International Journal of Advanced Culture Technology Vol.11 No.1 395-402 (2023)
DOI https://doi.org/10.17703/IJACT.2023.11.1.395

IJACT 23-3-48

Bridging the Connectivity Gap Within a PLC-Wi-Fi Hybrid Networks

[1]Shafi Ullah Khan, [2]Taewoong Hwang, [3]In-Soo Koo

[1,2,3]Department of Electrical Electronics and Computer Engineering,
University of Ulsan, Republic of South Korea
16pwele4945@uetpeshawar.edu.pk, yuio124@naver.com, iskoo@ulsan.ac.kr

Abstract

The implementation of a hybrid network utilizing Power Line Communication (PLC) and Wi-Fi technologies has been demonstrated to improve signal strength and coverage in areas with poor connectivity due to internet shadow areas. In this study we strategically positioned Wi-Fi relays and utilized the capabilities of PLC technology to significantly improve signal strength and coverage in areas with poor connectivity. We also analyzed the effects of metallic obstacles on Wi-Fi signal propagation and proposed a solution to strengthen the signal enough to pass through them. Our experiment demonstrated the feasibility and potential of using this hybrid network in industrial scenarios for real-time data transmission. Overall, the results suggest that the use of PLC and Wi-Fi hybrid networks can be a cost-effective and efficient solution for overcoming internet connectivity challenges and has the potential to provide high-speed internet access to areas with unreliable signals.

Keywords: *Power Line Communication, Hybrid PLC-Wi-Fi Communication Technology, Real Time Data Communication*

1. INTRODUCTION

In recent years, the Internet has emerged as a versatile platform, encompassing several functions including e-commerce, online education, telemedicine, e-banking, online transactions, and research. This has been facilitated by advancements in technology, which have enabled people to access and exchange information at unprecedented speeds. According to the International Telecommunication Union, as of 2020, around 51% of the global population is using the internet, and this number is projected to continue rising in the coming years [1]. The lack of reliable signal and stable internet connections in some areas in wireless network often impedes access to digital services. In order to enable the provision of digital services such as e-commerce, online education, telemedicine, e-banking, and online transactions, it is essential to have a communication network with mobile accessibility, flexible data dissemination, and high data transfer capabilities. The transmission networks must also provide guaranteed throughput and Quality of Service (QoS) due to the nature of digital data. In recent times, both public and private sector organizations have adopted communication and networking technology for digital applications, to provide customers and employees with these digital services. Several recent technologies such as Local Area Networks (LANs), Radio Frequency (RF), ZigBee, and Wide Area Networks (WANs) are being used for real-time applications [2-3]. Among them, wireless technologies have become increasingly popular in various fields, including e-commerce, online education, telemedicine, and e-

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Manuscript received: February 19, 2023 / revised: March 5, 2023 / accepted: March 15, 2023

Corresponding Author: iskoo@ulsan.ac.kr
Tel: +82-52-259-1249
Professor, Department of Electrical, Electronic and Computer Engineering, University of Ulsan, Korea

banking applications. However, these technologies present several challenges related to signal dispersion and coverage range, especially when used across large regions [4-5]. For instance, Radio Frequency (RF) and Bluetooth-based devices face limitations when operating in areas with concrete walls and other obstructions [6-7]. Additionally, Ethernet-based systems may lack flexibility and may require expensive setup processes, particularly in buildings with multiple stories. To overcome these challenges, it is necessary to develop and integrate different technologies to build a hybrid network that combines the most used wireless technology with wired technology, resulting in a cost-effective and flexible solution. A hybrid network offers benefits such as improved coverage and reliability, increased bandwidth, and the ability to transmit large amounts of data even over a long distance. By integrating wired and wireless technologies, a hybrid network can overcome the limitations of each technology and leverage their respective strengths. The implementation of a hybrid network requires careful planning and design to ensure that it meets the specific requirements of the intended application. This involves selecting appropriate network components, such as routers, switches, Wi-Fi relays, and access points, and configuring them to work together seamlessly. Furthermore, it is essential to consider factors such as security, scalability, and manageability when designing a hybrid network.

