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An Empirical Study of HomePlug AV2 PowerLine Performance in Real-World Residential Electrical Networks

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Abstract. PowerLine Communication (PLC) represents a class of wired communication technologies that leverage existing low- and medium-voltage electrical wiring to transmit high-frequency modulated data signals, enabling network connectivity without the need for dedicated cabling. While PLC has gained significant traction as a practical alternative to Wi-Fi extenders and Ethernet cabling for in-home broadband distribution, empirical evidence on its real-world performance – particularly under diverse electrical topologies and noise conditions—remains limited. This paper presents a controlled measurement study of a commercial HomePlug AV2 1000 Mbps kit (TP-Link TL-WPA8631P + TL-PA8010P), operated exclusively in wired Ethernet mode with Wi-Fi disabled. We evaluate throughput and jitter across multiple residential scenarios, including same-phase baseline measurements, the use of power strips, and the presence of electromagnetic interference (EMI) sources. Our findings show that although the data throughput provided by PLC technology falls short of the rates advertised by vendors, it is nevertheless capable of maintaining stable communication over distances of several tens of meters. Jitter remains at a negligible level, which makes the technology suitable for multimedia transmission. Furthermore, neither the use of power-strip extensions nor the presence of electromagnetic interference introduces any substantial degradation in PLC-based data delivery. These results highlight both the progress and the constraints inherent to PLC systems, providing useful insights for smart-home integrators and emphasizing how strongly PLC performance depends on the characteristics of a home's electrical network.

Keywords: PLC, HomePlug AV2, in-home network, performance, smart home

1. Introduction

PowerLine Communication (PLC) has emerged as a significant networking trend over the past decade. While initially introduced in foundational networking curricula as an alternative connectivity method, its practical deployment has grown substantially. PLC technology offers a viable solution for extending network coverage across multiple floors or rooms without the need for invasive cabling, drilling through reinforced concrete, or installing aesthetically intrusive cable ducts. After observing the practical benefits of PLC deployments over a two-year period, and noting the lack of empirical performance data in recent literature, this study aims to examine the advantages and limitations of PLC technology through detailed, industry-standard performance measurements [1–5, 7, 10].

PLC utilizes the existing electrical wiring infrastructure for data transmission [8, 9]. Deployment requires only a PLC kit containing at least two adapters. The first adapter is connected to a wall socket and to the wired Ethernet network. A second adapter is plugged into another outlet on the same electrical phase elsewhere in the building, allowing it to receive the network signals injected by the first adapter and provide connectivity—either wired or wireless, depending on the model.

Recent studies have highlighted the potential of PLC in smart grid and IoT applications [2, 3], while others have focused on physical layer security and broadband service limitations [9, 10]. However, as noted by [8], real-world performance can vary significantly based on local electrical topology. Our empirical results align with the observations of Ribeiro et al. [6] regarding the complementary nature of PLC and wireless systems. Specifically, our measurements demonstrate that while throughput drops compared to nominal values, latency (jitter) remains highly stable, making PLC a viable and reliable option for specific multimedia and smart-home applications where traditional cabling is impractical.

2. Operating Principle of PLC Technology

PowerLine Communication operates by superimposing a high-frequency data signal onto the standard 230 V / 50 Hz AC mains voltage. Although these two signals propagate along the same physical conductor, they occupy distinct frequency domains and therefore do not interfere with one another. Mathematically, the combined waveform is expressed as the sum of v_{mains}, representing the 220 V AC voltage, and v_{data}, representing the approximately 5 V data signal.

$$v_{\text{mains}}(t) = V_{\text{peak}} \sin(\omega t)$$

where $V_{\text{peak}} = 325$ V (because $230 \cdot \sqrt{2} \approx 325$ V) and $\omega = 2\pi \cdot 50$ rad/s

$$v_{\text{mains}}(t) = 325 \sin(2\pi \cdot 50t)$$

$$v_{\text{data}}(t) = V_{\text{data}} \sin(\omega_{\text{data}} t)$$

where $V_{\text{data}} = 5$ V and $\omega_{\text{data}} = 2\pi \cdot 10^6$ rad/s

$$v_{\text{data}}(t) = 5\sin(2\pi \cdot 10^6 t)$$

In a PLC-based communication:

$$v_{\text{line}}(t) = v_{\text{mains}}(t) + v_{\text{data}}(t)$$

$$v_{\text{line}}(t) = 325\sin(2\pi \cdot 50t) + 5\sin(2\pi \cdot 10^6 t)$$

They do not interfere because, in a linear system:

- signals at different frequencies are orthogonal, and
- they can be effectively separated using filters (e.g., OFDM – Orthogonal Frequency Division Multiplexing).

