CHANNEL ESTIMATION AND MODELING OF POWER LINE COMMUNICATION

A THESIS SUBMITTED IN PARTIAL FULFILLMENT

OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Technology

In

Communication and Signal Processing

by

Vanitha Devi R

Roll No: 211EC4087

Department of Electronics & Communication Engineering

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Department of Electronics and Communication Engineering

National Institute of Technology Rourkela

Rourkela-769 008, Odisha, India.

Certificate

This is to certify that the thesis entitled, "CHANNEL ESTIMATION AND MODELING OF POWER LINE COMMUNICATION" submitted by Vanitha Devi R (211EC4087) in partial fulfillment of the requirements for the award of Master of Technology degree in Electronics and Communication Engineering with specialization in "Communication and Signal Processing" at National Institute of Technology, Rourkela (Deemed University) and is an authentic work by her 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.

Date:

Prof. Poonam Singh
Dept. of E.C.E
National Institute of Technology
Rourkela-769008

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Vanitha Devi R

Roll No.211EC4087

Department of ECE

NIT Rourkela

Dedicated to My Parents and Teachers

ABSTRACT

This thesis deals with modeling of power line communication. A two-port network model is theoretically described. A substantial part is focused on the mathematical description of distribution network using the method, which uses chain parameter matrices describing the relation between input and output voltage and current of the two-port network. This method is used for modeling sample power line topology. Furthermore, taps length and taps impedance influence on the transfer functions for different topology are examined.

In this thesis, a decision–directed method is proposed for channel estimation and equalization in Power line communication (PLC) based on orthogonal frequency division multiplexing (OFDM). This method does not require a priori knowledge on the power line. Simulations on a realistic indoor power-line system show that the method achieves very good channel estimation and equalization performances and that it is robust to impulsive noise and nonlinearities. Later multilayer perceptron (MLP) based algorithm called back propagation algorithm has been proposed in power line communication. The present method (back propagation algorithm) is a OFDM based model which exploited for the channel estimation. Simulations on a realistic indoor power-line system show that the results obtained from the channel estimation using present model are significantly improved when compared with competitive neural network. It is also noteworthy to mention that the computational complexity is decreased using the present algorithm.

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ACRONYMS

ADSL	Asymmetric Digital Subscriber Line
AMR	Automatic Meter Reading
BER	Bit Error Rate
CP	Cyclic Prefix
DSM	Demand Side Management
FFT	Fast Fourier Transform
FSK	Frequency Shift Keying
GMSK	Gaussian Minimum Shift Keying
IBI	Inter Block Interference
ICI	Inter Symbol Interference
LAN	Local Area Network
MLP	Multi-Layer Perceptron
OFDM	Orthogonal Frequency Division Multiplex
PSK	Phase Shift Keying
PLC	Power line communication
PLT	Power line Telecommunication
QAM	Quadrature Amplitude Modulation
SNR	Signal-to-noise Power Ratio

CHAPTER I

INTRODUCTION

1.1 Introduction

The communication flow of today is very high. Many applications are operating at high speed and a fixed connection is often preferred. If the power utilities could supply communication over the power-line to the costumers it could make a tremendous breakthrough in communications. Every household would be connected at any time and services being provided at real-time. Using the power-line as a communication medium could also be a cost-effective way compared to other systems because it uses an existing infrastructure, wires exists to every household connected to the power-line network.

The deregulated market has forced the power utilities to explore new markets to find new business opportunities, which have increased the research in power-line communications the last decade. The research has initially been focused on providing services related to power distribution such as load control, meter reading, tariff control, remote control and smart homes. These value-added services would open up new markets for the power utilities and hence increase the profit. The moderate demands of these applications make it easier to obtain reliable communication. Firstly, the information bit rate is low, secondly, they do not require real-time performance.

The use of Internet has increased in these days . If it would be possible to supply this kind of network communication over the power-line, the utilities could also become communication providers, a rapidly growing market. On the contrary to power related applications, network communications require very high bit rates and in some cases real time responses are needed (such as video and TV). This complicates the look of a communication system however has been the main focus of the many researchers throughout the last years. Systems under trial exist today that claim a bit rate of 1 Mb/s, but most commercially available systems use low bit rates, about 10-100 kb/s, and provides low-demanding services such as meter reading.

The power-line was initially designed to distribute power in an efficient way, hence it is not adapted for communication and advanced communication methods are needed. Today's research is mainly focused on increasing the bit rate to support high-speed network applications.

1.1.1. Power Line Communication

Power line communication (PLC) carries data on a conductor that is also used simultaneously for AC electric power transmission or electric power distribution to consumers. It is also called as power line carrier.

The different applications that need power line communications ranges from home automation to internet access. The two line nature of PLC includes: first one is the integration into wide area communication systems as the access part (i.e. the "last mile") in competition with other technologies like Asymmetric Digital Subscriber Line (ADSL) wireless local loop or telephone line; the other is the use as Local Area Network (LAN) inside buildings or plants where we have to avoid new and complicated wirings. One of the main hindrances in modeling a good power line channel is the harsh and noisy transmission medium. Moreover, the power line channel is frequency selective, time-varying, and is impaired by colored background noise and impulsive noise. Furthermore, the wavelengths corresponding to the signals are comparable with the distances covered by a power line network and this requires the use of transmission line models to analyze the system.

PLC systems operate by impressing a modulated carrier signal on the wiring system. Differing kinds of PLC use completely different frequency bands, depending on the signal transmission characteristics of the power wiring used. Since the power distribution system was originally meant for transmission of AC power at typical frequencies of fifty or sixty Hz, power wire circuits have solely a restricted ability to hold higher frequencies.

Data rates and distance limits vary widely over many power line communication standards. Low-frequency (about 100–200 kHz) carriers fascinated on high-voltage transmission lines could carry 1 or 2 analog voice circuits, or measure and management circuits with the same data rate of a few hundred bits per second; but, these circuits could also be several miles long. Higher information rates usually imply shorter ranges; a local area network in operation at a lot of bits per second could only cover one floor of an associate office block, however eliminates the need for installation of dedicated network cabling.

1.1.1.1 Varied applications of power line communication

Power line communication technology is used for various smart grid applications and the main functionality is to transmit the control and diagnostic information like measurement of temperature, vibration, humidity and the time duration and this is all done to achieve better efficiency and energy management which is becoming the most important essential of today while considering the growing demand for the energy and higher diminishing rate of existing resources. Although the power line communication find applications at all levels i.e. high medium and low voltage levels. But being more specifically we are mainly concerned about management of energy at the consumers level i.e. low voltage applications.

1. Automatic Meter Reading (AMR) - The most enduring feather of this application is the availability of information to the customer on a real time basis and enables him to get through the electricity pricing whenever desired and helps him to reduce the operational cost and losses as it also enables the customer's remote connect/disconnect.
2. Demand Side Management(DSM) – This is the one which is gaining interest at a very fast pace due to its ability to make demand in accordance with the generation and hence it may provide a lot better control especially under peak power conditions and allows customer to be central part of energy management program.

Vehicle to Grid Communication-It provides a facility to charge the battery when it is connected to electric vehicle supply equipment which in turn is connected to nearby wiring cables, in the areas like parking lots, airports etc. The most basic advantage of this can be the association between the vehicle and electrical vehicle provide instrumentality that isn't possible just in case of wireless communication.

1.1.2 Digital Communications

In this section we study some preliminaries from digital communications. A model of a digital communication system is given in the next section and the last two sections give a short introduction to bandwidth and diversity.

1.1.2.1 System model

Figure 1.1 shows a simplified model of a digital communication system. Recommended textbooks on this subject are [1], [2] and [3]. The objective of the communication system is to connect digital information (a sequence of binary information digits) over a noisy channel at as high bit rates as attainable. The data to be transmitted could origin from any source of information. In case the information is an analog signal, such as speech, then an A/D converter must precede the transmitter.

The source encoder outputs data that are to be transmitted over the channel at a certain information bit rate, R_b. As a measure of performance we define the bit error probability, P_b, as the probability that at the destination a bit is incorrectly received. As we will see later, the channel may interfere with the communication, thus increasing the bit error probability.

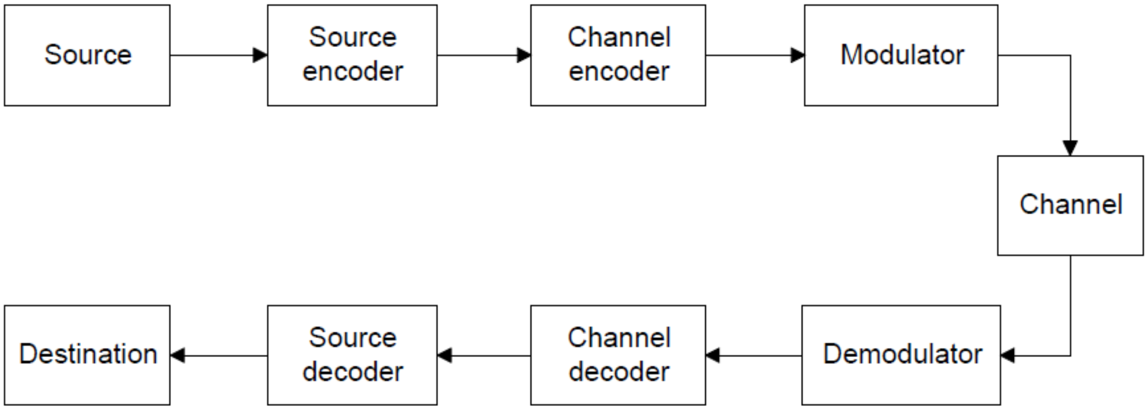


Figure 1.1 A model of a digital communication system.

