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Common Phase Estimation in Coherent OFDM System Using Image Processing Technique

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Abstract: **OFDM is widely used as the modulation standard in all Wireless transceiver systems and recently optical transceiver systems due to its inherent advantage over other modulation standards. The main drawback of the OFDM system is it suffers from the phase noise errors. Common Phase Error (CPE) and Inter Carrier Interference are the two main errors that occur in OFDM systems as result of phase induced noise. Several techniques have been proposed to combat the CPE, such as RF pilot carrier based, Digital Pilot Aided (PA) based, MBB based etc. In this paper a framework for evaluating the performance of MBB and PA based method in estimating the CPE and correcting it is proposed. The framework is designed and implemented in MATLAB 15 Software and the BER is computed for both the methods to compare their performance.**

***Keywords*—OFDM, Common Phase Error (CPE), MBB, PA, BER**

I. INTRODUCTION

Data rate is the major demand in today's digital communication devices using wireless communication such as wi-fi routers, wireless broadband and cellular data services. To increase the data rate conventional modulation standards have been replaced by OFDM in the recent times. The advantages of OFDM are it has no multi-path fading effect, less ISI, offers more bandwidth as it does not require any guard band separation compared to the conventional Frequency Division Multiplexing. Hence OFDM has been the most widely used form of modulation in almost all digital wireless communication devices. OFDM is also being used as the modulation scheme in Optical Fibre communication systems as COOFDM systems.

One of the major limitations that OFDM systems suffer is related to phase noise. A phase noise results as the difference in the phases of received subcarriers and the local oscillator or local laser signals. The error introduced by phase noise is termed as Common Phase Error and Inter Carrier Interference. The rotation of constellation points in the complex plane is termed as CPE while ICI refers to an additive noise term. Several methods have been proposed to compensate the CPE and ICI. Analog and digital approaches for compensating the CPE effect have been introduced [8]. Analog approaches use a RF pilot carrier which is added intentionally in the transmitted signal and at the receiving end they are recovered to identify the phase changes on the RF-pilot carrier. Blind –aided (BA) and non-blind PA methods are the digital approaches. The use of this PA and RF carriers for CPE estimation requires additional bandwidth and thus reduce the spectral efficiency and in turn the data rate of the OFDM system. Non-Blind PA Methods makes use of a large number of pilot subcarriers while BA methods use smaller number of pilot signals and Decision direct algorithms. The DDPE (Decision Direct based Phase Estimation) method for optical OFDM systems and a CPEC (Common Phase Error Correction) algorithm based on DDPE was proposed for OFDM systems in Broadband wireless system. These methods suffer from error propagation and cannot be used under large phase errors [9]. CPE estimation with the help of Image Processing algorithms was proposed in [7].

In this paper a framework for comparing the performance of PA based CPE estimation and an image processing based CPE estimation is performed. The image processing algorithm used here is MBB algorithm termed as Minimum Bounding Box. This algorithm is based on the occurrence of a phase rotation on the OFDM subcarriers. This rotation angle can be found by finding the rotation angle of the bounding box which holds the constellation points in the IQ plane. Considering the IQ plane as a graph, skew estimation can be done using MBB. A framework is designed which generates a synthetic signal and it is OFDM modulated. The demodulation is performed on the modulated signal combined with AWGN noise. MBB and PA methods are used to estimate the CPE from the demodulated signal and the constellation maps are corrected based on the estimation. An analysis is made based on the performance of PA and MBB methods considering the BER and SNR computed from the two methods.

The paper is organised with section II presenting the Overview of the CO OFDM system, section III presenting the Literary works on CPE estimation in COOFDM systems Section IV presents the design of the framework Section V presents Algorithm Implementation Section VI presents the Results and Discussion and Section VII Conclusion.

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II. BACKGROUND

OFDM modulation has been recently introduced in the optical fiber communication system. Such systems are referred to as Optical OFDM systems. There are two categories of Optical OFDM 1) Direct Detection based 2) Coherent based.
DD based systems are conventional which makes use of a photo-diode at the reception side.

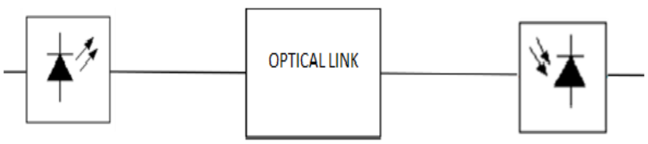

Figure.1 Block diagram of DD based OFDM

A Coherent detection system used in Optical OFDM is called as CO-OFDM system where the receiver of this system consists of local laser source for coherent detection.

