UNIVERSITI PUTRA MALAYSIA

A BROADBAND COOPERATIVE RELAY-BASED SYSTEM FOR POWER LINE COMMUNICATION

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By

AIYELABOWO O. P

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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DEDICATION

To the memories of my late wife, Victoria Omolara Ibikemi Aiyelabowo (nee Ibidun), who died in the course of the programme.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

A BROADBAND COOPERATIVE RELAY-BASED SYSTEM FOR POWER LINE COMMUNICATION

By

AIYELABOWO O. P

October 2018

Chairman : Professor Nor Kamariah Noordin, PhD
Faculty : Engineering

Demand for data for various broadband applications has placed the power line communication (PLC) in a prime place. In PLC, the existing electrical power installation in the last mile is used as the transmission medium, hence no new installation is required.

Since transmission of broadband data was not intended over the electrical power installation, the network (power line) poses a great deal of impediment to broadband data as it traverses the medium. These impediments are, attenuation over the length of the cable, noise (impulsive and Gaussian), and multipath fading. Hence, signals propagation over the line is either received corrupted at the destination or lost out rightly. This work implements a technique to maximize channel capacity, reduce attenuation characteristic, symbol error rate and outage probability in the PLC. Performance of the system is compared with those of MIMO-PLC and PLC-repeaters (PLC-rep.).

In the first instance, the attenuation over the long length of the power line network was combatted. A customized cooperative relaying system, implementing amplify-and-forward (AF) and decode-and-forward (DF), with placement of the relay modem at three different locations along the network in the PLC was developed. A noise mitigation system was incorporated to improve the system's bit error rate (BER). The systems' performance for channel capacity improvement between 18.32% and 73.5% and 144% and 260% over the MIMO-PLC and PLC-rep. was achieved for AF and DF schemes respectively. SER reduction on the PLCC AF and DF are 43.41% and 85.16% over the MIMO-PLC and 69.26% and 91.9% over the PLC-rep., while outage probability reduced by 96.2% and 99%. Attenuation reduction to 31.4%

was achieved with the DF link when the relay was placed 10 m away from source node.

To achieve performance maximization inspite the branches on the network, PLCC multiple relaying scheme, having three different multiple relay scenarios was arrayed. Selective relaying, implementing best relay channel instantaneous SNR, was deployed for AF and DF, hence, best relay is selected. Selective relaying improved the system's channel capacity by 201%, 303% and 70.6% over MIMO-PLC, PLC-rep. and PLCC (fixed) respectively. Owing to the noise mitigation system, the SER reduced 400% over the duo of MIMO-PLC and PLC-rep. and by 79.37% over the PLCC (fixed) schemes. Outage probability achieved a land marking drop over the benchmark links and 87.5% over the PLCC (fixed) link. Further reduction in attenuation was achieved to 64.1% with the 7 relay DF deployment.

Finally, to keep the system's maximized performance within the electromagnetic compatibility framework, optimal power ratio was developed for optimal power allocation between source and relay modems. Objective function for maximizing and minimizing the direct and cooperative transmission power was developed for optimal power ratio. The optimal power allocation (OPA) algorithm allocates one-third and two-third of the transmitted power (Pt) to the source and relay modems, direct and cooperative transmissions respectively. Channel capacity improved by 274% and 44.37% over the MIMO-PLC and equal power allocation (EPA) scheme and achieved 457% improvement over the PLC-rep. SER with OPA reduced drastically over the benchmark links and 76.1% over the EPA scheme, while outage probability further reduces with OPA largely over the benchmark links and 90% over the EPA. The attenuation reduction is also prominent with the OPA scheme. The abstract is a digest of the entire thesis and should be given the same consideration as the main text. It does not normally include any reference to the literature. Abbreviations or acronyms must be preceded by the full term at the first use.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

SISTEM KOMUNIKASI KOOPERATIF JALUR KUASA BERASASKAN GEGANTI JALUR LEBAR

Oleh

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Pengerusi : Profesor Nor Kamariah Noordin, PhD
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Tuntutan data untuk pelbagai aplikasi jalur lebar telah meletakkan komunikasi jalur kuasa (PLC) di tempat yang paling penting. Dalam PLC, pemasangan kuasa elektrik sedia ada dalam perbatuan terakhir digunakan sebagai wadah transmisi, oleh itu pemasangan baru tidak diperlukan.

