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Review Manuscript

Data Communication Over Power-lines: A Review on Technical, and Applications Challenges

Abdi T. Abdalla[1†], Kwame S. Ibwe[1], Godwin Mruma Gadiel[1] and Abdullah F. Ally[2]

[1]Department of Electronics and Telecommunications Engineering, University of Dar es Salaam, Dar es Salaam, Tanzania
[2]Department of Computer Science and Engineering, University of Dar es Salaam, Dar es Salaam, Tanzania
[†]Corresponding author: abdit@udsm.ac.tz

[†]ORCID: https://orcid.org/0000-0002-6333-410X

ABSTRACT

This paper presents a review study on the data communication over power-lines, commonly referred to as power-line carrier, power-line communication (PLC), mains communications, or power-line digital subscriber line (PDSL). This study examines the technical and application advantages and challenges associated with adopting PLC as a preferred alternative technology for wideband or broadband data communication. The broader coverage area of the PLC network gives it a distinct advantage over other communication network technologies. Additionally, implementing a communication system using the existing power-line network is more cost-effective and less time-consuming compared to constructing a new network from scratch. However, the primary challenge lies in the fact that the power-line network is primarily designed for the distribution of electrical power within the frequency range of 50-60 Hz including the harmonics. This poses various obstacles such as electrical noise from appliances, signal distortions caused by the unregulated nature of the wiring, transformer bypassing, interference from high-frequency modulation, and variations in characteristic impedances, among others. Despite these challenges, the emergence of robust modulation techniques like Orthogonal Frequency Division Multiplexing (OFDM) and Direct-Sequence Spread Spectrum (DSSS), along with the development of Application-Specific Integrated Circuit (ASIC) density with improved processing speeds, as well as advancements in signal processing and error control coding techniques, have made the PLC network the most promising telecommunications access network.

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INTRODUCTION

The concept of data transmission over power lines emerged as a result of the successful transmission of data through voice channels by telephone companies without interference. This technique, which enabled data transmission at rates exceeding 1 Mbps over twisted pair lines, can also be applied to power-line networks (Held, 2019). Telephone companies recognized that twisted-pair telephone lines could support a frequency range of up to approximately 1 MHz, despite only utilizing around 3 kHz of bandwidth for telephone conversations. Through frequency division multiplexing, it becomes feasible to transmit data at higher frequencies than those employed for voice transmission (Afshar *et. al*., 2018). Similarly, power-line cables possess capacities of the order of hundreds of megabytes, despite electric power signals typically operating within the 50-60Hz frequency range, resulting in a significant amount of unused capacity (Mlýnek *et al*., 2021). By applying appropriate modulation techniques, this remaining capacity can be harnessed for data transmission (Varunkumar, 2018). This consequently renders power-line communication (PLC) capable of fulfilling a wide range of applications, including email services, voice over IP, home automation, smart grid management, and broadband internet access (Hosseinpour *et al*., 2015). PLC has emerged as a viable option for email communication due to its capacity to facilitate high-speed data transfer rates. A study conducted by Hosseinpour *et al*. (2015) investigated the feasibility of employing PLC as a means to deliver broadband services to homes and offices. The findings revealed that PLC exhibits similarities to wireless communications in terms of signal propagation and security. In a related research endeavor, Manohar & Kumar (2015) examined the practicality of utilizing PLC for email communication in a home automation system. The Universal Power-line Bus (UPB) communication protocol was employed, thereby enabling data transmission over power lines in residential and commercial buildings (Suárez-Albela et al., 2016). UPB presents a cost-effective, reliable, and easily installable alternative to conventional wired and wireless communication protocols for home automation and lighting control applications. Furthermore, Liu *et al*. (2011) explored the potential of integrating PLC into smart grid communications, encompassing the realm of email services. Their investigation resulted in the development of a communication model utilizing PLC to transmit data types, including email messages, across a smart grid network. The findings suggested that PLC holds promise as a technology for smart grid communications, albeit further research is warranted to optimize the system and address potential challenges such as interference and security concerns (Machowski *et al*., 2018; Varunkumar, 2018).

Voice over Internet Protocol (VoIP) serves as a technology facilitating voice communication and multimedia sessions over Internet Protocol (IP) networks. Within the context of power-line communication (PLC) systems, VoIP can be employed to transmit voice and multimedia signals over the power grid (Ivanova, 2022). VoIP effectively converts these signals into digital packets and subsequently transmits them over the internet. At the receiving end, these packets are reassembled to restore the original voice or multimedia signal (Arora, 2000). The versatility of VoIP allows for its utilization with a range of devices, including desktops, laptops, tablets, mobile phones, and other internet-connected entities (Carmona & Pelaes, 2012).

Incorporating VoIP into PLC systems offers several advantages, such as reducing the need for additional wiring and infrastructure (Lee *et. al*., 2005). This feature becomes particularly valuable in scenarios where alternate communication channels are either unavailable or unreliable, such as in rural or remote areas. However, PLC systems face certain challenges of their own, most notably interference, which can significantly impact the quality and reliability of VoIP communications over the power grid (Febridiani & Wibisono, 2010).

