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Review of Cooperation between Visible Light Communication Networks and 5th Generation Cellular Networks

Mokhtar Esmail [1*]

[1] Computer Engineering Department, Cyprus International University, Northern Cyprus.

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***Corresponding Author:**
Mokhtar Esmail
E-mail:
ma_ismaeel@hotmail.com

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ABSTRACT

Ultra-fast wireless networks, such as Visible Light Communication (VLC) and Cellular 5th Generation (5G), are gaining more attention because of increased demand for higher speeds. These technologies promise to provide a higher transmission rate at a reasonable cost. This paper investigates the collaboration of both technologies by reviewing three papers in the field. Reviewing is done by contrasting several aspects of the technologies, such as their architecture, technology, and even used bandwidth. Findings showed that it is difficult to precisely decide whether both technologies will collaborate or not due to their structural differences and the target applications of each technology.

Keywords: VLC, 5G, Cellular, wireless, Wi-Fi

1. Introduction

The primary objective of the research is to determine if these technologies will compete in the wireless industry or collaborate to enhance service for wireless users (Ahson & Ilyas, 2018). Although the answer to this issue may be intricate and contingent upon multiple aspects, we will concentrate on pinpointing the primary elements that influence the compatibility or disparities between the two technologies. This will yield two advantages: executing the investigation and conserving time. Since the introduction of VLC as a viable wireless technology in 2011, capable of transmitting high-speed data streams primarily via Line Of Sight (LOS), attempts have been made to adapt this technology to meet contemporary network requirements. Standard variants were adopted in 2015, 2017, and 2019. This enhanced scalability permitted more channels, significantly augmenting reliability (Andrews et al., 2007). The advancements of VLC in facilitating extremely high speeds across short distances have rendered it a prospective future technology, garnering interest from numerous investors in the communications sector for specific applications. Examples include hospitals and aircraft. Furthermore, the technology guarantees enhanced user service efficiency as a last-mile solution. This is attributable not only to its incredible speed but also to its cost-effective installation. Moreover, numerous contemporary wireless applications might leverage this technology to enhance their services and augment efficiency. Specific applications have efficient, high-speed infrastructures that link WiFi hotspots and provide rapid internet access to urban regions. Furthermore, VLC has incorporated other potential uses, including rapid data transmission (such as audio and video) and providing high-speed internet access to computer users (Asif, 2018). The latter may include conventional laptop users and numerous applications, such as delivering Audio/Video over the Internet and Voice over IP.

Table 1. Visible Light Communication technology standards (Asif, 2018)

	802.15.7	**802.15.13**	**802.11bb**
Published	April 2019	August 2023	June 2023
Technology	Specifies PHY and MAC for impulse radio ultra-wideband (UWB) ad hoc connectivity	Introduces a novel MAC and two PHY layers that provide excellent dependability, minimal latency, and reduced power consumption.	Specifies the methodology for reapplying the 802.11 MAC and OFDM-based PHYs in optical optically
Wavelength	10 nm to10,000 nm	10 nm to 10,000 nm	800 to 1,000 nm
Data rate	12 kbps to 96 Mbps	12 kbps to 10Gbps	10 Mbps to 9.6 Gbps
Transmission scheme	Single carrier only	Single carrier, 256 OFDM or 2048 OFDM	Single carrier, 256 scalable or OFDM with 128, 512, 1024 or 2048 sub-carriers
Uses	Indoor localization and vehicular networking	Industrial and medical applications	Residential applications such as WI-FI

On the other hand, 5G technology has been present in the market in recent years. The aim of 5G wireless technology is to provide a more consistent user experience, increased multi-Gbps peak data rates, ultra-low latency, higher reliability, significant network capacity, and improved accessibility for a larger user base (Forge & Bohlin, 2008). Emerging sectors are interconnected, and enhanced performance and efficiency empower novel user experiences. This research will assess several pertinent resources,

focusing primarily on two categories of these networks. Numerous methods exist to compare, contrast, or assess various technologies. For instance, one technology may exhibit a significant advantage over another in a specific domain, whereas in a different domain, both technologies may have equivalent prevalence. Initially, the research aimed to select certain subject areas that could successfully evaluate both technologies and facilitate predictions on their shared future. Additionally, to enhance the readability and comprehension of the research, each technology will be examined individually and thoroughly. Subsequently, an examination of the capacity of either to assume control or collaborate with the other. The final phase will summarize the data and incorporate realistic forecasts derived from the preceding processes.