Mathematically:

$$\int_0^T \sin(2\pi 50t) \cdot \sin(2\pi 10^6 t)\, dt = 0$$

While the mathematical orthogonality described above holds true in ideal linear systems, it is important to note that real-world electrical networks do not perfectly meet these conditions. Practical power grids introduce non-linearities, impedance variations, and background noise from various connected devices. Consequently, real-world PLC systems must employ robust modulation techniques (such as OFDM) and advanced error correction to mitigate these interferences. This discrepancy between ideal theoretical models and practical network behavior is the primary motivation for the empirical measurement approach presented in this paper.

Figure 1 depicts the composite signal on the electrical network: the red component has high amplitude and low frequency, whereas the blue component exhibits low amplitude and high frequency.

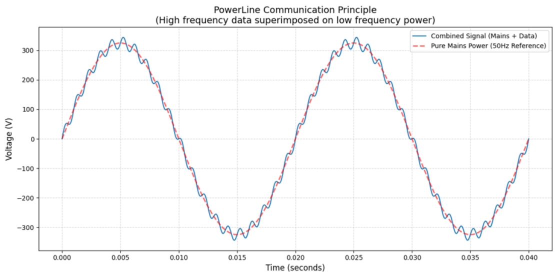


Figure 1. PLC composite signal.

Figure 2 presents the separation of the two signals on a logarithmic scale, highlighting the substantial spectral distance that enables concurrent, interference-free transmission. On a linear scale, this distance would span several kilometers.

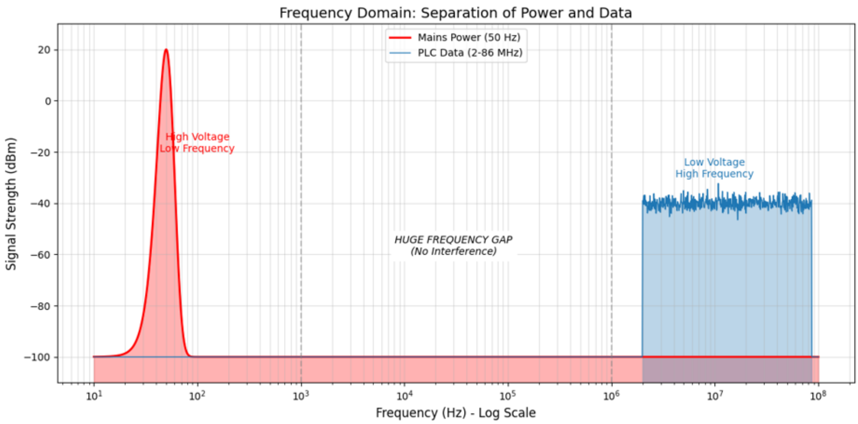


Figure 2. Separation of electrical and data signals during PLC transmission.

3. Types of PLC Technologies

In recent years, several PLC standards have been introduced. Table 1 summarizes the most relevant technologies. For our measurements, we utilized PLC adapters based on the HomePlug standard.

Table 1. Types of PLC standards.[1]

Category	Technology	Frequency	Range	Data Rate	Standards
Narrowband	G3-PLC	< 148.5 kHz (EU) < 490 kHz (FCC)	Long	< 280 kbps	ITU-T G.9901 ITU-T G.9903 IEEE 1901.2
Mid-band	HPLC	0.7 - 12 MHz	Middle	150 kbps to 10 Mbps	IEEE 1901.1
Broadband	HomePlug	1.8 - 86 MHz	Short	< 1.3 Gbps	IEEE 1901
Broadband	G.hn	2.0 - 80 MHz	Short	< 1.5 Gbps	ITU-T G.9960 ITU-T G.9961 ITU-T G.9962 ITU-T G.9964

[1] Source: https://nessum.org

4. Measurement Environment

We conducted all PLC-based measurements in the building of the Faculty of Informatics at the University of Debrecen (see Figure 4). Our measurement environment consisted of two computers, two PLC adapters, and a laptop (see Figure 3).

