Performance Enhancement of Power Line Communication Using OFDM and CDMA

A Thesis submitted in partial fulfilment of the Requirements for the degree of

Master of Technology

In

Electronics and Communication Engineering

Specialization: Electronics and Instrumentation

By

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June 2013

Dedicated to my Loving Parents

DEPT. OF ELECTRONICS AND COMMUNICATION ENGINEERING
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Certificate

This is to certify that the work in the thesis entitled Performance Enhancement of Power Line Communication using OFDM and CDMA by ANUJ GOYAL is a record of an original research work carried out by him during 2012 - 2013 under my supervision and guidance for the partial fulfilment of the requirements for the award of the degree of Master of Technology in Electronics and Communication Engineering (Electronics and Instrumentation), National Institute of Technology, Rourkela. Neither this thesis nor any part of it has been submitted for any degree or diploma elsewhere.

Place: NIT Rourkela | **Dr. Sarat Kumar Patra**

Date: 30^{th} May 2013 | Professor

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ABSTRACT

Power line communication is basically meant for carrying not only the electric power but also the data over the conductors and as the application alters so do the need to change the technologies, like the requirement to alter the technology in case of home automation and for internet access and in order to create a sufficient level of separation between them, they are usually differentiated by means of frequency alteration. In general the transformer present at the substation usually prevents the propagation of signal. Data rates and the distance vary in accordance with power line communication standards.

Power line communication has been emanated as one of the most enduring means of communication for smart grid applications especially while considering the biggest advantage i.e. an already established infrastructure, therefore sending out the control information over the same network will add only a little cost and hence opens the door for a plethora of applications.

The communication over Power Line is not so new when we are concerned about generation, transmission or deliverance of power but here our main concern is control and management of power rather than transmission or deliverance of power and this purpose can only be accomplished if we are utilizing the available resources in an efficient manner which in turn is dependent on the fast and effective transmission of data or control information over these channels. To ensure the fulfilment of these requisites there is a requirement to analyse the basic topological connections and the circuit modelling and thus determined the various control and traffic problems associated with the transmission of this information which usually varies according to applications.

Therefore OFDM (BPSK, QPSK, and QAM) has been utilized for the purpose of analysis of the channel performance while ensuring the speed and robustness of the channel to be the main criteria for any kind of services or applications .Moreover there usually arises a problem of power failure and reliable communication over remote locations and therefore the solution for it is an interfacing between wired and wireless communication technologies and hence in the thesis work, a comparison of the bit error probability had been shown between the performance of the channel while using OFDM and CDMA and this comparison provides an solution to choose the technology according to the requirement of application .

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ABBREVIATIONS

PLC .... Power Line Communication
SG..Smart Grid
SCADA .... Supervisory Control and Data Acquisition System
AMR...Automatic Meter Reading
PHEV ....Plug in Hybrid Electric Vehicle
DSM ....Demand Side Management
HA ....Home Automation
SCADA .... Supervisory Control and Data Acquisition
BPSK ....Binary Phase Shift Keying
QPSK ....Binary Phase Shift Keying
QAM ....Quadrature Amplitude Modulation
OFDM ....Orthogonal frequency division multiplexing
CDMA ....Code Division Multiple Access

1

INTRODUCTION

1.1 Background

The Power Line Communication has been emanated in the early 1900's and at that time it was mainly concern about transmission of power to various different utilities and as the year goes by these power lines have started finding its usage for the transmission of voice and data. The main reasons responsible for its origin was that the communication over telephone was very poor therefore the engineers at the operating power plants makes use of Power Lines for management of operation with colleagues. But the communication was very slow and also susceptible to distortion and noise to a large extent till the introduction of digital techniques.

The other reason for the power lines to find its application for data communication is its already established infrastructure and having the capability to switch the devices On/Off, especially those devices which consumes a large amount of power such as air conditioners, water heater etc. The advantage of this is to ensure a better management of energy which is more often called as Demand Side Energy Management. [1], [5]

The communication over Power Line usually alters in data rate in-accordance with the application and hence to differentiate the communication they had been categorized in frequency i.e. they utilize different frequency bands. Therefore the Power Line Communication is categorized as Ultra Narrowband, Narrowband and Broadband.

Ultra Narrowband PLC

The first deployment regarding the UNB-PLC technologies involve the Turtle system and TWACS. Both system makes use of outbound communication for voltage (substation to meter) and inbound communication for current (meter to substation).The Turtle system has been mostly used for the Automatic Meter Reading , the first available products allows only one way communication whereas the two way communication system became available after 2002. As the demand is increasing for higher data rates CENELAC EN 50065 standards allows communication over Low Voltage distribution PL in the frequency range from 3 kHz to 148.5 kHz.

The first deployment regarding the ultra-narrowband power line communication technology involves four frequency bands defined as (see [1])

1. 3-95 kHz: reserved exclusively to power utilities.
2. 95-125khz: any application
3. 125-140 kHz: in home networking systems with mandated carrier sense multiple accesses with collision avoidance protocol.
4. 140-148.5 kHz: alarm and security.

CENELAC mandates a CSMA/CA mechanism in the C-band and stations that wish to transmit must use 132.5 kHz frequency to inform that the channel is in use [14, 15]

Broadband PLC

In this field the first research had been started for internet access applications and successively for HAN and A/V applications. In UK the Nor-web communication have started working to provide the broadband internet access to the customers on a trial basis and successfully achieved the deliverance of services on the line at the rate of 1Mbps. Later a multilayer project funded by the European community-OPERA led most of the recent research efforts in the field of BB-PLC for internet access.

Over the last few decades, several industry alliances came into the market especially to set a technology standard mostly for in-home PLC e.g. Home-plug Power Line Alliance, Universal Power Line Association, High Definition Power Line Communication Alliance and Home

Grid Forum. However none of these technologies are interoperable with each other. BB_PLC was acting as a complementary for Wi-Fi but still it had not achieved a significant share in the market. [1,20]

1.2 Literature Survey

PLC was introduced in early 1900's and from then a number of standards has been defined for different types of power line communication which had been categorized on the basis of frequency bands i.e. Ultra-Narrowband and Narrowband PLC and broad band PLC. The role of communication over power line is not limited to and for electric utilities only but also finds applications for smart grid which makes use of SCADA (Supervisory Control and Data Acquisition). The key problem associated with SCADA is the proper selection of architecture required for information gathering which would be needed to contain it. [1]

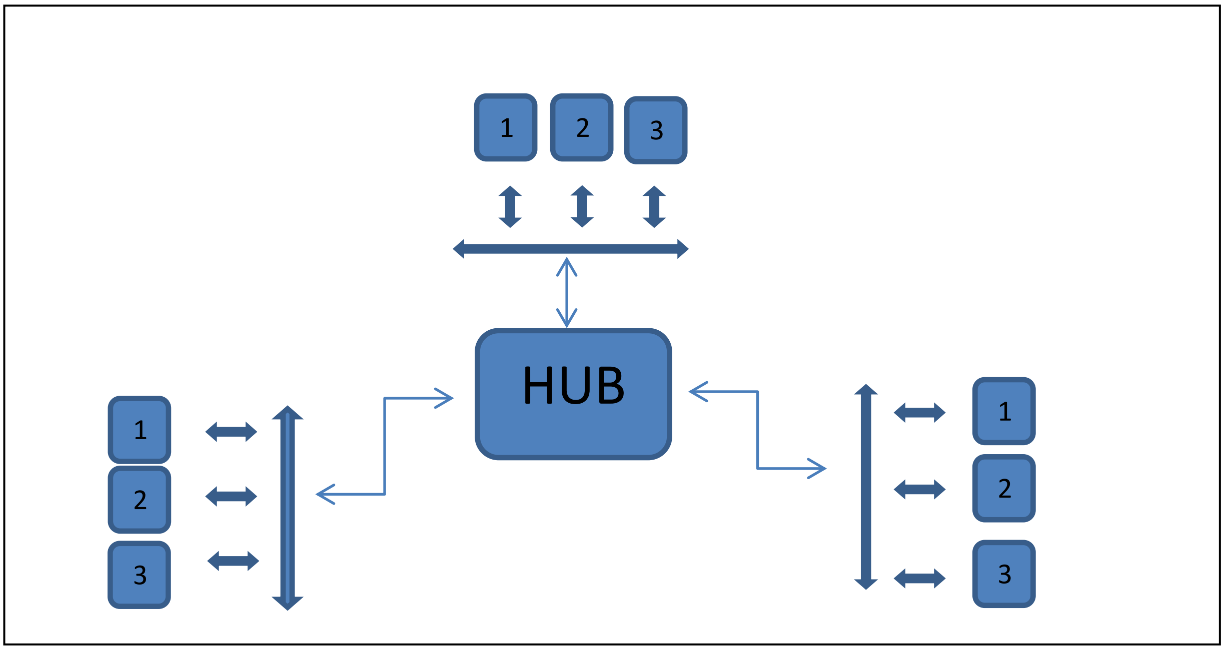


Fig-1.1 Block diagram of Supervisory Control and Data Acquisition (SCADA) [1]

1,2,3 – Remote Stations

The basic model for the indoor power line channel and its circuit analysis had been defined which includes the wiring topological connection used in the residential and commercial premises which has a number of receptacles and outlet. In multi-conductor power line cables, usually two modes remain in existence – Differential mode and Common mode. Due to the presence of a number of shunt connections and impedance mismatches at these terminals, instead of a presence of a single path in between the transmitter and receiver there arises a condition of multiple paths from where the signal reflection occurs which causes a degradation in the signal quality with distance and time and the measure of it is defined by reflection coefficient which ranges from 0 to 1. [3,4]

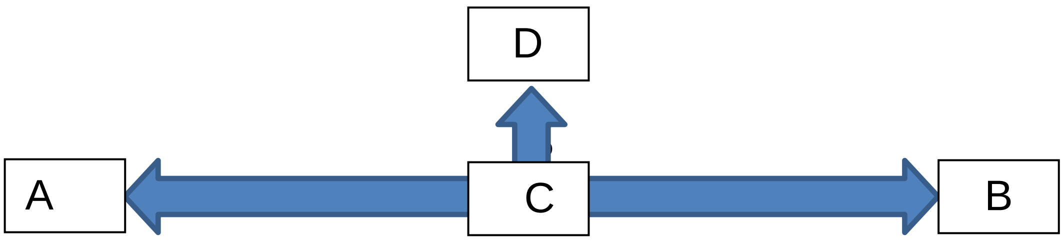


Fig-1.2 Representation of Multipath signal propagation [4]

Therefore on the basis of this model the overall transfer function has been defined considering all the effects of attenuation, skin effect and dielectric losses while utilizing the scattering matrix or transmission matrix. [4,9,12] .

Power Line network consist of a large variety of conductor types connected at random, therefore it results in a wide variety of characteristic impedances to be encountered in the network. Furthermore the terminal impedance of the network varies as the communication signal frequency varies and also with the load pattern at the customer premises. This mismatching of impedance results in multipath signal effects which causes deep notches at some specific frequencies. Moreover in case of power line communication the major source of noise is from electrical appliances which may extend to the high frequency spectrum. Some common electrical noise sources are halogen or fluorescent lamps, motors, light dimmers, switches and many more. In addition to these the radio broadcast signal, military, commercial and amateur stations causes a severe impact on certain frequency bands in the power line communication. Therefore to achieve a reliable communication under the adverse conditions requires error detection, coding, interleaving and many other techniques, along-with this there is a necessary requirement of the selection of a proper modulation scheme which can easily let the data transmission and reception to undergo through without much impact on the signal quality and hence the purpose of maintaining a two way communication can be successfully achieved which is required for achieving a better efficiency and energy management.

This thesis then constitutes the performance evaluation of the power line channel using OFDM and then defines a solution of interfacing between wired and wireless communication for the elimination of one of the biggest problems of Power failure and long haul communication and for that a comparison of performance of power line channel using OFDM has been made with CDMA.

1.3 Objective of the work

The main objective of this work is to enhance the performance of data transmission over power line cables to achieve a higher data rate and robustness to ensure a better management of available energy resources and also to counter the limitations of existing Power line communication technology. Various analysis and investigations are needed in support of the above statement which includes:

- Determination of Bit Error Rate using OFDM (BPSK, QPSK and QAM) and to enhance the performance by suppressing some of the carriers.
- Determination of bit error rate using CDMA and then a comparison between the two to reach out to the best possible selection of technology as per to the requirement of application and conditions.

1.4 Motivation

The current Power line communication system is considered as an interference-limited system mainly due to the existence of Multiple number of paths which arises because of requirement of a number of device terminals to be connected to a to the main line which usually results in impedance mismatch and hence the undesired signal reflections occurs at those terminals that leads to a multipath scenario and hence leads to a degradation in the quality of transmission of data.

The data transmission over Power line cables was proposed a few decades ago by researches, in which many impairing factors exist, such as external interferences, multipath propagation etc. The most serious problem arises as the number of end terminals increases, at the time of power failure and also when the data is required to be transmitted over remote locations where there is no presence of a well-established infrastructure. Therefore OFDM (BPSK, QPSK AND 16-QAM) had been used for the analysis of channel performance while ensuring the speed and robustness of the channel whereas considering the factor of requirement to provide an interface between the wired and wireless network under adverse conditions to achieve an uninterrupted means of communication over the channel and hence ensure an effective data transmission over the channel to accomplish the target of better utilization of available resources of energy.

1.5 Thesis Organization

This thesis is organized into five chapters. The current chapter begins with the background details of cellular networks. The objective for this thesis work is framed after literature review and this chapter ends with the outline of the thesis.

Chapter-2

This chapter discusses in more detail about the Power Line Communication, Functionality of the Power line communication in the smart grid. It also contains the details about the smart grid and its application along-with the advantages and limitations of the smart grid.

Chapter-3

This chapter deals with the types of Power Line Communication, the modelling of the indoor power line communication which involves basic wiring topological connection and the detailed analysis of the multi-conductor power line cables which is followed by the procedure of determination of the transfer function (while considering attenuation, skin effect and dielectric losses) using scattering matrix or transmission matrix.

Chapter-4

The purpose of this Chapter is to present the Basics of OFDM and CDMA and the evaluation of the power line channel performance to reach out to a best possible solution or selection of the modulation technique which suits best the requirement of data transmission to fulfil the main purpose of energy management to ensure the best possible utilization of the available resources.

Chapter-5

The last chapter is a summary and discussion on the work presented in this thesis where also further work is outlined

2

Power Line Communication

This chapter discusses in more detail about the Power Line Communication, Functionality of the Power line communication in the smart grid. It also contains the details about the smart grid and its application along-with the advantages and limitations of the smart grid.

2.1 Basics of Power Line Communication

Power Line Communication is defined as a technology that utilizes high, medium and low voltage electrical networks to provide various services like voice and data transmission in addition to providing the power to the electrical utilities required for their operation.

In the initial stages, the power line communication was meant for deliverance of power only but as the time had ripen up it had started gaining more importance in high frequency applications , also known as Broad-Band Power Line. Since then these electrical networks had been used by the electricity producers and distributors for the purpose of remote controlling and network monitoring as well.

It operate with electric power distribution system and provides a highly reliable means of communication among PLC devices which are electrically coupled to each other or located in proximity to the premises of power distribution system . A system for PLC comprises repeaters, bypass devices, backhaul devices, wireless backhaul devices, communication interfacing units etc.

2.2 PLC and Various Technologies

Although the power line communication has been defined on the basis of frequency i.e. the frequency band that it occupies .Moreover it can also be defined corresponding to the voltage level i.e. Power Line Communication for High, Medium and Low voltage networks. It could be a little advantageous to define PLC in terms of voltage levels since the applications can be more precisely defined in terms of voltage levels.

2.2.1 PLC for High Voltage Networks

Power Line communication mainly finds its application on the distribution side but over the period of time, it had also started finding some applications at the transmission side. This is mainly useful at this side for the purpose of state determination, Power controlling, surveillance of remote stations and for supervisory control and data acquisition. In the high voltage network, PLC technologies operate up to 1100KV in the frequency band of 40-500 kHz. The level of attenuation is much low at the high voltage side as compared to that at the medium and low voltage side.

The first ever effort in this direction had been made around 1920s for providing operational telephone services and that uses single sideband amplitude modulation schemes. Power Line Communication in addition to provide the connectivity to the transmission side it can also be used for detection of fault at the remote location. The need of a reliable communication on the transmission side is not only necessary but also an essential requirement so as to support several applications as well as managing the things properly. Today the network for power line communication is well established and is proving out to be to useful to serve the stations and the utility centres in around 120 countries with a total length of about millions of kilometres.

