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An Experimental Study on Channel Estimation and Synchronization to Reduce Error Rate in OFDM Using GNU Radio

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Abstract

Orthogonal Frequency Division Multiplexing (OFDM) is a particular case of multicarrier transmission in which, higher data rates are achieved using carriers that are densely packed. In this paper, implementation of OFDM communication system with channel estimation and synchronization is carried out and the bit error rate (BER) of OFDM system with and without channel estimation is observed and correspondingly a plot is traced. The choice has been made because of the advantages that OFDM and SDR has shown in terms of channel capacity and cost. Implementation of the prototype has been in GNU Radio; an open source software.

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Keywords: OFDM ;GNU Radio; BPSK; Channel Estimation; Synchronization; FFT; IFFT; Bit Error Rate(BER).

1. Introduction

Nowadays the scope of wireless communication has increased to a great extent because of the use of multicarrier modulation techniques, among which OFDM (Orthogonal Frequency Division Multiplexing) is one of the most popular technique. OFDM technique divides a high rate encoded data into sub streams which are parallel to each other. Orthogonal carriers are used to modulate these parallel sub streams, which transmits at different frequencies simultaneously in parallel. Modulation schemes used can be PSK, BPSK, QAM, 16QAM, QPSK. Pilot subcarriers

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are used to prevent frequency and phase shift errors. Since the subcarriers in OFDM systems are precisely orthogonal to one another, they overlap without interfering and also maximum spectral efficiency is attained without causing adjacent channel interference[1]. OFDM is a part of WLAN, DVB and BWA standards and is a strong candidate for some of the 4G wireless technologies. The popularity of OFDM is due to the use of IFFT/FFT which has efficient implementations[2]. Multipath channels results in loss of orthogonality in carriers. Cyclic prefix can be used to restore the orthogonality back by converting a linear convolution channel into a circular convolution channel and also allow the signal to be decoded even if the packet is detected after some delay.

OFDM efficiently deals with multipath fading, channel delay spread, enhancement of channel capacity, modification of modulation density and robustness of narrowband interference[3]. It is sensitive to small carrier frequency offsets, high frequency phase noise and sampling clock offsets. OFDM carrier is generated with all the modulated subcarriers by Inverse Fast Fourier Transform (IFFT) at the transmitter end and the same carrier is demodulated by Fast Fourier Transform (FFT) at the receiver end[4].

2. Channel Estimation

OFDM communication system consists of channel model through which data symbols are transmitted to the receiver. This channel model produces line of sight communication and also various reflections due to which multipath effect come to picture. To minimize the multipath effect and noise introduced by the channel, we go for channel estimation. Generally, the received signal obtained through a frequency selective multipath fading channel contains the channel impulse response and additive white Gaussian noise which is given by, $y_g(\mathrm{n}) = \mathrm{x}_g(n) \otimes h(n) + w(n)$, where $\mathrm{x}_g(n)$ is the resultant samples obtained after inserting the guard interval. The channel impulse response $h(n)$ can be represented as,

$$\mathrm{h(n)} = \sum_{i=0}^{r-1} h_i e^{j2\pi f_{Di} T \frac{n}{N} \delta(\lambda - \tau_i)} \tag{1}$$

In equation (1), λ is the delay spread index, h_i is the complex impulse response of the i^{th} path, f_{Di} is the i^{th} path's Doppler frequency shift, τ_i is the i^{th} path delay time normalized by the sampling time, and r is the total number of the propagation path. After removing the guard interval from $y_g(\mathrm{n})$, the received samples are obtained and which is then demuxed to obtain $Y(k)$. After that the received pilot signals are extracted from it. The transmitted data samples $X(k)$ can be recovered by simply dividing the received signal by the channel response,

$$X(k) = \frac{Y(k)}{\hat{H}(k)} \tag{2}$$

In equation (2), $\hat{H}(k)$ is an estimate of $H(k)$ [5,6].

Pilots can be made use at both time domain and frequency domain in OFDM systems. Pilots can be arranged in couple of ways namely, block type and comb type. In block type arrangement, pilots are sent periodically in time domain which suits more for slow-fading radio channels. Since, all the pilots are in training block, channel interpolation in frequency domain is not required and is insensitive to frequency selectivity. In comb type pilot arrangement, the pilot signals are distributed uniformly with in each OFDM block and retransmission rate is higher. Comb type arrangement is utilised for fast-fading channels and sensitive to frequency selectivity. In case of subcarriers without pilots, channel response is estimated by interpolating adjacent pilot subcarriers. Channel estimation techniques can be classified into two types such as blind channel estimation techniques and data-aided channel estimation techniques. The first technique is to estimate the channel information state without the knowledge of the transmitted signal and the later estimation technique is to estimate the channel response by the known information added to the transmitted signals[6].

