IMPLEMENTATION OF ZIGBEE PHY AND COMPARISION WITH FPW AND RPW

A Project Report

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THESIS CERTIFICATE

This is to certify that the thesis titled **IMPLEMENTATION OF ZIGBEE PHY AND COMPARISION WITH FPW AND RPW**, submitted by **POORNA CHANDRA**, to the Indian Institute of Technology, Madras, for the award of the degree of **MASTER 'OF TECHNOLOGY** is a bona fide record of the research work done by him under our supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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ABSTRACT

ZigBee is a low-cost, low-power, wireless standard targeted at the development of long battery life devices in wireless control and monitoring applications. In this thesis, I have implemented the ZigBee Physical layer in real time on USRP (Universal software radio peripheral) and compared the performance of ZigBee with FPW (Fixed polarization wave) and RPW (Rotatition polarization wave) in wired and wireless environment in terms of BER(Bit error rate) ,FER(Frame error rate) and the channel power. Also have implemented Half duplex which can transmit and receive using USRP's at different instants of time.

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CHAPTER 1

INTRODUCTION

1.1 ZigBee/IEEE 802.15.4

ZigBee is a standard that defines a set of communication protocols for low data-rate short-range wireless networking. ZigBee-based wireless devices operate in 868 MHz, 915 MHz, and 2.4 GHz frequency bands. The maximum data rate is 250 K bits per second. ZigBee is targeted mainly for battery-powered applications where low data rate, low cost, and long battery life are main requirements. In many ZigBee applications, the total time of the wireless device is engaged in any type of activity is very limited; the device spends most of its time in a power-saving mode, also known as sleep mode. As a result, ZigBee enabled devices are capable of being operational for several years before their batteries need to be replaced.

One application of ZigBee is in-home patient monitoring. A patient's blood pressure and heart rate, for example, can be measured by wearable devices. The patient wears a ZigBee device that interfaces with a sensor that gathers health related information such as blood pressure on a periodic basis. Then the data is wirelessly transmitted to a local server, such as a personal computer inside the patient's home, where initial analysis is performed. Finally, the vital information is sent to the patient's nurse or physician via the Internet for further analysis.

Another example of a ZigBee application is monitoring the structural health of large scale buildings. In this application, several ZigBee-enabled wireless sensors (e.g., accelerometers) can be installed in a building, and all these sensors can form a single wireless network to gather the information that will be used to evaluate the building's structural health and detect signs of possible damage. After an earthquake, for example, a building could require inspection before it reopens to the public. The data gathered by the sensors could help expedite and reduce the cost of the inspection. A number of other ZigBee application examples are shown in Fig 1.1.

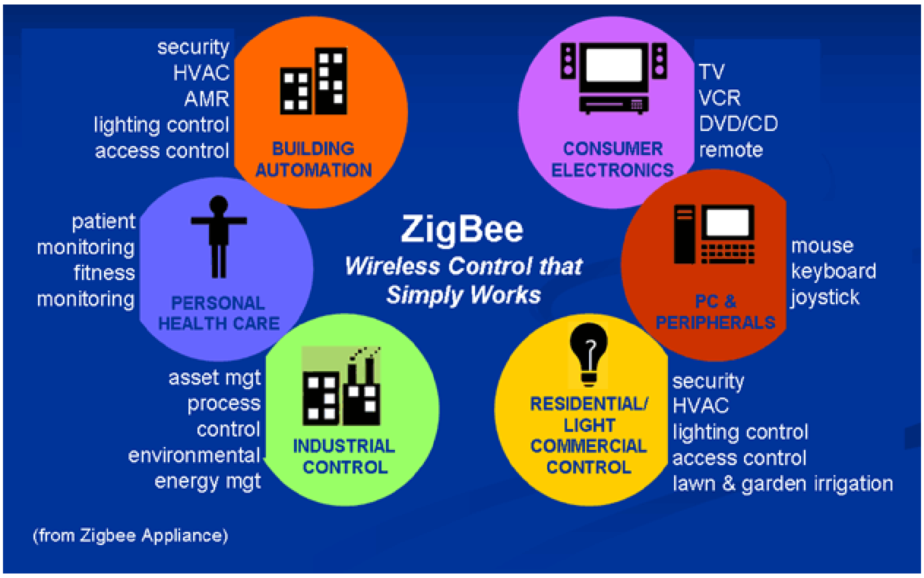


Fig 1.1 Applications of ZigBee

The ZigBee standard is developed by the ZigBee Alliance, which has hundreds of member companies, from the semiconductor industry and software developers to original equipment manufacturers (OEMs) and installers. The ZigBee Alliance was formed in 2002 as a non-profit organization open to everyone who wants to join. The ZigBee standard has adopted IEEE 802.15.4 as its Physical Layer (PHY) and Medium Access Control (MAC) protocols. The complete Open Systems Interconnection model (OSI model) is shown in Fig 1.2.

There are three frequency bands in IEEE 802.15.4.

Frequency(MHz) : 868 - 868.6

Number of channels : One

Modulation : BPSK

Chip rate(chips/sec) : 300

Bit rate (kbps) : 20

Symbol rate(Ksymbols/s) : 20

Spreading method: : DSSS (Direct Spread Spectrum Sequence)

Direct Sequence Spread Spectrum(DSSS) helps improve performance of receivers in multipath environment.

