AN OFDM BASED COMMUNICATION SYSTEM USING USRP

by

Mete YILDIRIM

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APPROVAL PAGE

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

____
Assoc. Prof. Dr. Onur TOKER
Head of Department

This is to certify that I have read this thesis and that in my opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

____
Assist. Prof. Dr. Özgür ÖZDEMİR
Supervisor

Examining Committee Members

Assoc. Prof. Dr. Onur TOKER ________________________

Assist. Prof. Dr. Özgür ÖZDEMİR ________________________

Assist. Prof. Dr. Tuğrul YANIK ________________________

It is approved that this thesis has been written in compliance with the formatting rules laid down by the Graduate Institute of Sciences and Engineering.

____
Assoc. Prof. Dr. Nurullah ARSLAN
Director

Date
July 2011

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Mete YILDIRIM

M. S. Thesis – Electrical Electronics Engineering
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Supervisor: Assist. Prof. Dr. Özgür ÖZDEMİR

ABSTRACT

Today’s telecommunication systems have accepted OFDM based modulation one of major technics due to its spectral efficiency and less inter symbol interference. One of major drawbacks of OFDM system is due to its high sensitivity to frequency offset. Many studies have been done for synchronization of frequency.

In this thesis we design a complete OFDM based transmitter and receiver in MATLAB environment and use two different approaches to calculate frequency offset at receiver and compare their performance. The USRP helps us to take our experiments beyond simulation and test it in miniature communication environment.

Keywords: modulation, frequency, ofdm, usrp, synchronization, wireless communication

OFDM TABANLI KOMÜNİKASYONUN USRP KULLANILIRAK GERÇEKLEŞTİRİLMESİ

Mete YILDIRIM

Yüksek Lisans Tezi – Elektrik Elektronik Mühendisliği
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ÖZ

Bugünün telekominikasyon sistemeleri OFDM tabanlı modülasyonu frekans bandını verimli kullnaması ve semboller arasında oluşabilecek karışmayı aza indirgemesinden dolayı vazgeçilmesi zor ana bir teknik olarak kabul etmişlerdir. Bununla birlikte OFDM sistemlerin frekans değişimine olan hassasiyeti onun en temel sorununu oluşturmaktadır. Bu sorununun çözümü için bir çok çalışma yapılmıştır.

Bu tezde biz MATLAB ortamında OFDM tabanlı alıcı ve verici tasarlayıp USRP üzerinde test etmekle birlikte, alıcı kısmında frekans farkını hesaplamak ve zamanlama senkranizasyonunu sağlamak için pilot bilgi temelli iki farklı yaklaşımın performanslarını karşılaştırdık.

Anahtar sözcük: modülasyon, frekans, usrp, ofdm, telzis haberleşme, senkranizasyon.

"Although science and all branches of knowledge are beneficial to almost everyone, one cannot possibly acquire all of them, for people's life-spans and resources are limited. Therefore, learn and use only that which benefits yourself and humanity at large. Do not waste your life."

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LIST OF SYMBOLS AND ABBREVIATIONS

BER	Bit Error Rate
CPU	Central Processing Unit
FDM	Frequency Division Multiplexing
FPGA	Field Programmable Gate Array
IO	Input Output
MIMO	Multi Input Multi Output
OFDM	Orthogonal Frequency Division Multiplexing
PC	Personal Computer
USRP	Universal Software Radio Peripheral
QAM	Quadrature Amplitude Modulation

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

In today's communication system OFDM has an important place with its different application or combination with other technics for providing better communication. To name a few we can mention the applications or environments it is being used such as IEEE 802.11a wireless standards, High Performance LAN type 2, Mobile Multimedia Access Communication (MMAC) systems, Digital Subcarrier Line (DSL), Digital Video/Audio broadcasting (DVB/DAB) and so on.

OFDM promises a broadband communication along with robustness against frequency selective fading, narrowband interference, low complexity equalization of the multipath channel in frequency domain. It owes these above mentioned abilities to be a multicarrier system which also doesn't make it suffer as a result of single carrier system failure which cause its depending system complete down.

OFDM is a special case of FDM which is known quite long time ago and used in many areas of communication. But using OFDM requires large computation complexity therefore its usage had been delayed to the time when digital signal processing (DSP) applied into communication systems and development of faster electronic devices done. The development in electronic technologies let some special devices appear which can do faster calculations which may not be done enough faster in ordinary computers such as USRP which handles hard part of communication calculations such as decimation, interpolation or digital up down conversation on its own.

1.2 MOTIVATION

OFDM has been studied in research areas of telecommunication due to its requirements for very sensitive time, frequency synchronization, phase noise detection and suppression. A lot of studies have been done providing different technics for better synchronization. Since use of OFDM in telecommunication is spreading and promising a broadband communication at lower cost day by day in line with development in technology, there may be need of research in developing synchronization technics.

USRP helps us to have experience on wireless communication as working receiver and transmitter simultaneously. It uses USB port for communication to a computer. It receives data from a computer USB port at the one end and it sends data to another computer at the other and of our wireless study. It has toolboxes to be used in MATLAB programing in WINDOWS operating system. A code may be written in MATLAB program to act as transmitter or receiver for USRP by the help of its toolbox for MATLAB. Even if it provides offline communication in windows environment it is enough and better for us to have our studies in real wireless communication environment rather than having studies completely depending on simulation program which may not be offering right results always and sometimes being quite far away of realities.

Keeping in mind these advantageous of using USRP to build a real wireless communication system and having results close to real life experience which inspire us to have more acceptable arguments for carrying necessary simulation for our studies we have decided to have communication based on OFDM technics by using USRP.

1.3 AREA OF STUDY

As we try to design a simple transmitter and receiver in MATLAB environment establishing communication with USRP we much focused on synchronization of timing and phase noise reduction of received data based on preamble fixed into transmitted data. We used different types of preamble and evaluate their performance on subject matters of synchronization.

1.4 CONTRIBUTIONS

In Chapter 2, we give definition of modulation technics for digital systems and provide more on QAM which is what we use as modulation technic. Their related formulas are shown also graphs are provided to make it more clearly to reader. FDM and OFDM are explained with supportive figures. Wireless system standards are mentioned briefly. USRP is introduced and its technical abilities are mentioned.

In Chapter 3, we explain how we built the transmitter and receiver in MATLAB and then how we used it to communicate USRP for wireless transmission. Since synchronization is so important in OFDM we focused on timing, phase offset, and channel estimation and showed how to used pilot based estimation for providing these synchronization. We used two different pilot structures and compare them in performance and provided essential figures for better understanding.

In Chapter 4, we conclude by giving an evaluation of this thesis.

1.5 SIMULATION ENVIRONMENT

The experiments are first done on real wireless environment having two PC with CPU 1.2 GHz, and 1024 MB of memory and two USRPs (its properties are given in chapter 2 in details) for wireless communication. Then we use a laptop with Intel core 2 Duo CPU 2.4GHz with 2.00GB of memory for simulation

CHAPTER 2

LITERATURE REVIEW

2.1 MODULATION TECHNIQUES USED IN COMMUNICATIONS

“It is not right to ask a man to swim across Atlantic Ocean without putting his life at stake so you had better ship him to other coast”

It will be appropriate to give definition of modulation before going into some details of its techniques in communication applications.

Generally a signal has three properties such as amplitude, frequency and phase. By changing this signal attributes we modulate it. In telecommunication we modulate signals so that we can carry them in different medium. For example human-being voice can travel in air for a certain distance due to its limited power. When we want to transfer it on a cable such as telephone line we do modulate it by changing it some electrical signals therefore it can travel over a cable. Depending on the medium which will be used as a means of communication we change the original signal, such as voice, to something else which can be light, RF, ultrasound, electrical signal and so on. But in wireless communication we mostly modulate a high frequency signal’s properties, carrier signal with a baseband signal (information, human speech so on) or say modulating signal. Modulation benefits us in respect to sending information for long distance, preventing collision etc. Depending on what properties of carrier signal changed for modulation process we can have different technics of modulation.

Before moving to these technics we like to remind that there are two types of signals called Analog Signals (AS) and Digital signals (DS). The definition of these two are: The real signal which is continuous over a certain period of time such as living being voices we hear and discrete or noncontinuous signals such as music files we keep on personal computer (PC) respectively. Depending on which one we modulate we can have modulation type such as Analog Modulation (AM) or Digital Modulation (DM).

In this thesis analog modulation of signal is done on USRP which we will not talk about it but we will mention about digital modulation and its types and give more details on QAM (Quadrature Amplitude Modulation) as digital modulation which we use in this of thesis.

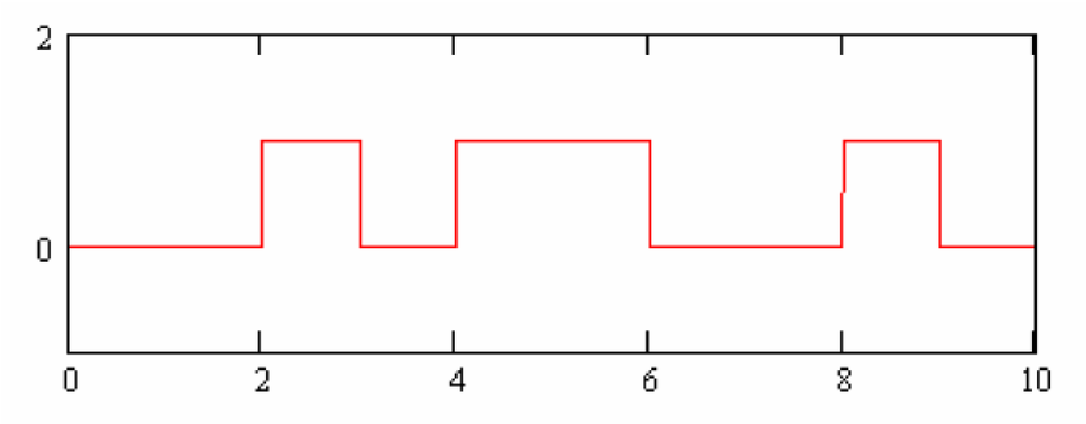

Figure 2.1 Information signal or modulating signal (www.complextoreal.com)

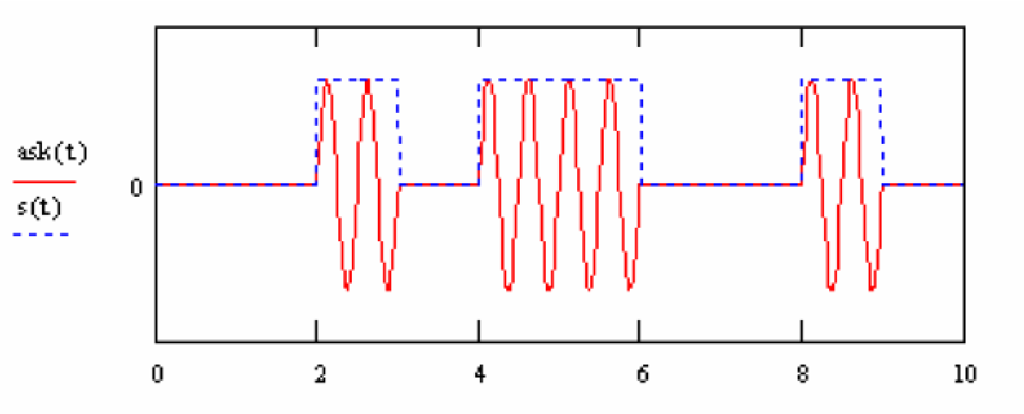

Figure 2.2 Modulated signal with ASK (Amplitude shift keying) (www.complextoreal.com)

Figure 2.1 shows an information signal and it is modulated with a sinusoidal signal with a technic called ASK (Amplitude shift keying).