3. Synchronization and Channel Equalization

In OFDM communication systems, at the transmitter digital to analog conversion and at the receiver, analog to digital conversion is carried out. DAC and ADC never have exactly the same sampling period. Due to this, intercarrier interference and the slow shift of the symbol timing point occurs and so orthogonality is lost. This results in need of Synchronization and Channel Equalization. Using suitable cyclic prefix and considering the guard time of each symbol is identical, both time and frequency synchronisation is exploited. Correlation between guard time and delay time is made and several peaks are produced due to different symbols and peak amplitudes. Due to the above correlation, many side lobes are introduced. When correlation is performed over a very large number of samples, the ratio of side lobes to peak amplitude will go to zero. This is due to independent samples proportional to subcarriers. Since the receiver needs to consider the source of each symbol correctly, synchronization plays a very important function on the receiver side. With the help of the incoming signals calculations are made to find the parameters. In order to set all these parameters, redundancy often brought up to as pilots or preamble depending on its place in the whole transmitted signal[7].

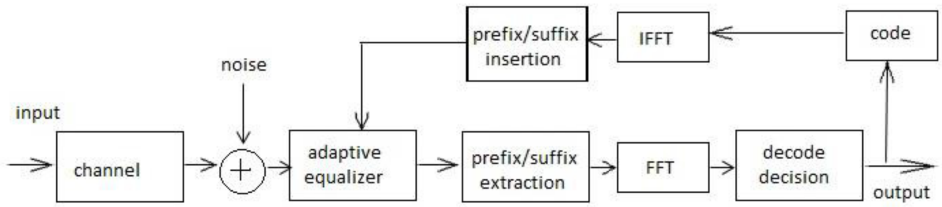


Fig. 1. Channel Equalization

Reliable estimation of the channel in time and frequency can be ensured using a cyclic pilot pattern. For initial training, preambles of symbol are used and then the inserted pilots with in the data symbol can be made used for tracking the remaining offsets. Fig. 1. shows the channel equalization model in which equalization is done as an adaptive system with relatively simple structure. Comparing with the features of frequently used algorithms like Minimum Mean-Square Error (MMSE) and Least Mean Squares (LMS), adaptive algorithm has three unique features: robustness in fixed point implementation, high adaptation rate and low computational complexity. The adaptive equalizer works in two modes namely, training mode and decision direction fashion. The difference between the original signal and the estimate available through the pilot signal is the estimation error. The difference between the estimate and the detected symbols are determined in decision direction fashion[8,9].

4. GNU Radio Implementation

GNU Radio includes some software modules dedicated to the OFDM modulation. In order to show their basic use and as a kind of documentation for customized OFDM implementations and variations, an example application is available in the GNU radio's examples directory which is a basic OFDM system with transmitter and receiver. It moves completely in a software environment and simulates the whole transmission, which also includes the channel model. For the implemented OFDM system, this model works as the infrastructure source code[10,11].

The OFDM modulator is turned up in the python file *ofdm.py* together with the OFDM demodulator. The demodulator is made up of many C++ and Python files. Fig. 2. shows the GNU Radio blocks of Modulation and Demodulation in OFDM with channel model. At the modulation side, the input signal or data is first changed to parallel streams and IFFT is performed to make orthogonal subcarriers. These subcarriers are then modulated using a modulation scheme like BPSK, QAM, etc. Cyclic prefix is added to avoid ISI and other delays. After modulating the subcarrier, the parallel flows are again converted to serial and transmitted through the duct. In real case, channel is free space and for simulation purpose, we use channel model through which multipath and noise can be appended.

On the receiver side, using demodulation block of OFDM, the signal is demodulated using the same system used for modulation and FFT is performed to make orthogonal subcarriers to single signal. Occupied tones are employed to transfer and receive pilot signals for estimation of the channel. Noise is added using channel model and SNR is controlled at demodulation block. Due to channel model, there will be noise and multipath distortions added to signal and at receiver many errors occurs. To minimize it, channel estimation and synchronization with equalization is performed. Fig. 3. shows the implementation of OFDM with channel estimation and synchronization techniques using GNU Radio.

