Experimental Investigation Of Data Transmission Using Powerline Communication

Capstone Project Report

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Abstract:

Powerline Communication (PLC) has emerged as a promising technology for data transmission, offering a cost-effective and versatile solution for various applications. The primary objective of the project is to assess the performance of PLC network through the development of experimental setups using PLC adapters. The study tests PLC under different scenarios in real-world conditions. As a result of this project, conclusions were made whether the performance of PLC network is comparable to that of Ethernet network.

Contents

Preface

I would like to express sincere gratitude to my supervisor Refik Kizilirmak who provided guidance and encouragement throughout this project. Most importantly, I dedicate this research to the global community, with the hope that it will contribute to the ongoing dialogue and development of PLC technology, ultimately bringing us closer to a more connected and digitally inclusive world.

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Chapter 1

Introduction

In the era of information technology, which is rapidly becoming an integral part of our lives, the need for the ability to constantly be connected is high. Therefore, it becomes necessary to explore and utilize innovative technologies that will ensure efficient and smooth communication. In this regard, Power Line Communication (PLC) acts as a promising technology that will make it possible to transfer information.

PLC technology is a technology that uses existing electrical networks as a means to transmit a signal. Power lines were originally designed to transmit electricity. However, the development of cutting-edge technology has made it possible to use these lines as a cost-effective and efficient means of transmitting information [1],[2].

The development of PLC technology has a long history. The idea of using existing power lines as a way to transmit information appeared at the beginning of the 20th century [3], [4]. In the early days, PLC technology faced problems such as high noise levels and low data transfer rates. By the end of the 1980s, PLC modems with complex coding techniques appeared on the market [5]. PLC standards have continually evolved over the years, resulting in digital transmission lines by the end of 1994. PLC technologies have emerged as a promising solution to provide efficient and inexpensive Internet access for customers [6], [7]. Since the 2010s, the role of PLCs in modern connection technologies has increased significantly: PLCs began to be used in smart grid networks to provide two-way communication and energy management [8],[9],[10].

The underlying principle of PLC is related to the transfer and modulation of the data through the devices. In this process, the data is being turned into modulation at the transmitter and then the modulated signal is passed over the AC or DC power supply voltage [11]. At the receiver, the data is extracted with the help of applying filter to cut off the modulated signal and the power supply voltage; then the signal is demodulated [12]. PLC is mostly implemented in AC lines, however, it is a flexible method that can also be adopted for DC lines like the power stations are storage batteries, lightening, EV charging, and other such counterparts.

PLC network features variety of the benefits that contribute to its wide usage level. The repurposing of existing power wiring infrastructure is one of the benefits of this approach, as it avoids additional wiring dedicated to the application. This not only reduces installation costs but also improves scalability and the flexibility in deploying the systems that are communication based [13]. With PLC it is possible to transmit data over long distance without needing cables to be extensive and hence it is very suitable in circumstances where it is difficult or impractical to lay new wires. On top of that, PLC can develop the link reliability in places with fragile wireless coverage resulting in the solid communication process. The versatility of this technology finds its application in various settings, such as smart homes and industrial automation, as well in electric vehicles chargers, demonstrating its adaptability at different tasks [14],[15],[16],[17]. To summarize, Powerline communications offer high efficiency and low cost-effectiveness alongside being adaptable, hence a reliable and convenient means of data transmission.

The main objective of this research project is to develop experimental setups using Ethernet cable and Powerline Communication modems and determine whether the performance of powerline network is comparable to that of Ethernet network. To achieve this goal, experiments were carried out in real home conditions. This will result in gaining valuable information about the reliability of the PLC technology and overall efficiency. Understanding the strengths and potential limitations of PLC is critical to determining its applicability and competitiveness compared to conventional communication methods.

The rest of the paper is divided into the following sections: Section II contains Background information about PLC communication technique. Section III brings closer to the methodology of the experiments followed by Section IV including first results, obtained using PLC modems, and discussion of the results. Section V summarized our obtained results and contains conclusion.

Chapter 2

Background

The potential of PLC systems has attracted significant attention in the communications industry due to the benefits they offer to the end user. Therefore, various researchers worldwide have conducted thorough studies of PLC systems. This part of the report will discuss detailed background information on PLC systems, specifically, communication protocolcs and standards used in PLCs, as well as PLC systems used in home communications networks. The discussion continues with challenges and limitations of PLC that can negatively affect signal quality. Moreover, this section introduces the existing literature, explaining the experimental work that has been conducted by researchers and presenting new study perspectives for us.