Shabro (2015) explored the possibility of implementing VoIP services in digital PLC systems. The authors recommended the utilization of data compression methods to optimize channel capacity for VoIP services within these systems.

Santos *et al*. (2016) introduced a data traffic and Voice over Internet Protocol (VoIP) model for Power Line Communication (PLC) networks, employing Markov Modulated Fluid Models (MMFM). Nevertheless, the severe PLC environment, characterized by attenuation, multipath propagation, and noise, presents formidable obstacles to effective data communication. The authors argue that the assumption of traffic obeying the Poisson distribution may not be suitable, particularly in the context of home automation, and therefore more complex Markov models are needed.

Home automation refers to the integration of electronic devices, appliances, and systems within a household in order to improve convenience, comfort, security, energy efficiency, and connectivity (Kuruppu et al., 2017; Mlýnek *et al*., 2021). Power-line communication (PLC) systems can be employed for automation purposes, ranging from simple protocols such as X10 to complex systems like consumer electronic bus (CEBus) employing spread spectrum techniques (Shwehdi & Khan, 1996). X10-based PLC systems are particularly favored for residential applications (Patil *et al*., 2015). However, despite the ease of installation, broad coverage, stability, and reliability offered by PLC for home automation, the presence of certain electrical devices can introduce noise or interference on the power-line network, thereby affecting the quality of data transmission (Komarovskyi, 2021).

PLC technology can also be utilized for the management of smart grids (Passerini & Tonello, 2019). The smart grid is an advanced electrical grid system that utilizes modern communication, information technology, and automation to enhance the efficiency, reliability, and sustainability of electricity generation, distribution, and consumption (Abdalla & Ibwe, 2023; Kimambo *et al*., 2022; Maziku *et al*., 2021; Sharma & Saini, 2017). It facilitates demand response programs by establishing a connection between utility companies and consumer devices, such as smart appliances, electric vehicle charging stations, and energy storage systems (Berger *et. al*., 2013). Through this connection, utilities can transmit price signals or control commands to these devices, allowing them to manage and optimize energy consumption during periods of peak demand. As a result, faster responses and improvements in overall grid reliability and efficiency can be achieved (Abdalla & Ibwe, 2023; Zhang *et al*., 2018).

PLC technology enables utilities to monitor and control loads at various points in the distribution network. By integrating PLC with smart meters and smart devices, utilities can implement load management techniques such as load shedding, load balancing, and peak shaving (Masood *et al*., 2018). The real-time data collected via PLC communication assists utilities in proactively identifying potential equipment failures or maintenance needs (Nowotarski & Weron, 2018). This proactive approach to asset management enhances grid reliability, reduces downtime, and improves overall performance. Furthermore, PLC can facilitate the integration of renewable energy sources, such as solar panels and wind turbines, into the smart grid (Klumpner *et al*., 2021). By enabling communication capabilities, PLC allows utilities to monitor and manage intermittent generation from these sources, optimize their utilization, and seamlessly integrate them with the existing grid infrastructure (Yang *et al*., 2020).

PLC has been recognized as a means of accessing broadband internet (Ullah et al., 2020). The utilization of broadband connection enables users to have access to high-speed internet with enhanced data transmission capacity (Hossain *et al*., 2014). One notable advantage of PLC is its ability to eliminate the need for additional cabling or infrastructure installation, which can be especially advantageous in rural areas that lack developed broadband infrastructure (Nancy *et al*., 2021). However, it is important to acknowledge that the quality and condition of a building's electrical wiring can have an impact on the broadband connection through PLC (Thakur, 2018). Various factors, such as electrical noise, signal attenuation, and interference from appliances, must be taken into consideration in order to ensure a reliable broadband connection (Debita *et al*., 2022).

This paper reviews the advantages of power-line networks as a data communication medium, analyzes its challenges, and predicts its future in the communication industry.

POWER-LINE NETWORK STRUCTURE

The electrical low-voltage supply network is frequently utilized for data communication in a variety of settings. This network begins at the transformer and extends all the way to the residential property through the advanced metering infrastructure (Abdalla & Anatory, 2013). In the telecommunications industry, this network is referred to as the Access Network. It is connected to the medium and high-voltage network by means of transformers, as depicted in Figure 1. The base station located at the transformer unit is a vital component within the network.

Its role is to convert the signal received from the communication backbone into a suitable format for transmission through the access network to the subscribers. Some power supply companies possess their own telecommunications networks, thereby interconnecting their transformer units to create a backbone network. Alternatively, the transformer units can be linked to a conventional telecommunications network. At the receiving end, subscribers can only access the data signal by utilizing a PLC modem. This modem is typically installed either within the electrical power meter unit or any socket within the internal electrical network. Its primary function is to convert the received signal into a standard format that can be processed by conventional communication systems (Abdalla & Anatory, 2013; Hrasnica *et al*., 2005). If the meter unit is employed, subscribers within the building will be connected using alternative communication technologies such as DSL or WLAN. When the latter approach is adopted, the internal electrical installation serves as the transmission medium, and this is commonly known as in-home PLC (Hrasnica *et al*., 2005).