Regarding the applications some of the experiments had been successfully implemented like the detection of insulator breakage, circuit breaker and cable rapturing. Today the interest is also growing correspond to achieving a higher data rate via PLC over HV lines and the success on it had been achieved by the department of energy of US .While ensuring the higher data rate the power line communication is mainly used for tele-communication, tele monitoring, and tele-protection between electrical substations at high voltage levels such as

110KV, 220KV, 400KV. The major benefit of this is the union of two applications into a single system which is very useful for monitoring of the systems and the management of energy utilizing various energy management techniques

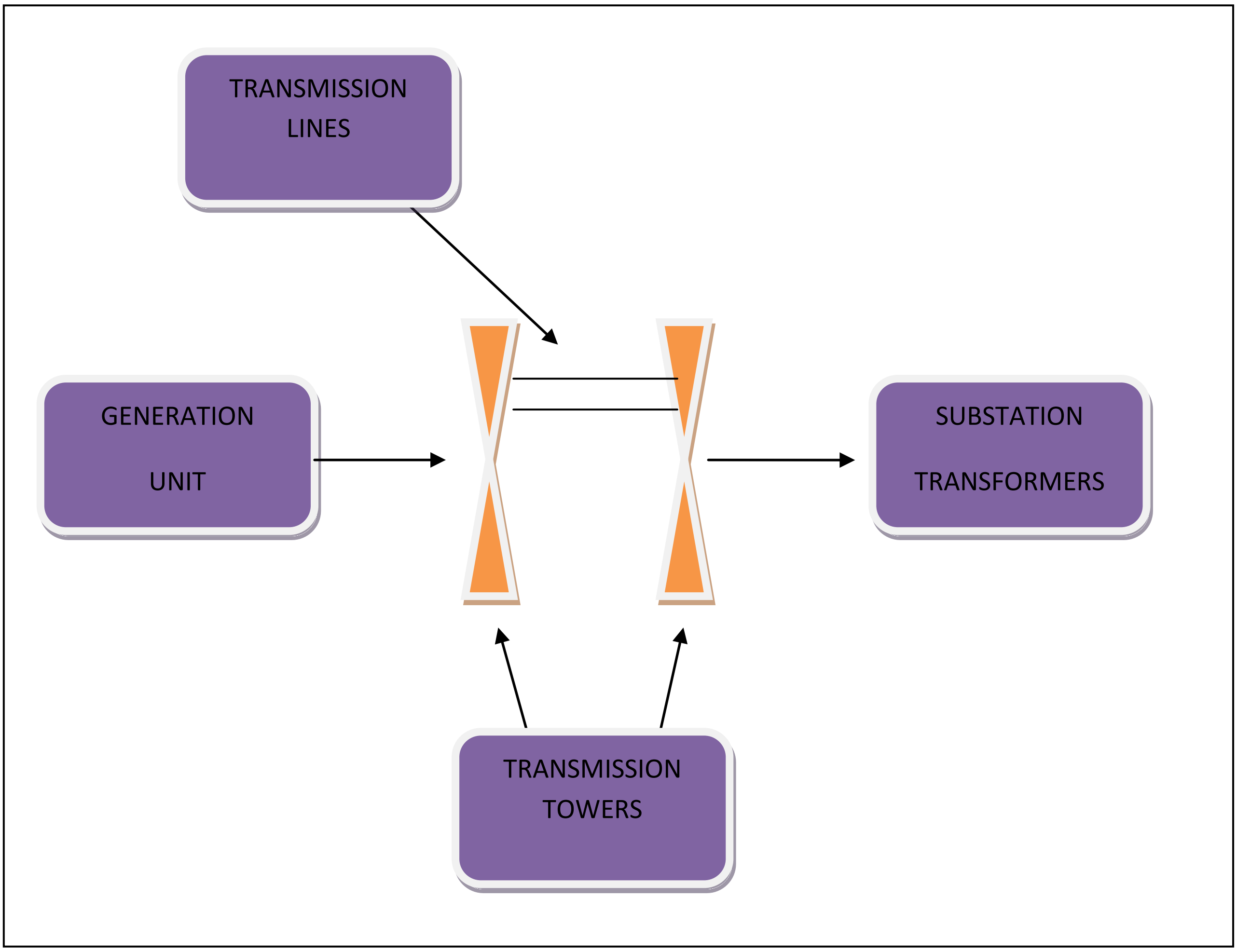


Fig.2.1 –Power Line Communication for High Voltage Networks

2.2.2 PLC for Medium Voltage Networks

The Power Line Communication for the medium voltage network is mainly concerned about the transmission in between substations within the grid and that is meant for state determination of equipment and for power flow conditions. To establish a communication link in between these substations IED's are required to communicate with the external IED's (like switches, re-closers, sectionalizes) for fault locations, fault isolation and service restoration. Moreover, for the voltage distribution on the distribution side requires communication between substation IED's and distribution feeder IED's served by the substation. Some other applications on the medium voltage side also include temperature measurement of oil, measurement of voltage on the secondary side of the transformer, fault surveys and the power quality measurement.

At the medium voltage site it is used to communicate the data in two directions using the electrical distribution wiring between transformer and customer outlets, thus it eliminates the requisites of expenses and endeavours needed for a separate network that may either be a wired network or a wireless network.

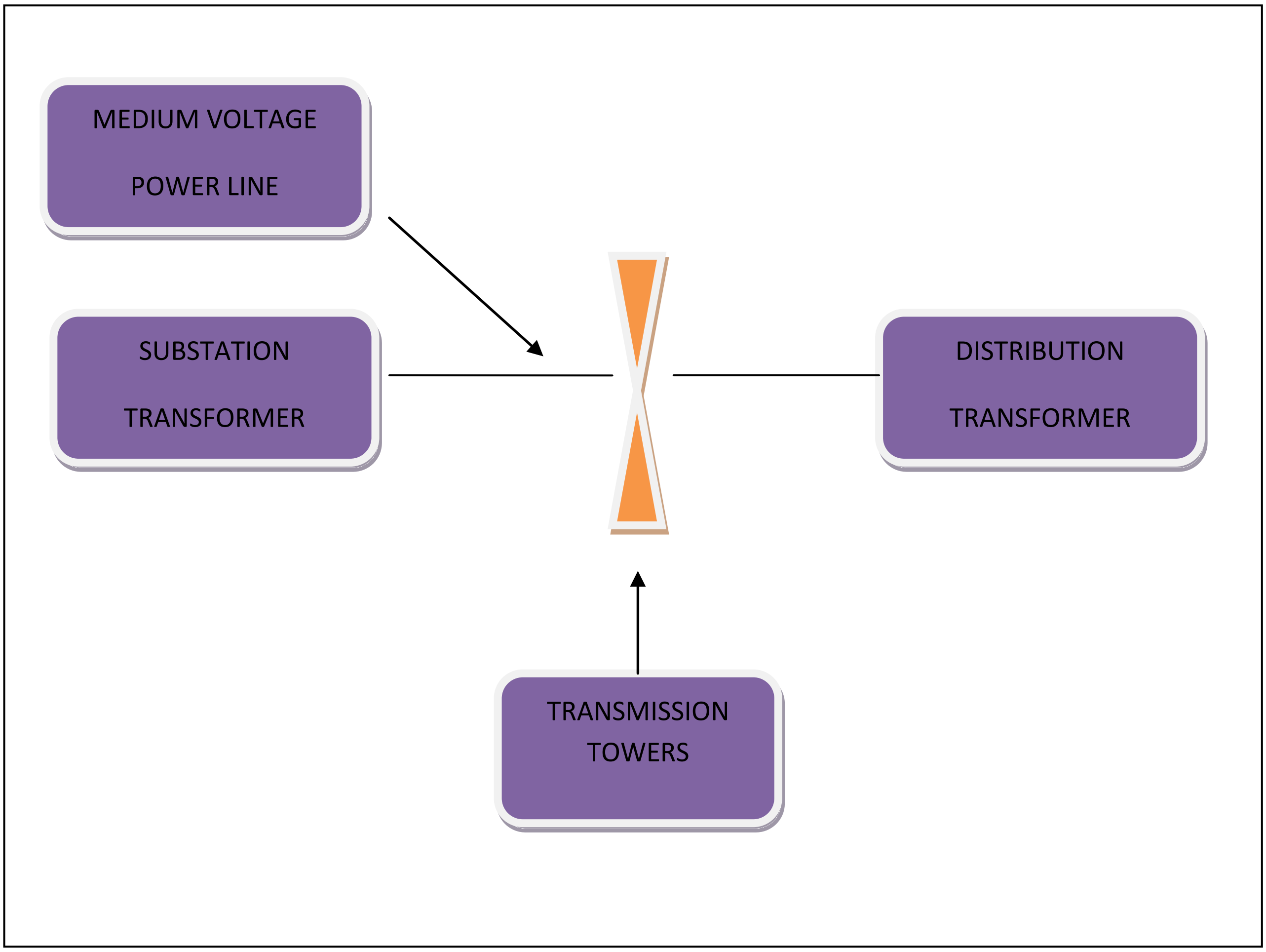


Fig.2.2 –Power Line Communication for Medium Voltage Networks

2.2.3 PLC for Low Voltage Networks

The Power Line Communication finds most of the applications on the low voltage side because ultimately the main purpose of any sort of communication means is to provide services to the consumer. Some of these applications involve AMR, PHEV and DSM etc. Without altering the things at the low voltage site the purpose of transformation of grid to a smart grid doesn't get fulfilled. The detailed description of what is Smart Grid and its applications are defined on a later part of this chapter.[1,6]

Power line communication can be used to connect the devices at the low voltage site so as to provide interconnection between the devices (home computer, peripherals and home entertainment devices) to communicate with each other using an Ethernet port. For enabling the signal compatibility, the power line adapters are used to provide connectivity between the devices and the power outlets and hence provide an Ethernet connection using the electrical wiring and thus it can also serve the purpose of home automation i.e. remote controlling of appliances, lightning and power control without requiring any additional wiring for control.

As these devices are usually connected using an Ethernet protocol which in general is based on two methodologies – either CSMA/CD or CSMA/CA, which stands for carrier sense multiple access with collision detection and carrier sense multiple access with collision avoidance.

In case of carrier sense multiple access with collision detection, the sending device checks the line first whether it is freely available for the data transmission or not by sending a voltage signal and if there would be any collision then it will be indicated by the high voltage pulse in the line, multiple access refers to the fact the bus connecting all the devices are available for everyone and anyone can access it any point in time provided sensing the channel before making an actual transmission. If there would be any collision and the high voltage pulse be generated the device will wait for a random period of time before starting to transmit the data.

This is the way by which the collision could be detected (by sensing a high voltage pulse on the line) and then by waiting for a random period of time before making the actual transmission it could be avoided.

Ethernet Frame

A data packet in the Ethernet link can be said as Ethernet frame. It starts with a preamble and a header which contains the destination and the source address, followed to this is the payload data and then ends with a cyclic redundancy check which is required to avoid the error resulted during transmission of data.

In between every two frames there is a presence of an idle time which constitutes a minimum of 96 bits . this is all done to prevent the overlapping of the frame with the next frame.

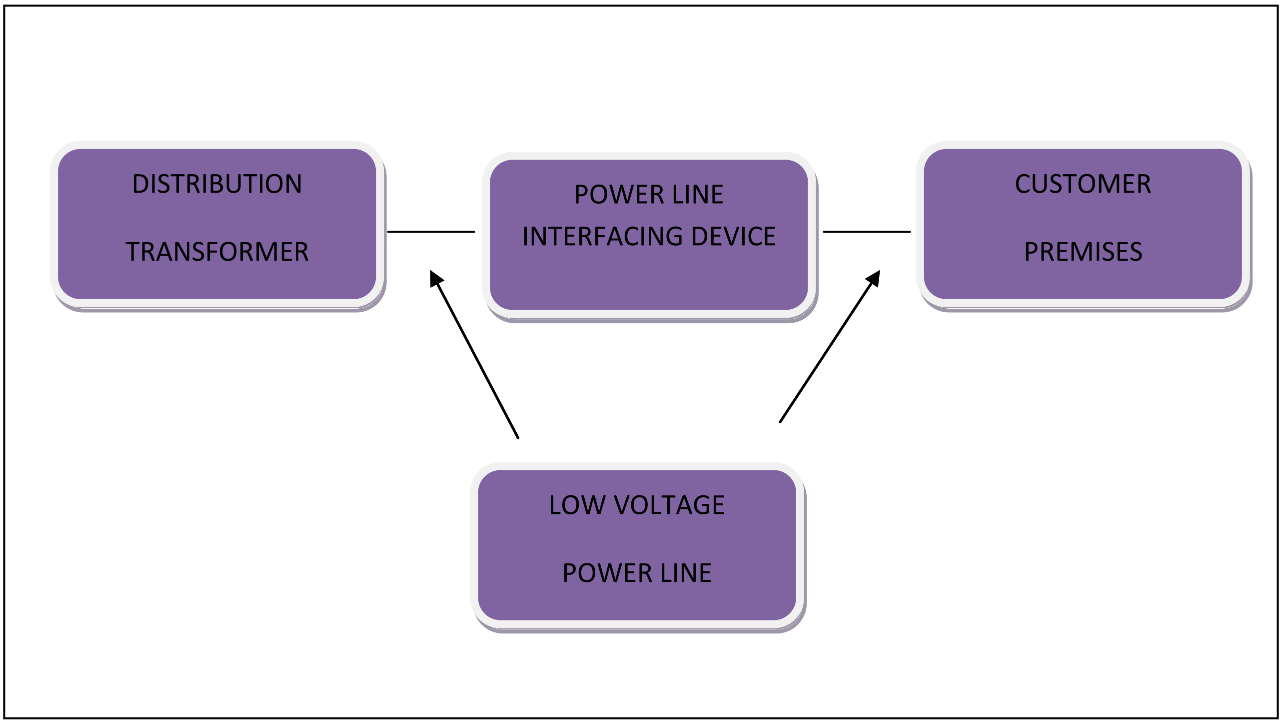


Fig.2.3 –Power Line Communication for Low Voltage Networks

2.3 Advantages of Power Line Communication

- One of the biggest advantages of Power Line Communication Network is the availability of an already established infrastructure which reduces the establishment cost as well as endeavors. Moreover it will also eliminate the requirement to handle a separate network therefore reduces the level of congestion which could have risen if another network had been placed.

- Because of a well-established infrastructure in case of a local area network connection which usually operates at millions of bits per second and meant for office building or a limited geographical premises there will not be any requirement for a separate dedicated network cabling.

- Unlike Wireless Communication, a dedicated link is present in between transmitter and receiver therefore the signal will not be affected by a Doppler’s shift which is one of the major limitations of wireless network.[1,5]

2.4 What is Smart Grid?

Smart grids is mainly based on the usage of the smart energy technologies that refers to the power control by means of digital information systems like the smart meters and the smart appliances that communicate through the internet using the electrical power lines so as to optimize the generation, delivery and the end user demands for energy. Thus the smart grid and the internet are the two separate infrastructures which this model consists off.

These smart grid technologies can offer some unprecedented advantages in energy efficiency and thus using a two way communication linking between the devices a new pathway will get open which can enable the adjustment of the power in accordance with the real time conditions and power prices and for this a common infrastructure is required for the real time data collection to meet the needs of dynamic energy market.

Moreover the existing and the new electric grid components can be made to communicate with each other to achieve a better monitoring, collection of information and remote controlling of the devices, all this transform a Grid to a smart Grid.

A smart grid requires the ability to send and receive information from its distribution assets as well as from its customers. The exchange of information could be responsive, data-driven grid would result in a system that is more reliable, more efficient, and more capable of integrating resources like wind, solar or other non-conventional sources of energy.

