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A Systematic Review of Using Visible Light Communication as an IoT Network System in a Smart Home Environment

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ABSTRACT

The expansion of the Internet of Things (IoT) within smart home environments creates challenges for traditional Radio Frequency (RF) networks which experience spectrum shortages and unstable connections and increased security threats. The study conducts a systematic literature review (SLR) to assess how organizations implement Visible Light Communication (VLC) as a secure and high-performance solution for their IoT network systems. The study combines quantitative performance data with qualitative thematic patterns to evaluate VLC's indoor performance based on analysis of peer-reviewed research obtained from 2021 through 2026. Research results show that system throughput increases significantly because commercial LEDs transmit data at 1 to 3 kilobits per second while experimental laser diode modules achieved record data transmission speeds of 51.05 gigabits per second over a distance of 100 meters. The system demonstrated lower latency through VLC which achieved an 8.2 millisecond delay time that surpassed the performance of comparable radio frequency systems. The synthesis process found that the physical layer security of the system derives from light which creates an energy-efficient "green" network through its dual-purpose ability to provide illumination and the system prevents spectrum exhaustion. The study identifies ongoing restrictions which include the need for direct line-of-sight (LoS) connectivity and the system's susceptibility to human movement and external light interference. The review concludes that VLC has developed into an effective technology which needs to solve the "dynamic mobility gap" problem and create common industry standards through IEEE 802.11bb to achieve widespread commercial use. Future research should shift from static laboratory simulations toward large-scale field testing in complex, real-world smart home environments.

INTRODUCTION

According to Kumar (2024), the Internet of Things or IoT, is a network of devices with sensors, software, and communication technologies that facilitate the collection and exchange of data between devices. Additionally, according to Kumar (2024), these devices are used in smart homes, and healthcare systems, where the constant exchange of data enhances their efficiency. According to Sebestyen et al. (2025) and AlSalem et al. (2023), although IoT usage is now prevalent in smart homes, where they generate huge amounts of personal data, issues such as unstable connections and increased vulnerability to security threats limits the effectiveness of data transmission, making it more enticing for cyberattacks. Consequently, an alternative communication technology that is capable of supporting high bandwidth demands while improving security is needed. Visible Light Communication or VLC, which uses LEDs to transmit data, has been considered as an alternative due to its wide spectrum, immunity to electromagnetic interference, and natural security because light cannot pass through walls (Yu et al., 2021).

Although there are promising advantages of VLC, assessments on the viability of Visible Light Communication in terms of its effectiveness in the context of an IoT network system in a smart home are still lacking. Many existing studies show scarce findings on the performance of Visible Light Communication in terms of its data transmission rate, latency, reliability, and communication range, as well as the limitations of this technology, such as line-of-sight dependency and mobility constraints (Oyewobi et al., 2022). Thus, the problem of this study is the absence of a comprehensive report of both quantitative performance data and the implementation problems of VLC-based IoT systems in an indoor smart home setting.

Conceptual Framework

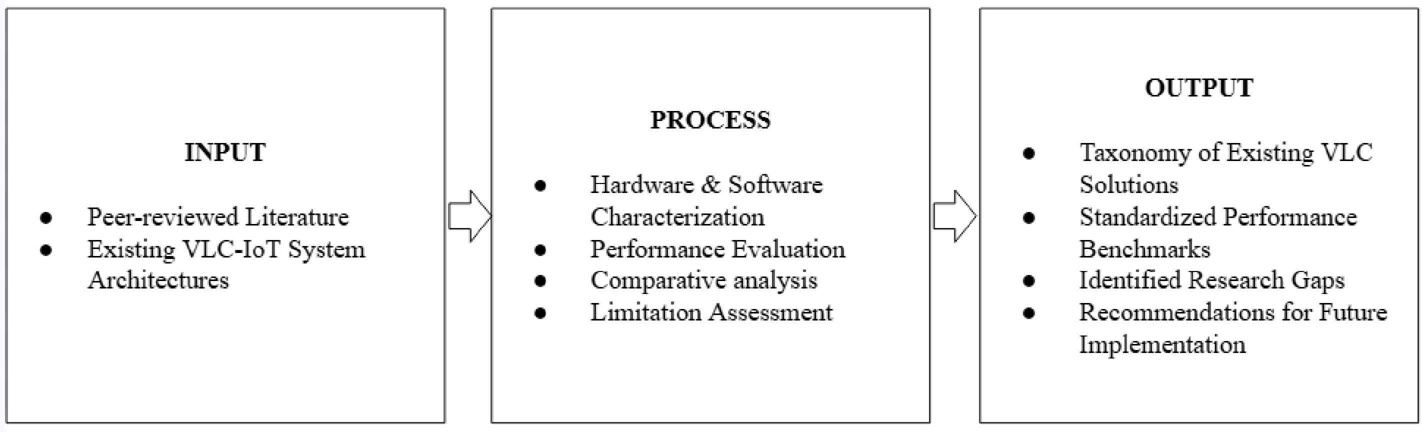

Figure 1. Conceptual Framework

Figure 1 illustrates the study's Input-Process-Output (IPO) conceptual framework. The inputs consist of peer-reviewed literature and existing VLC-IoT system architectures gathered from academic databases. The process involves the systematic review and analysis of these inputs, specifically through hardware and software characterization, performance evaluation, comparative analysis, and limitation assessment. Finally, the output presents a taxonomy of existing VLC solutions, standardized performance benchmarks, identified research gaps, and strategic recommendations for future implementation.