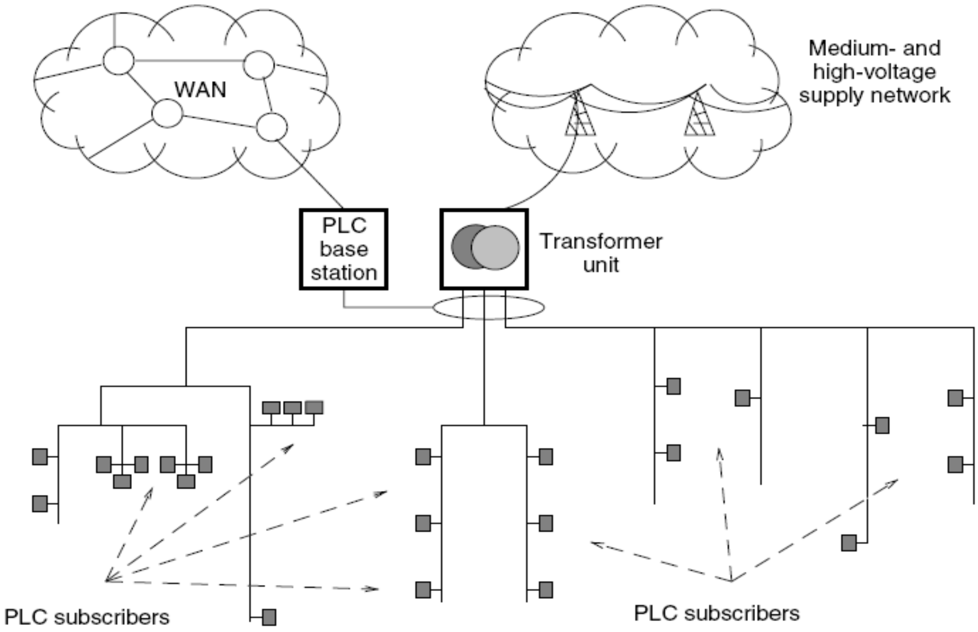

Figure 1: PLC Access Network (Hrasnica et al., 2005).

PLC NETWORK ELEMENTS

In order to facilitate communication within a PLC system, the signal must undergo preparation before being transmitted through the power-line network or from the power-line to the subscriber. Put simply, interfaces are required between the user and the power-line, as well as between the power-line and the backbone network. These interfaces are known as the PLC Modem and the PLC Base Station, and they are essential components for the functioning of the PLC network. In some instances, repeaters and gateways may also be utilized (Hrasnica *et al*., 2005).

The modem functions as the intermediary between the subscriber's conventional communication equipment and the power-line transmission medium. On the user-side connectivity, diverse standard interfaces can be provided for different communication devices, such as Ethernet and Universal Serial Bus (USB) interfaces for data, and S_0 and a/b interfaces for telephony (Hrasnica *et. al*., 2005). On the network-side, the modem establishes a connection to the power grid through a specific coupling method, enabling the smooth transmission of signals to and from the power-line, as depicted in Figure 2. Typically, the coupling acts as a high-pass filter to differentiate the communication signal (above 9 kHz) from the electric power signal, which typically operates at either 50 Hz or 60 Hz. The coupling occurs between two phases in the access network and between the phase and the neutral in the indoor network, in order to minimize the adverse effects of electromagnetic emissions originating from the power-line (Dostert, 2001). In terms of functionality, the modem undertakes tasks associated with the physical layer and data link layer, including modulation, coding, and the Media Access Control mechanism (Walke, 1999).