Source Coding

Most data contains redundancy, which makes it possible to compress the data. This is done by the source encoder and minimizes the amount of bits transmitted over the channel. At the receiver the source decoder unloads the data to either an precise replica of the source (lossless data compression) or a distorted version (lossy data compression). If the received sequence does not have to be an exact copy of the transmitted stream then the degree of compression can be increased.

Channel coding

In order to reduce the bit error probability the channel encoder adds redundancy (extra control bits) to the bit sequence in a controlled way. When an error appears in the bit stream the extra information may be used by the channel decoder, to detect, and possibly correct, the error. The redundancy added is depending on the amount of correction needed but is also tuned to the characteristics of the channel. We have two coding techniques which are used mostly are

1. block codes
2. convolutional codes.

Modulator

The modulator produces an information-carrying signal, propagating over the channel. At this stage the data is converted from a stream of bits into an analog signal that the channel can handle. The modulator has a set of analog waveforms at its disposal and maps a certain waveform to a binary digit or a sequence of digits. At the receiver, the demodulator attempts to detect which waveform was transmitted, and convert the analog information back to an order of bits. Numerous modulation techniques exists, e.g., spread-spectrum, OFDM (Orthogonal Frequency Division Multiplex), GMSK (Gaussian Minimum Shift Keying), QAM (Quadrature Amplitude Modulation), FSK (Frequency Shift Keying) and PSK (Phase Shift Keying)

Channel

The channel might be any physical medium, such as coaxial cable, air, water or telephone wires. It is important to know the characteristics of the channel, such as the attenuation and the noise level, because these parameters directly affect the performance of the communication system.

1.1.2.2 Bandwidth

The frequency content of the information-carrying signal is of great importance. The frequency interval used by the communication system is called bandwidth, W. For a precise communication method, the bandwidth needed is proportional to the bit rate. Thus a higher bit rate needs a larger bandwidth for a fixed method. If the bandwidth is doubled then the bit rate is also doubled. In today's environment bandwidth is a limited and precious resource and the bandwidth is often constrained to a certain small interval. This puts a restriction on the communication system to communicate within the assigned bandwidth. To compare different communication systems the *bandwidth efficiency*(ρ*)*is defined as

$$\rho = \frac{r_b}{w} \qquad (1.1)$$

and is a measure of how good the communication system. Today, an advanced telephone modem can achieve a bit rate of 56.6 kb/s using a bandwidth of 4 kHz and the bandwidth efficiency is 14.15 b/s/Hz. A meter reading system for the power-line channel that has a bit rate of 10 kb/s and communicates within the CENELEC A band has a bandwidth efficiency of 0.11 b/s/Hz, thus the performance of the telephone modem is much higher.

1.1.2.3 Diversity

To reduce the error probability of severe channels, diversity techniques [2] may be used. Examples are time diversity and frequency diversity. In time diversity the same information is transmitted more than once at abundant different time instants. If the channel is bad at some time instant the information might pass through at some other time when the channel is good (or better). This is especially useful on time-varying channels. Frequency diversity transmits the same information at different locations in the frequency domain. It may be compared to having 2 antennas sending at completely different frequencies, if one in all them fail the opposite may work.

1.1.3 The Power-Line as a Communication Channel

In this section we tend to study the power-line as a channel and discuss this analysis. In Section 1.1.1, we tend to outline a channel as a physical path between a transmitter and a receiver. Note that a low-voltage grid consists of the many channels each with its own characteristics. **Figure 1.2** below shows a digital communication system using the power-line as a communication channel. The transmitter is shown to the left and also the receiver to the right. Essential parameters of the communication system are the output impedance, Z_t, of the transmitter and the input impedance, Z_l, of the receiver.

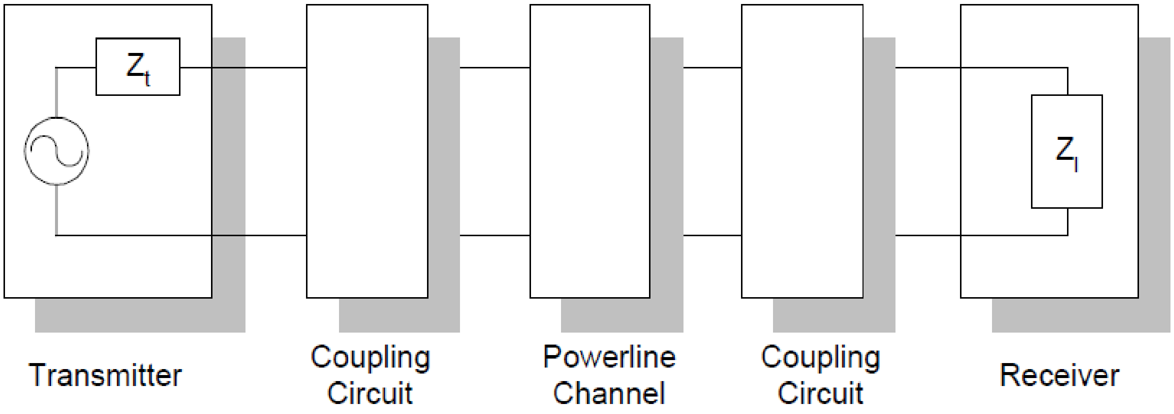


Figure 1.2 A digital communication system for the power-line communication.

A coupling circuit is employed to connect the communication system to the power-line. The aim of the coupling circuits are: Foremost, it prevents the damaging 50 Hz signal, used for power distribution, to enter the equipment. Secondly, it certifies that the main part of the received/transmitted signal is inside the frequency band used for communication. This will increase the dynamic range of the receiver and makes sure the transmitter introduces no meddlesome signals on the channel. In the following sections we study different behaviors and properties of the power-line channel.

1.1.3.1 Bandwidth limitations

As designated above the bandwidth is proportional to the bit rate, so an outsized information measure is required so as to communicate with high bit rates .In Europe the allowed bandwidth is regulated by the CENELEC standard, see [4]. The quality solely permits frequencies between 3 kHz and 148.5 kHz. This puts a hard restriction on power-line communications and might not be enough to support high bit rate applications, such as real-time video, depending on the performance needed.

Figure 1.3 shows the bandwidth, as specified by the CENELEC standard. The frequency range is subdivided into five sub-bands. The first two bands (3-9 and 9-95 kHz) are limited to energy providers and the other three are limited to the customers of the energy providers. In addition to specifying the allowed bandwidth the standard also limits the power output at the transmitter.

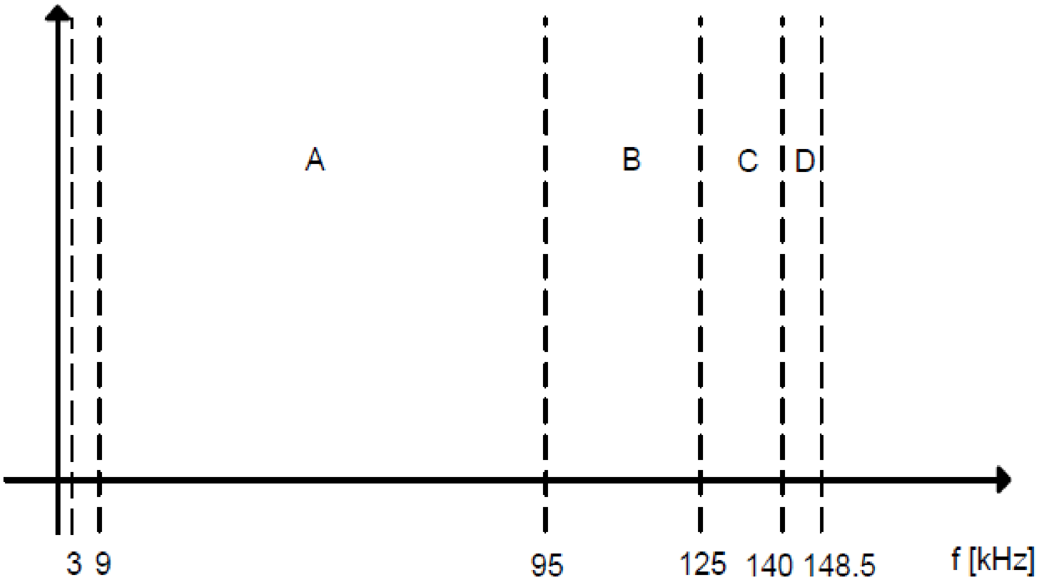


Figure 1.3 The frequency bands in the CENELEC standard.

In order to increase the bit rate, larger bandwidth may be needed. Recent research has suggested the use of frequencies in the interval between 1 and 20 MHz. If this range could be used it would make an enormous increase in bandwidth and would perhaps allow high bit rate applications on the power-line. An important problem is that parts of this frequency band is assigned to other communication system and must not be disturbed. Other communication systems using these frequencies might also disturb the communication on the power-line. Examples of communication systems in this interval are broadcast radio, amateur radio and airplane navigating.

1.1.3.2 Radiation of the Transmitted Signal

When transmitting a signal on the power-line the signal is radiated. One will think about the power-line as an enormous antenna, receiving signals and transmitting signals. It is vital that the signal radiated from the power-line does not obstruct with other communication systems.

When using the frequency interval 1-20 MHz for communication the radiation is extremely important because many other radio applications are assigned in this frequency interval. It is not appropriate for a system to interfere with, e.g., airplane navigation or broadcast systems. Recent research has studied this problem and tries to set up a maximum power level of transmission. It is important that this work is finished in the near future meanwhile it limits the use of this bandwidth and the development of communication systems for the power-line channel.

When the cables are below ground the radiation is small. Instead it is the radiation from the households that makes the major contribution. Wires inside households are not shielded and thus radiate heavily. A key might be to use filters to chunk the communication signal from entering the household.