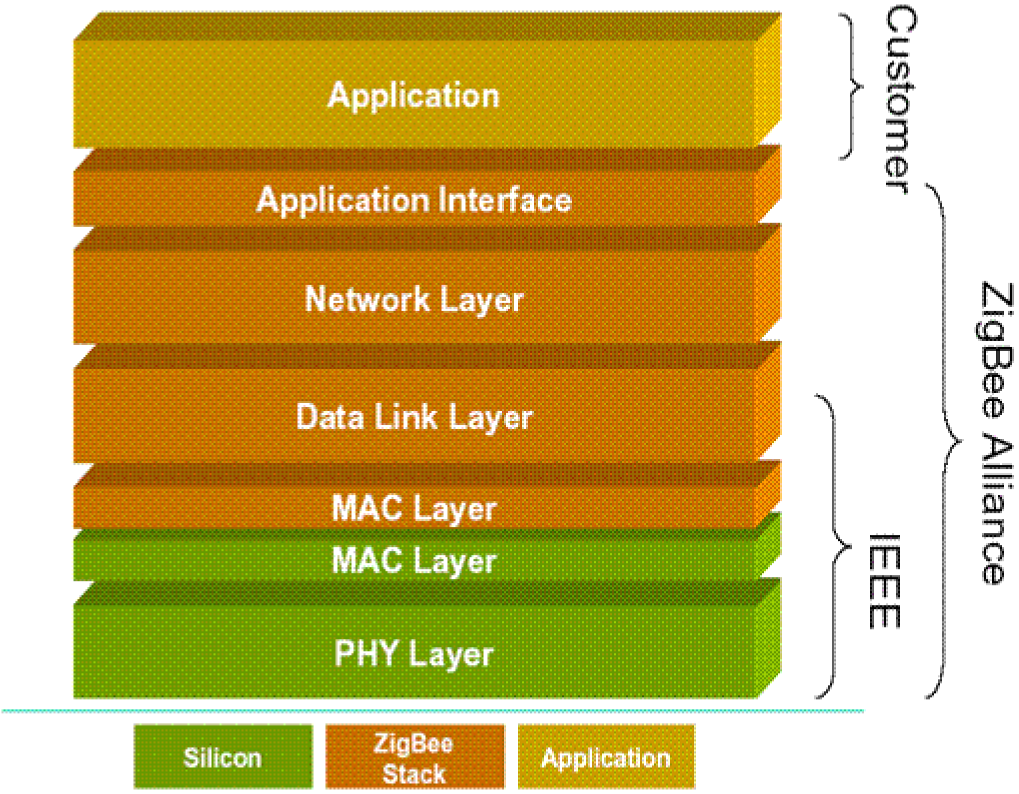


Fig 1.2 ZigBee wireless Networking protocol stack

1.2 Rotating Polarization Wave

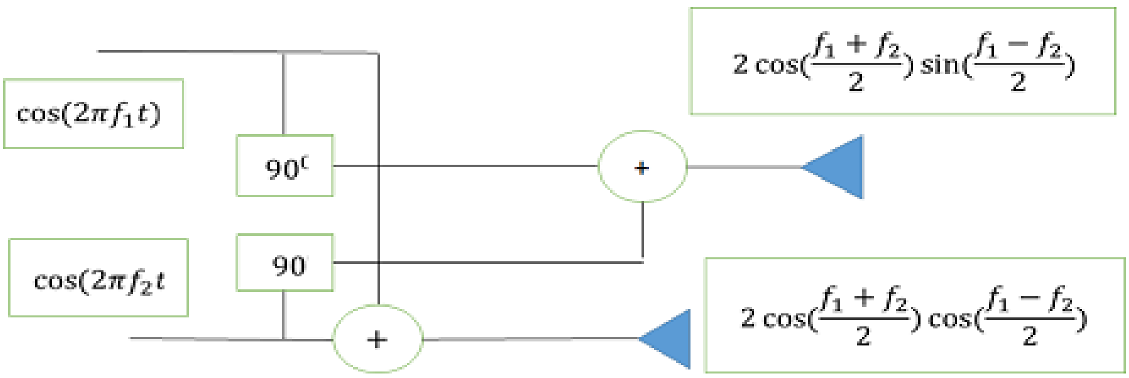


Fig 1.3 Generation of Rotation Polarization wave

Unlike FPW and Zigbee , signal is transmitted on both the horizontal and vertical antennas. The signal at the horizontal is the sum of the cosine signals and the signal at the vertical antenna is the result of sum of the cosine signals undergoing a phase shift of 90 individually. The resultant signal at the horizontal and the vertical antenna has two frequency components :

$\frac{f_1+f_2}{2}$ - Carrier Frequency ; $\frac{f_1-f_2}{2}$ - Rotation Frequency

Rotation Frequency: The frequency at the which the transmitted electromagnetic wave rotates through 360 degrees.

Steps to fix the rotation frequency:

1. Number of polarizations needed : 64
2. Sampling frequency : 1 Msps
3. Over Sampling factor : 4
4. Sampling time : 1 microseconds
5. Symbol duration : 4 * 64 microseconds
6. Rotation Frequency : 3906.25 Hz

At the receiver, the signals received at both antennas are added through phase shifter so that the inphase and quadrature components are generated.

CHAPTER 2

Comparison of ZigBee , FPW and RPW in wireless environment

2.1 Zigbee Physical Layer

Before Comparing Zigbee with FPW and RPW, there is need for repetition for the data bits to match the data rates of RPW and FPW as they are using 64 PN sequence. So to match the rates the first eleven bits are repeated 4 times and the next four bits are repeated 5 times.

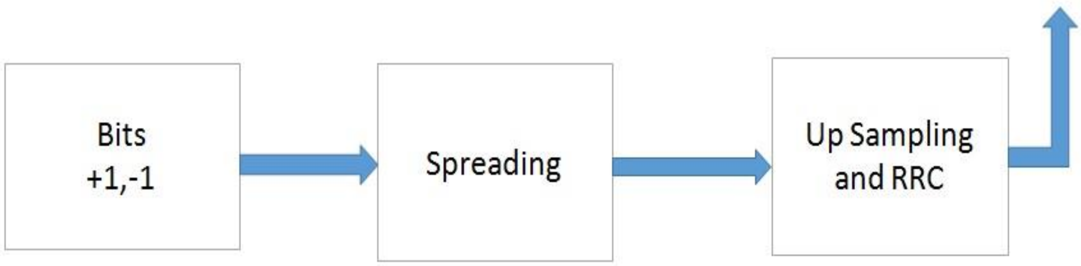


Fig 2.1 : Transmitter

Length of Chip sequence : 15

Up sampling factor : 4

Length of RRC : 9

Chip sequence for '0' and '1'.

Input bits	Chip value
-1	1 1 1 1 -1 1 -1 1 1 -1 -1 1 -1 -1 -1
+1	-1 -1 -1 -1 1 -1 1 -1 -1 1 1 -1 1 1 1

Fig 2.2 : Chip values

Preamble : 32 Zeroes

Channel estimation : 8 ones

Number of Frames : 5000

Data bits : 192

Rake Receiver:

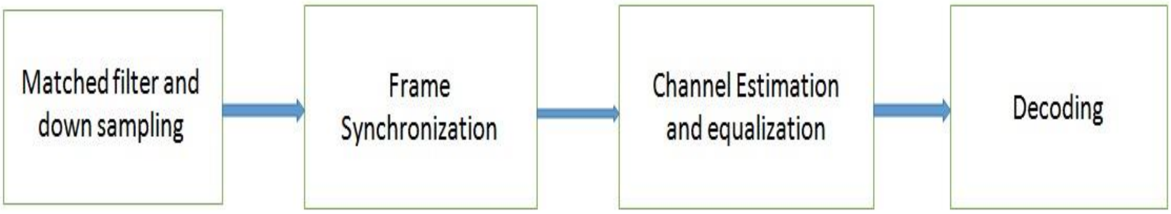


Fig 2.3 Receiver

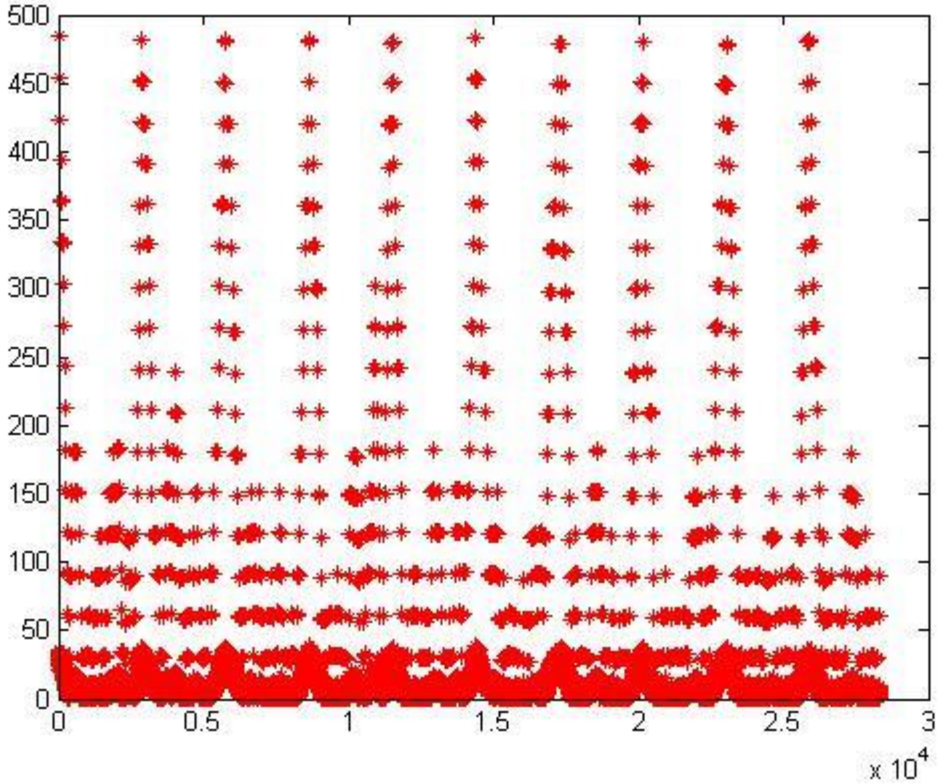


Fig 2.4 Frame Synchronization

As we can see very clearly from the above figure that as the preamble correlates with the frame, the peaks occur at the regular intervals indicating the start of the frame.

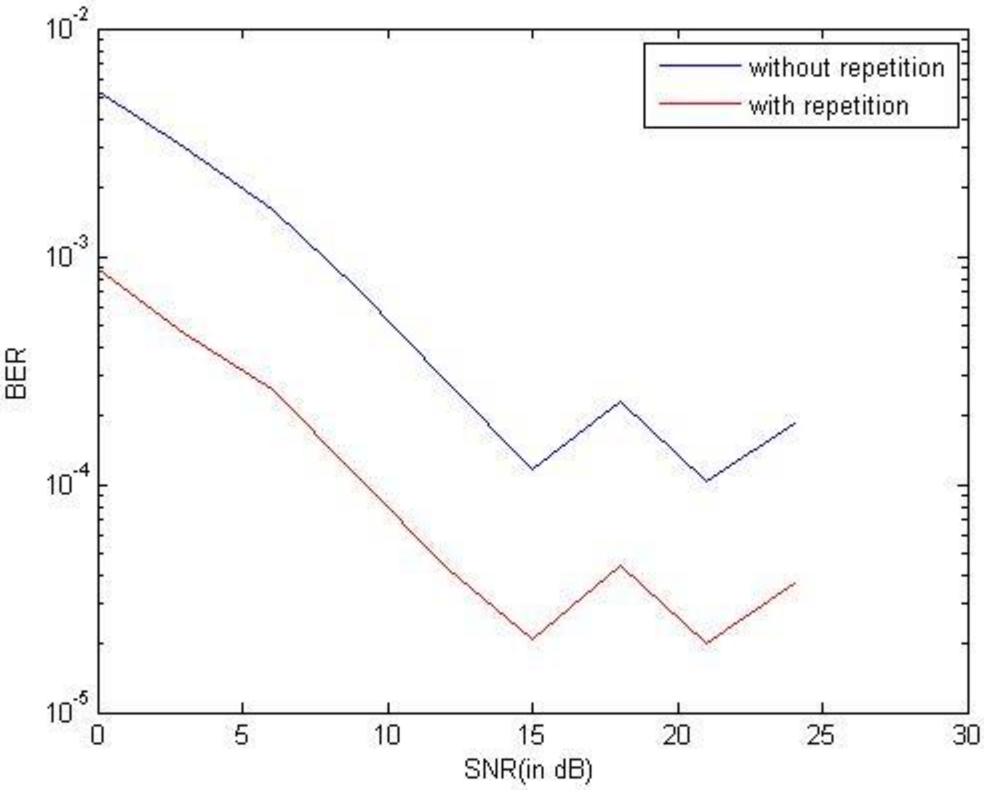


Fig 2.5 : BER with and without repetition

2.1 Experimental Setup

In case of Fixed Polarisation Wave(FPW), the received signal strength varied with the orientation of the antenna. The antenna orientation was changed manually and the signal strength was observed from the spectrum shown by gnuradio at the receiver USRP. Among the possible antenna orientations, an orientation with strong signal reception of FPW was identified and referred henceforth as 'Good' case and another orientation with weak signal reception of FPW was identified and referred henceforth as 'Poor' case.

At each location, the antenna was rotated to achieve the 'good' FPW case and data was collected for the three radio schemes i.e. FPW, RPW and Zigbee for comparison. The same experiment was repeated at the same location with antenna orientation changed to achieve 'poor' FPW case as described above. The transmitter gain was varied in a specified range in each experiment to analyse the Bit Error Rate(BER). As the distance between the transmitter and receiver was increased the beyond location 1 and 2 the received signal strength started to decrease significantly. Therefore, the

Bit Error Rate was observed to be very high in the 'Poor' case at location 4 for the transmitter gain range of 36 to 48 dB as seen in the BER table 2(). Accordingly, the transmitter gain range was extended further to observe the decrease in BER at higher gains at location 3. From the BER readings of location 3 it was considered that the transmitter gain range of 51 to 66 dB should suffice to demonstrate a BER trend in the location 5 and 6. Therefore, the transmitter gains were chosen as given in the Table 1. Receiver Gain was kept at 35dB throughout the experiment and centre Frequency as 430 MHz.

The experiment was conducted in Machines lab in the Electrical department and the layout of the machines lab is in the following figure.