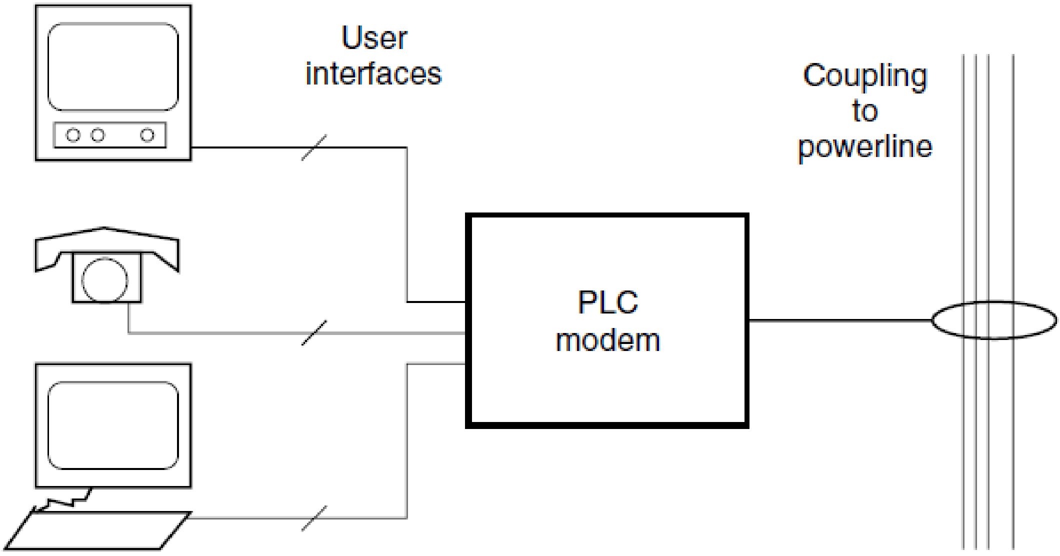

Figure 2: PLC Modem connection (Hrasnica et al., 2005).

The PLC base station, also known as the master station, functions as an intermediary between the power-line network and the backbone network. Unlike its predecessor, this device does not establish connections with individual subscriber devices. Instead, it offers multiple network communication interfaces, such as xDSL, Synchronous Digital Hierarchy (SDH), and Wireless Local Loop (WLL) for wireless interconnection (as illustrated in Figure 3). Consequently, the PLC base station enables the establishment of connections with backbone networks utilizing various communication technologies. Typically, the base station governs the operation of a PLC access network. Nevertheless, network control and its specific functions can also be distributed among multiple devices. In a unique scenario, each PLC modem can manage network operation control and forge connections with the backbone network (Abdalla, 2010; Hrasnica *et. al.*, 2005).

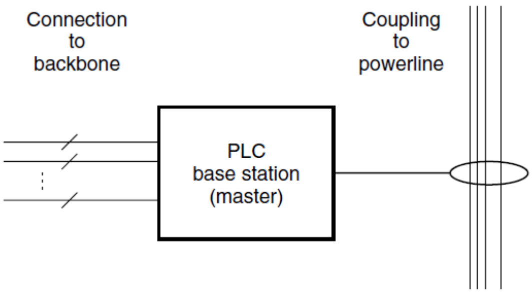

Figure 3: The PLC Base station connection (Hrasnica et al., 2005).

POWER-LINE CHANNEL MODEL

Transmission lines with distributed branches, as depicted in Figure 4, possess a comprehensive transfer function that can be represented by equation (1) (Anatory *et al*., 2008). These branches can be distributed along the line or positioned at a particular node, such as node 1 in Figure 4. In either scenario, the aforementioned transfer function can be employed.

$$H_{mM_T}(f) = \prod_{d=1}^{M_T} \sum_{\substack{M=1 \\ \neq m}}^{L} \sum_{n=1}^{N_T} T_{Lmd}\alpha_{mnd} H_{mnd}(f); n \quad (1)$$

$$\alpha_{mnd} = P_{Lnd}^{M-1} \rho_{nmd}^{M-1} e^{-\gamma_{nd}(2(M-1)l_{nd})} \quad (2)$$

$$P_{Lnd} = \begin{cases} \rho_s & d = n = 1(at\ source) \\ \rho_{Lnd} & otherwise \end{cases} \quad (3)$$

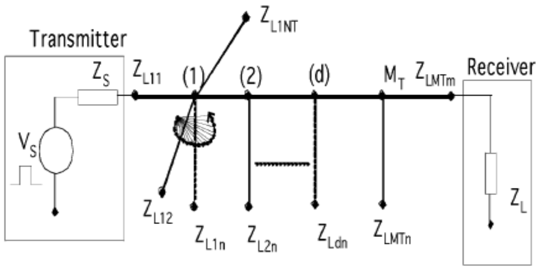

Figure 4: Power-line network with distributed branches (Anatory et al., 2008)

In equation (1), NT denotes the number of branches connected to a specific node and ending in arbitrary loads. The variables $n, m, M, H_{mn}(f)$ and T_{Tm} represent a branch number, a referenced load, the number of reflections (with a total of L reflections from each load terminal), the transfer function between a particular source point (transmitter) and a referenced load termination m, and the transmission factor with reference to any load termination m, respectively.

The signal contribution factor α_{mnd} at a referred node d is given by equation (2), where ρ_{mnd} represents the reflection factor at the referred node d between line n and the referenced load m , and γ_{nd} is the propagation constant of line n at the referred node d, which has a line length of l_{nd}.

According to equation (3), P_{Lnd} represents terminal reflection factors excluding the source. Here, $\rho_{L1} = \rho_s$ represents the source reflection factor, and Z_s, and V_s represent the source impedance, and source voltage, respectively based on Figure 4 whereby M_T signifies the total number of distributed nodes.