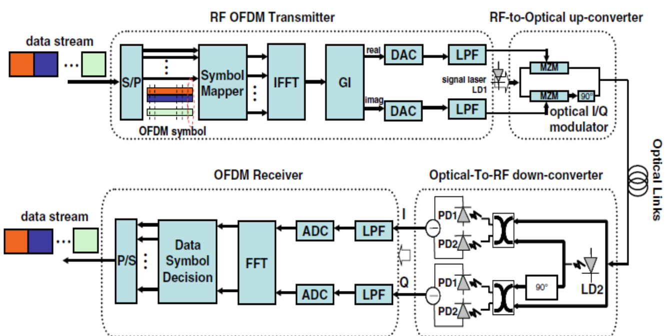

Figure.2 Block diagram of CO-OFDM

A typical CO-OFDM system comprises of the following blocks, an OFDM RF transmitter, a RF to Optical Converter, Optical Channel link, an optical to RF converter and an OFDM receiver. The serial to parallel converter present in the RF transmitter block splits the incoming data into multiple numbers of segments. Each segment is assigned a subcarrier along with the pilot carrier. OFDM symbols are generated using modulation schemes such as QAM or PSK. The frequency domain OFDM symbols to time domain conversion are performed by IFFT block. A cyclic prefix block is used to avoid channel dispersion effect. DACs perform the digital signal to analog signal conversion and LPFs cut-offs the irrelevant sidebands. The optical signal conversion is done by RF to Optical converter which is then fed to the optical channels. At the receiver end the optical OFDM signals are received by the Optical to RF converter block which uses a local laser to down convert the optical signal to RF signal. The RF OFDM signal is fed to a RF OFDM receiver where the signal is first filtered and digitized using ADC for further processing. The first and the last OFDM symbols are found with windowing and frequency synchronization and also frequency offset is estimated and compensated. OFDM signal is partitioned with each partition consisting of OFDM symbol. The frequency domain partitioned signal is obtained using FFT block. Then using the training symbol and pilot subcarriers channel estimation and phase estimation is performed. The phase compensation is performed and the data stream is recovered.

A.Phase Noise in Coherent OFDM

Phase noise is a major problem with any Coherent receiver systems and can be removed by improving the Oscillators and this applies to Coherent Optical OFDM systems where phase noise is introduced due to lasers. Phase noise creates two different errors namely Common Phase error and Inter Carrier Interference.
The received signal affected by phase noise Ө represented as

$$s(n) = x(n).\exp(i\theta(n)) \qquad ....1$$

Where x(n) is the transmitted OFDM signal. If θ is considered to be small then $\exp(i\theta(n)) = 1 + i\theta(n)$.
The de-multiplexed signal is represented as

$$z(m) \approx Sm + {}^{i}/_{N} \sum_{r=0}^{N-1} Sr \sum_{n=0}^{N-1} \theta(n) \exp(i({}^{2\Pi}/_{N})(r-m)n$$

$$z(m) \approx sm + cm \qquad ......2$$

From the above equation it is clear that an error term for each subcarrier is added.

If r = m a constant then it represents a CPE

$$\frac{i}{n} \sum_{r=0}^{N-1} Sr \sum_{n=0}^{N-1} \theta(n) = i.Sr.\theta \qquad ....3$$

A common error id added to all the subcarriers that is proportional to θ which represents the rotation of constellation which results from phase noise. As the rotation remains same for all subcarriers, pilot carriers are used to measure the phase difference among the OFDM symbols and corrected.

If r! = m then it represents ICI

$$\frac{i}{n} \sum_{r=0}^{N-1} Sr \sum_{n=0}^{N-1} \theta(n).\exp(j\frac{2\Pi}{N})(r-m)n) \qquad ....4$$

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The equation represents an ICI in which a sum of N-1 subcarriers multiplied with a complex number is added to each subcarrier.

The phase noise introduced will affect the system performance w.r.t SNR. A phase noise variance of 1.33 can result in decrease in SNR value in the range from 10-25 db. Several correction methods which include the use of pilot carriers, RF carriers, decision directed methods, image processing methods have been proposed to reduce phase noise. With the use of these methods the system performance can be improved without adding extra constraints on laser source design used at the receiver side.

