# Implementation of OFDM-IDMA System Based on Low Complexity Polar Decoder for DVB in 5G

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**Abstract**

Presently turbo codes have provided high-performance communication in 3G and 4G cellular standards. However, the turbo decoding process works on the serial structure, one at a time and in the right order. Furthermore, turbo decoders require more computations and have greater decoding complexity. 3GPP standardization group is currently proposing the replacement of turbo codes with polar codes in 5G. This paper proposes modified mean sum product polar decoding algorithm to reduce the implementation complexity of OFDM-IDMA system to support digital video broadcasting application. The system is simulated with QPSK and 16PSK modulation technique under the different number of subcarriers and code length.

*Keywords:* OFDM, IDMA, PSK, LTE

## I. INTRODUCTION

In cellular communication systems, wireless transmission is used to transfer data between handsets and base stations. Base stations act as gatekeepers to the internet and telephone networks. However, the received data typically differs from the transmitted data, due to communication error produced by noise, interference or weak signal strength. Channel codes can be used to correct these communication errors caused by noise. Therefore, channel coding is a dynamic component of cellular communication systems, which is used for correcting the communication errors. The turbo code was chosen to provide channel coding in 3G and 4G mobile systems, but the 3GPP standardization group is currently enunciating whether it should be replaced by the Low-Density Parity Check (LDPC) or polar code in 5G [19]. A new family of codes has recently proposed by Arikan. They are capacity achieving codes with low complexity encoding and decoding. Therefore, good channel codes are ones which allow the successful detection and correction of transmission errors at coding rates that are as close as possible to the theoretical limit that is imposed by the channel capacity. Since the channel decoder must overcome the uncertainty introduced by noise, interference or weak signal strength, it typically has much greater complexity than the channel encoder. Due to this, it is the channel decoder that is usually the primary concern when designing a channel code. To construct codes with low computational complexity and high performance is an active research activity.

Single-carrier modulation schemes on wireless channels such as multi-path distortion and frequency- selective fading suffers from inter-symbol interference (ISI). Wherein the multi-carrier modulation system known as Orthogonal Frequency Division Multiplexing (OFDM) resolves the ISI problem. Interleaved Division Multiple Access (IDMA) is a multiuser system which suppresses the multiple access interference (MAI). Due to compatibility to high data rates, the hybrid combination of OFDM-IDMA scheme has been chosen in IEEE 802.16 standards to support Video Broadcasting. 5G aims to offer greater user experience and various applications for cellular communications. This imposes many requirements upon the channel code. High throughput of 20 Gbps and achieving low latency of 0.5 ms are the thrust areas in 5G. This work focuses on designing low complexity decoding algorithm for polar code based OFDM-IDMA system.

Section II reviews the literature containing the theoretical propositions, algorithms and implementation details from various technical articles. Section III provides design steps of construction of polar codes for OFDM-IDMA system. Section IV proposes a min-sum product decoding algorithm. Section V deals with results and discussions followed with conclusions in section VI.

## II. LITERATURE SURVEY

The reviewed literature is divided into two parts. The first part deals with the research activities of OFDM-IDMA system and the second one talks about the benefits of polar codes for 5G applications.