BROADBAND POWER-LINE (BPL)

Initially, PLC technology was primarily used for low data-rate applications, such as home automation and power system monitoring and control (commonly referred to as narrowband PLC). However, in recent years, it has been discovered that PLC technology is capable of supporting high data-rate transmission, reaching speeds of hundreds of megabytes. This makes it well-suited for broadband services, including internet and video communications. This specific application of PLC technology is known as Broadband Power-line (BPL) communication (Ercan, 2024).

BPL communication involves leveraging existing power-line networks to achieve high-speed data communication between residential homes and small offices. Compared to narrowband PLC systems, BPL offers significantly higher data rates. While narrowband networks can only support a limited number of voice channels and low-bit rate data transmissions, BPL networks can accommodate more advanced telecommunications services. These services include multiple voice connections, high-speed data transmission, video signal transfer, as well as narrowband services (Hrasnica *et. al*., 2005).

The ability to deliver broadband communication services over power-line grids presents a cost-effective solution for establishing telecommunications networks, as it eliminates the need for laying new network cables. However, it is important to acknowledge that electrical supply networks were not originally designed for data transfer. As a result, there are certain limitations to the application of BPL technology. These limitations encompass the maximum distances that can be covered and the achievable data transfer rates by BPL systems (Hrasnica *et. al*., 2005).

Merits of PLC in Access Network

The access networks in communication companies are of great importance to network providers due to their high costs and the potential for direct access to end users or subscribers. According to (Abdalla, 2010), approximately 50% of all telecommunications infrastructure investment is allocated to telecommunication access networks. However, unlike transport communication networks, they only connect a limited number of individual subscribers. The maximum number of end users per phase in a power-line access network is 70. Therefore, the power-line access network is a crucial component of the communication system and the need for efficient utilization is undeniable (Abdalla, 2010).

Typically, network providers aim to establish their own access networks at a low cost in order to enhance their competitiveness in the deregulated telecommunications market. In most cases, the access networks remain the property of incumbent network providers. New network providers, therefore, seek solutions to establish their own access networks. Apart from PLC networks, there are several options for creating new access networks, including wireless access networks, satellite systems, and new cable/fiber-optic networks. The first two methods tend to be expensive and incapable of offering high transmission rates. Conversely, constructing new cable or optical networks not only requires higher costs but also takes longer to implement (Hrasnica *et. al.*, 2005). Thus, PLC technology offers a promising possibility for access network implementation, as it utilizes existing infrastructure and eliminates the need for new cable installations, reducing both time and cost.

From the authors' perspective, this technology may be less attractive to well-developed countries with advanced communication infrastructures that already reach the outskirts, providing satisfactory service quality, capacity, and future scalability. However, these countries still have the option to adopt In-home PLC networks, where buildings or houses are connected through the electrical grid. With this technology, the entire building can be connected as long as there is an available electrical socket (smart house). Unfortunately, the situation is different in developing countries, where power-line networks often represent the only available coverage over large areas (Anatory et al., 2008). Therefore, Broadband over Power Line Communication (BPLC) is a promising solution for telecommunication access networks, particularly in the developing world, taking into account their relatively limited financial resources.

Taking Tanzania as an example of a developing country, records indicate that despite having numerous cellular mobile companies, fixed telephone lines, public data networks, and various Internet Service Providers, the country has a relatively low tele density for both mobile and fixed lines. However, the power-line network, which has demonstrated sufficient capacity to support communication services, has surpassed other existing networks in terms of coverage (Anatory et al., 2008). Clearly, the BPL network emerges as the optimal solution for improving access, as it can reach a larger geographic area and serve more end users compared to any other currently deployed network.

By implementing BPL, operational costs and expenses for establishing new telecommunication networks are significantly reduced, leading to a decrease in subscription costs for end users. Taking into consideration the aforementioned advantages, such as cost-effectiveness, installation time, and penetration capability, it becomes evident that the power-line network represents a promising solution for achieving broadband telecommunication access networks, particularly in the developing world.

Challenges of Power-line Communication

The power-line network was initially designed for the distribution of electrical power within the frequency range of approximately 50-60 Hz. However, using this medium for high-speed communication presents certain technical challenges (Abdalla, 2010). The technology is susceptible to significant signal distortions caused by electrical noise from appliances and the unregulated nature of the wiring. Typically, the overall power-line noise arises from various loads. Appliances connected to the grid, such as TVs, computers, and radio receivers, generate noise that travels back through the power-line. To improve the Signal-to-Noise Ratio (SNR), it is possible to install a suitable filter at each end user's location to block noise from entering the grid, but this introduces further complexity. In conventional communication networks, impedance matching is desirable, such as using 50-ohm cables and 50-ohm transceivers. However, in PLC, the channel consists of different types of conductors, as depicted in Figure 4. Additionally, the network terminal impedance tends to vary with frequency and time, depending on the consumer's load pattern and device types (Abdalla, 2010). Consequently, this variation in characteristic impedance leads to multipath effects, resulting in significant signal loss at certain frequency ranges. These channel imperfections make the transmission of signals over a power-line highly challenging (Barnes, 1998).

