Channel Equalization of a Signal with Tilted Phase

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Abstract: *Orthogonal Frequency Division Multiplexing (OFDM) is closely related to frequency division multiplexing technique but it is a multicarrier modulation technique. In this scheme, there are orthogonal subcarriers that will be closely spaced. These subcarriers are used for carrying data as parallel streams. Hence its said to be a parallel transmission scheme as well. A channel is affected by several factors that can degrade the overall performance of the system. There are certain impairments like Clock Frequency Offset (CFO), Chromatic Dispersion(CD), and polarization Mode Dispersion(PMD). This can cause Common Phase Error (CPE) on the OFDM symbol. This CPE can be compared with the skewed image in image processing domain and algorithm like Minimum Bounding Box (MBB) can be used for its correction. Traditional methods for CPE correction is also simulated and algorithms implemented are Least Mean Square (LMS) and Constant Modulus Algorithm (CMA).*

Keywords: Skewed image, CPE, Image processing, MBB, LMS, CMA.

1. Introduction

In modern communication, data rate is one of the most important factor that's being considered by service providers in order to meet the requirements of their customers. Its essential for the service providers to incorporate large number of users in a limited bandwidth. OFDM is a multicarrier modulation technique that has the potential to accommodate much number of users. Fiber OFDM systems can be categorized into Direct Detection Optical (DDO) and Coherent Detection Optical (CO) systems. A single photodiode is only required in DDO systems whereas coherent detection systems optical mixing is used. CO-OFDM has greater tolerance to dispersion and OSNR requirements make it preferable for long distance communication.

OFDM is a reliable and efficient scheme that can be utilized to transmit data even in multipath environments. Orthogonality helps us to reduce interference and hence it allows multipath data to be sent across in a common channel. Guard period can also be used to reduce the effect of Inter Symbol Interference (ISI) on an OFDM signal. Guard period or Cyclic Prefix (CP) is prefixing of a symbol with a repetition of the end. CP as two important functions eliminates ISI and allows frequency domain processing such as channel estimation and equalization. The major drawback of OFDM systems is that it is greatly prone to phase noise which is created by oscillators.

CPE and Inter Carrier Interference (ICI) that arise due to phase noise. CPE is common rotation of all constellation points in a complex plane and ICI is more like Gaussian noise. OFDM receivers are very sensitive to phase noise. Traditional methods are Pilot Aided (PA) and blind channel estimation methods. In PA method, channel estimation is done by using pilot sequence and symbol which are inserted into some fixed positions of signals sent by transmitter. Hence it lowers the spectral efficiency and power utilization. Blind channel estimation is focused at the finding the similarity between the data sent and received without any knowledge about transmitted data. In contrast to the PA scheme, it gives higher spectral efficiency and power utilization but it needs more data for analysis. In this paper, a method to compensate CPE using image processing technique for OFDM system is implemented and simulated using MATLAB R2015b software. MBB algorithm is used for skewness correction in image processing. Considering an OFDM symbol with CPE, it has greater similarity to a skewed image. LMS algorithm and CMA algorithms are also implemented in the same with which channel estimation and equalization is also done.

In section 2, system overview is discussed. The OFDM system is explained in section 3. In section 4 and 5, MBB, LMS and CMA algorithms are briefed. Simulation results are explained in section 6. Finally, the work is concluded and future scope is discussed in section 7.
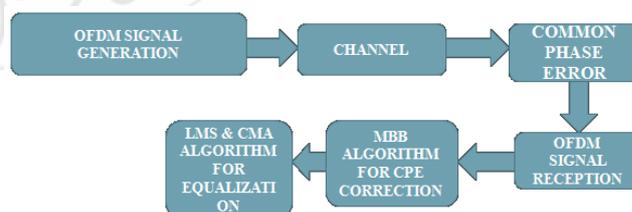
2. System Overview

Figure 1: System Overview

The channel state information is used to obtain the channel properties which can be achieved using blind channel estimation and pilot based channel estimation. This information describes how a signal gets propagated from transmitter to receiver and represents the combined effect of power decay, fading, scattering, etc with distance [9].

The system overview is shown in figure 1. First of all an OFDM signal is generated. Its transmitted through a channel which is Additive White Gaussian in nature and in this

channel the CPE is induced. At the receiver, an OFDM signal is received with CPE is obtained. Then MBB algorithm is implemented to correct the CPE. Then LMS and CMA algorithm is also implemented to the signal and channel equalization is done.

3. OFDM signal generation and reception

OFDM signal is generated by modulating the input data using Quadrature Amplitude Modulation (QAM). QAM has efficient conservation of data rate. Then the serial data is converted to parallel data streams and each of them are modulated by orthogonal subcarriers using Inverse Fast Fourier Transform(IFFT). Pilot symbols and CP are added. The data is again converted back to serial format and is transmitted. Its transmitted through an AWGN channel. The channel impairments causes phase shift on individual subcarriers, i.e, CPE is induced.