In [4] authors have proposed OFDM -IDMA approach to wireless communication systems. The proposed method has a number of striking features comprising low cost iterative multi-user detection, flexible rate adaptation, frequency diversity, and efficient spectral as well as power efficiency. There are still some dazzling issues in OFDM IDMA such as pilot signal design, channel estimation, closed loop power control, adaptive transmission, and resource allocation. In [5] auto repeat request OFDM IDMA system have been proposed. The proposed system has improved BER performance than that of the conventional OFDM IDMA system under the same channel conditions. In [6] joint minimum mean square error (MMSE) channel estimation and iterative estimation using space-alternating expectation maximization (SAGE) are proposed for OFMD-IDMA system. No single channel estimator is providing the best trade-off. Both the algorithms differ in terms of complexity, and performance as well. In [7] innovative algorithm for subcarrier-wise power allocation for OFDM-IDMA system is proposed. The proposed algorithm maximizes the channel capacity under the constraints of user-wise average powers. The proposed algorithm provides improved BER performance. In [8] tree interleaving technique is proposed for OFDM-IDMA system. The proposed system always outperforms conventional IDMA in the presence of intersymbol and multiple access interferences. Hence, it can be deployed in above 4G and 5G technologies in mobile and digital communication for achieving better BER performance. In [9] the elementary signal estimator (ESE) and iterative interference cancellation (IIC) multiuser detection techniques for OFDM IDMA systems are proposed. Both the proposed methods have almost the same computational complexity, but the BER performance using IIC MUD technique is superior to the ESE for multipath channel system.

In [10] joint detection and decoding (JDD) scheme are proposed to reduce the decoding complexity of polar-coded OFDM-IDMA scheme. It is shown that a sign aided JDD scheme further reduces the complexity to half in comparison to that of JDD without any performance degradation at high SNR region. The polar-coded system provides better BER performance than the un-coded system. In [11] regularized correlated time-averaged-based variable forgetting factor recursive least square based channel estimation scheme for OFDM-IDMA systems is proposed. The proposed estimator shows better performance but at the cost of higher computational complexity. In [12] particle swarm optimization algorithm is proposed for OFDM-IDMA system. Pilot positions affect the performance of channel error estimation. For pilot design process, only the upper bound of mean square error is considered as the fitness function of the proposed algorithm which helps to reduce the system complexity. The proposed estimator shows better bit error performance than the least square algorithm.

Author [13] has reviewed the performance of Turbo, LDPC and Polar code where Turbo code achieves the FER of $10^{-3}$ at $E_s/N_0$ of 1.9 dB while polar code attains it at only 1.6 dB. Author has concluded that the overall performance of polar code under list 32 decoding with Cyclic Redundancy Check is comparable to codes used in present wireless standards. Authors [14] presented recent advances in capacity approaching codes. The paper provides an overview of polar codes, spatially coupled codes, LDPC codes, coding theory and coding applications from different authors, which motivates to continue research in the fascinating area of capacity approaching codes. Both polar codes and spatially coupled LDPC codes are the potentials for future coding standards. Researchers [15] have used polar coding method for two-user multiple-access channels, and it is shown that if the users of the channel use the Arikan construction, the resulting channels will polarize to one of five possible extremals, on each of which un-coded transmission is optimal. The sum rate achieved by this coding technique is the one that corresponds to uniform input distributions. The method described retains the quality of being low complexity and has similar error probability scaling as the single-user case. Authors [16] have proposed low-complexity stack-based decoding algorithm. It employs information about the quality of not-yet-processed frozen bit sub-channels to reduce the number of times the decoder switches between different paths in the code tree while processing a received vector. The proposed algorithm avoids probability-domain calculations. Its complexity was shown to be substantially lower compared to the existing list and stack decoding algorithms. However, it enables one to use a much larger list size, allowing thus to obtain significant performance gain at the same complexity level. Complexity reduction is achieved at the cost of negligible performance degradation.

Authors [17] have given a brief comparison of Turbo codes, LDPC codes and polar codes in terms of iterative decoding and simulation. For a fair comparison, the input word length of 3568 is used in Turbo and LDPC codes. Further, the input word length of 4096 is used in polar codes. The code rate considered is half. The maximum number of iterations was set to 100. The performance of LDPC codes is better than Turbo codes at the lower SNR. A polar code has a slight better BER performance at low SNR and has significantly lower trellis complexity. In [20, 21] the polar code based OFDM system was designed to support voice and data applications. It is observed from the literature survey that still there is a scope to design decoding algorithm with less number of computations to cater to the latency demand of 5G. Further, it is observed that the polar code based OFDM-IDMA system has not been designed with less number of decoding computations to cater the latency demand of 5G. This paper attempts to propose a min-sum iterative based decoding algorithm using the polar code for OFDM-IDMA system. Here the system is assumed to be free of carrier frequency offset and symbol time offset. It is thus providing proper synchronization.