In order to ensure reliable data communication over power lines, there are several key components that are essential. These components include a robust Forward Error Correction (FEC) coding, interleaving, error detection, Automatic Repeat Request (ARQ) techniques, appropriate modulation schemes, and a reliable Medium Access Control (MAC) protocol. In the past, the lack of affordable signal processing techniques posed a hindrance to the development of power-line communications in challenging environments. However, advancements in Application-Specific Integrated Circuit (ASIC) density, increased speeds, and improvements in signal modulation, and error control coding have made it possible to establish communication over power-lines (Lin *et al*., 2003).

The presence of transformers within the power line network brings an additional challenge. The electrical signal can only pass through transformers via electromagnetic induction, which means that there is no direct connection between the primary and secondary networks. Therefore, bypassing the transformers during data transmission becomes necessary. It is important to carefully consider the cost of bypassing transformers and implementing equalizers to overcome attenuation issues (Abdalla, 2010). Moreover, power-line cables are typically unshielded, which means that they function as antennas when data is modulated and transmitted at high frequencies. This can lead to interference that renders certain types of radio systems unusable if they are in close proximity to power-line networks (Abdalla, 2010). One potential solution to this issue is to avoid using RF frequencies that are already occupied by radio applications, public safety services, and long-range airplane communications. However, this approach restricts the available bandwidth, resulting in lower data rates and making the technology less competitive in the market. Therefore, mitigating the effects of interference remains a significant challenge that requires further research (Abdalla, 2010).

Research Opportunities

The demand for research on this emerging technology remains high, with a primary focus on enhancing its performance. Performance enhancements can be achieved through various factors, including coding schemes, modulation techniques, and Media Access Control (MAC) protocols. Another area of research involves mitigating the interference caused by power-lines, which function as radiating antennas at high frequencies. There is a pressing need for an efficient and cost-effective approach to address this issue. Furthermore, there is potential for exploring the application of this technology to address societal concerns, such as traffic and street light control, irrigation control, and energy generation. Some researchers have underscored the importance of efficient energy utilization in the next generation, along with other potential applications that rely on the reader's ingenuity and creativity.

CONCLUSION

Despite the numerous technical challenges, including radiation of the transmitted signal, impedance mismatch, time and frequency variant behavior, and signal-to-noise ratio (SNR), communication over power lines still shows promise as a viable solution for providing broadband services. A cost analysis of power line access networks, encompassing installation and maintenance costs, reveals that BPL offers affordable subscription rates while maintaining quality of service and reasonable transmission speeds. In comparison to other transmission technologies in terms of installation time, implementation cost, and penetration ability, BPL emerges as the optimal choice for the economic development of any given country, as it has the capacity to connect a larger number of subscribers compared to other technologies currently in use. It is evident that the aforementioned advantages outweigh the challenges, as advancements in reliable signal processing, robust channel coding, and efficient modulation techniques are gradually mitigating the impact of these challenges over time. Ongoing research in this field has significantly enhanced the performance of BPL technology, both in terms of data rate and robustness, thanks to innovative multiplexing techniques such as OFDM and DSSS. These techniques have demonstrated greater resistance to narrowband interference and multipath effects, making them ideal for high-speed data communications. Based on the development trend presented, continuous research and improvement in BPL technology are likely to establish its dominance in the communication industry in the forthcoming years. This achievement will connect virtually all individuals, given the near-ubiquitous nature of power grids

REFERENCES

Abdalla, A. T. (2010). Performance Evaluation of Different Media Access Control Protocols with Application to Broadband Powerline Communication. *University of Dar es Salaam*.

Abdalla, A. T., & Anatory, J. (2013). Performance improvement of MAC protocols for broadband power-line access networks of developing countries : A case of Tanzania Performance Improvement of MAC Protocols for Broadband Power-Line Access Networks of Developing Countries : A Case of Tanzania. **7**: 1487–1490.

Abdalla, A. T., & Ibwe, K. (2023). Smart Grid in Tanzania: Research Opportunities. *Tanzania Journal of Engineering and Technology*, **42**(2): 170–183. https://doi.org/10.52339/tjet.v42i2.838

Afshar, S., Tousi, S. M. R., & Karami, H. (2018). Wireless Power and Full-Duplex Data Transfer System Using the Combination of TDM and FDM Through a Same Inductive Link. *26th Iranian Conference on Electrical Engineering, ICEE 2018*. https://doi.org/10.1109/ICEE.2018.8472488

Anatory, J., Theethayi, N., Thottappillil, R., Kissaka, M. M., & Mvungi, N. H. (2008). Broadband power-line communication channel model: Comparison between theory and experiments. *IEEE ISPLC 2008 - 2008 IEEE International Symposium on Power Line Communications and Its Applications*, 322–324. https://doi.org/10.1109/ISPLC.2008.4510447

Arora, R. (2000). Voice over IP : Protocols and Standards. *Components*.

