MODELLING AND ESTIMATION OF PLC CHANNEL FOR SMART GRID SYSTEMS

A THESIS SUBMITTED IN PARTIAL FULFILLMENT

OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Technology

in

Communication and Networks

by

K RAVI KUMAR

Roll No: 212EC5174

Department of Electronics & Communication Engineering

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Rourkela-769 008, Odisha, India.

Certificate

This is to certify that the thesis entitled, **"MODELLING AND ESTIMATION OF PLC CHANNEL FOR SMART GRID SYSTEMS"** *submitted by K Ravi Kumar (212EC5174) in partial fulfillment of the requirements for the award of Master of Technology degree in* **Electronics and Communication Engineering** *with specialization in* **"Communication and Networks"** at *National Institute of Technology, Rourkela and is an authentic work by him under my supervision and guidance.*

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other university/institute for the award of any Degree or Diploma.

Place: Rourkela

Date: 27-05-2013

Prof. Poonam Singh

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Acknowledgements

I take this opportunity to express my gratitude to **prof. Poonam Singh,** for allowing me to work under her expert supervision, for her guidance and help throughout my course of post graduate studies. I highly appreciate her continuous motivation and direction which kept me focused towards my goal here at NIT, Rourkela.

Next, I would like to express my respects to Prof. S. K. Patra, Prof. S. Meher, Prof. K. K. Mahapatra, Prof. S. K. Behera, Prof. U. C. Pati, Prof. Samit Ari, Prof. S.Maiti, Prof. A. K. Sahoo, and Prof. D. P. Acharya for teaching me and also helping me how to learn. They have been great sources of inspiration to me and I thank them from the bottom of my heart.

In addition to my supervisor I would like to acknowledge sincere efforts of faculty and staff of the Electronics and Communication Engineering (ECE) Department for sharing Knowledge and making things smooth.

I am particularly thankful to my family for their emotional, moral and financial support. I would like to thanks my friends for making me feel better even when I was doing real bad. I would like to thank my mom, because she is my biggest strength and supported me throughout my life and encouraged me to do anything.

Finally I would like to thanks to google, Wikipedia and MS word for being very resourceful to me, without these tools I would not have been able to succeed in academics.

K Ravi Kumar

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Dedicated

to

My Parents and Teachers

ABSTARCT

Today's power grid system has been from the years and has become old and unable to meet the future needs of this generation. In about a decade, our surroundings been digitalized progressively and we are more reliant on electricity than before. There is fast development in innovations in the market that depend incredibly on power. As correspondence innovations are digitalized step by step our power grid ought to additionally advance to a more up to date one. Our power grid ought to advance rapidly to adjust the changes that are occurring in our undeniably computerized society. The best answer for this is Smart Grid. Smart grid networks will have the capacity to screen the stream of power progressively. Smart grid networks will proficiently handle our expanding vitality requests and decrease the natural effect by consolidating renewable assets. They give a more effective, dependable, environment and secure option to our current grid system. Smart grid will be equipped to restore itself after a power outage or a climate related blackout.

Smart grids will depend on several new and different innovative technologies. These new technologies will join together with the current grid to make a more productive, efficient and intelligent grid system. Smart grids will depend incredibly on two-way communications. Employing communication technologies into smart grid is difficult task. There is ongoing research for deciding what should be the best communication for smart grid and PLC creates a great interest because, power lines are everywhere and there is no need of installation cost. Power lines will reach to the last mile but problem with it is the noise and this can be reduced by using techniques like OFDM and allows high data rates of data.

This thesis deals with modelling of power line communication channel. This model is a combination of communication model, power line model and noise model. The communication model is realized as the OFDM system, power lines are modelled from the transfer function of multipath signal environment and noise model are modelled as white noise. Estimation of the channel is done by using neural networks after modelling of the channel. Radial Basis Function (RBF) networks are used to estimate the channel by using gradient decent method. In this method the weights and centers are updated to minimize the error.

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LIST OF ABBREVATIONS

AMI	Advanced Metering Infrastructure
AMR	Automatic Meter Reading
AWGN	Additive Gaussian Noise
BER	Bit Error Rate
BPL	Broadband over Power Line
BPSK	Binary Phase Shift Keying
CP	Cyclic Prefix
DG	Distributive Generation
DSM	Demand Side Management
FFT	Fast Fourier Transform
IFFT	Inverse Fast Fourier Transform
ICI	Inter Carrier Interference
ISI	Inter Symbol Interference
PLC	Power Line Communication
QPSK	Quadrature Phase Shift Keying
SG	Smart Grid
SNR	Signal to Noise Power Ratio

CHAPTER I

INTRODUCTION

1. Introduction

The existing power grid system has been from the ages and now it has become old and unable to meet the today's energy demands. In the past decade the world is becoming digitalized and dependent on electricity than ever before. As everything is getting digitalized, the electricity from the power grid is not sufficient for the user and we may face so many problems in the future. This power grid has to be evolved to a newer one called as "smart grid". This smart grid provides a clean energy by including infrastructure into the power grid by using intelligent devices. A smart grid delivers current from generation unit to customers using digital technology by adding sensors.

As mentioned, to upgrade the power grid to a smarter one, the IT infrastructure has to be integrated into the power grid. By adding smart devices like sensors and intelligent devices to the power grid, we are able to control the appliances. The information gathered by the intelligent devices should be provided to the consumers, operators and generator and utilities which provide an opportunity to respond to the changes that are occurring in the grid conditions.

The central power generation and distribution system, first designed by Nicole Tesla, is based on a cascading design and has not been updated ever since its inception. Failure in one part of the grid leads to failure of other parts due to its cascade design. Other major reasons which demand the upgrading of the grid is the transmission and distribution loss of power while transferring it to the end user. As of today, one cannot afford such losses, seeing as the demand of power supply is consistently increasing.

Another way to cope with the high power consumption rate is to implement the variable demand and supply [2] method. An end user-domestic, commercial or industrial – can request an increase or decrease in the power supply depending upon their current or future load requirements. Variable demand and supply allows the power distribution system to efficiently channel the power to areas with lower requirements as well as those with higher requirements. Inclusion of alternative sources of energy contributes to clean energy and plays a vital role in energy management. As more and more renewable sources are included, power grids not only have to deal with bidirectional flow of current, but also variable power supply in the region. Complexity of the existing grid is increased by manifolds when alternative sources of energy like solar and wind energy are added to the power grid. Effective implementation of the power grid with additional functionalities, improved reliability and enhanced security requires a systematic and well established communication system.

The said communication network can be set in two ways. The first approach is to install a communication network parallel to the grid using a wired/wireless medium. The second approach uses existing power cables for data transmission, which serves a dual purpose of controlling the network as well as internet access through power lines. The biggest advantage in pursuing power line communication is to utilize the existing power grid network, which can significantly reduce the cost of adding a new infrastructure to the system. Additionally, PLC can provide internet access for rural areas. However, as power grid cables were designed for electrical current, the power transmission line acts as a harsh environment for data signals, which may yield lower throughput or higher error rate at the receiver's end.

2. What is Smart Grid??

As far as general vision, the smart grid is

Intelligent: Equipped for sensing current overloads and in this way rerouting the way to anticipate or minimize the issue of blackout speedier than a human reacting to that case.

Efficient: Able to take care of the expanding purchaser demand without including the additional infrastructure.

Accommodating: Accepting energy from any fuel source including sunlight based and wind as effortlessly as coal and natural gas and equipped to incorporate altogether improved thoughts and innovations.

Motivating: Empowers continuous correspondence between the buyer and utility.

Opportunistic: Creates new open doors and markets.

Quality focused: Fit for conveying the power quality needed to our increasingly digitalized society.

Resilient: Highly resistant to the attacks and natural disasters.

Green: Diminishing the development of worldwide environmental change and offering a right way towards a critical natural change.

3. Power line communication:

Power line communication (PLC) also known as BPL (Broadband over Power line) uses power lines as a medium for achieving effective bidirectional communication along with electric current flow. The concept of communicating through PLC is quite old but not brought into use on massive scale for commercial purpose. Power companies have been using this service and keeping it restricted to them only.

PLC means the existing power cables can be simultaneously used for data transmission, which serves as dual purpose of controlling the network as well as internet access through power lines. The biggest advantage in pursuing power line communication is to utilize the existing power grid. Additionally, PLC can provide internet access for rural areas. However, as power grid cables were designed for electrical current, the power transmission line acts as a harsh environment for data signals, which may yield lower throughput or higher error at the receiver's end.

4. Thesis outline

Chapter-1: Introduction to the thesis is given about smart grid, power line communication and radial basis functions.

Chapter-2: background and literature review

Chapter-3: power line is modelled using multipath signal propagation and reference channels are given.

Chapter- 4: estimation techniques are proposed for power line communication channel as OFDM and RBF estimation technique.

Chapter-5: conclusion and future work to be done.

CHAPTER II

BACKGROUND AND LITERATURE SURVEY

2.1 Electrical grid or Power grid:

Power grid or electrical grid is a complicated interconnected network with wires and other components, delivering electricity from point of generation to the consumer. The layers of the power grid are

- Power generation
- Power transmission
- Power distribution
- Power consumption

Power generation: this includes the power generation at central and distributed locations.

Power transmission: this refers to the carrying of high-voltage bulk power from the generation unit to the distribution unit.

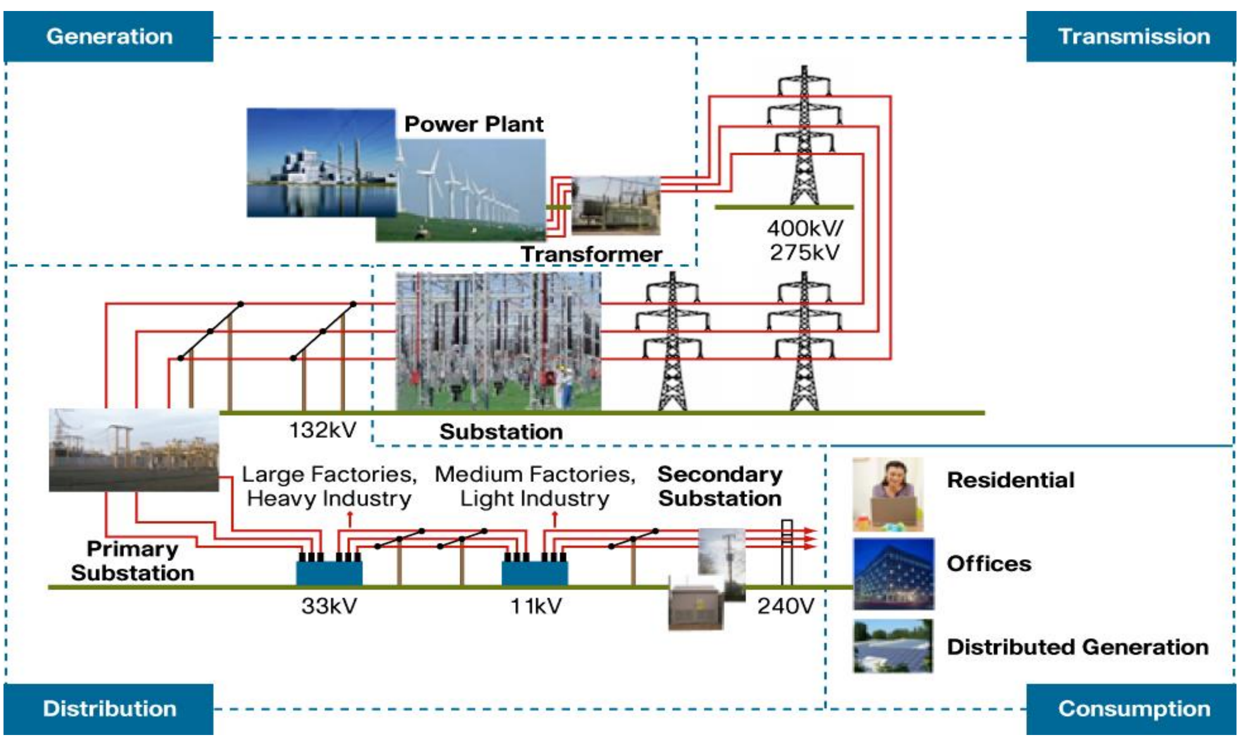

Figure 2.1 Physical view of electricity in power grid.

Power distribution: in this section high-voltage power is down converted to low-voltage for the consumption purpose.

Power consumption: this unit refers to the consumption of power that comes from the distribution unit.

