above-given figure3 shows the comparative analysis for the MLD detector. The outcome illustrates that the MLD detection scheme achieves better performance when compared with the ZF detector. In this experiment, the performance of the MLD detector with rate ¼ and frequency selective model with rate ½ is almost similar whereas the performance of frequency selective polar code with coding rate ¼ is better when compared with other systems. Moreover, the proposed approach for coding rate ½ and ¼ provides better performance. The average BER is obtained as 0.1481, 0.1329, 0.1213, 0.0615, 0.0547, 0.0537 by using MLD with conventional polar code with ½ coding rate, MLD with conventional polar code with ¼ coding rate,MLD with frequency selective with ½ coding rate,MLD with frequency-selective with 1/4 coding rate, the proposed model with coding rate ½ and proposed model with coding rate 1/4, respectively.

Further, we present the FER and BER analysis of proposed polar code for varied simulation parameters. The obtained outcome is presented in below given table 2. Below given table shows the comparative analysis in terms of BER and FER for polar and systematic polar codes.

Table 2. BER and FER comparative analysis for polar and systematic polar codes for coding rate ½.

	Polar code		Systematic polar code	
Eb/N0 Range	FER	BER	FER	BER
0	0.699	0.2296	0.74	0.1323
0.4	0.606	0.1842	0.605	0.0916
0.8	0.477	0.1374	0.462	0.0558
1.2	0.364	0.0932	0.314	0.03358
1.6	0.224	0.0535	0.243	0.0289
2	0.1328	0.033	0.1395	0.0158

According to this experiment, we obtained the average FER performance as 0.417133333 and 0.41725 for polar and systematic polar code, whereas the BER performance is obtained as 0.121816667 and 0.059663333. The systematic polar code achieves less error rate. Further, we extended this experiment and presented a comparative analysis for coding rate ¼. Below given table 3 below shows the comparative analysis.

Table 3. BER and FER comparative analysis for polar and systematic polar codes for coding rate ¼.

	Polar code		Systematic polar code	
Eb/N0 Range	FER	BER	FER	BER
0	0.44	0.1603	0.445	0.1234
0.4	0.353	0.1251	0.348	0.0936
0.8	0.255	0.09	0.25	0.0647
1.2	0.1767	0.0598	0.1742	0.0456
1.6	0.1225	0.0398	0.1105	0.0273
2	0.2756	0.027	0.07	0.0161

The average FER performance is obtained as 0.270466667 and 0.23295 using polar and systematic polar codes. Similarly, the average BER is obtained as 0.0836and 0.06178 using polar and systematic polar codes. Thus, these experiments shows that the proposed approach can be helpful to reduce the bit error and frame error rates in forward error correcting schemes.

Further, we measured the performance of proposed polar coding scheme for ½ coding rate for the block fading channel scenario and compared the performance in terms of block error rate. Below given figure depicts the comparative analysis where we have considered the Polar BICM, LDPC, polar code with block fading with L=1,4,and 16 as mentioned in [27].

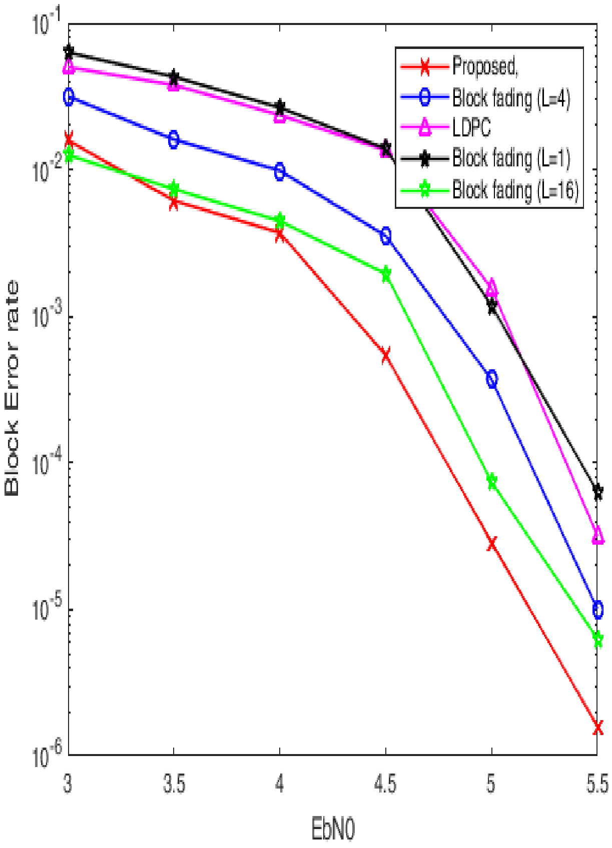

Fig.4. Block Error rate Performance

The average block error rate is obtained as 0.0031, 0.0059, 0.0082, 0.0197, and 0.0221 using proposed approach, block fading L=16, Block fading L=4, LDPC, and block fading L=1. This experiment shows that proposed approach achieves better performance when compared with stat-of-art techniques.