The first ever effort in this direction has been applied by the US department of energy with an objective to solve the problem of energy crisis by means of energy conservation i.e. by allowing the devices to operate for the duration require otherwise they should be brought either to low power mode or switch off mode. [1, 5, 6]

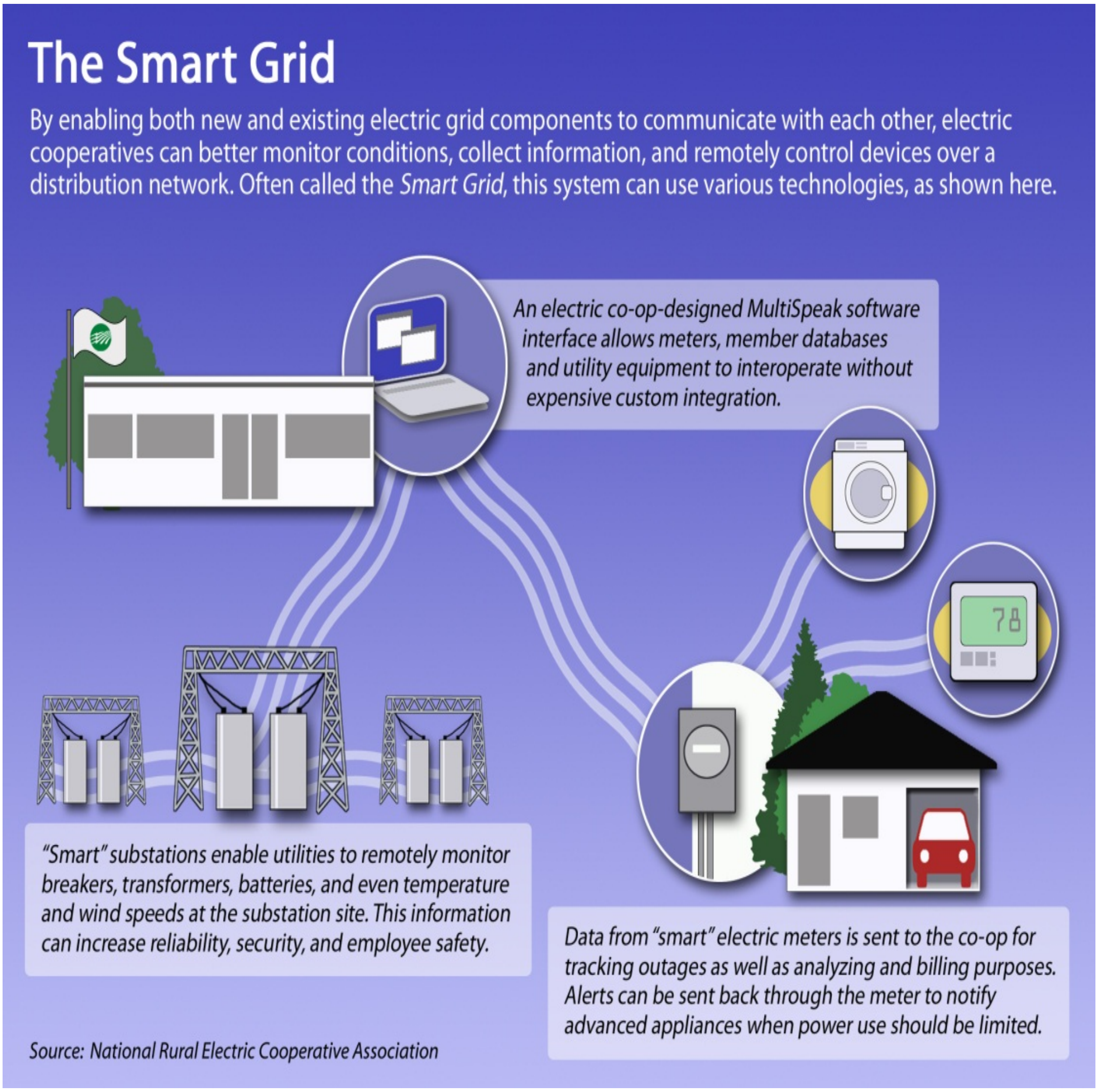


Fig.2.4

2.4.1 Need of Smart grid

It is a well-known fact that the demand of energy is growing at a much faster pace as compared to the rate of generation and the existing conventional sources of energy are also responsible to a large extent for the emission of greenhouse gases and climatic changes. Moreover the things are becoming more critical because of the increasing rate of dwindling of available energy resources. Thus to meet the demand of energy, the only real possibility is the energy saving and the preservation of the existing resources which could be achieved by saving and managing the available resources in a proper manner. This is all becoming an essential requirement since the current model based on growth and consumption will not sustain for a very long even if free and inexhaustible sources of energy be discovered.

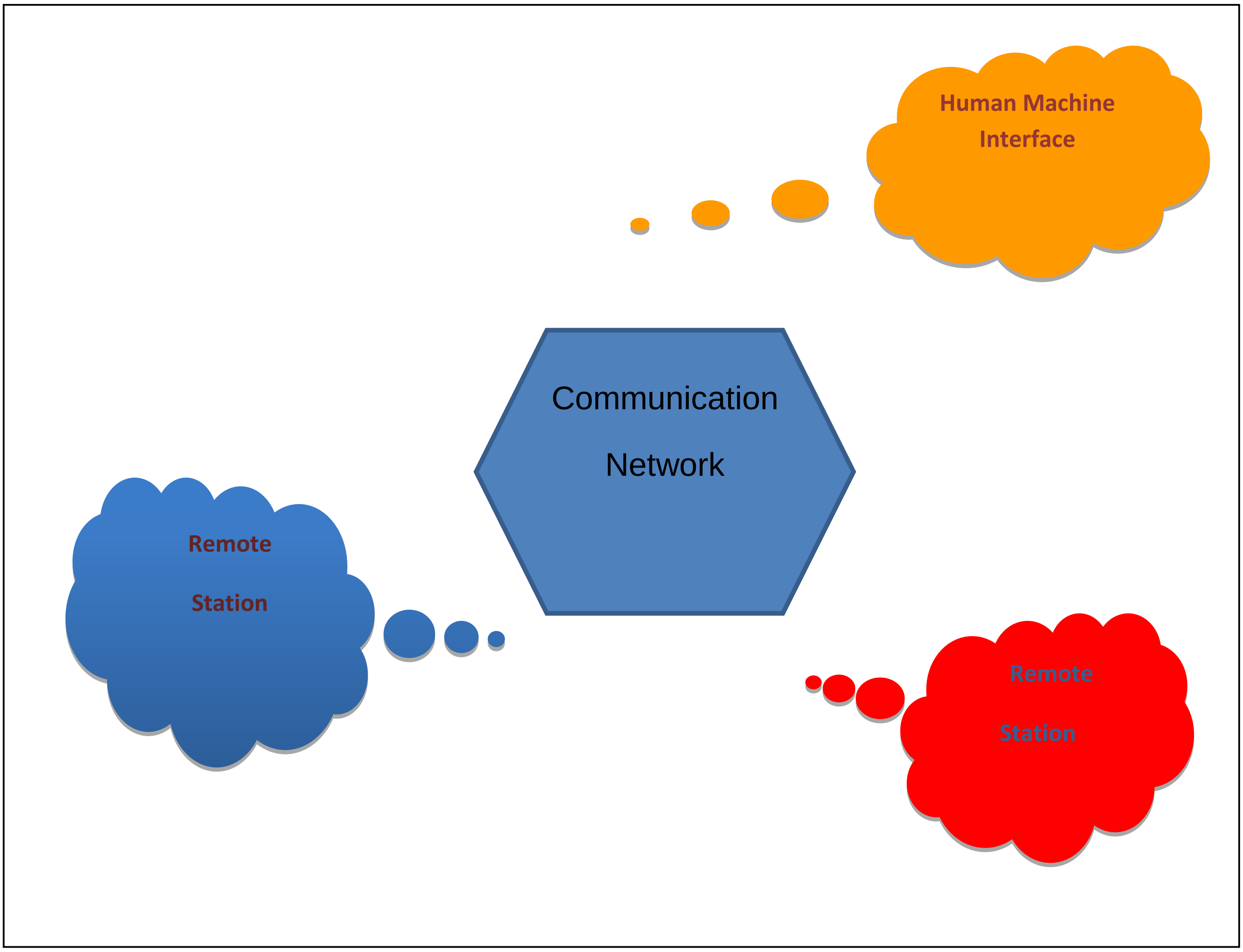


Fig.2.5 – Supervisory Control and Data Acquisition System

Therefore to maintain the things in a proper way one way is the supervisory control and data acquisition system which has been depicted above:

Moreover the basic and essential needs which creates the necessity of the today to implement the smart grid. Some of those reasons are mentioned below:

- The Smart Grid is thus required to handle the things more smartly so as to achieve a better management of energy and the available resources such that the demand and supply could be brought to a closer level with each other.
- It also enables us to handle the device and terminals from a remote location which will eliminate the requirement to take care of devices and energy all the time and it will also be useful to provide the information to the user on a real time basis.
- It could be useful for providing an amalgamation between the existing sources of energy and non-conventional sources of energy which could be the future of tomorrow while considering the urgency to take some steps for the prevention of climate changes.

2.4.2 Applications

Smart Grid could be used at all voltage levels HV, MV and even at the Low voltage sites inside the buildings. Although it finds its utility for medium voltage and high voltage networks up to some extent .PLC over high voltage lines can be used for the purpose of fault detection and in case of medium voltage networks it is useful for checking out the power flow conditions but it mainly finds its applications with a high growth rate at Low Voltage sites. Some of the applications are illustrated below:

Automatic Meter Reading

It allows not only one way communication but a two way communication as well; that is required to exchange information between the system and the devices at the customer premises. Moreover it also enables the customer to get through the real time information of the billing services. This is all achieved with the help of smart meters which proves to be very useful to

- ❖ Reduce the operational cost and susceptibility of energy losses due to energy theft.
- ❖ It works by sending a proper command signal from the server at the main station office which travels via a radio link from office to substation. At the substation, signal is injected on to power lines. By the time it reaches to the meter, it will be decoded first and then the meter responds correspondingly to the substation from there it goes back to the server site.

Fig-2.6

Vehicle to Grid Communication

- ❖ This is widely deployed service in developed countries. Although in developing countries it may take some time to become feasible. It allows the charging up of the batteries of the vehicle whenever they get connected to the premises wiring or the outlet cables (airport, parking lots etc.)

- The most important requirement for this is the presence of a link in between the vehicle and Electric Vehicle supply Equipment and this is the most important advantage of power line communication that a dedicated link could be established in between vehicle and EVSE which is not feasible in case of wireless communication even if the range is small and hence increases the liability of authenticated data transmission

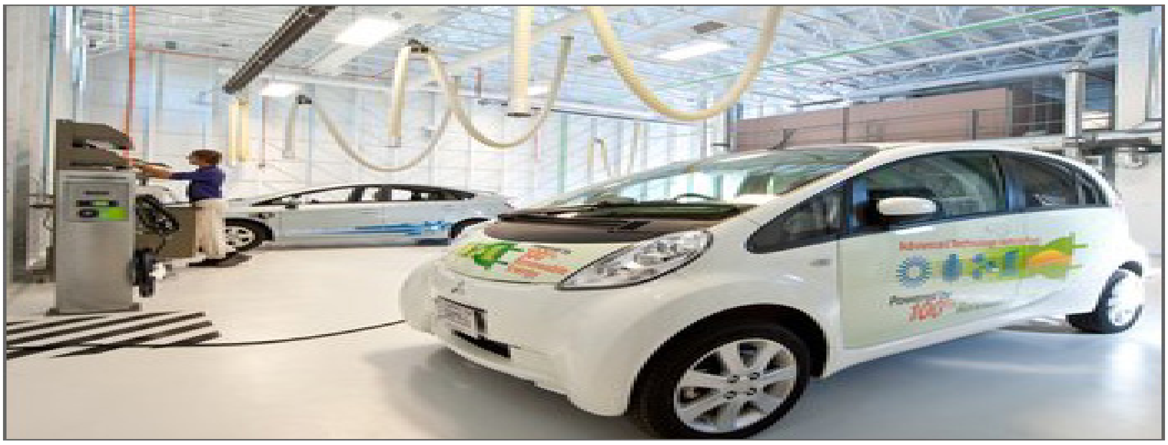


Fig.2.7

Demand Side Management

- It could be said as an enhancement over the existing applications as this allows the management of power in accordance with the generation rate and hence finds out the applications mostly at the low voltage site. Because of its ability to alter the rate of management in accordance with the generation rate which alters according to season especially the non-conventional sources of energy like solar energy and wind energy and hence it can provide some real time information to the user which enables them to make demand according to generation and supply rate.

- The biggest advantage of this is that it could reduce the possibility of power failure which is becoming very often now days such that the users will make a peak demand only when the generation rate is in accordance with that, ultimately it will increase the efficiency of the grid and also results in increase in energy management.

Fig.2.8

Home Automation

- The Power Line Communication could be used for the purpose of achieving automation at the customer premises. In the industrial and commercial premises there is a presence of a multiple number of devices which uses different protocols and came up from different manufacturers and therefore results in a completely unrealistic environment where there arises a need to not only provide the information to various terminating devices but also to provide a conversion of protocols while conveying the information from one device to the other which may or may not be a part of the same LAN network.
- The major advantage of this application is that it provides a direct path between controllers and IEDs (Intelligent Electronic Devices) unlike packet switched public network. [1,17]

Fig.2.9

Summary

This chapter consists of the basic description of the power Line Communication, the availability of the current technological standards and the various advantages of the power line communication. Then some of the ways had been defined that how the PLC could be used to transform a grid to a smart grid, this is followed by the description about the smart grid, need of smart grid and its applications.

3

Modelling of Power Line Channel Using Different Approaches

This chapter deals with the types of Power Line Communication, the modelling of the indoor power line communication which involves basic wiring topological connection and the detailed analysis of the multi-conductor power line cables which is followed by the procedure of determination of the transfer function (while considering attenuation, skin effect and dielectric losses) using scattering matrix or transmission matrix.

3.1 Different Approaches of Modelling of Power Line Communication

There is usually a presence of two different approaches for the modelling of high frequency Power Line Communication channels –Top-Down Approach and Bottom-Up Approach.

- *TOP-DOWN Approach* - These models are simply based on the measurements like the Echo model which is extracted from the transfer function measurement and the Resonant Circuit model extracted from impedance measurements.

- *BOTTOM-UP Approach* – In this approach the power lines are considered as distributed networks and therefore the two basic/intrinsic parameters - characteristic impedance and propagation constant are measured first and then the transfer function is determined using the scattering matrix or transmission matrix.[7]

Although both the approaches find their utility according to applications, however over the period of time Bottom-Up approach had started gaining more importance.

3.2 Power Line Channel models

Ascertaining the transfer function of the Power Line Channel is a non-trivial task since it depends on several variables, topology of the network and cable parameters, wiring and grounding practices and impedance of the attached appliances. Considering these factors two models have been defined

3.2.1 Time-Domain multipath model

The Power Line channel model has been described considering that it is predominantly affected by multipath effects. The multipath nature of Power Line channels arises due to the presence of several branches at which impedance mismatch causes multiple reflections.[2,4]

A number of reflected signals affect the quality of the main signal which is required to reach to the receiver reliably for successful completion of data transmission.

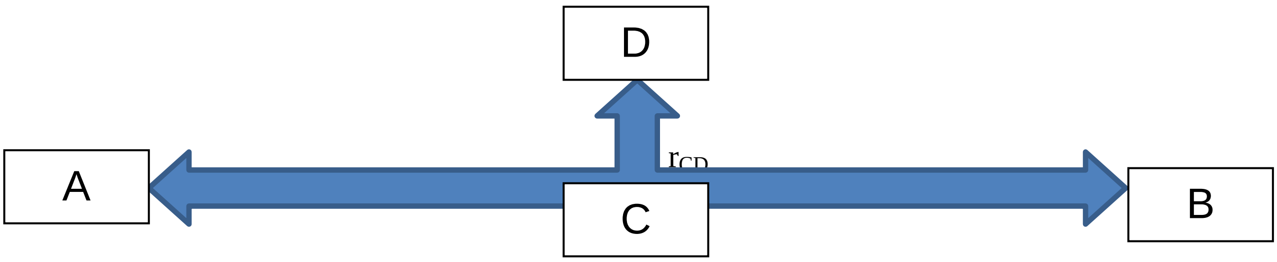


Fig-3.1 Multipath signal propagation cable with one tap.[4]

r_{CD} – Reflection coefficient between C and D

If there is a presence of only a bridged gap at B then the distance between A and C is denoted as L_{AC}. For this configuration, the signal follows a first direct path (A→B→C) and virtually infinite number of secondary paths arises as the signal bounces in between B and D.

For i=1 : A→B→D→B→C

For i=2 : A→B→D→B→ D→B→C

The number of reflections and so do the impact on to the main signal increases as the value of i increases and also with the increase in the number of discontinuities.

Physical Signal Propagation Effects

This section examines the effects on the communication signals over power line networks. The signal propagation takes place not only along a direct line of sight path but additional echoes must also be considered. This results in a multipath scenario with frequency selective fading. All the reflection and transmission factors are less than or equal to unity and the product of it is defined as weighting factor g_i. Furthermore the longer the transmission paths the higher the attenuation.