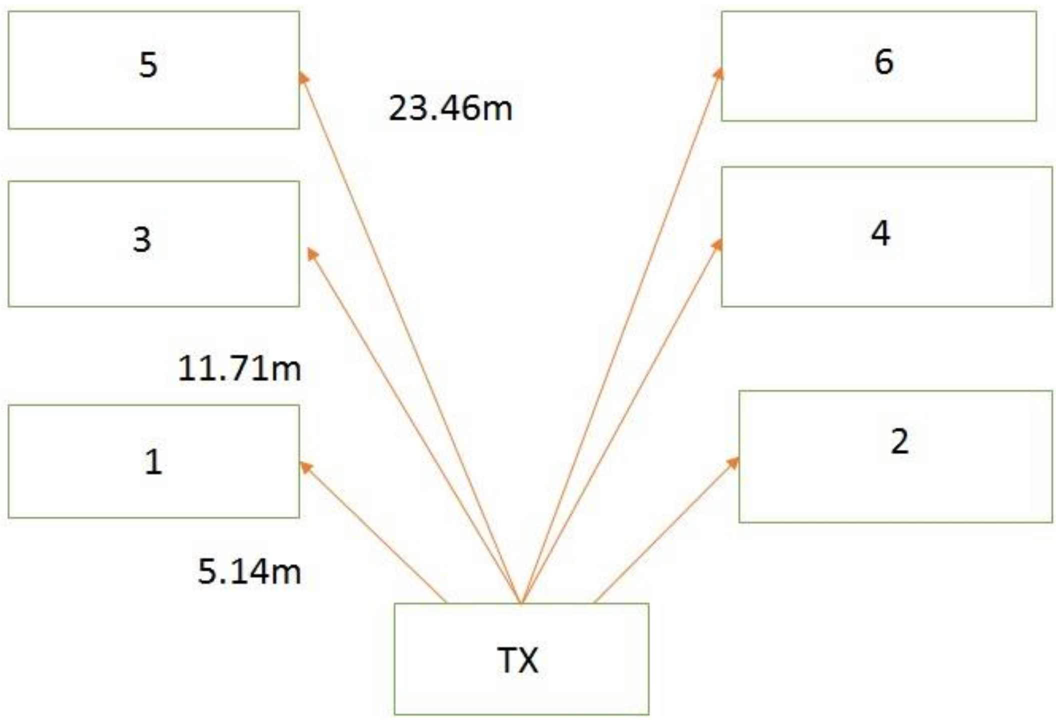


Fig 2.6 : Layout of the machines lab

Range of TX gains (in dB)	Positions
36 to 48 (steps of 3)	1, 2
36 to 60 (steps of 3)	3
36 to 48 (steps of 3)	4
51 to 66 (steps of 3)	5, 6

Table 2.7: TX Gain Range vs RX Location

2.2 BER Comparison

All the data files obtained were processed to obtain the Bit Error Rates in all cases. The Bit Error Rates are given in the tables 3(a) to (f) for various locatons. The different colours are used in the table to highlight the scheme which has given least BER i.e. best performance for particular location, Tx Gain and antenna orientation (Good or Poor case). The colours and corresponding scheme are given in Table 2 below.

Tx Gain	Position 1 Poor Case			Position 1 Good Case		
	Fixed	**RPW**	**ZigBee**	**Fixed**	**RPW**	**ZigBee**
36	0.410355	0.05169	0.29952	0.03375	0	0.0081067
39	0.14558	0.002815	0.1105067	0.000125	0.00002	0.0072533
42	0.137015	0.00001	0.0443733	0	0.000045	0.000535
45	0.00872	0.00001	0.0016	0.000025	0.000035	0
48	0.0005	0.00007	0.0048	0	0.000025	0

Table 2.2 : **BER READINGS IN POSITION 1**

Tx Gain	Position2 Poor Case			Position 2 Good Case		
	Fixed	RPW	ZigBee	Fixed	RPW	ZigBee
36	0.433	0.000245	0.1058133	0.00713	0.001115	0.0183467
39	0.04675	0.00001	0.1245867	0.00014	0.00038	0.0026747
42	0.011355	0.00007	0.07936	0.000055	0.000065	0.0007069
45	0.004055	0.00009	0.0005349	0.00005	0.000075	0
48	0.0005	0.00002		0	0	0

Table 2.3 : **BER READINGS IN POSITION 2**

Tx Gain	Position 3 Poor Case			Position 3 Good Case		
	Fixed	RPW	ZigBee	Fixed	RPW	ZigBee
36	0.49685	0.17311	0.5064533	0.001325	0.1409	0.5000533
39	0.496675	0.291635	0.5009067	0.00003	0.34012	0.0110933
42	0.497645	0.06436	0.5077333	0.00008	0.11858	0.04
45	0.497725	0.01131	0.4770133	0.00004	0.053445	0.011
48	0.459115	0.00011	0.1173333	0.000045	0.004725	0
51	0.45649	0.00003	0.06528	0	0.00069	0
54	0.19431	0.00001	0.34688	0	0.000015	0
57	0.12656	0.00005	0.0256	0.000105	0.000055	0
60	0.043755	0.00003	0.0064	0.00003	0.000045	0

Table 2.4 : **BER READINGS IN POSITION 3**

Tx Gain	Position 4 Poor Case			Position 4 Good Case		
	Fixed	RPW	ZigBee	Fixed	RPW	ZigBee
36	0.49695	0.416615	0.49664	0.00011	0.492975	0.0366933
39	0.49818	0.48859	0.50304	0.000065	0.489195	0.0042667
42	0.496285	0.396375	0.4893867	0.00005	0.08951	0.0075
45	0.49393	0.14047	0.2927	0	0.02465	0
48	0.457675	0.042845	0.1376	0.000095	0.0001	0

Table 2.5 : BER READINGS IN POSITION 4

Tx Gain	Position 5 Poor Case			Position 5 Good Case		
	Fixed	RPW	ZigBee	Fixed	RPW	ZigBee
51	0.49436	0.485186	0.5085867	0.337605	0.227635	0.3771733
54	0.460925	0.261275	0.35584	0.078395	0.397255	0.02176
57	0.233105	0.16037	0.16896	0.012185	0.17408	0.00896
60	0.078765	0.057385	0.2973867	0.002345	0.074845	0
63	0.012955	0.01406	0.0648533	0.00004	0.00866	0
66	0.002235	0.00002	0.0183467	0.000045	0.00017	0

Table 2.6 : BER READINGS IN POSITION 5

Tx Gain	Position 6 Poor Case			Position 6 Good Case		
	Fixed	RPW	ZigBee	Fixed	RPW	ZigBee
51	0.34278	0.03191	0.1913	0.06467	0.06702	0.1762133
54	0.13201	0.001495	0.1228	0.002055	0.00379	0.0379733
57	0.007535	0.008725	0.0348	0.000575	0.001905	0.0038783
60	0.002215	0.000825	0.0203	0.000055	0.00002	0.0038783
63	0.00064	0.000015	0.0016	0.000045	0.00007	0
66	0.00006	0.000015	0.0005349	0.0013	0.00078	0

Table 2.7 : **BER READINGS IN POSITION 6**

It is seen from the readings of Table 3 that RPW has performed better than the other two schemes at all the locations when the antenna orientation is set in the 'poor' FPW reception case. The performance of Fixed Polarised Wave and ZigBee is heavily dependent on the antenna orientation. Therefore, it is required to carry out measurements and fix the antenna orientation in certain way to achieve satisfactory performance in case of FPW and Zigbee in a given scattering environment. It also means that if the scattering environment is changed, the same antenna orientation may not guarantee the satisfactory performance by FPW and Zigbee schemes. However, it is seen that the RPW performance is not drastically affected by change in antenna rotation and therefore, it can guarantee satisfactory performance irrespective of the antenna orientation.

2.3 Channel Plots

The figure 2 illustrates the channel powers observed at locations 1, 4 and 6 for the three schemes RPW, Fixed and Zigbee when antenna orientated to achieve 'Good' FPW and 'Poor' FPW reception.