Oleh kerana transmisi data jalur lebar tidak dirancang untuk pemasangan kuasa elektrik, jaringan (jalur kuasa) memberi rintangan yang besar kepada data jalur lebar oleh kerana ia mengharungi medium tersebut. Halangan-halangan ini termasuk pengecilan pada panjang kabel, hingar (impulsif dan Gaussian), dan pemudaran pelbagai laluan. Oleh itu, penyebaran isyarat ke atas jalur tersebut sama ada diterima dalam keadaan yang korup di destinasinya atau hilang sama sekali. Kajian ini melaksanakan satu teknik untuk memaksimakan kapasiti saluran, mengurangkan ciri-ciri pengecilan, kadar ralat simbol dan kebarangkalian gangguan dalam PLC. Prestasi sistem dibandingkan dengan sistem MIMO-PLC dan pengulang PLC (PLC-rep.).

Dalam contoh pertama, pengecilan ke atas jaringan jalur kuasa yang panjang cuba diatasi. Satu sistem geganti yang direkacipta khas, yang menggunakan amplify-and-forward (AF) dan decode-and-forward (DF), dengan meletakkan modem geganti di tiga lokasi yang berbeza di sepanjang jaringan di PLC telah dibangunkan. Satu sistem pengurangan hingar telah digunakan untuk memperbaiki kadar ralat bit sistem (BER). Prestasi sistem untuk penambahbaikan kapasiti saluran di antara 18.32% dan 73.5% dan 144% dan 260% ke atas MIMO-PLC dan PLC-rep. telah dicapai untuk skim-skim AF dan DF. Pengurangan SER ke atas PLCC AF dan DF adalah 43.41% dan 85.16% ke atas MIMO-PLC dan 69.26% dan 91.9% ke atas PLC-rep., sementara

kebarangkalian gangguan dikurangkan sebanyak 96.2% dan 99%. Pengurangan pengecilan kepada 31.4% dicapai dengan pautan DF apabila geganti diletakkan 10 m daripada nod sumber.

Untuk memaksimakan prestasi walaupun terdapat cabang-cabang pada saringan, skim pelbagai geganti PLCC, tiga senario geganti telah disusun. Geganti selektif, yang menjalankan SNR segera saluran geganti yang terbaik, telah digunakan untuk AF dan DF, oleh itu geganti terbaik telah dipilih. Geganti selektif memperbaiki kapasiti saluran sistem sebanyak 201%, 303% dan 70.6% merentas MIMO-PLC, PLC-rep. dan PLCC (tetap). Disebabkan oleh sistem pengurangan hingar, SER berkurangan 400% merentas kedua-dua MIMO-PLC dan PLC-rep. dan sebanyak 79.37% merentas PLCC (tetap). Kebarangkalian gangguan mencapai satu kejatuhan yang ketara ke atas pautan penanda aras dan 87.5% ke atas pautan PLCC (tetap). Pengurangan lanjut dalam pengecilan telah dicapai kepada 64.1% dengan penggunaan 7 geganti DF.

Akhir sekali untuk mengekalkan prestasi maksima sistem dalam rangka kerja kesesuaian elektro magnetik, nisbah kuasa yang optima telah dibangunkan untuk mendapatkan pembahagian kuadsa yang baik di antara modem sumber dan modem geganti. Kefungsian objektif untuk memaksima dan meminimakan kuasa transmisi yang langsung dan koperatif telah dibangunkan untuk nisbah kuasa yang optima. Algoritma optimal power allocation (OPA) memperuntukkan satu pertiga dan dua pertiga kuasa yang dihantar (Pt) kepada modem sumber dan geganti serta penghantaran langsung dan koperatif. Kapasiti saluran bertambah baik sebanyak 274% dan 44.37% merentas MIMO-PLC dan peruntukkan kuasa yang sama banyak (EPA) dan mencapai 457% peningkatan ke atas PLC-rep. SER dengan OPA berkurangan secara drastik merentas pautan penanda aras dan 76.1% merentas skim EPA, sementara kebarangkalian gangguan terus berkurangan dengan OPA merentas pautan penanda aras dan 90% merentas EPA. Pengurangan pengecilan juga ketara dengan skim OPA.