The delay of a path is defined as

$\tau_i = d_i/v_p$

The losses along the cable increases with length and frequency. Therefore according to this model the overall frequency response is defined as

$$H(f) = \sum_{i=1}^{N} g_i * e^{(-j2\pi f ({d_i}/{v_p}))} * e^{-(a_0+a_1*f^k)} \qquad (1)$$

Where, N is the number of paths and g_i, $\alpha(f)$, τ_i are the gain/weighting factor , attenuation coefficient (which takes into account both the skin effect and dielectric losses) and delay associated of i^{th} path respectively.[4]

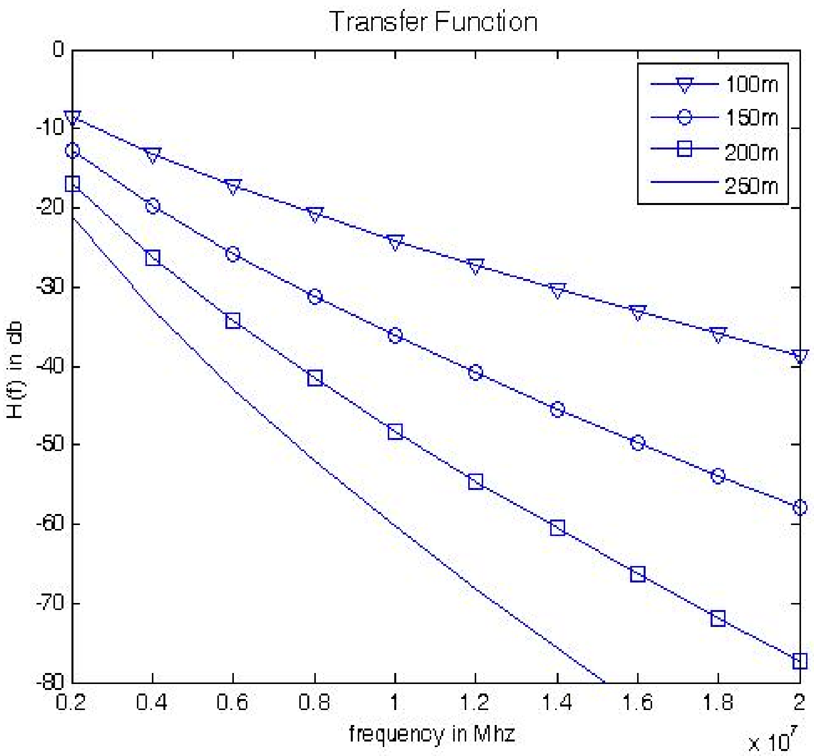


Fig-3.2 Transfer Function of PLC in the frequency range of 2 MHz -20 MHz

3.2.2 Frequency-Domain multipath model

A number of attempts have been made to model the power line channel as a two conductor transmission line using either transmission matrix or scattering matrices but those models led to an incomplete circuit representation and that is not capable of explaining the signal propagation completely since these analysis neglects three major points.

- The presence of a third conductor, which could be solved by using multi-conductor transmission line theory.
- The effects of particular wiring and grounding practices.
- Estimation of mode currents, related to electromagnetic compatibility

Therefore a more accurate approach to channel modelling based on multi-conductor transmission line has been proposed for power line channel and in that case a common wiring topology is used which had been proposed first followed to this is the analysis of the multi-conductor Power Line Cables.[4,9]

Common Wiring Practices Used in Residential and Business Buildings

In general the power cables used for single phase indoor wiring consist of three or four conductors in addition to the ubiquitous earth ground. These usually include hot (black), return (white), safety ground (green or bare) and the occasional runner(red) wires, all confined by an outer jacket that maintains close conductor spacing between two directions of propagation. The spatial modes are often referred to as differential mode or balanced mode and common mode is referred to as the longitudinal mode.

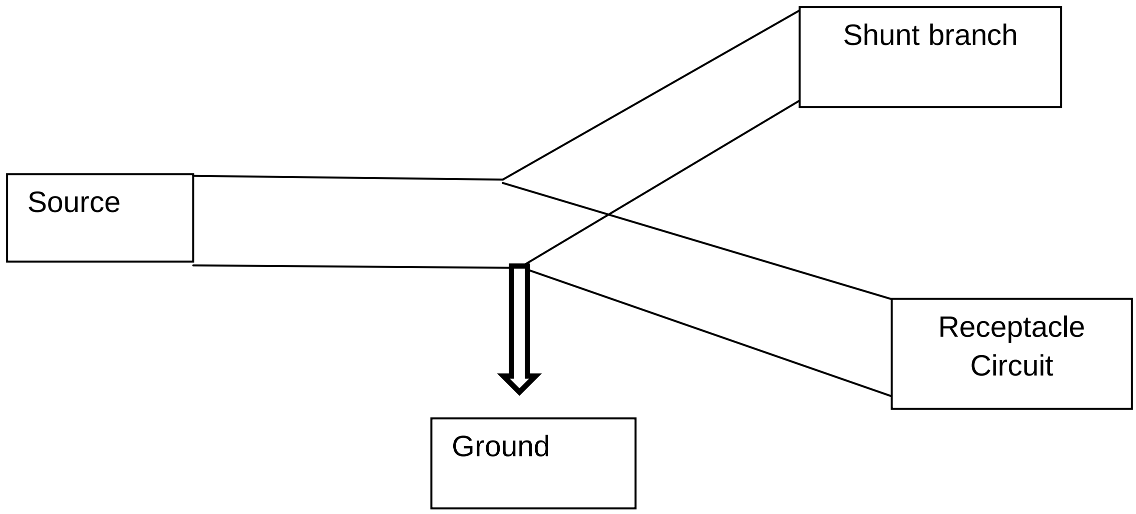


Fig-3.3 Layout of typical residential and commercial premises [3]

Analysis of Multi-conductor Power Line Cables

Consider a transmission Line consisting of two isolated conductors. Such a configuration supports four modes of propagation along the transmission line in the TEM approximation, two spatial modes each with two direction of propagation. The spatial modes are often referred to as differential mode (or balanced or odd mode) and common mode (or longitudinal mode or even mode).

The differential mode current is almost always the functional current responsible for carrying the data signal along the line. It is possible to excite only a differential propagating mode along a two conductor transmission line e.g. a twisted pair cable, by differential signalling i.e. by driving the signal with antipodal signals. But due to some imbalances there could be a presence of a common mode signal.

Although the presence of a common mode current does not inherently degrade the performance of the differential mode data signals. However if there is a presence of some mechanism to transfer the energy from common mode to differential mode, then the common mode current can become a dominant interference signal. This phenomenon is called as mode conversion or mode coupling.

In case of Indoor Power Line networks, the modes propagating along the cable are not independent and the mode coupling often occurs. In particular strong mode coupling occurs at the point of ground bonding at the breaker box, the mains feed and the lighting circuits interrupted by switches. Since the lighting and outlet circuits are usually fed from separate breakers, the effect of bonding often occurs.[12,13]

Analysis of three Conductor Transmission Lines

A three conductor cable supports six propagating modes i.e. three spatial modes (differential, pair, common modes) each for two direction of propagation. The differential mode current I_{dif} represents an odd mode signal with the current confined to the white and black wires and is generally the desired signal.

The pair mode signal I_{pr} represents an even mode signal with current flowing between the safety ground wire and the white /black wire tied together.

The common mode current in cable acts as an imbalance which creates a current loop with earth ground It highly depends on cable installation and the characteristic impedance for this mode is variable and not readily characterized $Z_{cm} \approx 150\text{-}300\ \Omega$.

The voltage and current in a three wire power line cables consists of V_{blk} (I_{blk}),V_{wht} (I_{wht}) and

V_{gnd} (I_{gnd}) respectively.

The propagating voltages are $V_1^+=(V_{dif}^+, V_{pr}^+, V_{cm}^+)$and $V_1^-=(V_{dif}^-, V_{pr}^-, V_{cm}^-)$,correspondingly the current relationship is given by $I_1^+=(I_{dif}^+, I_{pr}^+, I_{cm}^+)$ and $I_1^-=(I_{dif}^-, I_{pr}^-, I_{cm}^-)$ represents differential , pair and common-mode currents for waves propagating in forward and backward direction .[see-3]

The propagating voltages and current is related to each other by a diagonal matrix of characteristic impedance Z_0

$$V_1^+ = \begin{bmatrix} V_{dif}^+ \\ V_{pr}^+ \\ V_{cm}^+ \end{bmatrix} = \begin{bmatrix} Z_{dif} & 0 & 0 \\ 0 & Z_{pr} & 0 \\ 0 & 0 & Z_{cm} \end{bmatrix} \begin{bmatrix} I_{dif}^+ \\ I_{pr}^+ \\ I_{cm}^+ \end{bmatrix} = Z_0 \; I_1^+ \tag{2}$$

Similarly the voltage and current in the reverse direction are related as follows

$$V_1^- = \begin{bmatrix} V_{dif}^- \\ V_{pr}^- \\ V_{cm}^- \end{bmatrix} = \begin{bmatrix} -Z_{dif} & 0 & 0 \\ 0 & -Z_{pr} & 0 \\ 0 & 0 & -Z_{cm} \end{bmatrix} \begin{bmatrix} I_{dif}^- \\ I_{pr}^- \\ I_{cm}^- \end{bmatrix} = -Z_0 \; I_1^- \tag{3}$$

Therefore the overall voltage and current along a line consist of the transmitted as well as the reflected signals

$$I_1 = I_1^+ + I_1^-$$

$$= \begin{bmatrix} \frac{(1+\varepsilon)}{2} & -\frac{(1-\varepsilon)}{2} & 0 \\ 1-\theta & 1-\theta & -\theta \\ 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} I_{blk} \\ I_{wht} \\ I_{gnd} \end{bmatrix} = B\, I_C \tag{4}$$

and

$$V_1 = V_1^+ + V_1^-$$

$$= \begin{bmatrix} 1 & -1 & 0 \\ \frac{(1-\varepsilon)}{2} & \frac{(1+\varepsilon)}{2} & -1 \\ \frac{(1-\varepsilon)}{2}\theta & \frac{(1+\varepsilon)}{2}\theta & 1-\theta \end{bmatrix} \begin{bmatrix} V_{blk} \\ V_{wht} \\ V_{gnd} \end{bmatrix} = A\,V_C \qquad (5)$$

Where A and B are related as

$A^{-1} = B^T$ or $B^{-1} = A^T$

Where the parameter $\varepsilon \approx 0.05 - 0.3$ and it describes an asymmetry between black and white wires relative to the ground conductor whereas the factor $\theta \approx 0.5$ -0.15 and it represents the shielding produced by the ground conductor.

The forward and reverse voltage (similarly current) are related to each other by a factor called as reflection coefficient and the relation is given by

$$V_1^- = \rho_v V_1^+ \qquad (6)$$

and the reflection coefficient can further be defined in terms of an arbitrary linear network described as Z_{term} which is given by

$$\rho_v = (A^T Z_0^{-1} + Z_{term}^{-1} B^T)\,(A^T Z_0^{-1} - Z_{term}^{-1} B^T) \qquad (7)$$

Where A and B are modal matrices as define in [3, eqs (3) and (4)], Y_{term} is defined as

$$Y_{term} = (Z_{term})^{-1} = A^T Z_0^{-1} A + Y_{sh} \qquad (8)$$

On substituting this in the above equation we get

$$\rho_v = -(2A^T Z_0^{-1} + Y_{sh} B^T)^{-1} Y_{sh} B^T \quad (9)$$

Moreover reflection coefficient is related to resistance under bonding and fault conditions and is described below and these are mainly resulted due to multiple number of shunt branches as depicted in the basic topological diagram

The differential mode reflection coefficients for each case are

$$\frac{-1}{\rho(dif_{sd})} = 1 + \frac{2*R_{sd}}{Z_{dif}} \quad (10)$$

$$\frac{-1}{\rho(dif_{sb})} = 1 + \frac{8*R_{sb}}{(1-\varepsilon)^2 * Z_{dif}} + 4 \quad * \frac{Z_{pr}}{(1-\varepsilon)^2 * Z_{dif}} \quad (11)$$

$$\frac{-1}{\rho(dif_{sf})} = 1 + \frac{8*R_{sf}}{(1+\varepsilon)^2 * Z_{dif}} + 4 \quad * \frac{Z_{pr}}{(1+\varepsilon)^2 * Z_{dif}} \quad (12)$$

The reflection coefficient varies as function of resistance and hence the relationship is as shown in fig.4 for two conditions:-Bonding (R_{sf}=R_{sd}=infinite) and Fault (R_{sd}=R_{sb}=infinite)

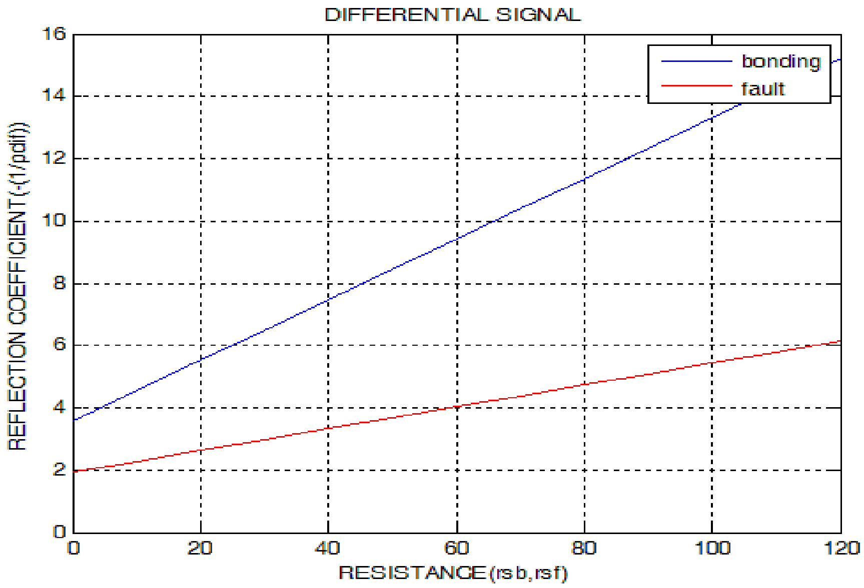


Fig-3.4 Variation of reflection coefficient for bonding and fault condition with respect to resistance [3]

3.3 Advantages of Frequency Domain Model

The computational complexity is nearly independent of the topology complexity and the number of mismatched branch terminations. Since it takes a composite of all signals reflected by the discontinuities (multipath) over the measured frequency range, whereas in time domain model it is necessary to generate all the different paths individually.

3.4 Disadvantages of Frequency Domain Model

The main drawback of the frequency domain model is that everything about the link must be known in advance and it includes topology of the network, cable type, their characteristics and the terminating impedance at every branch. Incomplete knowledge about these quantities can impair the accuracy of these channel models in case if they constitute part of the dominant path at a given frequency.[12,13]

Summary

This chapter constitutes different approaches employed for modelling of power line channel and determined that bottom-up approach is better than the other approaches and on the basis of that time domain and frequency domain analysis has been accomplished and the overall transfer function is obtained while considering all the factors involving the reflected signals from multiple number of shunt connections which is the main factor responsible for the degradation of the desired signal quality.

4

Performance Evaluation of Power Line Channel using OFDM and CDMA

The purpose of this Chapter is to present the Basics of OFDM and CDMA and the evaluation of the power line channel performance to reach out to the best possible solution or selection of the modulation technique which suits best the requirement of data transmission to fulfil the main purpose of energy management to ensure the best possible utilization of the available resources.

4.1 OFDM Basics

OFDM is a parallel transmission scheme where a high rate serial data stream is split into a set of low rate sub-streams, each of which is modulated on a separate subcarrier ,thereby the bandwidth of subcarriers becomes small compared with coherence bandwidth i.e. the individual subcarriers will experience flat fading which allows the use of simple equalization. This implies that the symbol period of the sub-streams is made long compared to the delay spread of the time dispersive radio channel.

Therefore a major requirement is to select a set of completely orthogonal signals; a high spectral efficiency can be obtained because of being completely orthogonal the mutual influence among the subcarriers can be completely avoided although the spectra of the subcarriers overlap with each other. [21]

Mathematically Expression:

$$s(t) = \sum_{i=-\infty}^{\infty} \sum_{k=1}^{N_{SC}} c_{ki} s_k(t - iT_s)$$

(1)

$$s_k(t) = \Pi(t) e^{j2\pi f_k t}$$

(2)

$$\Pi(t) = \begin{cases} 1, & 0 < t \leq T_s \\ 0, & t \leq 0, t > T_s \end{cases}$$

(3)

where, c_{ki} = i^{th} information symbol for the k^{th} subcarrier

s_k = Waveform for k^{th} subcarrier

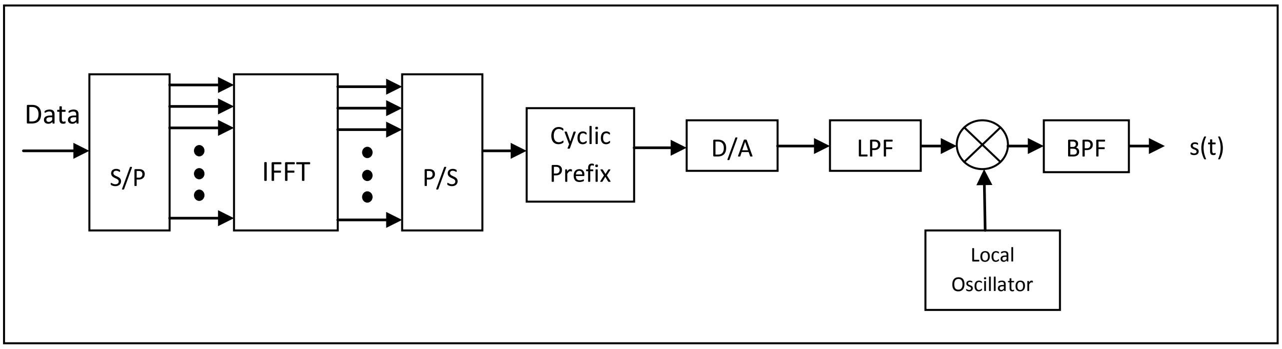
N_{SC} = Number of sub-carriers

f_k = Frequency of k^{th} subcarrier

T_s = Symbol Period

$\Pi(t)$ = Pulse shaping function (rectangular in this case)

The basic block diagrams of the OFDM transmitter and receiver is as shown in figure and it is shown that the baseband signal is modulated by using an IFFT block followed by an up-conversion whereas at the receiver the signal is down-converted to baseband and then the demodulation is performed using an FFT block.