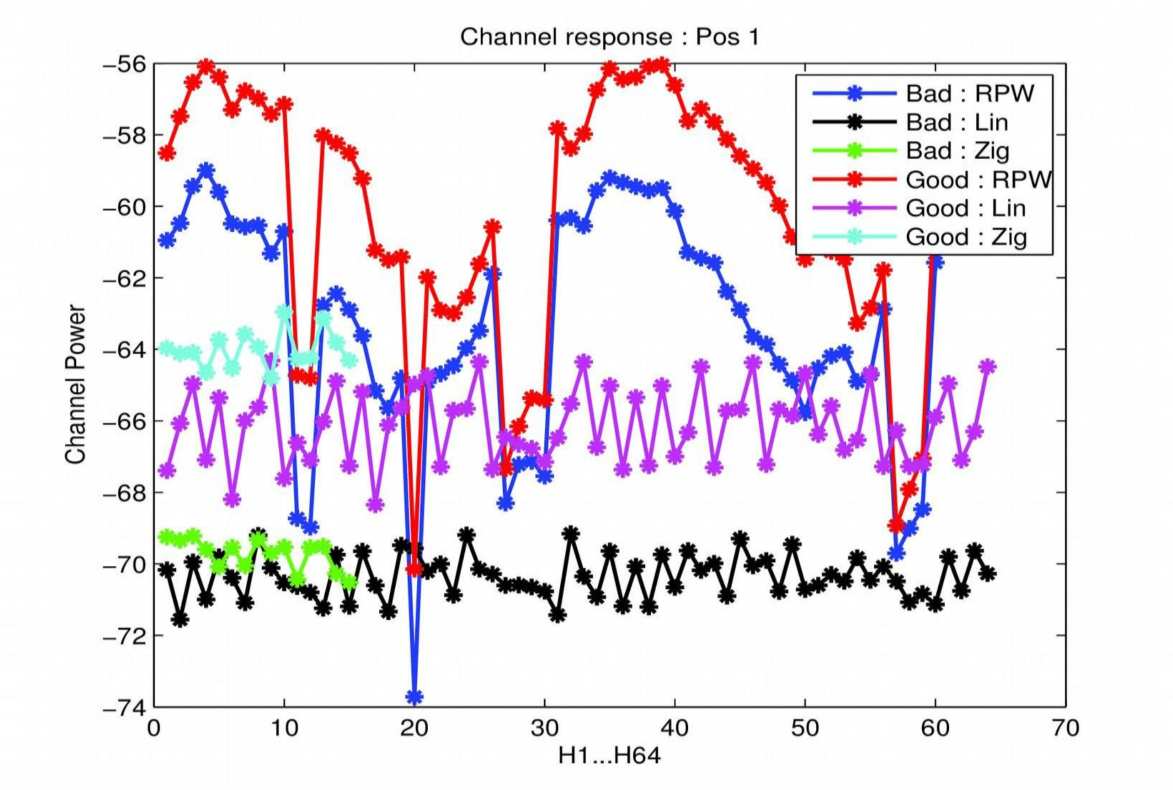


Fig 2.8: Channel response in Position 1

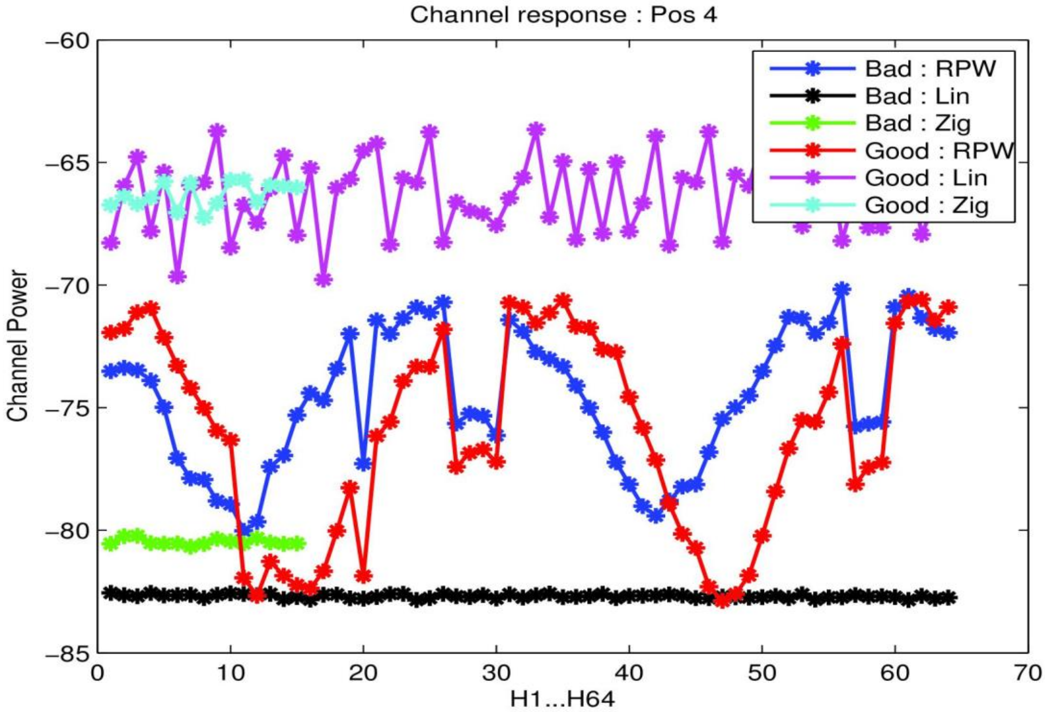


Fig 2.9: Channel response in Position 4

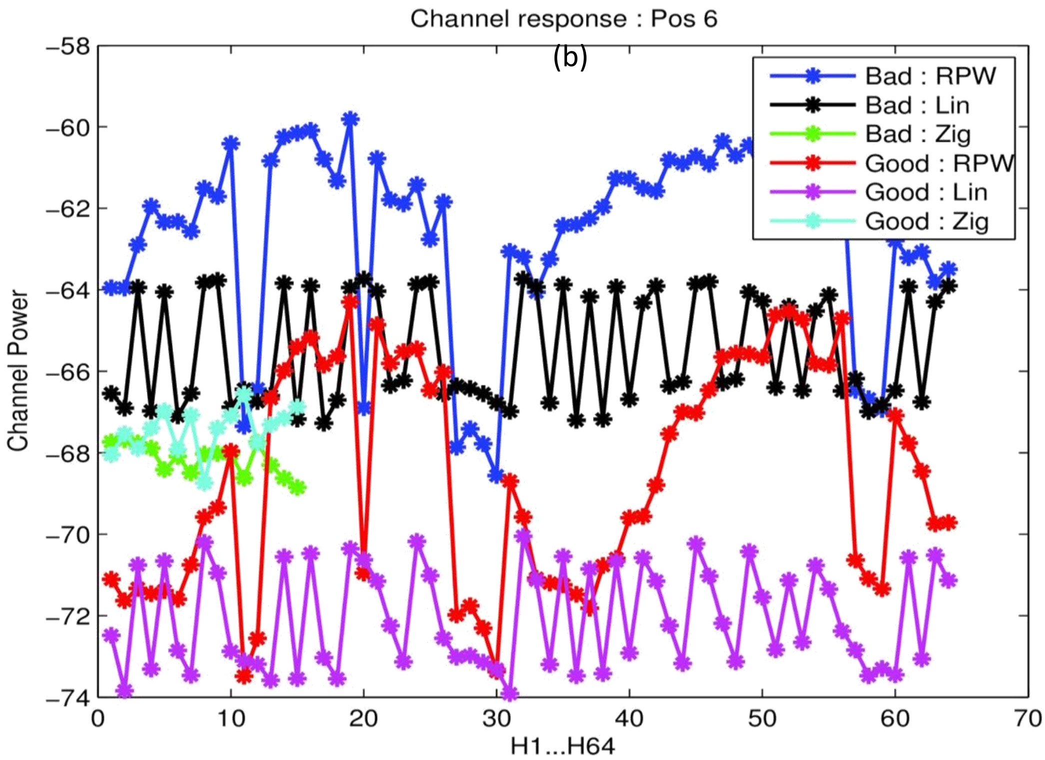


Fig 2.10: Channel response in Position 6

CHAPTER 3

REAL TIME IMPLEMENTATION

The set-up as existed before this stage is shown in figure below. The data frames to be

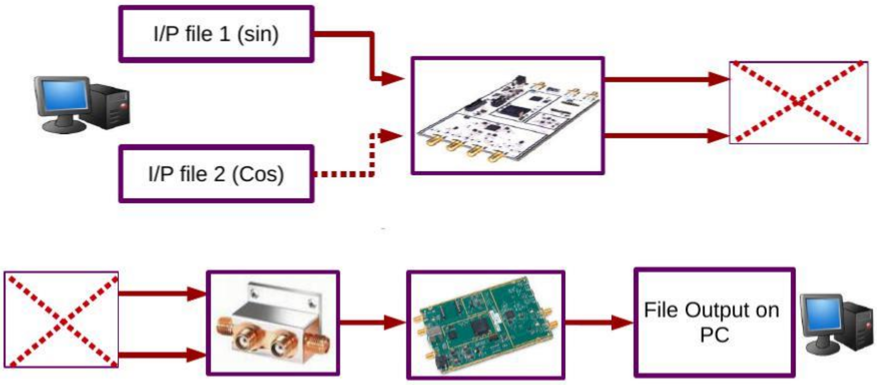


Figure 3.1: Transmitter and Receiver USRP configurations

transmitted are generated a priori and written into les. These les are read from a host PC and fed to the transmitter USRP. The data samples from the receiver USRP are stored in a binary le for further processing such as frame decoding, bit error rate calculation etc.

This online process has to be converted to real time to implement involving the following tasks.

(a) UHD (Universal Hardware Driver) interface between USRP and the host PC

(b) Real Time Transmitter

(c) Real Time Receiver

(d) Half Duplex communication

3.1 Real Time transmitter

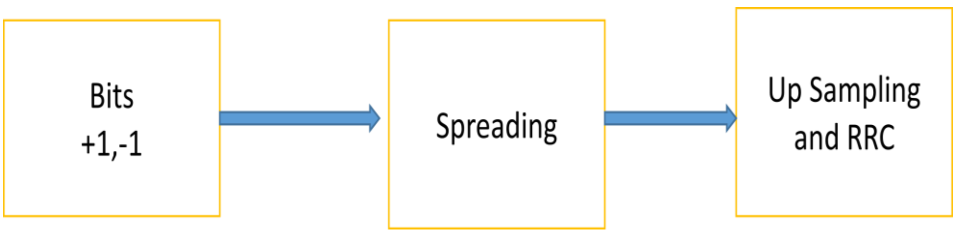


Fig 3.2 : Real time Transmitter

Length of Chip sequence : 15

Up Sampling factor : 4

Length of RRC : 9

3.2 Frame Structure :

Preamble : 32 Zeros.

Channel estimation bits: 8 ones.

Data :250

Preamble after Spreading: 32*15 = 480

After Up Sampling and RRC: (479*3+480) + 9 – 1 = 192

C.E after Spreading: 8*15 = 120

After Up Sampling and RRC: 119*3+120) + 9 - 1 = 485

Data after Spreading: 250*15 = 3750

After Up Sampling and RRC = (3749*3+3750) + 9 - 1 = 15005

Preamble 1925	C.E 485	Data 15005

Fig 3.3 : Frame Structure

Frame is fed to the buffer in parts as buffer size is limited i.e. 2044 samples.

Frame repetition rate = 17.415 ms (timing shown below).

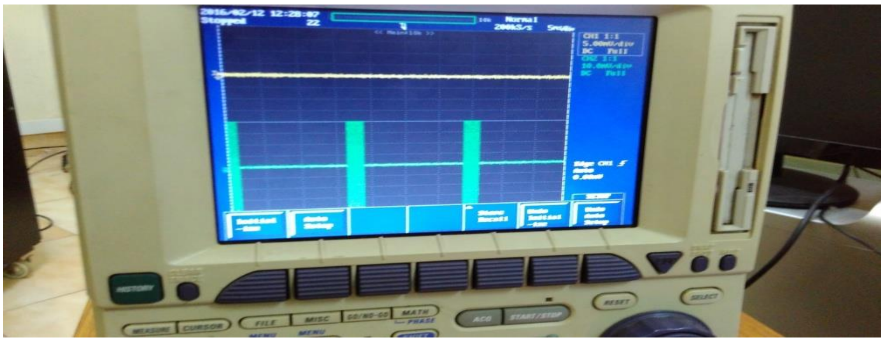


Fig 3.4 : Transmitted frame in Oscilloscope

3.3 Configuring the USRP