Barnes, J. (1998). A physical multipath model for power distribution network propagation. *Proceedings of International Symposium on Power-*

Line Communications and Its Applications, 76–89.

Berger, L. T., Schwager, A., & Escudero-Garzás, J. J. (2013). Power line communications for smart grid applications. In *Journal of Electrical and Computer Engineering*. https://doi.org/10.1155/2013/712376

Carmona, J. V. C., & Pelaes, E. G. (2012). Analysis and performance of traffic of voice and video in network indoor PLC. *IEEE Latin America Transactions*, **10**(1). https://doi.org/10.1109/TLA.2012.6142472

Debita, G., Falkowski-Gilski, P., Zamłyńska, M., Habrych, M., Miedziński, B., Kupczyk, T., & Polnik, B. (2022). Analysis of Video Transmission Capabilities in a Simulated OFDM-Based Supplementary BPL-PLC System. *Energies*, **15**(10). https://doi.org/10.3390/en15103621

Dostert, K. (2001). *Powerline Communications*. Prentice Hall.

Ercan, S. U. (2024). Engineering Science and Technology , an International Journal Power line Communication : Revolutionizing data transfer over electrical distribution networks. *Engineering Science and Technology, an International Journal*, **52**:101680. https://doi.org/10.1016/j.jestch.2024.101680

Febridiani, L. D., & Wibisono, G. (2010). Analisis SWOT untuk Implementasi Voice over Internet Protocol (VoIP) pada Powerline Communication (PLC). *INKOM Journal*.

Held, G. (2019). Understanding Broadband over Power Lines. In *Understanding Broadband over Power Line*. https://doi.org/10.1201/9781420013894-1

Hossain, M. B., Rahman, M. T., Asif, O., Rahman, M. A., & Chowdhury, M. E. H. (2014). Broadband over Power Line (BPL): An Emerging Technology for Bangladesh. *International Journal of Communications, Network and System Sciences*, **7**(9). https://doi.org/10.4236/ijcns.2014.79036

Hosseinpour, A., Hosseinian-Far, A., Jahankhani, H., & Ghadrdanizadi, A. (2015). Security and feasibility of power line communication system. *Communications in Computer and Information Science*, **534**. https://doi.org/10.1007/978-3-319-23276-8_22

Hrasnica, H., Haidine, A., & Ralf, L. (2005). *Broadband Powerline Communications: Network Design*. Wiley.

Ivanova, M. (2022). Scientometric Analysis “Voice Over IP.” In *Studies in Systems, Decision and Control* (Vol. 421). https://doi.org/10.1007/978-3-030-97008-6_29

Kimambo, J., Ibwe, K. S., Kalinga, E., & Abdalla, A. T. (2022). Resource Efficient Advanced Metering Infrastructure Model. *Tanzania Journal of Science*, **48**(1): 57–72. https://doi.org/10.4314/tjs.v48i1.6

Klumpner, C., Rashed, M., De, D., Patel, C., & Asher, G. (2021). Experimental evaluation of an energy storage system for medium voltage distribution grids enabling solid-state substation functionality. *IET Smart Grid*, **4**(2). https://doi.org/10.1049/stg2.12019

Komarovskyi, M. M. (2021). Signal Attenuation of Data Transmission by Power Lines. *Electronic and Acoustic Engineering*, **4(**3). https://doi.org/10.20535/2617-0965.eae.227843

Kuruppu, K. D. R. S., Gunathilaka, K. T. R., Wijesinghe, W. L. P. K., & Thayaparan, S. (2017). Power line communication for home automation in low income households. *3rd International Conference on Power Generation Systems and Renewable Energy Technologies, PGSRET 2017, 2018-Janua*. https://doi.org/10.1109/PGSRET.2017.8251796

Lee, J. J., Park, Y. J., Kwon, S. W., Oh, H. M., Park, H. S., Kim, K. H., Lee, D. Y., & Jeong, Y. H. (2005). High data rate internet service over medium voltage power lines. *2005 International Symposium on Power Line Communications and Its Applications, ISPLC 2005, 2005*. https://doi.org/10.1109/ISPLC.2005.1430540

Lin, Y. J., Latchman, H. A., & Newman, R. E. (2003). A comparative performance study of wireless and power line networks. *IEEE Communications Magazine*, **41**(4): 54–63. https://doi.org/10.1109/MCOM.2003.1193975

Liu, J., Zhao, B., Geng, L., Yuan, Z., & Wang, Y. (2011). Communication performance of broadband PLC technologies for smart grid. *2011 IEEE International Symposium on Power Line Communications and Its Applications, ISPLC 2011*. https://doi.org/10.1109/ISPLC.2011.5764448

Machowski, W., Stepien, J., Tarnawski, A., & Kolodziej, J. (2018). The influence of power lines non-homogeneity on PLC data transmission protocols efficacy. *2018 14th Selected Issues of Electrical Engineering and Electronics, WZEE 2018*. https://doi.org/10.1109/WZEE.2018.8749125

Manohar, S., & Kumar, D. M. (2015). E-mail Interactive Home Automation System. *International Journal of Computer Science and Mobile Computing*, **4**(7).