III. IMAGE PROCESSING METHOD

Since the phase noise effect causes rotation of constellation points, then considering this constellation plane as a graph and rotation as skew problem in images, image processing algorithm such as MBB algorithms can be made use of for CPE estimation and correction.

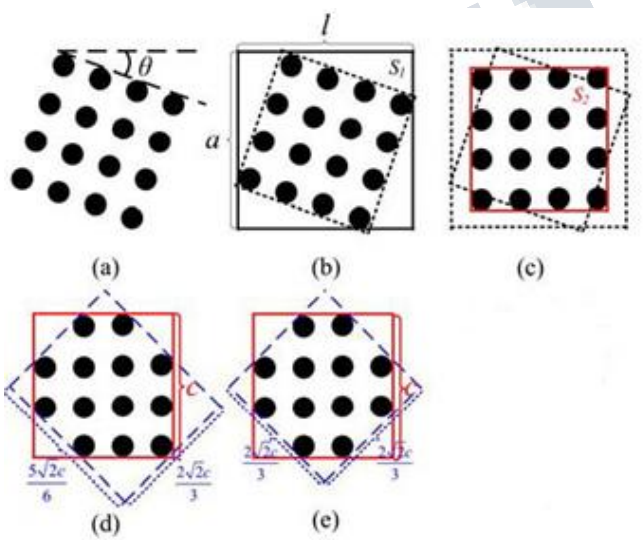

Figure 3 describes the principle of MBB.(a) shows skew in constellation diagram (b) outer bounding box (c) minimum bounding box (d) box with 3 points left out (e) box with 4 points left out

MBB refers to minimum area of rectangle that covers the entire constellation points. Considering a 16 bit QAM received sample, the sample is rotated by M test phases parallelly and the area of the rectangle covering all points in the constellation diagram is measured. The phase is estimated as the phase of the sample corresponding to the least measured area of the rectangle.

IV. LITERATURE REVIEW

This part discusses the literature review of the Digital Pilot Aided (PA), MBB researches

A RF pilot based CPE estimation was proposed by (Jansen et al.) [10].Here a RF pilot was introduced in the OFDM signal, with the assumption that the rf pilot will undergo the same phase change as the OFDM symbols. Then at the receiver end the RF pilot can be made use of to estimate the CPE and compensated using suitable adaptive filtering techniques. The method suffers from power overheads and requirement of frequency guard bands affecting the spectral efficiency of OFDM.

The study of Yi et al. [1] proposed a CPE estimation method using PA methods. The PA based method obtained the PD between the transmitted and the received pilot signals and averaged to estimate the CPE. The authors compared the performance of the conventional data-aided subcarrier phase estimation method with the proposed pilot based method and found that the pilot based estimation method was able to estimate CPE with a very noisy signal while the former method suffered from phase ambiguity issues and required complex computations. The improvement of 0.5 db performance using PA based was observed relative to data-aided methods. The drawback with PA based method was that it suffered from spectral efficiency.

A Quasi-PA based method was proposed by Kanesan et al.[2] to reduce the number of subcarriers used in PA method. The pilots are introduced at known frequencies and phase is estimated based on the related data channel. In Quasi –pilot the a modulation of pilot with respect to data signal is done in contrast to PA based where the pilot is kept in known state. At the receiver side demodulation is done and pilots are recovered and then used in phase estimation. The proposed method improved the spectral efficiency of PA based method by reducing the number of pilot carriers by a factor of two.

In former methods of phase compensation each symbol at the receiver end was taken and their mean phase rotation from their subcarriers was estimated and then the received symbols were rotated. The drawback with this method was that it required symbols to be short which had to be generated using costly lasers. The study of (Randel et al.) [3] provided us with a comparison of the former method and RFP based phase noise tolerance. Compared to former method the RFP based method provides with an improvement of tolerance in phase noise along with the removal of ICI .The drawback found with the RFP method was that computation complexity was more compared to former method because of more complex multiplications involved.

The study of Pasandi and Plant [4] discussed the phase noise compensation method based on DDPE method to increase the accuracy and reduce the power head of RF pilot based method. DDPE consist of two equalizing stages where the first equalizing stages the fiber dispersion effects. The initial stages in DDPE updates the estimation parameters for the first stage and the phase noise is estimated by the first stage by extracting the phase rotation angle for each symbol. The second stage of equalization uses this phase noise estimate and compensates for it and the compensated signal is sent to decision device for detection. The drawback with DDPE algorithm is that they suffer from error propagation in higher order OFDM.