2.2 Smart Grid:

The smart grid is the modernization or up-gradation of the current power grid. SG provides power along with two way digital communication to control home appliances to save energy, reduce the cost, and increase the reliability and transparency. Smart grid implements changes to the traditional grid including some major changes such as Distributive power generation [1]. Role of communication and the concept of Advance Metering Infrastructure (AMI) [3]. These new meters account for various advantages over traditional meters, becoming an effective communication interface between the grid and the consumer. The purpose of AMI is too utilize domestic, renewable and non-renewable power sources, and share them with consumers via an internet-style smart transmission grid. With new policies, innovative technologies and infrastructure upgrades, the Smart Grid is poised to change the way we go about our lives.

Smart Grid aim is to achieve a wide range of prospects, ranging from automated control of appliances at home to an overall reliable, secure and flexible grid. It will benefit both the power supply companies and the end user. There will be a reduction in the peak load thanks to a demand-based supply, the inclusion of renewable sources, intelligent devices and an adaptive grid.

2.3 Traditional Grid to Smart Grid

The existing power grid has been from the years and become old and needs an extensive upgrade and modernization. Grid failure is not only a problem but also a national security threat and serious economic losses.

Smart Grid provides elegant, eco-friendly and efficient solutions to most of the problems posed by power grid. A strong communicating network is required as a backbone of the power grid makes it a more robust system. Including of distributive generation reduces the peak over-load on central power generation which allows the grid to separate itself from the affected section. Following the trend of digitization, power network is digitized from analog version under Smart Grid. Electricity and information flow in power grid follows a broadcasting pattern with generators as starting point and user as end point. Smart Grid provides power along with two way digital communication to control home appliances to save energy, reduce cost, increased reliability and transparency.

Advanced Metering Infrastructure (AMI), accounts various advantages over traditional meters by becoming an effective communication interface between grid and consumer. Following are some features of AMI:

- Remote meter reading
- Control of appliances via remote sites
- Live tracking of current charges and current load

Smart Grid contributes to clean energy by including alternative sources of energy. Inclusion of alternate sources like wind mills and solar panel would reduce pressure off the thermal power units. The concept of Net metering [4] allows the customers to sell extra power generated from privately owned solar panel/wind mill/vehicle battery to the grid. The opposite flow of electricity from consumer to grid rolls the meter in reverse direction reducing the number of already consumed electrical units. A customer is only charged for net units used, obtained by subtracting units given to grid from units consumed by using electricity from grid.

A strong communication system provides reliable and efficient platform upon which Smart Grid is based. Communication in Smart Grid is not only responsible for notifications or reminders but also includes software based transmission, control, re-routing algorithms, fault recognition and self-healing.

It is required to understand existing power grid architecture to make some significant moves in Smart Grid. Power is generated and transmitted at very high voltage from power plant to transmission substation (TS) then it is down converted and brought at medium level voltage to distribution substation (DS) and control center [5]. Here again power is down converted to low level voltage to make it suitable for user utilities. The flow of current in different levels poses some challenges while designing effective communication.

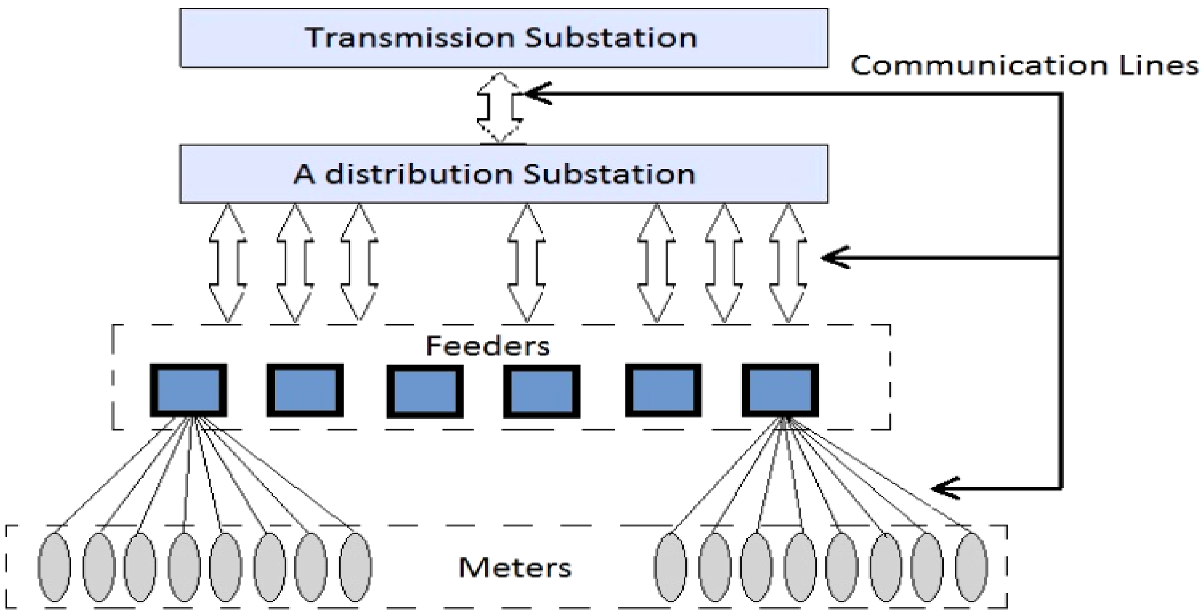

Figure 2. 2 Diagram showing distribution of power from TS to end user.

Communication media act as interface between energy source, distribution system and consumer entities. Smart Grid comes up with option of joining all transmission interfaces directly to the sources or can be controlled by central grid. The key concept is that all interactions between transmission interfaces and consumers are multi-directional i.e. uncommon to traditional grid now that users can also participate in reverse direction. Communication infrastructure is laid over physical infrastructure of existing grid; doing so achieves automation, robustness and efficient power grid.

By designing communication architecture to support Smart Grid, one can choose from currently available communication technologies; among wireless, wired/cable, cellular, or power line itself. Each has different advantages and disadvantages even hybrid combination of them could be used.

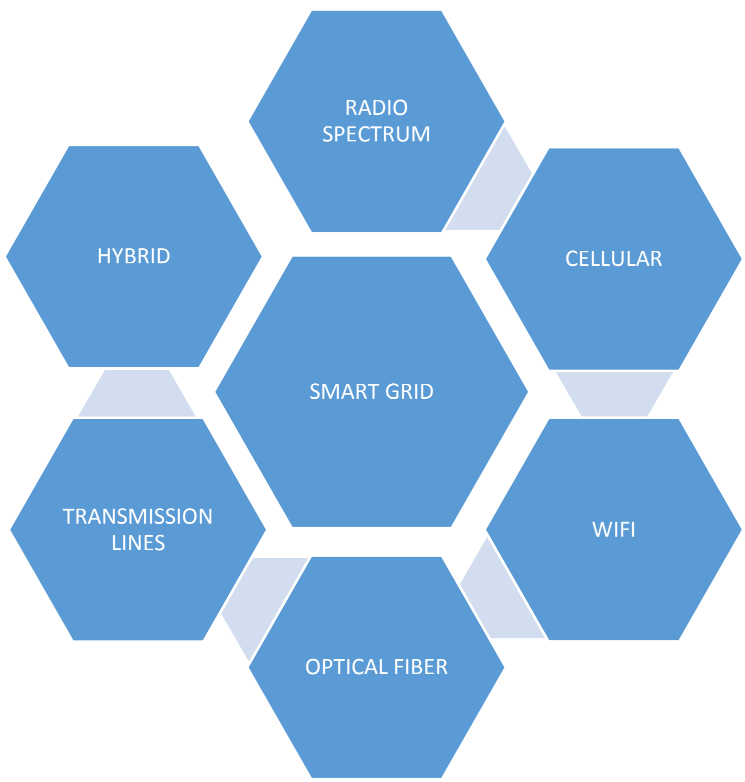

Figure 2. 3 Communication alternatives in Smart Grid.

The communication alternatives in Smart grid are

1. Radio spectrum
2. Cellular
3. Wi fi
4. Optical fiber
5. Transmission lines and
6. Hybrid.

From these alternatives we select transmission lines as the best one for our consideration because, they are already installed and no installation cost. Power lines are spread to every rural area and communicating from these provide a large number of users. Power lines are used for both power transmission and communicating medium, hence they are of great interest.

2.4 Power Line Communication

Power line communication (PLC) also known as BPL (Broadband over Power line) uses power lines as a medium for achieving effective bidirectional communication along with electric current flow. The concept of communicating through PLC is quite old but not brought into use on massive scale for commercial purpose. Power companies have been using this service and keeping it restricted to them only.

PLC means the existing power cables can be simultaneously used for data transmission, which serves as dual purpose of controlling the network as well as internet access through power lines. The biggest advantage in pursuing power line communication is to utilize the existing power grid. Additionally, PLC can provide internet access for rural areas. However, as power grid cables were designed for electrical current, the power transmission line acts as a harsh environment for data signals, which may yield lower throughput or higher error at the receiver's end. Some factors discussed above prohibit PLC from becoming a complete mature communication network for Smart Grid [6]. Some architecture also has been proposed for Smart Grid using PLC based upon packet oriented approaches [7].

2.4.1 Existing PLC Implementations:

The existing power line communication being implemented at various places and enumeration of standards evolved. In Europe PLC is termed as narrow band PLC because allocated frequency band for PLC is 3 KHz to 148.5 KHz, which is further divided into four sub-bands for different applications.

- CENELEC A (9 KHz to 95 KHz)
- CENELEC B (95 KHz to 125 KHz)
- CENELEC C (125 KHz to 140 KHz)
- CENELEC D (140 KHz to 148.5 KHz)

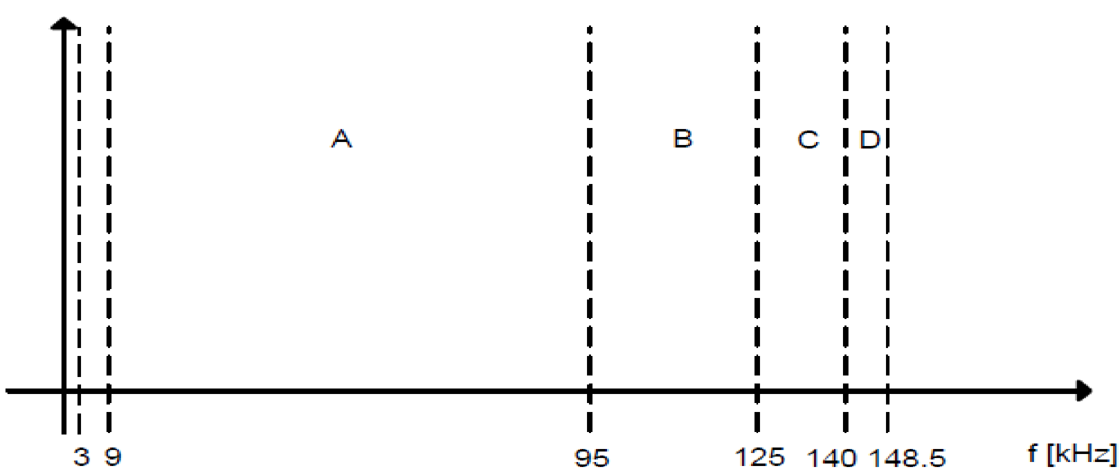

Figure 2. 4 Different frequency bands for PLC.

Details of operation in different bands such as type of modulation, data rate, symbol size and encoding-decoding technique are enlisted in [8]. CENELEC the controlling body of PLC mechanism in Europe, follows the Stds EN 50065 (CENELEC), IEC 61000. In China PLC operates at a single frequency band of 3 to 500 KHz. The frequency band in USA for PLC purpose is FCC band 10 KHz – 490 KHz. There is only single band with no subdivisions.

Standard IEEE P1901 [9] regulating the operations of PLC, outlined two different techniques to be followed for PLC based upon modulation method to be implemented PHY layer.

- FFT OFDM: it uses Forward error correction (FEC) scheme with Convolutional Turbo Code (CTC) as underlying coding technique.
- Wavelet OFDM: it involves FEC, using concatenated Reed-Solomon (RS) and Convolutional Code, and also provides an option to add Low-density Parity Check (LDPC) to reduce errors.

2.4.2 Noise in PLC:

A PLC could be categorized as follows:

- Narrow band PLC (<450KHz)
- Wideband/broadband PLC (~MHz)

The wires that are connecting from substations to the houses are the low voltage power line cable. The noise at the low voltage power line can be internal or external. Noise [10] in the power lines can be classified in to five types they are

1. Colored Background Noise: The home appliances which uses low voltages generates a noise with low power spectral density.