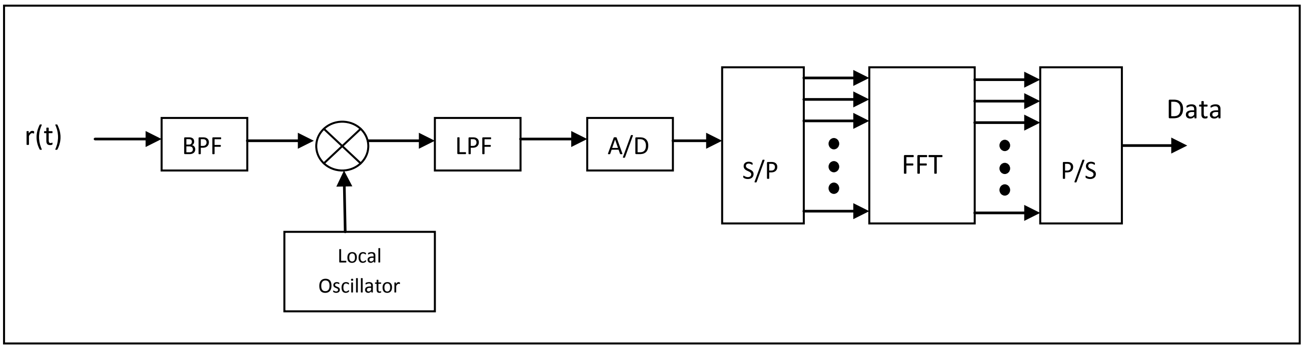


Fig. 4.1 - Block Diagram of OFDM Transmitter and Receiver Sections

The main advantage of using IFFT and FFT blocks is that it eliminates the need of a large number of modulators and demodulators that would otherwise be required.

- **An example of OFDM spectrum is shown in the following figure**

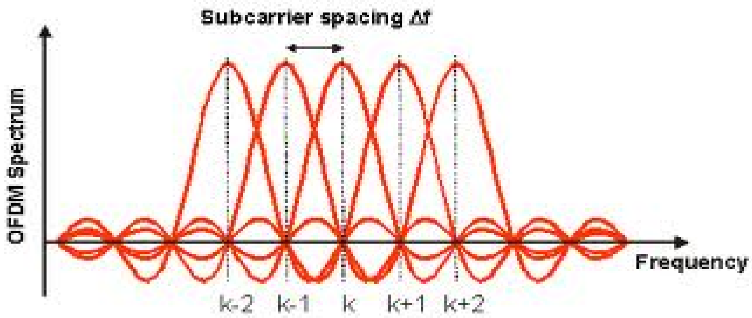


Fig 4.2 OFDM SPECTRUM

This shows the presence of a large number of subcarriers which although are overlapped with each other but because of the capability of performing the sampling at the correct instance, the entire information can be acquired faithfully and hence the fidelity of the baseband signal remained intact.

Cyclic Prefix- It is defined as the process of insertion of a part of OFDM symbol at the beginning of the OFDM symbol, i.e. it is the copy of the last part of the OFDM symbol and it is introduced to preserve the orthogonally of the subcarriers and the duration of it should be larger than the maximum excess delay of the radio channel.

Windowing - Windowing is a technique which is used to reduce the levels of side-lobes and this is mainly done to preserve the amount of power required to transmit these side-lobes, In an OFDM system , the applied window must not influence the signal during its effective period therefore cyclically extended parts of the symbol are pulse shaped. To achieve the windowing of the transmitted pulse, a raised cosine pulse can be used which can be obtained by convolving the extended rectangular pulse of duration T with a half sine wave.

Over the last few decades OFDM has proven to be one of the most promising technologies meant for the data transmission. It is currently used in DSL technology, terrestrial wireless distribution of television signals, and also for IEEE's high rate wireless LAN standards (802.11a, 802.11g). In this work an endeavour has been made to analyse the performance of the power line channels such that some sort of enhancement could be made to improve the performance of data transmission over these lines. In case of OFDM a single carrier is divided into a number of subcarriers and to achieve a high spectral efficiency the frequency response of the subcarriers are overlapping and orthogonal. More importantly using an OFDM technique a frequency selective channel is divided into many flat fading sub channels and this is the reason which eliminates the requirement of a sophisticated equalizer.

Home Plug 1.0 is one of the technology that makes use of the orthogonal frequency division multiplexing using three different variants of modulation schemes under it , that involves BPSK(Binary phase shift keying), DBPSK(Differential BPSK), DQPSK(Differential Quadrature PSK). The data is transmitted as in form of frames that contain the preamble and frame control information present at the start and at the end of the frame.

4.1.1 *Advantages of OFDM*

- Efficient way to deal with multipath, for a given delay spread, the implementation complexity is significantly lower than that of a single carrier system with an equalizer.
- In relatively slow time varying channels, it is possible to enhance capacity significantly by adapting the data rate per sub-carrier according to SNR of that particular sub-carrier.
- OFDM is robust against narrowband interference because such interference affects only a small percentage of sub-carriers.
- OFDM makes single frequency networks possible which is attractive especially for broadcasting applications.

4.1.2 Disadvantages of OFDM

- It is more sensitive to frequency offset and phase noise.
- It has a relatively large Peak to Average Power Ratio which tends to reduce the power efficiency of the radio frequency (RF) amplifier.

4.2 CDMA Basics

CDMA stands for Code Division Multiple Access and it is a type of algorithm used to squeeze more usable channels within the same bandwidth. CDMA is a 2G technology and is one of the most widely deployed technologies. It is a multiple access technology that was introduced after TDMA and FDMA. Unlike TDMA and FDMA where the users are separated in terms of time and frequency, CDMA separates the users with separate code sequences. When we consider the CDMA system design multiple access and interference handling are totally different from the narrow-band systems. In CDMA, each user spreads his signal over the entire bandwidth using direct sequence spread spectrum, whereas for the other users it is shown as pseudo white noise.

4.2.1 Direct Sequence Spread Spectrum

Direct Sequence Spread Spectrum signal is obtained when a bipolar data modulated signal is linearly multiplied by the spreading signal in a balanced modulator called spreading co-relator. The rate at which the code is spread out is $R_{CW} = 1/T_C$, where T_C is defined as the duration of bipolar pulse.

In general the chip rates are usually 100 to 1000 times faster than the data message or in other words T_C should be 100 to 1000 times shorter in duration than the time of a single data bit. Therefore the transmitted output signal will have 100 to 1000 time wider bandwidth compared to the initial PSK data modulated signal.

Block Diagram of Direct Sequence Spread Spectrum

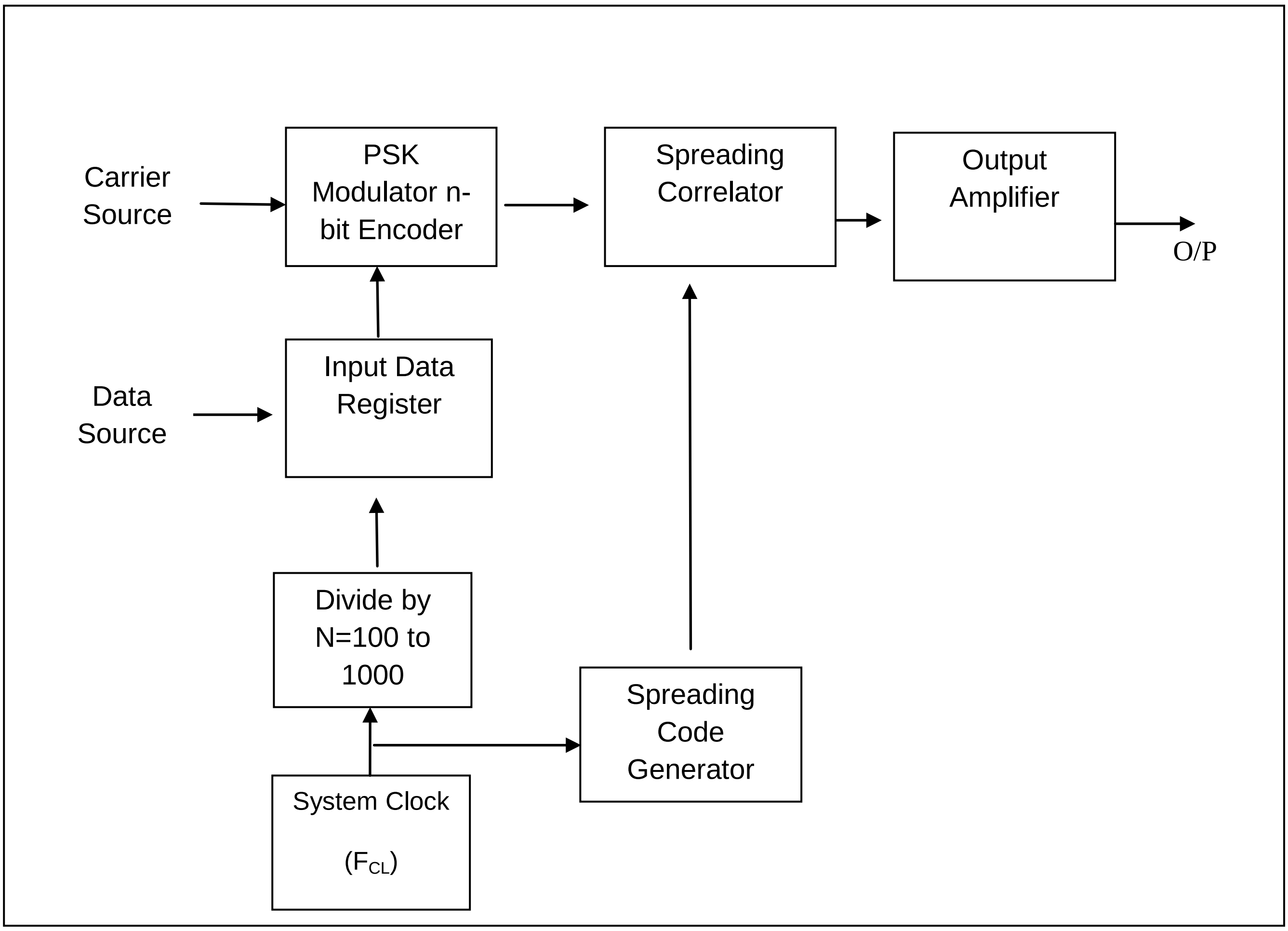


FIG. 4.3

In this the data from the source directly modulates the carrier signal which is then further modulated in the spreading co-relator by the spreading code word. The spreading codes employed in case of direct sequence spread spectrum technique is in general the maximal-length code or Gold code. For a reasonable number of users it is possible to achieve a set of completely orthogonal codes.

4.2.2 Frequency Hopping Spread Spectrum

Frequency hopping is defined as another technique of CDMA in which a digital code is used to change the frequency of the carrier on a continuous basis. In this, the carrier is firstly modulated in accordance with the message signal or data signal which is then up-converted using a frequency synthesized local oscillator which is dependent on an n-bit pseudo random noise code generated by a spreading code generator. The basic block diagram is shown below:

Block Diagram of Frequency Hopping Spread Spectrum

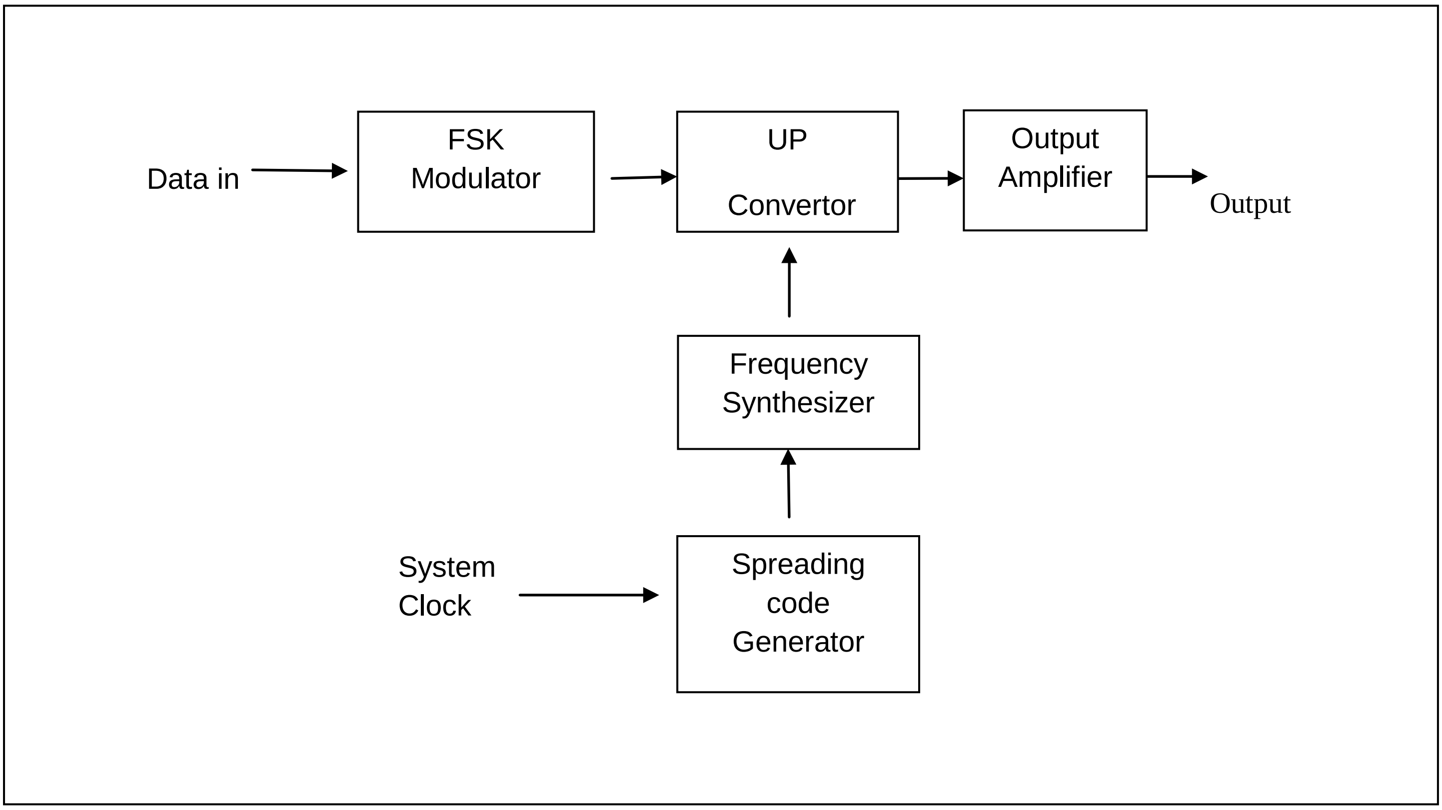


FIG 4.4

In frequency hoping the total available bandwidth is divided into a number of frequency bands and the total transmission time is divided into a number of time slots. The main purpose of this is to transmit the information within a limited frequency band for a short interval of time then switch on to another frequency band one after the other, this process remained continued indefinitely. Each station utilizes a different code sequence. The frequency hopping pattern is determined by a binary spreading code and the representation of this frequency hopping pattern had been depicted below:

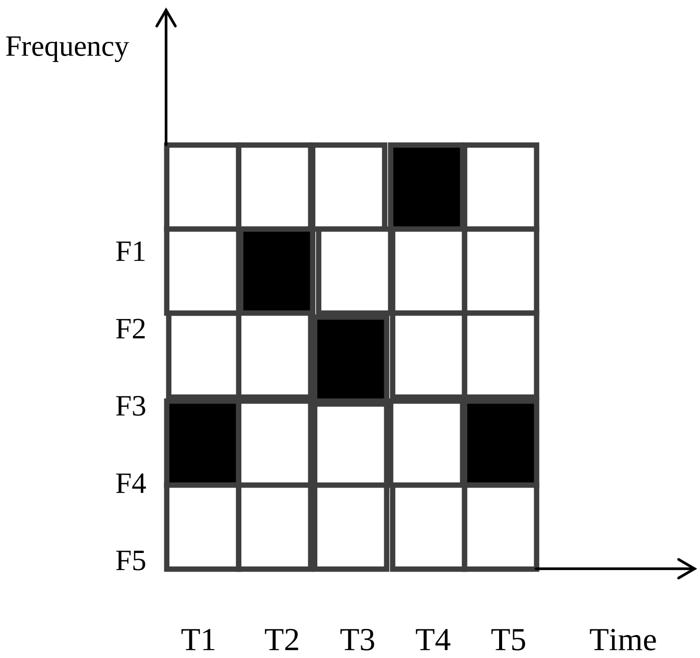


Fig 4.5- Frequency-Time Hopping Pattern

■ - Frequency selected at different time slots

Each earth station is thus assigned a different frequency hopping pattern in a CDMA network. Each transmitter switches from one frequency band to the other according to the pre-assigned pattern. Thus each earth station occupies the entire RF spectrum but never occupies the entire spectrum at any one time.