2. Employed Methodology

Research design is governed by the principle of 'fitness for purpose.' The objective of the research is to ascertain the approach and design employed. Research is fundamentally an activity or process, and despite the multitude of research methodologies, specific generic qualities delineate its essence. (*3GPP News*, 17 decembre 2018). Various research methodologies were employed to gather information for the study. This document outlines the methods used for data collection and analysis. Two research methodologies exist: deductive and inductive. The inductive approach involves data collection, analysis, and theory generation. Conversely, the deductive approach involves a theory and a defined research topic or hypothesis. Data is subsequently gathered and employed to evaluate the theory.

2. 1. Deductive Approach

It is a technique of theory testing that commences with a recognized theory or generalization and aims to determine its applicability to particular circumstances (*3G W-CDMA and CDMA2000 Infrastructure Markets Up.*, 2017). The deductive technique often begins with a review of the theory, followed by data collection, from which conclusions are subsequently drawn.

2. 2. Inductive Approach

This method can be regarded as a manifestation of the deductive approach. This methodology transitions from empirical evidence to theoretical frameworks. Observations serve as the foundation for this methodology, aiming to build theory rather than evaluate it. An inductive methodology is employed in this research, progressing from broad principles to specific details. The wireless networks possess more theoretical and identifiable variables, making their analysis more specific. Research planning assists the researcher in identifying necessary activities, organizing sub-tasks sequentially, and calculating the time required to complete the research (*CDG : Technology : 5g – VLC* 2019). The research plan, illustrated in Fig. 1, is a reference for determining the timing and methodology of subsequent research steps. This streamlines the study duties and facilitates the seamless execution of subsequent phases. The data is collected by choosing a set of papers in the scope and then by applying critical thinking to develop results.

Three papers were selected in this study and discussed in more detail in the following sections.

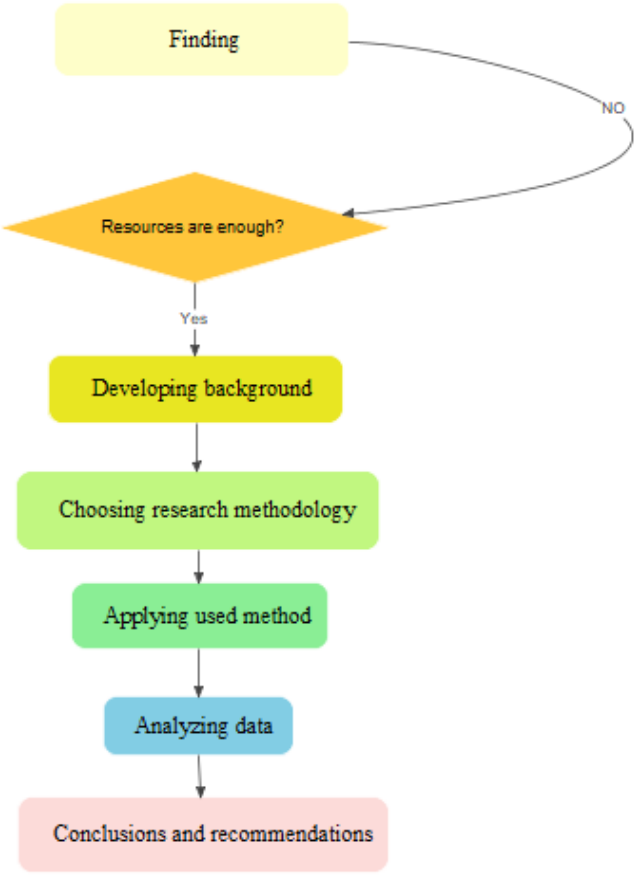

Figure 1. Research Plan

3. Results and Discussion

The mentioned papers are utilized as case studies. These case studies were carefully selected to provide the best evaluation of both technologies. These papers are:

- Facilitating 5G indoor services for home settings with VLC technology.
- Implementation of VLC in 5G Networks: Frameworks and Essential Technologies.
- Visible Light Communications in 5G Wireless Networking Systems: Transitioning from Fixed to Mobile Communications.