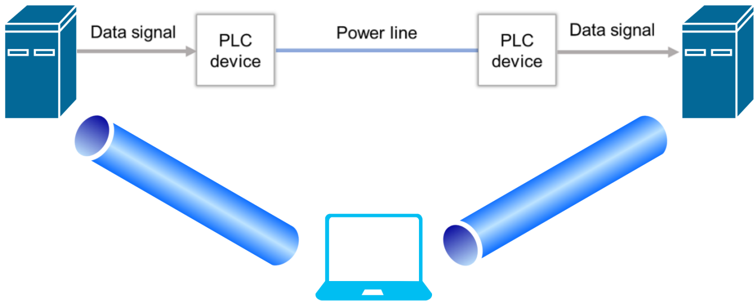


Figure 3. PCL measurement environment.

The computers ran a Linux Server operating system with the following configuration:

- Gigabyte Z77-D3H motherboard with Intel Z77 chipset
- Intel Core i7-3770K 3.50 GHz processor (4 cores / 8 threads)
- 4 × 4 GB 1600 MHz DDR3 SDRAM
- Intel quad Gigabit Ethernet server adapter
- Ubuntu 24.04 LTS (Noble Numbat), 64-bit
- Linux kernel: 6.8-generic

Initially, the PLC adapters were connected to adjacent electrical outlets. We then progressively increased the distance between outlets to 3 m, 5 m, 10 m, 13 m, and 20 m (see Figure 4).

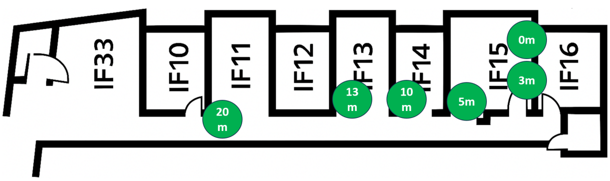


Figure 4. Floor plan of the measurement environment. The numerical values shown indicate the distances between the connectors.

(a) TL-WPA8631P and TL-PA8010P PLC adapters. **(b)** Building a PLC-based network.

Figure 5. TP-Link HomePlug AV2 1300 kit.

We performed baseline *iperf3* measurements to assess UDP and TCP throughput as well as UDP jitter. The left-side PC was configured as the *iperf3* server, and the right-side PC executed the following commands:

- `iperf3 -u -b 1G -c 192.168.1.1 bidir -t 60`
- `iperf3 -c 192.168.1.1 -t 60 -i 1 -f m`
- `iperf3 -c 192.168.1.1 -u -t 60`

Each measurement lasted 60 seconds and was repeated ten times. The Wi-Fi modules of the PLC adapters were disabled during all tests. The laptop was used for remote SSH management. In addition to baseline measurements, we evaluated the impact of a basic power strip, a surge-protected power strip, and a microwave oven on PLC transmission.

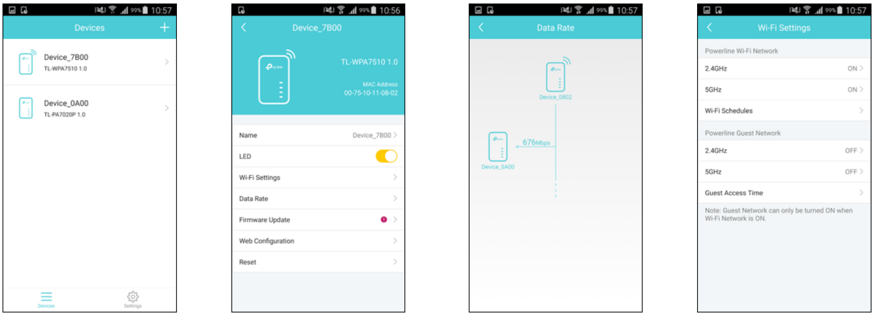
Further environment parameters:

- Location: Faculty of Informatics, University of Debrecen, IF-15 room (see Figure 4)
- Ethernet cables: AMP Netconnect AMPTRAC CAT6 FTP
- Wall outlets: Legrand Valena
- Power strip (basic): no-name
- Surge-protected power strip: Intertek
- Microwave oven: Samsung M182DN, 850 W

5. The TP-Link PLC Kit

For our experiments, we used the TP-Link HomePlug AV2 1300 kit (TL-WPA8631P + TL-PA8010P) (see Figure 5).