2.1.1 Digital Modulation

Digital modulation helps us to transfer a bit stream over an analog channel. We can categorize basic digital modulations as follows;

- ASK (amplitude-shift keying), a predefined number of amplitudes are used.
- PSK (phase-shift keying), a predefined number phases of carrier signal are used.
- FSK (frequency-shift keying), a predefined number frequencies of carrier signal are used.
- QAM (quadrature amplitude modulation), a predefined number of phases amplitudes are used.

The other type of modulation seen in literature is based on these fundamental principles of modulation.

ASK modulation offers changes in amplitude of carrier in line with information such as to transmit binary 1 we use particular amplitude and to transmit binary 0 we use different amplitude. For example at figure 2.1 and 2.2 is OOK (on off keying) is ASK where for transmitting 0 we use amplitude zero.

PSK modulation offers changes in phase of carrier signal in respect to information. How it happens is to change a sin wave by 180 to transmit 0. PSK is formulated as follows

$$PSK(t) = \sin(2\pi ft) \quad for\, bit\, 1$$

$$PSK(t) = \sin(2\pi ft + \pi) \quad for\, bit\, 0$$

FSK modulation offers changes in frequency of carrier signal in response to information, say uses different frequencies for presenting 0 and 1 and mathematically it is written as follows

$$FSK\ \ t\ = \sin\ \ 2\pi f_1 t \quad for\,bit\,1$$

$$FSK\ \ t\ = \sin\ \ 2\pi f_2 t \quad for\,bit\,0$$

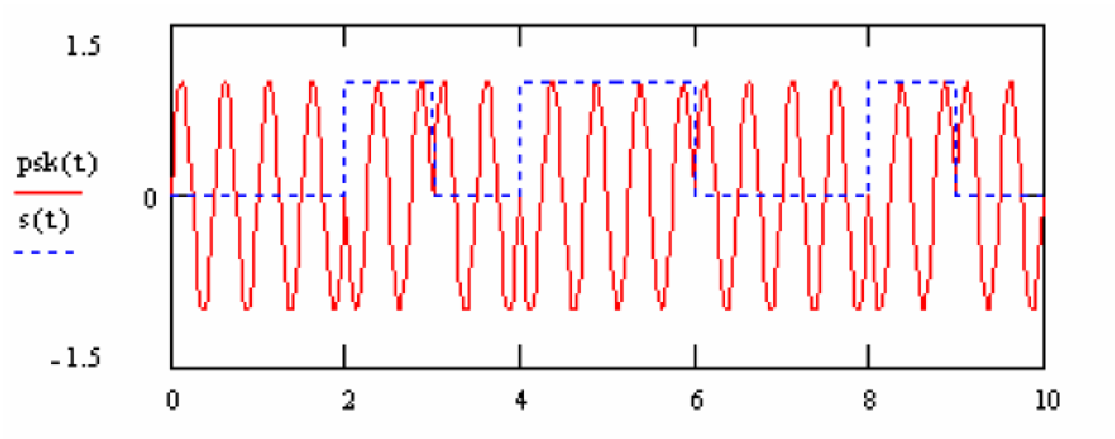

Figure 2.3 PSK mod. at the edge of a bit 180˚ change in phase of carrier (www.complextoreal.com)

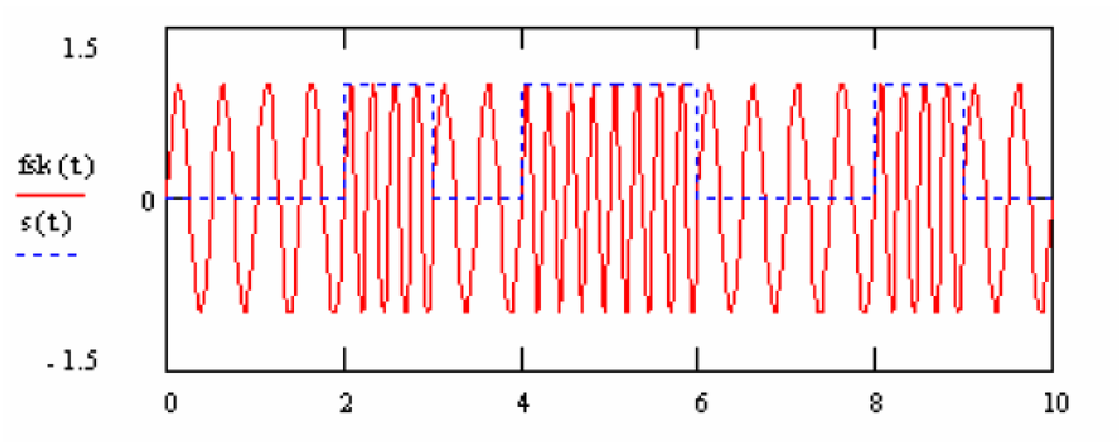

Figure 2.4 FSK modulation, higher frequency for bit 1 (www.complextoreal.com)

Before explaining QAM modulation we can give a little information about I and Q channel to help it be clearer.

A vector can be presented in polar form or rectangular form at X and Y axis with I and Q projections respectively as shown on following figure.

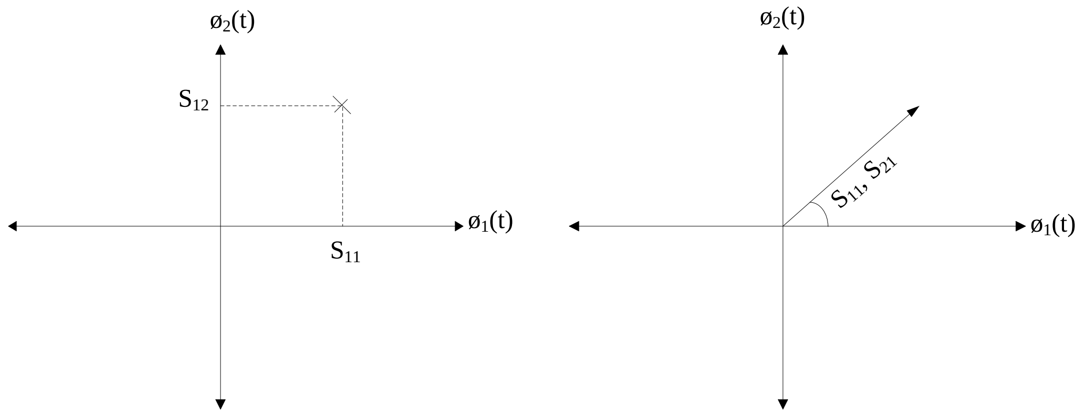

Figure 2.5 Vector shown on rectangular form at left and polar form on right.

For conversation from one to other is done mathematically with the formulas provided down.

To calculate magnitude $S = \sqrt{I^2 + Q^2}$

To calculate angle $= \tan^{-1} I / Q$ are used.

In QAM modulation these two channels are used to carry information and since they are orthogonal to each other no collision occurs.

To define QAM it is said that two orthogonal sinusoidal signals are used to transmit the data in channel at same frequency and they are call I and Q signal. QAM is able to carry twice more information than standard ones such as pulse amplitude modulation without suffering more BER (bit error rate) for a given bandwidth.

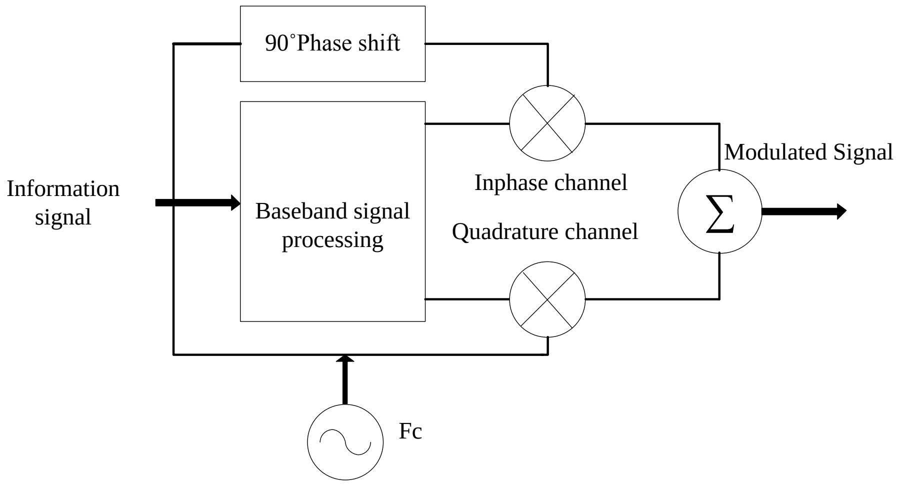

Figure 2.6 QAM modulation schematic display

QAM is shown in Figure 2.6 schematically. At baseband signal processing a symbol is separated in two as real and imaginary part and modulated with cosine and sine waves then combined as one. And the final mathematical definition is given as follows

$$s(t) = x(t)\cos\omega_c t - y(t)\sin\omega_c t$$

This is done at transmitter side. For receiver side the *s(t)* is multiplied same frequency sin and cosine signal separately and filtered with low pass filter to get back to original signal as follows.

$$[x_I(t)\cos\omega_c t - y_Q(t)\, sin\omega_c t]*\cos\omega_c t$$

When necessary calculations are done and filtered with low pass filter we have

$$\frac{x_I(t)}{2}$$

For calculating $y_Q(t)$ same mathematical way is followed but this time second multiplier is $\sin\omega_c t$ and we have

$$\frac{y_Q(t)}{2}$$

The sum of two calculated signal gives us half of *s(t)*. If it is wished the amplitude can be adjusted by multiplying with 2 to the same at transmitter.