To overcome this drawback Ha and Chang [5] improved the DDPE method by incorporating DM derotor stage ahead of DDPE equalization stage. The DM derotor is a blind phase adaptive algorithm which performs the rough phase estimation while DDPE stage performs a fine estimation.

A multiplier free BPE method is proposed by Le et al. [6] to efficiently implement the phase estimation method on the hardware.

The systems which use Image processing based algorithms were initially proposed and then improved using Quasi-pilot based method is proposed in Bo et al. [7]. An MBB algorithm which solves the skew related issues in images is utilized to find the CPE estimate. The square constellation problems in MBB are solved using quasi-pilot scheme along with it. This scheme reduces the number of subcarriers compared to the PA schemes by employing a single pilot for carrying two symbols. This method provided improved performance and spectral efficiency compared to the conventional PA based method.

In this paper a framework for comparing the performance of both MBB based method and the PA based method. The BER of the two methods are computed and used as comparison metric.

V. SYSTEM DESIGN

This section introduces to the design of the framework to attain the intended objective.

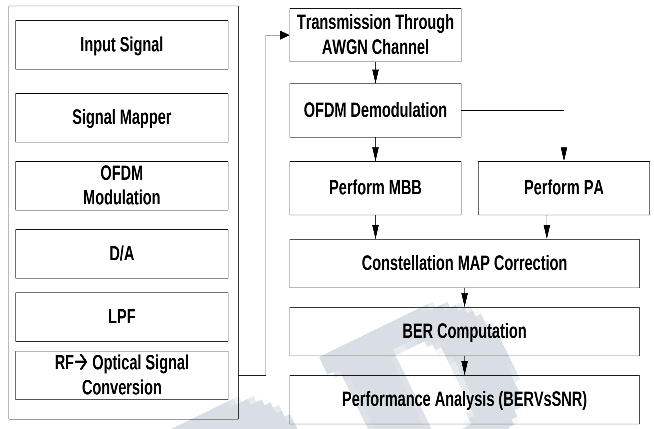

Figure 4 block diagram of the proposed framework

The framework introduced estimates the CPE using both MBB and PA method. The framework evaluates the performance by comparison in terms of BER of the two methods. A synthetic signal is first developed as a starting step in the framework. A QAM block maps the input signal into QAM symbols. The frequency domain form data is converted into time domain using an IFFT block. DAC converts the digital signal to analog signal and Low pass filters used to remove the alias sub bands. The RF to Optical conversion and the channel transmission models are used to represent the transmitted Optical OFDM signal. The demodulation of the OFDM signals and CPE estimation and correction using both PA and MBB methods are performed. A comparison is done with the BER computed from the two methods.

VI. ALGORITHM IMPLEMENTATION

A discussion about the algorithmic implementation of the proposed framework is described in this section.

The algorithm below shows the steps in generating a synthetic signal.

Algorithm: Synthetic signal generation

INPUT: Signal Frequency (S_f)

OUTPUT: Synthetic Signal Generation (S)

START

1. Initialize $S_{f,}$ M , t , S
2. Define a time interval row vector
   t = [0, 0.001, 0.002…1]
3. IF (M_Array ~= 2)
4. COMPUTE Eq.1
5. ELSE_IF (M_Array = 2)
6. COMPUTE Eq. 2
7. END

8. Display S

END

$$S = \left\{ \left[\left(\frac{M}{2} - 2 \right) * Sin(2\Pi f t) \right] + \frac{0.5M}{2} \right\} \quad \ldots\ldots\ldots\ldots 1$$

$$S = \left\{ \left[0.5\, Sin(2\Pi f t) \right] + 0.5 \right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots 2$$

The algorithm takes in the signal frequency as an input parameter and generates an Output signal. The Signal frequency (S_f), Micro-Array data length (M), time interval (t) are initialised and based on the value of M, a synthetic signal S is generated using suitable functions.

