

# Analysis of Root Mean Square Error by varying Cyclic Prefix in MIMO-OFDM system using Polyphase Filter Bank

Mandeep Mehra

Department of Electronics and Communication, Punjab Technical University, India.

Gagandeep Kaur Cheema

Department of Electronics and Communication, Punjab Technical University, India.

**Abstract** -Orthogonal Frequency Division Multiplexing (OFDM) is a popular scheme designed for high data rate wireless communication. OFDM can be combined with antenna arrays at the transmitter and receiver to increase the diversity gain and to enhance the system capacity resulting in a multiple input multiple output (MIMO) configuration. MIMO wireless technology in amalgamation with OFDM is an attractive air interface for next generation wireless applications such as wireless metropolitan area networks (WMANs), wireless local area networks (WLANs) and 4G mobile cellular wireless systems. In the proposed technique, the Polyphase filter bank structure with bandpass filter is used for filtering the OFDM signal, at receiver side. The bandpass filter is used here for spectrum efficiency. The root mean square error (RMSE) has been used as a standard statistical metric to measure system performance. So, in this paper Performance evaluation is done using the parameter RMSE with respect to Signal to noise ratio (SNR). The simulation result demonstrated that the value of RMSE is lowest when the value of cyclic prefix (CP) is sufficiently large (at CP = 256).

**Index Terms** – Orthogonal Frequency Division Multiplexing (OFDM), Multiple Input Multiple Output (MIMO), Cyclic Prefix, Frequency offset, Delay spread, Polyphase Filter Bank (PFB), Root Mean Square Error (RMSE), Signal to Noise Ratio (SNR), Cyclic Prefix (CP).

## 1. INTRODUCTION

Communication is one of the important aspects of life. With the advancement in age and its growing demands, there has been rapid growth in the field of communications. Signals, which were initially sent in the analog domain, are being sent more and more in the digital domain these days. In a basic communication system, the data are modulated onto a single carrier (SC) frequency in which the available bandwidth is totally occupied by each symbol. This kind of SC system leads to inter-symbol-interference (ISI) in case of frequency selective channel. Consequently, for better transmission, these single-carrier waves are being replaced by multi-carriers. The concept of using parallel data transmission and frequency division multiplexing (FDM) was developed in the mid-1960s

[1, 2]. The total signal bandwidth, in a classical parallel data system, can be divided into N non-overlapping frequency sub channels. Each sub-channel is modulated with a separate symbol and then the N sub channels are frequency multiplexed. The general practice of avoiding spectral overlap of sub channels was applied to eliminate inter-carrier interference (ICI). However, this leads to inefficient use of the available spectrum. To cope with the inefficiency, the ideas proposed in the mid-1960s were to use parallel data and FDM with overlapping sub-channels. A U.S. patent was filed and issued in January 1970 [3]. In an OFDM scheme, a large number of orthogonal, overlapping, narrow band sub-carriers are transmitted in parallel. These carriers divide the available transmission bandwidth.

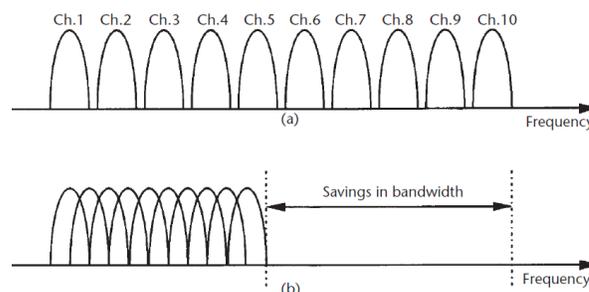


Fig. 1 a) Conventional multicarrier technique, and b) orthogonal multicarrier modulation technique. [4]

The difference between the conventional non-overlapping multicarrier technique and the overlapping multicarrier modulation technique is demonstrated in Fig.1. By using the overlapping multicarrier modulation technique almost 50% of available bandwidth can be saved. The OFDM scheme has been adopted for digital audio broadcasting (DAB), digital video broadcasting [5, 6] and wireless LAN [7].

In this paper, Section 1 illustrates the introduction to OFDM system, Section 2 gives the introduction to MIMO-OFDM

system, Section 3 illustrates the MIMO-OFDM system model, Section 4 describes the proposed technique, Section 5 illustrates the result of proposed technique and the future work and conclusion is discussed in Section 6.