In literature it is sometimes shown in complex notation. For example for given x (t) signal as follows

$$Re\left[X_I\ \ t\ \ + jX_Q\ \ t\ \ \right]e^{-j\omega t}$$

For digital transmission it can be written as follows

$$.\ X_I\ \ t\ \ = \sum_{n=-\infty}^{\infty} a_{I,n}g(t-nT)$$

$$X_Q\ \ t\ \ = \sum_{n=-\infty}^{\infty} a_{Q,n}g(t-nT)$$

2.2 WIRELESS SYSTEMS AND STANDARDS

Wireless systems and standards vary over time. There are many unions as nongovernmental put some standards such as International Telecommunication Union, the International Organization for Standardization, the Telecommunications Industry Association, and the American National Standards Institute. That is why explaining it will be somehow hard. First of all we like to show electromagnetic spectrum or say frequency spectrum.

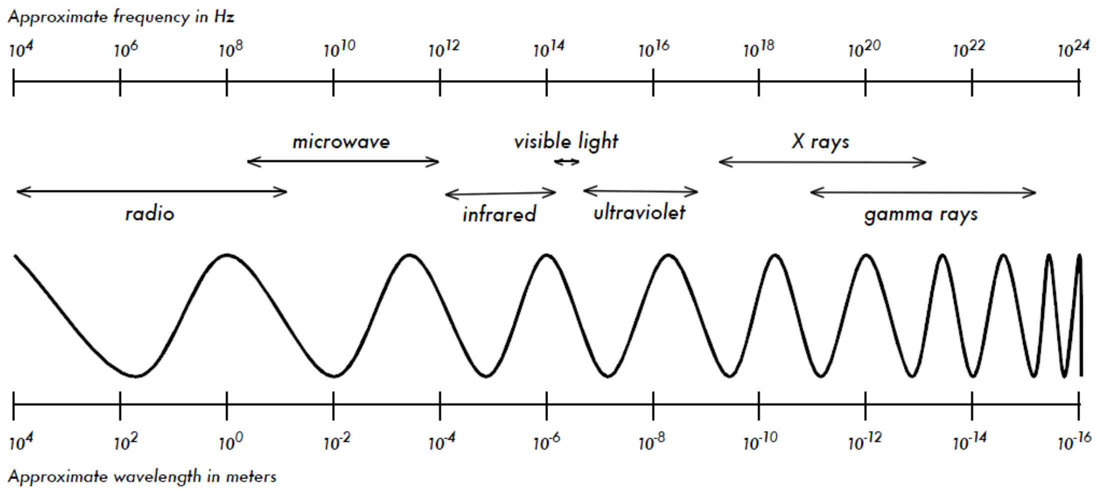

Figure 2.7 Electromagnetic spectrum (wndw.net)

In figure 2.7 it is clearly indicated what range in the spectrum called what. For example the range starting 10^4 to 10^9 called radio is known RF band. All wireless equipment operates in this range. In this range there is a part for unlicensed use called ISM band which stands for Industrial, Scientific, and Medical. The rest parts of RF are strictly controlled by state authorities.

The 802.11b and 802.11g radio standards use 2.400 - 2.495 GHz, other commonly available equipment uses the 802.11a standard, which operates at 5.150 - 5.850 GHz.

To have better idea of how this free band is used let us look at the standard of 802.11b at figure 2.8. Each channel are given 22 MHz wide, and separated with 5MHZ (2417-2412) which means they overlap each other. In same environment if they are to be deployed it is better use channels 1,6,11 since they don't overlap each other.

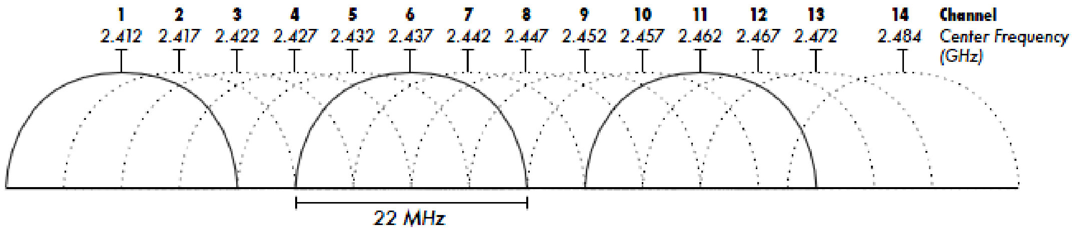

Figure 2.8 Frequency spread for 802.11b (wndw.net)

Also we can name wireless equipment depends on their coverage ability as follows

- Wide Area (WAN)
- Local Area (WLAN)
- Personal Area (WPAN)

By giving some examples we can understand these standards better.

Bluetooth and Wireless USB are counted in Wireless PAN System.

Wi-Fi is most known application of WLAN and used to provide wireless Internet access for computers, printers and other devices in a local place such as in a company building.

For wide area network we can 3G systems and WiMAX as well-known.

2.3 OFDM BASED SYSTEMS

2.3.1 Definition of OFDM

OFDM is known orthogonal frequency division multiplexing and it is a multicarrier system unlike FDM. We will be explaining OFDM in comparison to FDM system. FDM means frequency division multiplexing. Considering the figure 2.9 , let say we have a dedicated band of frequency over which we like to broadcast as many as possible. When the case is to follow the way of FDM technic what we are supposed to do is locate 1st channel on a certain center frequency than place 2nd channel after giving enough gap from the 1st one. The reason for keeping a gap between channels is due to stop interference. In the case OFDM the station is quite different such as that neighboring carrier (latter called subcarrier) overlap each other but this doesn't cause interference as long as orthogonality is provided between these two. Leaving the detail information of this latter we can give conclusion as that OFDM band efficiency is very greater than FDM.

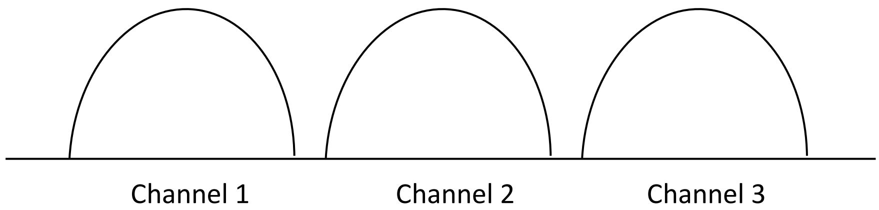

Figure 2.9 FDM

To make it clearer we can comment on the following figure

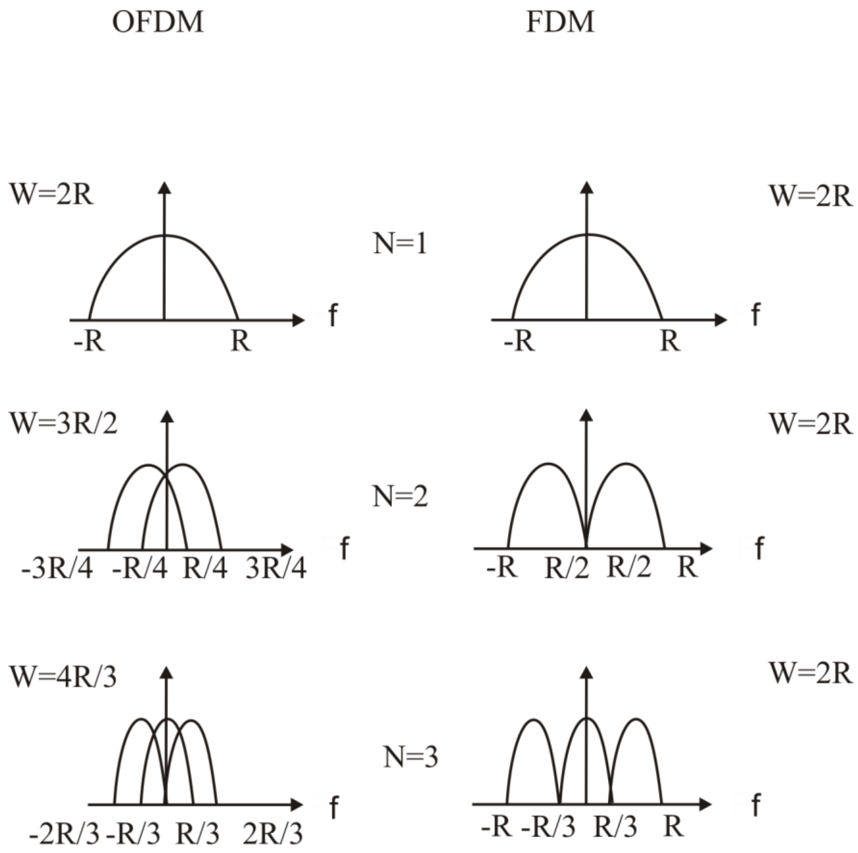

Figure 2.10 OFDM and FDM bandwidth comparison (COULON, 1999)

Looking at picture above we can easily say that as number of channel increased, (N) increment of bandwidth (W) in OFDM is increase less than FDM bandwidth such that when N=3, W=4R/3 and W=2R for OFDM and FDM respectively.

To understand greatness of multicarrier system to single carrier system the following figure can help us. Considering the cables pictures at figure 2.11 has the same size but the left one is multi cable we can say, in the case they are used to transmit information, the right one can carry one information while the other one can carry as many as numbers of its branches. Also it must be said that failure of one branch in multi cable will not stop flowing of information but in the case of the right cable the system will be completely down.

 

Figure 2.11 Multicarrier cable and single carrier cable

After giving this we can give the working principle of OFDM. To build an OFDM system we split the data stream and carry each one on a different subcarrier. As we say earlier these subcarrier must be orthogonal. Since orthogonality is essential for OFDM we must briefly explain it.

The subcarriers used in OFDM are all sinusoidal wave. For a sinusoidal wave (figure 2.12) total area must be equal zero in one period. If we multiply a sinusoidal wave with another one both which having frequency as m, n respectively what we get is as total area is again zero and it can be formalized as

$$f\,(t) = \sin mwt * \sin nwt$$

Taking into account trigonometric identities it can be written as follows

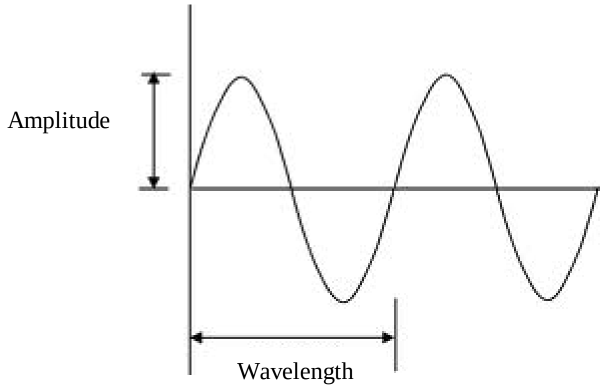

Figure 2.12 Sinusoidal wave

$$\sin m * \sin n = \frac{1}{2}\cos \;\; m - n \;\; - \frac{1}{2}\cos(m+n)$$

When we have integral of above equation as

$$= \int_{0}^{2\pi} \frac{1}{2}\cos \;\; m - n \;\; \omega t - \int_{0}^{2\pi} \frac{1}{2}\cos \;\; m + n \;\; \omega t$$

=0-0

It shows us that any sinusoidal signal multiplied with its harmonic produces a total area of zero therefore it is said, in general, for any integer m and n *cos* mx, *cos* nx, *sin* mx, *sin* nx are *orthogonal* to each other and these are called harmonics.