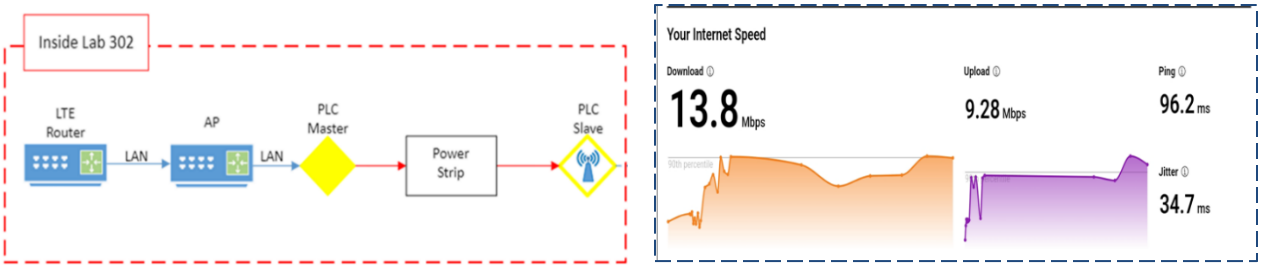
Now a days, power line communication (PLC) has been extensively used to develop broadband networks with high data transmission rates based on power grids [8]. The PLC technology is designed to achieve burst data speeds of up to 20 Mbit/s over power-line connections, making it suitable for in-building multimedia applications. The superimposition of high-frequency signals on the low-frequency power line signals enables communication over the power line network. The data rate of PLC technology has reached up to 200Mbps on the physical layer, which is higher than its theoretical value. This high data rate, like Wi-Fi and domestic Ethernet, makes it suitable for various applications, such as high-definition video streaming, video conferencing, online gaming, and cloud computing. One of the primary benefits of employing PLC networks is the ability to reuse the existing wired electrical network to offer communication capabilities, making it cost-effective for broadband communication applications. Moreover, the PLC technology offers a robust and reliable communication infrastructure without the need for new cabling, thus avoiding wireless propagation issues. Hence, the smart grid remains one of the most appealing uses of PLC technology, and research in this field is extensive. In addition to smart grid applications, PLC technology has also proven its effectiveness in smart city [9], in-home automation [10], and telemetry [11] applications, where new cabling is not required, and wireless propagation issues are avoided. Furthermore, PLC-based plug-and-play extenders are gaining popularity in the market due to their easy installation and connectivity [12]. Therefore, PLC technology has become a promising solution for both broadband (BB) applications, such as interactive multimedia home with video conferencing, and narrowband (NB) communication, such as IoT smart house.

The integration of wired and wireless technologies in a hybrid network can address the limitations of each technology while leveraging their strengths. However, the use of wireless technology in the hybrid network can also lead to signal dispersion issues, resulting in shadow areas where signal strength is weakened or absent due to obstructions such as walls, floors, or other physical barriers. These shadow areas can negatively impact network performance and security, leading to decreased productivity and efficiency. To address this issue in PLC-Wi-Fi hybrid networks, we propose a cost-effective solution for enhancing Wi-Fi signal penetration through obstacles, including metallic barriers. We conducted laboratory experiments to analyze the throughput of the proposed method and established a client-server setup to evaluate its feasibility for real-time applications. Our results demonstrate the effectiveness of our proposed approach in improving network coverage and overcoming shadow area problems in hybrid networks. Also, the proposed PLC-Wi-Fi can be used as a candidate for a real time data transfer within a network.

The rest of this Paper is organized as follow: section 1 consists of the brief introduction to PLC and literature background of the Power Line Communication systems. Section 2 describes the overview of network architecture and basic parameters. Section 3 shows the performance analysis of the PLC-Wi-Fi network by transferring real-time data through this hybrid network and finally, Section 4 concludes the paper.

2. NETWORK STRUCTURE

This research article focuses on the construction and evaluation of a hybrid network structure utilizing Power Line Communication (PLC) and Wi-Fi technology. The study was conducted in Building 7, Lab 302 of the University of Ulsan. To establish the network, an LTE router was connected to an Access Point (AP), which was then linked to the Tenda PLC Master via Ethernet cable. The Tenda P3 Master was connected to a Tenda PA7 Slave using a Power line cable, as depicted in Figure 1. The Tenda Power Line adaptor kit is designed to operate in two modes: 2.5GHz and 5GHZ. For this study, we utilized the Tenda Power line Adapter Kit in 2.4 GHz mode. We measured the speed of the Tenda PA7 slave by accessing the Cloudfare.com website on a client device. The results revealed a download speed of 13.8 Mbps, an upload speed of 9.28 Mbps, and a pinging delay of 96.2ms, as shown in Figure 2.