1.1.3.3 Impedance Mismatches

Normally, at conventional communication, impedance matching is attempted, such as the use of 50 ohm cables and 50 ohm transceivers. The power-line network is not matched. The input (and output) impedance varies in time, with different loads and location. It can be as low as milli Ohms and as high as several thousands of Ohms and is especially low at the substation. Except the access impedance several other impedance mismatches might occur in the power-line channel. E.g., cable-boxes do not match the cables and hence the signal gets attenuated. Recent research has suggested the use of filters stabilizing the network. The cost of these filters might be high and they must be installed in every household and perhaps also in every cable-box.

1.1.3.4 Signal-to-noise-ratio

A key parameter when estimating the performance of a communication system, is the *signal-to-noise power ratio*, *SNR*:

$$\mathrm{SNR}=\frac{\text{Received power}}{\text{Noise power}} \qquad (1.2)$$

This parameter is related to the performance of a communication system. The noise power on the power-line is a summation of many different disturbances. Loads connected to the grid, such as TV, computers and vacuum cleaners generate noise propagating over the power-line. Other communication systems might also disturb the communication, thus introducing noise at the receiver. Noise measurements are found in. When the signal is spreading from the transmitter to the receiver the signal gets attenuated. If the attenuation is very high the received power gets very low and might not be detected. The attenuation on the power-line has shown to be very high (up to 100 dB) and puts a restriction on the distance from the transmitter to the receiver. An option might be to use repeaters in the cable-boxes, thus increasing the communication length. The use of filters could improve the signal-to-noise ratio. If a filter is placed at each household blocking the noise generated indoors from entering the grid, the noise level in the grid will decrease, but the cost is a higher complexity. It is important to point out that although the power-line is considered a harsh environment when it comes to attenuation and disturbances, these parameters exists in any communication system used today.

1.1.3.5 The Time-variant Behavior of the Grid

A problem with the power-line channel is the time-variance of the impairments, The noise level and the attenuation depend partly on the set of connected loads, which varies in time. A channel which is time-variant, complicates the design of a communication system. At some time instants the communication might work well but at other times a strong noise source could be inherent on the channel, thus blocking the communication. To solve this a possible solution is to let the communication system adapt to the channel [2]. At any time the characteristics of the channel are predictable, e.g., through measurements, and the effect is evaluated to make a better decision. The cost of this is higher complexity.

1.1.3.6 A Channel Model of the Power-Line Communication Channel

In the previous section we have seen some impairments that reduce the performance of a power-line communication system:

- Impedance mismatches at the transmitter
- Channel attenuation
- Disturbances (noise)
- Impedance mismatches at the receiver
- Time-variations of the impairments

Figure 1.4 indicates a model of the power-line channel with the parameters above. All impairments except the noise are shown as time-variant linear filters characterized by its frequency response. The disturbance is shown as an additive interfering random process.

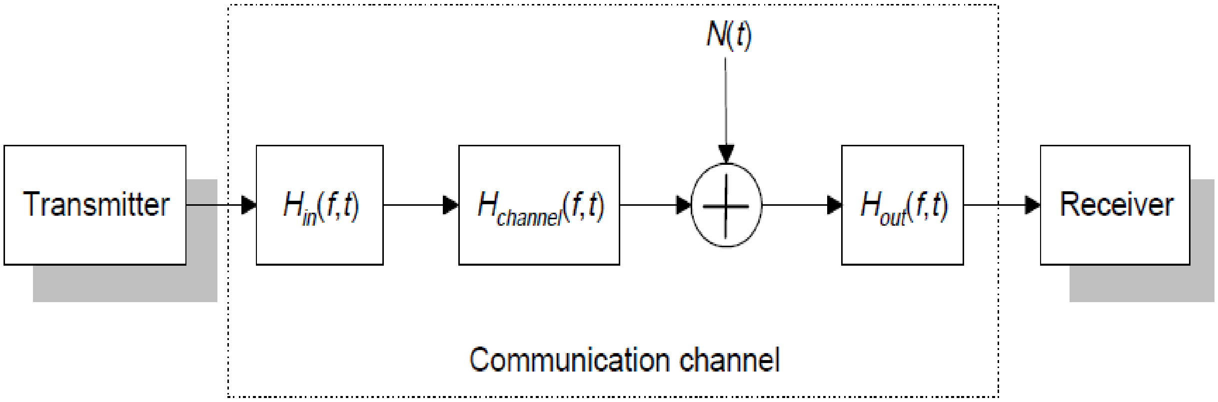


Figure 1.4 Impairments present on the power-line channel.

All the impairments above can be incorporated into a single filter model, shown in **Figure1.5**, consisting of a time-variant filter and additive noise.

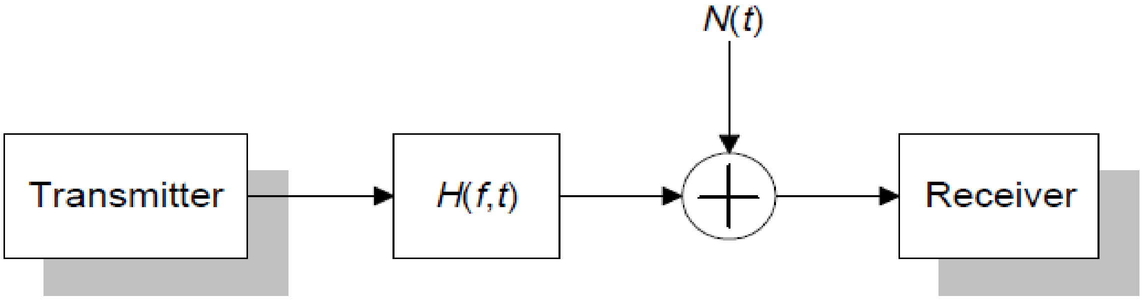


Figure1.5 A simplified model of the power-line channel.

Despite of its simple form this model captures a whole range of properties essential to communication system design and to the consistent performance. The transfer function and the noise can either be estimated through measurements or derived by theoretical analysis.

1.1.4 Outline of Thesis

In this chapter introduction to digital communication and power line communication is given.

In chapter 2 modeling of PLC channel , its dependence on increasing in number of taps, tap length and impedance is discussed.

In chapter 3 two types of channel estimation techniques are given and compared there performance in the case of PLC.

Chapter 4 concludes the present work and predicts some work to be done in future.

CHAPTER II

CHANNEL MODELING OF POWER LINE COMMUNICATION

2.1 Introduction

The determination of the transfer function of the power line is a non trivial task since it depends on a number of variables, topology, network, cable parameters and impedences of the terminated appliances.

2.1.1 Transmission Line Model

Various methods used to simulate and study the transmission line behavior are described[5-7]. Most of them are obtained from the time dependent telegrapher's equations which are for the elementary line transmission cell.

$$\frac{\partial v(x,t)}{\partial x} + R' i(x,t) + L' \frac{\partial i(x,t)}{\partial t} = 0 \tag{2.1}$$

$$\frac{\partial i(x,t)}{\partial x} + G' v(x,t) + C' \frac{\partial v(x,t)}{\partial t} = 0 \tag{2.2}$$

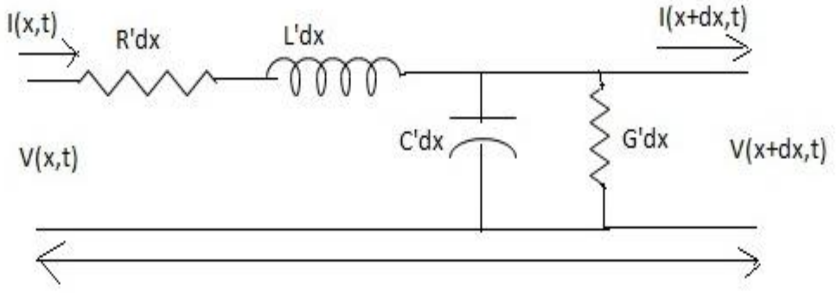


Figure 2.1 Elementary cell of a transmission line.

The Elementary cell of a transmission line is depicted in **Figure2.1**. In the above equations *x* denotes the longitudinal direction of the line and R', L', G' and C' are per unit length resistance (Ω/m), inductance (H/m), conductance (S/m) and capacitance (F/m), respectively. The electric quantities are dependent on the geometric and constitutive parameters. Transmission lines are described using the characteristic impedance Z_c and the propagation constant γ:

$$Z_C = \sqrt{\frac{R'+j\omega L'}{G'+j\omega C'}}$$
$$\gamma = \sqrt{(R'+j\omega L')(G'+j\omega C')} \qquad (2.3)$$

The characteristic impedance Z_c and the propagation constant γ are related to the per-unit-length parameters of the transmission line. It is supposed that the per-unit parameters depend on frequency as [8].

$$r = r_1; l = l_1 + l_2 / \sqrt{f}; g = g_1 f; c = c_{1,} \qquad (2.4)$$

2.2.2 Power Line Channel Modeling

The power line model is considered as a black box described by transfer function, the method for modeling the transfer function of a power line channel uses the chain parameter matrices describing the relation between input and output voltage and current of two-port network. In **Figure 2.2**, the relation between input voltage and current and output voltage and current of a two port network can be represented as:

$$\begin{bmatrix} U_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} AB \\ CD \end{bmatrix} \begin{bmatrix} U_2 \\ I_2 \end{bmatrix} \qquad (2.5)$$

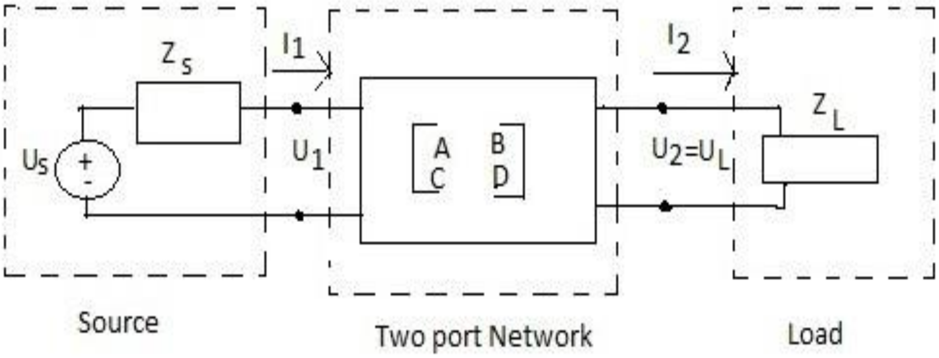


Figure 2.2 Two port network.

$$H = \frac{U_L}{U_S} = \frac{Z_C}{AZ_C + B + CZ_C Z_S + DZ_S} \tag{2.6}$$

H is a transfer function of PLC channel. The ABCD matrix for the transmission line with characteristic impedance Z$_c$, propagation constant γ and length d can be calculated as.