After giving definition of orthogonally of sinusoidal wave, which is a must for OFDM system, we can give more the detail of OFDM. Looking the figure 2.13 we can say in OFDM system the received data will be divided into N parallel data, which we call as from now serial to parallel conversion, then we take IFFT to convert it to time domain then it comes to add of cyclic prefix, then we do parallel to serial conversion. As all these are done our data is ready to be sent. At the receiver side the data converted to parallel and added cyclic prefix removed then FFT is taken to take it back freq. domain which is vice versa processing of transmitter side.

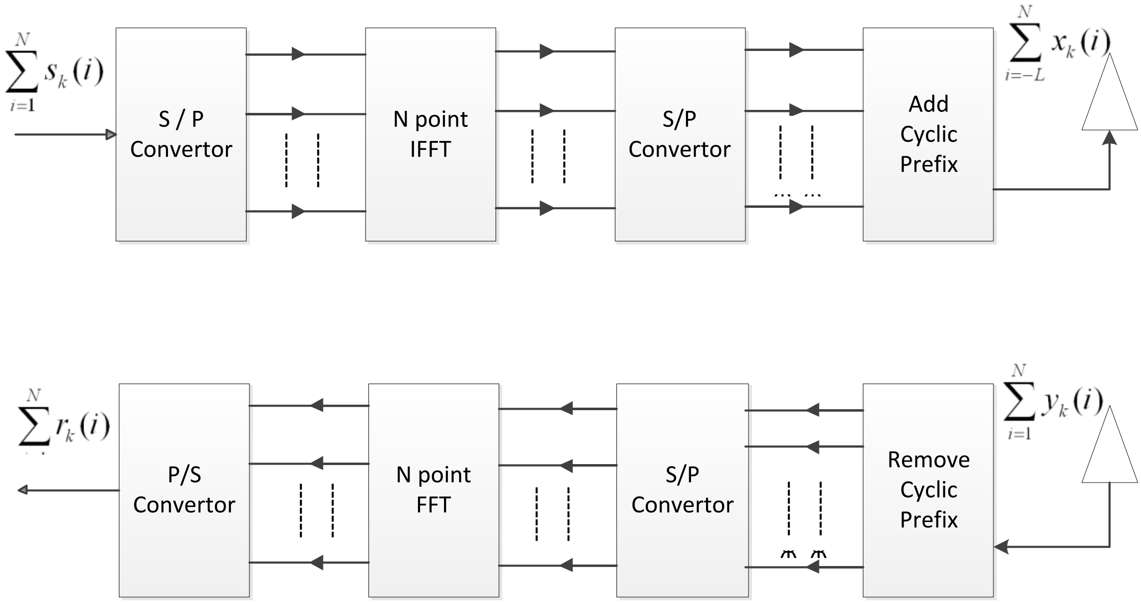

Figure 2.13 OFDM based transmitter and receiver in block diagram

As it is seen in Figure 2.13, N symbol data becomes N+L symbol data, which is done after taking of IFFT of the input symbols, with addition of cyclic prefix. In easy saying it is taking last N symbols and adding beginning of data streams.

2.3.2 Mathematical Model for OFDM

The OFDM signal is produced by taking the Inverse Fast Fourier Transform of modulated signal (here it is QAM) at baseband. An OFDM symbol size is predefined. Suppose the required period of an OFDM symbol is T. At the beginning of every OFDM symbol there is a cyclic prefix of length T_g , created by taking last L symbol in a OFDM sysmbol and adding to begining. T_g must be channel impulse response to be useful. For each subcarrier the following formula given

$$v(t) = \sum_{k=-N}^{N} c_k \exp(j2\pi f_k t), \quad 0 \leq t \leq T$$

Where $f_k = k/T$ is the frequencies of complex exponentials of one OFDM symbol and 2N+1 is number of subcarrier or say an OFDM symbol size. Then this signal is up converted and transmitted through a channel.

At the receiver it is down converted, timing synchronization is done, cyclic prefix is removed and FFT is applied

2.3.3 Synchronization at OFDM Receiver

Synchronization is one of major challenge in OFDM based system. There are tens of paper published offering different types of synchronization method.

We can examine synchronization in three groups

1. Timing Synchronization
2. Frequency Synchronization
3. Phase noise suppression

All of them can be done in two categories.

A. Pilot-based methods

   i. Non-OFDM-based pilot symbols
   ii. OFDM-based pilot symbols

B. Non-pilot-based methods

In our project we used pilot based estimation and suppression. What kind of pilot is used and how the estimation is done explained in chapter 3

2.3.4 Advantageous and disadvantageous of OFDM

A. Advantages of OFDM
   a. Spectral efficiency
      i. Use of orthogonally
   b. Simple implementation
      i. Use of IFFT/FFT block and ADC/DAC block
   c. Mitigation of ISI
      i. By using cyclic prefix interval

B. Disadvantages of OFDM
   a. Peak to average power ratio (PAPR) is high
      i. It results linearization in transmitter amplifier and wide dynamic range amplifier.
   b. Capacity and power loss due to guard interval
   c. Frequency offsets and phase noise sensitivity

It may be right to say for anything entered into our life lately that what advantageous it offer us today used to be its disadvantageous in old days because those days times were not able to handle the problems and offer solution such as FFT and IFFT calculation for OFDM system .

2.4 USRP

2.4.1 Definition and Overview

USRP stands for Universal Software Radio Peripheral and is made to enable common used computer work as high bandwidth receiver (radio). To better understanding we can say it takes responsibility of digital communication and IF section of receiver or transmitter part of radio system.

Figure 2.14 USRP inside and outside look (www.ettus.com)

The designer of USRP has planned to provide engineers an opportunity to build their own software radio in an affordable way. When using USRP along with a computer, USRP will be handling digital-up and down-conversion, decimation and interpolation on its FPGA, which is the part, may not be done on the computer and the computer will be used modulation, demodulation and other wave processing.

The USRP essentially is combination of motherboards and daughterboards. As for now it has two version called USRP and USRP2. The motherboard has an FPGA used for high speed digital signal processing (DSP). The interchangeable daughterboards are available to be used in various frequencies ranging from DC to up to 5.9 GHz which is to say it can cover AM, FM, GSM, UHF as well as other wireless applications and beyond.

2.4.2 Hardware Specifications

As to say for USRP (first version of its kind) it communicate with a computer through USB 2.0 (480 Mb/s) port, and able to work on 16 MHz of bandwidth in either direction. It has followings specifications:

- An FBGA which can be reprogrammed
- 4 high-speed Analog to Digital Converters (ADCs)
- 4 high-speed Analog to Digital Converters (ADCs)
- 4 high-speed Digital to Analog Converters (DACs)
- and many auxiliary analog and digital IO
- It can have 2 transceiver daughterboards for experiencing MIMO studies.

The later version of USRP is called USRP2 which has extended capabilities such as

- Providing connection to a computer through Gigabit Ethernet card which can have 50 MHz bandwidth in both directions simultaneously.
- An FBGA with greater capabilities for standalone usage
- ADCs and DACs with higher speed and higher precision
- And capability to be used with other USRP2s to build MIMO systems (up to 8x8)

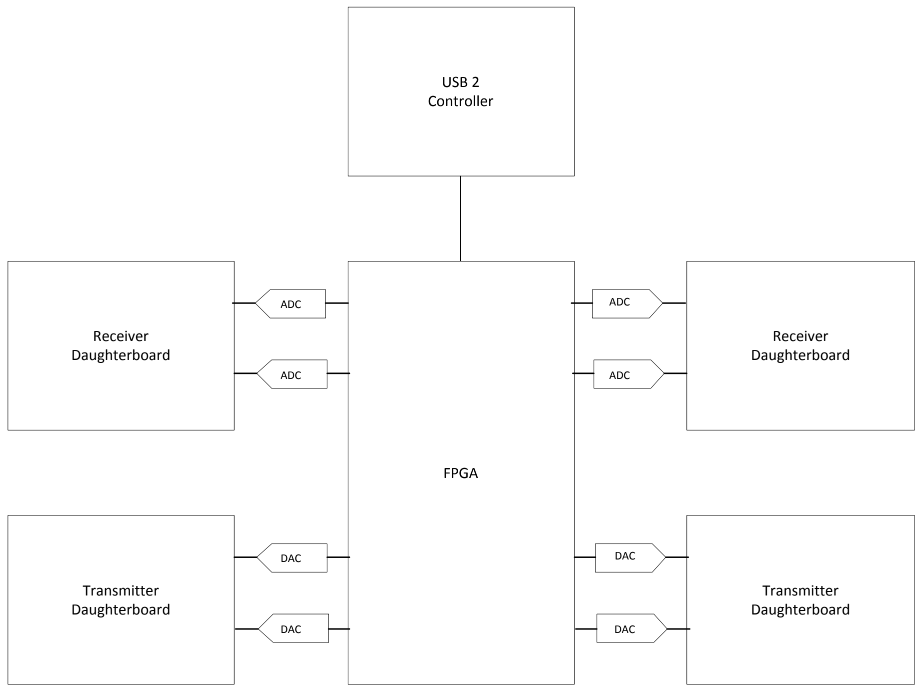

Figure 2.15 Universal Software Radio Peripheral

2.4.3 Software Specifications

It is supported by Windows XP, Windows 2000, Linux, Mac OS and some other operating systems. Its software is totally based on open source code understanding. It also provides a developer environment to build software defined radio. It is found most common radio needs such as GMSK, PSK, QAM, OFDM modulation, error correcting codes, signal processing tools such as equalizers, FFTs within its software package. It is also possible to develop applications in C++ or Python.

2.4.4 Applications

It is known that it has much commercial application like medical imaging, sonar and so on. It is used in military applications, teaching facilities for studies such as

FPGA design, Software Defined Radio, Digital Signal Processing, and Communications systems. It is well used in wireless researches studies. Also we can mention name of some well-known applications such as IEEE 802.11, Bluetooth, 802.15.4, GSM

CHAPTER 3

IMPLEMENTATION

3.1 INTRODUCTION

In this part we will talk about design of transmitter and receiver in MATLAB and transmission over USRP. At the other end we receive and examine the data then do necessary synchronization as timing, frequency offset. As we said earlier easy processing are done on computer such as modulation, IFFT, FFT

3.2. TRANSMITTER

The parameters we used for designing transmitter are given in Table 3.1 which gives the parameters used for simulation. After carrying real experiment on USRP we design and run a simulation program for which we used parameters close to our real experiment from on USRP to be able to have faster result of some parameters we change for synchronization in particular size of sd4all preamble and proposed preamble.