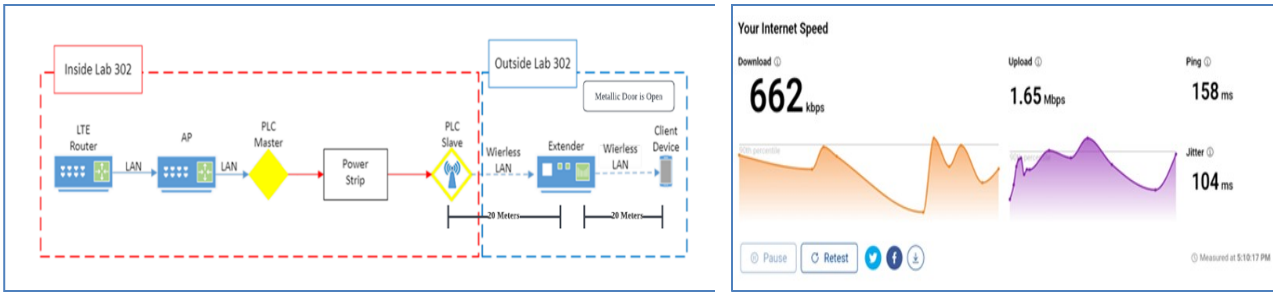
(a) (b)

**Figure 1. (a) System setup inside laboratory,
(b) Throughput of Tenda PLC Slave in 2.4 GHz Mode**

In our experimental setup, we utilized a Wi-Fi relay to facilitate wireless connectivity between a PA7 PLC Slave and a client device. The relay was positioned 20 meters away from the PLC Slave and was able to establish a wireless connection with it. In order to investigate the effect of metallic obstacles on the Wi-Fi signal propagation and the subsequent impact on the client device, we analyzed two configurations. The first configuration involved no metallic obstacle between the line of propagation of Wi-Fi signals and the client device. The second configuration introduced a metallic obstacle between the client device and the Wi-Fi relay. Through these analyses, we aimed to gain insights into the performance of the wireless system in challenging environments with the presence of metallic barriers.

2.1 Wi-Fi Relay Connection without Metallic Obstacle

Our aim was to evaluate the internet connection speed on the client device that was also 20 meters away from the Wi-Fi relay. It should be noted that the signal had to traverse through a steel door enroute from the relay to the client device, which remained open during these measurements. The entire setup consisted of the Wi-Fi relay, the PLC Slave, and the client device, as shown in Figure 2(a). Cloudflare.com was utilized to measure the internet speed on the client device. Our findings, depicted in Figure 2(b), demonstrate that the upload speed was 1.65 Mbps, while the download speed was 662 Kbps. The pinging delay was recorded as 158ms. In this case the steel door was open meaning that there was no metallic obstacle in the between the client device and Wi-Fi relay to which the client device was connected.

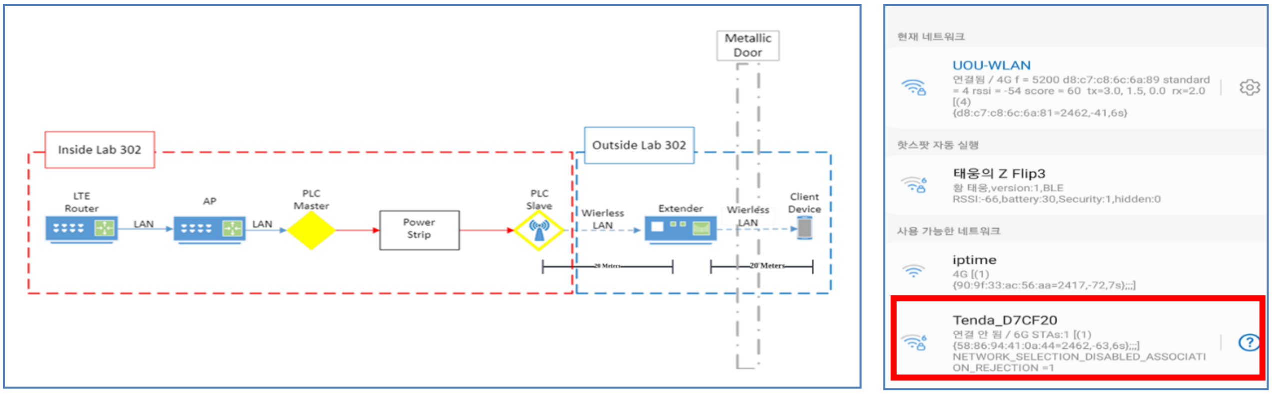


(a) (b)