One of the crucial areas in PLCs is assembling and testing different communication protocols to ensure maximum data throughput over already deployed power networks. Among the wide range of protocols, the HomePlug AV and IEEE 1901 stand out as prominent standards for home networking [18],[19],[20]. HomePlug AV is one of the important protocols that have been in subsequent releases for better performance and reliability. HomePlug technology operates on the principle of orthogonal frequency division multiplexing (OFDM), which ensures reliable and efficient data transmission [21]. Numerous studies have examined the performance and reliability of HomePlug-based PLC systems in home environments. For example, a study by [22] evaluated the throughput HomePlug AV systems under various operating conditions. The results demonstrated that the average throughput of HomePlug AV systems were 95.01 Mbit/s and the average round trip time (RTT) was 170.09 msec. These results highlighted the suitability of PLC systems for streaming and Internet access in residential environments. Moreover, the subsequent releases of HomePlug AV as HomePlug AV2 were developed in order to improve the throughput and performance of PLC technologies as shown in a study by Slaick et al. (2018) in [23]. Researchers in [23] have experimentally proved that HomePlug AV2 devices can provide users with throughput of 200 Mbit/s under conditions with minimal noise and with throughput of 100 Mbit/s under noisy conditions. Meanwhile, IEEE 1901 is also a widely used protocol in PLC technologies. A study conducted by Galli et al. in 2008 emphasized that IEEE 1901 protocols employ frequencies below 100 MHz, which allowed IEEE 1901 protocols to be usable for all types of PLC devices. The use of the IEEE P1901 protocol had a very significant impact in the widespread adoption of PLC technology [24].

The choice of modulation methods plays an important role in determining the performance, reliability and throughput of PLC devices. The following modulation schemes were discussed as suitable for PLC: frequency-shift keying (FSK), code-division multiple access (CDMA) and orthogonal frequency division multiplexing (OFDM) [25]. Frequency Shift Keying (FSK) modulation, while suitable for low-cost, low-data-rate applications such as power line protection and telemetering, faces limitations beyond a few kilobytes per second due to frequency selective fading [26]. CDMA has been explored for its immunity against narrowband noise and interference, making it an attractive candidate for PLC applications [27]. The authors in [27] demonstrated the effectiveness of CDMA in achieving excellent performance in broadband power line communications, particularly in scenarios where impulsive noise is prevalent. Moreover, the CDMA system can enhance its BER performance by sacrificing data rate and increasing processing gain without risking potential electromagnetic interference issues [28]. This flexibility allows CDMA to adapt better to dynamic and noisy environments. Furthermore, Orthogonal Frequency Division Multiplexing (OFDM) has emerged as a preferred modulation technique for high-data applications in PLC systems [29]. The authors in [29] study highlighted OFDM's ability to divide the available bandwidth into multiple subcarriers, mitigating the effects of multipath interference and narrowband noise.

Despite the various benefits that PLC technology offers, it still faces limitations that hinder its performance. One significant constraint is the low noise immunity, which arises from various electrical devices. This interference can degrade signal quality and reduce transmission efficiency [30]. Moreover, the low noise immunity leads to low throughput high packet loss rates. Furthermore, the attenuation of signals over long distances poses a challenge, limiting the range and coverage of PLC systems [31]. Additionally, the multipath propagation phenomenon in powerline networks can result in signal distortion and unpredictable behavior, further complicating data transmission [32].

Powerline communication (PLC) technology has attracted significant interest due to its potential application in home networks, offering a convenient and cost-effective solution for transmitting data. With the growing demand for high-speed Internet connections and the proliferation of smart home devices, PLCs represent a promising alternative to traditional wired and wireless network technologies [33].

In addition, efforts have been made to develop practical implementations and standards for PLC-based home networking solutions. The HomePlug Powerline

Alliance has defined specifications and certification programs to ensure interoperability and compatibility between PLC devices from different manufacturers [34]. Moreover, advances in PLC technology have led to the introduction of integrated solutions that combine PLC with other home networking technologies such as Wi-Fi and Ethernet, providing users with seamless connectivity.

In summary, powerline communication holds great potential for home networks, offering a robust and scalable solution for data transmission over electrical wiring. Ongoing research and development efforts are focused on enhancing PLC performance, optimizing network design, and standardizing implementations to meet the growing demand for reliable and high-speed connectivity in residential environments.