2. Narrow band noise: this noise is caused by broadcasting radio stations due to sinusoids produced by amplitude modulated signals.

3. Periodic impulsive noise asynchronous: This noise is caused when power supply switches from one mode other mode.

4. Periodic impulsive noise synchronous: This noise is produced when the power supply switches from one mode to other mode by cutoff and threshold voltages of rectifier diodes and transistors.

5. Asynchronous impulsive noise: This noise is produced when transients are switched.

Collective noise is the sum of all the five noise types mentioned. Background noise is considered to be Additive Gaussian Noise (AWGN) W_k for PLC analysis.

The impulsive noise is given by:

$$i_k = b_k * g_k$$

Where, b_k is the Poisson process which is the arrival of the impulsive noise, g_k is the white Gaussian process with mean zero and variance $2\sigma^2$. b_k is the probability of getting hit by noise.

The total noise is given by:

$$n_k = W_k + i_k$$

$$n_k = W_k + b_k * g_k$$

CHAPTER III

CHANNEL MODELLING

3.1 Power line modelling

The power line channel is required to simulate PLC communications. There exist two possible methods for the modelling of power line channels. The first one used to model power lines for electricity distribution networks called as chain parameter matrices which describes the relation between input and output voltage and current of two-port network. The second method is used for the modelling of radio channels. In this method power line channel is assumed to be a multipath propagation environment. From these two methods we choose the first second one, because the topology of the pilot distribution network is known.

3.2 Multipath channel model

In power line transmission the propagation of data signals do not follow a single path, but they follow a multipath [12] following a pattern very similar to wireless signals involved in cellular transmission. Power grid (LV) is a single transmission line with shooting stems terminating at the end users place, as shown in Figure below. Tx is the point of transmission (substation/service provider) and Rx is the point of receiver (automated meter, customer or other appliances).

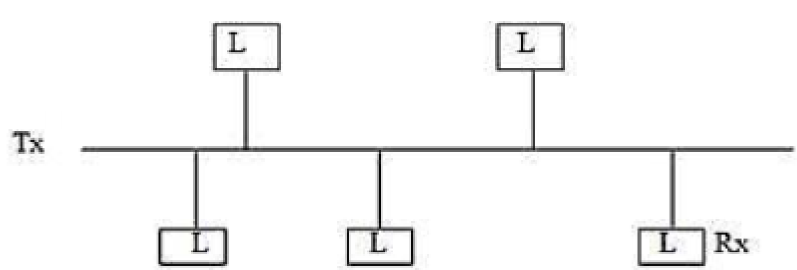

Figure 3. 1 Typical topology of end mile transmission line in power grid.

A small figure 3.2 could be singled out to review multipath propagation of signal.

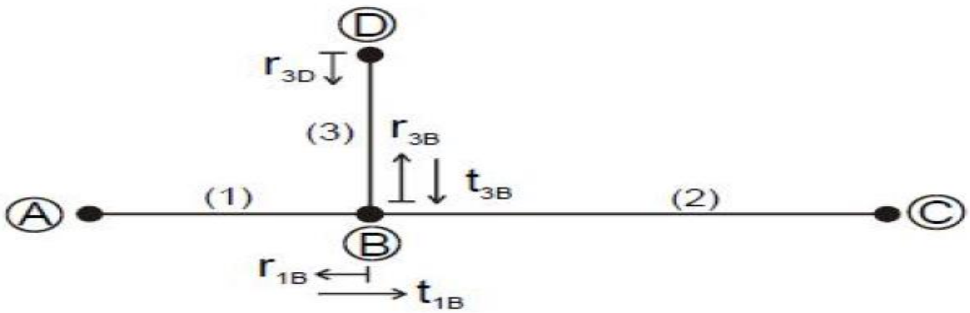

Figure 3. 2 Multipath propagation of signal from D to C.

Let D be the point of transmission and C be the point of receiving. Signal generates at point D could take following possible routes:

1. D – 3 – 2 – C
2. D – 3 – 3 – D
3. D – 3 – 1 – 3 – D
4. D – 3 – 1 – 1 – 2 – C

Expressions mentioned here list the different propagation routes. Signal power and BER of received signal depends upon the path followed and the length of the path. Multipath propagation is also responsible for delay (τ_i) in PLC, which is given by:

$$\tau_i = \frac{d_i}{v_p} \qquad (3.1)$$

d_i is the length of the path, v_p is the phase velocity.

$$\mathrm{H(f)} = \sum_{i=1}^{n} g_i . A(f, d_i) e^{j2\pi f \tau_i} \qquad (3.2)$$

H(f) is frequency response of channel between two points. When the grid network grows big and complex it could be separated into sub-channels for individual study. $A(f, d_i)$ are cable losses which could be in the form of heat or signal leakage etc. f is the frequency of operation, g_i is weight factor which is directly proportional to number of reflections and path followed:

$$|g_i| \leq 1 \qquad (3.3)$$

The values of g_i and $A(f, d_i)$ are determined experimentally. Based upon above given factors a mathematical model of multipath PLC is proposed in [11]:

$$\mathrm{H(f)} = \sum_{i=1}^{n} g_i . A(f, d_i) e^{j2\pi f \tau_i}$$

Based upon extensive investigation [11] on experimental data $A(f, d_i)$ can be approximated by the mathematical formula for attenuation factor (α)

$$\alpha(f) = a_0 + a_1 . f^k \qquad (3.4)$$

a_0 and a_1 are attenuation parameters leading to:

$$A(f, d) = e^{-\alpha(f).d} = e^{-(a_0 + a_1 . f^k).d} \qquad (3.5)$$

Using, equations (3.4) and (3.5) in H(f) gives the channel model for PLC transmission line:

$$\mathrm{H(f)} = \sum_{i=1}^{n} g_i . e^{-(a_0 + a_1 . f^k) d_i} . e^{j2\pi f \tau_i}$$

g_i = weighing factor

$e^{-(a_0 + a_1 . f^k) d_i}$ = attenuation portion

$e^{j2\pi f \tau_i}$ = delay portion.

The weighing factor can be calculated as the product of reflection and transmission coefficients along the path. To calculate the reflection and transmission coefficients, first the characteristic impedance along the line is calculated. Let the points A and C are matched, which means $Z_A = Z_{L1}$ and $Z_C = Z_{L2}$

The reflection coefficients are given as

$$r_{1B} = \frac{(Z_{L2}||Z_{L3})-Z_{L1}}{(Z_{L2}||Z_{L3})+Z_{L1}} \qquad (3.6)$$

$$r_{3D} = \frac{Z_D-Z_{L1}}{Z_D+Z_{L1}} \qquad (3.7)$$

$$r_{3B} = \frac{(Z_{L2}||Z_{L1})-Z_{L3}}{(Z_{L2}||Z_{L1})+Z_{L3}} \qquad (3.8)$$

and transmission factors

$$t_{1B} = 1 - |r_{1B}| \qquad (3.9)$$

$$t_{3B} = 1 - |r_{3B}| \qquad (3.10)$$

By using the equations from (3.6) to (3.10) g_i is calculated.

Table 1: signal propagation along the line with weighing factor and length

Path no. i	Way of the signal path	Weighing factor g_i	Length of path d_i
1	A→B→C	t_{1B}	$l_1 + l_2$
2	A→B→D→B→C	$t_{1B}.r_{3D}.t_{3B}$	$l_1 + 2l_{3+}l_2$
--	...	...	...
...	.....	.....	...
N	A→B$(\to D \to B)^{N-1}$→C	$t_{1B}.r_{3D.}(r_{3B.}r_{3D})^{(N-2)}.t_{3B}$	$l_1 + 2(N-1).l_{3+}l_3$

3.3 Reference channels

To cover various real channel characteristics, we simulate some reference channels [13] based on length and quality. Based on distance or length of the path, the channels are divides into three categories. They are

1. Short distance, about 150m length
2. Medium distance, about 250m length
3. Long distance, about 350m length.

Based on quality again they are divided into good, medium and bad qualities. In this except for 250m length, others have all the three qualities of length and one theoretical channel model is given. So, total there are nine reference channels for the network.

For simulation of the reference channels the frequencies are used up to 20MHz. Hence, a sampling frequency of 50MHz is enough for our simulations. The modelling parameters are considered throughout the reference channels as same and the speed of medium for all channels is given by $v_p = 1.53*10^8$ m/s.

3.3.1. Reference channel 1 (150m good)

This channel has no branches and hence 5 paths are enough for realization and this channel shows a little low pass characteristics from the frequency response. This curve doesn't have any frequency notches.

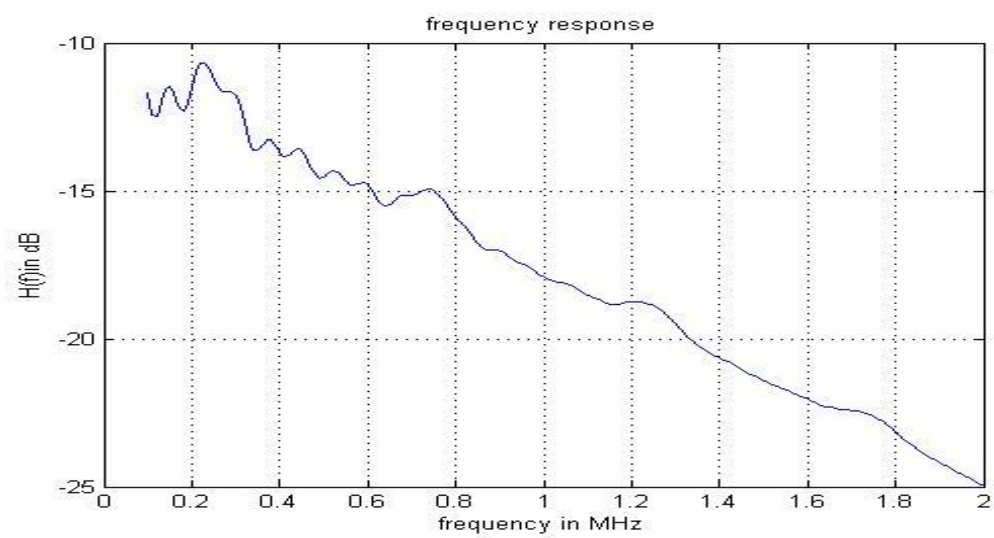

Figure 3. 3 Frequency response for reference channel "150m good".

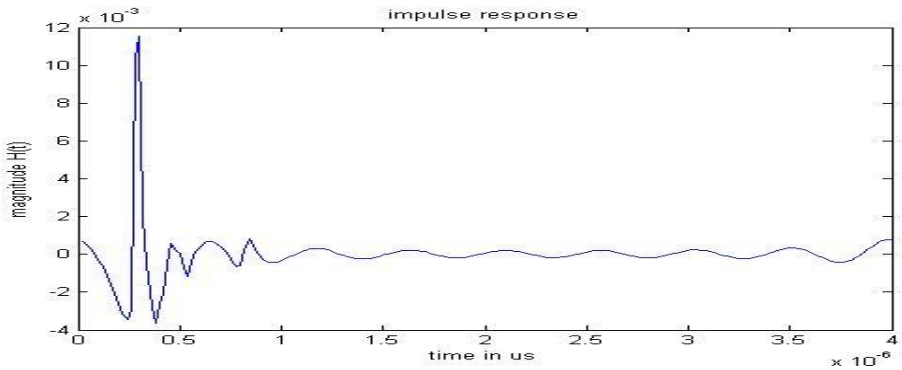

Figure 3. 4 Impulse response for reference channel “150m good”.

Table 2: parameters for reference channel “150m good”

Attenuation parameters			$a_0 = 0$	$a_1 = 1.65*10^{-9}$ s/m		K=1
Path parameters						
i	g_i	d_i/m	i		g_i	d_i/m
1	0.09	100	4		-0.012	190
2	-0.012	130	5		0.022	300
3	0.012	160				

3.3.2. Reference channel 2 (150m medium)

This channel requires 17 paths for the realization and shows a more distinct low pass characteristics and high frequency notches from the frequency response curve.