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \cosh(\gamma d) & Z_c \sinh(\gamma d) \\ (1/Z_c)\sinh(\gamma d) & \cosh(\gamma d) \end{bmatrix} \tag{2.7}$$

2.2.3 Sample Network for Modeling of Distribution Network

However power line communication systems do not usually consist of simply a source, transmission line and a load as depicted in figure 1. Bridge taps with different cable lengths and cable types usually exists along the transmission line to form a power line network made of sections. For a power line communication network with several sections, the transfer function for the whole network is still the same as equation; however, the ABCD matrix for the system differs. The ABCD matrix is determined by utilizing the chain rule which involves multiplying the ABCD matrices for the different sections of the network to produce the overall ABCD matrix. While the ABCD matrix for a transmission line is give in equation (2.7), the ABCD matrix for a serially connected load Z_s is:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & Z_s \\ 0 & 1 \end{bmatrix} \quad (2.8)$$

and the ABCD matrix for a load impedance Z_l connected in parallel is:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 1/Z_l & 1 \end{bmatrix} \quad (2.9)$$

A bridge tap terminated with load impedance Z can be considered to be equivalent to impedance Zeq calculated as:

$$Z_{eq} = Z_c \frac{Z + Z_c \tanh(\gamma_{br} d_{br})}{Z_c + Z\tanh(\gamma_{br} d_{br})} \quad (2.10)$$

Where Z_c and γ_{br} are the characteristic impedance and the propagation constant of the branch circuit respectively. Consider the transmission line with one bridge tap connection as shown in **Figure 2.2** which can be replaced by an equivalent network shown in **Figure 2.3** where Z_{eq} is calculated using equation (2.10).

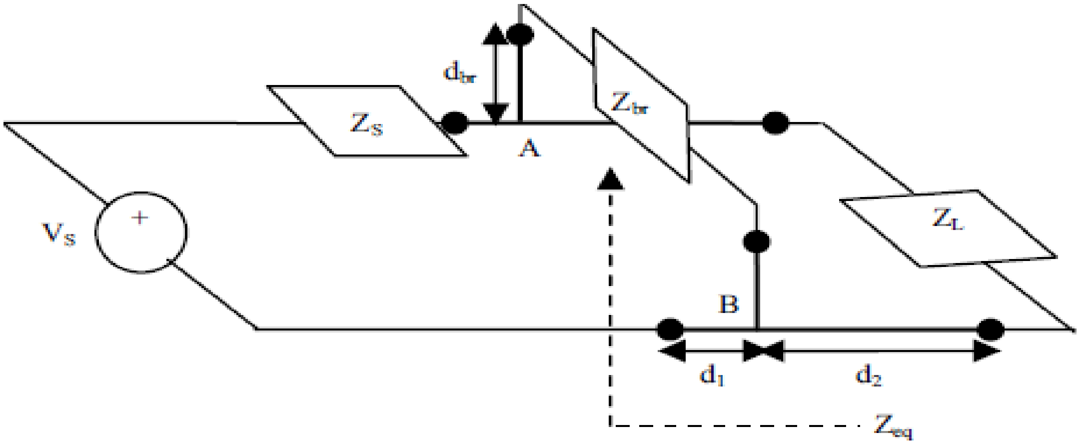


Figure 2.3 Transmission line with bridge tap connection.

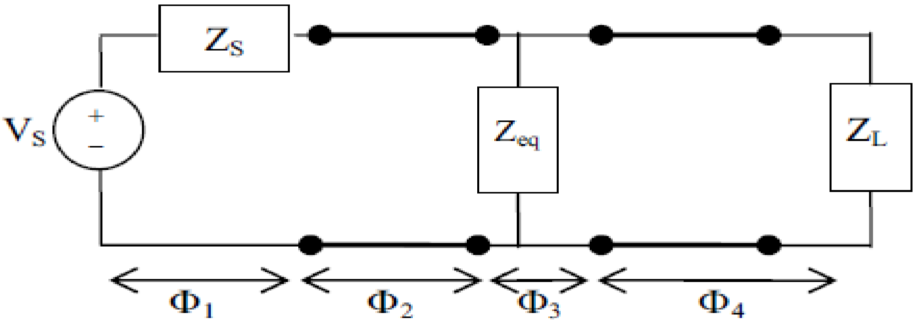


Figure 2.4 Equivalent network for bridge tap connection.

A power line network of **Figure 2.4** can be partitioned to four sub-circuits denoted by $\emptyset_0$, $\emptyset_1$, $\emptyset_2$and $\emptyset_3$. It can be noted that sub-circuit $\emptyset_0$ is a serially connected load, sub-circuits $\emptyset_1$ and $\emptyset_3$ are transmission line sections while $\emptyset_2$ is a load impedancein parallel. Hence, the ABCD matrix for the transfer function is calculated as:

$$\emptyset_0 = \begin{bmatrix} 1 & Z_s \\ 0 & 1 \end{bmatrix} ,\emptyset_1 = \begin{bmatrix} \cosh(\gamma_1 d_1) & Z_1 \sinh(\gamma_1 d_1) \\ (1/Z_1)\sinh(\gamma_1 d_1) & \cosh(\gamma_1 d_1) \end{bmatrix} \tag{2.11}$$

$$\emptyset_2 = \begin{bmatrix} 1 & 0 \\ 1/Z_{eq} & 1 \end{bmatrix} ,\emptyset_3 = \begin{bmatrix} \cosh(\gamma_2 d_2) & Z_2 \sinh(\gamma_2 d_2) \\ (1/Z_2)\sinh(\gamma_2 d_2) & \cosh(\gamma_2 d_2) \end{bmatrix} \tag{2.12}$$

Resultant ABCD matrix can be calculated as[9]:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \emptyset_0 * \emptyset_1 * \emptyset_2 * \emptyset_3 \tag{2.13}$$

Where Z_1, γ_1, Z_2, and γ_2 are the characteristic impedances and propagation constants for the second and fourth sub-circuits. Given the value of the ABCD matrix, the transfer function of the power line can be computed easily. However, as the number of bridge taps increases, the complexity involved and the formula for calculating the ABCD matrix increases in size.

2.2.4 PLC channel topology analysis

The **Figure 2.5** is an indoor power line network which is used here to analysis power line channel transfer function changes with respect to change in number of connected bridge taps, impedances, length of power line.

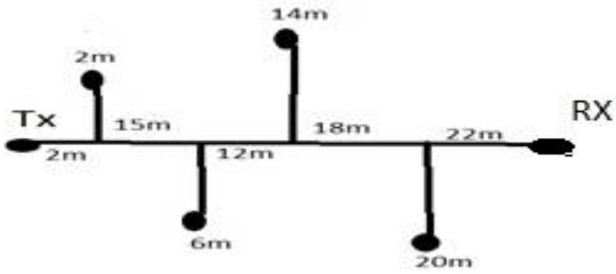
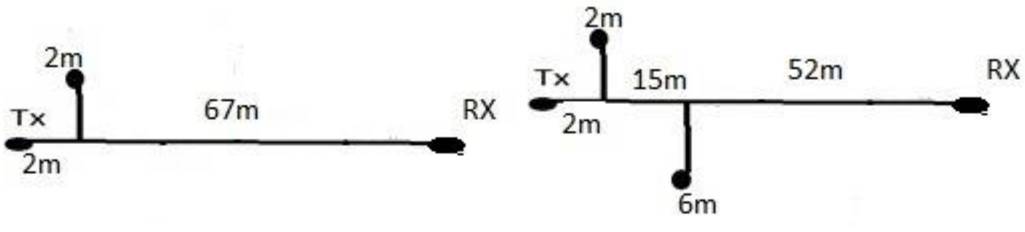


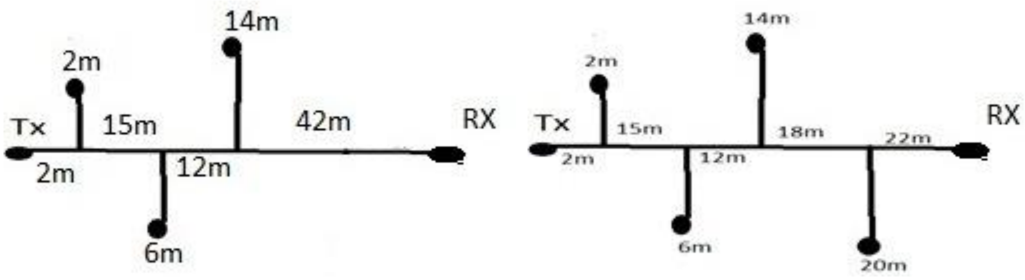
Figure 2.5 Topology of a realistic typical apartment indoor power line network.

