Transforming Underserved Communities Through Smart Home Solutions Based on IoT and PLC Integration

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Abstract- This research looks into how Power Line Communication (PLC) can be combined with the Internet of Things (IoT) to build an affordable, reliable, and scalable solution for remote home automation and monitoring. Since PLC uses the existing electrical wiring in a house, there's no need for extra communication cables, making it a practical option for data transmission in residential spaces.

The proposed system allows users to easily control and monitor smart appliances and sensors in real time through IoT platforms, improving convenience, saving energy, and strengthening home security. The study focuses on creating a hybrid architecture that integrates PLC-enabled microcontrollers with wireless IoT modules to provide wider coverage and lower latency.

It also tackles major challenges like signal loss, electrical noise, and the need for smooth communication between different types of devices. Ultimately, this research aims to develop a strong and dependable framework for smart homes, especially in rural or remote areas where wireless infrastructure is weak or unreliable. The goal is to support sustainable and inclusive digital living by making smart home technology more accessible to everyone.

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

I. INTRODUCTION

The idea of smart homes has advanced quickly over the last decade thanks to improvements in the Internet of Things (IoT), embedded systems, and wireless communications. Modern home automation aims to make daily life more comfortable, cut energy use, and strengthen security by enabling real-time monitoring and remote control of appliances and building systems. Most current smart-home setups rely on wireless standards like Wi-Fi, ZigBee, Bluetooth, and Z-Wave. While these protocols work well in many cases, they also suffer from limited range, interference, crowded bandwidth, and a heavy reliance on stable high-speed internet—shortcomings that become especially problematic in rural or remote regions where wireless infrastructure is patchy or unreliable.

Power Line Communication (PLC) presents a promising alternative. PLC sends data over the same electrical wiring that already runs through buildings, removing the need for extra communication cabling. Because it uses ubiquitous power lines, PLC can be a cost-effective, wide-coverage option for sending both power and information. Though PLC began in industrial and utility contexts for telemetry and automation, recent advances in modulation and noise-filtering techniques have made residential PLC far more practical. With appropriate signal conditioning, PLC can deliver secure, dependable links even in electrically noisy environments.

Marrying PLC with IoT has the potential to reshape smart-home deployments—especially in areas where wireless connectivity is weak. IoT sensors and actuators can gather and exchange live data to automate lighting, HVAC, security cameras, and appliance control. Using PLC as the home's communication backbone lets devices across different rooms and floors talk to each other reliably, without falling victim to signal loss through walls or electromagnetic interference. PLC also narrows some attack surfaces associated with open wireless networks, offering a comparative security advantage when properly implemented.

II. LITERATURE REVIEW

The growth of smart home technology has increasingly brought together Power Line Communication (PLC), the Internet of Things (IoT), and artificial intelligence to improve home automation, monitoring, and energy optimization. The reviewed studies present a range of strategies and system designs, each addressing challenges related to communication methods, scalability, user interaction, and efficient energy management.

Visan and Lita (2021) made a direct contribution to PLC-based automation by developing a remote-control system that uses existing electrical wiring to transmit control signals. Their work demonstrated how PLC can effectively overcome the limitations of wireless networks, particularly in environments with weak signals or bandwidth restrictions. Their design emphasized low-cost, compact hardware capable of real-time switching. However, their study remained largely hardware-focused and did not extend into IoT or cloud integration.

In contrast, the architecture proposed by ManojKumar et al. (2021) centered on a server-based IoT framework with distributed device control. Their system utilized a combination of embedded controllers and RESTful APIs to manage appliances independently through the internet. This design offered strong scalability and improved user accessibility. Although their system relied on wireless communication, the modular backend structure they introduced could be adapted to work

Artificial intelligence also plays a growing role in home automation.

Gladence et al. (2020). They developed an AI-powered recommender system capable of learning user habits and providing personalized appliance control suggestions. Although their study did not involve PLC, the intelligent automation layer they proposed could greatly enhance PLC-IoT systems by enabling predictive control and smarter energy usage.

Cloud integration was a focal point in the work of Etuk et al. (2023), who proposed a cloud-based automation model that supports real-time data access, system scalability, and remote management. Their architecture aligns well with the concept of a hybrid PLC-IoT system, where PLC handles internal communication while cloud services expand control and analytics capabilities.

Priya and K (2021) contributed by developing an IoT-enabled load scheduling and energy management system. Their model prioritized appliance usage based on user needs and grid conditions. Such scheduling algorithms can complement PLC by enabling power-aware communication and improving overall energy efficiency within a PLC-based IoT framework.