The USRP is interfaced using UHD in C/C++ environment. The USRP is configured for various parameters like Tx frequency, Clock rate, Bandwidth, Sampling frequency, choice of transmission port etc. using various commands. A brief code snippet example related to USRP configuration is displayed in figure 3.

3.4 Generation of Data frames

The subparts of the frame i.e. preamble, channel pilots and data are generated separately and appended together before transmitting it through USRP. The particular data bits could be generated randomly for each frame transmission or it could be read from a text file. However, we have implemented the CRC check sum algorithm at both transmitter and receiver and therefore, we have preferred to generate random data at each frame transmission to check the efficacy of CRC algorithm in the process.The USRP buffer can accommodate only 2044 complex oat data type samples. Accordingly, the USRP buffer is fed with those samples in a loop from the complete frame of 17415 data samples in the code snippet below.

Presently, a frame repetition rate of 20 ms is used. Once the real time transmission is done the waveform can be observed on the oscilloscope to notice the frame repetition time between two preambles. In order to visibly demarcate between frames, the data is kept zero.

3.5 Need for C/C++ Libraries

The transmitter and receiver signal processing chain requires frequent generation of vectors and matrices. It is also required to perform signal processing, arithmetic and logic operations on these vectors and matrices. The conventional C/C++ programming using arrays would not only become highly exhaustive but also make it difficult to debug the programme for errors. In order to overcome these issues, the Armadillo library, which has MATLAB like functions for various applications, is used. At the receiver end, a combination of faster library i.e. Intel IPP and Armadillo is used to enhance the processing speed. The details are explained below.

