Performance Analysis of sub interleaver for turbo coded OFDM system

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Abstract

4G LTE / 5G is the high speed communication system developed for smart phones and other mobile devices in the recent era. The current level of mobile device usage and data exchange over the internet has raised the need for such a fast and secure communication system. One of the important feature in an LTE system is the use of OFDM technique, owing to its advantage namely robustness to multipath fading and interference. This paper proposes an improved OFDM based 4G LTE system fused with turbo code encoding technique to further reduce the bit error rate over noisy real-time channels. The proposed turbo codes system has a hybrid two stage interleaver which is a combination of 3GP interleaver and block interleaver. This interleaver reduces the time required for interleaving processing while maintaining the BER criteria up to the levels. The traditional decoder has been replaced with a threshold-log-MAP algorithm based interleaver for improved noise tolerance. The proposed system has been tested over various channels like Rayleigh, rician and nakagami channels. The experimental results prove that the performance of the stem has improved in comparison by the addition of turbo codes.

Keywords : turbocode, interleaver, ofdm, decoder, performance of the stem

I.   Introduction

Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier modulation scheme. OFDM is a technique widely used in 4G communication. The first step of this technique is to break the data into small portions. Then with the help of parallel orthogonal sub carriers the data will is transmitted to the receiver. The

conventional transmission uses a single carrier communication, which is modulated with all the data to be sent.Up to 3G communication, the data transmission process uses single carrier communication. The multicarrier technique is used in 4G technology where the data is divided into different streams and each stream consists of an individual carrier. Different streams are modulated with different carriers. These streams should be orthogonal to each other. Here the sinusoidal, sinc signals or complex exponential orthogonal signals will be used for carrying the information [XXI].

OFDM is a special case of Frequency Division Multiplexing (FDM). In conventional FDM, there will not be any special relationship between the carrier frequencies. The guard bands should be inserted into the FDM signalto avoid adjacent channel interference.In contrast, in an OFDMsystem, there will be a strict relation between the carriers. Here the carriers are orthogonal and can be packed together. The carrier frequency f_k can be defined as shown in equation 1.

$$f_k = k.\Delta f \tag{1}$$

where $\Delta f = \frac{1}{T_u}$ and T_u is the symbol period.

The OFDM communication system is used because it consists of higher spectral efficiencies and lower multi-path distortion when compared to FDM. The image below says that the spectral efficiency in OFDM is higher than the FDM.
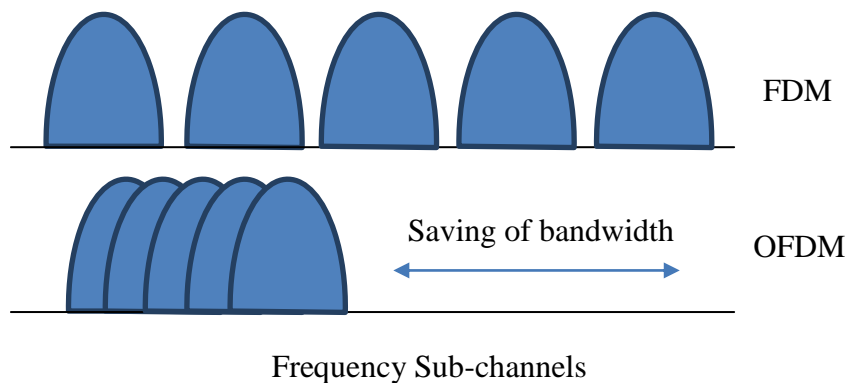

Fig. 1. Frequency sub-band allocation

An important concern while formulating an OFDM system is that the subcarriers should be aligned perfectly with each other so that orthogonality is maintained. A very small change in the sub carrier frequency can lead to Inter Carrier Interference (ICI) [XXIII]. The figure 2 shows the spectrum comparison for same data rate transmission. OFDM is better than multi carrier and single carrier techniques.
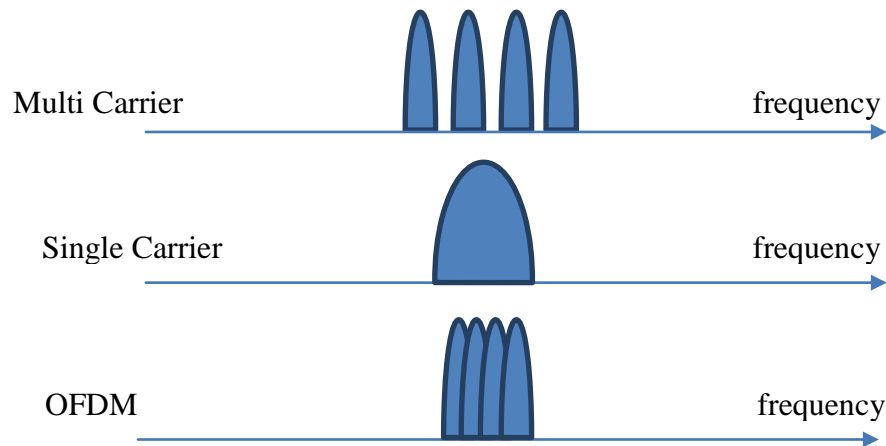

Fig. 2. Spectrum comparison for Different systems

The addition of error correction schemes (ECS) was thoroughly studied in the literature. The addition of ECS increased the data reliability in various communication systems. The basic and easiest technique adapted by the industry is the automatic repeat request (ARQ) [XIX]. In this technique the transmitter re sends the data if the receiver finds an error in the data. Error detection techniques like cyclic redundancy check and block parity codes are employed at the receiver end to accomplish this task. Positive acknowledge (ACK) and Negative Acknowledge (NACK) signals are exchanges between the transmitter and receiver for the process of information exchange. The main drawback present in this scheme of transmission is the delay imposed because of the retransmission of the entire data in case of errors.