Device management can be performed via the *tpPLC* mobile application (see Figure 6)—which requires Wi-Fi—or through a browser-based GUI (see Figure 7). Both interfaces allow convenient configuration of essential parameters such as device naming, LED control, IP configuration, Wi-Fi settings, and firmware updates.



(a) Device list. **(b)** Device settings. **(c)** Connection speed. **(d)** Wi-Fi settings.

Figure 6. PLC adapter management - *tpPLC*.

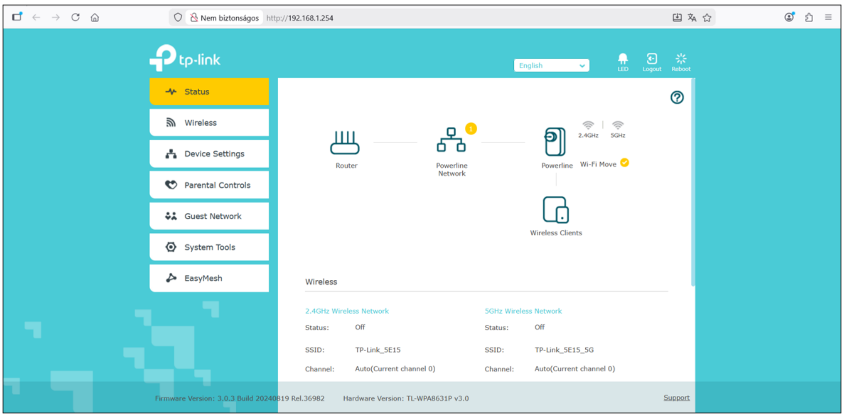


Figure 7. PLC adapter management – tp-link GUI.

6. Measurement Results

6.1. Throughput

We began with UDP-based throughput tests to determine the maximum achievable transmission rate without PLC adapters. Baseline measurements consistently showed 956 Mb/s. TCP throughput, representing real-world file transfer performance, was slightly lower at 941 Mb/s due to TCP header overhead. When PLC adapters were introduced, throughput decreased to roughly half of the baseline and then declined linearly as the distance increased (see Figure 8). The full results are summarized in Table 2).

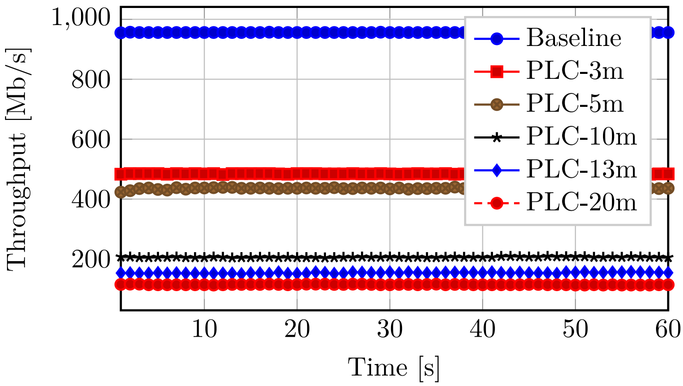


Figure 8. PLC throughput over UDP.

Table 2. PLC throughput over UDP.

Wall socket distance [m]	Baseline Throughput over UDP [Mb/s]	Baseline Throughput over TCP [Mb/s]	PLC Throughput over UDP [Mb/s]	PLC Throughput over TCP [Mb/s]
3	956	941	484	444
5	N/A	N/A	433	378
10	N/A	N/A	203	182
13	N/A	N/A	147	136
20	N/A	N/A	114	104

6.2. Jitter

Jitter measurements were performed exclusively using UDP, as TCP does not support jitter assessment. Baseline jitter averaged 0.021 ms and showed only minimal degradation at 20 m. Although jitter fluctuations increased with distance, all values remained below 0.1 ms—well within the 30 ms QoS threshold for voice transmission (see Figure 9 and Table 3).

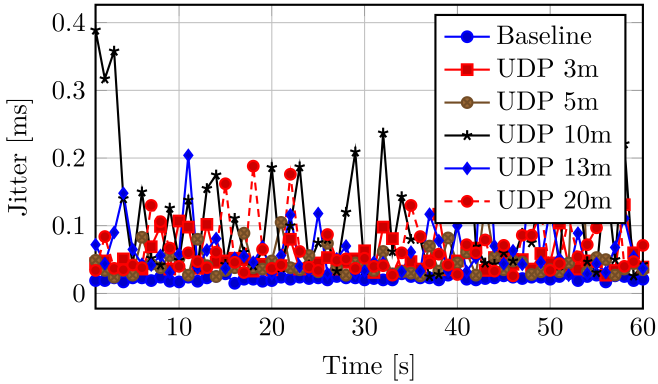


Figure 9. PLC jitter over UDP.