At the receiver, data is converted to parallel bit streams and then CP and pilot symbols are removed. After FFT operation, Demodulation and demapping is done and data is converted back to serial data and is received as explained in the below figure.
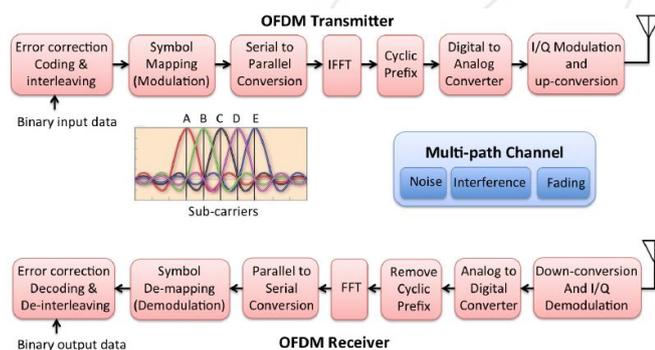

Figure 2: OFDM transmitter and receiver

4. Minimum Bounding Box(MBB)

The phase noise induces common rotation to all subcarriers in one OFDM symbol even after coherent detection and traditional demodulation procedures. The following figure shows a skewed image and it can be compared with the constellation diagram of a 16-QAM mapping. This can be considered as a square with skewness of angle θ. The bounding box is the minimum out rectangle in horizontal direction that can cover all the constellation points [1]. The area of the bounding box is a function of the tilt angle and reaches minimum when the constellation is squared [1].

Figure 3: Skewed image

The above show is an example of skewed image. Considering the constellation diagram of CPE affected signal as shown below.
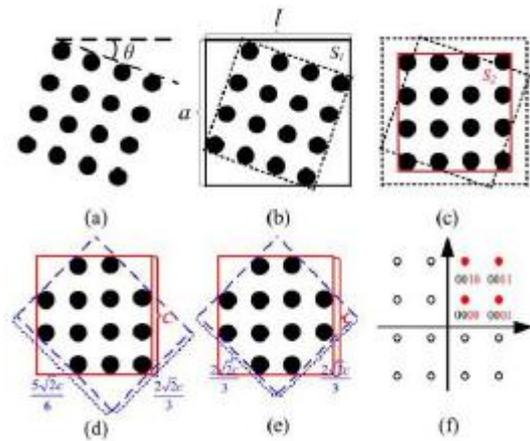

Figure 4: Principle of MBB

The reduction in area of the bounding box makes the recovery of the phase shift possible. The area can be measured using the following equation:

$$A(\psi_k) = l.a \qquad (1)$$

Where l and a are the lengths of 2 sides of the bounding box. The suitable estimated phase can be determined at the test phase that minimizes the area A

$$\theta^{'} = \arg\min(A(\psi)) \qquad (2)$$

The major computation needed is the measurement of the area A and hence the computational load is minimized. The ambiguity can be discarded by using one TS and the rest can be used for transfer of data. This technique can be applied to 32-QAM and 128-QAM as well with different constellations. The bounding box is determined using the outer part of the constellation and thus the inner part can be discarded. The phase shift can be recovered even if some of the outer points are not present.

5. LMS and CMA

Adaptive equalization is technique that automatically adapts to time varying properties of the communication channel [7]. Conventional methods for channel equalization in an OFDM system are pilot aided and non pilot aided or blind equalization method. There are different techniques in pilot aided method such as LMS, LMSE, MMSE, etc. Phase shift compensation using LMS equalizer is obtained.It is one of the popular method used for adaptive channel equalization. The criterion used in this is to minimize the Mean Square Error (MSE) between the desired equalizer output and actual equalizer output [7].

$$Error = desired output - actual output \qquad (3)$$

The basic relation used in LMS algorithm is

$$w(n+1) = w(n) - \alpha e^*(n)u(n) \qquad (4)$$

From equation (4), $u(n)$ is the input signal, $w(n)$ is the equalizer filter taps and α denotes the step size and it controls the rate of convergence [7].