## 2. MIMO-OFDM

The use of multiple antennas at both ends of a wireless link (MIMO technology) grasps the potential to significantly improve the spectral efficiency and link reliability in wireless communications systems. Multiple-Input-Multiple-Output (MIMO) antennas with Orthogonal Frequency Division Multiplexing (OFDM) provide high data rates and are robust to multipath delay in wireless communications. In 1996, Greg Raleigh invented MIMO, when he demonstrated that different data streams could be transmitted at the same time on the same frequency by taking benefit of the fact that signals transmitted through space bounce off objects (such as the ground) and take multiple paths to the receiver [8]. That is, by employing multiple antennas and pre-coding the data, different data streams could be sent over different paths. Later, Raleigh proved that the processing requisite by MIMO at higher speeds would be most manageable using OFDM modulation, because OFDM converts a high-speed data channel into a number of parallel, lower-speed channels.

MIMO multiplies the capacity of a wireless link by transmitting different signals over multiple antennas, and OFDM, divides a radio channel into a large number of closely spaced sub channels to provide more reliable communications at high speeds. This is accomplished without the need for additional power or bandwidth. MIMO can be used with other popular air interfaces such as time division multiple access (TDMA) and code division multiple access (CDMA), but the research conducted during the mid-1990s showed that the conjunction of MIMO and OFDM is most practical at higher data rates. Fig.2 shows the basic diagram of MIMO-OFDM system.

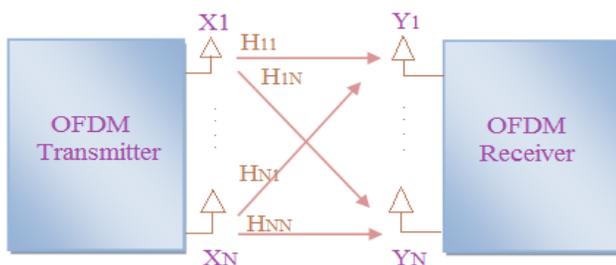


Fig.2 MIMO-OFDM System.

### 2.1 Advantages

- High spectral efficiency.

- Provides more capacity.
- Reliable transmission in highly obstructive environment.
- Slight degradation in PAPR compared to SLM approach.

### 2.2 Disadvantages

- System complexity.
- Cost for added antennas.

## 3. MIMO-OFDM SYSTEM MODEL

For a MIMO channel,

$$y = Hx(n) + g(n) \quad (1)$$

Where,  $g(n)$  is additive white Gaussian noise (AWGN) and  $H$  is MIMO channel matrix and can be expressed as,

$$H = \begin{bmatrix} h_{11} & h_{12} & \dots & h_{1J} \\ h_{21} & h_{22} & \dots & h_{2J} \\ \vdots & \vdots & \dots & \vdots \\ h_{I1} & h_{I2} & \dots & h_{IJ} \end{bmatrix} \quad (2)$$

and  $x(n)$  is the OFDM symbol at receiver and is given by,

$$x(n) = [\sum_{l=0}^L a_l r(n - \tau_l)] \exp\left(\frac{j2\pi n \epsilon}{N}\right) + g(n) \quad (3)$$

Where  $\epsilon$  is the frequency offset,  $a_l$  and  $\tau_l$  are the amplitude and time delay of the  $l$ th path respectively.

The multipath signal in (2) is given by,

$$m(n) = \sum_{l=0}^L a_l r(n - \tau_l) \quad (4)$$

Now, the received OFDM signal with MIMO channel is,

$$\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_I \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & \dots & h_{1J} \\ h_{21} & h_{22} & \dots & h_{2J} \\ \vdots & \vdots & \dots & \vdots \\ h_{I1} & h_{I2} & \dots & h_{IJ} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_J \end{bmatrix} + \begin{bmatrix} g_1 \\ g_2 \\ \vdots \\ g_I \end{bmatrix} \quad (5)$$

## 4. PROPOSED TECHNIQUE

In the proposed technique, polyphase filter bank (PFB) is used at the receiver end. Here, the bandpass filter is used in the polyphase form which saves the maximum possible available spectrum. To reduce the bandwidth to the channel bandwidth complex heterodyne low-pass filter is used in the basic polyphase structure for the process of down conversion of the selected channel [9]. According to the equivalency theorem [10], same process is completely equivalent to the process of a bandpass filter followed by a down conversion, which also increases the spectrum efficiency. Thus, this is the reason of using Bandpass FIR filter in the proposed approach. Polyphase filters were invented by Gingell Michael John in 1971, to generate quadrature signals in audio applications and were implemented first using discrete components [11].