Similarly, we measured the performance in terms of computational complexity for varied window size. Below given figure 4 depicts the decoding computational complexity. This computational complexity is computed as:

$$D_s = L(1-P_u)^{L-1} + \sum_{i=1}^{L-1} IP_u(1-P_u)^{l-1} \qquad (9)$$

Where L denotes the coded blocks, P_u is the BER of uncoupled polar coded block, l is the current decoding block.

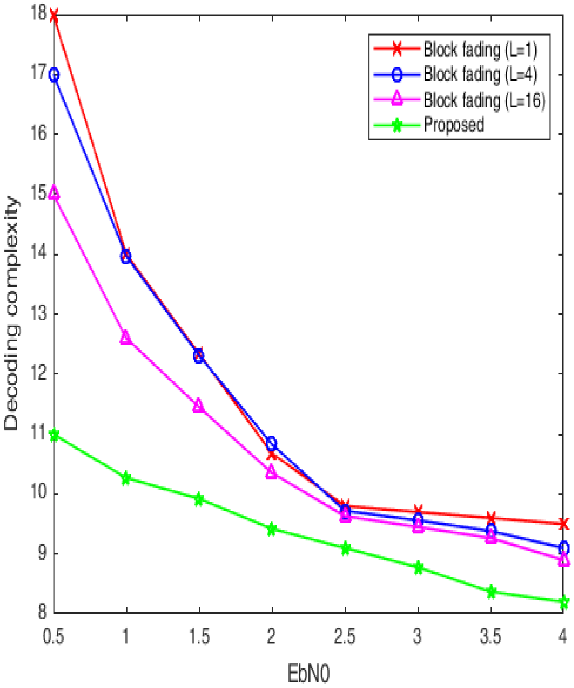

Fig.5. Decoding Complexity Measurement for Varied Block Fading.

V. CONCLUSION

In this article, we have focused on development of an efficient approach of forward error correction in next generation cellular communication systems. Currently, MIMO-OFDM systems are the backbone of these communication standards which suffer from power consumption, signal detection, and channel estimation error but significant amount of works has been carried out in this field. Currently, reducing the error due to channel is a challenging issue which affects the QoS of these systems. Forward error correction is a promising technique to reduce the bit error rates during communication. In this work, we used polar codes as the FEC scheme and concatenated it with convolution codes. Moreover, a belief propagation coding scheme is also incorporated to improve the performances of polar codes. The experimental analysis shows a significant improvement in performances of systems in terms of bit error rate and frame error rate.

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References

[1] Index, C. V. N., Global mobile data traffic forecast update, (2016) Cisco white paper, 9.

[2] Forecast, G. M. D. T., Cisco visual networking index: global mobile data traffic forecast update, (2019).

[3] Mirfarshbafan, S. H., Shabany, M., Nezamalhosseini, S. A., & Studer, C., Algorithm and VLSI Design for 1-Bit Data Detection in Massive MIMO-OFDM. IEEE Open Journal of Circuits and Systems, 1 (2020) 170-184.

[4] Sidramayya S M,Ramesha K., Precoding Aided Data Correlation Scheme for Channel Estimation Technique in MIMO-OFDM System, WSEAS TRANSACTIONS on SYSTEMS and CONTROL, 2224-2856, 16 (2021) 146-154.

[5] Ramteke, S. B., Deshmukh, A. Y., & Dekate, (March)., A review on design and analysis of 5G mobile communication MIMO system with OFDM. In Second International Conference on Electronics, Communication and Aerospace Technology (ICECA), IEEE,(2018) 542-546

[6] Kageyama, T., Muta, O., & Gacanin, H., Enhanced peak cancellation with simplified in-band distortion compensation for massive MIMO-OFDM, Ieee Access, 8 (2020) 73420-73431.