2.2.4.1 The Influence of connected taps on transfer function

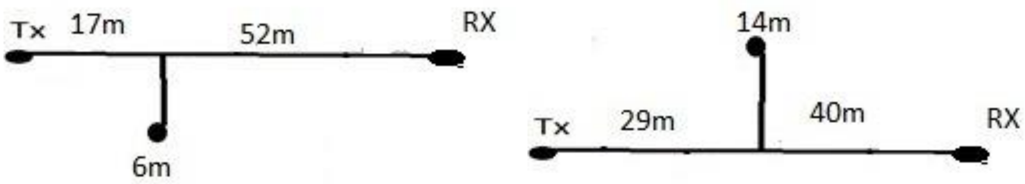
For the topologies in **Figure 2.6 (a),(b),(c),(d)** transfer functions were calculated by the help of two-port network modeling using Matlab/Simulink. The transfer functions of the topology with one, two, three and four taps are shown in the **Figure 2.7** which gives the information that as number of taps increases attenuation will increase.



Top (a) **Top (b)**



Top (c) **Top (d)**



Top (e) **Top (f)**

Figure 2.6 Different types of topologies.

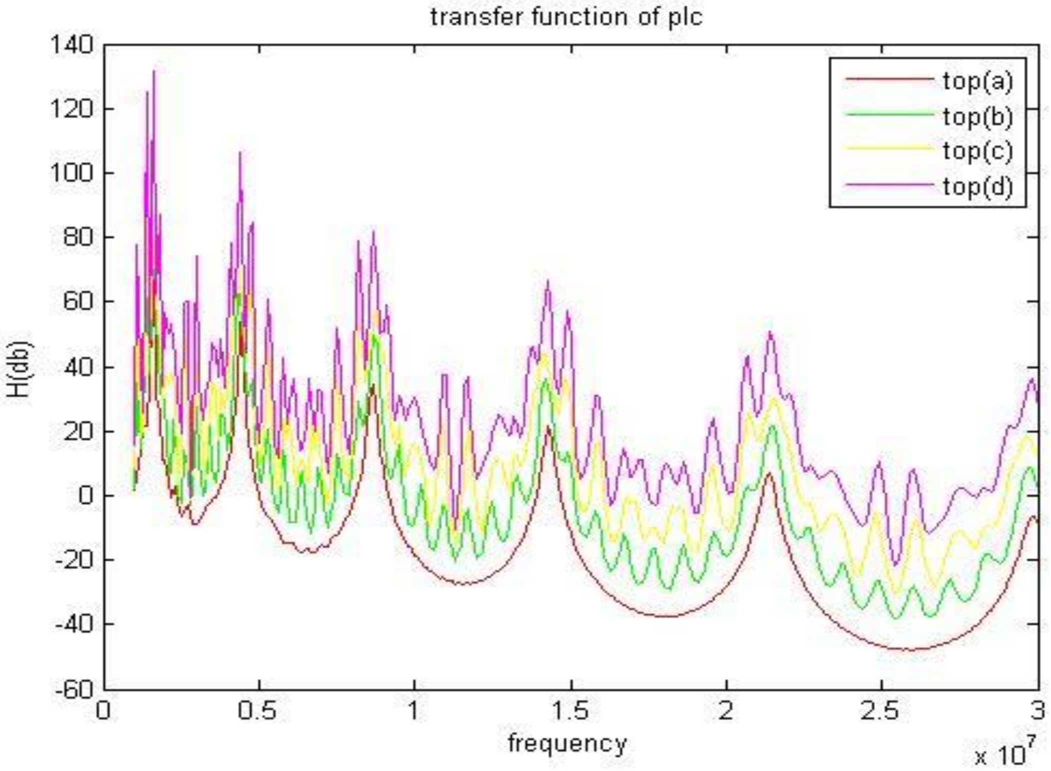


Figure 2.7 Simulation of the transfer functions for the topologywith one, two, three and four taps.

2.2.4.2 The influence of tap length on transfer function

The shape of the transfer function is strongly influenced by the length of the connected tap. In **Figure 2.8** and **Figure 2.9**, transfer functions for different taps length were calculated. The topology a) and e) from **Figure 2.6** were considered. The lengths ranges were set up from 0 to 15 meters. These values are derived for urban application. In **Figure 2.8** and **Figure 2.9**, the influence of the tap length on the transfer function for the topology a) and e) are shown respectively. The increasing length of the tap causes increase of the periodical notches in the transfer function waveform [10].

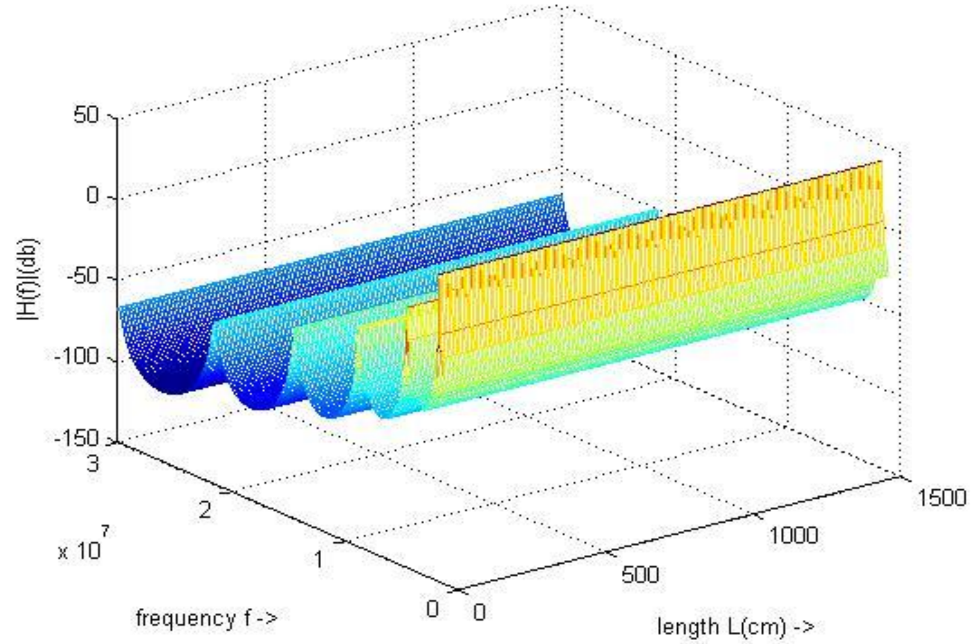


Figure 2.8 The influence of the tap length on the transfer function for topology (a).

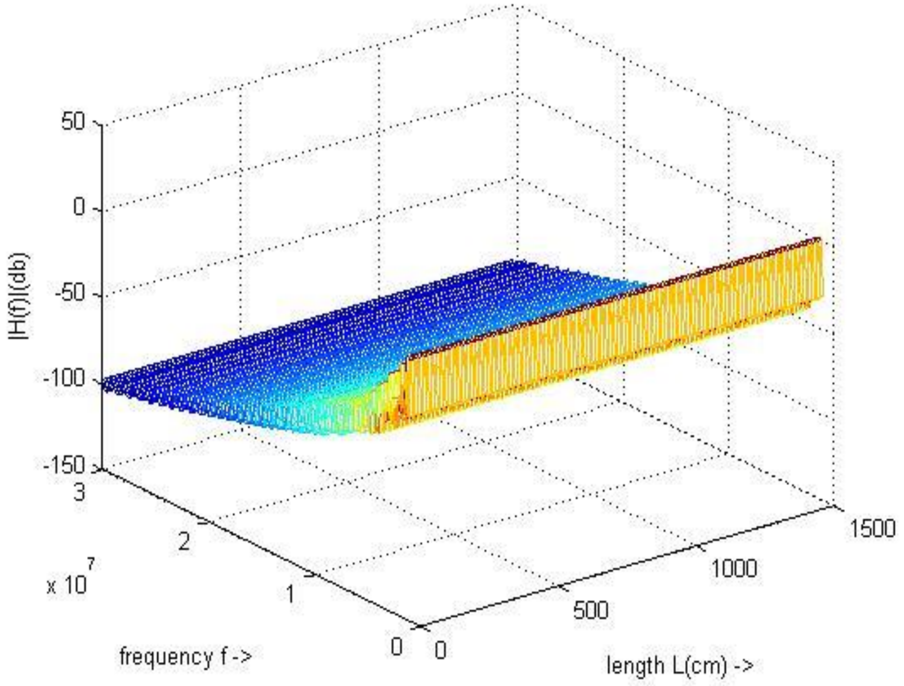


Figure 2.9 The influence of the tap length on the transfer function for topology (e).

2.2.4.3 The influence of connected tap impedance on transfer function

The impedance mismatch causes reflections on line and therefore the impedance values influence the transfer function. The topology f) in **Figure 2.6** was chosen for calculate on the influence of impedance value on the transfer function. The impedance values were set up from 0 to 600 Ω. **Figure 2.10** shows the attenuation increasing in local minima of periodical notches with impedance increasing.

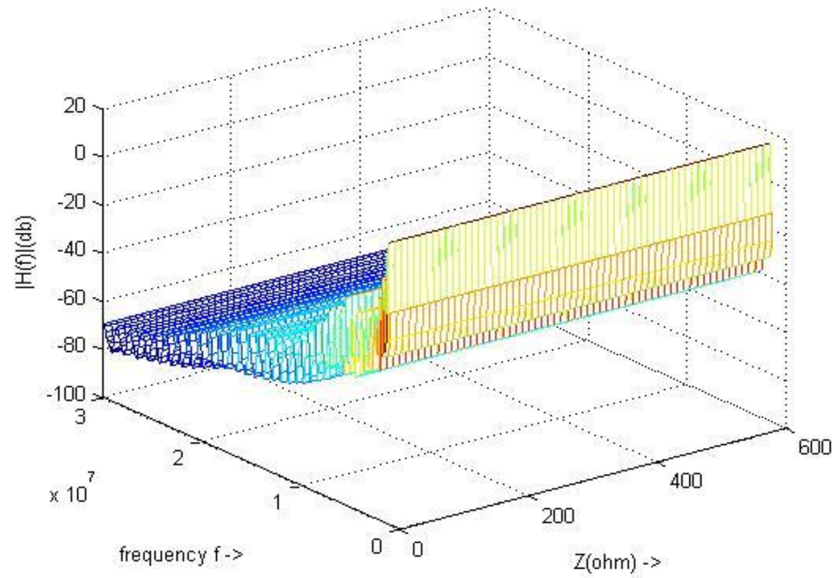


Figure 2.10 The influence of the connected tap impedance on the transfer function for topology (f).