To understand the mathematical concept of polyphase filters, consider a filter with impulse response  $h(n)$ . The transfer function of  $h(n)$  is given by,

$$H(z) = \sum_{n=-\infty}^{\infty} h(n)z^{-n} \quad (6)$$

The polyphase structure is used here at the receiver which is known as polyphase decomposition and this M-fold decomposition of  $H(z)$  is given by,

$$H(z) \sum_{m=0}^{M-1} z^{-m} H_m(z^M) \quad (7)$$

Where the polyphase components are given by,

$$H_m(z) = \sum_{n=-\infty}^{\infty} h(nM + m)z^{-n} \quad (8)$$

The polyphase signal is a set of two or more data vectors having same frequency and different phase. The block diagram of proposed scheme is shown in Fig.3. In the proposed approach OFDM signal having, multipath delay and frequency offset is sent as an input to PFB for the analysis purpose. The RMSE is then calculated.

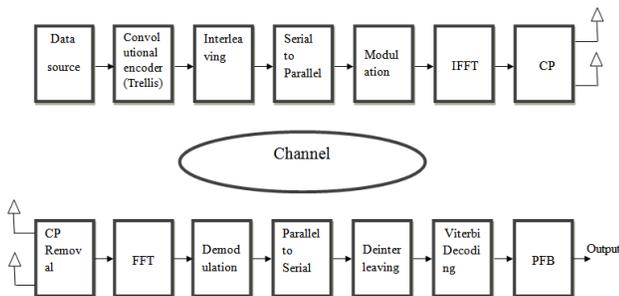


Fig. 3 OFDM-MIMO system with polyphase filter bank (PFB)

Steps of the proposed technique are given below,

- Step 1: Generation of random bits and framing of that bits.
- Step 2: Encoding (trellis) and Interleaving of data frames.
- Step 3: Modulation.
- Step 4: Insertion of pilot signals to the modulated symbols then IFFT of that symbols for subcarriers.
- Step 5: Addition of Cyclic prefix to the IFFT signal.
- Step 6: Addition of frequency offset, delays and awgn to the OFDM signal at the channel.
- Step 7: Removal of CP then perform FFT.
- Step 8: Pilot synchronization and demodulation of the synchronized signal.
- Step 9: Deinterleaving and decoding (Viterbi) of demodulated data.

Step 10: Decoded signal of particular band is passed from Band Pass Filter.

Step 11: Selection of polyphase signal and polyphase filter from decoded signal and BPF respectively.

Step 12: Filter each polyphase component and addition of each component.

Step 13: Calculate RMSE of the filtered signal at different values of CP i.e., at 64, 128 and 256.

The simulation parameters used in this approach for the analysis of system performance in terms of RMSE are given in Table 1.

Sr. No.	Parameters	Value
1.	OFDM subcarriers, N	512
2.	CP length (K)	64, 128, 256
3.	Modulation	16 QAM
4.	Path delays	0, 16, 32
5.	Frequency offset	0.3
6.	Noise	AWGN
7.	SNR	0 to 25 dB
8.	Channel	Rayleigh Fading
9.	Bandwidth	200 MHz
10.	No. of transmit and receive antennas	2

Table 1 Simulation Parameters

### 5. RESULT AND DISCUSSION

Simulation process is carried out to illustrate the performance of proposed approach.

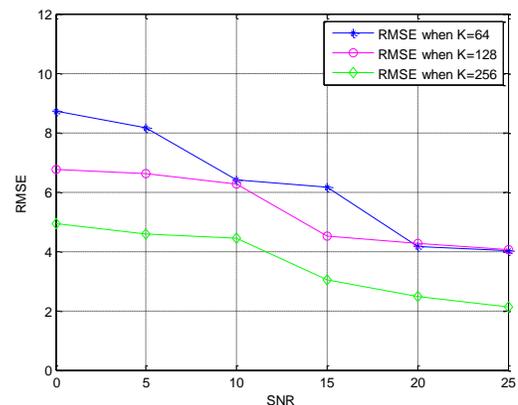


Fig.4 RMSE of OFDM signal after implementing PFB.

In this paper, performance evolution is done using RMSE parameter with respect to SNR for 16-QAM modulation under Rayleigh channel. The main motive of this technique is to

reduce the RMSE in the system and it is very much clear from the graph that RMSE is lowest when the value of CP is large i.e. 256.

## 6. FUTURE WORK

In future, infinite impulse response (IIR) filters [12] and square root raised cosine pulse shaping filters can be used in polyphase structure to enhance the system performance without any major degradation in signal quality. Different channel coding can also be used in future. The concept of polyphase transmission and reception can also be used for software defined radio.

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Authors

**Mandeep Mehra** received the B.Tech degree in Electronics and Communication, from College of Engineering and Management, Kapurthala, India and, pursuing the M.Tech in Wireless Communication from Punjab Technical University (Main Campus), India.

**Gagandeep Kaur Cheema** Assistant Professor in Punjab Technical University (Main Campus), India. She received the B.tech degree and M.tsch degree from HP University and PTU, India respectively.