Enabling Digital Homes in Underserved Areas Through IoT and Power Line Communication Synergy

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Abstract- This research explores the integration of Power Line Communication (PLC) with the Internet of Things (IoT) to develop a cost-effective, reliable, and scalable solution for remote home automation and monitoring. Leveraging existing electrical wiring infrastructure, PLC eliminates the need for additional communication cabling, making it an ideal medium for data transmission in residential environments. The proposed system enables seamless control and real-time monitoring of smart appliances and sensors via IoT platforms, enhancing convenience, energy efficiency, and security. The research focuses on designing a hybrid architecture that combines PLC-enabled microcontrollers with wireless IoT modules to ensure wide coverage and low latency. It also addresses key challenges such as signal attenuation, noise interference, and interoperability across heterogeneous devices. This study aims to establish a robust framework for smart homes, particularly beneficial for rural and remote areas where traditional wireless infrastructure may be limited or unreliable, promoting sustainable and inclusive digital living.

Keywords: KNX, Addressable, RS485, Address space, firmware

INTRODUCTION

Smart home technology has advanced quickly with the help of IoT, embedded hardware, and wireless protocols, but in rural environments, these solutions are limited by poor infrastructure and interference. Power Line Communication (PLC) uses existing electrical wiring to transmit both data and electricity, enabling more reliable and cost-efficient smart home automation without the need for strong wireless signals or extra cabling. By combining PLC with IoT, smart home systems become easier to deploy in remote areas, allowing seamless connectivity of sensors and devices across rooms and floors. This hybrid approach improves system security and stability, though challenges remain with electrical noise and compatibility between technologies. The proposed architecture leverages PLC's robust in-home connectivity with IoT's broad control features to deliver an affordable, scalable, and secure solution for smart home automation in underserved regions This research not only addresses the technological gap in smart home deployments in rural areas but also contributes to the broader vision of inclusive and sustainable digital infrastructure. Through simulation, prototyping, and performance evaluation, the study aims to validate the effectiveness of the hybrid approach and set a foundation for future smart infrastructure development leveraging existing utilities.

LITERATURE REVIEW

The evolution of home automation has seen the convergence of Power Line Communication (PLC), Internet of Things (IoT), and artificial intelligence to enhance control, monitoring, and energy efficiency. The reviewed literature collectively presents a diverse set of methodologies and architectures focused on enabling smart home systems, each addressing unique challenges such as communication medium, system scalability, user control, and energy management. Home automation has evolved by integrating Power Line Communication (PLC), Internet of Things (IoT), and artificial intelligence to improve control, monitoring, and energy efficiency. Visan and Lita (2021) demonstrated PLC's use of existing power lines for low-cost, real-time device control, addressing wireless limitations. ManojKumar et al. (2021) proposed a modular, decentralized IoT-based system for independent device management via RESTful APIs. Kumar and Bala (2024) focused on secure, real-time energy monitoring with multi-layer authentication. AIdriven user-behavior optimization was introduced by Gladence et al. (2020). Cloud integration enhancing scalability and remote access was highlighted by Etuk et al. (2023). Priya and K (2021) tackled intelligent load scheduling, while Parial (2022) and Venubabu & Rama (2020) showcased adaptable IoT prototypes. Fitriyan et al. (2024) emphasized IoT-based security monitoring, complementing PLC's secure data exchange. These studies collectively provide a foundation for secure, scalable, and intelligent PLC-IoT smart home systems.

PROPOSED WORK

To address the growing demand for efficient, reliable, and cost-effective home automation, this proposed solution integrates Power Line Communication (PLC) with Internet of Things (IoT) technologies, leveraging existing power infrastructure for data transmission while enabling remote access through an IoT gateway. The system eliminates the need for dedicated communication wiring or full reliance on wireless protocols, thus reducing installation costs and improving communication resilience in environments with poor Wi-Fi coverage. The core of the solution is a hybrid design involving a dedicated in-house control hub, PLC-enabled smart nodes, and a remote IoT interface.

a. System Architecture and Components

The proposed system architecture consists of three main layers. The device layer includes electrical appliances connected to PLC-enabled control modules, which use microcontrollers with power line transceivers to interpret commands and control devices such as lights, fans, and security systems. Various sensors like temperature, motion, gas, and intrusion detectors are also integrated to continuously monitor home conditions. At the core is a control hub that connects the internal PLC network with the external IoT platform. This hub features dual interfaces—a PLC modem for power line communication within the house and a microprocessor gateway (such as Raspberry Pi or ESP32) with internet access for remote control. The hub runs embedded software for command processing, local automation rules, and synchronizes real-time data to the cloud.

b. Communication and Control Design

The communication backbone of the system relies on PLC, which uses modulated data signals superimposed onto the AC power lines to enable bi-directional communication between the control hub and end devices. To ensure data integrity and reliable performance, the system adopts error correction coding and frequency modulation techniques such as OFDM (Orthogonal Frequency Division Multiplexing), which are effective in mitigating noise and attenuation challenges commonly faced in power line environments. The hub continuously polls or listens to device feedback on the PLC network and updates the cloud interface. It is designed to operate in two modes: manual local control via physical switches or mobile applications connected to the local network, and remote control through an IoT dashboard or smartphone app. Commands issued from the remote app are transmitted to the hub via secure MQTT or HTTPS protocols, which then relay the appropriate control signals through the PLC channel.