3. 1. Enabling 5G indoor services for residential environment using VLC technology

With the rise of 5G-based applications that require higher levels of connectivity and (QoS). The IEEE established the 802.11bb "Light Communications (LC) for Wireless Local Area Networking" standardization group as part of current efforts to improve VLC standards (Dawson, 2005). This study uses VLC to examine the network needs of 5G indoor services, including high-definition (HD) video and virtual reality (VR), for home settings. Using Reproducing Kernel Hilbert Space (RKHS) techniques, a parameter-free hyper-mitigation strategy is presented for such common VLC cases. This includes additional impairments like light-emitting diode (LED) nonlinearity and faulty channel feedback.

Utilizing an adaptive VLC transmission method founded on direct current-biased optical orthogonal frequency division multiplexing (DCO-OFDM) to attain the intended outcomes. This employs adaptive BER-based modulation-order switching and precomputed bit error rate (BER) expressions as RKHS-based detection methodologies. The adaptive transmission method demonstrates significantly improved error rates and enhanced performance, as Channel Impulse Response (CIR) simulations

indicate. It is a promising choice for high data rate VLC-based 5G indoor applications. A site-specific channel simulator (Murawwat & Ahmed, 2008) is introduced to develop channel models for high data rate 5G indoor communication systems employing an advanced ray-tracing technique. Moreover, the study addresses the advancement of 5G-based applications necessitating high quality of service and extensive connection demands. There are three primary steps in the channel modelling approach. Initially, a 3D platform is developed that accurately specifies the indoor environment's dimensions, shape, and reflection characteristics. Subsequently, the physical layer (PHY) strategies that can be considered for IEEE 802.11bb (3G W-CDMA and CDMA2000 Infrastructure Markets Up., 2017) are thoroughly discussed, taking into account the channel models described in the previous section. To reduce ISI for the frequency-selective VLC channels, OFDM was suggested in (NGUYEN-VUONG Quoc-Thinh et al., 2016) since the standards cover the desired peak data speeds of up to 10 Gbps. Nonetheless, it should be stated that specific adjustments are needed to establish optical OFDM to guarantee that the signal is genuine and non-negative. To fulfil the high data rate needs of 5G indoor applications like VR and HD films, an adaptive data transmission technique for VLC systems was developed in this study. To fully integrate the user model and artificial objects into the channel model and meet the illumination requirements.

3. 2. Applying VLC in 5G Networks: Architectures and Key Technologies

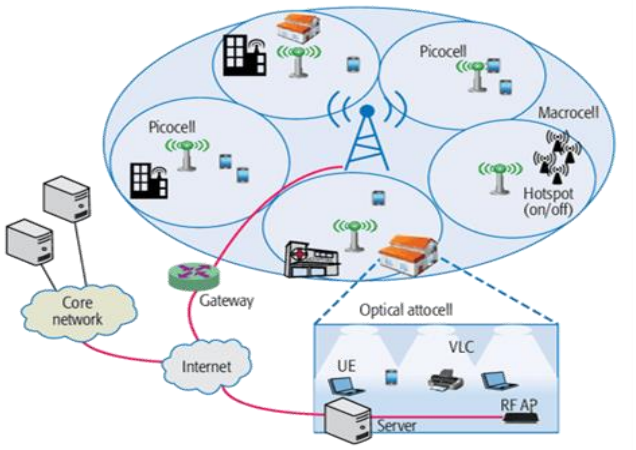

Figure 2. A multi-layer 5G cellular architecture (Feng et al., 2016).

In short-range communication scenarios for forthcoming 5G networks, visible light communication has lately garnered significant interest as an adjunct technology to millimeter-wave communication. To satisfy the stringent 5G system requirements for substantial capacity, elevated data rates, enhanced spectrum efficiency, superior energy efficiency, minimal battery consumption, and reduced latency, VLC offers several significant advantages. Numerous gigabit-per-second data rates, reduced energy usage, little installation expenses, and ample license-free spectrum. This research introduces a heterogeneous multi-layer 5G cellular architecture that delineates the control plane from the user plane. This architecture comprises three layers, each addressing specific coverage and communication requirements: the Macro-cell layer, functioning below 3 GHz; the Pico-cell layer, operating within the millimeter wave spectrum; and the optical Atto-cell layer, utilizing the visible spectrum. We also examine potential techniques for downlink communications in an optical Atto-cell, backhaul connectivity, and uplink communications. The text also addresses several critical technologies utilized in VLC downlink communications, including modulation, multiple access, and error control systems.