Research Objective

Therefore, this study aims to systematically review recent literature to: (1) identify and compare quantitative performance data based on research method, setup, and key findings; and (2) analyze qualitative insights in terms of thematic patterns, limitations, and research gaps. With this systematic review, this study seeks to determine the feasibility of Visible Light Communication as a secure and efficient alternative communication technology for smart home IoT systems.

METHODOLOGY

Research Design

Systematic Literature Review or SLR is used as the research design for this study. According to Carrera-Rivera et al. (2022), Systematic Literature Review is a research methodology that collects, identifies, and critically analyzes recent research studies that are relevant to the study being conducted. Instead of developing prototypes, the goal of Systematic Literature Review is to assess critical areas of current knowledge on a specific topic regarding research questions to recommend areas to further expound on (Carrera-Rivera et al., 2022). Given that this study is about the usage and feasibility of Visible Light Communication as a network IoT system, using Systematic Literature Review as the research design is applicable. This helped the researchers evaluate the current state of Visible Light Communication as IoT systems by compiling findings from recent studies, instead of relying on a single experimentation.

Research Sample

This study uses Systematic Literature Review as the research design, thus the population of this study consists of recent studies that are about Visible Light Communication as IoT systems. The sample consists of 18 recent studies that are selected with the limitations that it is conducted within a smart home environment and published between the years 2021 and 2026. These studies provided the researchers quantitative data on four performance matrices which are: data transmission rate, latency, reliability, and range. This ensured that the data collected from the secondary data sources are relevant to the study's focus, which is the usage of Visible Light Communication as IoT systems in a smart home environment.

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Rsearch Instrument

The instrument used in this study is a data collection table developed by the researchers, it is used to record and organize data that are collected from the selected relevant studies. The table is used to separate information into two main areas, the hardware and software components, and performance metrics. First, the hardware and software components are identified to record the types of LED and the modulation techniques used in the studies collected. Secondly, the performance metrics are recorded, which are the data transmission rate, latency, reliability, and range. This data collection table ensured that the data gathered from different sources can be compared between different Visible Light Communication system designs.

Data Collection Procedure

The data gathering procedures conducted by the researchers are as follows. First, the researchers searched through academic databases such as Google Scholar, IEEE Xplore, and ScienceDirect using keywords such as "Visible Light Communication", "Internet of Things", "Smart Home", and "Security" to identify recent literature that are relevant to the study. After collecting enough study samples, the researchers made sure that these studies meet the scope of the study, focusing on indoor smart home environments and published only in the years between 2021 and 2026. Finally, the researchers read and analyzed the full text of the selected papers and used the data collection table created by the researchers to record the data transmission rate, efficiency metrics reported by the original authors. This procedure replaced developing a prototype and experimentation and ensured that the analysis is based on verified peer-reviewed data.

Data Analysis

The data that will be gathered from the systematic literature review will be organized and synthesized to provide analysis of the current state of the VLC networks in a smart home environment. Instead of using direct statistical methods, this research will use a descriptive analysis of quantitative data that will be gathered, like speed, range, modulation technique, and type of LED used. As for qualitative data, this research will use thematic analysis to reveal thematic patterns, limitations, and research gaps across studies.

Ethical Considerations

This study is a Systematic Literature Review, thus measures for ethical considerations for human respondents are not applicable. Instead, the researchers made sure that the study adhered to rules and avoided plagiarism, protecting academic integrity by citing the sources used and compiling peer-reviewed data without fabrication as well as employing a specific selection process to minimize search and publication bias, which ensured a fair representation of the literature used on Visible Light Communication and IoT systems.

RESULTS AND DISCUSSION

Results

This part displays the results of the systematic literature review that was done. It exhibits the quantitative and qualitative data regarding usage of Visible Light Communication (VLC) as an IoT network in a smart home environment.