## III. CONSTRUCTION OF POLAR CODES FOR AWGN CHANNEL IN OFDM-IDMA SYSTEM

Polar codes construction deals with the problem of finding the set of the most unreliable bit positions, known as the frozen set. These unreliable positions are fed with foreknown bits, while the other set is used to transport information. The receiver has to know the frozen set. Otherwise, it cannot tell which bits are used for information transport. Unfortunately, this set is not only dependent on the code length and rate, but also on the channel conditions as well. This polar code was invented by Erdal Arikan in 2009 using a novel concept called channel polarization. The polar codes are constructed using Bhattacharya parameter given by (1) [18]

$$Z\left(b_i^{(s)}\right) = Z\left(b_i^{(s-1)}\right)^2 \tag{1}$$

Where $Z\left(b_i^{(s)}\right)$ is the Bhattacharya parameter of the $i^{th}$ bit channel at the $s^{th}$ stage.

Bhattacharya parameter of the underlying AWGN channel with unity power and a noise variance of $\sigma^2$, is given by (2)

$$Z_{AWGN} = \exp\left(-\frac{1}{2\sigma^2}\right) = \exp\left(-\frac{SNR}{2}\right) \tag{2}$$

Figure 1 shows the test engine model for simulation of polar-code based OFDM –IDMA system for the single user. The simulation is carried with MPSK modulation techniques. The simulation is done using communication toolbox in MATLAB. The proposed system consists of two sections; the transmission system consists of polar-code based encoder, MPSK modulator, and IFFT blocks. A pre-cyclic code is added to remove intersymbol interference (ISI). Subcarrier symbols are passed through AWGN and Rayleigh channel. At the receiver end, the pre-cyclic symbols are removed, and the FFT is calculated, MPSK demodulation is done, and then symbols are decoded using the polar decoder. The decoded binary output bit stream is compared with the binary input bit stream to evaluate performance in terms of BER.