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For all who have been an inspiration to me, I say thanks so much.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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AF	Amplify-and-Forward
AMR	Automatic Meter Reading
AV	Audio and video
AWGN	Additive White Gaussian Noise
BEP	Bit error probability
BPL	Broadband power line
CC	Channel capacity
CDF	Cumulative Density Function
CF	Compressed and-forward
CM	Common Mode
CNR	Carrier-to-noise ratio
CPE	Customer Premises Equipment
CSI	Channel State Information
CTF	Channel Transfer Functions
CTP	Cooperative transmission protocol
CTS	Clear-To-Send
DF	Decode-and-forward
DTF	Discrete Fourier Transform
DMT	Diversity Multiplexing Trade-off
DSL	Digital subscriber line
DSSS	Direct Sequence Spread Spectrum
D-STC	Distributed Space Time Code
e2e	End-to-end
ECC	Error Control Coding
EMC	Electromagnetic compatibility
EPA	Equal power allocation
ERC	Equal Ratio Combining
ESNRC	Enhanced Signal to Noise Ratio Combining
FAF	Fixed Amplify-and-Forward
FDF	Fixed Decode-and-Forward

FER	Frame Error Rate
FFT	Fast Fourier Transform
FRC	Fixed Ratio Combining
GMSK	Gaussian Minimum Shift Keying
HE	Head End
HPAV	Homeplug Audio and Video
IDFT	Inverse Discrete Fourier Transform
IEEE	Institution of Electrical Electronics Engineering
IFFT	Inverse Fast Fourier Transform
LV	Low Voltage
HV	High Voltage
MAM	MIMO Artificial Mains
MIMO	Multiple Input Multiple Output
MRC	Maximum Ratio Combining
MV	Medium Voltage
NBS	Nash Bargaining Solution
OFDM	Orthogonal Frequency Division Multiplexing
OPA	Optimal Power Allocation
PDA	Personal Digital Assistant
PER	Packet Error Rate
PHY	Physical Layer
PL	Power Line
PLC	Power Line Communication
PLCC	Power Line Cooperative Communication
PSD	Power Spectral Density
PSK	Phase Shift Keying
QAM	Quadrature Amplitude Modulation
RS	Reed-Solomon
RTS	Request-To-Send
SAF	Selective Amplify-and-forward
SDF	Selective Decode-and-forward
SDV	Singular decomposition Value
SEP	Symbol Error Probability

SER	Symbol Error Rate
SISO	Single Input Single Output
SNR	Signal-To-Noise Ratio
SNRC	Signal to Noise Ratio Combining
SPLCC	Selective Power Line Cooperative Communication
VNA	Vector Network Analyser

CHAPTER 1

INTRODUCTION

An issue in the research world across all fields of engineering and economics is the numerous recurring challenges of achieving a balance between supply and demand. The upsurge in data requirements for various applications is such a challenge. Although various technologies have been deployed for this data requirement, it is still not matching or adequate for the demand. This technologies include wireless and wired. Due to cost of deploying these technologies, some potential consumers could not afford it. Another technology which is readily affordable, owing to its channel presence at the consumer end, is already deployed for the data provision. This technology is the power line communication (PLC) system, which utilizes the electric power network as its channel for broadband data transmission.

However, because the channel was not intended for broadband data transmission, the channel poses a severe challenge to signal propagating through it. These challenges ranges from attenuation, multipath fading and noise corruption. This necessitates the need for channel capacity maximization.

1.1 Background

Consequent upon the demand of broadband data for various applications, several technologies have been deployed for its provision. The technologies used for the provisions of applications in education, health, entertainment, gaming, advertising, business and home networking includes wired, wireless and satellites. Various methods of wired provision and their characteristics is specified in Table 1.1.