Sangmahamad (2025) created a VLC network using a 4x4 LED array as a transmitter and BPW34 as a receiver, which achieved 1 kbps at 16.30 m to 4 kbps at 3.25 m. Atiba (2023) evaluated the performance of Li-Fi, a derivative of VLC , reaching an uplink of 21.30 mbps and a downlink of 24.60 mbps at 1.04 m to 7.49 mbps uplink and 1.79 mbps at 9 m. Other studies used micro-LED instead of LED to improve the performance even further. Fang et al. (2024) was able to transmit a 720p video transmission and up to a 10 Mbps rate at only an 80 cm range. A more specialized micro-LED was also used, specifically an InGaN/GaN micro-LED. Wang et al. (2021) demonstrate an on-off keying modulation and quadrature phase shift keying-orthogonal frequency-division multiplexing using a blue micro-LED, achieving 2 Gbps and 4 Gbps, respectively, at 3 m. Chang et al. (2022) also used yellow phosphor film in addition to blue micro-LED to achieve a white light, and this reached

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a speed of 2.805 Gbps with the same modulation. Zhu et al. (2022) achieved a speed of 0.25 Gbps at low power to 2 Gbps at high power at 0.5 m with the same modulation as the previous two.

Thematic patterns were identified regarding VLC-based IoT network systems in a smart home environment. Yu et al. (2021), Oyewobi et al. (2022), and Eltokhy et al. (2023) reported that VLC signal prevents external data hijacking and eavesdropping since visible light cannot penetrate opaque obstacles. Devi & Maddila (2021), Matter et al. (2022), Ullah et al. (2022), and Atiba (2023) state that we can integrate VLC into existing LED infrastructure to serve as illumination and communication, promoting a sustainable network. According to Okine et al. (2021) and Oyewobi et al. (2022), VLC has a large spectrum range of 400 to 800 THz, thus providing a viable solution to the spectrum crunch. A hybrid architecture of VLC and RF/Zigbee favors a practical smart home implementation since it ensures continuous coverage if the light is blocked, according to Bravo Alvarez et al. (2023) and Atiba (2023).

Limitations were also identified regarding VLC-based IoT network systems in a smart home environment. According to Atiba (2023) and Maraqa et al. (2023), VLC transmission must require an uninterrupted path between transmitter and receiver, meaning any line-of-sight interruption will lead to immediate signal degradation or disconnection. Other sources of light can serve as interference, which means it is necessary to use optical filters according to Beguni et al. (2023), Atiba (2023), and Almothafar et al. (2025). Okine et al. (2021), Ullah et al. (2022), and Barmaki et al. (2025) state that establishing a VLC uplink is difficult because handheld mobile devices have limited battery power to support active light sources.

The research gaps that were present in the other research are presented here. Almothafar et al. (2025) state that most current studies rely on static environments, and this does not reflect dynamic home usage. Expanding on this, most existing research only consists of small-scale simulation or static prototypes, which may or may not scale in the real world according to Poulose (2022) and Bravo Alvarez et al. (2023). There is also a critical gap regarding universal protocols to ensure interoperability between VLC-enabled LEDs and various IoT sensors from different manufacturers, as stated by Oyewobi et al. (2022) and Bravo Alvarez et al. (2023).

Discussion

Based on the synthesized studies, it indicates that the modulation capability of LEDs matters a lot for their performance. An off the shelf LED can only do so much due their limited and slow modulation. On the other hand, much more powerful and expensive micro-LEDs can achieve speeds up to gigabits.

The results also revealed a theme around VLC-based IoT Network systems in a smart home environment. VLC gives an inherent physical layer security which is suitable for carrying out personal data and information that will be transmitted through the network. LEDs can be used not only for lighting the room but also transmit data making it energy efficient. It also serves as a spectrum alleviation which can solve spectrum crunch that might happen in the future as the demand for wireless connection increases. Hybridization is revealed to be the practical smart home implementation where VLC manages the downlink while other wireless connections handle the uplink, which is one of the limitations of VLC networks in a smart home environment.

As mentioned above, uplink connection seems to be the main bottleneck. Devices need to also have an active light source to establish an uplink connection, making an already limited battery lifespan even shorter. VLC is revealed to be limited by line of sight and optical interference. A proper positioning and multiple LED transmitter could lessen the LoS interruption but it will be hard to solve this problem entirely. Optical interference required the use of complex optical filters or adapting thresholding schemes.

The results also revealed a theme around VLC-based IoT Network systems in a smart home environment. There seems to be a lack of advanced channel models that accurately simulate the randomness of humans and devices which can affect signal stability in real-time. Most existing research only consists of small-scale simulation or static prototypes, which leads to a lack of standardization and real-world scaling considerations. Future researchers must look into these gaps in order to improve VLC-based IoT network systems in a smart home environment.

CONCLUSION

The systematic review of literature published between 2021 and 2026 revealed that the main limitation in speed is the modulation capability of the LEDs. VLC-based IoT network systems in a smart home environment showed a trend in physical layer security, green networking, spectrum alleviation, and hybridization. It has its limitations, which are the line of sight, optical interference, and uplink bottlenecks. There is also a research gap on dynamic mobility, standardization, and real-world scaling.

RECOMMENDATION

Based on the findings of this paper, it is recommended for future researchers to address the research gap on dynamic mobility. For future and IoT developers, it is encouraged to prioritize a hybrid network where VLC serves as the uplink and RF as the downlink to maximize reliability. Future systems design must also address the scalability and interoperability of different systems.

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