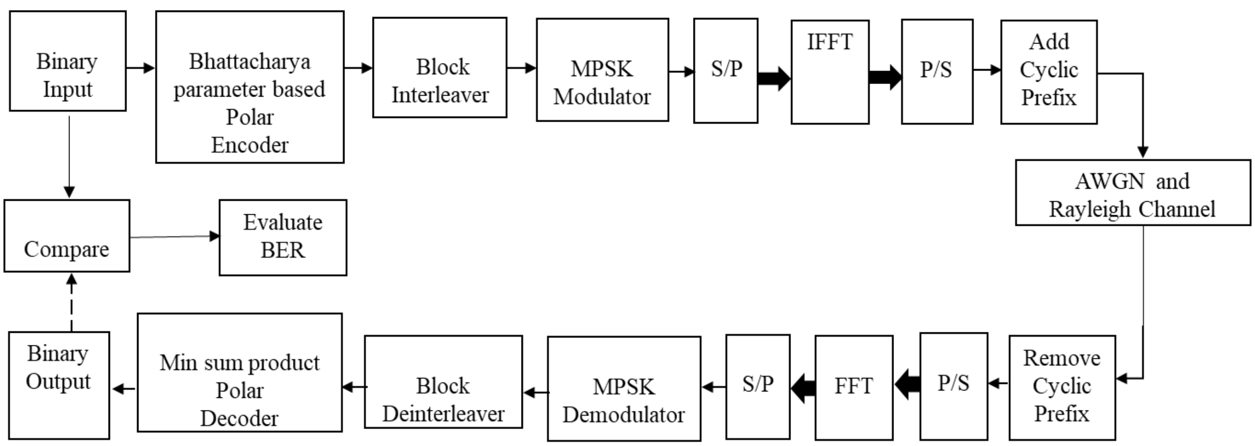


Figure 1. Test Engine Model for simulation of Polar-code Based OFDM-IDMA System

**Algorithm of OFDM-IDMA Transmitter**

- Initially, the text document is opened, which is in ASCII form and then converted into a serial binary bit stream.
- The binary input is interleaved after passing through the polar encoder.
- A cyclic prefix of length equal to 25% of FFT size is added as recommended in IEEE 802.16 standard**.**
- The resultant serial bit stream after addition of cyclic prefix is then converted into parallel bit streams.
- The parallel bit streams are then modulated using QPSK/ 16PSK.
- N-point IFFT operation is done on MPSK symbols.

**Algorithm of OFDM-IDMA Receiver**

At the receiver, the reverse procedure to that of the transmitter is done as follows:

- Removed cyclic prefix from the received OFDM-IDMA signal.
- Initially, the N-point FFT of the OFDM-IDMA signal is calculated
- After this, the signal is demodulated using MPSK demodulator, and the required bit stream is obtained.

- The signal is decoded after deinterleaving.
- Binary to decimal conversion is performed which gives equivalent ASCII representation.
- The BER is evaluated.

## IV. IMPLEMENTATION OF OFDM-IDMA SYSTEM WITH MIN-SUM PRODUCT DECODING ALGORITHM

The sum-product algorithm is a soft input, soft output decoding algorithm based on iterative belief propagation. Tanner graphs are used to estimate code words with iterative probabilistic decoding algorithms based on soft decisions. It is a soft decision algorithm which accepts the probability of each received bit as an input. The input bit probabilities are called the a-priori probabilities for the received bits because they were known in advance. The bit probabilities returned by the decoders are called a-posteriori probabilities. The decoding algorithm works with the following steps:

1. Initialization
   Input the parity check matrix, the maximum number of iterations to count equals to 15 and the received vector.
2. Message passing from check nodes to bit nodes
   Compute for each i, j information probabilities in bottom up (horizontal) approach with (3-6)

$$P_{j,i}^{ext} = \frac{1}{2} - \frac{1}{2}\prod_{i'\in B_j, i'\neq i}\left(1-2P_{i'}^{int}\right) \tag{3}$$

$\because P_{j,i}^{int}$ =current estimate, available to check j, of the probability that bit i' is a one.

$$E_{j,i} = \log\left[\frac{\frac{1}{2}+\frac{1}{2}\prod_{i'\in B_j, i'\neq i}\left(1-2_{i'}^{\text{int}}\right)}{\frac{1}{2}-\frac{1}{2}\prod_{i'\in B_j, i'\neq i}\left(1-2_{i'}^{\text{int}}\right)}\right] \tag{4}$$

$$\tanh\left(\frac{1}{2}\log\left(\frac{1-P}{P}\right)\right) = 1-2P_i \tag{5}$$

$$E_{j,i} = \log\left[\frac{1+\prod_{i'\in B_j, i'\neq i}\tanh\left(M_{j,i'}/2\right)}{1-\prod_{i'\in B_j, i'\neq i}\tanh\left(M_{j,i'}/2\right)}\right] \tag{6}$$

To test the intrinsic and extrinsic information probabilities for each bit are combined in (7), total LLR of the i$^{th}$ bit is sum of these LLR's

$$L_i = LLR\left(P_i^{\text{int}}\right) = r_i + \sum_{j\in A_i} E_{j,i} \tag{7}$$

The decision to detect whether the bit is 1 or 0 is decided by the total LLR sum.