CHAPTER III

CHANNEL ESTIMATION OF PLC

3.1 Overview

In-house PLT (Power line Telecommunication) allows new and highly convenient networking functions without the need for extra cables on mains-powered devices. Since wireless networks are not able to reach enough throughputs between different rooms or even floors, PLC is considered to be the perfect backbone home network medium, providing balancing and unified interaction with wireless networks.

3.2 OFDM System Model

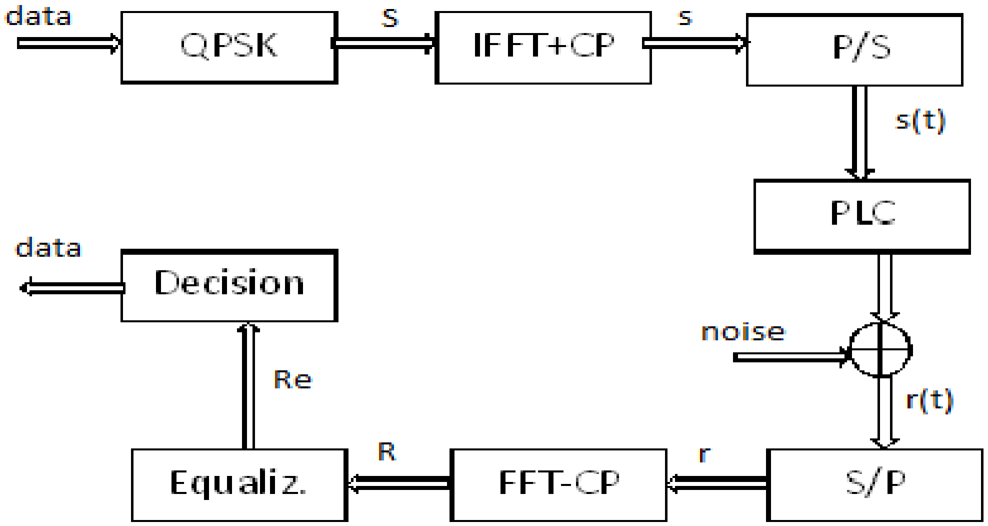


Figure 3.1 OFDM system with cycle prefix.

s(t) is a transmitted signal

h(t) is channel impulse response

r(t) is a received signal

Figure 3.1 presents a classical OFDM transmission scheme that uses Fast Fourier Transform (FFT). The input data sequence is baseband modulated, using a digital modulation scheme. Various modulation schemes could be employed such as BPSK, QPSK (also with their differential form) and QAM with several different signal constellations. There are also forms of OFDM where a distinct modulation on each subchannel is performed (e.g. transmitting more bits using an adequate modulation method on the carriers that are more "confident", like in ADSL systems). The modulation is performed on each parallel sub stream that is on the symbols belonging to adjacent DFT frames. The data symbols are parallelized in N different sub streams. Each sub stream will modulate a separate carrier through the IFFT modulation block, which is the key element of OFDM scheme. A cyclic prefix is inserted to remove the inter symbol interference (ICI) and inter block interference (IBI).

This cyclic prefix of length L is a circular extension of the IFFT-modulated symbol, obtained by copying the last L samples of the symbol in front of it. The data is back-serial converted, forming an OFDM symbol that modulates a high-frequency carrier before transmitting through the channel. The radio channel is generally referred as a linear time variant system. To the receiver, the inverse operations are performed; the data is down converted to the baseband and the cyclic prefix is removed. The coherent FFT demodulator will ideally retrieve the exact form of transmitted symbols. The data is serial converted and the suitable demodulation scheme is used to estimate the transmitted symbols.

3.2.1 Inter Symbol Interference

Inter symbol interference (ISI) is a form of distortion of a signal in which one symbol interferes with subsequent symbols. This is an unwanted phenomenon as the previous symbols have similar effect as noise, which makes the communication as some sort of unreliable. It is usually caused by multipath propagation or the intrinsic nonlinear frequency response of a channel causing successive symbols to distort together. Thepresence of ISI in the system introduces error in the decision device at the receiveroutput. Therefore, in the design of the transmitting and receiving filters, the objective is to minimize the effects of ISI and there by transport the digital data to its destination with the smallest error rate possible.

3.2.2 Inter Carrier Interference

Presence of Doppler shifts and frequency and phase offsets in an OFDM system causes loss in orthogonality of the sub-carriers. As a result, interference is observed betweensub-carriers. This phenomenon is known as inter - carrier interference (ICI).

3.2.3 Cyclic Prefix

The Cyclic Prefix or Guard Interval is a periodic extension of the last part of an OFDMsymbol that is added to the front of the symbol in the transmitter, and is removed atthe receiver before demodulation. According to the figure 1.5 the addition of CyclicPrefix (CP) takes place after the parallel to serial conversion and being removed atthe receiver side before the DFT operation. The OFDM symbol with considering theCyclic Prefix is shown in **Figure 3.2**.

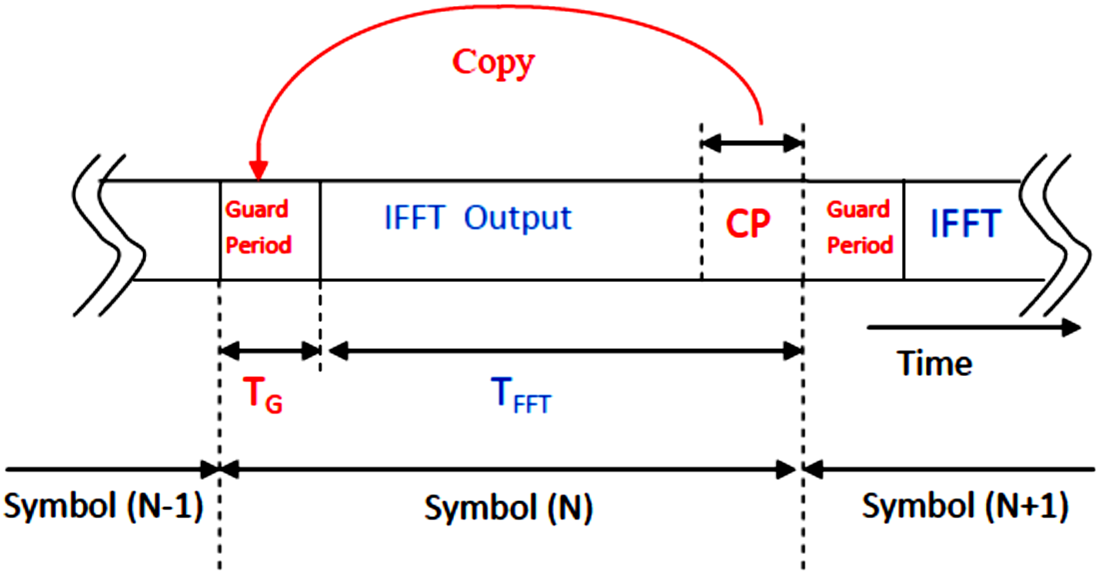


Figure 3.2 Inserting cyclic prefix to an OFDM symbol.

The channel used in this communication system is a PLC(Power Line Communication)channel.

3.3 Channel Estimation Using Competitive Neural Network

The transmitted data symbols on each subcarrier *n* will then be received with a scaling of amplitude and a phase rotation given by the channel. After the FFT in the receiver, we have

$R_n=X_n.H_n+D_n$

where R_n is the received value at the n^{th} subchannel, H_n is the channel complex gain at the frequency of the n^{th} subcarrier ,D_n is complex additive noise formed by a mixture of Gaussian and impulsive noise and S_n is the transmitted symbol at subcarrier n . Transmitted symbols are belong to a QPSK constellation, i.e. S_n {1,j,-1,-j} though the method is applicable to others M-QAM choices. Under this condition, after several OFDM frames being transmitted and considering a stationary channel, the received values at a fixed subcarrier n are liabled in the complex plane in four clusters ideally centred in { H_n, jH_n , $-H_n$, $-jH_n$}. Non linearities and disturbances can affect the symmetry of the constellation, . Let the centres of the distorted constellation of the subcarrier n be called { $N_{n,1}$,$N_{n,2}$,$N_{n,3}$,$N_{n,4}$}. We are made-up to track independently these four clusters presenting the received symbol R_n to a competitive neural network with four neurons. Each neuron is associated with its weight $N_{n,i}$,i=1,2,3,4 that is a complex number representing the value of one of the four centroids. Thus for each subcarrier we have a separate competitive network with four neurons. When the symbol R_n is presented to the network, the neuron with the minimum Euclidean distance from R_n is selected. In this way the equalization-decision task is completed. Then the winner neuron is updated according to the Kohonen [11] update rule:

$$N_{n,w}^{k}=N_{n,w}^{k-1}+\alpha(R_n^k-N_{n,w}^{k-1}) \tag{3.1}$$

$$N_{n,q}^{k}=N_{n,q}^{k-1}+\beta(R_{n,q}^k-N_{n,q}^{k-1}),q=1\ldots4,q\neq w \tag{3.2}$$

where the time index k means k -th OFDM frame, $w\in\{1,2,3,4\}$ is the index of the winner neuron and $\alpha \in (0,1)$ is the learning rate of the winner neuron. The other neurons are updated according to where , $R^{k}_{n,q}$ is the symmetric point of $\boldsymbol{R}^{k}_{n}$ in the quadrant of the neuron *q* :

$$R^{k}_{n,q} = j^{q-w}\ \boldsymbol{R}^{k}_{n} \qquad (3.3)$$

and$\beta \in [0, \alpha\ ]$ is the learning rate of non-winner neurons. For $\beta = 0$ only the winner neuron is updated and for $\beta = \alpha$ the symmetry of the sending constellation is preserved, hence this case is equivalent to the base DDE algorithm. If symbols are not equiprobable and only the winner neuron is updated then less probable neurons will difficultly follow the variations of the channel. An intermediate value of β allows the other neurons to be adjusted according to new data, without being rigidly constrained to the QPSK symmetry.