Figure 2. (a) System setup (b) Measurement results

2.2 Metallic Obstacle Impact on Wi-Fi Relay Connection

In the context of examining the penetration of Wi-Fi signals through metallic obstacles, the configuration used in a previous experiment was replicated. However, in this instance, a closed metallic door was inserted between the signal route from the Wi-Fi extender to the client device. The purpose of this new configuration was to investigate the effect of a metallic obstacle on signal strength. Figure 3 (a) shows the metallic door placement between the signal route, while Figure 3 (b) depicts the resulting restricted network access due to the degraded signal strength caused by the metallic door. The experiment showed that the Wi-Fi signal strength was significantly attenuated to the extent that the client device was unable to connect to the network. This experiment demonstrates the importance of understanding the factors that can impact Wi-Fi signal strength and accessibility, particularly when dealing with metallic obstacles. The findings can inform the development of strategies to improve Wi-Fi signal penetration through such obstacles to enhance network connectivity and accessibility.



현재 네트워크

UOU-WLAN
연결됨 / 4G f = 5200 d8:c7:c8:6c:6a:89 standard = 4 rssi = -54 score = 60 tx=3.0, 1.5, 0.0 rx=2.0
[(4)
{d8:c7:c8:6c:6a:81=2462,-41,6s}

핫스팟 자동 실행

태웅의 Z Flip3
황 태웅,version:1,BLE
RSSI:-66,battery:30,Security:1,hidden:0

사용 가능한 네트워크

iptime
4G [(1)
{90:9f:33:ac:56:aa=2417,-72,7s};;;]

Tenda_D7CF20
연결 안 됨 / 6G STAs:1 [(1)
{58:86:94:41:0a:44=2462,-63,6s};;;]
NETWORK_SELECTION_DISABLED_ASSOCIATION_REJECTION =1

(a) System Setup (b) Wi-Fi available connection at client device

Figure 3. Experimental setup with metallic door

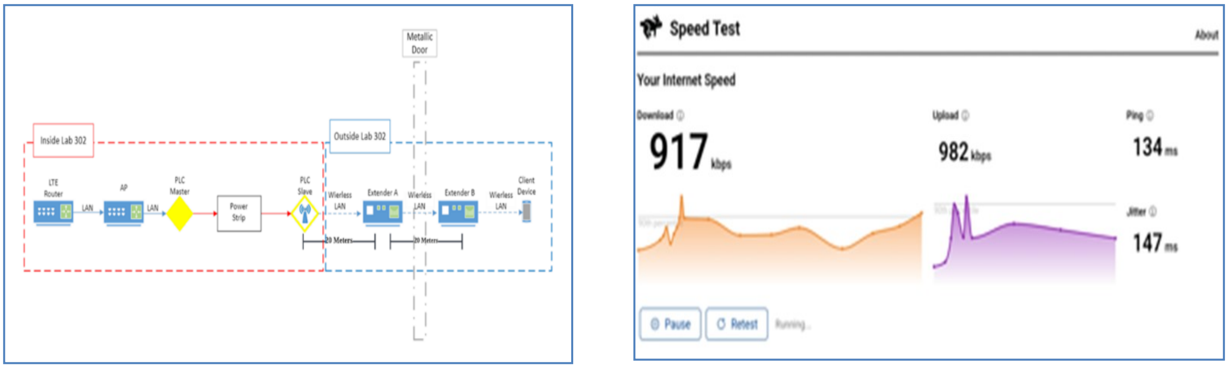
2.3 Improving Wi-Fi Coverage in Obstructed Areas

In order to improve Wi-Fi signal coverage in areas with obstacles or shadowed regions, a mesh network approach can be employed using two compatible Wi-Fi relays. The relays are strategically located and configured as mesh network nodes, with one relay serving as the master node connected to the network router. The two relays are then wirelessly connected by entering the Service Set Identifier (SSID) and password on the configuration interface, and the signal strength is checked to confirm successful establishment of the connection.

To test the efficacy of this approach, we conducted a case study wherein we installed a second relay on the opposite side of a metallic obstacle, as shown in Figure 4(a), to address issues with weak signal and unstable internet coverage. Both relays were wirelessly linked using the mesh network approach, and the signal strength was measured using cloud-based speed assessment tools such as Cloudflare.com. Experimental findings showed in Figure 4(b) depicts that the signal power improved, resulting in calculated upload and download speeds of 982 kbps and 917 kbps, respectively, and with a response time of 134ms.