3. Message passing from bit nodes to check nodes
   Compute information probabilities from bit to check nodes in top down (vertical) approach by (8-11)

$$M_{j,i} = \sum_{j'\in A_i, j'\neq j} E_{j',i} + r_i \tag{8}$$

$$\alpha \tanh^{-1}\left(P\right) = \log\left[\frac{1+P}{1-P}\right] \tag{9}$$

$$\prod_{i'} \equiv \prod_{i'\in \mathrm{B}_j, i'\neq i} \tag{10}$$

$M_{j,i'}$ can be factored as

$$M_{j,i'} = \alpha_{j,i'}\beta_{j,i'}$$
$$\because \alpha_{j,i'} = sign\left(M_{j,i'}\right) \tag{11}$$
$$\beta_{j,i'} = \left|M_{j,i'}\right|$$

4. Decoding and soft outputs
   The cross product of detected code word with transpose of parity check matrix is used to check whether the detected code word is a valid code word
5. If the decision fails, i.e. it's not a valid code word then go to step 2.
6. Further, if the decision exceeds the count of 15, declare a decoding failure.

A minimum sum algorithm simplifies the extrinsic message from a check node to bit node by recognizing that the term corresponding to the smallest messages sent from bit nodes to check nodes dominates the product term and therefore the product term is approximated by the minimum term further. The product of the signs can be calculated by using modulo two addition of the hard decision on each message sent between the bit nodes to check nodes of a given parity check matrix. Thus the resulting min-sum algorithm requires calculations of only minimum multiplications and additions as compared to belief propagation decoding algorithm.

## V. RESULTS AND DISCUSSIONS

This study concentrates in designing strong error correction capability and low implementation complexity polar code based OFDM-IDMA system polar codes for 5G in the working platform of MATLAB13 in the presence of Rayleigh and AWGN channel. We determined the performance in terms of bit error rate for different subcarriers (N-point IFFT/FFT size), code length, QPSK and 16PSK modulation techniques at half code rate. IFFT size selected for simulation is N-point where simulation is carried for N=64, 128, 256 and 512 and the code length of polar code considered as 8, 16, 32, 64 and 128 to observe effect for performance in terms of BER versus $Eb/N_0$ as shown in figure 2(a)-(b) to 3(a)-(b). Various modulation schemes considered as QPSK and 16 PSK for estimation of the performance of the system in terms of BER achieved for different values of $Eb/N_0$. The OFDM-IDMA system is implemented using polar code to show error correction capability in terms of reduced BER.