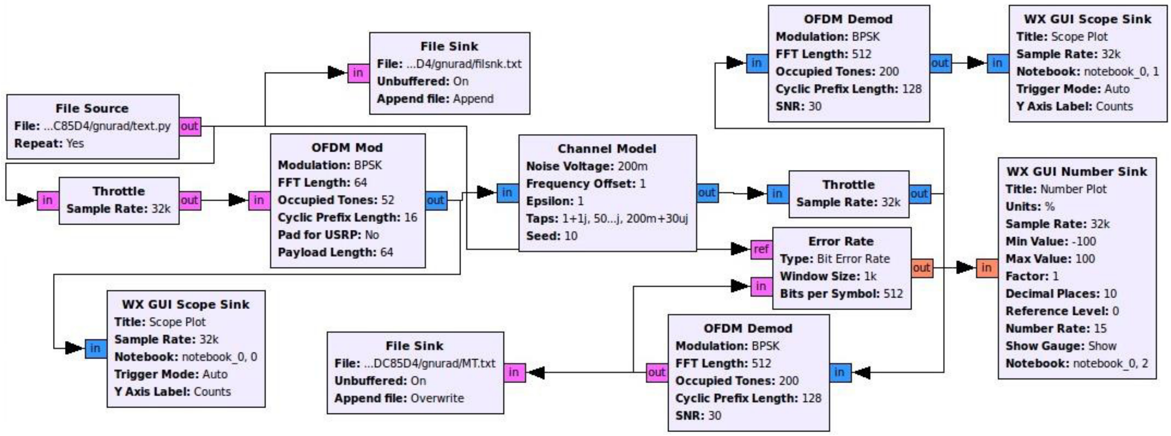


Fig. 2. Implementation of OFDM modulation and demodulation with Channel model

In Physical layer, packets are used to break down the transmission in digital transceiver. Getting into the bundle structure, it primarily consists of four elements such as *Preamble, Header, The payload and Checksum*. *The payload* does detection, synchronization and initial channel state estimation. The *Header* being of fixed length stores the information about packet length, packet number, its intended recipient etc. *Checksum* is a CRC value, for packet contents validation. These constituents, are modulated and prepared for transmit with a forward error correction code at the transmitter stage, since it recognizes the package length, it is a trivial thing to create the transmit frames using the tagged stream blocks. To receive the packet again at the receiver section, it has to do a plurality of matters. Generally it needs a conversion of infinite streams into packetized tagged streaming. Packet receiver section contains four main parts, namely *synchronization or detection, demux or packetize, header demodulation and payload demodulation*. The primary factor to get back packetized state is *Header/Payload Demux* block in *demux or packetize* part. In its first input, the receiver device gives a continuous flow of sample data and incoming samples all are discarded until the packet start is signed either by a trigger signal on the second input or by a stream tag. If such beginning of a packet is signed, the preamble and header are copied by the de-multiplexer to the first turn out.

Header data is converted into a message by a *Packet Header Parser* block, which is to provide metadata that can be understood by GNU Radio from the information stored in the demodulated header bits. It is then given back to the *Header/Payload Demux*. Along with all the metadata held in the *header demodulation* chain, the length of the payload is also passed in second output. In the packet detector and synchronizer, the samples that are presented in the *Header/Payload Demux* are fine frequency corrected and it sent a trigger signal for the marking of burst beginning. Succeeding, the header demodulation receiver section is triggered off. In which, the frequency domain shift of the FFT to OFDM symbols is performed. The preamble information is added as tags to the stream. The OFDM symbol with header is passed to an equalizer, which also corrects the coarse frequency offset. The data symbols picked by serializer, result in a sequence of scalar complex values, which are then demodulated and converted into bits. The header parser interprets the bits, which uses packet header OFDM object and the result from it is fed back to demux, in which length of payload and tagged stream output is known. The *payload demodulation* chain is the same as the *header demodulation* chain, only the channel estimator block is unnecessary because the channel state information is available as metadata on the payload tagged stream. Generally GNU Radio has three different synchronization mechanisms implemented for OFDM. One of them is the Maximum Likelihood (ML) synchronization, the other one is based on the correlation of pseudorandom noise (PN) numbers. The third one is an enhanced variant of the PN mechanism that uses initial cross-correlation. In our implementation, we have used the *Schmidl & Cox OFDM Synch* block available in GNU Radio which helps in robust frequency and timing synchronization of OFDM signal. This block uses different normalization factor in the timing metric and evaluation of the coarse frequency offset is carried out.

5. Simulation Results

This section discusses the simulation results that were performed based on the information and mathematics discussed above. For the simulation of OFDM system with channel model, channel estimation and synchronization, we used the following parameters as shown in Table 1. Using GUI scope, time spectrum of both modulated and demodulated signal is observed. Fig. 4. (a) shows the spectrum of modulated OFDM signal and (b) the spectrum of demodulated OFDM signal respectively. Modulated signal consists of carrier signals with noise and demodulated signal is the noise free useful information. BER of the OFDM system without channel model is obtained as zero percentage, since no multipath and noise are introduced.