c. IoT Integration and Remote Accessibility

For seamless integration with IoT platforms, the hub is connected to a cloud server such as AWS IoT, Google Cloud IoT Core, or a custom backend. The cloud component enables device registration, data logging, user authentication, and mobile notifications. Through this, users can access the system remotely, schedule tasks, receive alerts, or review historical data for appliances and sensors. In terms of mobile control, a user-friendly mobile or web application is designed with interfaces for room-wise device grouping, live status updates, scheduling functions, and real-time alerts. This interface communicates with the cloud, which relays instructions securely to the home-based hub. Role-based access ensures multiple users within the household can safely operate the system with customized permissions.

d. Design Benefits and Wire Network Optimization

Using Power Line Communication (PLC) as the main communication channel in smart homes eliminates the need for extra wiring or rewiring, as it utilizes existing electrical wiring for both power and data transmission. This reduces installation costs and allows easy retrofitting in older homes where modifying walls is difficult or expensive. PLC also provides reliable communication across multiple floors or large houses without signal loss common with Wi-Fi, removing the need for additional repeaters or boosters. Combining PLC with IoT further enhances the system by enabling remote access and control through cloud-based platforms. This hybrid PLC-IoT design offers a cost-effective, scalable, and robust home automation solution that balances wired communication's reliability with IoT's intelligence and flexibility. It is particularly suited for areas with weak wireless coverage or limited infrastructure upgrades, delivering a future-ready smart home framework.

METHODOLOGY

The development of the proposed PLC-IoT home automation system follows a structured methodology involving system design, hardware selection, software and firmware development, communication protocol creation, cloud integration, mobile app development, and testing. Initially, the system architecture is defined with a layered approach, including device, control, and application layers that communicate via existing electrical wiring using PLC technology. Hardware like microcontrollers interfaced with PLC transceivers and sensors are selected and embedded in smart nodes connected to household appliances. Firmware is developed for both end devices and the central hub to manage communication, local control, and data synchronization. A lightweight, fault-tolerant communication protocol ensures reliable data exchange over PLC, while MQTT enables secure cloud messaging for remote access. Cloud platforms handle data logging, session management, and real-time control via mobile or web apps with user-friendly interfaces for monitoring, automation, and alerting. The system undergoes thorough testing for functionality, performance, and security, ensuring a reliable and scalable solution suitable for cost-effective smart home automation, especially in infrastructure-limited environments.

SYSTEM WORKFLOW

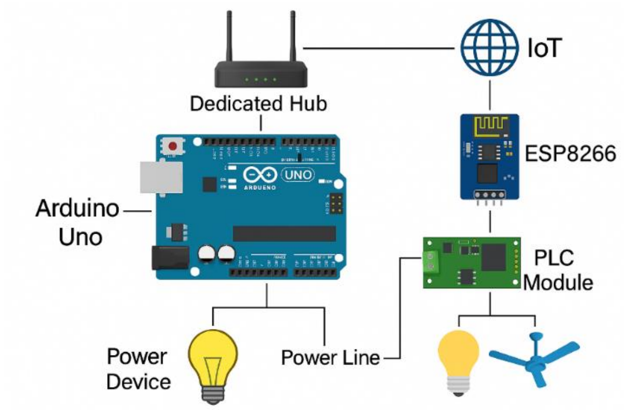

Figure 1.0: System block diagram

The system uses an Arduino Uno as the central controller, interfacing with sensors and actuators to process commands locally or from the cloud. A dedicated hub with an ESP8266 Wi-Fi module connects the Arduino to the internet, enabling secure MQTT or HTTP communication for remote control. The PLC module transmits data signals over existing electrical wiring, removing the need for extra cables. Appliances like lights and fans are controlled via relays triggered by PLC commands. Users can operate devices locally or remotely through mobile apps, with real-time feedback sent back for monitoring These appliances represent typical electrical loads that users may wish to control remotely. The light bulb and ceiling fan are connected to the Arduino via relay modules, which act as digital switches triggered by control signals. These devices are representative examples, and the system can be extended to support smart plugs, air conditioners, water heaters, or any other domestic electrical appliance. Control commands travel through the PLC and are interpreted by microcontroller units at each device end.

The diagram demonstrates an integrated and efficient approach to home automation using affordable, modular electronics. The use of Arduino Uno ensures local programmability and flexibility. The ESP8266 provides reliable cloud access for remote control. The PLC module smartly uses existing electrical wiring to reduce cost and improve reach, and the entire system scales well for a complete smart home with minimal infrastructure changes. This hybrid approach offers robustness in communication, flexibility in deployment, and ease of customization for various smart home applications.

CONCLUSION

The proposed PLC-IoT based home automation system presents a cost-effective, scalable, and efficient solution for smart living by utilizing existing power line infrastructure for communication. Integrating a dedicated control hub with PLC modules and IoT interfaces enables seamless local and remote control of home appliances without the need for extensive rewiring or reliance on unstable wireless signals. The system is especially suitable for rural and retrofit scenarios, offering real-time monitoring, automation, and enhanced energy management. In the future, the design can be extended to include artificial intelligence for predictive automation, adaptive scheduling, and anomaly detection. Integration with renewable energy systems, voice assistants, and blockchain-based data security frameworks can further enhance functionality and reliability. The adoption of advanced PLC chipsets and mesh networking protocols will improve communication robustness and coverage. Overall, this hybrid architecture lays the groundwork for a flexible and intelligent smart home ecosystem ready for evolving technological needs.

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