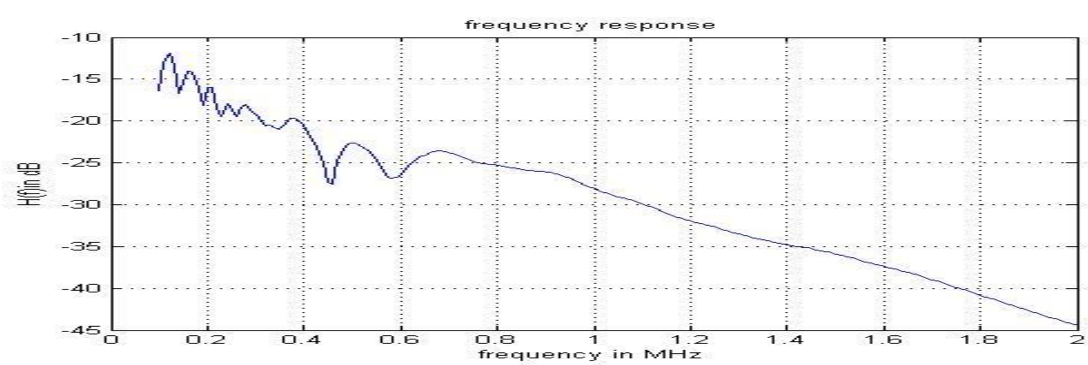

Figure 3. 5 Frequency response for reference channel “150m medium”.

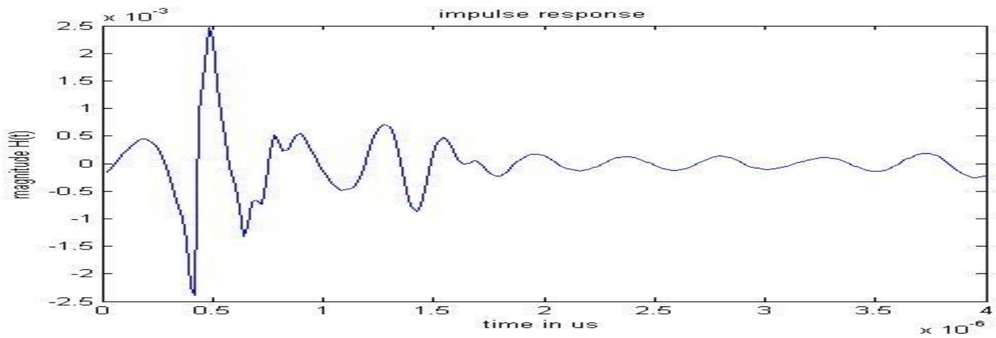

Figure 3. 6 Impulse response for reference channel "150m medium".

Table 3: parameters for reference channel "150m medium"

Attenuation parameters			$a_0 = 0$	$a_1 = 2.8 * 10^{-9}$ s/m		K=1
Path parameters						
i	g_i	d_i/m	i		g_i	d_i/m
1	- 0.15	150.8	10		0.04	435
2	0.165	152.3	11		0.02	468
3	0.032	172	12		- 0.015	494
4	- 0.014	210.4	13		0.0865	534
5	- 0.035	230	14		- 0.062	581
6	- 0.035	258	15		- 0.083	632
7	- 0.03	294	16		0.05	1070
8	0.015	370	17		- 0.035	1224
9	0.022	400				

3.3.3. Reference channel 3 (150m bad):

This third reference channel has same characteristics like second one but shows some extra frequency notches and low pass characteristics. Realization of this channel requires 15 paths.

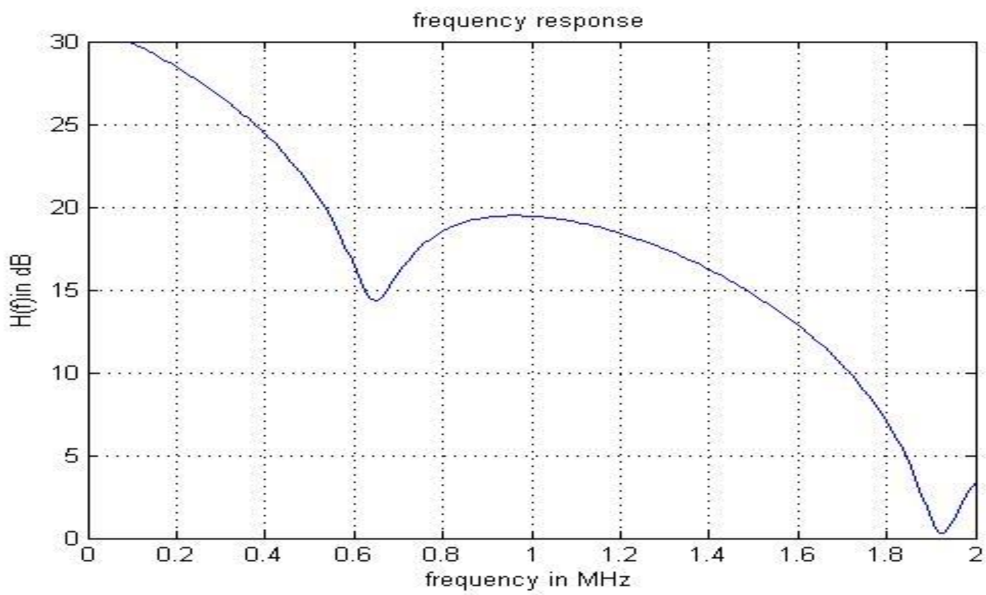

Figure 3. 7 Frequency response for reference channel "150m bad".

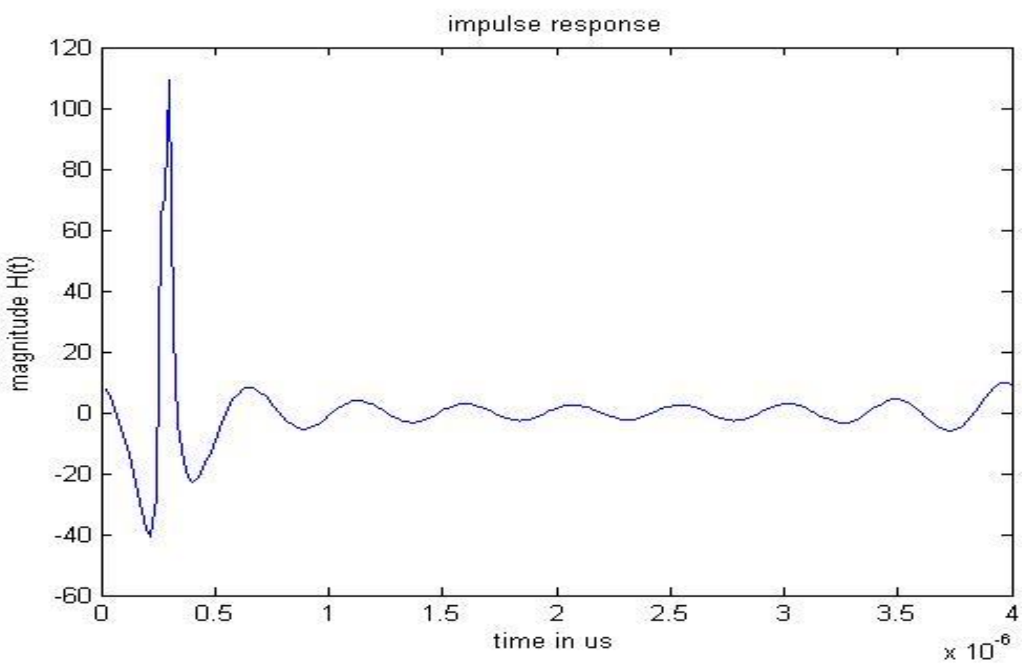

Figure 3. 8 Impulse response for reference channel "150m bad".

Table 4: parameters for reference channel "150m bad"

Attenuation parameters			$a_0 = 0$	$a_1 = 2.5 * 10^{-9}$ s/m	K=1
Path parameters					
i	g_i	d_i/m	i	g_i	d_i/m
1	1.832	113.2	9	1.263	411
2	0.516	90.1	10	- 0.622	490
3	0.765	101.8	11	1.156	567
4	- 1.031	143	12	- 0.978	740
5	- 0.800	148	13	0.747	960
6	- 0.711	200	14	- 1.049	1130
7	0676	261	15	0.871	1250
8	- 0.676	322			

3.3.4. Reference channel 4 (250m good):

These channels shows a more distinct low pass characteristics compared to the 150m class due to high attenuation factors. This model require 14 paths for the realization of the channel which shows a low pass distinct characteristics.

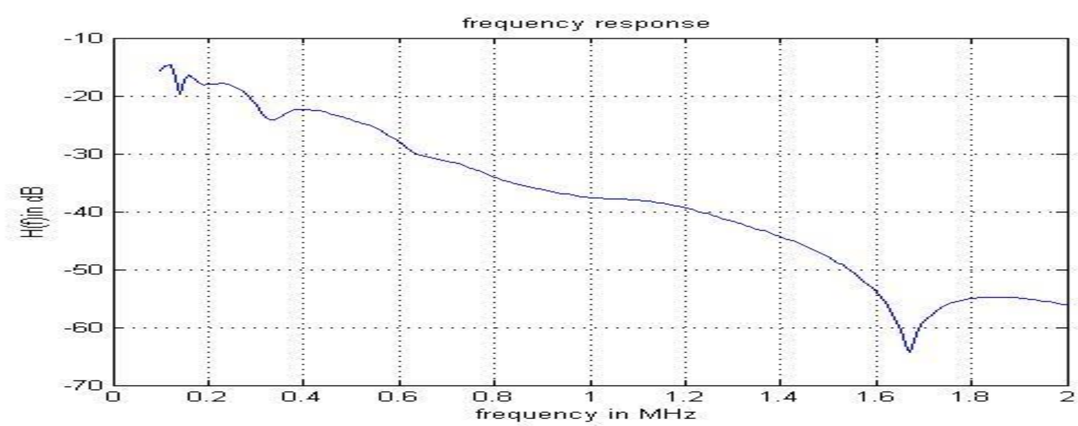

Figure 3. 9 Frequency response for reference channel "250m good".

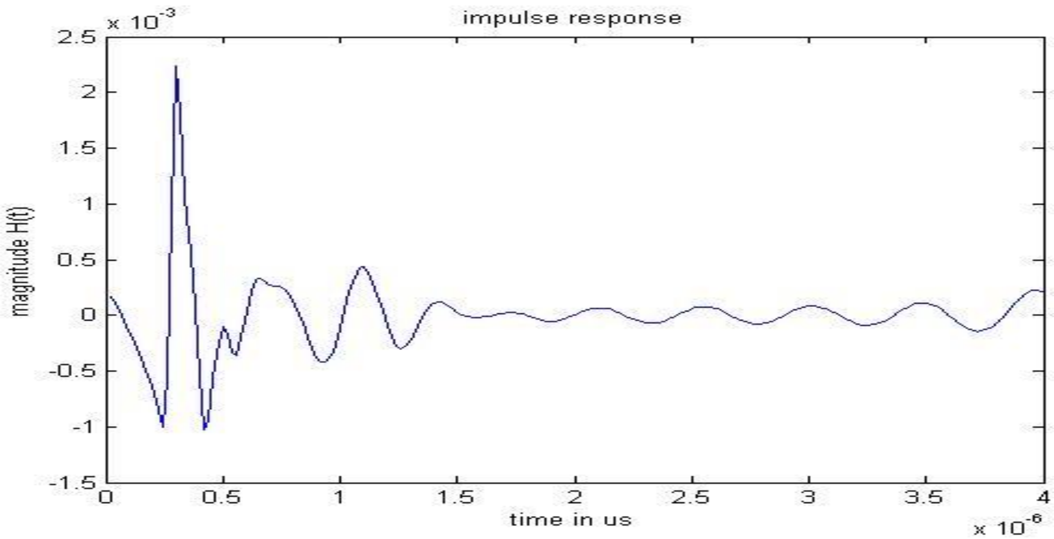

Figure 3. 10 Impulse response for reference channel "250m good".

Table 5: parameters for reference channel "250m good"

Attenuation parameters			$a_0 = 0$	$a_1 = 5 * 10^{-9}$ s/m	K=1
Path parameters					
i	g_i	d_i/m	i	g_i	d_i/m
1	- 0.007	85	8	- 0.022	438
2	0.034	103	9	0.07	476
3	- 0.03	148	10	- 0.04	530
4	- 0.031	195	11	- 0.052	660
5	- 0.013	245	12	- 0.04	800
6	- 0.015	315	13	0.088	1015
7	0.053	376	14	- 0.053	1450

3.3.5. Reference channel 5 (250m medium):

This channel shows a low pass characteristics and for realization of this model requires 12 paths.