The most commonly employed modulation scheme is FSK modulation. Whenever an earth station's turn is there to transmit the data, it sends one of the two frequencies (mark or space) for a particular band. The number of earth stations is limited by the number of unique frequency hopping patterns.

4.2.3 Equalization

Equalization is defined as the process which is applied to reduce the inter symbol interference which is one of the important requirement for the proper reception of the transmitted symbols. It may be a simple linear equalizer or a complex equalizer and the selection of the equalizer is made depending on the requirement of the application and conditions as there is a presence of a trade-off in between the reception quality and the complexity.

Zero Forcing Equalization

Zero Forcing Equalization is a form of linear equalization and to accomplish the task of equalization it makes use of inverse response of the channel transfer function i.e. it applies the inverse of the channel frequency response to the received signal to restore the original data or information.

Thus if the channel frequency response is F(f) then the Zero Forcing Equalizer will have the response as $H(f)=1/F(f)$ such that the combination of the equalizer and the channel response gives out a flat frequency response characteristics and a linear phase , given as $F(f).H(f)=1$.

Limitations of Zero Forcing Equalization

1. The channel response may be finite but the impulse response of the equalizer needs to be infinitely long.
2. The received signal may be too weak for some of the frequencies, in order to compensate it the magnitude of the zero forcing equalizer needs to be very large, but as a result of this the noise that might be present after the channel will be boosted by a large amount and hence

destroys the overall signal to noise ratio. Moreover the channel frequency response may have some of the zeros and that cannot be inverted.[23]

4.2.4 Advantages of CDMA

- Using a pseudo signal, original signal is modulated into a higher bandwidth where the original signal's spectral components sink in the noise. Therefore without the code the jammers can see the signal as noise.
- Uniqueness of CDMA based access method is the universal frequency reuse where all the users in the same cell and across different cells can transmit and receive on the same frequency.
- CDMA technology offers core advantages such as selective addressing capability for each user separately, message security and interference rejection. Proper selection of codes with low cross correlation leads to minimum interference between users and provides higher spectral efficiency
- The use of CDMA instead of OFDM eliminates the requirement to alter the modulation scheme in case of a requirement of an interfacing between wired and wireless means of communication.

4.3 Results and Discussion

The Performance Evaluation of Power Line Channel has been accomplished using OFDM (BPSK, QPSK, and 16-QAM) and the OFDM is being used considering the requirement of higher data rate and robustness. The obtained results had been shown below and the results indicate that there is a trade-off between the probability of error and the complexity and the major advantage of using OFDM is the requirement of a simple equalization technique which is an inverse model of the channel model.

The obtained results using OFDM as a modulation scheme shows that as if the length of the channel is less, then the effect of noise is more and also the multipath conditions resulted due to multiple number of terminals causes reflection of the signal over the main transmission line, affects the performance of the data transmission, and all these affects are clearly depicted in the scattering plots whereas as the length reaches to a mid-range value, the effect of eliminating the poor subcarriers gives a lot better performance as compared to using all the subcarriers. Moreover as the length reaches to a very high value, the noise impact will remain be the same and the elimination of poor subcarriers will not result in the betterment of the performance in terms of BER and the results will remain be the same as for the case of using all the subcarriers.

One of the major limitations of Power Line Communication is the requirement of availability of power for the devices or the terminals on a continuous basis so as to allow the devices to communicate with each other via power line links with the transceivers in the middle of it which transforms the signal in a suitable format to enable various terminating devices to upheld the communication, but under adverse conditions i.e. when there is power failure which is becoming very common now a days because of increase in loading effects and a higher demand in the power supply for various equipment– a solution had been proposed in these thesis with some results as that we can switch on to a different modulation method i.e. CDMA and the advantage of using CDMA as a modulation scheme is that at the time of switching on to satellite communication we will not require to alter the modulation scheme under adverse conditions, The results corresponding to OFDM followed by CDMA using DSSS and FHSS and the implementation of equalization techniques has been depicted.

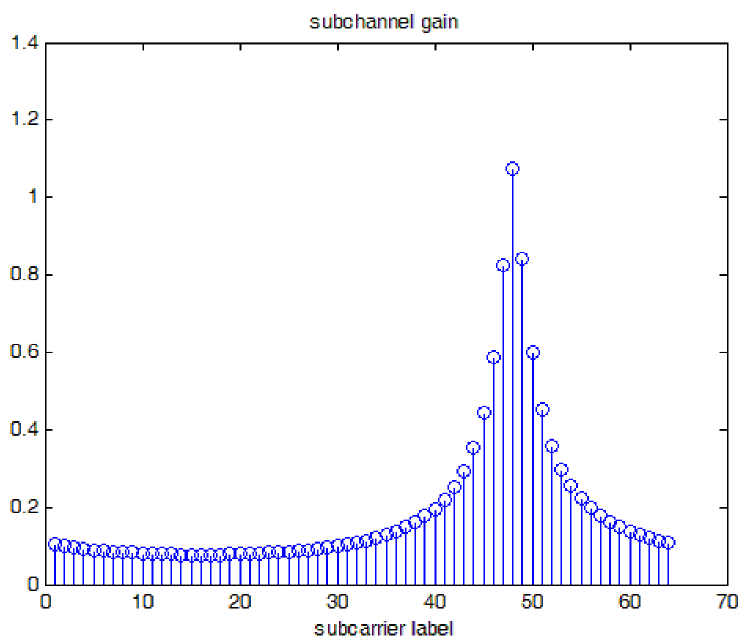


Fig 4.6- Representation of sub-channel gain for the length of 200m

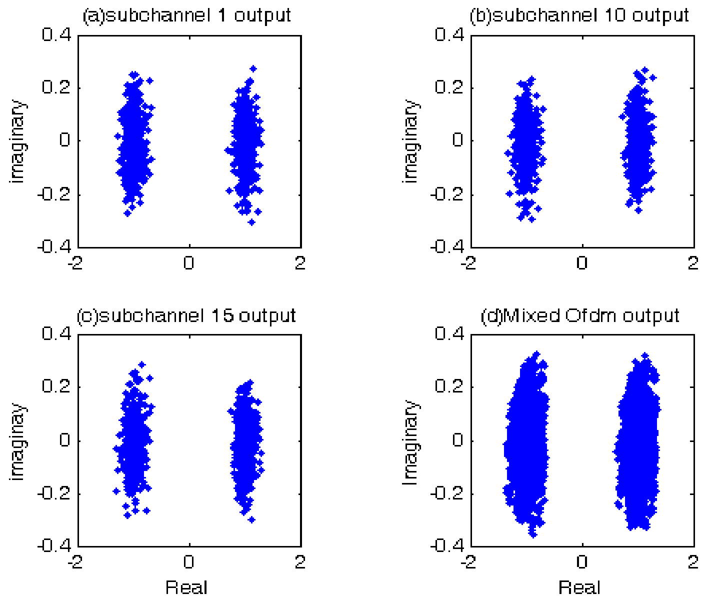


Fig 4.7- Sub-channel constellation scattering and the mixed OFDM-BPSK output for the length of 200m

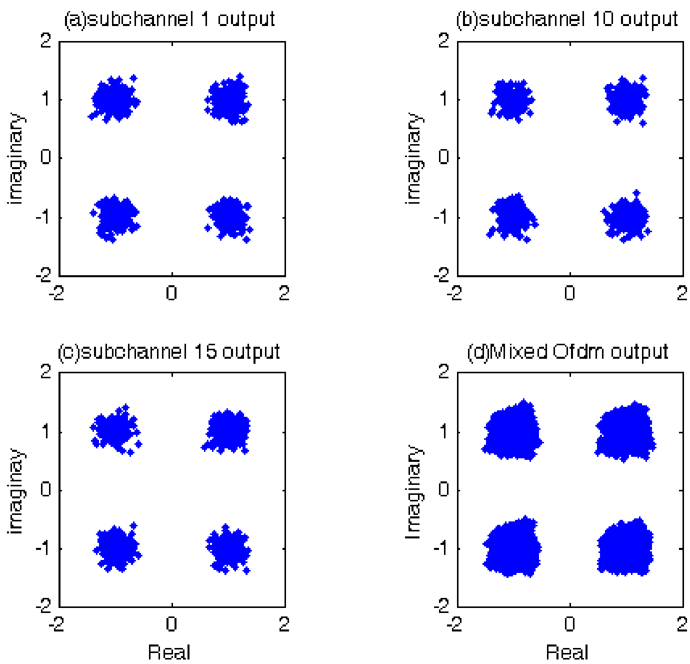


Fig 4.8- Sub-channel constellation scattering and the mixed OFDM-QPSK output for the length of 200m

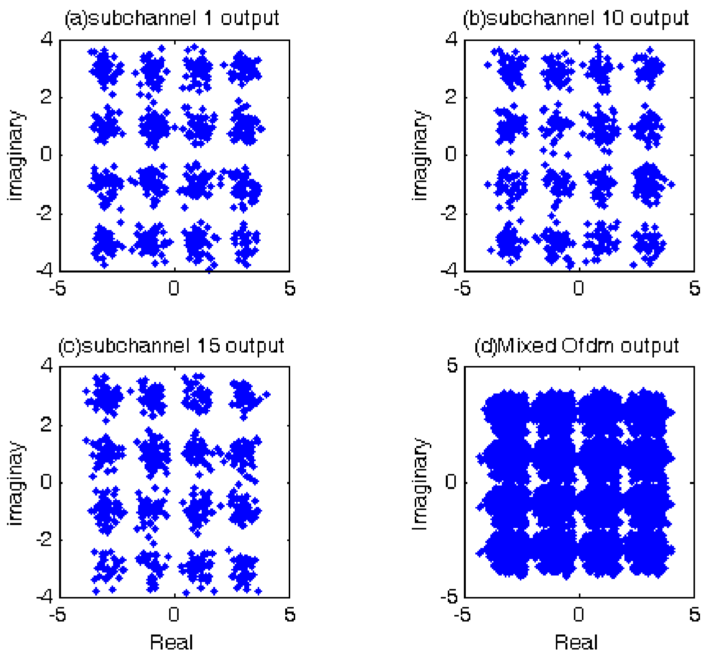


Fig 4.9- Sub-channel constellation scattering and the mixed OFDM-QAM output for the length of 200m

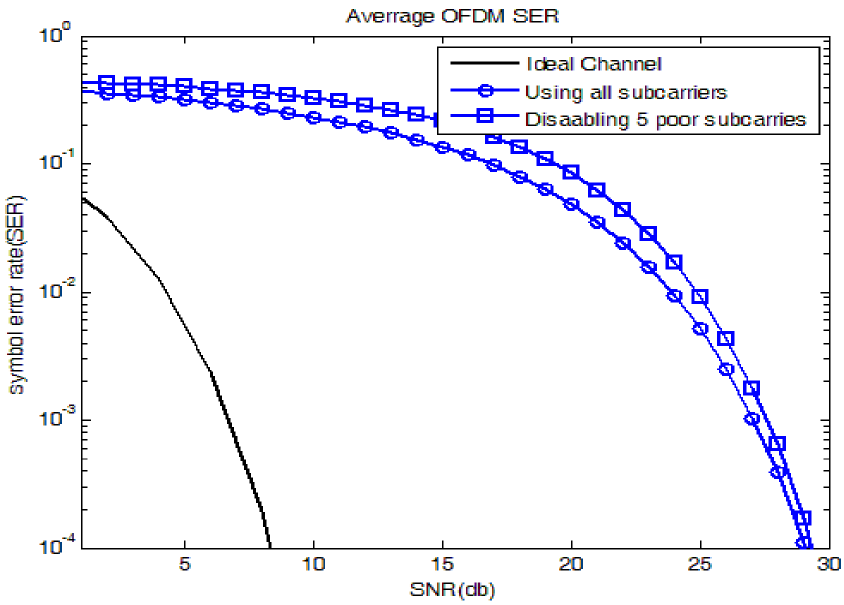


Fig 4.10- Determination of symbol error rate for OFDM-BPSK using all subcarriers and while suppressing some poor subcarriers, when the length is 200m

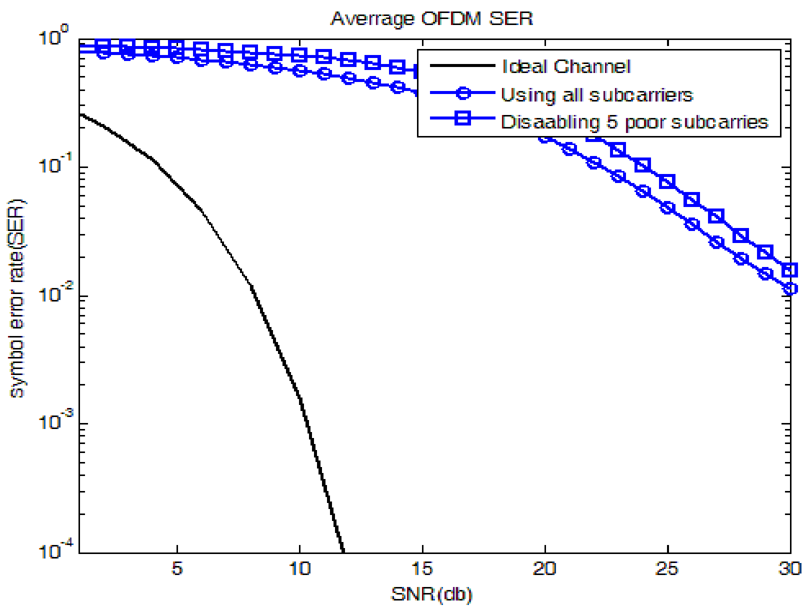


Fig 4.11- Determination of symbol error rate for OFDM-QPSK using all subcarriers and while suppressing some poor subcarriers, when the length is 200m

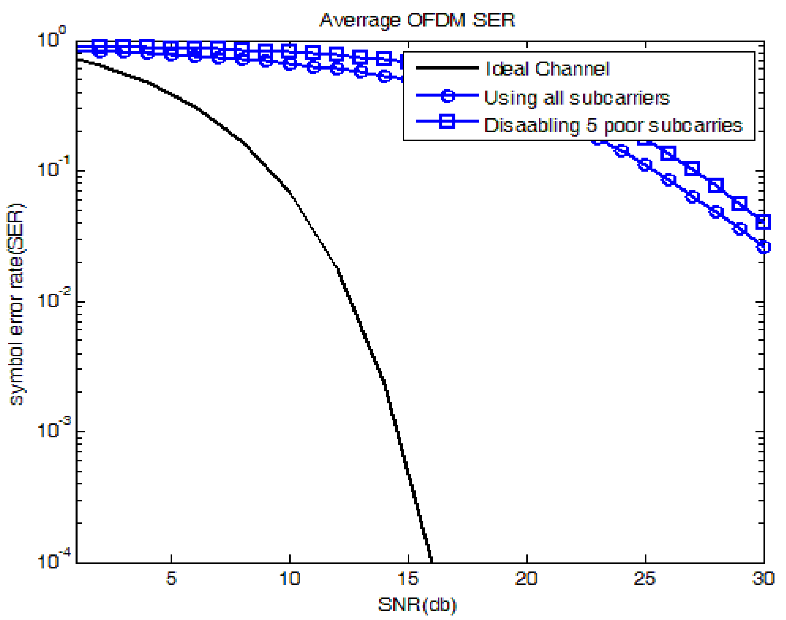


Fig 4.12- Determination of symbol error rate for OFDM-QAM using all subcarriers and while suppressing some poor subcarriers, when the length is 200m