2.4 Location of Different Network Elements in PLC-Wi-Fi Setup

The objective of this work was to enhance the flexibility of a hybrid PLC-Wi-Fi network in terms of coverage, signal propagation, and obstacle penetration. To achieve this, we utilized a Lidar sensor to generate a 2D map of the University of Ulsan's 3rd floor, which enabled us to analyze the environment and optimize the placement of network components. First, we placed the Wi-Fi Access Point (AP) at Point A and connected a Wi-Fi relay wirelessly at Point B to it, located 20 meters from the AP, to extend coverage and enable signal penetration through obstacles. However, we encountered a metallic doo r near Point B that could interfere with the signal's propagation. To overcome this issue, we installed another Wi-Fi relay at Point C, which created a mesh network that enabled the signal to bypass the metallic obstacle. To evaluate the network modifications, we analyzed the Wi-Fi signal at Point D using CloudCompare .com. This allowed us to measure the signal strength, coverage, and penetration capabilities of the network in real-time, which enabled us to fine-tune the placement of the network components. The mesh network we created enabled us to overcome signal attenuation caused by metallic obstacles, which improved coverage and flexibility in the hybrid PLC-Wi-Fi network. These modifications could have applications in environments where metallic obstacles may pose a challenge to signal propagation and coverage, such as factories or hospitals.



(a) System Model (b) Throughput measurement results

Figure 4. System setup with metallic obstacle with two relays

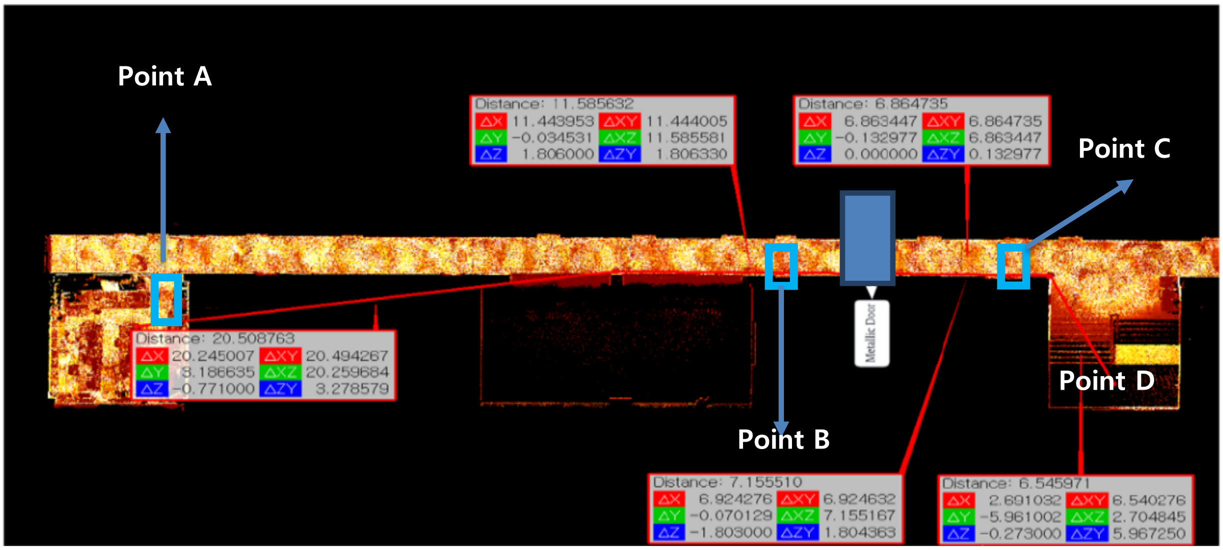


Figure 5. 2D-Lidar Map of the 3rd Floor and Location of Different Network Elements in PLC-Wi-Fi Setup