Algorithm: Minimum Bounding Box

INPUT: $Demod_{OFDM}$, M

OUTPUT: Constellation MAP correction using MBB, BER

START

1. Initialize $Demod_{OFDM}$, M ,
2. *Define* M = 16;
3. Initialize Data ← [0:M-1]
4. Perform QAM Modulation
5. Compute R_{Data}, , i_{Data}
6. Evaluate length (i_{Data})
7. FOR(k_1← 1:4:length(R_{Data})
8.   FOR (k_2 ← 1:4)
9.   Compute R_{Data} , i_{Data}
10.   END
11. END
12. FOR(k_1← 1:4:length(R_{Data})
13.   FOR (k_2 ← 1:4)
14. $R_{Data\,(MOD)}$ ← R_{Data} (k1) – dist (k2)
15. $i_{Data\,(MOD)}$ ← i_{Data} (k2) – dist (k1)
16.   END
17. END
18. Constellation MAP correction
19. Computation of (BER)

END

The above algorithm takes in the demodulated OFDM signal and corrects the constellation MAP using the MBB method and also finds out the BER. The size of the Microarray data (M) is initialized and QAM signals are obtained. The absolute value of demodulated signals $R_{Data\,(MOD)}$ & $i_{Data\,(MOD)}$ are calculated. Using this demodulated signal a constellation map is obtained and the phase is estimated and corrected using MBB. The BER of the resultant signal is also evaluated.

The algorithm described below shows the steps involved in CPE estimation using PA methods.

Algorithm for PA Method

INPUT: SNR_{Rec}, M

OUTPUT: Constellation MAP correction using PA, BER

1. Initialize SNR_{Rec} , M, N , Pi , Sub
2. Initialize G_i, Pi_{length}, , C_L , N_{iter} , BER
3. Activate location of pilots and data
4. Compare energy in pilot symbols with energy in data symbol
5. Compute FFT matrix
6. FOR (i ← 1:length (SNR))
7. SNR ← SNR_V_i
8. FOR (k ← 1: N_{iter})
9. Generate random channel coefficients
10. Normalization
11. Transmission of DATA
12. Induce Channel Effect
13. Normalization to Signal Power
14. Channel estimation with *TPi and RPi*
15. Estimation of channel coefficients in time domain
16. BER computation
17. END
18. END

END

The above algorithm illustrates the procedure for phase correction using PA based method and BER computation. The number of sub channel, data sub channels, number of pilots, guard interval, Microarray data (N, Sub, Pi, Gi, M) are initialized. The OFDM signal including the pilots and the channel estimated signal are generated respectively. Considering Transmitted pilot and the received pilot (TPi, RPi), the phase change in the received pilot is estimated. The Bit error rate of the phase corrected signal is computed.

VII. EXPERIMENTAL OUTCOMES

A comparison of the CPE estimation and correction using MBB and PA based methods with the help of BER is implemented as a framework. The possible outcomes of the different steps in the framework are as shown.

A.Constellation Map Correction

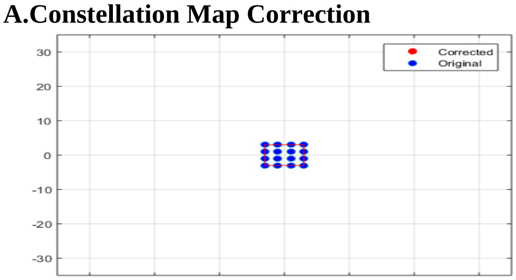

Figure 5 Constellation MAP correction using MBB method

B. Constellation map correction for mzm demodulated signal

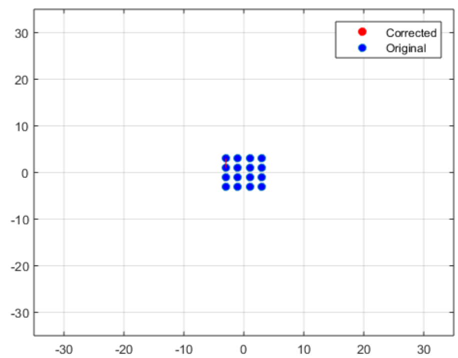

Figure 6 Constellation MAP corrections (MZM Demod)

C. Noisy signal for snr = -30, 30 (mbb)

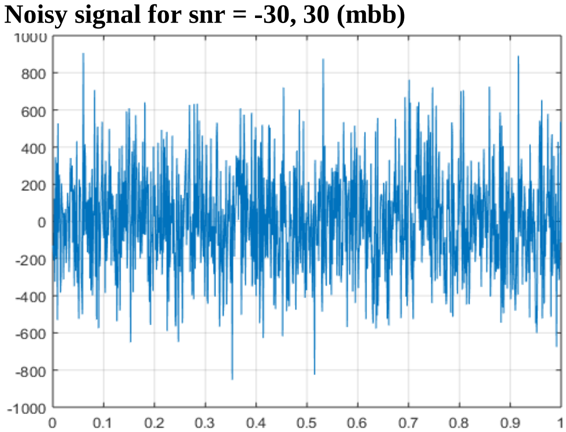

Figure 7 Noisy signal for SNR = -30 (MBB Method)