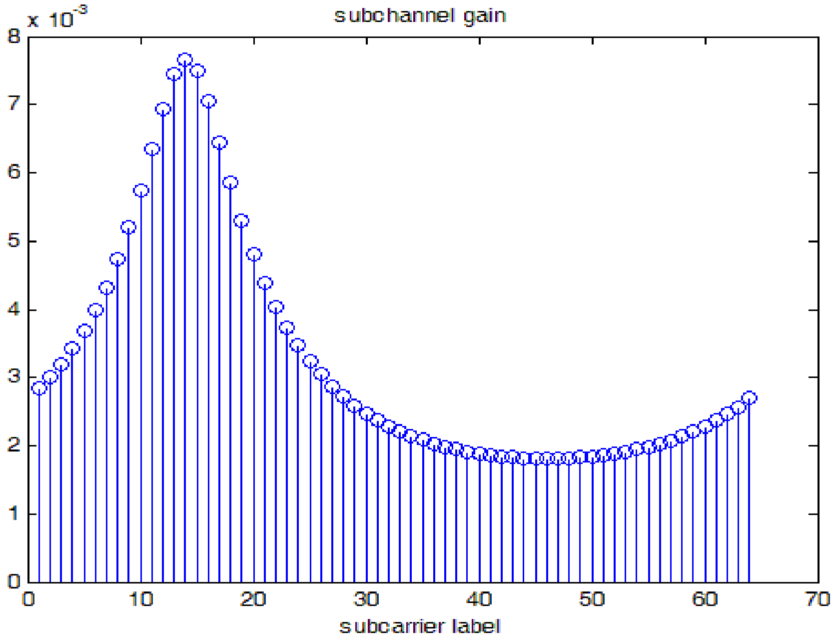


Fig 4.13- Representation of sub-channel gain for the length of 600m

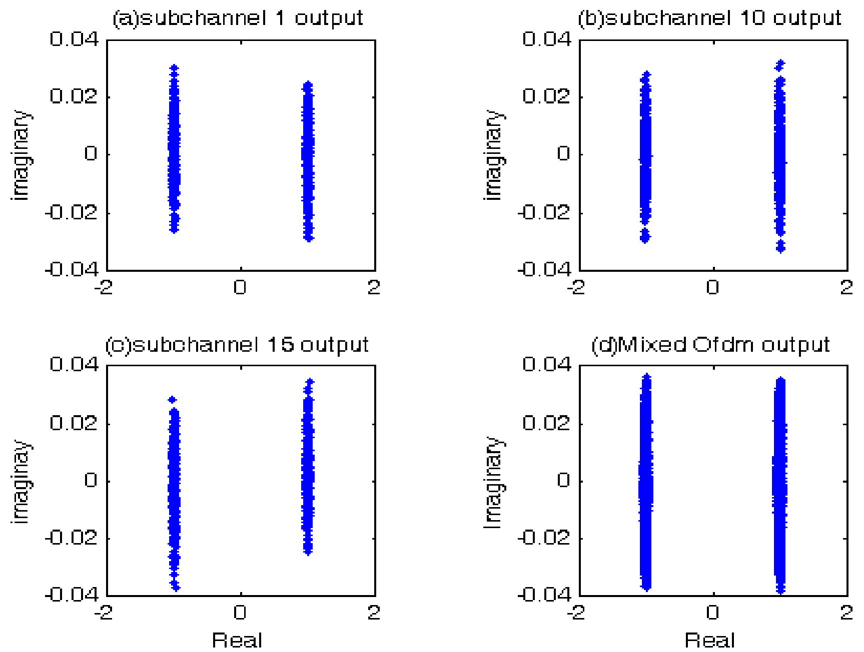


Fig 4.14- Sub-channel constellation scattering and the mixed OFDM-BPSK output for the length of 600m

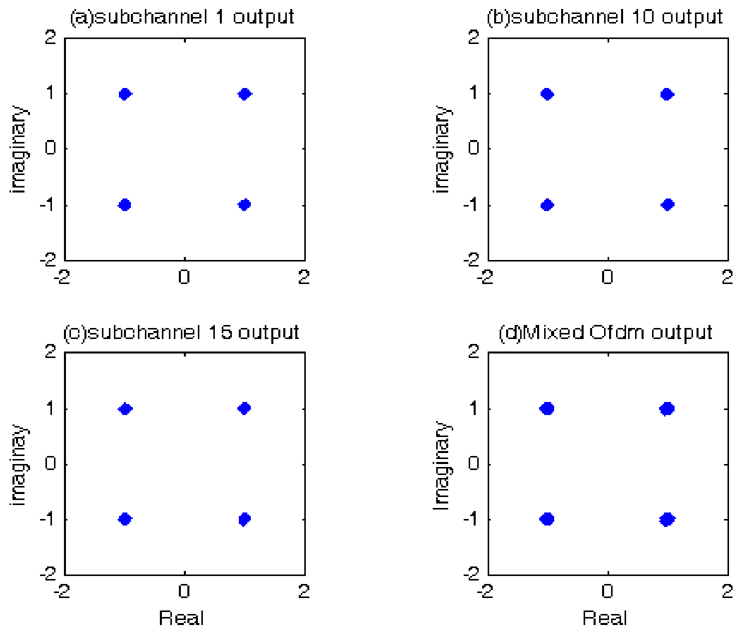


Fig 4.15- Sub-channel constellation scattering and the mixed OFDM-QPSK output for the length of 600m

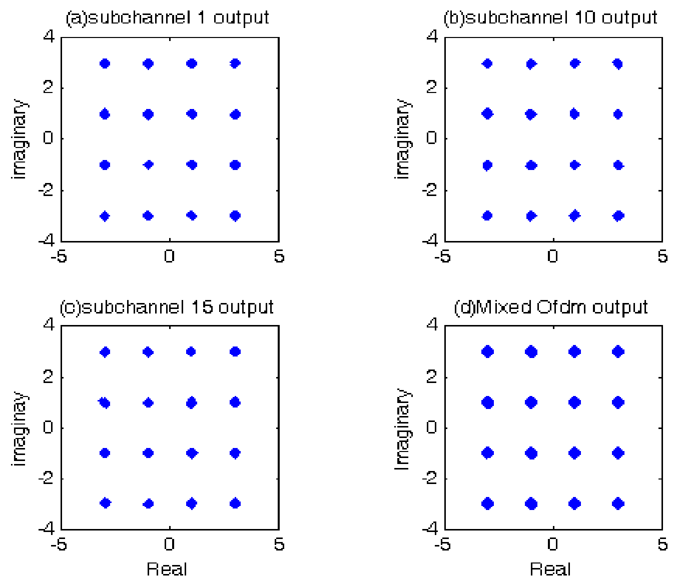


Fig 4.16- Sub-channel constellation scattering and the mixed OFDM-QAM output for the length of 600m

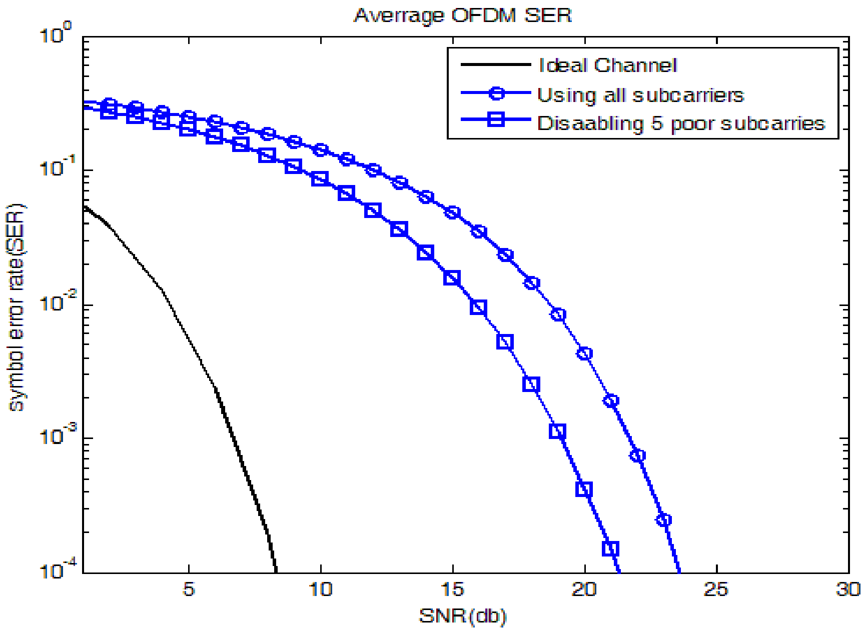


Fig 4.17- Determination of symbol error rate for OFDM-BPSK using all subcarriers and while suppressing some poor subcarriers, when the length is 600m

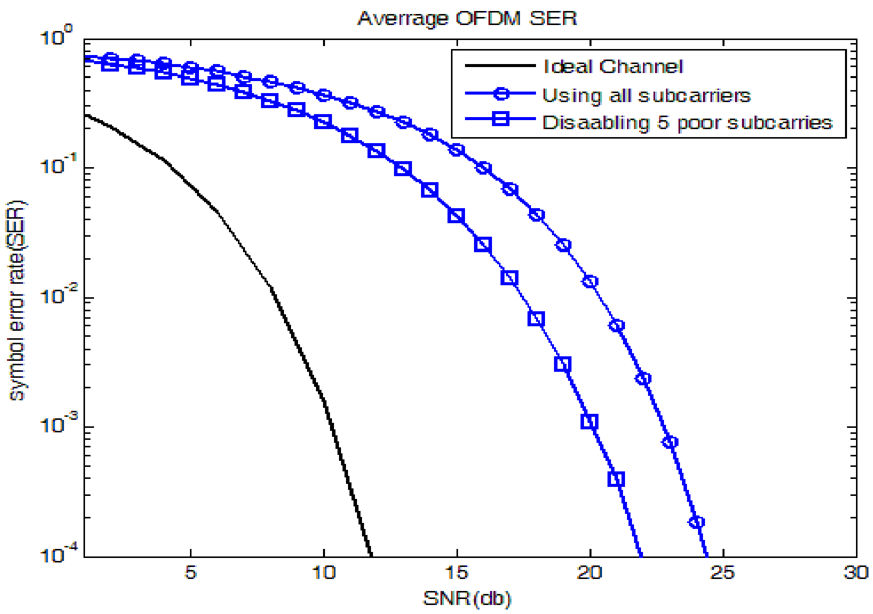


Fig 4.18- Determination of symbol error rate for OFDM-QPSK using all subcarriers and while suppressing some poor subcarriers, when the length is 600m

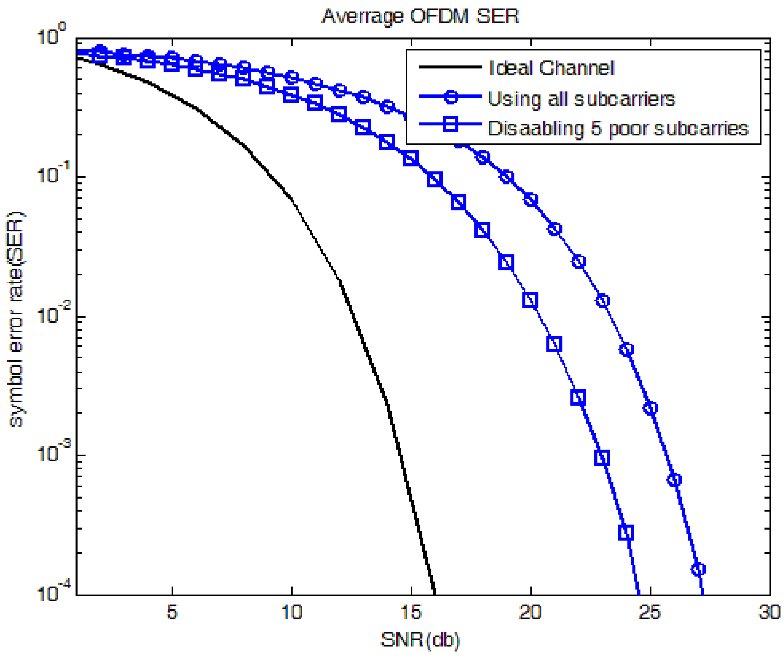


Fig 4.19- Determination of symbol error rate for OFDM-QAM using all subcarriers and while suppressing some poor subcarriers, when the length is 600m

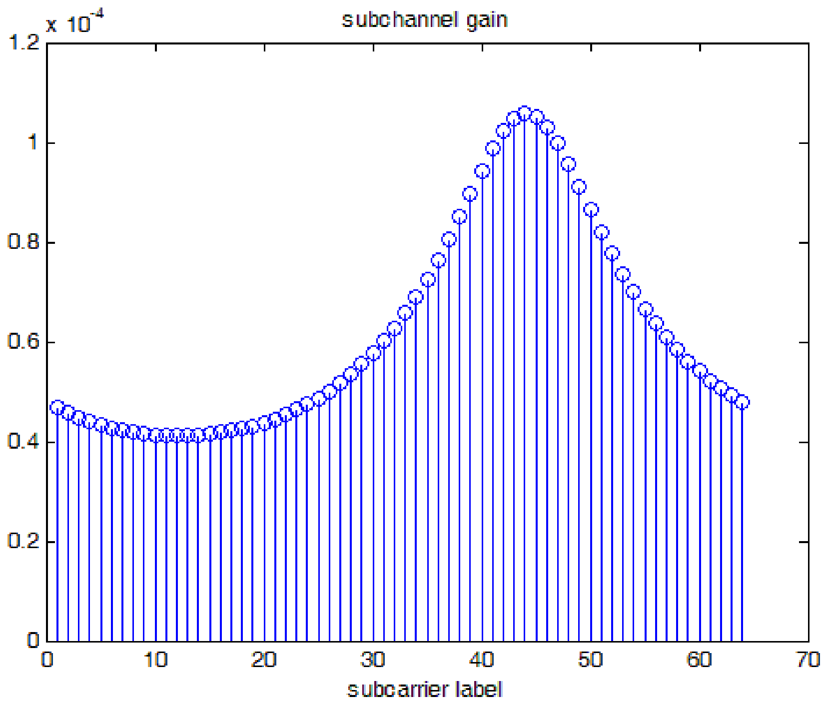


Fig 4.20- Representation of sub-channel gain for the length of 1000m

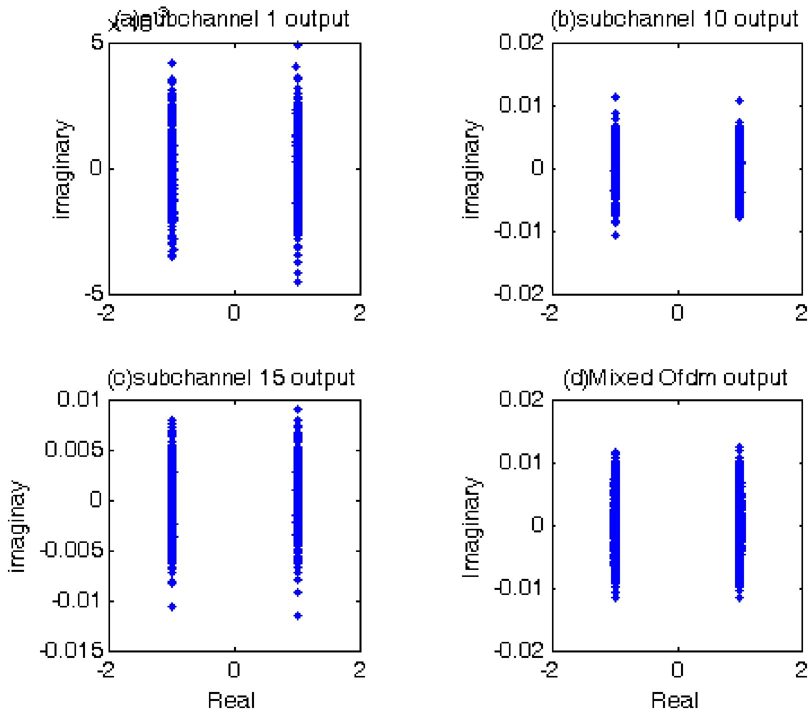


Fig 4.21- Sub-channel constellation scattering and the mixed OFDM-BPSK output for the length of 1000m

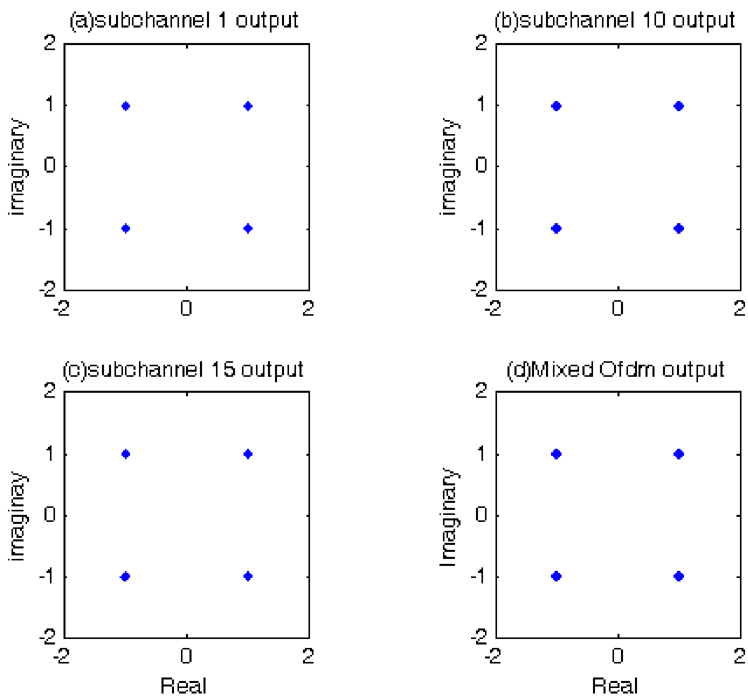


Fig 4.22- Sub-channel constellation scattering and the mixed OFDM-QPSK output for the length of 1000m