3.6 Real-Time Receiver

The receiver is also configured with the same parameters as that of the transmitter. Frame synchronization is done using correlation with the known preamble sequence at the receiver. The preamble portion of the frame does not contain the rotating polarization wave. It is linearly polarized. It is depicted in the figure 6. The complete frame except for the preamble undergoes rotating polarization and reaches the receiver. The channel estimation is done with the channel estimation bits using zero forcing technique. The data portion of the frame is then equalized using the estimated channel coefficients and then the frame error rate is calculated using CRC check sum.

3.7 Challenges Faced And Remedies Adopted

Any processing speed mismatch between the host PC and the USRP would result in over flow or under flow errors. These errors are illustrated in the following block diagram. Transmitter under flow errors resulted mainly from the erratic configuration of transmission timing parameters. If the feed to USRP transmit buffer is delayed for more than acceptable limit, the USRP will return the under flow errors. Similarly, if there is an unacceptable delay between two consecutive reading calls to USRP buffer due to extended processing, receiver USRP will return over flow errors. The transmitter under flow errors were eliminated using correct specification of USRP timing parameters.

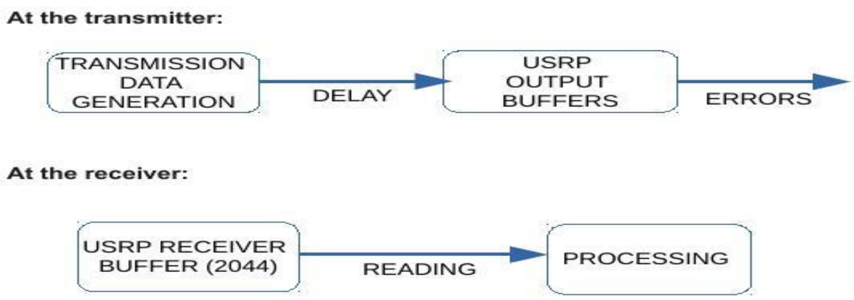


Fig 3.5 Consequence of processing speed mismatch at transmitter and receiver

3.8 BER and FER vs Gain

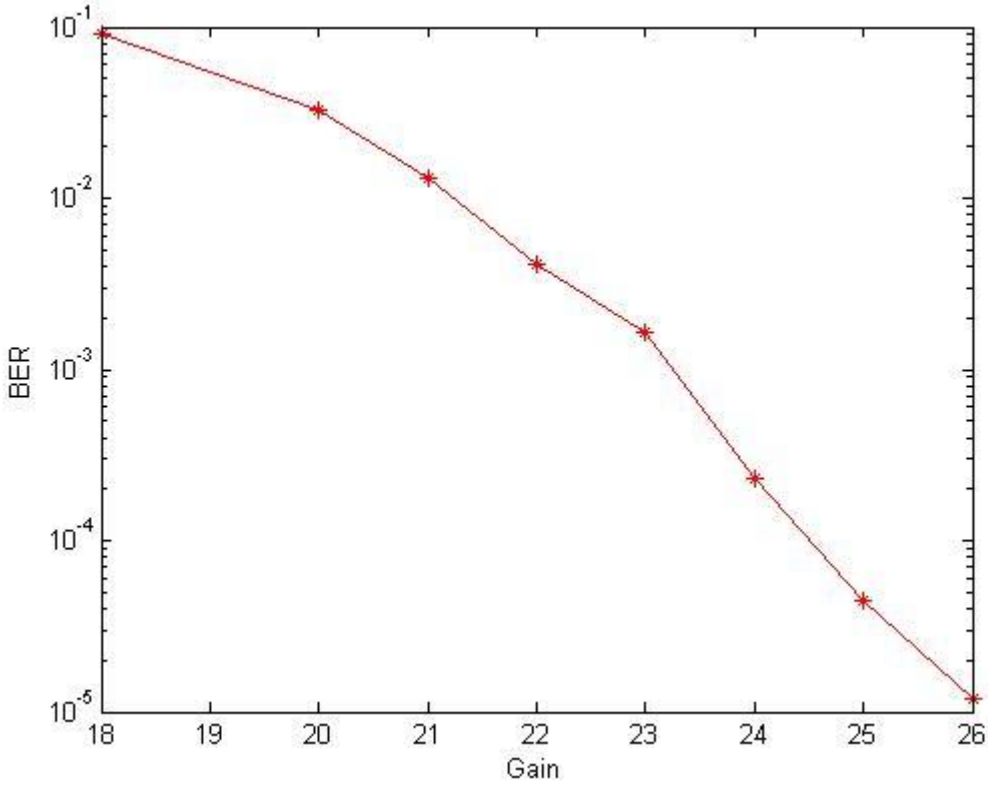


Fig 3.6 : BER vs Gain

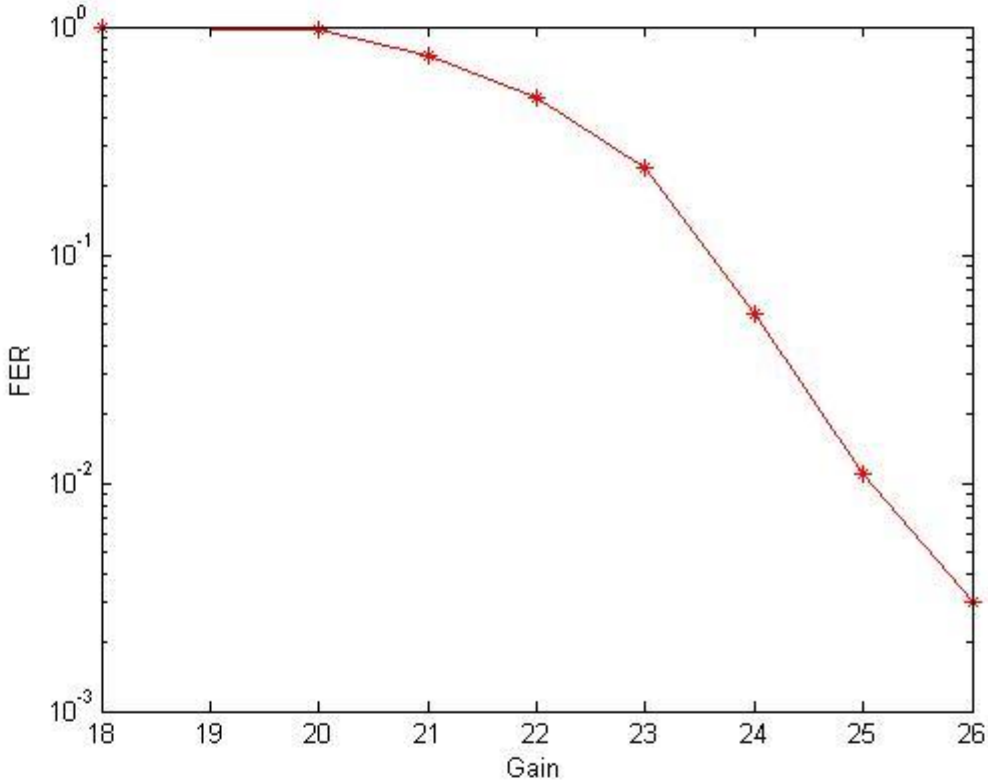


Fig 3.7 : FER vs Gain

CHAPTER 4

Point-to-Point Half-Duplex Radio

The half-duplex radio was developed in a step-by-step process. The development process is captured below.