In the case where the data retransmission in not possible, error correction schemes such as Forward error correction (FEC) [XXVII] and channel coding [XXVIII] is the approach employed. The transmitter adds redundant data so that the receiver can identify the error in the received data. Linear block codes such as Hamming codes [X], Low Density Parity Check (LDPC) [IX] and Repeat Accumulate (RA) [VI] are employed for improving the performance. Bose-Chaudhuri-Hocquenghem (BCH) [XI, V] and Reed-Solomon (RS) [IV] are categorized in to binary and non-binary

cyclic codes, respectively. There are various types of convolutional code and two common examples of convolutional codes are Parallel-Concatenated Convolutional Code (PCCC) [III], turbo code [XX], and RA code [VI].

Encoder plays a crucial role in improving the performance of the turbo code system. The turbo code module consists of generator polynomial based convolutional encoder. Several researchers have worked on the topic to a great extent [XXIV]. One of the decoder thoroughly discussed in the literature is the maximum a posteriori (MAP) [I] algorithm. The performance of this technique is far better when compared to the conventional algorithms. The drawback though is the computational complexity present in the algorithm. Hence the researchers also worked on the modified version of the MAP for to reduce the complexity.The interleaver is a very vital part of the design of the turbo code and has therefore influenced many researchers [II–VII].

Priti Subramanium et al., [XXV] presented the Turbo code OFDM system in terms of the BER performance of the system and addressed the issues of code length and code rate that accompany the turbo codes. The authors combined the Turbo code OFDM system with artificial intelligence layer to improve the BER of the system. The authors also claim to have reduces the delay of operation by intelligent choice of network properties.The authors Toshiaki Koike-Akino, Congzhe Cao and Ye Wang[XII] proposed a 5G communication system aided by turbo product codes resulting in good error performance along with low-power and low-latency decoding. The complexity of the system is further reduced by the introduction of the irregular polar codes with tuned polarization units. Houshou Chen et al., [XIII] presented an OFDM system with trellis decoding to reduce the peak-to-average power ratio (PAPR). The authors stated that by executing the partial transmit sequence (PTS) in minimal trellis, the complexity was reduced along with improved error correction capability.

Yih-Haw Jan [XXVI] implemented joint channel estimation and signal detection for OFDM system. The process was based on linear channel approximation and an iterative process was designed to improve the system performance. This iterative process searched the channels for valid channels and identified the reliable signals. Wael Abd-Alaziz, Martin Johnston and Stephane Le Goff [XIV] proposed an OFDM system non-linear preprocessing techniques, such as blanking, and clipping, have been utilized to eliminate the impulsive noise effects. Jason B. Coder and Yao Ma[XXX] presented a study on the impact of interference on BER. A comparison between low density parity codes (LDPC) and turbo codes has been presented in the paper.

This paper is organized into the following sections. Section 1 contains the introduction about orthogonal frequency division multiplexing. The second section

discusses the OFDM system in details. Section 3 presents the proposed concept where the Turbo code is added to the existing OFDM system. The results are discussed in section 4.

II. OFDM System

OFDM is an encoding technique designed for high speed digital communications. In this technique the data is modulated on to multiple carriers. This technique is currently being used in the latest mobile communication topologies. This system is designed to handle signal attenuation, inter channel interference, multi path frequency fading. The figure 3 shows the detailed block diagram of the OFDM system. The following sections explain the functionality of each bock.
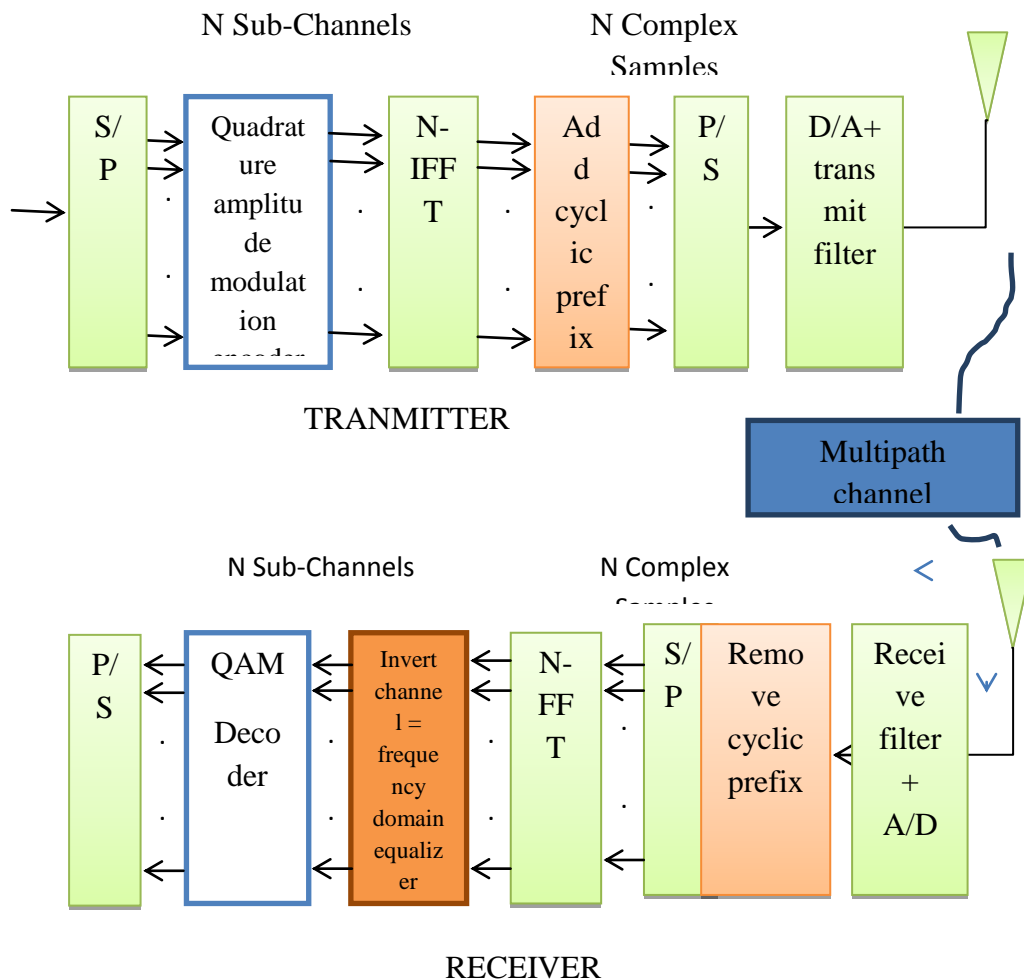
A. OFDM modem