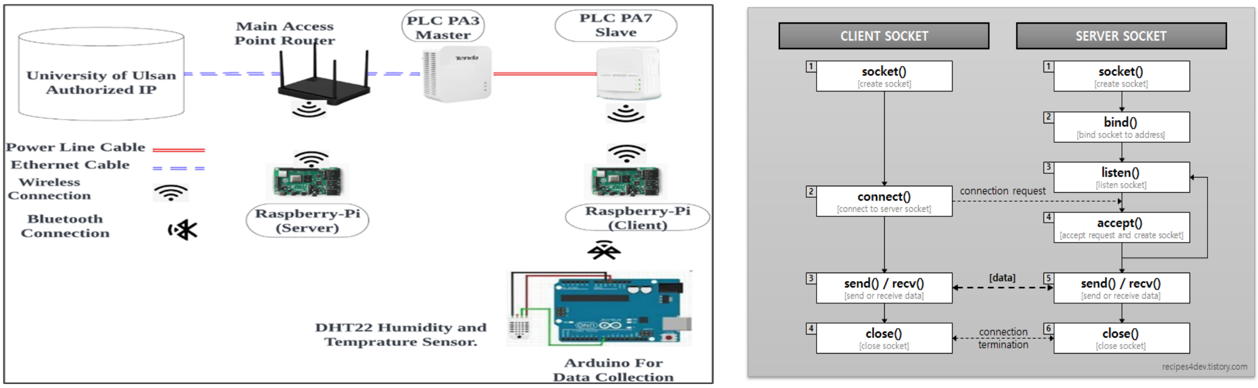
3. REAL TIME DATA TRANSFER

In order to evaluate the feasibility and robustness of a PLC and Wi-Fi hybrid network for industrial applications, it is necessary to transmit real-time data through the network. As a proof of concept, we conducted a demonstration in the laborat ory, as depicted in Figure 6 (a), where we transferred real-time temperature and humidity data through the network. The setup involved connecting a Tenda PLC Master to an access point router via LAN cable. The Tenda P3 Master was then linked to a Tenda PA7 Slave via a power line cable. Next, we connected a Raspberry Pi to both ends of the network via Wi-Fi. The Raspberry Pi connected to the main access point router was configured as a server, while the Raspberry Pi linked to the other end was configured as a client device. To transfer real-time data to the server Raspberry Pi, we utilized a DHT22 sensor, Bluetooth module, and Arduino. The data was then transmitted through the network to the server, which enabled us to analyze the network's feasibility and robustness in real-time industrial applications.

3.1 Socket Communication

Socket communication is a powerful and reliable means of communication between two programs running on a network. It allows for inter-process communication (IPC) by establishing named contact points between which data can be exchanged bidirectionally in a first-in, first-out (FIFO) manner. In essence, a socket is one endpoint of a two-way communication link between two programs, which enables them to exchange data in real-time. A socket is created at each end of the communication and has a specific address, which is composed of an IP address and a port number. This address provides a unique identifier for the socket, allowing other programs on the network to connect to it and exchange data.

Sockets are commonly used in client-server applications, where the server creates a socket and assigns it to a specific network port address, waiting for the client to establish contact. The client, in turn, creates its own socket and attempts to connect to the server's socket, initiating a connection-oriented communication model. Once the connection is established, data can be transmitted between the client and the server through the sockets.



(a) System model

(b) Socket Communication flow diagram

Figure 6. Real time temperature and humidity data transfer

For our experiment we also utilized Socket communication for the data transfer, which follows a standard sequence of steps. In a client-to-server model based on a connection-oriented approach, the socket on the server side is always ready to receive requests from a client. To accomplish this, the server first sets up (binds) an address for clients to locate it. After the address has been established, the server waits for clients to request a service. The client-to-server data exchange occurs when a client connects to the server using a socket. The server then processes the client's request and responds back to the client with the required data. A diagram of the flow can be observed in Figure 6(b).

4. CONCLUSION

In conclusion this project successfully implemented a hybrid network of PLC and Wi-Fi technologies to address the problem of internet shadow areas. By strategically positioning Wi-Fi relays and utilizing the capabilities of PLC technology, we were able to significantly improve the signal strength and coverage in areas that previously suffered from poor connectivity. We also proposed a solution to overcome signal obstruction caused by metallic obstacles. Our findings suggest that optimal placement of Wi-Fi relays can overcome the problem of shadow areas and signal obstruction. Furthermore, our experiment demonstrated the feasibility and potential of using this hybrid network in industrial scenarios for real-time data transmission. The use of PLC and Wi-Fi hybrid networks can be a cost-effective and efficient solution for overcoming internet connectivity challenges, providing high-speed internet access to people living in areas with unreliable signals. Future research can further explore the capabilities of this technology and investigate ways to optimize network performance for a wide range of applications.

ACKNOWLEDGEMENT

This work was supported in part by the ICT R&D innovation voucher conducted in 2022 with the support of the Institute of Information and Communications Technology Planning and Evaluation (IITP), funded by the government's Ministry of Science and ICT.(No. 2022-0-00805, Development of wired/wireless communication technology for installation safety communication network for workers in shaded areas of building ships). In addition, this result was supported by the “Regional Innovation Strategy (RIS)” through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (MOE) (2021RIS-003)

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