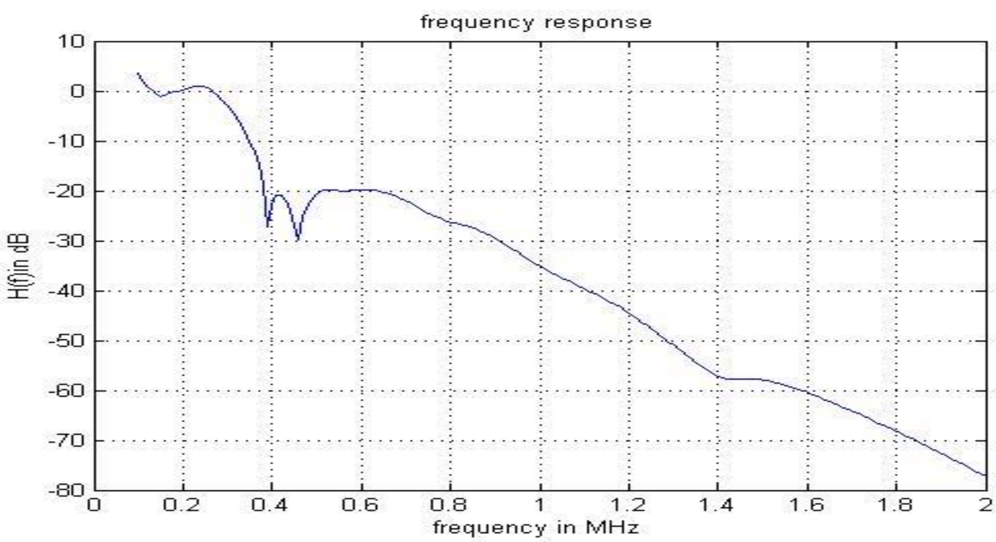

Figure 3. 11 Frequency response for reference channel "250m medium".

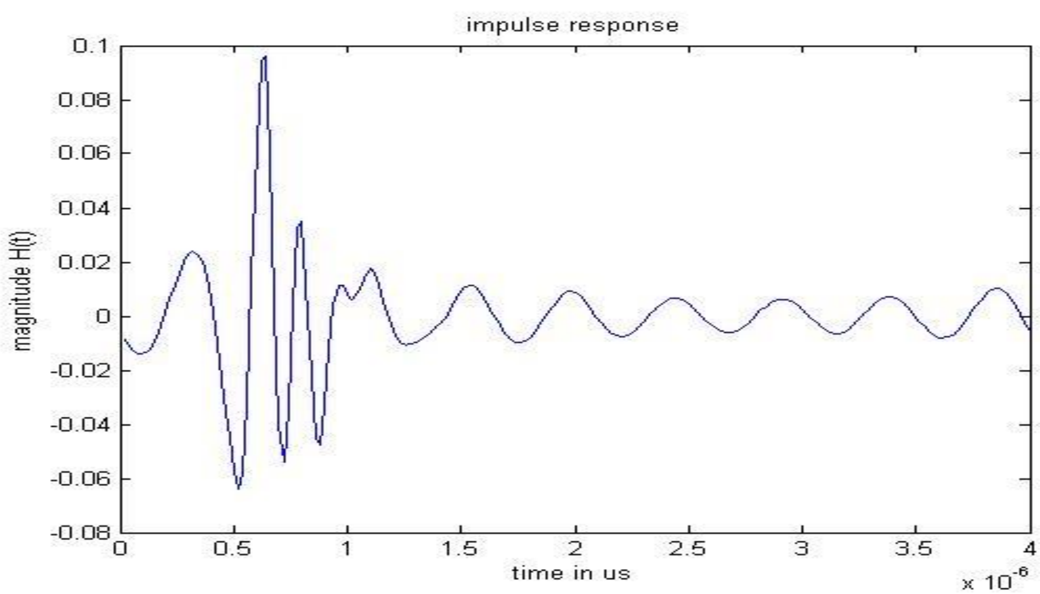

Figure 3. 12 Impulse response for reference channel "250m medium".

Table 6: parameters for reference channel "250m medium"

Attenuation parameters		$a_0 = 0$	$a_1 = 4.5 * 10^{-9}$ s/m		K=1
Path parameters					
i	g_i	d_i/m	i	g_i	d_i/m
1	3.02	211.5	7	3.20	330
2	4.45	228	8	- 3.56	360
3	- 1.78	243	9	0.89	390
4	- 2.13	254	10	- 2.67	420
5	5.87	278	11	2.67	540
6	- 6.58	306	12	- 2.67	740

3.3.6. Reference channel 6 (350m good):

This channel shows no distinct low pass characteristics with no frequency notches. Realization of this channel requires 5 paths.

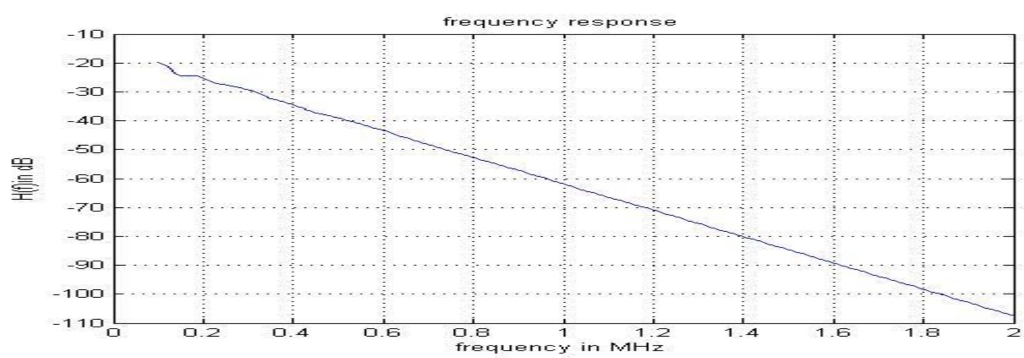

Figure 3. 13 Frequency response for reference channel "350m good".

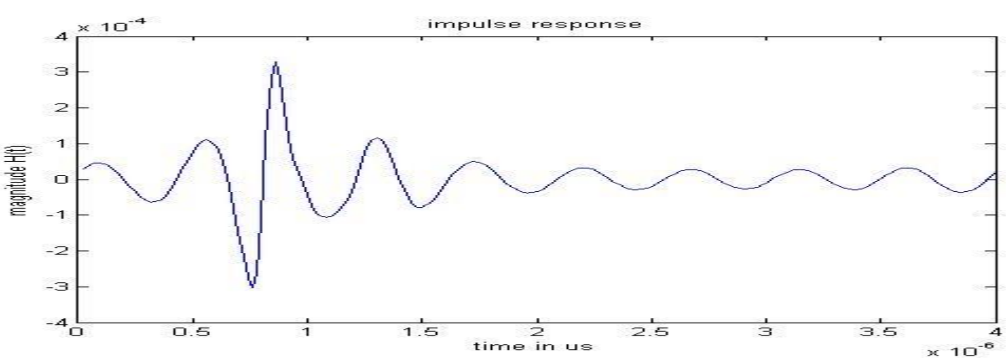

Figure 3. 14 Impulse response for reference channel "350m good".

Table 7: parameters for reference channel "350m good"

Attenuation parameters		$a_0 = 8*10^{-3}$ 1/m		$a_1 = 3.5*10^{-9}$ s/m	K=1
Path parameters					
i	g_i	d_i/m	i	g_i	d_i/m
1	0.28	300	4	0.25	450
2	0.05	350	5	- 0.35	510
3	- 0.03	370			

3.3.7. Reference channel 7 (350m medium):

This channel shows typical notches at certain frequencies and for realization of this channel requires 13 paths.

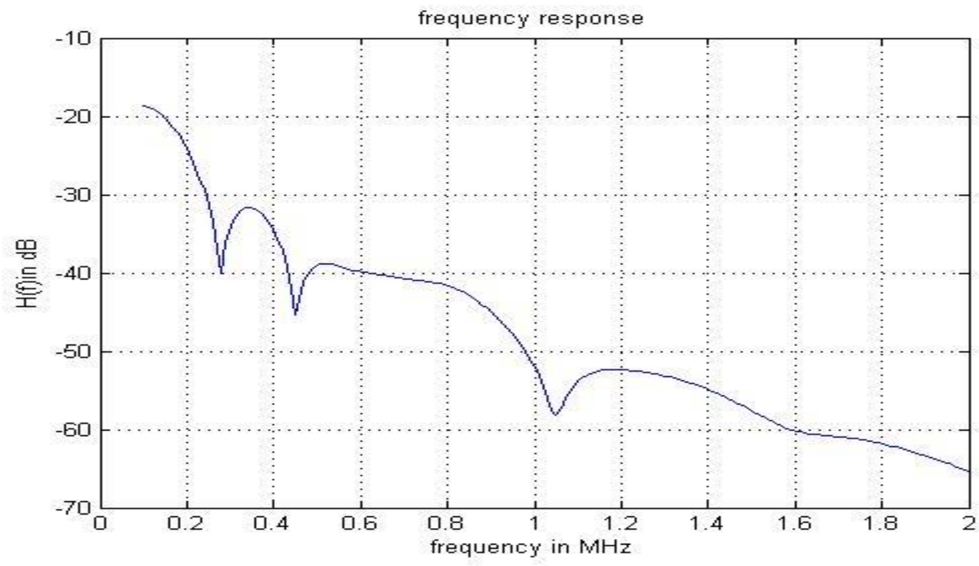

Figure 3. 15Frequency response for reference channel "350m medium".

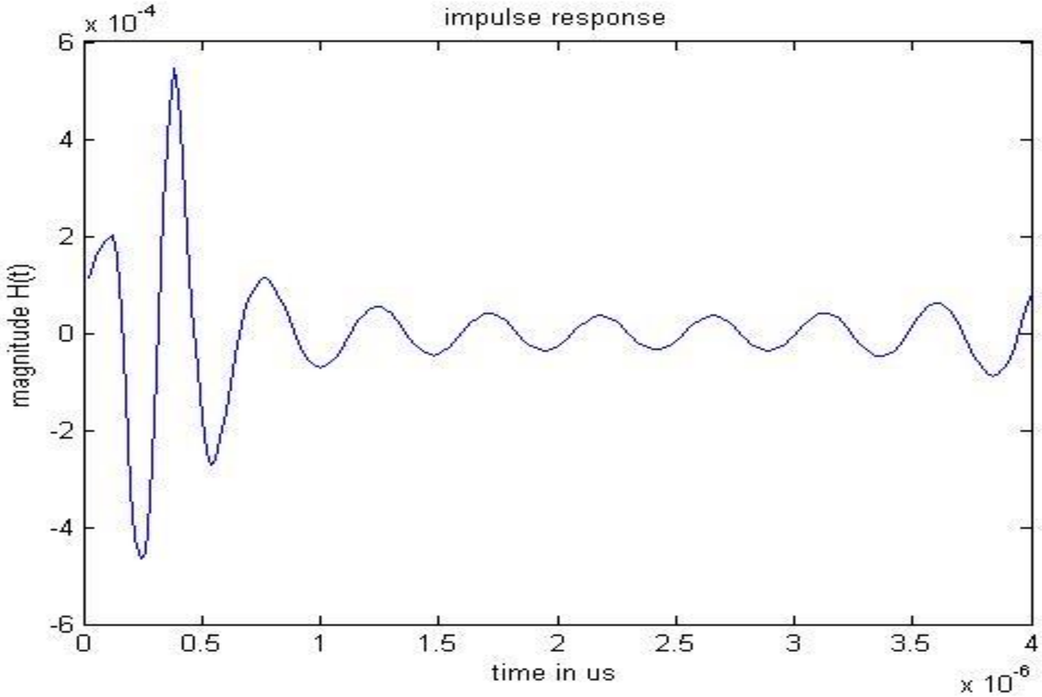

Figure 3. 16 Impulse response for reference channel "350m medium".

Table 8: parameters for reference channel "350m medium"

Attenuation parameters			$a_0 = 0$	$a_1 = 9 * 10^{-9}$ s/m		K=1
Path parameters						
i	g_i	d_i/m	i	g_i		d_i/m
1	0.00039	40	8	0.0051		230
2	- 0.0045	68	9	0.0112		450
3	- 0.0062	86	10	- 0.0141		560
4	0.0281	129	11	0.1125		830
5	- 0.0169	185	12	- 0.1687		895
6	- 0.0028	237	13	0.0675		1000
7	- 0.0056	235				

3.3.8. Reference channel 8 (350m bad):

This channel has high attenuation in low frequency range and this model requires 6 paths for realization.