CMA equalizer that belongs to blind equalization method can also be used for phase shift compensation. It correlates the data sent and received and estimates the signal received. It needs more data for analysis but no pilot or training symbols are required. Let $s(n)$ be the input to the channel and $x(n)$ be its output, which is the noisy and distorted version of $s(n)$. Let an equalizer be used to remove the channel distortion from the received signal. If f is the tap-weight vector of the equalizer of length L, the output of the equalizer $y(n)$ and $x(n)$ be the input vector can be represented [8] by:

$$Y(n) = f^H X(n) \qquad (5)$$

6. Simulation Results

The implementation tool used is MATLAB R2015b. The OFDM signal is given as the input. MBB, LMS and CMA algorithms are implemented at the receiver section. MBB algorithm is based on the area calculation of the bounding box and estimating the phase shift. LMS algorithm needs training symbols to obtain an estimate of the channel and its an iterative method that requires the equalizer weights to be adjusted. For CMA, no training symbols are required. The transmitted signals statistics and properties is only needed to equalize the phase shift.
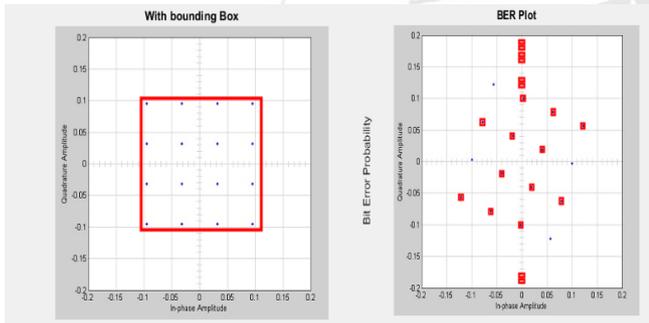

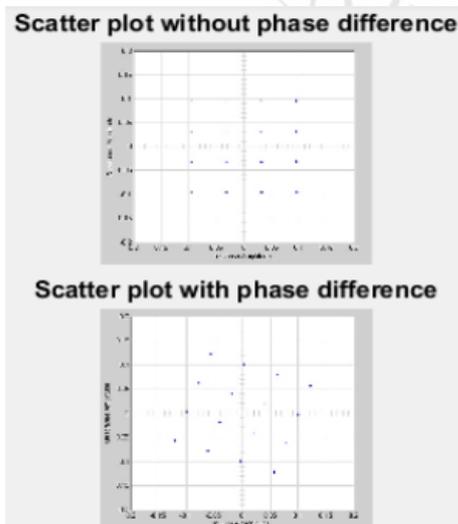**Figure 5:** Signal constellation with bounding box

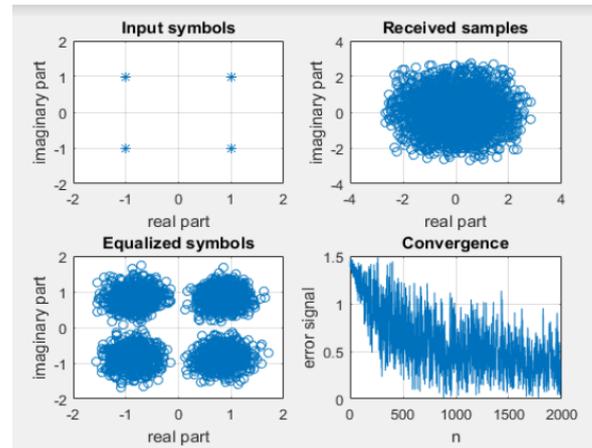**Figure 6:** scatter plot with and without phase difference

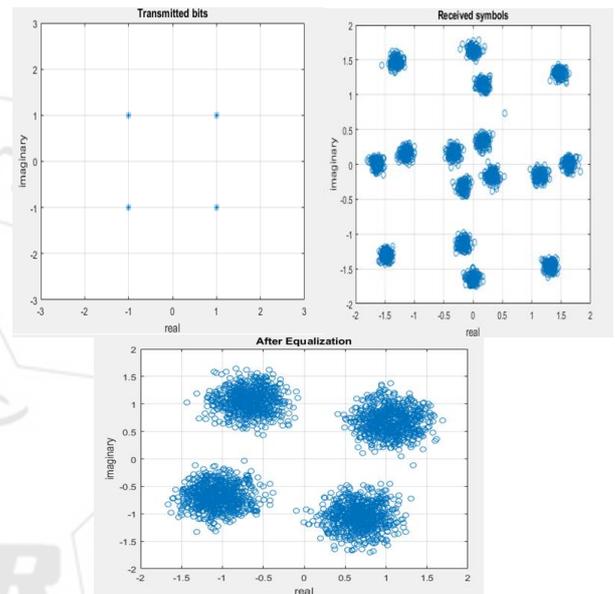**Figure 7:** Equalization using LMS algorithm

Figure 8: Equalization using CMA algorithm

7. Conclusion

A CPE estimation method based on MBB, which is a common image processing technique is implemented. LMS and CMA algorithms are used for channel equalization are the conventional techniques. CMA is simpler, good performance and robustness. The LMS algorithm has fast convergence than CMA but needs extra computations. But MBB algorithm has less computational complexity than the traditional techniques like LMS and CMA. MBB algorithm is less complexity and hardware requirements are fewer as well.

8. Acknowledgment

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