Table 1.1 : Transmission Media Comparison

Type	Distance(m)	Bandwidth (Mbps)	Active Device (Investment)
UTP Cat-5	100	100	Low
UTP Cat-6	100	1000	Low
Coaxial	1000	200	Low
Fiber MM	550	10000	Medium
Fiber SM	20000	10000	Medium

The demand for broadband data continues to increase as areas of application expand. This led to the consideration of the power line network for further provision of the broadband data, owing to its ubiquitous characteristics. The technology that implements the power line network for communication purpose is called power line communication (PLC). It performs the function of transforming the standard electric power network into a communication network pathway. Thereby propagating narrowband/broadband information over the entire length of the PL onto all devices connected to the grid/network and to all outlets [1], [2], [3], [4], [5]. In PLC, the existing house wiring is utilized as medium for broadband internet access provision. Thus, no new cable installation is required for achieving high-speed internet access, as it is achieved on every electrical outlet in the house.

Two architectures are achieved in PLC, these are narrowband [6], [7] and broadband [8] architectures. Frequency spectrum in narrowband architecture in Europe spans from 3 kHz to 148.5 kHz and in the US, can be above 500 kHz. It is designed to cover 1 km maximum distance and yields a data rate in the range kbps, [9], [10]. The frequency spectrum of the broadband architecture is wider, it spans from 1 MHz to 30 MHz, where outdoor and indoor applications makes use of 1 to 15 MHz and 15 to 30 MHz respectively. Data rates in this architecture is up to 300 Mbps [11]. Various modulation schemes have been deployed in high-speed PLC systems. These schemes are; Gaussian Minimum Shift Keying (GMSK), Direct Sequence Spread Spectrum (DSSS) [12], and Orthogonal Frequency Division Multiplexing (OFDM) [13], [14]. However, the OFDM scheme, for its robustness to selective fading multipath and different kinds of interference [15], was adopted for PLC.

1.1.1 Applications of PLC

The two obvious application of the PLC are; Power Line Outdoors Telecoms and Power Line Indoor Telecoms.

Power Line Out-door Telecoms contains Automatic Meter Reading (AMR). This is the reading of the power meter over the power grid homes to substation. It operates over the medium voltage (MV) levels at data rates that is low-level, 600 kpbs - 2.4 Mbps. Outdoor application in PLC is in the narrowband architecture, it comprises single directional communication for public light remote switching and bi-directional communications. Activities in bi-directional communication are meter reading and various home automation applications.

Power Line In-door Telecoms involves data communication in a local area (home). This data communication is carried out on home power grid and operates on the low-voltage (110V – 240V) lines, having data rates of 14 – 30

Mbps. PLC technology in the indoor covers a wide range of applications for, voice, multimedia, video and home networking.

1.2 Problem Statement

The deployment of power line communication (PLC) system has the capacity of maximizing broadband data provision to teaming population owing to its pervasive installation. However due to the nature of its medium, which includes, long length, branches across its length, the line's time varying characteristic and load terminations to mention a few, signal transmission through it suffers enormous degradation [16]. Hence, there is a need to develop a system that will in spite of all these challenges will render good system performance. Moreover the signal degradation increases with increase in the length of the channel, as its behaviour is time varying, this weakens the signal as it traverses the line. Therefore, there is need for a system which optimizes the system's performance over the entire length of the line. PLC is governed by the policy of electromagnetic compatibility (EMC), which streamlines the transmittable power in PLC. Thus, transmittable should also be optimized for increased system performance. In lieu of this, this thesis addresses the following problems;

1. In PLC, power line network is converted to a pathway for broadband data. Due to the characteristic of this medium (power line), signal is attenuated at both the medium and low voltage levels. These attenuations amounts to 100 dB/km and 10 dB/km on the low and medium voltage levels, respectively. Thus, in conventional PLC systems, the signal is severely attenuated and this attenuation increases over the vast length of the cable [17], [18], [19]. Researchers have proffered several techniques for the mitigation of the PLC attenuation characteristics. On the low voltage networks, repeaters were deployed to lessen the effect of signal attenuation. Further deployment of the repeaters were performed in the last mile to remedy the effect of this signal loss [20]. Multiple Input Multiple Output (MIMO) techniques were recently adapted to PLC systems for the purpose of achieving performance improvement in channel capacity. This was applied at indoor single phase and outdoor three phase levels [21], [22], [23], [24]. The best possible configuration of MIMO-PLC in the indoor application is the 2 x 2, since most indoor installations are single phase 3-wire, comprising three conductors, live, neutral and ground (earth) respectively [21]. The MIMO-PLC is challenged by its restriction to a 2 x 2 antenna configuration. A scheme is required that will yield unrestricted PLC system performance maximization with reduction in noise, which characterizes the MIMO-PLC system.