Moreover the proposed method possesses equalization capabilities that can be compared to those of the nonlinear technique proposed in elsewhere, but requiring less computational complexity, as the update formulasandrequire a minimum amount of calculation, whereas employs a sigmoidal neural network in which the update rule involves more demanding operations. One other advantage is the possibility to obtain an explicit estimate of the frequency In order to have coherent detection competitive layers have to be initialized with the channel information. One OFDM training frame is used to acquire the initial channel estimates H_n^0, $n = 1.N_c$and the competitive layers are initialized according to [12]

$$N_{n,i}^{0} = j^{i-1} H_n^{0} \qquad (3.4)$$

Where i=1..4 . Consequently the neuron of index *i* is associated with the QPSK symbol j^{i-1}, i.e. in the order $\{1,2,3,4\} \rightarrow \{1, j, -1, -j\}$. At the successive OFDM frames neurons will be blindly adjusted according to (3-2) and (3-3). It is worth mentioning that the proposed method condensates in one operation both the equalization process and the decision process. Additionally the weights of the neurons may be used to obtain an accurate estimate of the channel frequency response, as shown in (3.5)

$$\hat{H}_n^k = \tfrac{1}{4}\sum_{i=1}^{4} j^{1-i} N_{n,i}^k \qquad (3.5)$$

3.4 Proposed Back propagation algorithm

An MLP neural network structures with the back propagation-learning algorithm is used to get CIRs. This estimator is shown in **Figure 3.3**. As **Figure 3.3** shows the proposed MLP network has two inputs, two outputs and ten hidden neurons. In order to adopt the neural network to OFDM, each complex signals are separated into real and imaginary parts. The OFDM symbols consist of complex signals whereas neural network uses real signals. Then the separated signals are inputted to the network and the outputs of the network will be the estimated for channel impulse responses. During real time operation of the estimator; real and imaginary parts of the signals are fed through the network and every units are computed in the network. This is done by computing the weights sum coming into the nodes and applying the sigmoid function [8].

The activation function of the hidden layer is

$$net_j = \sum_{i=1}^{d} x_i w_{ij} \qquad (3.6)$$

$$o_j = f(net_j) = \frac{1}{1+e^{-net_j}} \qquad (3.7)$$

Where d is the number input units, X_i is input data to the network and w_{ij} is input-to-hidden layer weights at the hidden node j when we apply sigmoid function. Based on the hidden output signals each output nodes computes its net activation as:

$$net_k = \sum_{j=1}^{h} o_j w_{jk} \qquad (3.8)$$

$$o_k = f(net_k) \qquad (3.9)$$

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

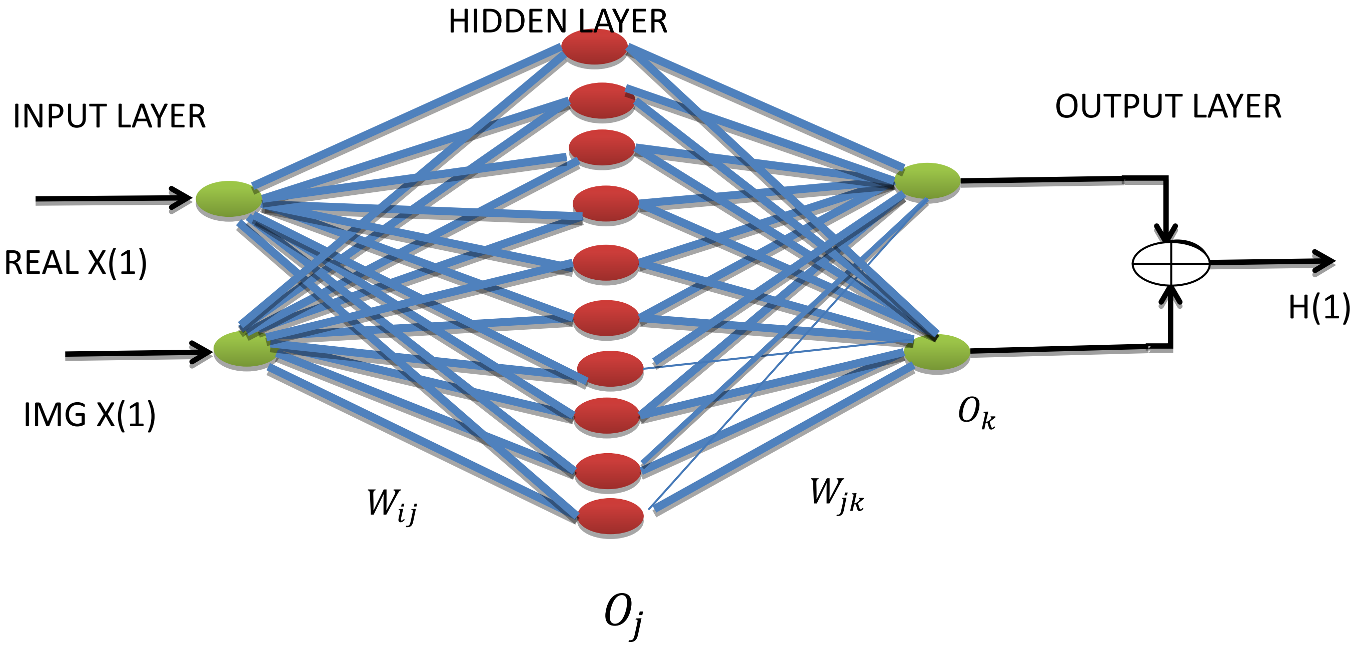


Figure 3.3 MLP structure for channel estimation.

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

$$E(w) = \frac{1}{2}\sum_{k=1}^{a}(t_k - o_k)^2 \qquad (3.10)$$

Where t_k is k_{th} desired output and a is the number of output points. The back propagation learning rule is based on gradient descent The weights are initialized with pseudo-random values and are changed in a direction that will reduce the error:

$$\Delta w = -\eta \frac{\partial E}{\partial w} \tag{3.11}$$

Where η is the learning rate that is chosen between 0 and 1. According to learning rate η the weights W are changed at each step. If η is so small, the algorithm will take a lengthy time to converge. Conversely, if η is too high the network is trained faster but we may end up bouncing around the error surface out of control – the algorithm diverges. This usually ends with an overflow error in the computer's floating-point arithmetic. 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]

$$\Delta w_{jk} = \eta (t_k - o_k) f'(net_k) o_j \tag{3.12}$$

The learning rule for the input to hidden weights is

$$\Delta w_{ji} = \eta [\sum_{k=1}^{a} w_{jk} (t_k - o_k) f'(net_k)] f'(net_j) X_i \tag{3.13}$$

The training process is finished when the value E of the goal is caught [13].

3.5 Simulation Result

Instead of using the BER (bit error rate), the following constellation error probability is used for performance analysis (**Figure 3.4**):

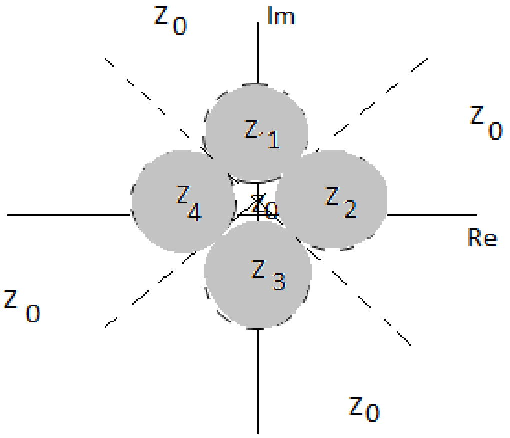


Figure 3.4 Limit of the equalizer output constellation.

Probability of error rate is given by

$$P_{er} = \frac{N(Z_o)}{N(\sum_{j=1}^{4} Z_j) + N(Z_o)} \tag{3.14}$$

where $N(\sum_{j=1}^{4} Z_j)$ gives number of samples inside the shadowed area.$N(Z_0)$ is the number of samples outside the shadowed area.

Parameter	**Value**
FFT size	64
Number of used subcarriers	64
Modulation type	QPSK
Learning rate	0.05
Z_l, Z_S	50Ω

Using the details of table we will get the results are as shown in **Figure 3.5** and **Figure 3.6** .which are giving the information that channel estimation using back propagation gives better result than competitive neural network.

The **Figure 3.5** gives the BER values for different estimation techniques.

The **Figure 3.6** gives the MSE values for different estimation techniques.

The **Figure 3.7** gives the BER VS SNR plot of a communication system using Power line as a channel and AWGN as a channel using BPSK modulation.

The **Figure 3.8** gives the BER VS SNR plot of a communication system using Power line as a channel and AWGN as a channel using QPSK modulation.