Table 3. PLC jitter over UDP.

Wall socket distance [m]	Baseline Jitter over UDP [ms]	PLC Jitter over UDP [ms]
3	0.021	0.043
5	N/A	0.058
10	N/A	0.075
13	N/A	0.037
20	N/A	0.048

6.3. PLC Through a Basic Power Strip

We then evaluated PLC performance using a conventional no-name power strip. Initially, both PLC adapters were connected to the strip; subsequently, only the second adapter was connected while the strip itself was plugged into a wall outlet 3 m away. Results (see Figure 10, Figure 11 and Table 4) indicate only negligible degradation in both throughput and jitter compared to the baseline.

Table 4. PLC jitter over power strip classic.

Wall socket distance [m]	PLC Throughput over UDP [Mb/s]	PLC Throughput over TCP [Mb/s]	PLC Jitter over UDP [ms]
0	488	464	0.099
3	473	433	0.063

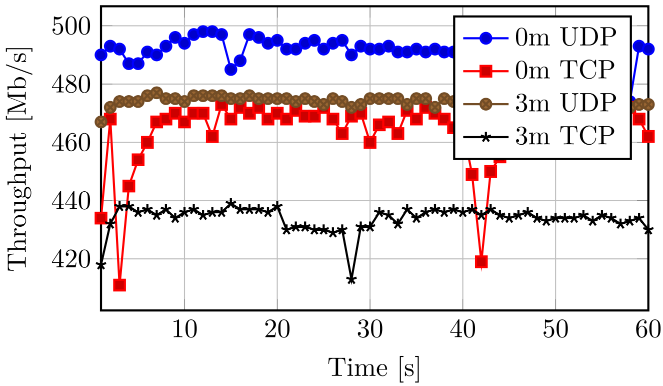


Figure 10. PLC throughput over power strip classic.

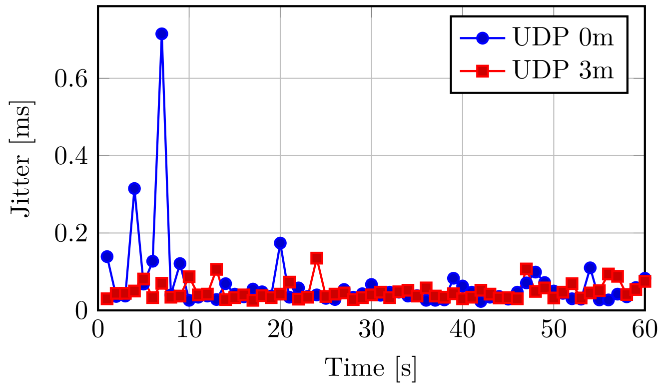


Figure 11. PLC jitter over power strip classic.

6.4. PLC Through a Surge-Protected Power Strip

Next, we repeated the measurement series using a surge-protected power strip. In this case, both throughput and jitter exhibited noticeably greater degradation. Detailed results are provided in Figure 12, Figure 13 and Table 5.

Table 5. PLC throughput and jitter over power strip with protection.

Wall socket distance [m]	PLC Throughput over UDP [Mb/s]	PLC Throughput over TCP [Mb/s]	PLC Jitter over UDP [ms]
0	489	463	0.077
3	396	302	0.103

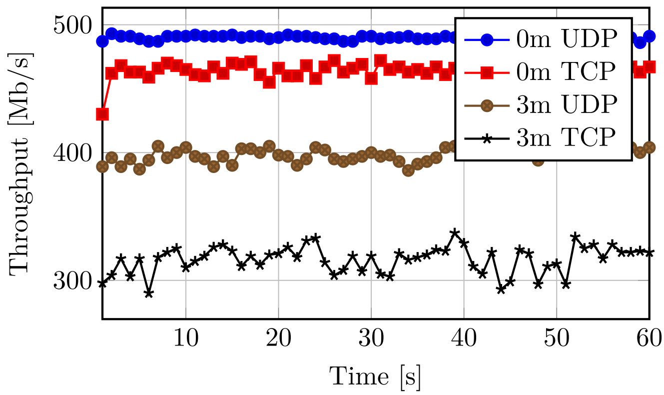


Figure 12. PLC throughput over power strip with protection.