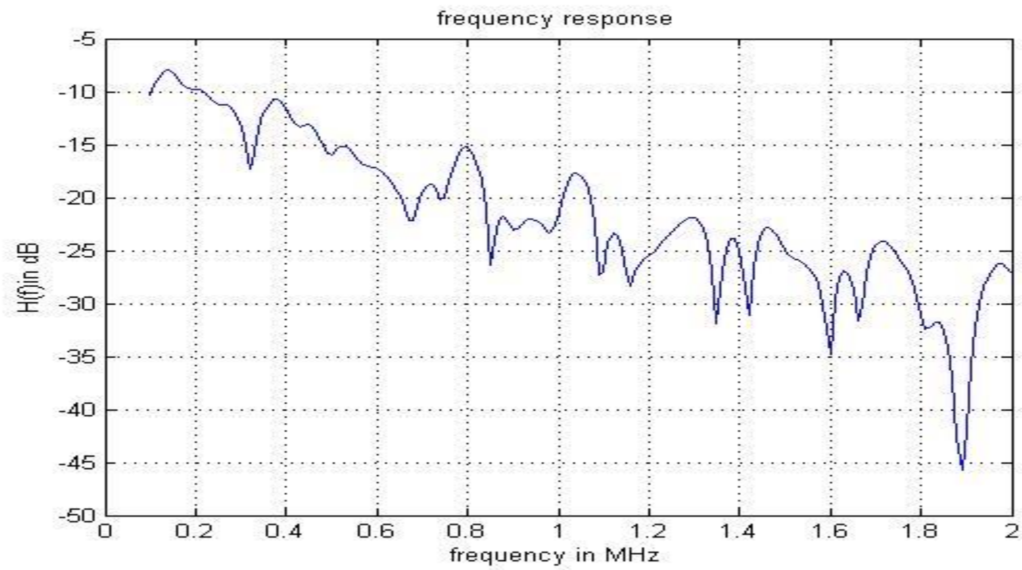

Figure 3. 17 Frequency response for reference channel "350m bad".

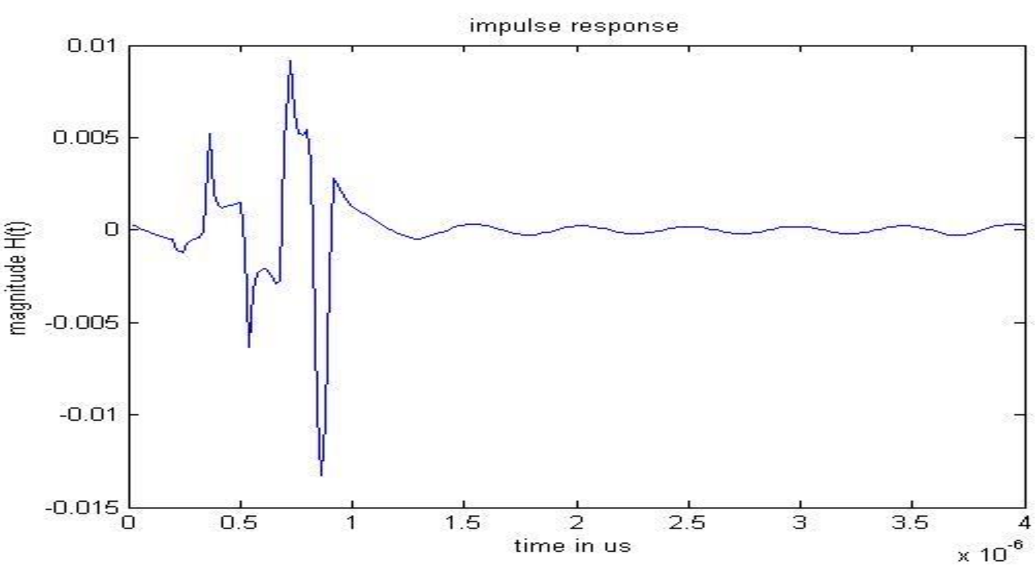

Figure 3. 18 Impulse response for reference channel "350m bad".

Table 9: parameters for reference channel "350m bad"

Attenuation parameters			$a_0 = 0$	$a_1 = 1.1 * 10^{-8}$ s/m		K=1
Path parameters						
i	g_i	d_i/m	i	g_i	d_i/m	
1	- 0.0039	78	4	0.0715	256	
2	0.0156	126	5	- 0.122	306	
3	- 0.034	191	6	0.076	330	

3.3.9. Theoretical channel model:

This last reference channel shows a frequency notches at regular intervals and causes a wavy attenuation and for realization it requires only two paths as it has one branch but other paths amplify the notches and cause a wavy attenuation.

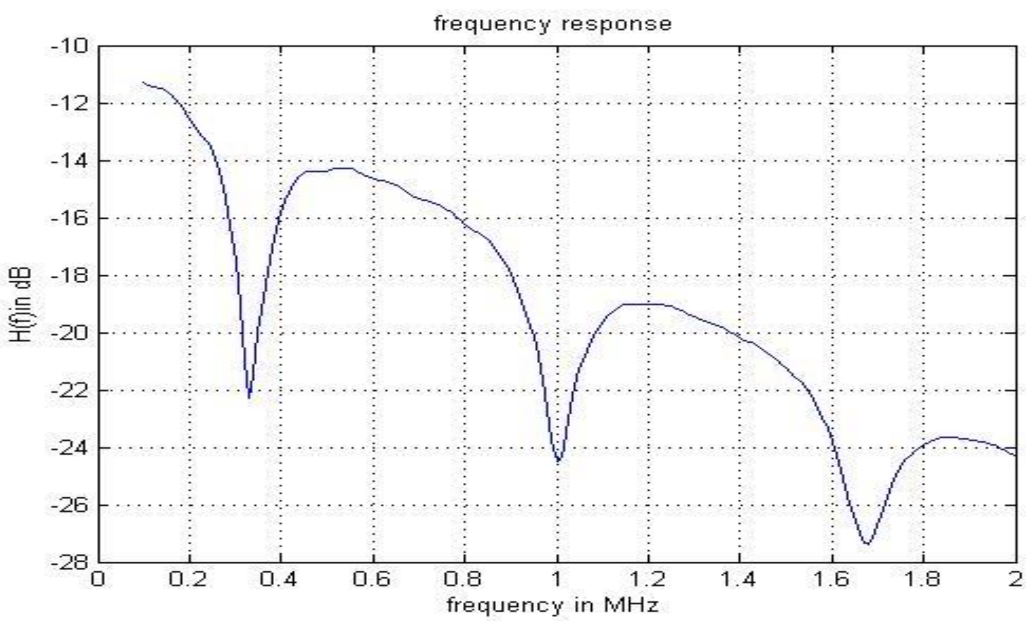

Figure 3. 19 Frequency response for theoretical channel.

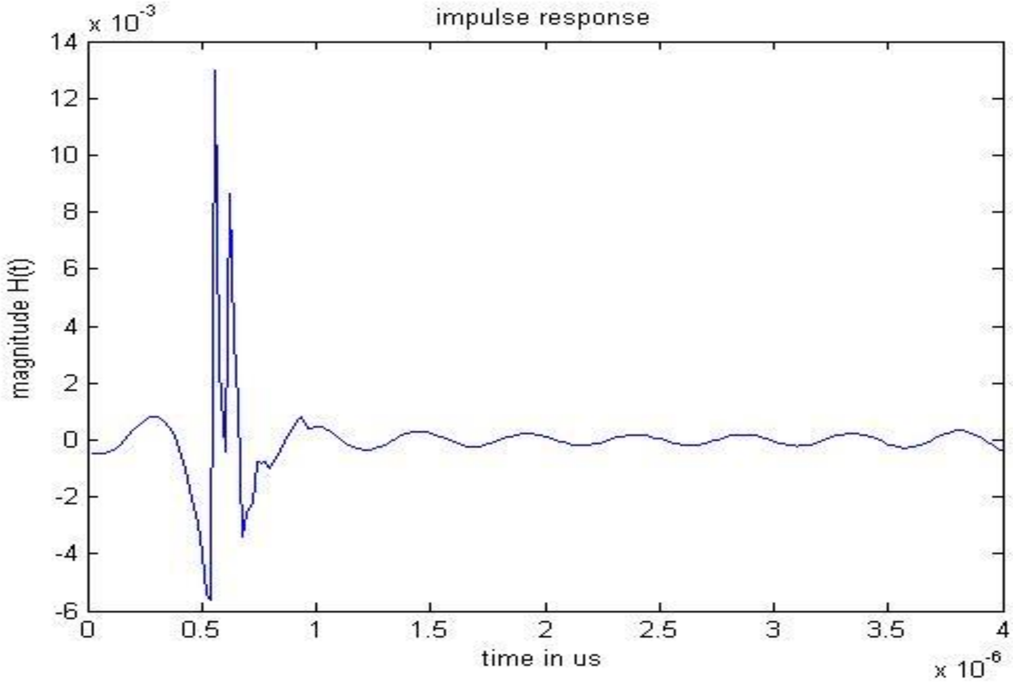

Figure 3. 20 Impulse response for theoretical channel.

Table 10: parameters for theoretical channel

Attenuation parameters			$a_0 = 0$	$a_1 = 7.8 * 10^{-10}$ s/m		K=1
Path parameters						
i	g_i	d_i/m	i		g_i	d_i/m
1	0.64	200	4		0.05	267.5
2	0.38	222.4	5		- 0.02	290
3	- 0.15	244.8	6		- 0.03	350

CHAPTER IV

CHANNEL ESTIMATION

4.1 Estimation techniques

We designed the power line model for PLC using multipath signal propagation. Now, we have to estimate the PLC channel for better performance of the system. Here, two models are presented one is the OFDM model and the other one is the model using neural networks.

Estimation of PLC can be done by using the same OFDM block diagram by including channel as a PLC and noise is taken as AWGN noise. The other method is estimated using RBF networks by considering a competitive neural network model.

4.2 OFDM system model

Orthogonal Frequency Division Multiplexing, OFDM [14] due to its high computational efficiency and flexibility is considered to be the most promising technique. It involves the combination of both multiplexing and modulation schemes.

- Modulation is a change in the parameters (frequency, phase and magnitude) of the carrier signal according to the message signal.
- Multiplexing is the method of sending multiple signals on the same channel; also maintaining their integrity at the receiver end.

OFDM coverts a given high bit rate data stream in to several low bit rate data streams and modulates each data stream on separate carriers, called as subcarriers or tones. It is an extension of FDM (Frequency Division Multiplexing), in which a given bandwidth is divided into narrow band channels to send multiple data streams at the same time. In FDM neighboring channels interfere with each other hence require guard bands to separate them. Introduction of guards reduces the individual sub-channel bandwidth.

OFDM introduces the concept of Orthogonality of sub carriers. Orthogonal subcarriers rule out the possibility of inter channel interference. Two signals are said to be orthogonal if they are uncorrelated over a symbol duration time.

$$\int_0^T S1(t).S2(t).dt = 0 \qquad (4.1)$$

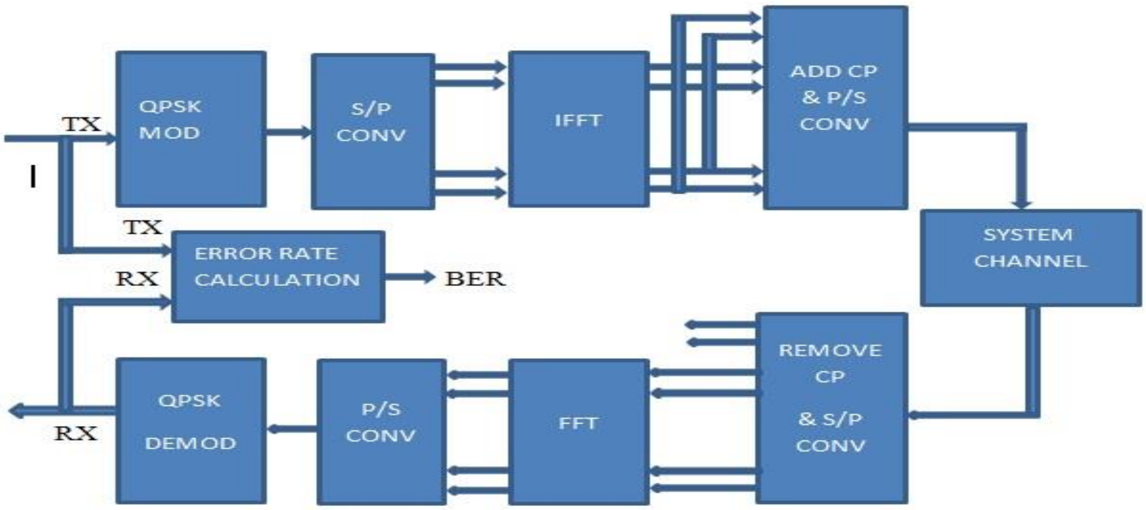

Figure 4. 1 OFDM block diagram.