4.1 Simple Relay

A set-up involving three USRPs are interconnected as follows.

1. A master transmitter: It is configured to transmit continuously at a fixed frame repetition rate every 4 s. The rate is chosen so large as to visually appreciate the transmission and reception on computer screen.

2. A half-duplex Node: It is configured to receive the data frame from the master transmitter and immediately retransmit it.

3. A master receiver: It is configured to only receive the data which could be from either the master transmitter or the half duplex node.

This demonstrates the scenario that a USRP can be configured to be in half-duplex mode which can switch from being a transmitter to being a receiver. It is observed that the master receiver receives two frames for every four seconds, one from the master transmitter and one from the half duplex node, as shown in figure 10.

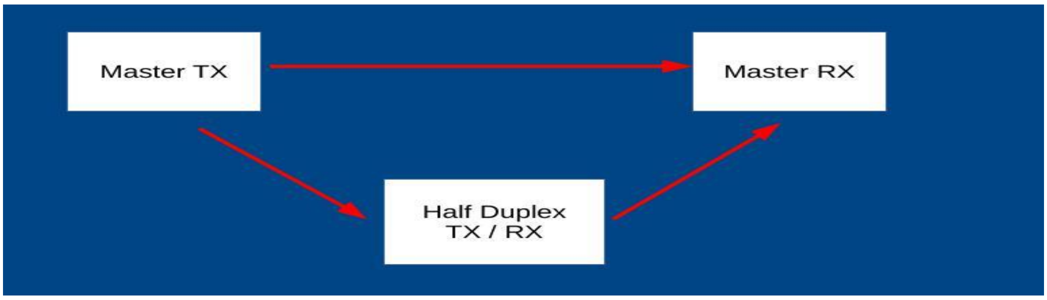


Figure 4.1: Simple Relay

4.2 Conditional Relay

Unlike a simple-relay which retransmits every received packet, a conditional relay transmits only certain packets fulfilling a pre specified condition. This requires for a relay to look into each received packet and decide whether to drop it or retransmit it based on the contents of the packet. A set-up involving three USRPs are interconnected as shown in figure.

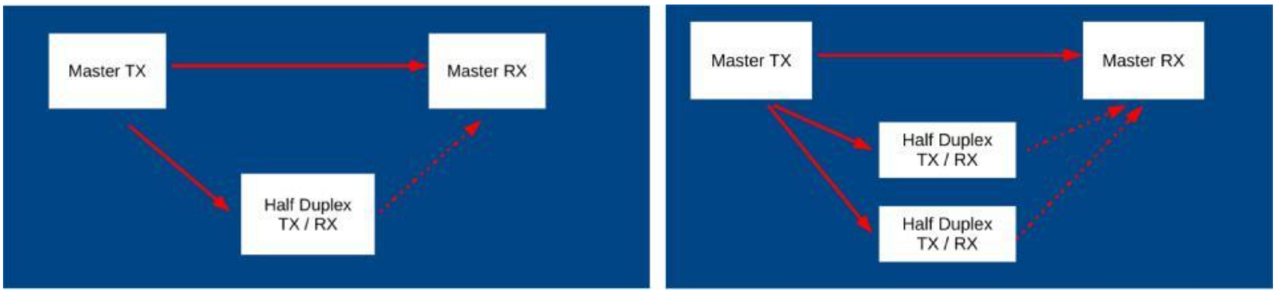


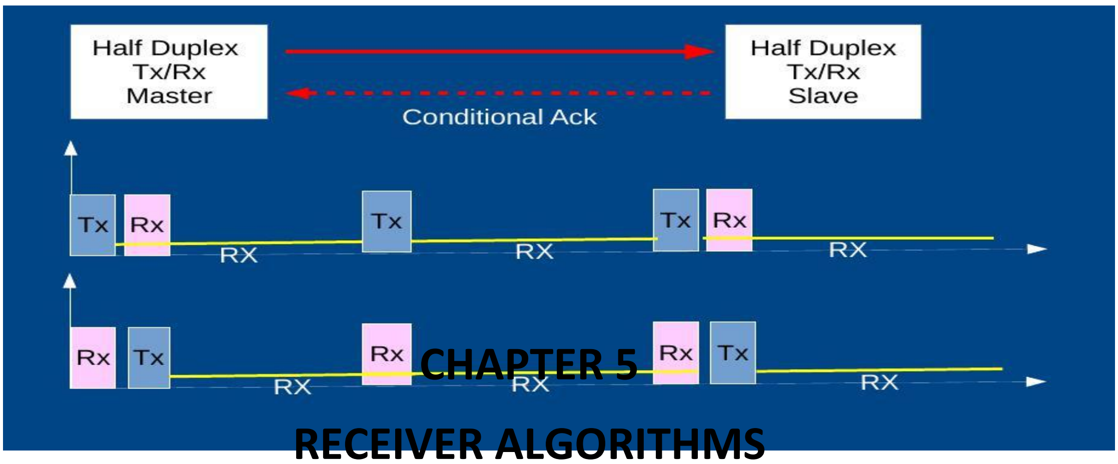
Fig 4.2: Configurations for (a) a conditional relay, and (b) two conditional relays

The conditional-relay idea is extended to cover two relays as shown figure 11 (b) in which there are two half duplex nodes, both of which will check for the certain condition in the received frame to decide whether to transmit or not.

4.3 Half-duplex operation

Two USRPs are configured to function in half duplex mode. One of them is designated as the master and the other as slave. The master node is programmed to continuously transmit for a duration of 20 ms at a repetition rate of 4 s for a better visual discrimination. At the end of the transmit duration, the master node switches to receive mode for the remaining 3.98 s. The slave which is normally in receive mode, will transmit an ACK packet, if the received frame contains a certain a certain pattern. This is shown below in the figure 12.

Fig 4.3 Final configuration of half-duplex operation



CHAPTER 5

RECEIVER ALGORITHMS

5.1 Frame Synchronization Algorithm

$$-1 < \frac{\sum_{i=0}^{Buffer\_size} <Preamble, Received\ signal>}{\sqrt{||Received\ signal||}\sqrt{||Preamble||}} < +1$$

For detecting the frames, we use the algorithm mentioned in the above formula which uses correlation between preamble and received signal and normalizing it with with their respective norms. If the above value is greater than the threshold (noise samples correlation), then the frame is detected.

5.2 Channel and Frequency offset estimation

Basic one channel LS estimate is used.

In channel estimation bits, we repeat the bits (after spreading) after 200 samples.

$$X[n] = x[n]e^{j2\pi\Delta f n} \; ; \; Y[n] = x[n+200]e^{j2\pi\Delta f(n+200)}$$

$$\Delta f = \frac{phase(X[n]Y[n])}{2\pi(200)}$$