Fig.3. OFDM transceiver

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Serial to parallel converter: The data rate is very high in the present day modulations due to the increment of the internet users. So for reducing that data length that is to be processed in cycle, the serial input bit streams are converted into parallel bit streams. This process will be done by S/P converter [XXIX].

Quadrature Amplitude Modulation (QAM) encoder: The signals exiting from S/P converter are narrow band signals, which given as input to the QAM encoder. The main purpose of the QAM encoder is to convert the time domain signal into frequency domain signal.

Inverse Fast Fourier Transform (IFFT): The spectrum is transformed into a real-time complex valued signal after applying IFFT. The same amount of complicated information with power of 2 is again converted in time domain with same value. N complex samples are executed as outputs in IFFT.

Cyclic Prefix: Cyclic Prefix converts the linear convolution LTI systems into cyclic convolution. This acts as a means to reduce inter symbol interference by acting as a guard band between the various carrier frequencies.

P/S Converter: The parallel to serial converter converts parts of information which is present in parallel format into huge serial information.

D/A Converter: the digital to analog converter converts the digital information into analog information. The output from this is sent as information to the receiving point.

The same procedure is applicable for receiver section in a reversible format.

B. OFDM Carriers

The figure 4 shows 6 different wave forms which are orthogonal to each other for one single period T [XXIX]. Assuming 6T is the value of the input transmitter. The data in the input transmitter is divided into 6 parallel streams. These 6 different streams consist of 6 orthogonal carriers. The frequency is represented as f_0. The subcarriers present in the OFDM will be with power of 2. By increasing the value of 2^n the complexity also goes on increasing.
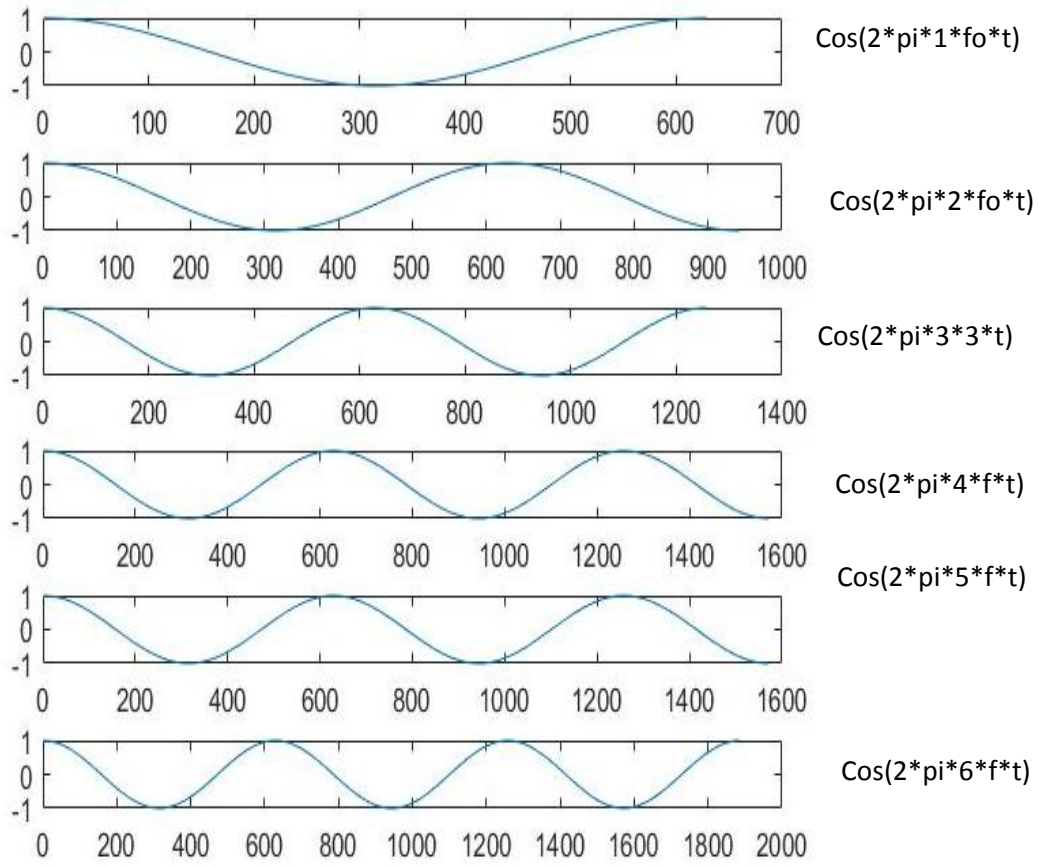
Fig.4. OFDM Carrier representation