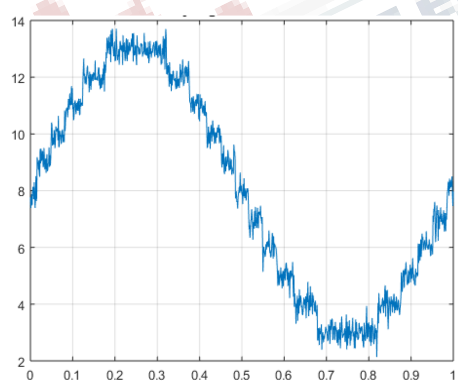

Figure 8 Noisy signal for SNR = 30 (MBB Method)

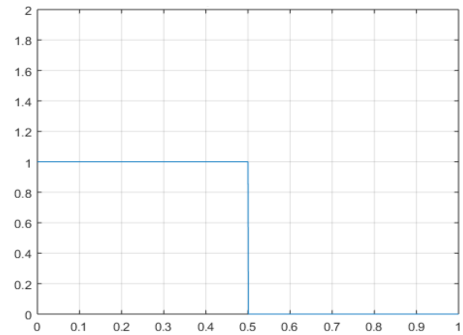

Figure 9 Rx Signal with BER =1

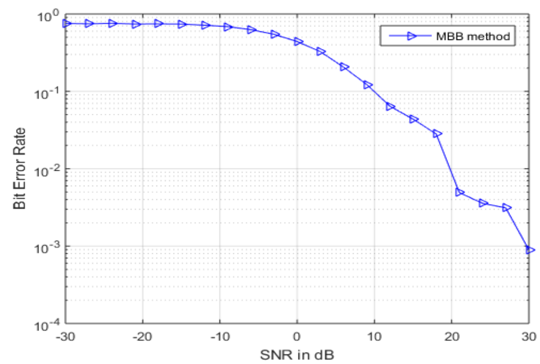

Figure 10 BER Vs SNR (PA Method)

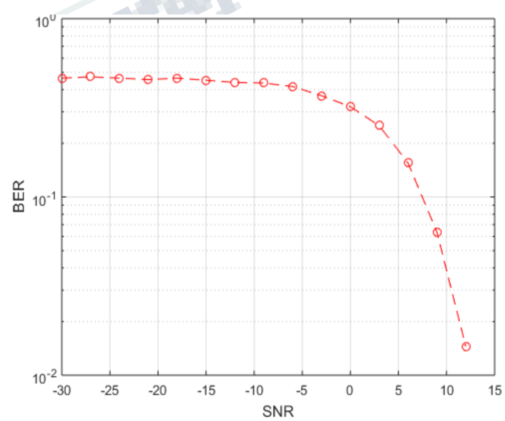

Figure 11 BER Vs SNR (MBB Method)

D. Comparative analysis

A comparison of BER computed from MBB method and PA method is performed. As can be seen MBB method has lesser BER compared to PA.

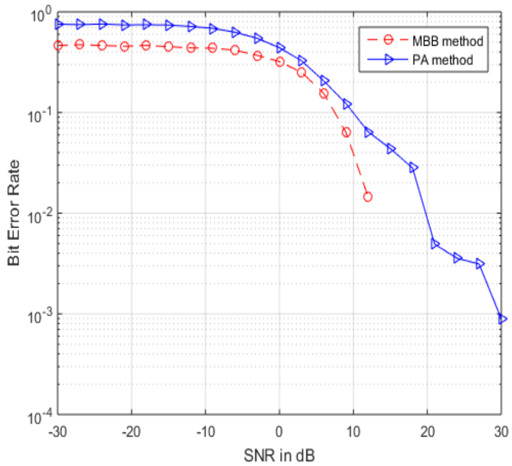

Figure 12 Comparative analysis

VIII. CONCLUSION

A framework for comparing the performance of MBB method and PA method was designed and implemented. From the outcomes of the study, it was found that the performance of MBB was better compared to PA in terms of BER.

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