We used a text as data to transmit. The text firstly converted into bits vector and modulated (16 QAM). It is converted to N by 64 data matrix. The pilot data is inserted into the data matrix and IFFT is applied. Cyclic prefix is taken and it is converted to vector again. After then the sdr4all preamble vector (10000 length consisting integer 1), silence period (10000 “0”) which used for calculating SNR, and proposed preamble added at beginning of first created vector. Sdr4all and proposed preambles are for same purpose for providing necessary synchronization timing and frequency offset. The reason we used both to have comparison of their performance.

Table 3.1 Parameters table for transmitter and receiver design

Parameter Name	Quantities /sizes/length	Explanation
OFDM symbol	64	One OFDM symbol consist of 64 QAM modulated symbol
Sdr4all Preamble	0..10000	Used for timing sync. Frequency offset estimation
proposed Preamble	0..2500	Used for timing sync. Frequency offset estimation
Pilot	20 OFDM symbol	Used for channel estimation
Frequency of Pilot	10	After every 10 OFDM symbol one pilot used

Table 3.2 Parameters table for simulation

Parameter Name	Quantities /sizes/length	Explanation
SNR	30	Signal Noise Ratio, used for simulation
Channel Tab	3	Number of Path of Channel, used for simulation
Invasive phase	-0.0021	Used for creating destructive phase effect

In Figure 3.1 numbers 1,2,3,5 indicates preamble period, silence period, proposed preamble, and the text data respectively while number 4 indicates pilot data and its repetition.

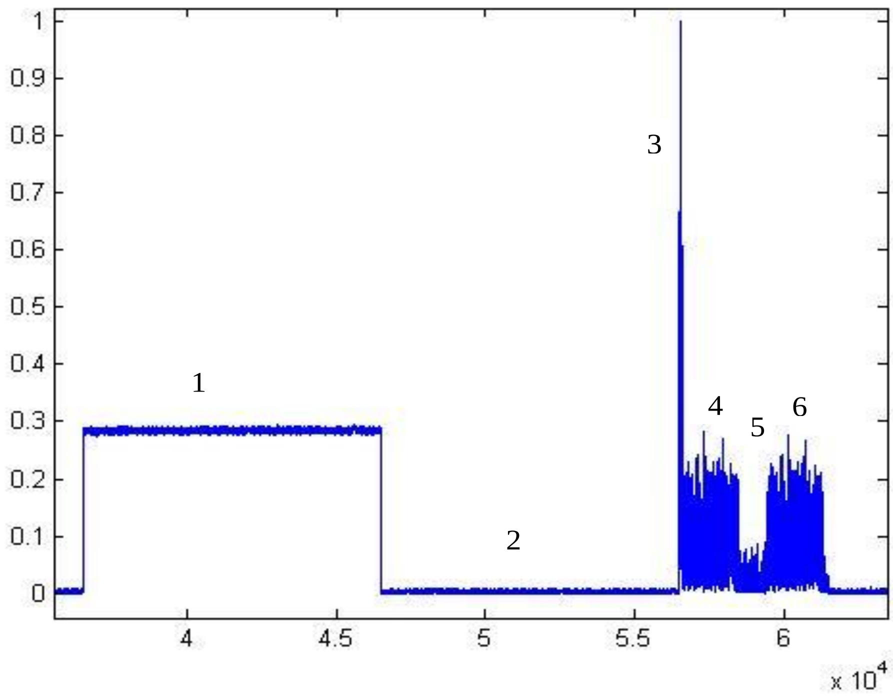

Figure 3.1 The vector at the end of transmitter

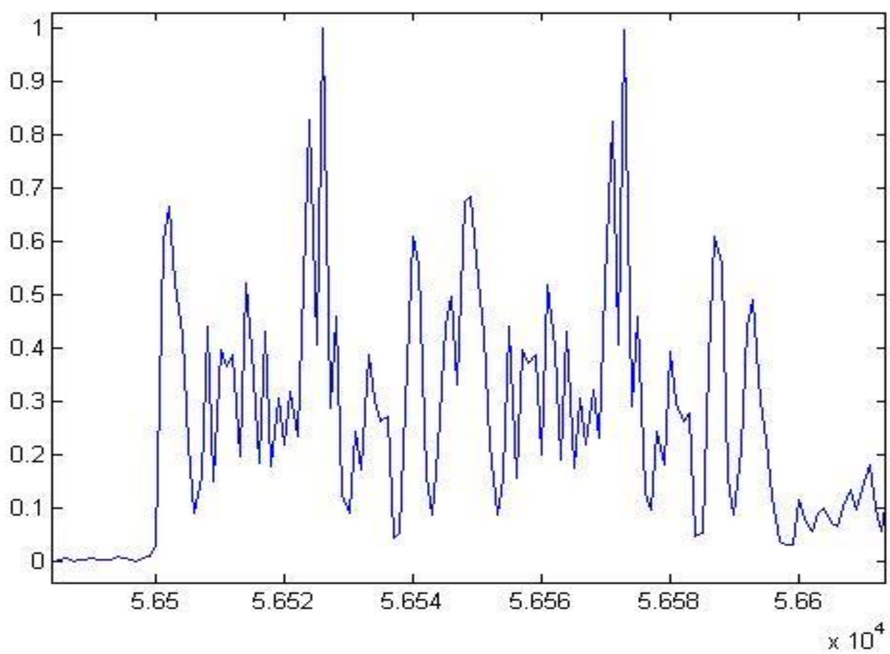

Figure 3.2 Proposed preamble which consist of two identical parts

The peak point in Figure 3.1 is the proposed pilot that has a different structure and so far we haven't mention of it. To have it firstly we made a discrete vector meaning that it has a symbol as first element then "0", 2nd symbol, "0" …When we have IFFT of this vector we have a periodic signal in frequency domain due to the fact that discrete in time domain = periodic in frequency domain. The figure 3.1 shows this proposed preamble.

3.3. RECEIVER

At receiver what we do first is timing synchronization. It is because timing synchronization gives us actual point where our real data is starting. Then we create the data frame, convert it parallel, remove cyclic prefix, and apply FFT. At the end of this we will have our real data in addition of phase offset and, channel effects whose effects we need to remove consequently. Before doing so we like to give figure of received data vector for both (real and simulation) at the receiver as shown Figure 3.1 where the data vector at the end of transmitter is ready to be sent.

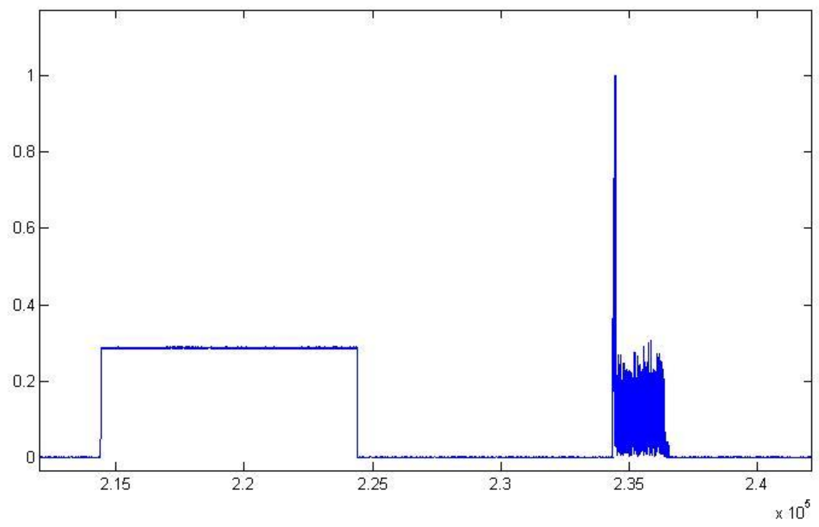

Figure 3.3 The real received data

The figure 3.3 is a real received data from receiver USRP. It is zoomed in. The time index difference has no importance so we can say it is very similar the one we sent shown at figure 3.1.

The figure below gives very similar result with those in Figure 3.13 and Figure 3.4 yet it is the received data of our simulation program.

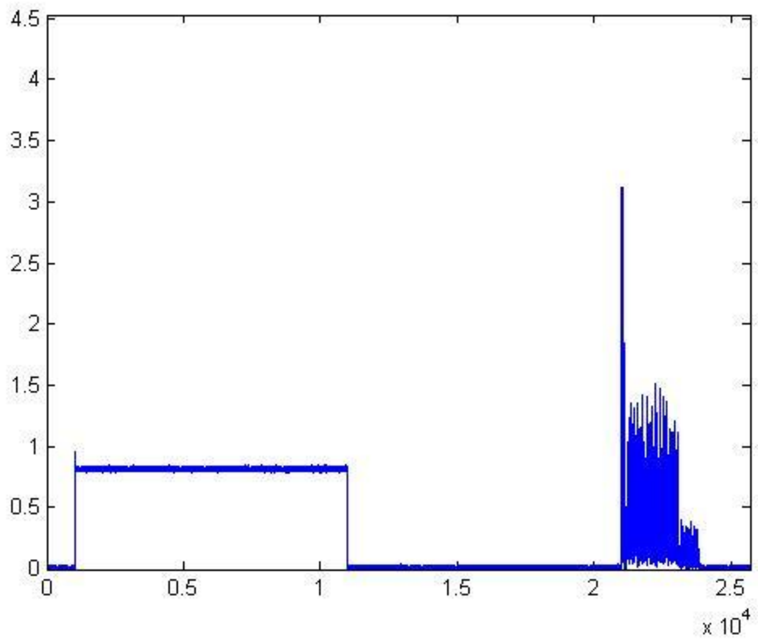

Figure 3.4 The received data of simulation program

3.4. PROCESSING THE RECEIVED DATA USING MATLAB

3.4.1 Timing Synchronization

For timing synchronization we used correlation technique. We have two preambles. For not causing confusion we call them as for the one combination of “ones” *sdr4all preamble* and the other one which has always two identical parts *proposed preamble*. Both preamble have predefined size which we use window size of correlation processing. It is enough to have correlation on one of them but for comparison reason we try both of them. Correlation will give a max point which is where the related preamble starts. Figure 3.5 show correlation function output of proposed preamble as the first one Figure 3.5 has all the picture within the second one figure 3.6 has zoomed in of the picture to show **maximum** point clearly.