Fig. 5. shows the comparison of BER with different E_b/N_0 on OFDM system before and after channel estimation and synchronization. Due to multipath effect (Line of sight and other reflections) created by channel model, noise gets added and bit error rate is observed to be high. Due to this, channel estimation and synchronization with equalization is carried out and bit error rate is reduced. And from the BER Plot it is evident that BER for OFDM system with channel estimation is less, which implies, performance is good.

Table 1. Simulation Parameters.

Parameters	Specification
FFT Size	64
Cyclic Prefix	16
Number of used Subcarriers	52
Modulation	BPSK
Number Taps/ Multipath	4

6. Conclusion

The OFDM technique is widely used in real time application such as Long Term Evaluation (LTE) systems, WiFi, WiMax. Implementation of wireless communications using Software Defined Radio (SDR) is open source and one of the emerging research areas. SDR is a technique for high speed wireless applications with minimal hardware devices and also cost efficient. In this paper, we have implemented an OFDM based communication system with channel model, channel estimation and synchronization using GNU Radio which is a open source. The BER of OFDM system with and without channel estimation is observed and correspondingly a plot is drawn, which shows that bit error rate of OFDM system with channel estimation is lesser when compared to one without channel estimation.

According to the simulation results in GNU Radio, OFDM with Channel estimation appears to be a good technique. Future work may be on making OFDM Channel Estimation model in real time using USRP and observing the error rate in it. Also research can be on, using different modulation schemes such as QPSK, QAM, 8QAM, etc instead of BPSK and choosing best synchronization schemes and channel estimation.

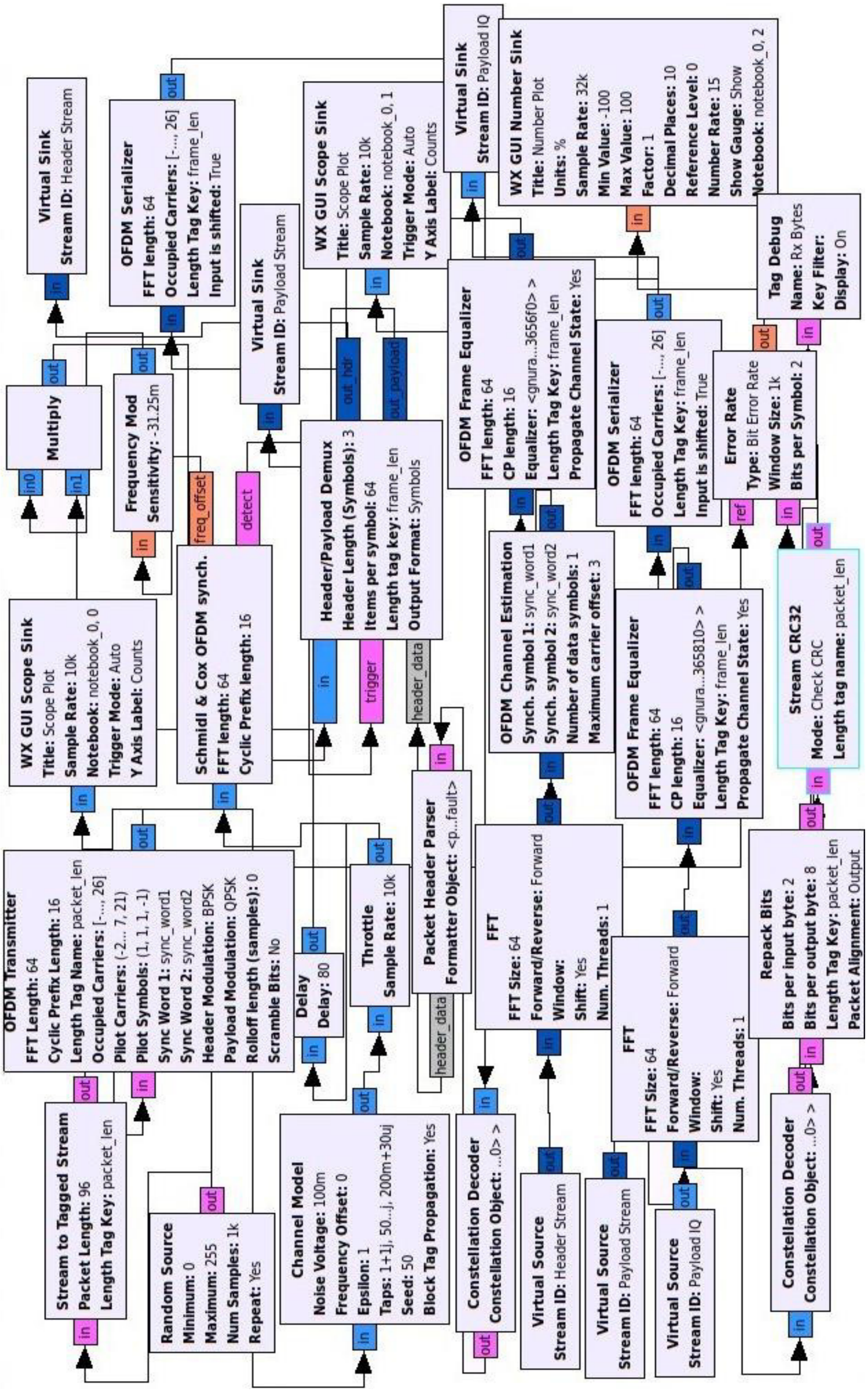
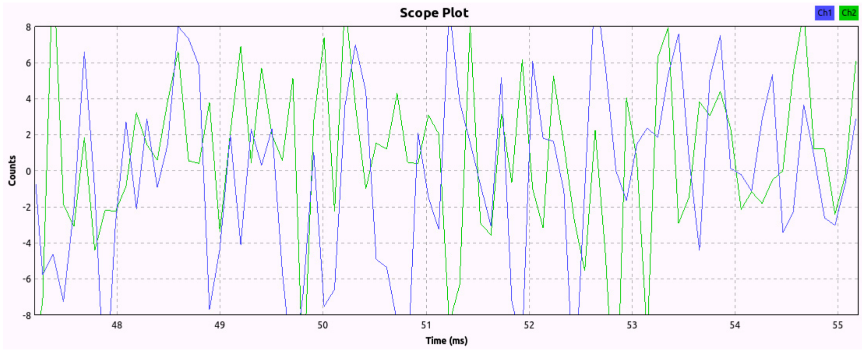