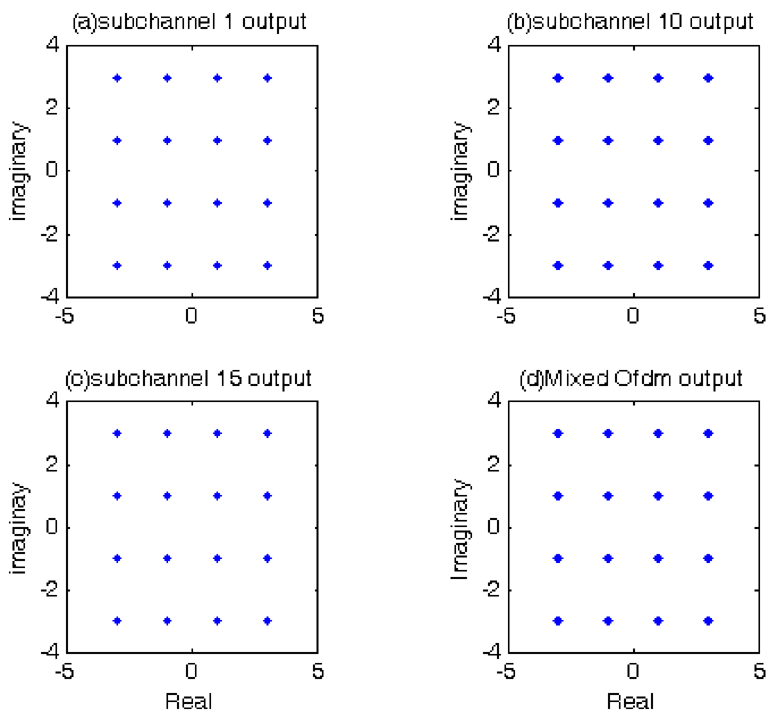


Fig 4.23- Sub-channel constellation scattering and the mixed OFDM-QAM output for the length of 1000m

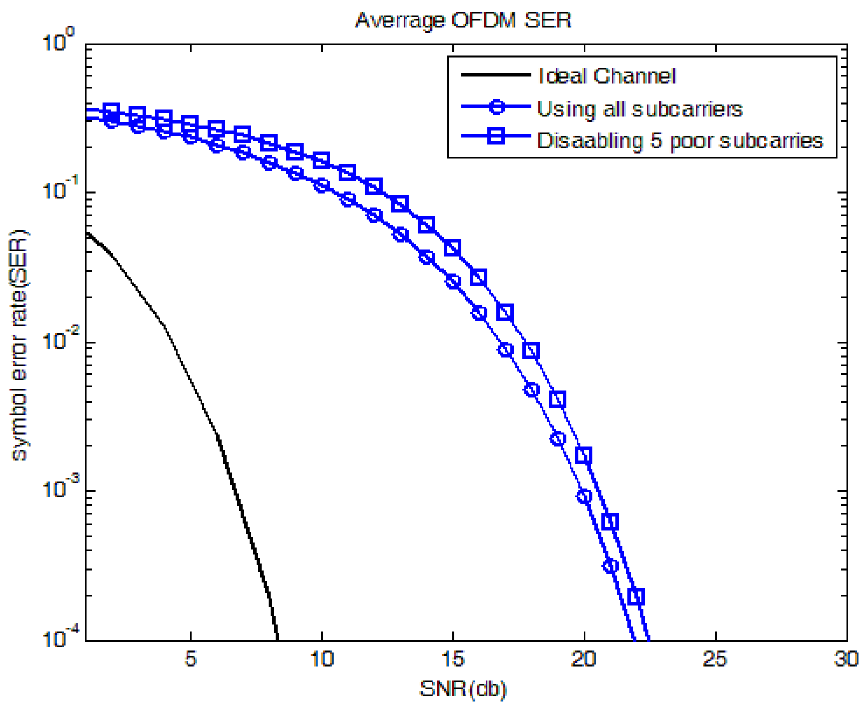


Fig 4.24- Determination of symbol error rate for OFDM-BPSK using all subcarriers and while suppressing some poor subcarriers, when the length is 1000m

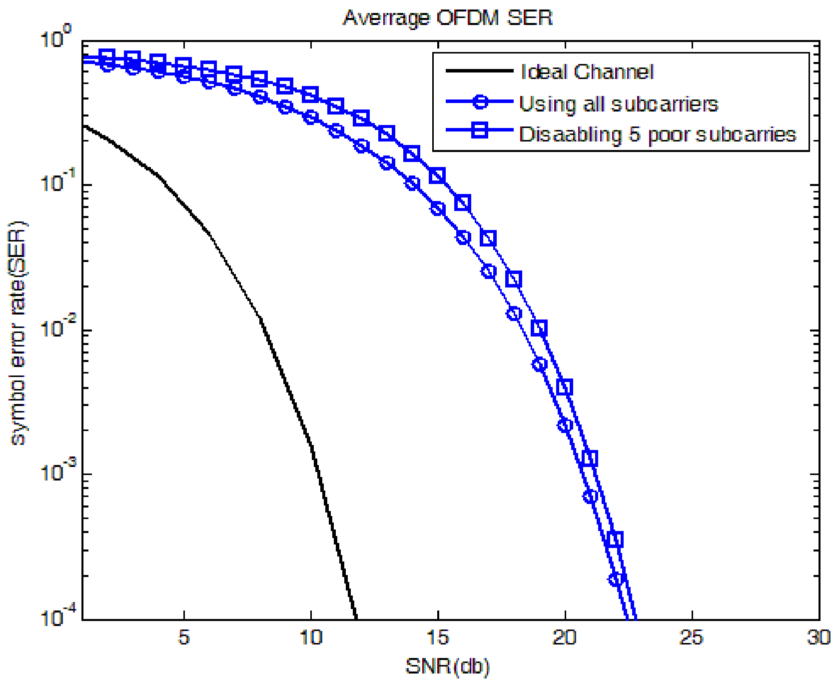


Fig 4.25- Determination of symbol error rate for OFDM-QPSK using all subcarriers and while suppressing some poor subcarriers, when the length is 1000m

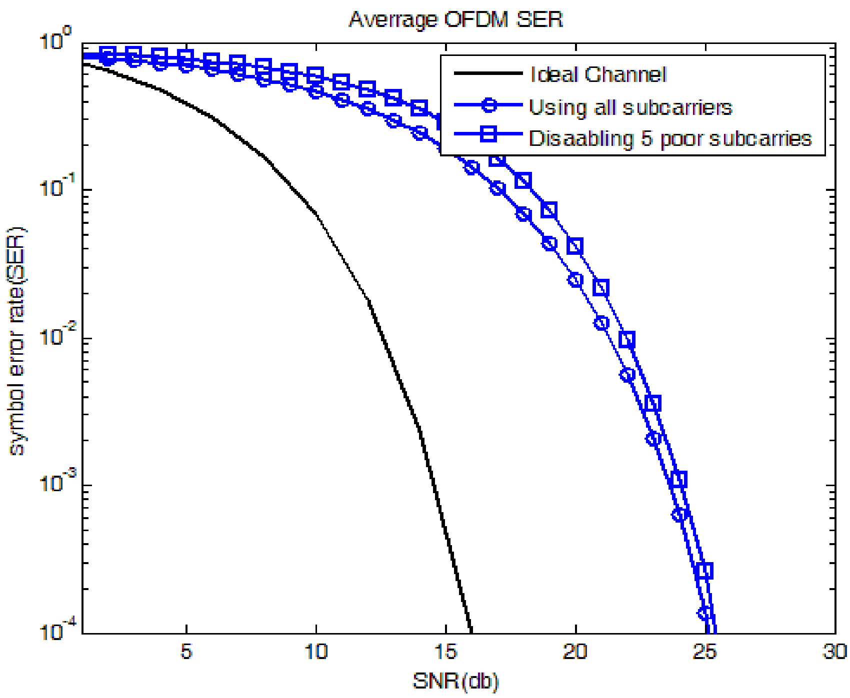


Fig 4.26- Determination of symbol error rate for OFDM-QAM using all subcarriers and while suppressing some poor subcarriers, when the length is 1000m

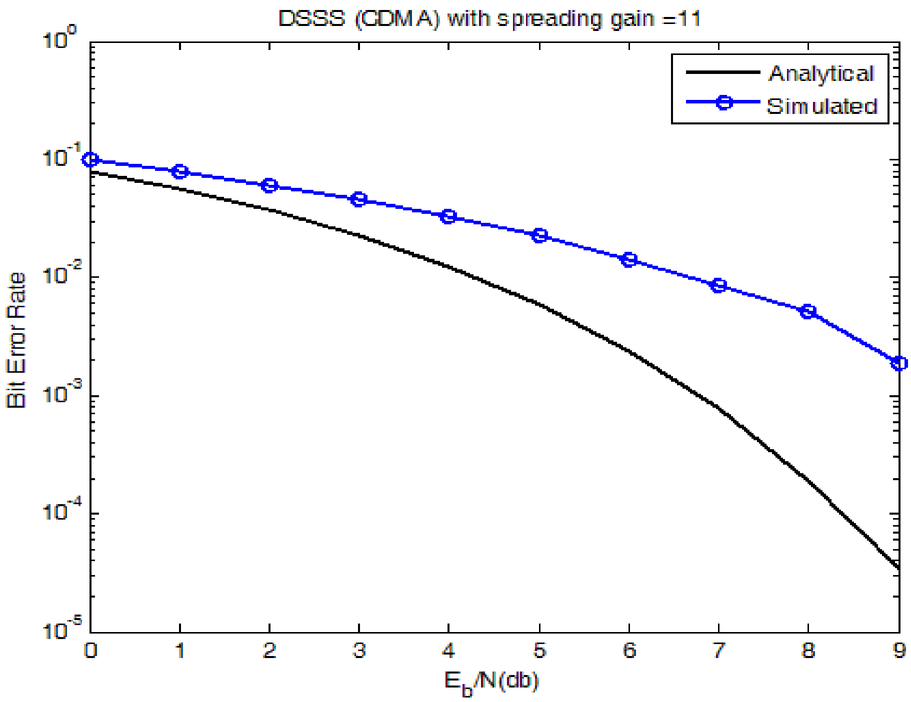


Fig 4.27- Determination of Bit error rate using CDMA-DSSS (BPSK), when the length is 600m

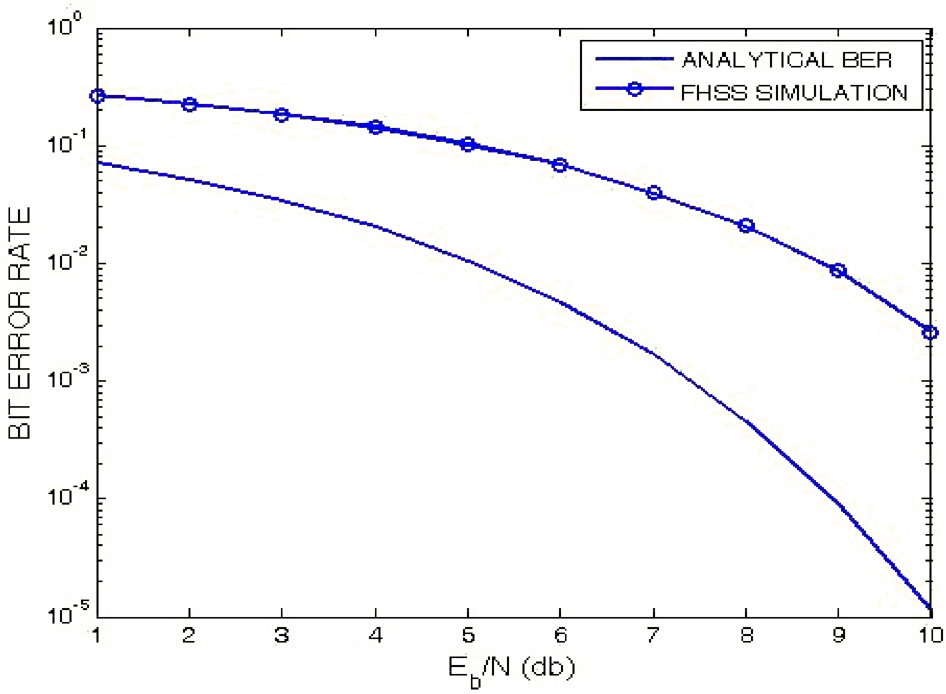


Fig 4.28- Determination of Bit error rate using CDMA-FHSS (BPSK), when the length is 600m

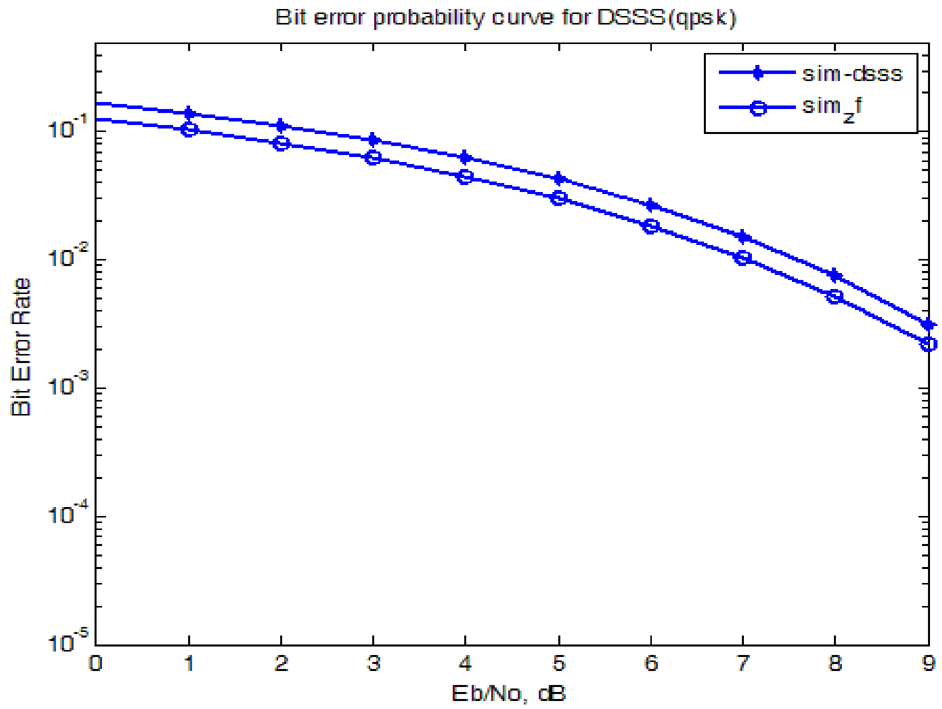


Fig 4.29- Determination of Bit error rate using CDMA-DSSS (QPSK) and using zero forcing equalizer, when the length is 600m

Summary

There is a presence of multiple numbers of technologies which are available and had been used over the period of time for modulating a carrier like ASK, FSK, etc. before the signal is transmitted over the power line cables but with the increasing demand for the higher data rate, robustness and reliability OFDM based BPSK, QPSK, 16-QAM need to be employed. Although a number of technology standards use it but here an attempt has been made to improve the performance a little ahead and also to find out the solution for long time existing problems like power failure and long haul communication.

In this thesis, the utility of Power line communication for smart grid applications has been presented and came to know the various limitation or hardships associated with the channel while requiring the control and management of energy thereafter the verification of the channel performance using different modulations schemes has been performed and finally came up with the solution for the problem associated as the biggest hurdle in the pathway of the sustainability and growth of the communication technique.

A comparison between the performance of channel using different modulation schemes shows that the OFDM is presenting its firmness while requiring speed and endurance whereas CDMA can be more beneficial in case of adverse conditions like power failure since it eliminates the need to switch on to a different modulation scheme.

5

CONCLUSION

5.1 Conclusion

This thesis work is mainly contributed towards the enhancement of the performance of power line channel so as to achieve a better rate, security, reliability and uninterrupted services. Under this context some of the major points are listed below.

- Analysis of the channel model has been made to determine the major factors responsible for the degradation of performance like interference from other means of communication, due to a presence of multiple numbers of branch terminals from where the reflection occurs resulting in multipath scenario, skin effect and dielectric losses.

- Evaluation of Bit Error Rate using different modulation schemes, so as to find the best possible technique is made which is required for the data transmission as this is the most important requirement to accomplish the task of energy management and other services like Broad-Band services.

5.2 Limitations of the work

- There is a trade-off between the performance and the need to switch on to a different modulation schemes in order to ensure that it leads to an uninterrupted means of communication.

- Although there is a presence of multiple number of technologies which usually alters as the application varies and hence still there is not an availability of a standardized technology which could suit if not all but to a group of technologies i.e. there they are not interoperable with each other.

5.3 Scope of Future Work

- Design of interference cancellation technique in multipath scenario.

- Utilization of a fuzzy logic equalization techniques to improve the performance while using CDMA which will eliminate the requirement of switching on to a different modulation scheme in case of power failure and long haul communication.

- The work can be extended to hardware implementation.

- An interface can be provided in between wired and wireless communication to enable services to be uninterrupted with the help of each other.

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