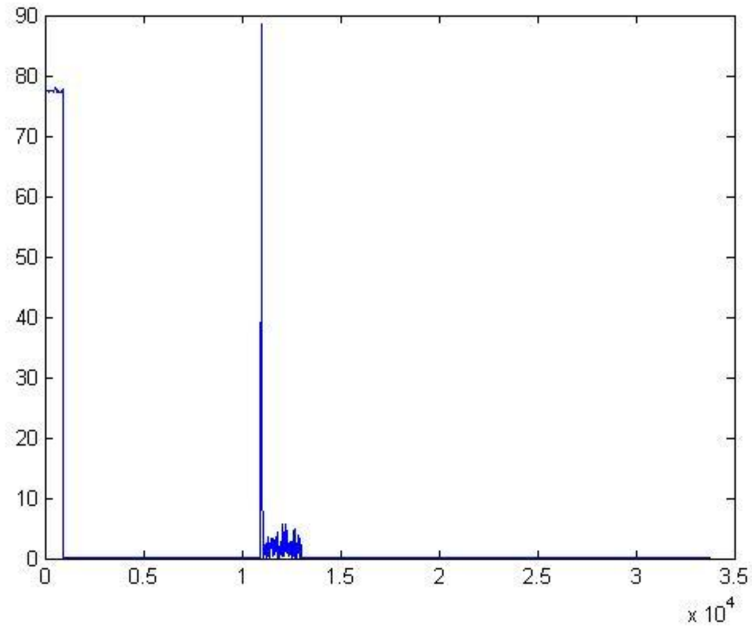

Figure 3.5 The output for autocorrelation

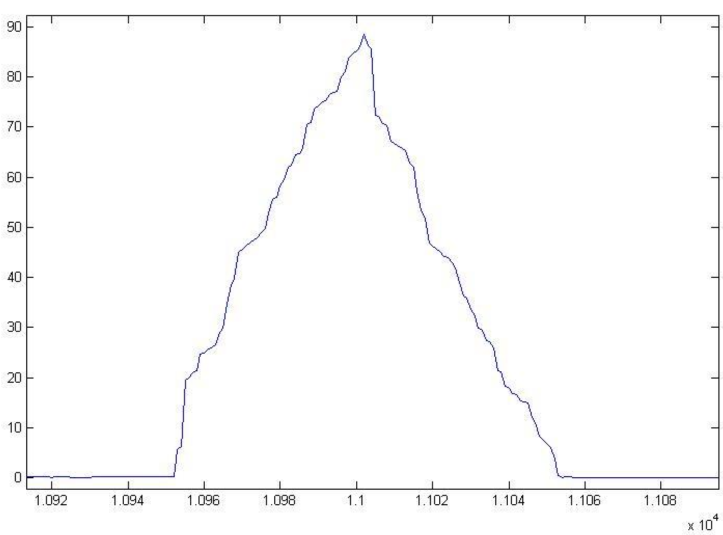

Figure 3.6 The magnified autocorrelation output

The maximum point is where the first symbol of proposed preamble which is very important for us to calculate phase offset.

Also we need to say that in some studies the graph for correlation doesn't provide maximum point but a plateau so computer gives arbitrary any point located on this plateau which size is proportional to size of cyclic prefix. Even it is said it will have no negative effect on result some studies gave some algorithms to get a stable max point. To overcome so-called flat top problem we kept our proposed preamble out of cyclic prefix process. Also we develop a program which can calculate actually max point from this flat top. The further discussion left for chapter 4.

3.4.2 Phase-Offset Suppression

We know that our proposed preamble is identical in two parts. Considering it has N symbols we say that the first symbol is actually same with N/2+1th symbol. For better understanding we will explain it with an example. For reminding, to create the proposed symbol we first create a discrete data vector and its IFFT result as shown table 3.1.

Table 3.3 The proposed preamble and its IFFT result as periodic wave

# of Symbol	Discrete Preamble	IFFT & Periodic
1st Symbol	-6.6667 + 6.6667i	-3.3333 + 2.0000i
2nd Symbol	0.0	-3.2808 + 1.0020i
3rd Symbol	-20.0000 + 6.6667i	6.3013 + 0.6334i
4th Symbol	0.0	-0.3384 - 4.4389i
5th Symbol	-6.6667 + 6.6667i	-2.6821 + 4.1368i
6th Symbol	***0.0***	***-3.3333 + 2.0000i***
7th Symbol	***20.0000 -20.0000i***	***-3.2808 + 1.0020i***
8th Symbol	***0.0***	***6.3013 + 0.6334i***
9th Symbol	***-20.0000 +20.0000i***	***-0.3384 - 4.4389i***
10th Symbol	***0.0***	***-2.6821 + 4.1368i***

As it is seen in Table 3.3 its identical two parts starting from 1st symbol equivalency to 6th symbol to 5th symbol equivalency to 10th symbol and it is true regardless of sizes of preamble as long as it is discrete in frequency domain.

Supposing an invasive phase -0.05 destructed the proposed preamble symbols we will calculate the invasive phase on proposed preamble using its identical symbols. Assuming $\varnothing$ is the phase between first two symbols, the phase difference between 6th and 1st symbols must be 5$\varnothing$. If we formulize this we get following equation for $\varnothing$

$$\varnothing = \frac{2}{N}\sum_{i=1}^{N/2}[phase\ \ S_i \ - phase(S_{\frac{N}{2}+i})]$$

After having $\varnothing$ we can remove its effects on the data vector by multiplying its every symbol with $\varnothing$ and timing index.

3.4.3 Channel Estimation

In our project we used pilot data located into data vector to estimate channel matrix $\bar{\lambda}$ which is later used in the following formula to calculate $\boldsymbol{Y}$ output vector.

Assuming vector sent is $\boldsymbol{X}$ **;**

$$\boldsymbol{Y} = \bar{\lambda} * \boldsymbol{X} + \boldsymbol{n}$$

is given for output. In the formula $\boldsymbol{n}$ represents the noise. Assuming X is the pilot that is known to receiver we calculate $\bar{\lambda}$ and use it to remove channel effect from rest of the data vector.

3.4.3 Adjustment on Phase-Offset

Fine tuning is an important matter for good quality. Looking at Figure 3.7 and Figure 3.8 we can understand if it is not done it can cause miscalculation.

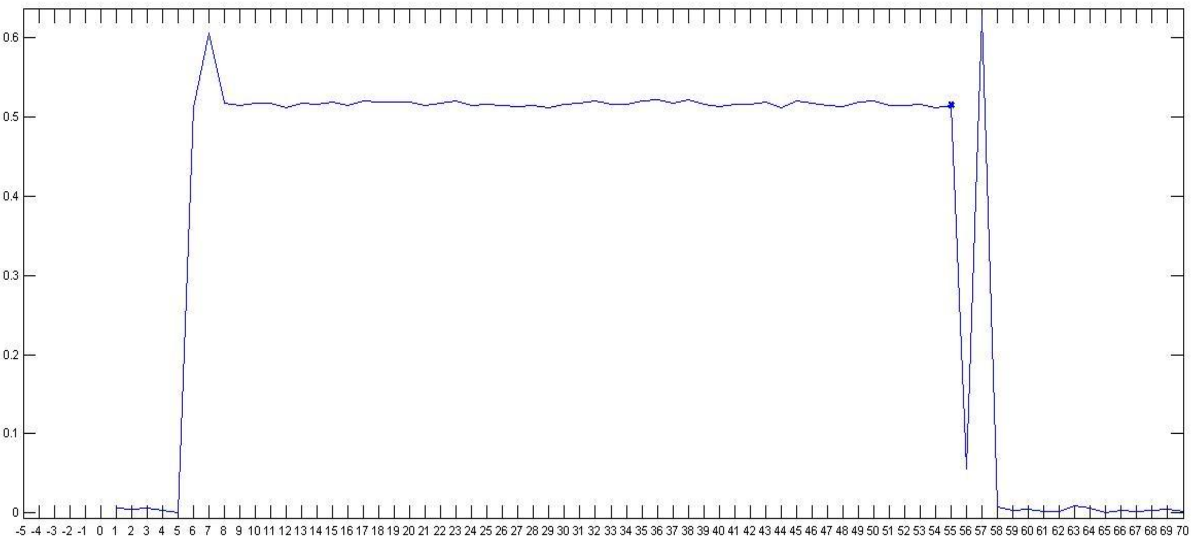

Figure 3.7 Sdr4all preamble

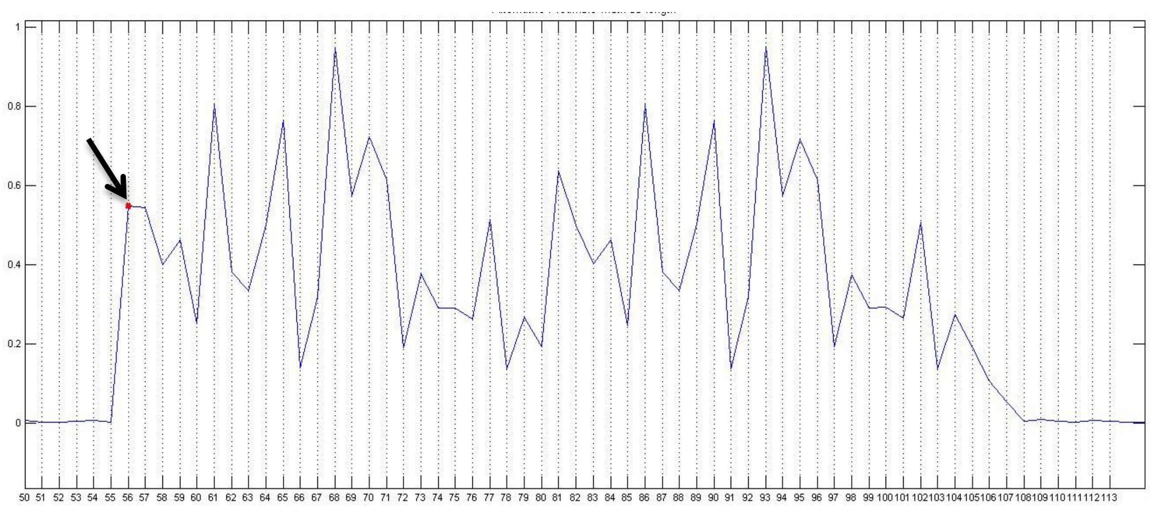

Figure 3.8 Proposed preamble

Simply when we look at the Figure 3.7 we can see some peak and drop abnormalities which are not planned to be there. What we need to do to overcome this problem. Definitely we need to determine timing index corresponding these abnormalities at the beginning and end of the preamble and not to use them in our calculations. This generally hits the less than 10 percent of preamble size.

Same problem with lesser degree is observed with proposed preamble at Figure 3.28 and it can be prevented in same way explained above with less percent of proposed preamble size likely %5.