Masood, B., Khan, W. A., Ellahi, M., Arshad, T., Amjad, M. F., Tahir, A., & Usman, M. (2018). Demand response control technique for smart air conditioners using NB-PLC. *IEICE Transactions on Communications*, *E101B*(3). https://doi.org/10.1587/transcom.2017EBP3105

Maziku, T. B., Ibwe, K. S., Abdalla, A., & Kalinga, E. A. (2021). Smart Electric Meter Deployment in Tanzania: A Survey. *Tanzania Journal of Science*, **47**(5): 1743–1752. https://doi.org/10.4314/tjs.v47i5.21

Mlýnek, P., Rusz, M., Benešl, L., Sláčik, J., & Musil, P. (2021). Possibilities of broadband power line communications for smart home and smart building applications. *Sensors (Switzerland)*, **21**(1). https://doi.org/10.3390/s21010240

Nancy, B., Gary Loh, C. W., Bazin, M. R., & Panceras, T. M. (2021). A Case Study: Broadband over Powerline for Rural Area Deployment in Sarawak. *E3S Web of Conferences*, **242**. https://doi.org/10.1051/e3sconf/202124203001

Nowotarski, J., & Weron, R. (2018). Recent advances in electricity price forecasting: A review of probabilistic forecasting. In *Renewable and Sustainable Energy Reviews*, **81**. https://doi.org/10.1016/j.rser.2017.05.234

Passerini, F., & Tonello, A. M. (2019). Smart Grid Monitoring Using Power Line Modems: Anomaly Detection and Localization. *IEEE Transactions on Smart Grid*, **10**(6). https://doi.org/10.1109/TSG.2019.2899264

Patil, U., Neha, C. B., Priya, P. S., & Arati, P. R. (2015). Data Transfer Through Power Line. *International Journal Of Engineering And Computer Science, 4*(4).

Santos, C. B., Vieira, F. H. T., Rocha, F. G. C., Araújo, S. G., Marques, F. S., Pereira, J. B. J., & Fernandes, D. C. (2016). Traffic modeling and analysis of PLC networks using Markov chains. *Proceedings - 2010 1st IEEE Latin American Symposium on Circuits and Systems, LASCAS 2010*. https://doi.org/10.1109/LASCAS.2010.7410251

Shabro, M. (2015). VoIP Codec Selection for Digital PLC Systems. *Journal of Electrical and Electronic Engineering*, **3**(2). https://doi.org/10.11648/j.jeee.s.2015030201.20

Sharma, K., & Saini, L. M. (2017). Power-line communications for smart grid: Progress, challenges, opportunities and status. In *Renewable and Sustainable Energy Reviews*, **67**. https://doi.org/10.1016/j.rser.2016.09.019

Shwehdi, M. H., & Khan, A. Z. (1996). A power line data communication interface using spread spectrum technology in home automation. *IEEE Transactions on Power Delivery*, **11**(3). https://doi.org/10.1109/61.517476

Suárez-Albela, M., Fraga-Lamas, P., Fernández-Caramés, T. M., Dapena, A., & González-López, M. (2016). Home automation system based on intelligent transducer enablers. *Sensors (Switzerland)*, **16**(10). https://doi.org/10.3390/s16101595

Thakur, K. K. (2018). Broadband Internet and Access Technology for Rural Connectivity. In *BSNL, akgec. ac. in*.

Ullah, M. W., Rahman, M. A., Kabir, M. H., & Faisal, M. M. A. (2020). Modelling a hybrid wireless/broadband over power line (BPL) communication in 5G. *International Journal of Advanced Computer Science and Applications*, **11**(4). https://doi.org/10.14569/IJACSA.2020.0110461

Varunkumar, S. (2018). Power line commnuication -a smart approach for efficient data transmission. *Proceedings of the International Conference on Power, Energy, Control and Transmission Systems, ICPECTS 2018*. https://doi.org/10.1109/ICPECTS.2018.8521571

Walke, B. (1999). *Mobile Radio Networks: Networking and Protocols*.

Yang, L., Fan, J., Liu, Y., Li, E., Peng, J., & Liang, Z. (2020). A Review on State-of-the-Art Power Line Inspection Techniques. *IEEE Transactions on Instrumentation and Measurement*, **69**(12). https://doi.org/10.1109/TIM.2020.3031194

Zhang, Y., Liu, F., Pang, H., Li, X., Ou, Q., & Liu, Z. (2018). Research on Smart Grid Power Line Broadband Communication System. *IOP Conference Series: Materials Science and Engineering*, **466**(1). https://doi.org/10.1088/1757-899X/466/1/012075

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