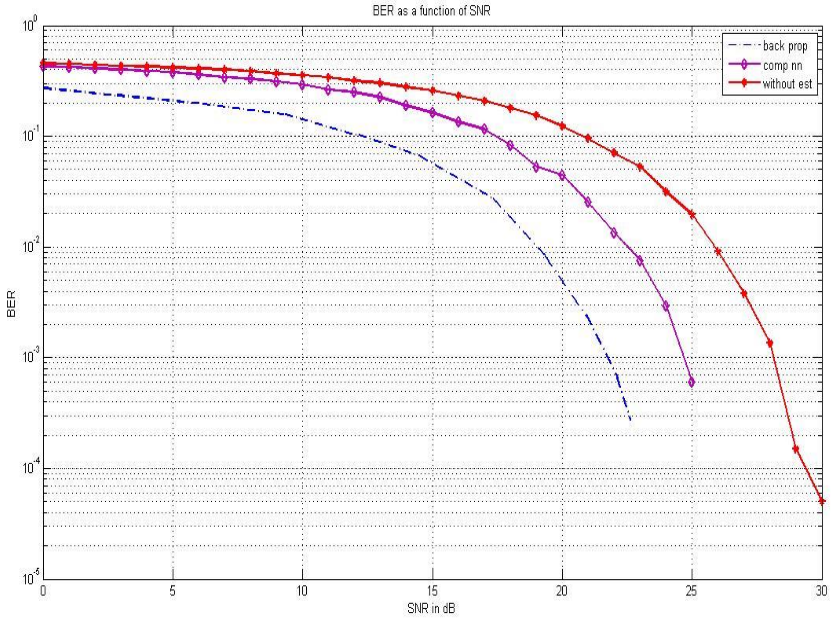


Figure 3.5 BER values for channel estimators.

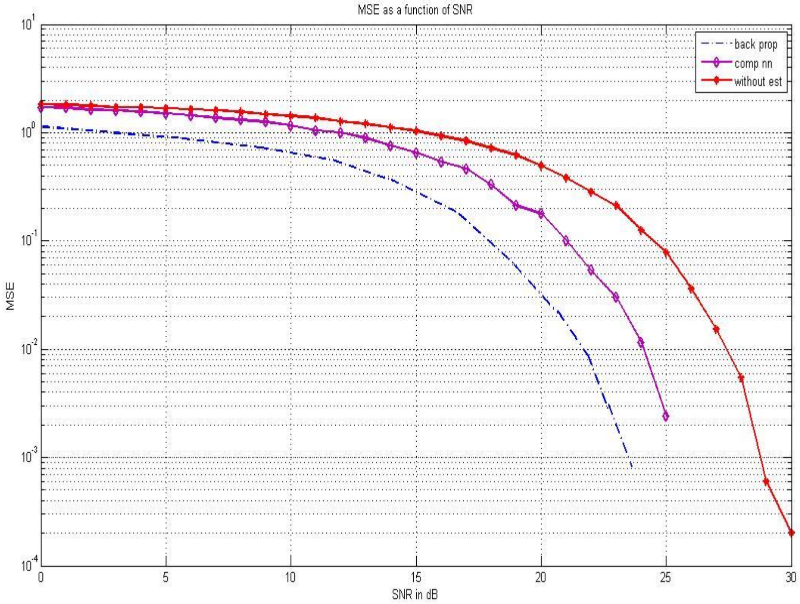


Figure 3.6 MSE values for channel estimators.

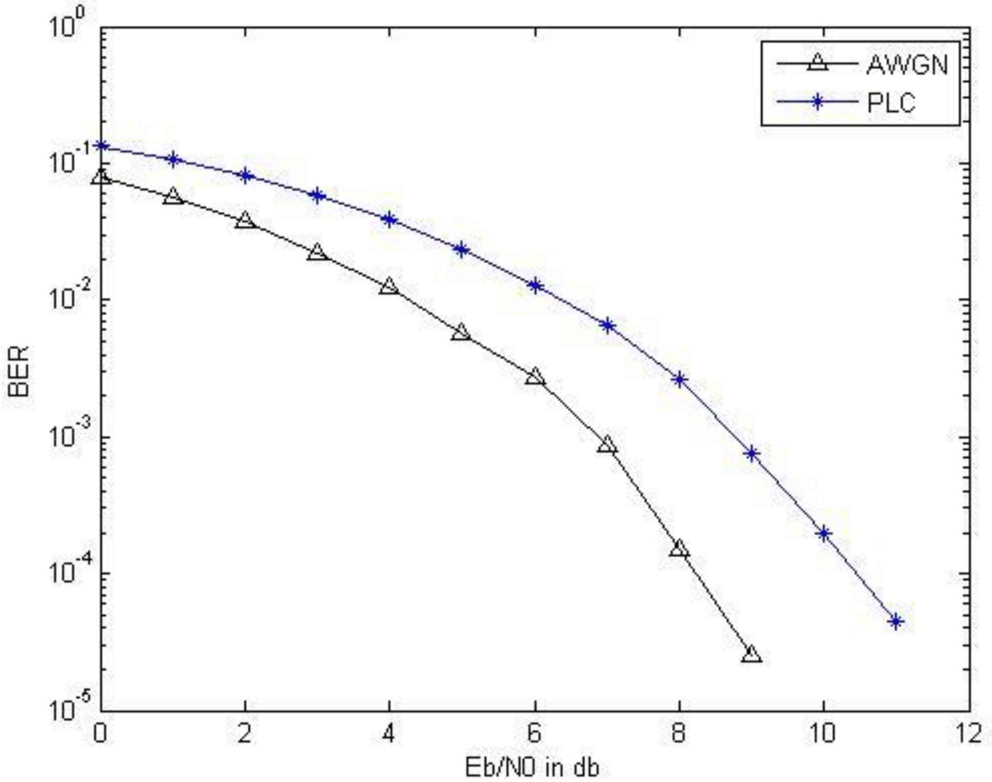


Figure 3.7 BER values of AWGN and PLC for BPSK.

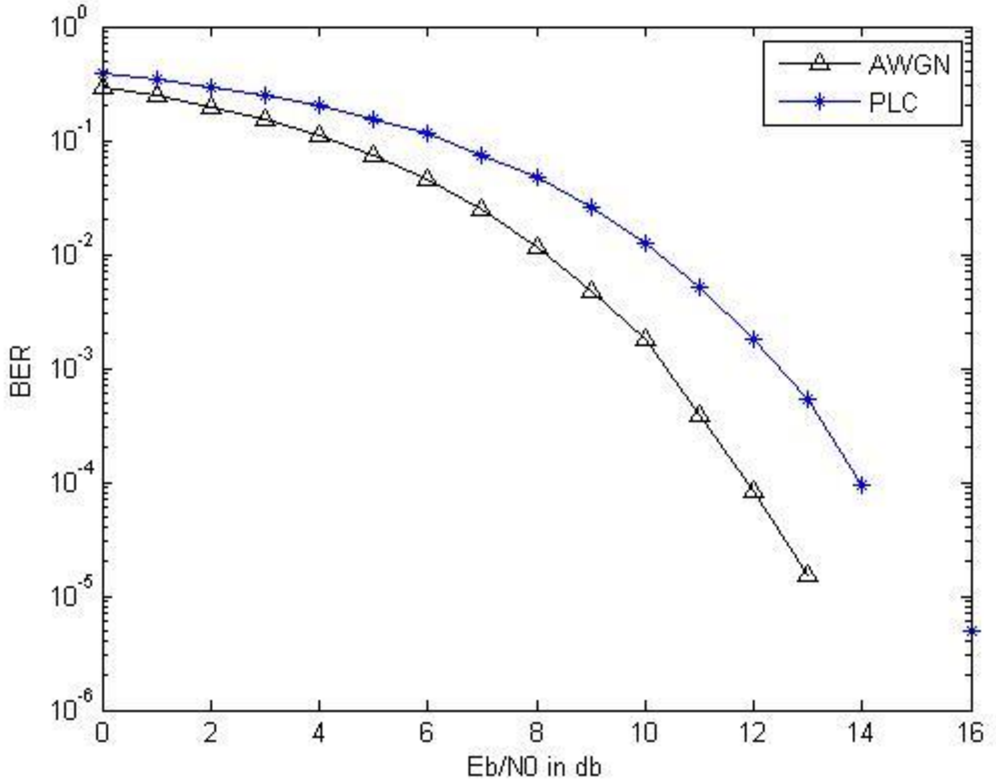


Figure 3.8 BER values of AWGN and PLC for QPSK.

CHAPTER IV

SUMMARY AND CONCLUSIONS

In most cases we cannot know the topology of the distribution network, because the topology is changing due to appliances connection or disconnection and therefore we were calculated transfer functions of power line modeling for different topologies. From the mentioned results of influence of connected taps on the transfer function the influence of individual branches on the resulting transfer function is evident.

If we wanted to use these models for the time changing topology of distribution network; the transfer function calculation would be complicated. The solution of this problem may be the algorithms, which could determine the structure of the distribution network at any given time.The waveform of the transfer function is also influenced by the size of the connected impedance to the tap and the tap length. Therefore transfer functions for these quantities were calculated.

The waveform shows the increase number of ripple with tap length increasing and attenuation increase of local minima in periodic ripple with impedance increasing. For the sample network topology power lines were modeled and the resulting channel model was constructed.Power lines are modeled through chain parameter describing the relation between input and output voltage and current of two-port network. The model of two-port network is characterized by its simplicity and does not require so much computing demands.

A channel estimation method based on MLP neural network is proposed for PLC using OFDM system. In our proposal, those trained networks which are obtained after the networks are trained using channel impulse responses are utilized as a channel estimator. So bandwidth is used efficiently. By observing simulation results, MLP neural network is better than competitive NN respect to BER. Besides the proposed MLP neural network has less computational complexity than competitive neural network.

Future work

- Performance analysis of the system which uses all the topologies mentioned in this thesis.
- Design of better channel estimation techniques.

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