CHAPTER 4

RESULTS AND CONCLUSION

4.1 RESULTS AND DISCUSSION

USRP is very useful to help for researcher, students to carry on their experiment. In this thesis we used it several times to test programs, see results, discover problems and develop solutions.

We have done communication with OFDM based modulation over USRP and do more studies on synchronization with the help of two different preambles named sdr4all preamble and proposed preamble. The preamble we named proposed preamble has put better performance in terms of timing index or phase offset synchronization.

We have done following studies to compare sdr4all preamble and proposed preamble and have shown their performance on graphs.

1. In simulation environment
   a. Phase offset calculation
   b. Timing index calculation
2. In real environment (with USRP)
   a. Phase offset calculation
   b. Timing index calculation

4.1.2 The Simulation Results

The two preambles are tested on MATLAB program. In the program the preambles are put in same date frame, their power levels and length were equalized. The program is tested for different level of SNR. The obtained results suggest followings graphs.

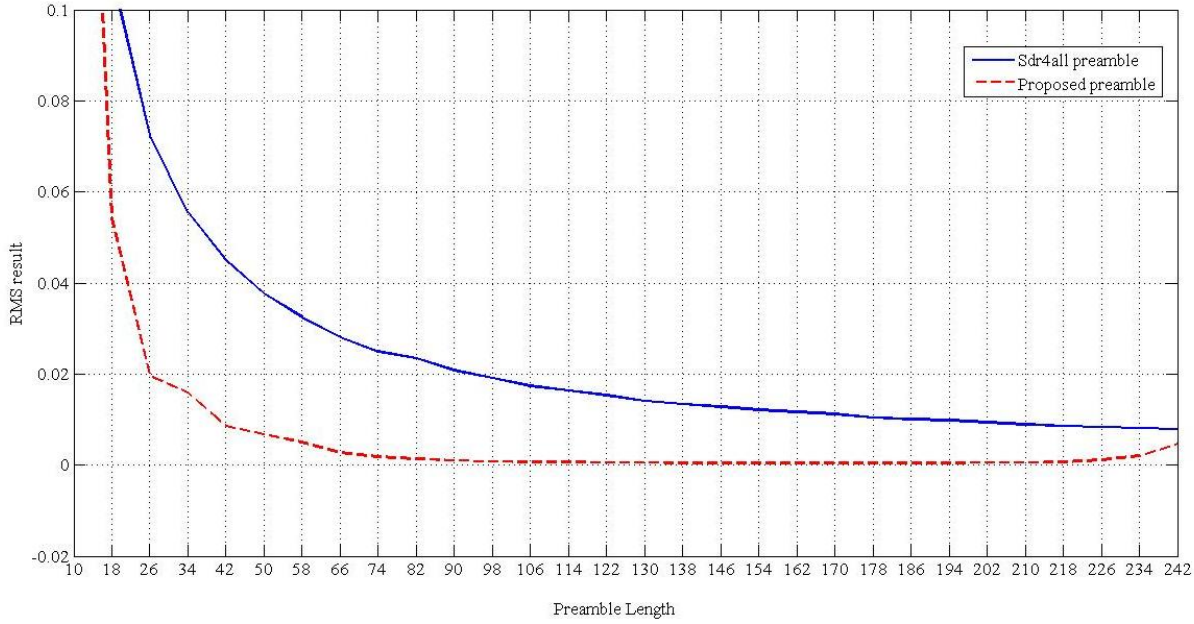

Figure 4.1 The preambles phase offset estimation at SNR 40

As it is seen on above figure proposed preamble phase offset estimation RMS result is increasing (worsening) after the length of 234. The reason for this can be explained such that if we are to estimate a phase offset 0.05 degree which means that the distance between corresponding symbols of proposed preamble can be $\frac{2pi}{0.05}=125$ and more than this will not estimate a right phase offset.

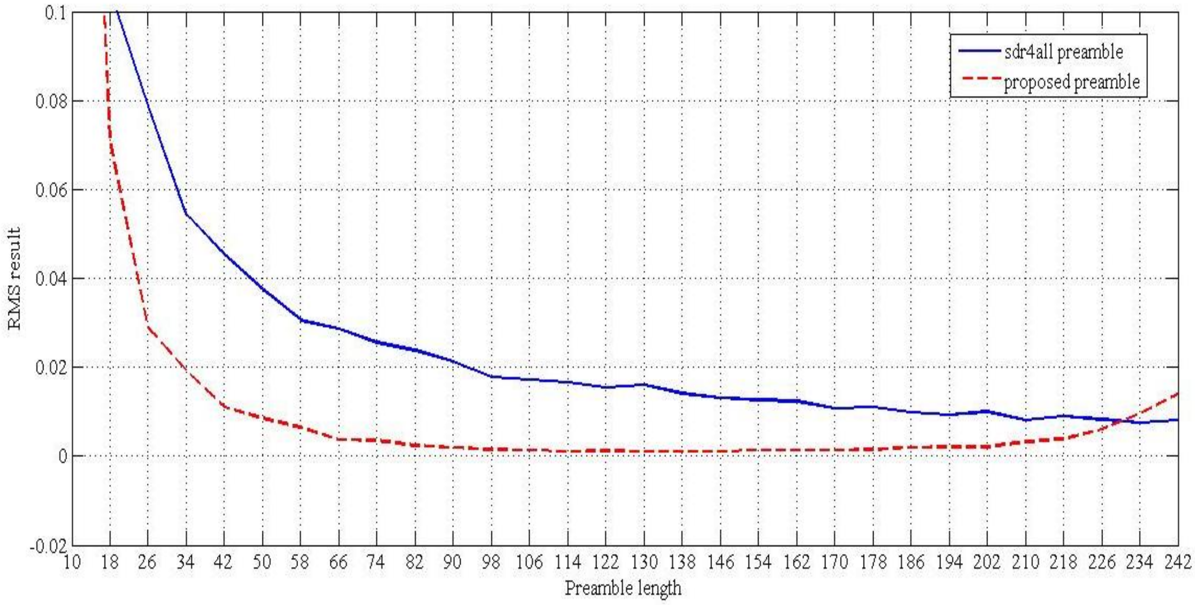

Figure 4.2 The preambles phase offset estimation at SNR 30

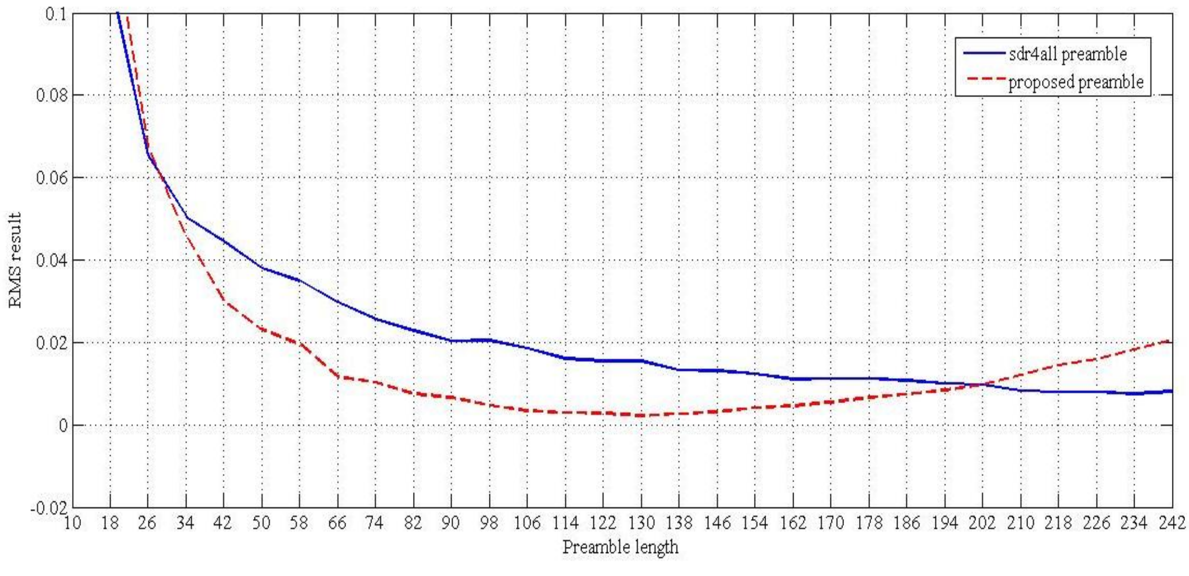

Figure 4.3 The preambles phase offset estimation at SNR 20

The next three graphs show the preambles timing index estimation comparison in terms of RMS for SNR level 40, 30, 20 respectively.