The attraction of OFDM is mainly due to how the system will handle the multipath signals at the receiver. By using orthogonality condition OFDM can reduce the effect of ISI (Inter Symbol Interference). The data sequence is given to the modulation block where we can use any type of digital modulation technique like BPSK, QPSK and QAM. After modulation they are passed to serial to parallel convertor block. In this block, the high bit serial data stream is divided into several low bit parallel data streams. On that parallel data streams, IFFT is applied which means the time components are converted to frequency components and then cyclic prefix is added. After adding cyclic prefix they are converted to serial data and transmitted through the channel. In the receiver section the reverse process is taken place and the BER is calculated as the difference of the transmitted and received data streams.

4.2.1 S/P and P/S convertor Block:

In S/P block high bit serial data stream is converted to several low bit parallel data streams.

In P/S block several low bit parallel data streams is converted to high bit serial data stream.

4.2.2 IFFT/FFT Blocks:

IFFT block is used to transfer the data from frequency to time area. FFT block is used to transfer the data from time to frequency area.

The OFDM symbol generate after IFFT is given by

$$x[n] = \frac{1}{\sqrt{N}} \sum_{i=0}^{N-1} X[i] e^{2\pi ni/N} \quad , 0<n<N\text{-}1 \qquad (4.2)$$

Each x[n] represents a sum of modulated symbols with frequency modulated by $e^{2\pi ni/N}$ factor.

4.2.3 Cyclic Prefix:

The multipath environment degrades the baseband signal, due to constructive and destructive addition of delayed signals. The process of delayed symbols distorting each other is known as ISI (Inter Symbol Interference). In OFDM this problem is tackled by the addition of CP to the symbol. After modulation, CP (Cyclic prefix) is added at the end of every symbol. CP serves the same purpose as guard bands in frequency division multiplexing. Addition of CP increases the symbol duration and eventually reduces the symbol rate across the channel. ISI is reduced on introduction of CP.

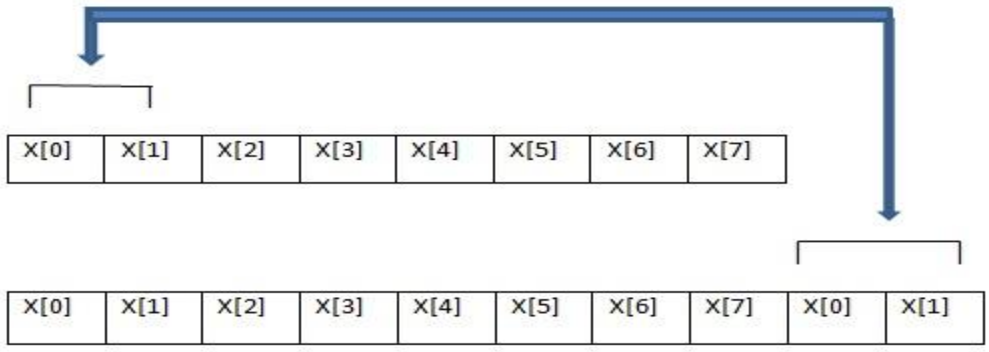

Figure 4. 2 Addition of cyclic prefix.

After the addition of CP to the symbols, they are passed through the parallel to serial converter. OFDM symbol preceding CP make convolution between channel and OFDM symbol, circular in nature.

4.2.4 Inter Symbol Interference (ISI):

When two adjacent signals are overlapped with each other then information present in the signals are lost and produces a noise called as inter symbol interference. ISI is usually caused by multi path propagation of the signals from transmitter to the receiver. This ISI produces an error at the decision device of the receiver output. Hence our aim is reduce the effect of ISI and deliver the digital data to the receiver with smallest error rate possible.

4.2.5 Inter Carrier Interference (ICI):

In OFDM systems the orthogonality of the subcarriers is lost due to the presence of Doppler shift, frequency and phase offsets. This causes the interference between subcarriers called as Inter Carrier Interference.

4.3 Channel estimation using neural networks

Artificial neural network (ANN) basically consists of non-linear functional blocks called neurons which are inter-connected to each other by a parallel synaptic weights. Neural network has learning ability which means the synaptic weights are updated according to the learning algorithm. So by using this learning algorithms the neural network reacts on the given input for the desired output.

4.3.1 Multilayer Perceptron using Back Propagation Algorithm:

The MLP neural network structures with the back propagation learning algorithm is used to get CIRs. This estimator is shown in **Figure 4.3**. which shows the proposed MLP network has two inputs, two outputs and ten hidden neurons. The complex OFDM signals are fed to network by converting them into real and imaginary parts because neural networks allows only the real format whereas OFDM signals are in complex format. These symbols are used as channel estimators and this process can be done by computing the weights sum coming into the nodes and applying the sigmoid function [15].

The activation function of the hidden layer is

$$net_j = \sum_{i=1}^{d} X_i w_{ij} \tag{4.3}$$

$$o_j = f(net_j) = \frac{1}{1+e^{-net_j}} \tag{4.4}$$

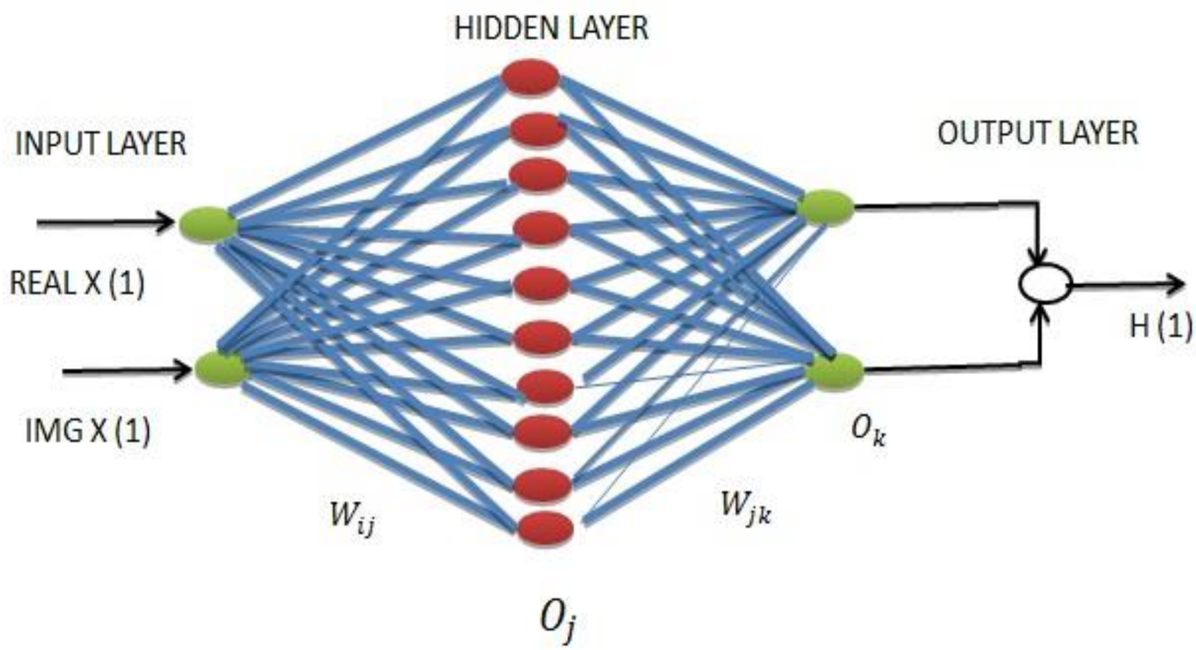

Figure 4. 3 MLP structure for channel estimator.

For the figure 4.3, the OFDM signals are converted into real and imaginary and fed separately to the network. From the input pattern of vectors they are converted to real and imaginary parts. X_i is input data to the network and w_{ij} is weights of the input to hidden layer with j as the hidden node index based on sigmoid function. Based on the output from the hidden layer the output layer computes its net activation as:

$$net_k = \sum_{j=1}^{h} o_j w_{jk} \tag{4.5}$$

$$o_k = f(net_k) \tag{4.6}$$

Where the subscript k indexes units in the output layer and h is the number of hidden units.

In training process; weights of input-to- hidden layer w_{ij} and hidden-to-output layers w_{jk}, are found by minimizing

$$E(w)=\frac{1}{2}\sum_{k=1}^{a}(t_k-o_k)^2 \tag{4.7}$$

Where t_k is k_{th} desired output and o is the number of output points. The back propagation algorithm is based on gradient decent method in which the weights are initialized using pseudo random values and are changed that will reduce the error:

$$\Delta w=-\eta\frac{\partial E}{\partial w} \tag{4.8}$$

Where η is the learning rate chosen between 0 and 1. If η is so small, the algorithm will take a lengthy time to converge and we need more time to converge then the actual one and it’s a time consuming process. Conversely, if η is too high the network is trained faster but we may end up in obtaining error hence the algorithm diverges. If the calculations are so fast we may miss some data and may obtain error, so η was chosen as 0.05 in our simulations.

The weight update (or learning rule) for the hidden-to output weights are calculated as[14]

$$\Delta w_{jk}=\eta(t_k-o_k)f'(net_k)o_j \tag{4.9}$$

The learning rule for the input to hidden weights is

$$\Delta w_{ji}=\eta[\sum_{k=1}^{a}w_{jk}(t_k-o_k)f'(net_k)]f'(net_j)X_i \tag{4.10}$$

4.3.2 RBF Network Architecture

RBF network is shown in figure 4.4 which one input, output and hidden layers. First one is the input layer which is of linear and has input data to be trained. The second one is the only hidden layer of the network which uses set or radial basis functions. There are many basis functions but we use a Gaussian radial basis function in our simulation. The third layer is the output layer which is the sum of the outputs coming from the hidden layers. The relation between input layer and hidden layer is of non-linear and relation between hidden to output layer is of linear one.

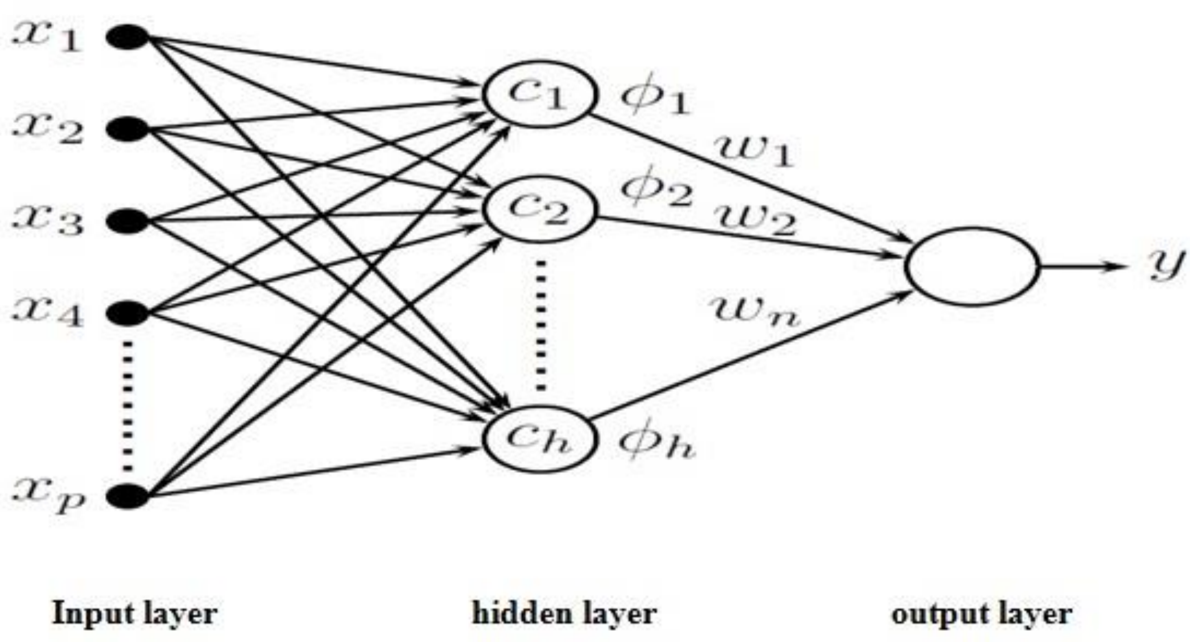

Figure 4. 4 Architecture of RBF network.