Mathematical representation of orthogonality is taken in equations (2)-(4):

- m,n: integer, T=1/f_0

$$\int_0^T \cos(2\pi m f_0 t) . \cos(2\pi n f_0 t) \, dt = \begin{cases} \frac{T}{2} & (m = n) \\ 0 & (m \neq n) \rightarrow orthogonal \end{cases} \tag{2}$$

$$\int_0^T \sin(2\pi m f_0 t) . \sin(2\pi n f_0 t) \, dt = \begin{cases} \frac{T}{2} \, (m = n) \\ 0 \quad (m \neq n) \rightarrow orthogonal \end{cases} \tag{3}$$

$$\int_0^T \cos(2\pi m f_0 t) . \sin(2\pi n f_0 t) \, dt = 0 \rightarrow orthogonal \tag{4}$$

The above equations consist of 2 frequencies represented as mf_0 and nf_0.

The above equations are the basic orthogonal conditions which will be used for getting FFT and IFT efficiently. The carrier frequency changes when the device getting moved from transmitter, receiver, at this condition mf_0 and nf_0 will not be orthogonal to each other.

C. Pass-band OFDM signal

One carrier will be used for all the strings in pass band OFDM signal. ICI problem occurs due to this pass band OFDM signal only [VIII]. Because of the transformation of the upconverted signal to the receiver end and transmitter end, there might be a change in any one of the frequency. Through which the problem of ICI may occur. By this orthogonality gets disturbed. But most of the practical applications uses pass band OFDM signals only.

- $S_B(t)$ is up converted to pass-band signal S(t), represented in equation (5)
  - $frequency shift will be taken as f_c$

$$S(t) = \sum_{n=0}^{N-1}[a_n \cos\{2\pi(f_c + nf_0)t\} - b_n \sin\{2\pi(f_c - nf_0)\}] \tag{5}$$

D. Actual OFDM Spectrum

If same pulse shown above is modulated for any sine wave with a period T then its value remains same except its center frequency. The center frequency changes to $f_c from f_0$.

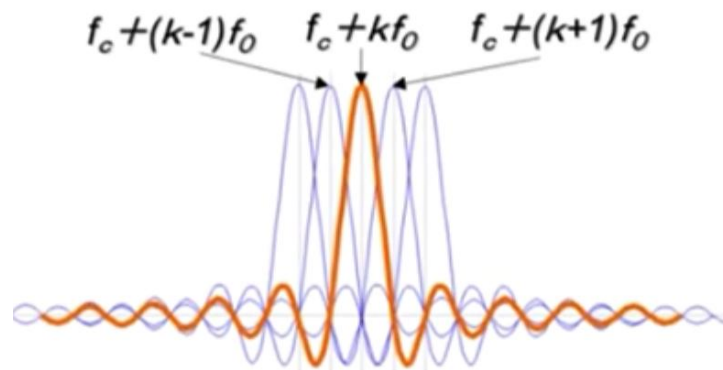$$f_c + (k-1)f_0 \quad f_c + kf_0 \quad f_c + (k+1)f_0$$

Fig 5. OFDM Spectrum

The figure 5 consists of 5 different streams whose carriers are also different. The f_c represents carrier frequency and f_0 represents time domine frequency. K is an integer which ranges from 0 to N. this consists of both positive and negative components [XVIV].

III. Turbo Codes

Turbo codes are among the latest state of the art techniques for Forward Error Correction (FCC). It was with the help of these codes that the channel capacity advanced to the next heights. 4G and 5G mobile communications use turbo codes. They are also used in deep space satellite communications and are also used in applications where reliable information is transferred over bandwidth or latency constrained communication in the existence of data corrupting noise. The addition of the turbo codes for the OFDM system will provide an additional error correction capability thus improving the performance of the system in noisy conditions [XXII].

A. Interleaving Techniques

The interleaving techniques shuffle the data to be transmitted. The addition of interleaving techniques introduces randomness to the data and thus makes the data robust to attacks and error. There are various interleaving techniques discussed in the literature. This section presents the 3GPP interleaver and the hybrid interleaver used in the proposed technique.

1. 3GPP Interleaver

The internal inter leaver turbo code input bits are represented as $x_1, x_2, x_3 \ldots \ldots \ldots x_k,$ where K is the integer bit ranging from 0 to 5114. The relation between the channel coding and the input bits and the turbo code inter leaver are taken as Bits-Input to Rectangular Matrix with padding.

The matrix form representation of the input bit sequence $x_1, x_2, x_3 \ldots \ldots \ldots x_k,$ of the turbo code internal inter leaver is taken as:

1. The rectangular matrix row, R, is given in equation (6)

$$R = \begin{cases} 5, & if\ (K \leq 159) \\ 10, & if\ (160 \leq K \leq 200)\ or\ (481 \leq K \leq 530) \\ 20 & if\ (K = any\ other\ value) \end{cases} \qquad (6)$$

2. There should be the determination of prime number as because they are used in the intra permutation, p, and the rectangular matrix column is represented with C, which is shown below

If $(481 \leq K \leq 530)$ then p = 53 and C=p.