Chapter 3

Methodology

3.1 Methods and Procedure of Data Collection

Methodology for testing PLC network involves the use of two experimental setups. All experiments are conducted within the confined space of 34.6 square meters apartment (Figure 3.1). The goal of these experiments is to evaluate the transmission rates and overall performance of the PLC adapters in a real-world home setting. In both of experimental setups, two PCs are positioned in different locations within the apartment. Measurements are obtained in TamoSoft ThroughputTest software application.

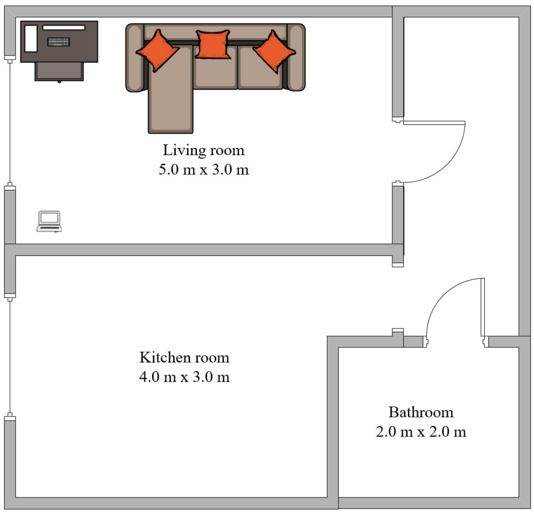

Figure 3.1: Apartment plan

Experimental setup 1:

In this experiment two PCs are connected by 100 Mbps Ethernet cable. We measure the transmission rate using TamoSoft ThroughputTest application (Figure3.2).

Figure 3.2: Experiment setup 1

Experimental setup 2:

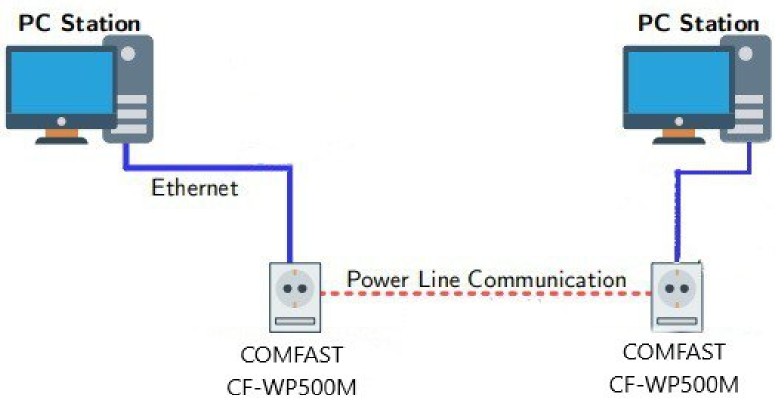

Figure 3.3: Experiment setup 2

In this experiment (Figure 3.3) two PCs are connected by a set of two COMFAST CF-WP500M PLC adapters (Figure 3.4). Both adapters have one Ethernet output with a RJ45 connector, which allows the connection of one device. PLC adapters are connected to the electrical outlets in their respective locations.

The COMFAST CF-WP500M adapter kit allows creating a home wireless network operating with a total transfer rate of up to 500Mbps. The adapters support the following protocols: HomePlug AV, IEEE 802.3, IEEE 802.3u. The transfer distance is up to 300 m, while coverage are is 5000 square feet. Adapters use 128-bit AES Encryption and OFDM protocol for communication. The configuration of the adapters is simple plug and play.

Multiple test scenarios are conducted to simulate varying conditions, including the presence of noise from household appliances. Generally, the test scenarios can be divided into two stages: without noise sources and with noise sources. For the first stage, we connect two PC's by Ethernet cable and measure the data rate, which is the first experimental setup (Figure 3.2). Subsequently, we connect PCs

Figure 3.4: PLC adapters CF-WP500M

to PLC adapters and measure data transmission rate again, which is the second experimental setup. Moreover, we will place computers in different rooms and connect them to PLC adapters. By measuring data transmission rates, we will evaluate the effect of distance on transmission behavior. This will demonstrate the performance of PLC adapters in real home networks and allow us to make a comparison between traditional communication technique and PLC.