Finally, Fitriyan et al. (2024) focused on IoT-based security monitoring using sensor networks and instant alert mechanisms. Their emphasis on real-time threat detection aligns with the potential of PLC to serve as a secure, internal communication channel. Integrating their sensor and alert systems with PLC can strengthen home security solutions without relying on Wi-Fi or cellular networks.

III. PROPOSED WORK

To meet the rising need for smart home systems that are dependable, efficient, and affordable, the proposed model blends Power Line Communication (PLC) with Internet of Things (IoT) technology. By using the existing electrical wiring for data transfer and an IoT gateway for remote connectivity, the solution removes the dependence on dedicated communication cables or fully wireless setups. This not only cuts installation costs but also ensures stronger communication performance in areas where Wi-Fi coverage is weak. The design is built around a hybrid framework that includes an in-house control hub, PLC-enabled smart nodes, and a remote IoT interface for monitoring and control.

a. System Architecture and Components

The system is organized into three main layers: the device layer, the communication layer, and the application layer.
At the device layer, everyday appliances are connected to PLC-based controller modules equipped with microcontrollers and power line transceivers. These modules read commands sent over the electrical wiring and operate appliances such as lights, fans, air conditioners, and security devices. A range of sensors—including motion detectors, temperature sensors, gas leak sensors, and intrusion detectors—are also integrated into the network to provide continuous monitoring of home conditions.

b. Communication and Control Design

The system's communication backbone is PLC, which works by sending modulated data signals over the AC power lines already installed in the home.
The control hub constantly receives updates from the smart nodes and synchronizes this information with the cloud. It supports two modes of operation:

1. **Local manual control**, using physical switches or a mobile app within the home network.
2. **Remote access**, through an IoT dashboard or smartphone application.

Commands sent remotely are securely transmitted via protocols such as MQTT or HTTPS to the hub, which then communicates the appropriate signals to the devices through the PLC network.

c. IoT Integration and Remote Accessibility

To enable seamless IoT functionality, the control hub connects to a cloud platform such as AWS IoT, Google Cloud IoT Core, or a custom-built backend. These cloud services support device management, data storage, user authentication, and real-time notifications. Through this cloud link, users can monitor their homes remotely, schedule appliance operations, view historical sensor data, and receive alerts from anywhere.

d. Design Benefits and Wiring Optimization

This approach is especially useful in large homes or multi-floor buildings where Wi-Fi signals may weaken. PLC maintains stable communication across all rooms and floors without needing repeaters or range extenders, maximizing the efficiency of the electrical wiring network. The addition of IoT connectivity ensures that the system can be accessed from anywhere in the world, giving users flexibility and convenience

IV. METHODOLOGY

The development of the proposed PLC-IoT home automation system follows a structured and sequential methodology that covers hardware selection, embedded programming, communication protocol design, cloud integration, and user interface creation.

The starting point is the system architecture design, where user requirements such as manual appliance control, sensor-based automation, remote operation, and scalability are clearly identified. A multi-layered architecture is then conceptualized. This includes the device layer (made up of sensors and actuators), the control layer (PLC-enabled microcontroller units), and the application layer (the central hub and cloud services). One of the core design decisions is the adoption of PLC as the internal communication medium, allowing the system to reuse the existing electrical wiring of buildings. The central controller or gateway is designed using microcontroller platforms such as ESP32, STM32, or Raspberry Pi, combined with a PLC modem and wireless connectivity module.

During the hardware implementation phase, suitable PLC transceiver modules are selected based on their performance over low-voltage AC lines. Components like the Yitran IT700 or STMicroelectronics ST7580 are evaluated and interfaced with microcontrollers using UART or SPI communication. These PLC transceivers are embedded into relay boards or switch modules that connect to household appliances. Firmware development plays a critical role in enabling device communication and system reliability. On the end-device side, embedded software is programmed to handle PLC data encoding and decoding, frame construction, and interrupt-driven communication routines. The firmware manages device control, sensor data processing, and real-time feedback to the hub.

A lightweight and robust communication protocol is designed specifically for PLC-based data exchange. The protocol includes a custom packet format with start and stop bits, device addressing, command type, payload, and CRC for error detection.

Cloud integration is achieved using platforms like AWS IoT Core, Firebase, or private MQTT servers. The hub publishes real-time device data and sensor readings to cloud topics while subscribing to control messages.

To enable user-friendly interaction, a mobile and web application is developed with a clean and intuitive interface. Users can monitor real-time device status, operate appliances, set schedules, and define custom automation rules.