2. Managing the attenuation on short power line can be easily achieved, but the problem becomes more vast and difficult to manage as the length of the line increases within the house environment. The effect of the attenuation is further made worsen as branches on the line increases, this results in transient behaviour of the line. So the nature of the line is not same all through its length. Hence attenuation effect is severe at some points than other points on the line. There is need for a system that will consider the characteristic of the line and then select the best channel for signal transmission. Thus achieving good system performance despite the length and varied characteristics of the branches on the line.

3. Increasing transmittable power always maximize the performance of a communication system, but in PLC system, there is restriction of transmittable power, this is regulated by electromagnetic compatibility (EMC) policy. Then, if the channel is not attenuation free, this limited power will be wasted over the noisy and harsh medium. Therefore, there is a need for effective power allocation to optimize the transmittable power as the signal traverses from the source to the destination over the power line channel.

1.3 Research Aims and Objectives

To deploy broadband data to all cronies and cranny effectively and efficiently goes beyond just provision but to maximizing the performance of the deployed technology. The PLC system must be seen to perform efficiently over the entire length of its channel with little or no attenuation of signal as it propagates from the source to the user in the destination. Noise inherent in channel and those from the surroundings must be mitigated for quality signal flow over the PL channel. The aim of this Thesis is to develop a technique for PLC that will ensure signal transfer from source to destination on the PLC channel, holistically, efficiently and devoid of severe attenuation, thus maximizing capacity and achieving interference and noise mitigation under an EMC power restriction. Therefore, achieving these aim requires this studies;

- To propose a power line cooperative communication system (PLCC), implementing amplify-and-forward and decode-and-forward protocols on the power line channel that will achieve performance maximization despite the network's attenuation characteristic.
- To investigate the principle of best relay selection algorithm and testing it for PLCC performance maximization over the varied characteristic of the network's branches.
- To investigate and obtain a power allocation ratio that will yield optimal power line cooperative communication (PLCC) system's performance while being within the EMC framework.

1.4 Research Questions

Resolving the aforementioned problems in the PL network for the PLC system and achieving maximal performance in terms of channel capacity and reduction of outage probability requires the formulation of these questions

1. How is the power line network characterized in literature and what are the parameters that are responsible for the harsh behaviour of the network to broadband data. Furthermore, what techniques can be deployed to mitigate the effects of these parameters of posing attenuation to signals on the network?
2. Taking into consideration the time variant nature of the network and loads termination, how can the network perform optimally over the entire length of the network? What technique can be developed to ensure that signal strength is maximum all through the cables length?
3. With the EMC policy that restrict the amount of power usage in PLC, what optimal power algorithm can be used for power allocation that will maximize the PLC system's channel capacity for effectiveness on the PL channel?

1.5 Motivation

The aim of home networking is to interconnect all digital electronic consumer devices in the home territory, so that data and services are accessed anytime, anywhere by consumers in the home domain irrespective of the location where the electronic device housing the data or service is domiciled.

Amongst the several links implemented in the market for home networking are wired network such as Ethernet, iLINK or USB and several wireless networks. All of these links are limited in their coverage area, performing excellently and efficiently for single room and local clusters. These limitation makes these links inappropriate for room-to-room connections. The data throughput of wireless connection at ISM (Industrial, scientific and medical) frequencies (2.4 GHz), reduces dramatically in situations when signal is required to penetrate through walls and ceilings made up of concrete. For wired networks, the major challenge is its inconvenience in inter-room connections.

In-home backbone, which connects individual devices and clusters in the home domain at a minimum installation effort, can enable the broadband throughput of the room-to-room connectivity. This is provided for by the PLC system. In PLC system, modern modulation techniques are implemented on the PL network to aid high-speed data services. The provision of home networking using PLC is shown in Figure 1.1.

The consumer electronic devices are connected to the mains via a PLC modem. Tablets, a wireless device, is connected via the PLC access point. Television signals are recived by the Satellite dish positoned on top of the house, it then distributes to the consumers within the building. Video signals of activities around the building premises are captured by the camera or the baby monitor for display.