Else

If the minimum p-value is evaluated from K$\leq Rx(p+1)$, then C will be determined. Where

$$C = \begin{cases} p-1, & if\ K \leq R.(p-1) \\ p, & if\ R.(p-1) < K \leq R.p \\ p+1, & if\ R.p < K \end{cases} \tag{7}$$

End if

The numbering process in the rectangular matrix column is done from left to right as 0,1,2,3,……………………, C-1.

3. The matrix form representation is shown in equation (8):

$$\begin{bmatrix} y_1 & y_2 & \text{... ...} y_C \\ y_{(C+1)} & y_{(C+2)} & \text{... ...} y_{2C} \\ y_{((R-1)C+1)} & y_{((R-1)C+2)} & \text{... ...} y_{RXC} \end{bmatrix} \tag{8}$$

The input sequence is represented in row by row, into a rectangular matrix in order of R X C, where y_1 in order of row(). Here $y_k = x_k$ for k=1,2,……..,K and if the rectangular matrix order is greater than K, then dummy bits are placed such that y_k value is 0 or 1, for k= K+1, K+2, ……., R X C. after the processing of the intra-row and inter-row permutations these dummy bits are eliminated from the output.

2. *Hybrid Inter leaver*

A hardware device which is used in the conjunction process of verifying the error codes present in the burst error and eliminating those error is known as inter leaver. The hybrid inter leaver is the advanced inter leaver where the time complexity is reduced during the fast communications [XVI].

B. *Decoding Algorithms*

The encoding system divides the data into multiple data streams for efficient transmission of data. The design of an interleaver is a crucial process in obtaining the transmitted data without errors. This section describes the decoding algorithms used in the proposed method.

1. *Map Algorithms*

One of the most advantageous algorithms is map algorithm. It is very difficult for the computation process of soft input and the output algorithms. The simplified versions of the MAP algorithm are Log-MAP, the Max-Log-MAP and finally the threshold-

Log-MAP. LLRs are computed in the MAP algorithm. The LLRs stores the information in the bits format. $L(d_k)$ is presented in equation (9).
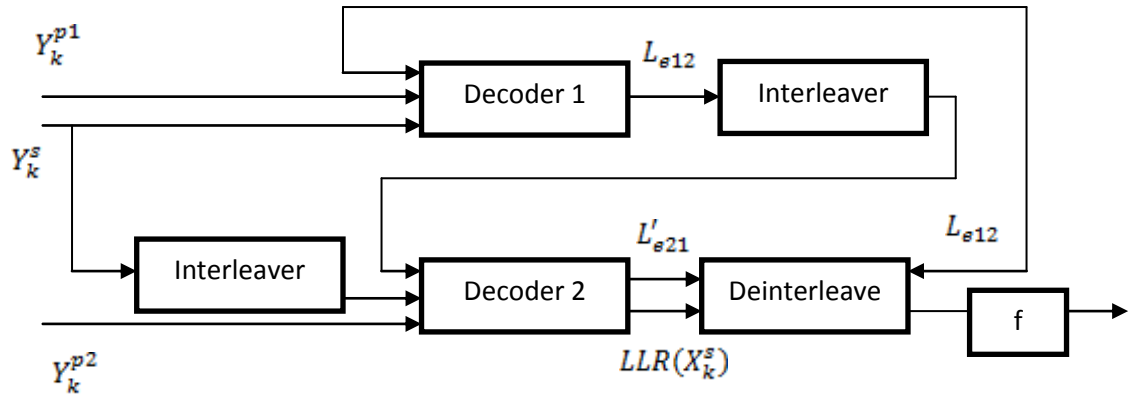

Fig 6. Turbo Decoder Architecture

$$L(d_k) = ln\left[\frac{\Sigma_{S_k}\Sigma_{S_{k-1}}\gamma_1(S_{k-1},S_k)\alpha(S_{k-1})\beta(S_k)}{\Sigma_{S_k}\Sigma_{S_k}\gamma_0(S_{k-1},S_k)\alpha(S_{k-1})\beta(S_k)}\right] \tag{9}$$

α = forward state metric

β = backward state metric

γ = branch metric

S_k = trellis state at trellis time k

2. *Log-MAP algorithm:*

The operation of MAP algorithm happens on the basis of regular algebra. The complexity of the algorithms are reduced by approximating the exponential and the logarithmic operations using a relation represented in equation (10).

$$max* \ (x,y) = ln(e^x + e^y) = max(x,y) + log\ (1+e^{-|y-x|}) \tag{10}$$

3. *Max-log-MAP algorithm*

The function $f_c = log\ (1+e^{-|y-x|})$ which is within the max *(.) can be implemented in many ways. The term correction max *(.) will be completely approximated with a max *(.) operator shown in equation (11).

$$Ln(e^x + e^y) \approx max\ (x,y) \tag{11}$$

The above equation is expensed at certain performance degradation techniques. The LUT is required for determining different matching correction factors which are present in max *(.) operations, which can be removed by using the above simplification. This performance is capable of destroying the approximation limit of about 0.5 dB than that of the Log-MAP algorithm.