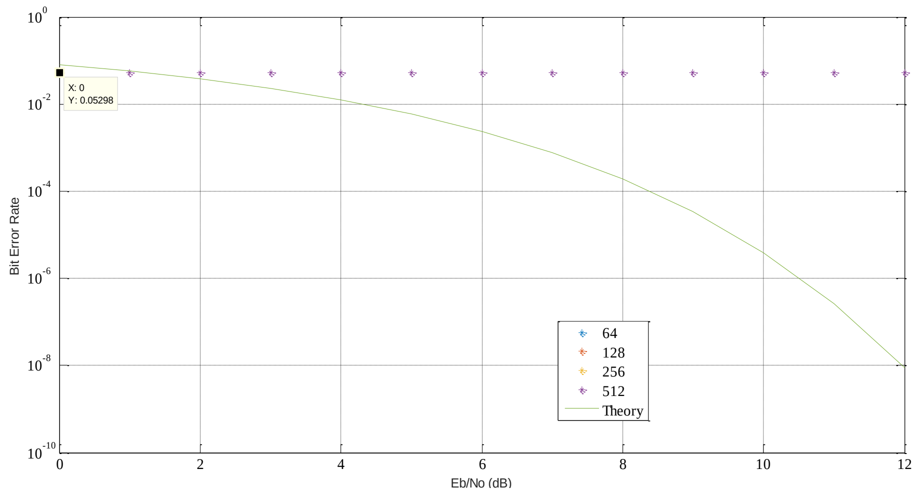


Figure 2(a). Without polar code

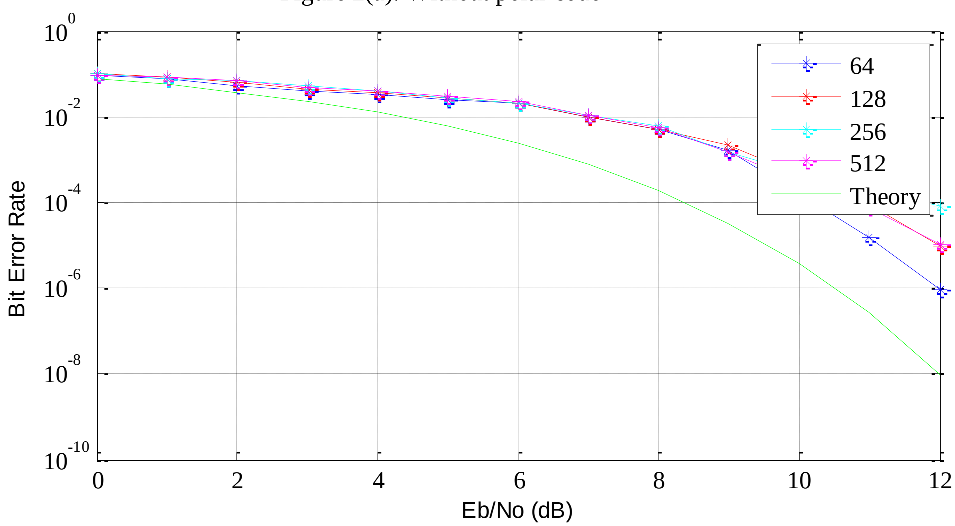


Figure 2(b). With code length of 128

Figure 2. BER versus $Eb/N_0$ performance for OFDM-IDMA with QPSK for different IFFT sizes

Table 1. Performance evaluation in terms of BER for OFDM-IDMA for different IFFT sizes and different required Eb/N$_0$ for un-coded system with QPSK modulation

| Eb/N$_0$ (dB) | BER | | | |
|---|---|---|---|---|
| | IFFT Length (N) | | | |
| | 64 | 128 | 256 | 512 |
| 0 | 0.05298 | 0.05298 | 0.05298 | 0.05298 |
| 5 | 0.05298 | 0.05298 | 0.05298 | 0.05298 |
| 10 | 0.05298 | 0.05298 | 0.05298 | 0.05298 |

Table 2. Performance evaluation in terms of BER for OFDM-IDMA for different IFFT sizes with QPSK modulation

| Eb/N$_0$ (dB) | BER | | | |
|---|---|---|---|---|
| | IFFT Length (N) with code length of 128 | | | |
| | 64 | 128 | 256 | 512 |
| 0 | 0.09454 | 0.1006 | 0.1023 | 0.08854 |
| 5 | 0.02467 | 0.02755 | 0.0285 | 0.02872 |
| 10 | 0.0001566 | 0.0004366 | 0.00048553 | 0.0003134 |