Power line networking provides huge gain consumer comfort. It has also the advantage of efficiently performing internet access delivery. In urban and industralised nations, Digital Subscriber Line (DSL) access via phone lines is often used for the deployment of this internet access, only a few number of customers can connect to this lines, but with the PLC, much more access is provided.

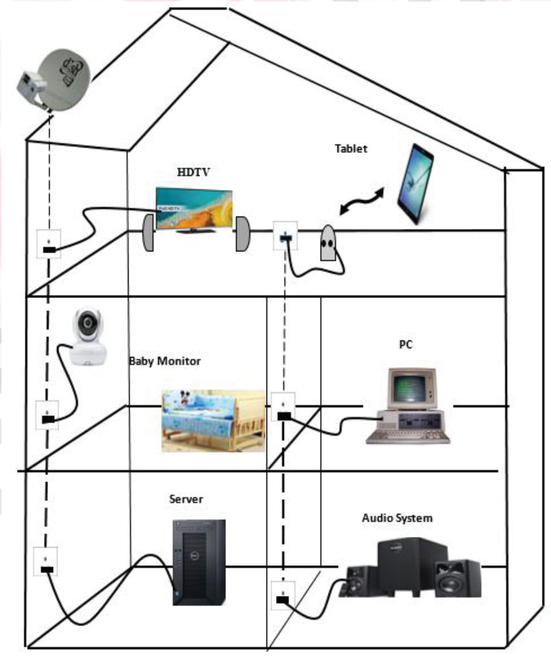

Figure 1.1 : In-house PLC applications

For the ubiquituos nature of the PL network, PLC is the choice for the provision of internet access in the rural areas where xDSL is not deployed and remote places where no tellecommunication network exists.

Automatic meter reading (AMR), a narrowband architecture PLC, allows new and flexible billing system, which requires no standby power generator, as the PLC is used for the AMR.

The World Bank report published in year 2018 puts the rural population in Malaysia 24.2% in 2017, undeniably, this population is not provided with wireless broadband. Malaysian electricity coverage is 99.4%, this implies that almost the entire population is provided with electricity supply (power line installation) [25]. Implementing PLC will meet the broadband data need of the population for various applications at a very low cost (no installation cost), since the existing electrical installation will be used.

1.6 Research Scope

Power line communication comprises of two architectures namely, narrowband and broadband and in terms of application, outdoor and indoor.

The scope of this thesis is the broadband, covering 1 MHz to 30 MHz. The methodology in this thesis was performed on the medium access of control (MAC) layer of the PLC, that is, maximizing performance of the system as the PLC base-station propagates signal to the PLC destination modem. The red highlighted section in Figure 1.2 depicts the scope of the research study.

A power line network of 20 m length was considered for the work.

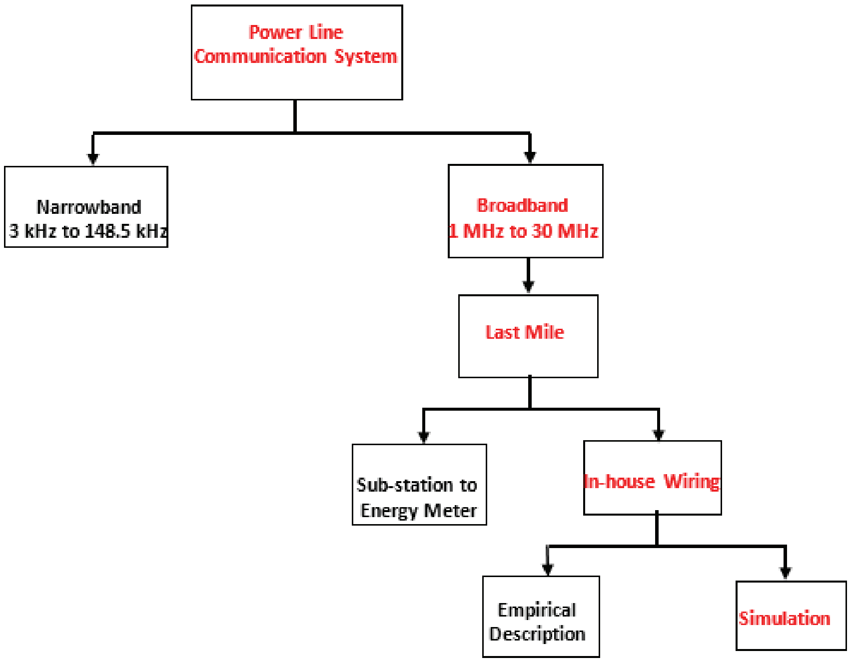

Figure 1.2 : Research scope description

As shown in the Figure, the method of system performance evaluation is simulation using Matlab package.