The training sequence is applied to the first layer known as input vector and this entire input vector is shown to the hidden layer. Hidden layer neuron stores a data called as center vector which is one of the vectors from the training vectors. Each neuron in the hidden layer compares with the input vector to the center and outputs a value between 0 and 1 to the third layer. If the input neuron is equal to the center, then the output of the hidden layer will be 1. If the distance between the input neurons and the center increases then the output gradually decreases and finally becomes 0. In third layer the inputs from the hidden neurons is added and gives the output. The RBF neuron will produce its large response when input is equal to center vector but as we move far from the center, the response falls exponentially. Every neuron has some contribution to the output and hence the similar neurons has great influence on the output but coming to the neurons far from center has less influence on the output of the network [16].

An input vector x_i which lies in the receptive field for center c_j , would activate c_j and by proper choice of weights the target output is obtained.

The output is given as

$$y = \sum_{j=1}^{h} W_j \phi_j , \qquad \phi_j = \phi\left(\left\|x - c_j\right\|\right). \tag{4.11}$$

W_j : weight of j^{th} center.

ϕ : some radial function.

Different radial functions are given as follows

Table 11: Different radial basis functions

Gaussian radial function	$\phi\,(z) = e^{-z^2/2\sigma^2}$
Thin plate spline	$\phi\,(z) = z^2 \log z$
Quadratic	$\phi\,(z) = (z^2 + r^2)^{1/2}$
Inverse quadratic	$\phi\,(z) = {}^{1}/_{(z^2 + r^2)^{1/2}}$

Here z = ||x-c_j||

The most popular radial basis function is Gaussian activation function.

Learning algorithm:

Gradient decent learning approach:

The most popular method to update weights and centers is gradient decent method which uses a supervised learning technique.

The rule for center leaning is

$$C_{ij}(t+1) = C_{ij}(t) + \eta_1 (y^d - y) w_i \frac{\phi_i}{\sigma^2}(x_j - C_{ij}) \quad (4.12)$$

The update rule for linear weights is

$$w_i(t+1) = w_i(t) + \eta_2 (y^d - y)\phi_i \quad (4.13)$$

These are the updated weights and centers for the given network by using supervised learning of RBF known as generalized RBF. The learning rate parameters η_1 and η_2 are chosen between 0 and 1 for simulations.

4.4 Simulation Results:

Table 12: simulation parameters

Parameter	**Value**
FFT size	64
Number of sub carriers used	64
Modulation type	QPSK
Learning rate	0.05
Z_L, Z_S	50 Ω

By using parameters from table 12, the graphs of BER for AWGN and PLC are plotted for both BPSK and QPSK modulation schemes in figure 4.5 and figure 4.6 respectively. BER graph is plotted for estimation using RBF networks and compared with competitive neural networks in figure 4.7 which gives better result than the competitive neural networks.

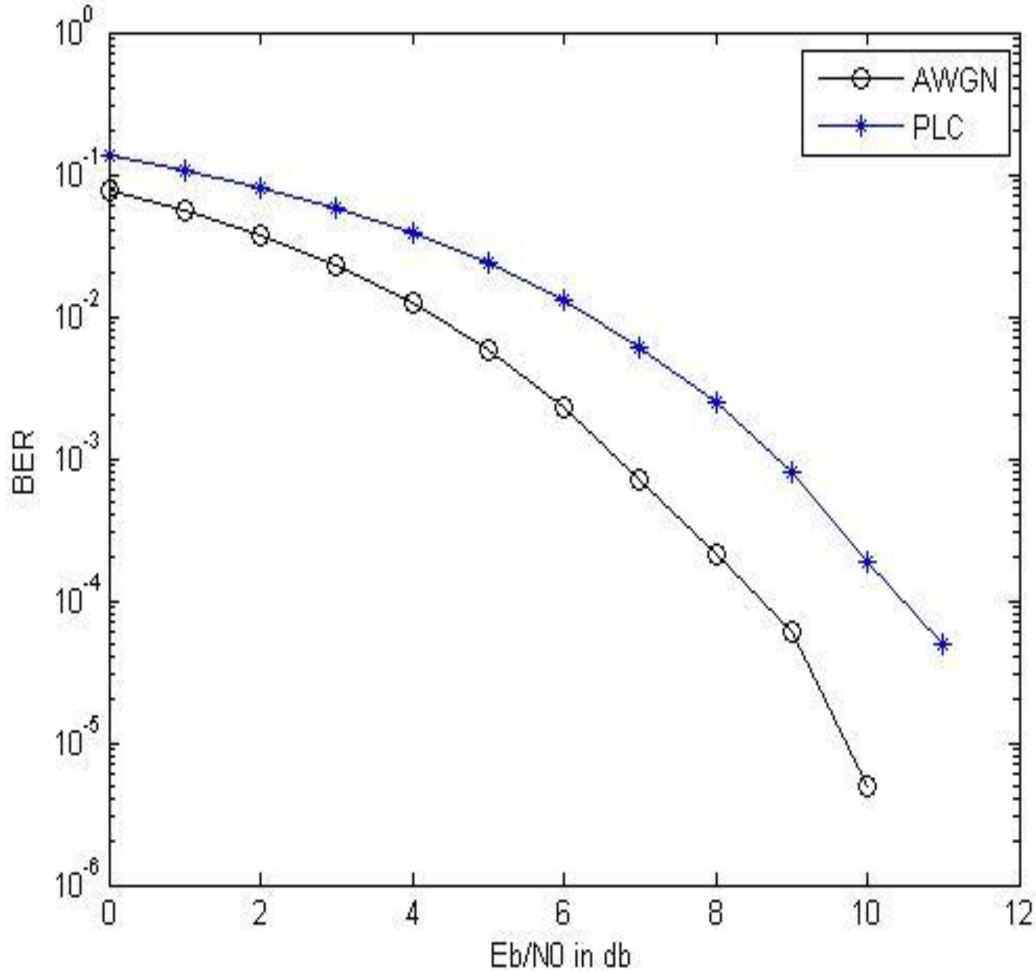

Figure 4. 5 BER values of AWGN and PLC using OFDM for BPSK.

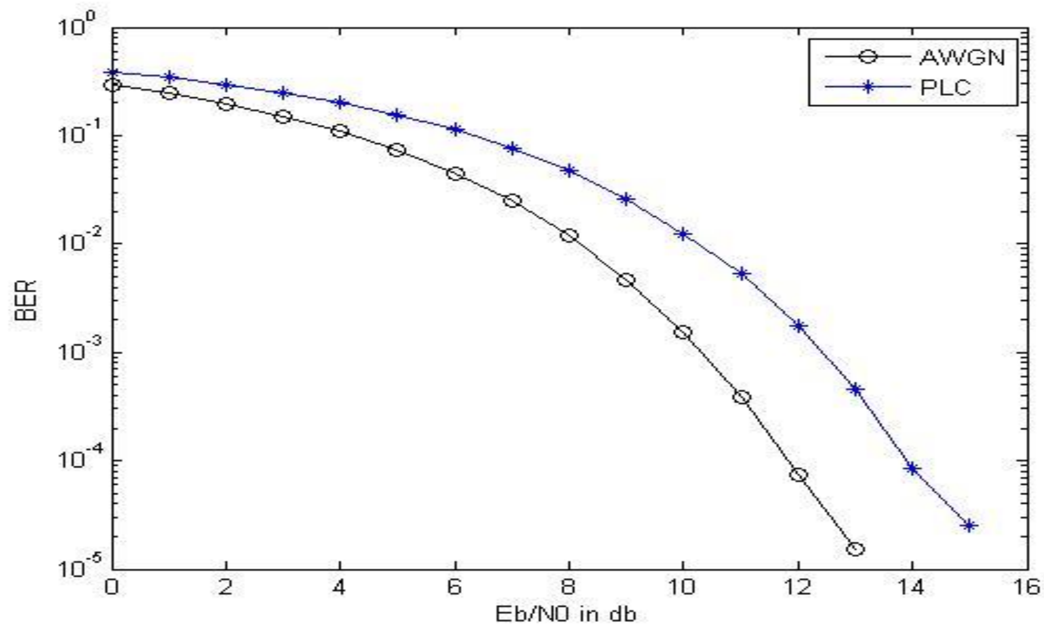

Figure 4. 6 BER values of AWGN and PLC using OFDM for QPSK.

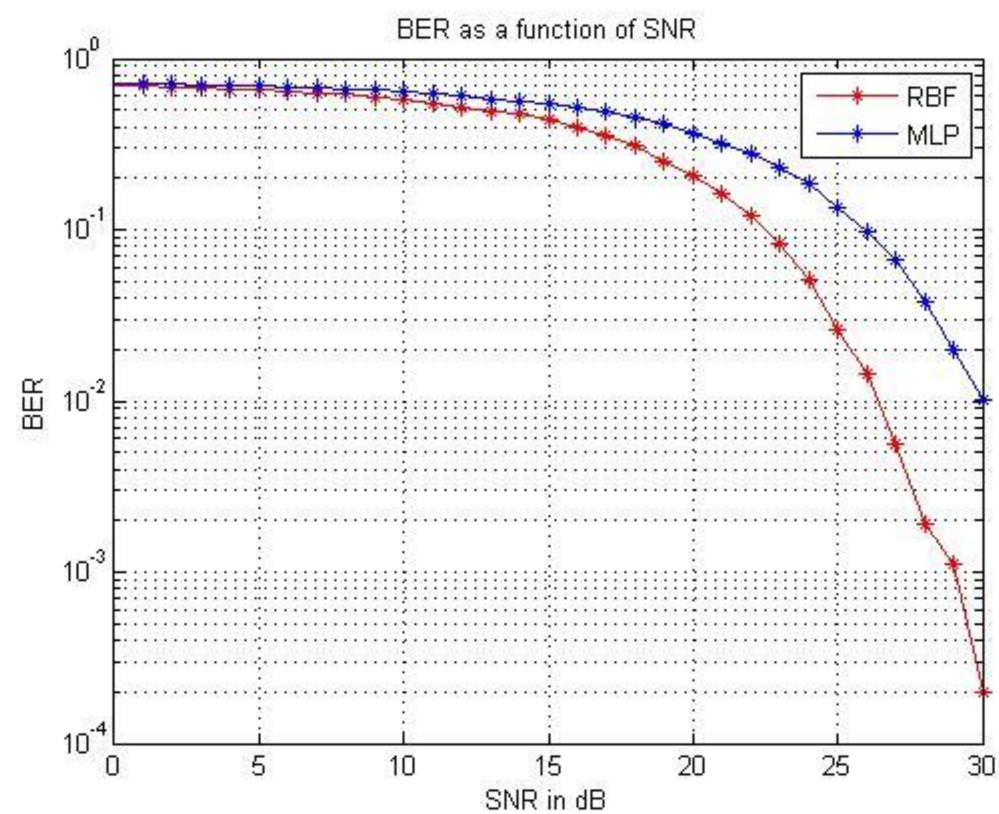

Figure 4. 7 BER values for channel estimators.

CHAPTER V

CONCLUSION

Conclusion

This thesis gives the overview of evolving technology Smart Grid. As, world is becoming modernized and digitalized, we are more dependent on electricity than ever before. From the past 100 years, the power grid is the same as it was built at the beginning but the world has become so much digitalized that we depend more on electricity. If this process continues, we are cannot provide electricity even for our basic needs. Hence the power grid has to be evolved quickly to a newer one which has the capability to serve the needs by integrating the renewable sources and efficient use of electricity. Smart Grids are emerging as a new technology and the customer participation is very important by encouraging it rather than the power grid. Customers should adopt to the changes and should install the required equipment for the smart grid to function efficiently.

From all the communication alternatives, PLC plays a crucial role because they are already installed and even reach to rural areas more easily than any other technology. In this thesis, a PLC channel model is modelled and to study the real channel characteristics of the channels outside world, some reference channels are proposed. Based on these channels we can obtain the transfer functions to the real channels similar to them.

Neural networks has the ability to learn things more faster and by using this advantage Channel is estimated using neural networks.in this thesis, after PLC channel modelling estimation is done by two types and compared the results with each other for better performance.

In this thesis, MLP and RBF techniques are used to estimate channel and compared their results based on PER values and best one is proposed for channel estimation.

Future scope

1. To get BER of the system which uses all the topologies mentioned in this thesis and analyze corresponding results.

2. To get better channel estimation technique for PLC than the proposed one for Smart grid Systems.

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