Fig. 3. OFDM Channel Estimation and Synchronization

a



b

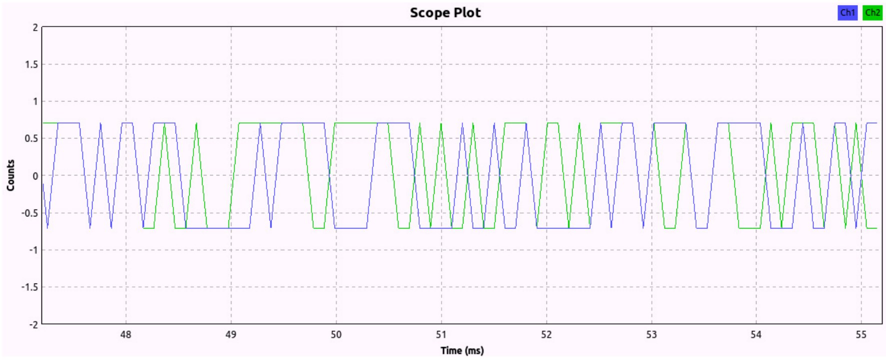


Fig. 4. (a) OFDM Modulated Signal; (b) OFDM Demodulated Signal.

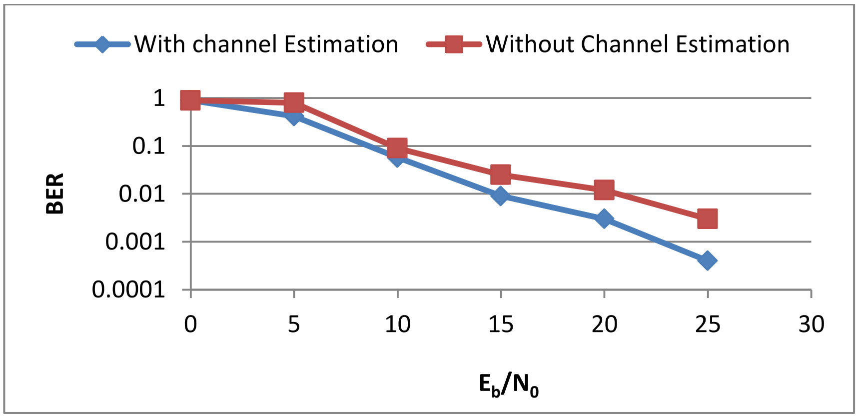


Fig. 5. Bit Error Rate Plot for channel taps specified in the block

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