Furthermore, the in-band full duplex situation was adopted on the power network, the line used for both transmission and reception.

1.7 Assumptions

The following assumption were made to achieve the set objectives in this thesis;

- There were 20 numbers of branches (taps) on the power line network considered.
- All cables in the network have the same characteristics.
- PLC source modem is PLC base-station.
- Same noise characteristic is experienced throughout the network.

1.8 Research Contribution

The highlights below are the summary of the contribution of this thesis on the power line cooperative communication (PLCC) system.

- Power line cooperative communication (PLCC) system, with noise mitigation system was developed and introduced. This system implements cooperative techniques of AF and DF to achieve reliability of the PLC system. This noise mitigation system was used to reduce the BER on the power line channel. The two cooperative protocols (AF and DF) achieved PLC performance maximization over the length of the power line network in increased channel capacity, reduction in symbol error rate and outage probability than the other techniques in literature.

- To further achieve improvement in the system's reliability over the numerous branches of the power line network, selective relaying on the PLCC system was proposed. A selection algorithm using instantaneous SNR was proposed and implemented. Thus, the relay node with the best instantaneous SNR was selected for cooperation with the destination node. The selective cooperation links, SAF and SDF for 3-R scenario achieved a laudable improvement over the fixed relaying, MIMO-PLC and PLC-repeater links. Symbol error rate and outage probability on same links and relay scenario yielded and enormous improvement too.

- For the transmittable power restriction in the PLC due to electromagnetic compatibility, an optimal power allocation algorithm, which allocates more power for the cooperative transmission to a chosen relay node was proposed to improve the performance of the SPLCC system. For the 3-R scenario, the channel capacity was increased on the SAR link, symbol error rate and outage probability reduced drastically with optimal power allocation (OPA) algorithm over the EPA algorithm, MIMO-PLC schemes and PLC-repeater.

1.9 Thesis Organization

A short introduction to the research area (PLC), which include the problem statement and study objectives, is presented in this Chapter. Research questions, which serves as a lead into the work, the driving force (motivation) and scope of the research were also highlighted. Other Chapters of the thesis are organized as follows;

In Chapter 2, literatures associated with the PLC are reviewed. This review covers the modelling of the power line characteristics and its inherent noise. Research activities performed to maximize the performance of the PLC were also reviewed, which include MIMO-PLC and PLC repeaters. The Chapter also has reviews on cooperative relaying in wireless communication and cooperative relaying in power line environment.

The methodologies of the three objectives described in Chapter 1 were presented in Chapter 3. The Chapter has three major sections namely, power line cooperative communication (PLCC) system, selective PLCC system and investigation and determination of best power ratio allocation for optimal performance. All these methodologies implement Amplify-and-forward and decode-and-forward cooperation protocols.

In Chapter 4 the results of the schemes proposed in chapter 3 were benchmarked with those in literature (MIMO-PLC and PLC repeaters). The Chapter further discusses the performance maximization of the various proposed system with the existing system in literature. Channel capacity, symbol error rate, outage probability and attenuation are the parameters used for system performance evaluation.

The summary of the thesis, followed by the salient contribution were presented in Chapter 5. Finally, research issues in the PLC are highlighted and direction is suggested for further investigation.

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LIST OF PUBLICATIONS

International Refereed Journals

Aiyelabowo, O. P., Sali, A., Samsul, B. N., Noordin, N. K. (2016), 'Performance Evaluation of Power Line Cooperative Communication System', *International Journal of Computer Science and Networks (IJCSN)*, vol. 2, Issue 6, pg. 893 - 906, ISSN: 2277-5420(Elsevier-indexed) (IF: 1.02).

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Submitted Article

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