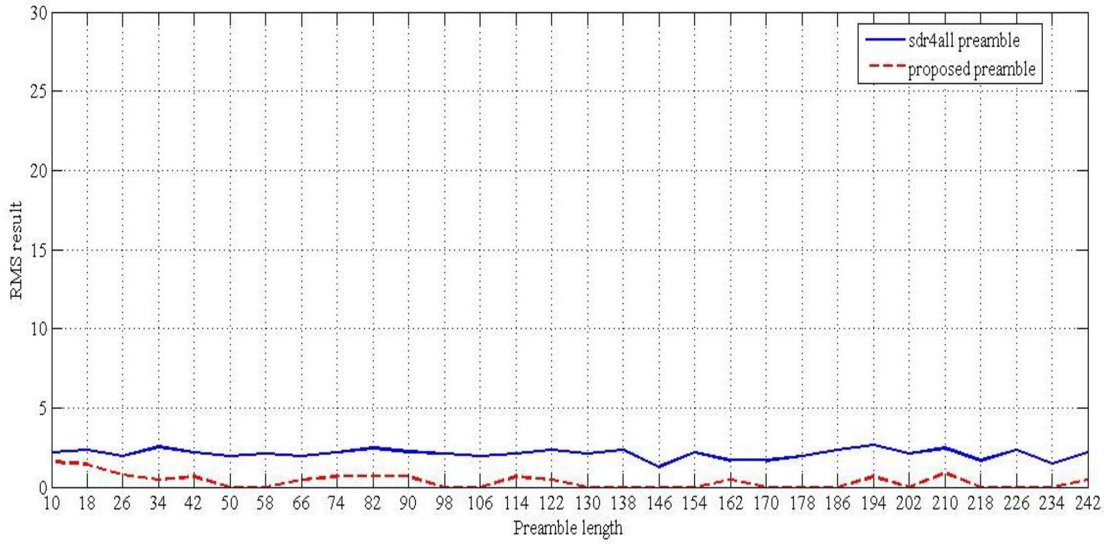

Figure 4.4 The preambles timing index estimation at SNR 40

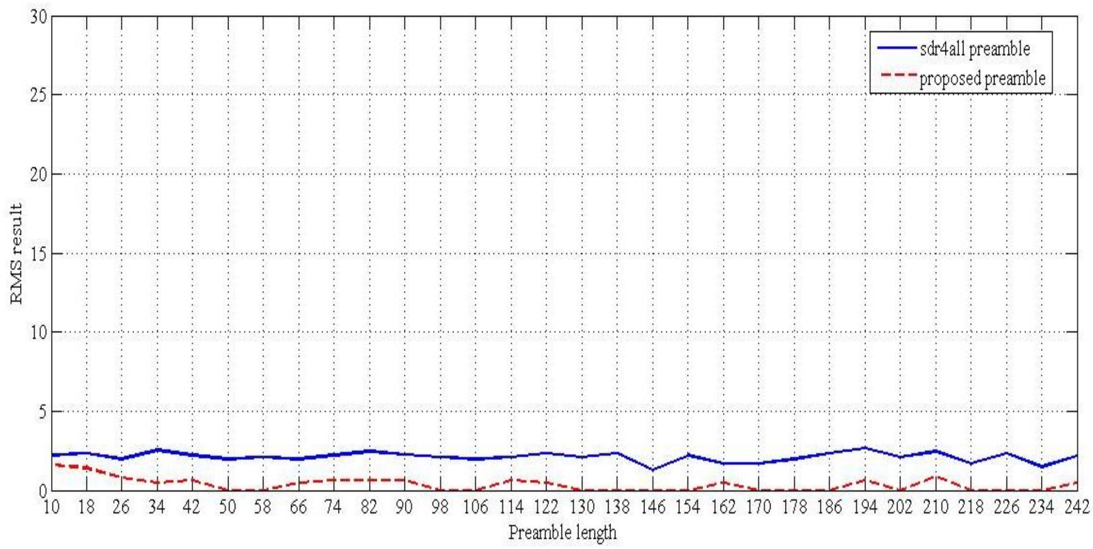

Figure 4.5 The preambles timing index estimation at SNR 30

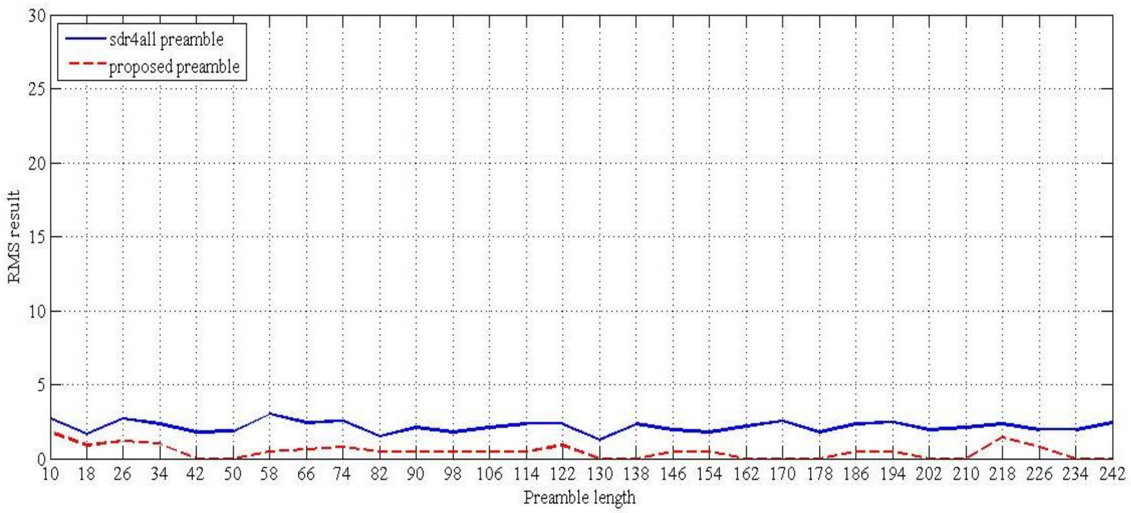

Figure 4.6 The preambles timing index estimation at SNR 20

4.1.3 The Experimental Results on USRP

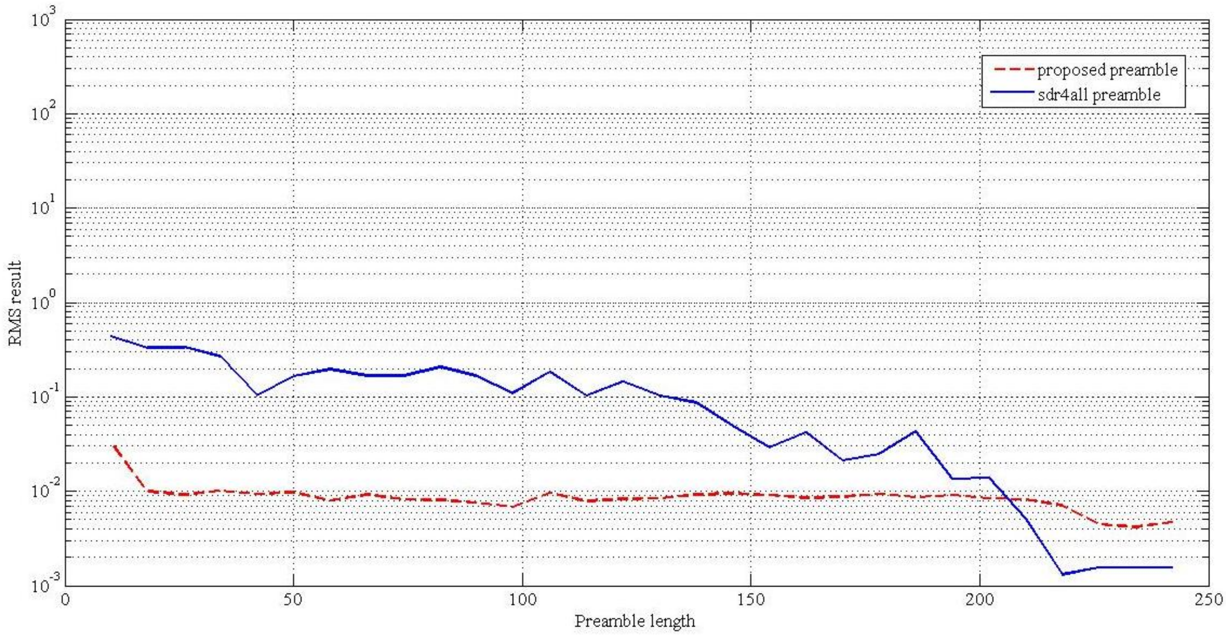

Figure 4.7 The preambles phase offset estimation

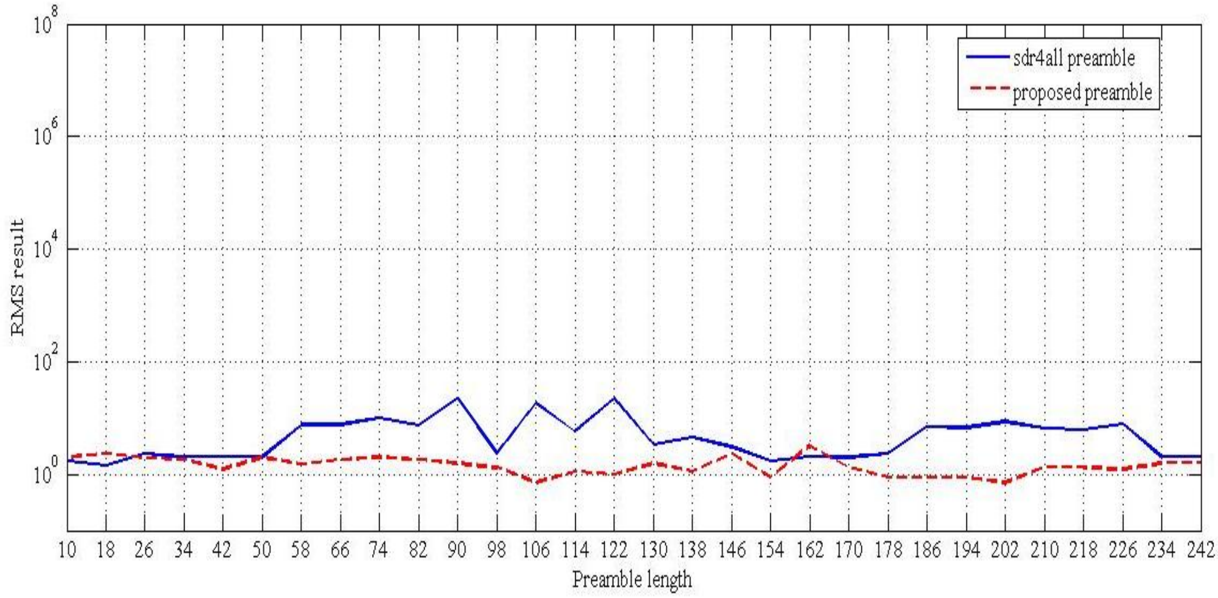

Figure 4.8 The preambles timing index estimation

When we are carrying on our experiment we intentionally reduced the power level of transmitter 10 times to increase noise level therefore to increase probability of wrong estimation to be able see the performance of the preambles better. The sharpness on graphs is due to number of repetition test for each preamble length which is kept far smaller than the one used in simulation due to the fact that it takes long times to finish.

4.2 CONCLUSION

As it was stated at the beginning, the main object of this thesis is to achieve wireless transferring of data from one USRP to other one and at the receiver maintain good synchronization in terms of phase offset and timing for which to use two structurally different preamble called sdr4all and proposed preambles and show and compare their performance both in matlab simulation program and on USRP devices. These two goals were successfully achieved. When we compare these two so mentioned preambles we reached following conclusions.

A. Both preambles can be used for synchronization purposes for both phase offset estimation and timing synchronization.
B. Figure 4.1 which is estimation done in simulation program and figure 4.7 which is result of USRP experimental test suggest that proposed preamble phase offset estimation is better than sdr4all estimation for short preamble length yet sdr4all preamble can have same performance with use of longer preamble length.
C. Figure 4.5, 4.6, 4.7 are timing index estimation of simulation program suggest that the two preambles put slightly different performance yet in real environment shown on figure 4.8 the proposed preamble put more stable and reliable performance.
D. For sdr4all preamble it can be said that to get the more correct phase estimation the more length of preamble needed yet it does not help to estimate better timing index unfortunately.
E. For proposed preamble, keeping in mind that it does estimation better, it has length limitation proportional to phase offset to be estimated such that the higher phase offset the shorter length of preamble. This problem can be overcome repletion of preamble. Unlike sdr4all preamble the proposed preamble make better estimation with increment of its length in the case of timing estimation.
F. For both preambles it is true to say that if very beginning and very end of preambles were kept out of calculation it would give better estimation.

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