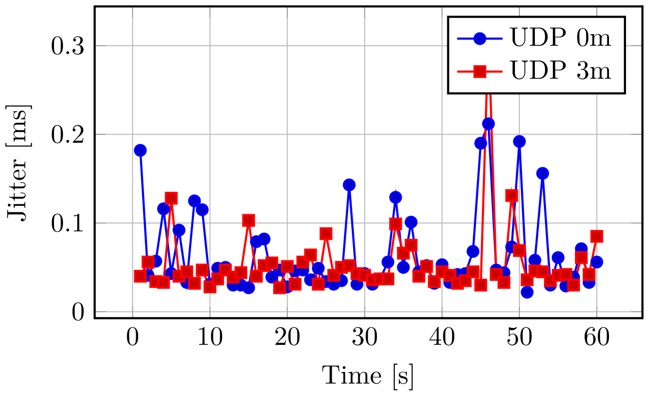


Figure 13. PLC jitter over power strip with protection.

6.5. PLC Operation Near a Microwave Oven

Finally, we tested the influence of a microwave oven on PLC data transmission. Although some articles and anecdotal reports claim that microwave interference can severely degrade PLC communication, our measurements indicate that its effect on wired PLC transmission is minimal. Figure 14, Figure 15 and Table 6 presents the measured results and averaged values.

Table 6. PLC throughput and jitter close to microwave oven.

Wall socket distance [m]	PLC Throughput over UDP [Mb/s]	PLC Throughput over TCP [Mb/s]	PLC Jitter over UDP [ms]
3	468	431	0.051

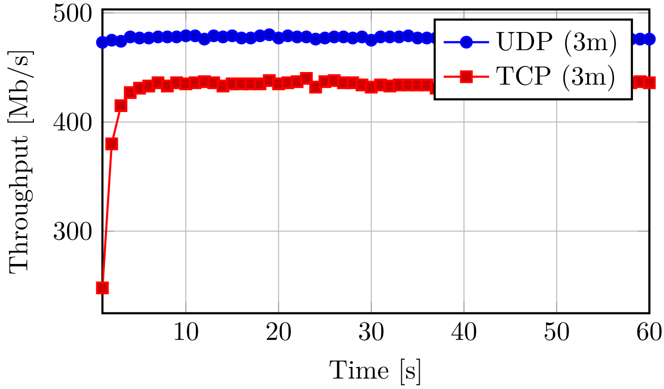


Figure 14. PLC throughput close to microwave oven.

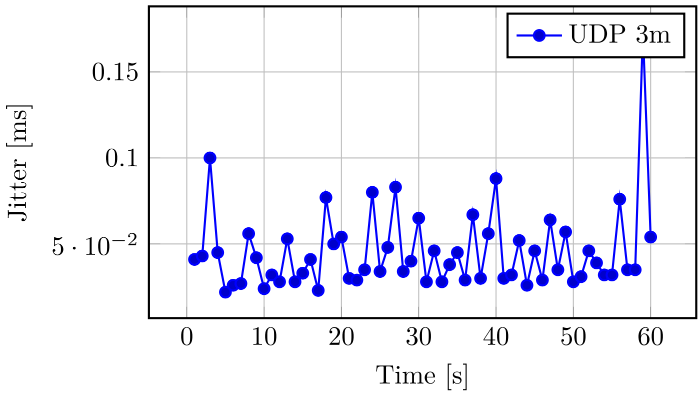


Figure 15. PLC jitter close to microwave oven.

7. Conclusion and Future Work

PLC technology proved highly effective for data communication. Even at 20 meters, it delivered adequate throughput and jitter values. Its performance characteristics place it between wired Ethernet and wireless Wi-Fi [6, 11, 12]. PLC can reliably support both IoT devices and latency-sensitive multimedia applications. The technology is particularly suitable for older multi-story buildings where retrofitting Ethernet cabling is impractical, Wi-Fi performance is suboptimal, drilling through reinforced concrete is undesirable, or wall aesthetics must be preserved.

In future work, we plan to extend our PLC performance analysis to include Wi-Fi environments.

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