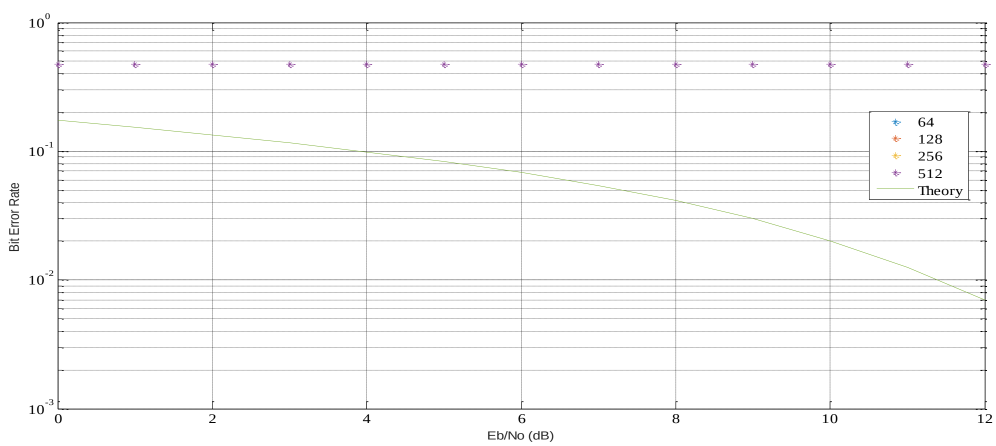


Figure 3(a). Without Polar code

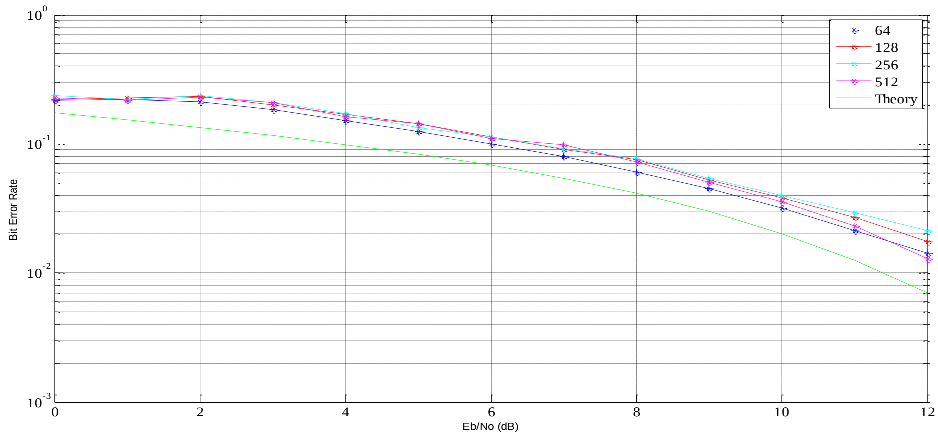


Figure 3(b). With code length of 128

Figure 3. BER versus Eb/No (dB) performance for OFDM-IDMA with 16PSK for different IFFT sizes

Table 3. Performance evaluation in terms of BER for OFDM-IDMA for different IFFT sizes for un-coded system with 16 PSK modulation

| $Eb/N_0$ (dB) | BER | | | |
|---|---|---|---|---|
| | IFFT Length (N) | | | |
| | 64 | 128 | 256 | 512 |
| 0 | 0.4768 | 0.4768 | 0.4768 | 0.4768 |
| 5 | 0.4768 | 0.4768 | 0.4768 | 0.4768 |
| 10 | 0.4768 | 0.4768 | 0.4768 | 0.4768 |

Table 4. Performance evaluation in terms of BER for OFDM-IDMA for different IFFT sizes with 16 PSK modulation

| $Eb/N_0$ (dB) | BER | | | |
|---|---|---|---|---|
| | IFFT Length (N) with code length of 128 | | | |
| | 64 | 128 | 256 | 512 |
| 0 | 0.2681 | 0.2751 | 0.2850 | 0.2901 |
| 5 | 0.185 | 0.185 | 0.185 | 0.185 |
| 10 | 0.055 | 0.055 | 0.055 | 0.055 |

## VI. CONCLUSIONS

A polar code based OFDM-IDMA system is simulated to evaluate the performance in terms of bit error rate (BER).

Following observations were met.

1. For all the modulation schemes and all the subcarriers with a code length of 128, it is observed that BER is improved with the increase in the value of $Eb/N_0$.
2. As the number of subcarriers increases at the value of $Eb/N_0$ = 0 dB, for all code lengths, the bit error rate decreases for QPSK. But BER degrades for 16 PSK.
3. With increase in $Eb/N_0$ above 2 to 12 dB, it is observed that BER increases with increase in the number of subcarriers for all the modulation schemes used. This is due to the increase in the fading effect of Rayleigh's channel. But the change is very small.
4. Performance in terms of BER is better for QPSK, the number of subcarriers equal to 64 and a polar code length of 128 which is approaching near to theoretical results.

**Future scope**

An effort in the design of universal polar codes at the cost of lower decoding performance, limitations on the code length or an increasing decoding complexity are the various challenges in the construction of polar codes at required receiver signal-to-noise ratio.

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