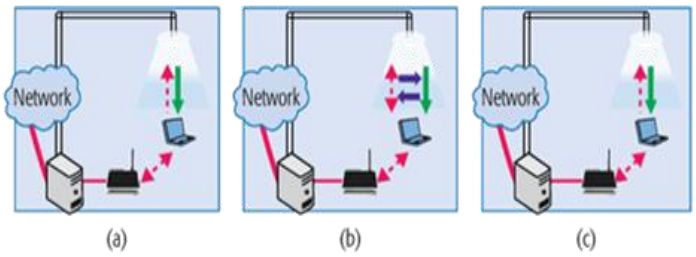

Figure 3. Downlink methodologies for an optical Attocell: a) VLC-downlink; b) mm-Wave backup downlink; and c) mm-Wave parallel downlink (Feng et al., 2016).

3. 3. Visible Light Communications for 5G Wireless Networking Systems: From Fixed to Mobile Communications

Visible light communication has garnered interest as a potential access method for 5G wireless communications. Both VLC's extensive bandwidth and energy efficiency contribute to this methodology. This study aims to provide a comprehensive review of the latest advancements in VLC research applicable to 5G wireless communication systems (Feng et al., 2016). This paper elucidates the advantages and disadvantages of VLC in comparison to RF-based communications, specifically concerning spectrum, spatial reuse, security, and energy efficiency. The various illumination sources proposed for VLC systems are also analyzed. The literature on VLC networking is divided into two categories: mobile and fixed VLC communications. The balance between spectrum and energy efficiency is considered. Consequently, bidirectional, fully networked wireless communication technology of VLC can satisfy the high-speed requirements of the future. VLC has the potential to utilize almost 300 THz of the visible light spectrum, which is nearly 139,000 times greater than the 2.16 GHz wireless gigabit channel of the IEEE 802.11ad standard. It has been shown that using orthogonal frequency division multiplexing, a single light-emitting diode (LED) may achieve a data rate of 10 Gbit/s. The optical OFDMA method is employed for multiple access in each VLC cell. The Wi-Fi Access Point is expected to comply with the IEEE 802.11ad standard for the Wi-Fi system. Each station STA is capable of communicating with the AP (uplink and downlink) or with other STAs (direct link) in compliance with this standard.

4. Conclusion

This research examined VLC and 5G to see whether these competing technologies will interact. The factors influencing the competency and collaboration of both technologies are significantly more complex. For example, a comparison of the technical architectures of both technologies is unfeasible for two reasons: VLC is constructed on the IP protocol and adheres to the OSI model, while 5G systems do not. Furthermore, even if a universal OSI model were to delineate the 5G systems, it would pertain solely to that specific system utilizing VLC, rather than encompassing all systems. The first case study examined a collaborative network architecture for VLC integrated with 5G technology. It was presumed that 5G performance would not be equivalent to VLC. This notion is partially valid, even though 5G remains in its nascent stage. The findings of this case study provide greater insights into the current state of 5G technology. The second topic pertains to the utilization of VLC in high-velocity web applications. This case primarily investigated the performance difficulties of VLC using many simulations. The results of the simulations were satisfactory, albeit several restrictions. Nevertheless, the example did not evaluate the performance of VLC; so, the simulations were regarded as general VLC simulations. The final study assesses the market of Information and Communications Technologies (ICTs). These technologies, particularly wireless networks, significantly contributed to economic progress. Furthermore, the model exemplifies one of the most prosperous sectors in wireless technology. Numerous wireless technologies now exist, with additional innovations forthcoming. The future is likely to depend significantly on wireless networks, potentially leading to the obsolescence of current wired systems. The multitude of existing and emerging wireless

technologies complicates the prediction of which will endure. The reasons influencing the proliferation or cessation of these technologies are numerous, and the duration and extent of the research were insufficient to assess all of them.

Conflict of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

Data Availability

No data was used for the research described in the article.

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