4. *Threshold-log-MAP algorithm*

The threshold-log-MAP algorithm's estimation will be done by using the Jacobi algorithm with an equation depicted in equation (12)

$$\max {}^*(x, y) = \max(x, y) + \begin{cases} 0 \; if \, |y - x| > T \\ C \; if \, |y - x| \leq T \end{cases} \tag{12}$$

The turbo code value of Universal Mobile Telecommunication System (UMTS) has a constant value of (C = 0.5) and with a time interval (T = 1.5). The main drawback of the threshold-log-MAP algorithm is that it is not capable of detecting the estimation errors occurring because of the noise variance as compared to log-MAP. The threshold-log-MAP algorithm consists of subintervals. The input information bits are processed by making them into two half portions. Four sub-intervals are used by the second one and eight sub-intervals are used by the third one. The accumulation will also be done on the count of sub-intervals. If the count is more than 8 sub-intervals then the BER functioning gets degraded to an unexpected range [XVII].

IV. Results

The following are the experimental results conducted on random data of length 9600. The table 1 displays the simulation time values of the algorithms under study. The columns indicate the interleaving techniques used. The first column indicates no interleaver, column 2 represents the block interleaver, columns 3,4, and 5 represent the proposed hybrid interleaver with 2,4 and 8 sub interleavers respectively. The rows denote the Log MAP, Max Log Map and Threshold Max Log Map algorithms. The simulation times of the proposed Hybrid 8 sub-interleaver are considerably less as compared to the others.

Table 1: Simulation time of the OFDM system with the proposed turbo code

	No Interleaver	Block	Hybrid – 2	Hybrid 4	Hybrid - 8
Log-MAP	36.942231	37.490630	39.485770	40.736305	35.748959
Max-Log-MAP	26.991517	27.128499	31.051397	25.327534	25.358098
ThresholdMax-Log-MAP	29.179354	30.492371	30.440956	31.250672	29.630843

The images from 7 to 13 are representing the BER to SNR graphs of the algorithms under study.
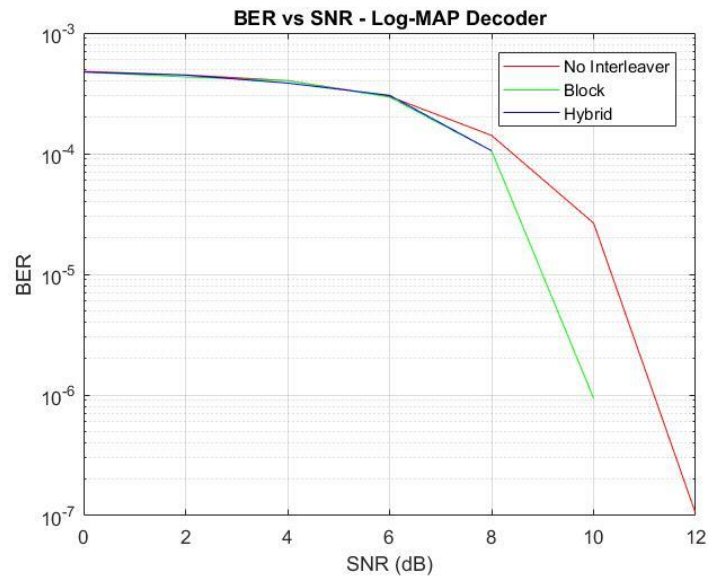

Fig. 7. BER vs SNR - Log-MAP Decoder

Figure 7 depicts the BER vs SNR graph of Log-MAP Decoder with different interleaving techniques, presenting the result of the system with no interleaver, block interleaver and hybrid interleaver. The performance of hybrid interleaver is better in comparison with the other two as the BER becomes 0 at SNR 8.
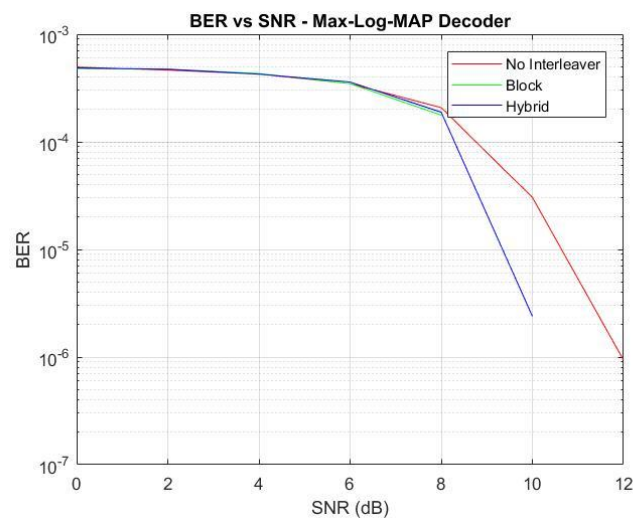