V. SYSTEM WORKFLOW

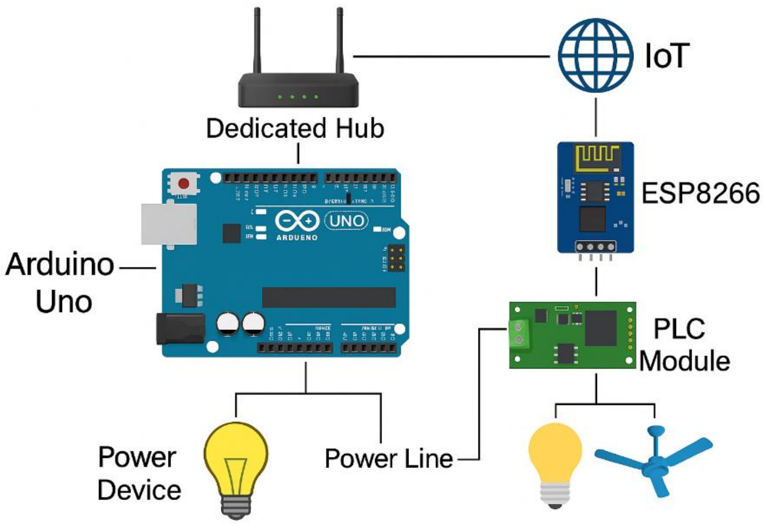

Figure 1.0: System block diagram

The regenerated block diagram illustrates a component-level view of a PLC-IoT home automation system built using commonly available, low-cost electronic components. Each block in the system plays a specific role, ensuring compatibility, performance, and practicality for real-world PLC and IoT applications. The following section explains each component and how it contributes to the functioning of the overall system.

The **Dedicated Hub** serves as the bridge between the home's PLC-based internal network and the external IoT environment. In this configuration, the Arduino communicates with the hub using an ESP8266 or similar wireless module. Acting as the gateway, the hub manages all MQTT or HTTP communication between the cloud and the local network. It enables secure remote access, so users can control devices or check system status from anywhere through a mobile application.

The **ESP8266 Wi-Fi module** provides the Arduino with internet connectivity. It links the system to a home Wi-Fi network and facilitates communication with cloud platforms such as Firebase, AWS IoT, or an MQTT broker. Known for its low cost, compact size, and built-in TCP/IP support, the ESP8266 is widely used in IoT systems due to its ability to efficiently handle HTTP and MQTT communication.

The **PLC Module** is a key part of the system because it allows data signals to be transmitted over existing household power lines. It converts digital data into modulated signals that travel over 110V/220V AC wiring and decodes incoming signals from other PLC-equipped nodes. The module interfaces with the Arduino through UART or SPI and acts as a communication bridge. By using PLC technology, the system removes the need for extra wiring and becomes especially useful for older buildings or locations with poor wireless coverage. Any device connected to the power network and equipped with a PLC interface can exchange data through this module.

The **Power Line** block in the diagram represents the home's existing electrical wiring, which now serves two purposes: delivering power to appliances and carrying data signals between PLC-enabled devices. This dual-use approach simplifies installation and significantly lowers system cost. Every device connected to the same electrical circuit can communicate seamlessly once outfitted with a PLC module.

The connected **appliances**—represented by a light bulb and ceiling fan—illustrate typical loads that users may remotely control. These appliances are connected to the Arduino through relay modules, which act as electronically controlled switches. The system can be easily extended to other devices like air conditioners, smart plugs, or water heaters. Control commands travel over the power line through PLC and are executed by microcontroller units at the appliance end.

The system supports both local and remote operation:

- **Local Control:** The Arduino executes commands from sensors or predefined routines and controls devices directly using the PLC network.
- **Remote Control:** User commands sent from a mobile application reach the cloud, then pass through the hub and ESP8266 before reaching the PLC module. The PLC module sends the modulated signals through the power line to activate the target device.
- Device status or sensor readings are sent back through the same route, allowing real-time monitoring in the mobile app.

VI. CONCLUSION

The proposed PLC-IoT home automation system offers an affordable, scalable, and efficient smart home solution by using the existing electrical wiring for communication. By combining a centralized control hub with PLC modules and IoT connectivity, the system supports both local and remote appliance control without requiring major rewiring or depending on unreliable wireless networks. This makes it especially valuable for rural areas and older homes where infrastructure constraints limit the use of conventional smart home technologies.

The solution provides real-time monitoring, automated device control, and improved energy management, creating a more convenient and responsive living environment. Looking ahead, the system can be enhanced with artificial intelligence to enable predictive automation, intelligent scheduling, and early detection of abnormal conditions. Additional improvements—such as integration with renewable energy systems, voice-controlled assistants, or blockchain-based security—can further strengthen system reliability and user experience. As more advanced PLC chipsets and mesh networking techniques become available, the communication range and stability of the system will continue to improve.

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