For the second stage, we connected household appliances such as kettle into the power line network. This created noise and interference in the network. Afterwards, we connected two PCs by PLC adapters and measured the data transmission rate under noisy conditions.

3.2 Methods and Procedure of Data Analysis

The methods and procedures used in this capstone project entail a comprehensive examination of data transmission performance employing both Ethernet and PLC adapters. The experiments involve varying condition such as presence of noise to assess transmission speed.

The primary metrics for analysis is throughput, which measures the amount of data transferred over the network within a specified time. Throughput serves as a direct indicator of performance, that allows comparisons between different setups and conditions.

Through the comparison of throughput across different setups and scenarios, the project aims to draw conclusions regarding the relative performance of Ethernet and PLC adapters.

Chapter 4

Results and Discussions

The results of experimental measurements are given in figures with graphs below. The results of experimental setup 1 is given in 4.1. The measurement results of experimental setup 2 are given in 4.2. The results of experimental measurements with PLC adapters and noise applied are in 4.3.

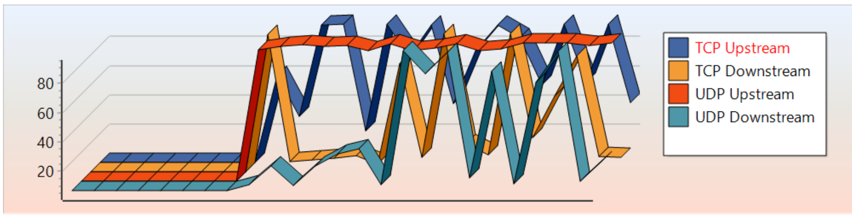

Figure 4.1: Ethernet Connection

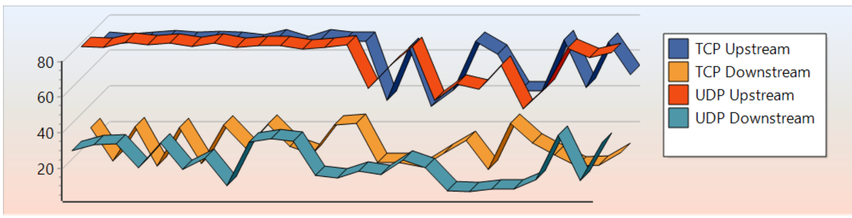

Figure 4.2: PLC Connection

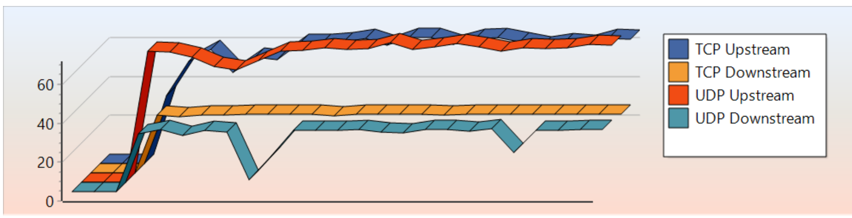

Figure 4.3: PLC Connection with noise

In the first experiment, we measured the throughput between two PCs connected by Ethernet cable. The average throughput recorded was 91.38 Mbps. For the second, we evaluated the throughput between two PCs connected via PLC adapters. The average throughput achieved was 66.26 Mbps. In the third experiment, we examined the throughput between two PCs connected by two PLC adapters under the influence of noise interference from household appliances. Despite the interference, the average throughput obtained was 59.81 Mbps.

Table 4.1: Average Values of Experimental Results

Setup	Throughput, Mbps	RTT, ms	Packet loss, %
1	91.38	2.7	0
2	66.26	3.2	16.4
2 (with noise sources)	59.81	3.4	28.1

The table 4.1 summarizes results from various experimental measurements. The values are averaged. The metrics included are throughput, measured in Mbps, Round-Trip Time (RTT) in ms and the percentage of packet loss. By analyzing these metrics across different setups, insights into network reliability and efficiency can be gained.

Chapter 5

Conclusion

In conclusion, this project aimed to evaluate the PLC technology in terms of transmission speed and reliability. In this project a setup for our methodology was built and experimental tests were conducted. Our results showed that the Ethernet cable was slightly faster than the Comfast CP-WP500M adapters. To be specific, our findings reveal that performance of PLC network is 27% less of Ethernet network. We can conclude that PLC network performance is comparable to that of an Ethernet network. Overall, this project provided valuable insights into the performance of these two transmission methods and highlighted the need for further research in this area.

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