Fig. 8. BER vs SNR - Max-Log-MAP Decoder

Figure 8 depicts the BER vs SNR graph of Max-Log-MAP Decoder with different interleaving techniques, presenting the result of the system with no interleaver, block interleaver and hybrid interleaver.
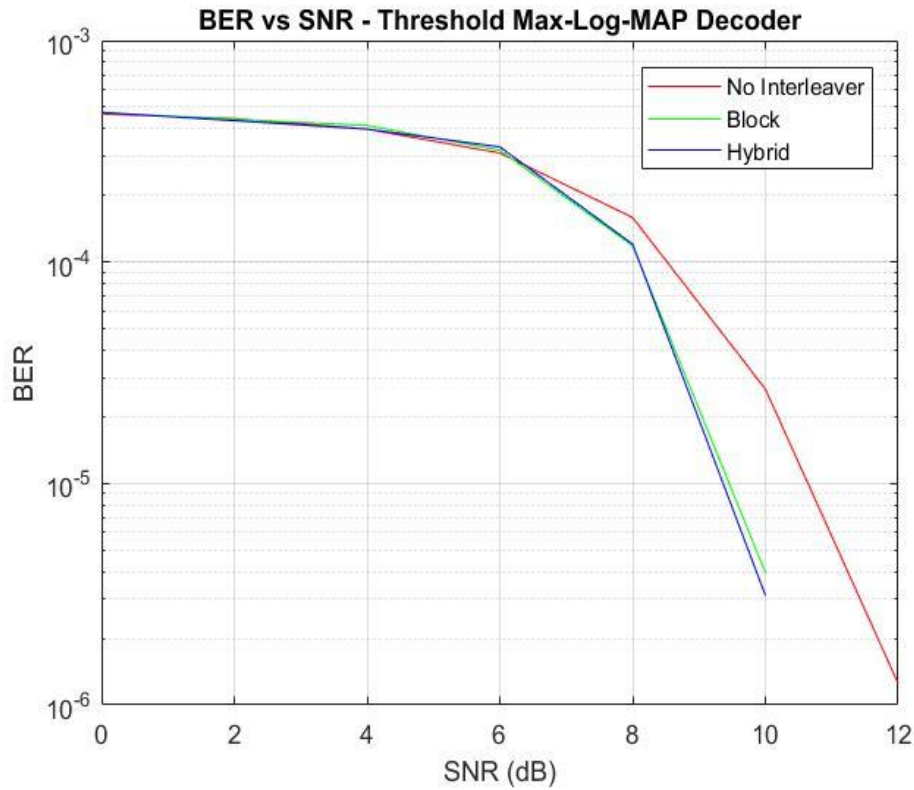

Fig. 9. BER vs SNR - Threshold Max-Log-MAP Decoder

Figure 9 depicts the BER vs SNR graph of Threshold Max-Log-MAP Decoder with different interleaving techniques, presenting the result of the system with no interleaver, block interleaver and hybrid interleaver. The performance of hybrid interleaver is better in comparison with the other two as the BER becomes 0 at SNR 10.
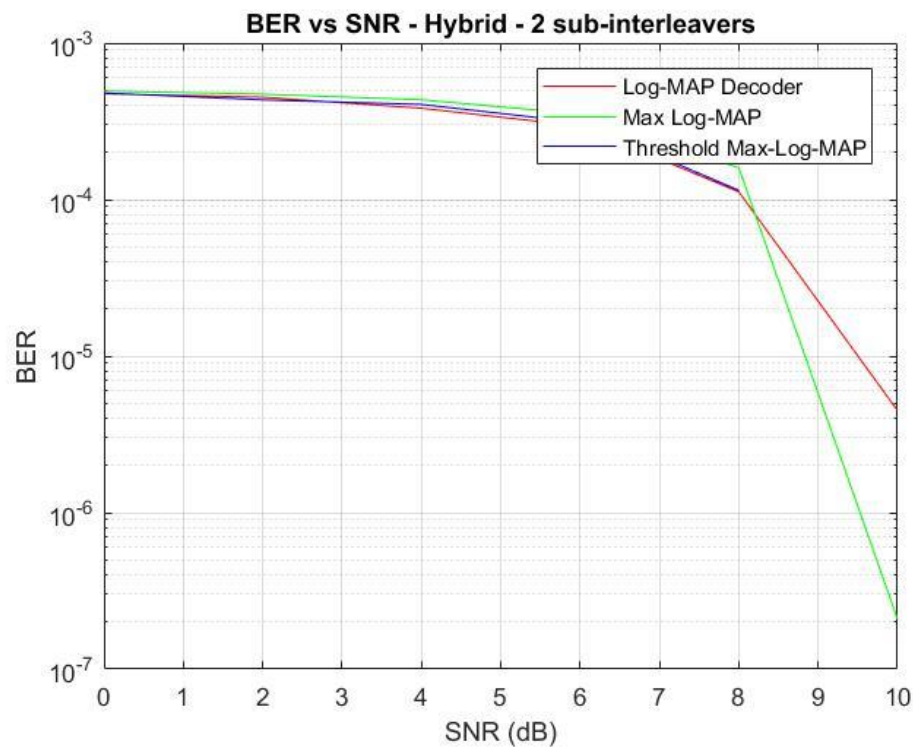
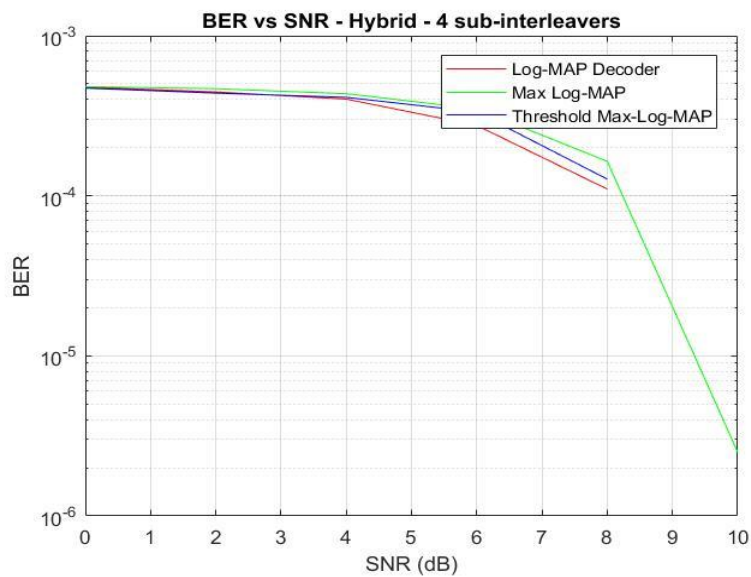Fig. 10. BER vs SNR - Hybrid Interleaver - 2 sub-interleavers