[7] Vucetic, B., & Yuan, J., Turbo codes: principles and applications,Springer Science & Business Media, 559 (2012).

[8] Youssef, M. I., Emam, A. E., & Abd Elghany, M., Performance Enhancement of MIMO-OFDM using Redundant Residue Number System, International Journal of Electrical and Computer Engineering, 8(5) (2018) 3902.

[9] Yavasoglu, O., Akcam, N., & Okan, T., Performance analysis of concatenated BCH and convolutional coded OFDM system, International Journal of Electronics, 107(10) (2020) 1574-1587.

[10] Agarwal, A., & Mehta, S. N., Performance analysis and design of MIMO-OFDM system using concatenated forward error correction codes, Journal of Central South University, 24(6) (2017) 1322-1343.

[11] Agarwal, A., & Mehta, S. N., PC-CC: An advancement in forward error correction using polar and convolutional codes for MIMO-OFDM system, Journal of King Saud University-Computer and Information Sciences, (2017).

[12] Kaya, H., & Öztürk, E., Performance analysis of distributed turbo coded scheme with two ordered best relays, IET Communications, 9(5) (2015) 638-648.

[13] Shubhi, I., & Sanada, Y., Joint turbo decoding for overloaded MIMO-OFDM systems. IEEE Transactions on Vehicular Technology, 66(1) (2016) 433-442.

[14] Jalali, A., & Ding, Z., A joint detection and decoding receiver design for polar coded MIMO wireless transmissions, In IEEE international symposium on information theory (ISIT), (2018) 1011-1015.

[15] Wang, K., & Ding, Z., Non-iterative joint detection-decoding receiver for LDPC-coded MIMO systems based on SDR, (2018). arXiv preprint arXiv:1808.05477.

[16] Watanabe, K., Higuchi, S., Maruta, K., & Ahn, C. J., Performance of polar codes with MIMO-OFDM under frequency selective fading channel, In 20th International Symposium on Wireless Personal Multimedia Communications (WPMC), IEEE, (2017) 107-111.

[17] Choudhary, U., & Janyani, V., Forward Error Correction Codes—Reed–Solomon and LDPC for OFDM Over the Optical Fiber

Communication Systems, In Optical and Wireless Technologies, (2020) 281-288. Springer, Singapore.

[18] Benaissa, A., Abdelmalek, A., Feham, M., Himeur, Y., & Boukabou, A., Hybrid forward error correction coding efficiency for MIMO-PLC with symmetric alpha-stable noise. Telecommunication Systems, 75(3) (2020) 319-329.

[19] Thaher, R. H., & Abed, M. S., Improvement the Performance of MIMO Channel Employing Concatenation (BCH–STBC) Codes, In IOP Conference Series: Materials Science and Engineering , 888(1) (2020) 012141. IOP Publishing.

[20] Deepa, T., & Bharathiraja, N., Performance Evaluation of Polar Coded Filtered OFDM for Low Latency Wireless Communications, Wireless Personal Communications, 116(3) (2021) 2023-2034.

[21] Koike-Akino, T., Cao, C., & Wang, Y., Turbo product codes with irregular polar coding for high-throughput parallel decoding in wireless OFDM transmission, In IEEE International Conference on Communications (ICC), (2018) 1-7. IEEE.

[22] Wei, Y., He, J., Deng, R., Shi, J., Chen, S., & Chen, L., An approach enabling adaptive FEC for OFDM in fiber-VLLC system, Optics Communications, 405 (2017) 329-333.

[23] Arikan, E., Channel polarization: A method for constructing capacity-achieving codes for symmetric binary-input memoryless channels, IEEE Transactions on information Theory, 55(7) (2019) 3051-3073.

[24] Vangala, H., Viterbo, E., & Hong, Y., A comparative study of polar code constructions for the AWGN channel, arXiv preprint arXiv:1501.02473, (2015).

[25] Bioglio, V., Gabry, F., & Land, I., Low-complexity puncturing and shortening of polar codes, In IEEE Wireless Communications and Networking Conference Workshops (WCNCW), (2017) 1-6. IEEE.

[26] Watanabe, K., Higuchi, S., Maruta, K., & Ahn, C. J., Performance of polar codes with MIMO-OFDM under frequency selective fading channel, In 20th International Symposium on Wireless Personal Multimedia Communications (WPMC), IEEE, (2017) 107-111.