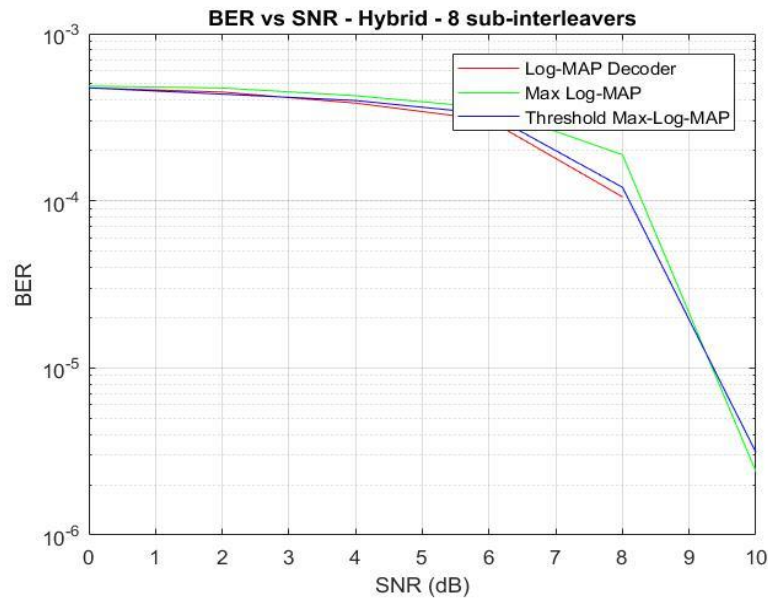Fig. 11. BER vs SNR - Hybrid Interleaver - 4 sub-interleavers

Fig.12. BER vs SNR - Hybrid Interleaver - 8 sub-interleavers

Figures 10, 11 and 12 depicts the BER vs SNR graph of Hybrid interleaver with 2, 4 and 8 sub-interleavers,, presenting the result of the system with Log-MAP, Max Log – Map and threshold max log map decoder. The performance of hybrid interleaver with 8 subinterleavers is better in comparison with the other two as the BER becomes 0 at SNR 8.

Table 2: Performance comparison of turbo codes with OFDM

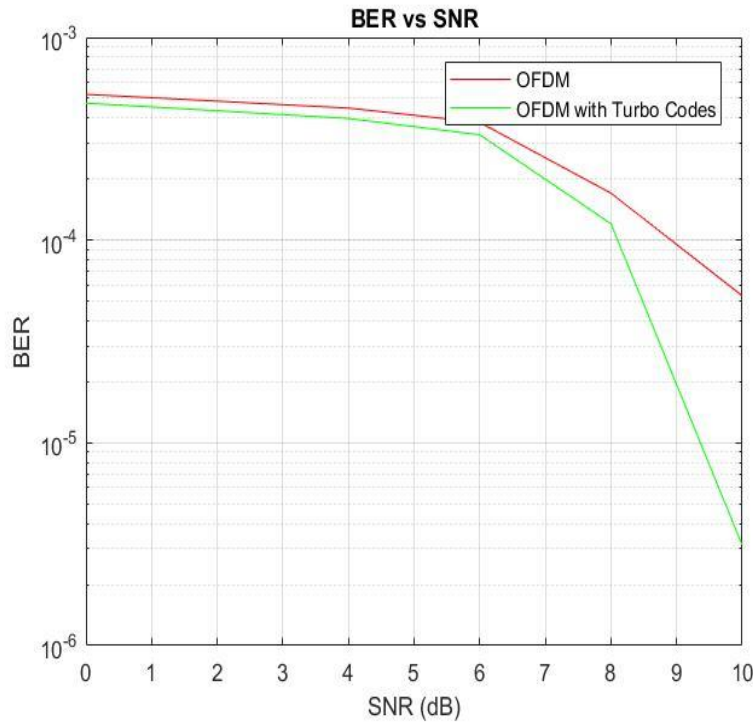| SNR	OFDM - BER ($10^{-8}dB$)	OFDM with Turbo codes - BER ($10^{-8}dB$)
0	0.5239	0.4739
2	0.4848	0.4348
4	0.4480	0.3980
6	0.3808	0.3308
8	0.1704	0.1204
10	0.0531	0.0031

Fig. 13. BER performance of OFDM with Turbo Codes

The Table 2 and figure 13 depicts the OFDM system performance before and after applying turbo codes. The proposed Hybrid 8 sub interleaver algorithm has better BER performance compared to the existing methods.

V. Conclusion

In the current era of technological development, faster, secure and efficient means of communication play a vital role. The OFDM technique is widely used in the latest communication technologies. The conventional OFDM techniques lack the ability to correct the corrupted bits. The addition of turbo codes to the existing OFDM systems brings in the property of error tolerance thus improving the bit error rate performance by 10%. The novel interleaving and the decoding algorithms used in the turbo codes help boost the performance of the system. The comparison results present the improvement in the bit error rate over various signal to noise ratios.

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