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# Assessing the impact of Visible Light Communication on our daily life usage of Ubiquitous Computing Technology

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***Abstract:*** **A better and calmer future is the destination of everybody's vision. Technology has similar theories to describe what technology will look like in the near and far future as a factor of human satisfaction and life feasibility. We are continuously dealing with digital data in this modern era, from social media memes to highly classified government data, which is dependent on more sophisticated technology that facilitates the sharing of that digital data. Those applications are under the concept of ubiquitous computing (UbiComp). Methods of sharing that digital data, on the other hand, differ and are transferred and received through various communication mediums, one of which is Visible Light Communication (VLC), which communicates via the visible portion of the electromagnetic (EM) spectrum. Therefore, by using the concept of Ubiquitous Computing, in this article, we will provide and analyze how Visible Light Communication touches Ubiquitous Computing.**

***Keywords:*** **Calm technology, Optical Communication, Radio Frequency Communication, Ubiquitous computing, Visible Light Communication.**

## I. INTRODUCTION

Light, importantly a fact, is what allows us to see with our eyes! And for that, our eyes operate like a light detecting tool; with our eyes, we can observe reflection light from the objects we see, allowing us to learn more about them, such as their properties, what kind of objects they are (e.g., pen, paper, computer, etc.) and their color! (For example, red, blue, green, and so on.) In our contemporary period, we are accustomed to using light for a variety of purposes, and it is remarkable to find so many devices providing and acting as a source of light in this modern period, due to advancements in semiconductors and evolving electronics, but in ancient times, humans utilized it mostly for lighting their dwellings and for combat with flames, mostly as a signal for distant communication. Humans realized that there are other light implementations as a result of scientific advancement through research, in addition to those regular and original applications for light.

The ability to use information (e.g., voice, text, video, etc.) for computation using light was a huge step forward for humanity. As Alexander G. Bell claimed after inventing the Photo-phone with his assistant Charles S. Tainter on February 19, 1880 [1], it was his "most important invention". Subsequently, the relative objectivity of our review is to express how Visible Light Communication satisfies the requirements of Ubiquitous Computing (UbiComp). Visible Light Communication (VLC) is described by how it interacts with ubiquitous computing systems and how it aids the reliable transmission of digital informational data in all areas involving human activity. It also refers to how the transfer of data packets using light, while simultaneously providing illumination and communications applications, has an impact on ubiquitous computing.

Generally, this paper is organized as follows, first, we step up on key points about Ubiquitous Computing and its vision. Second, we briefly oversee the literature on VLC. In the discussion section, we organize and demonstrate the associate reasons that VLC positively affects the UbiComp concepts and UbiComp devices.

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## II. UBIQUITOUS COMPUTING

Ubiquitous Computing also called Everyware and its rational perspective is a concept of simplification and makes life utilities and daily activities intelligible and easy to use [2]. This computing can come about using any device, in any format at any location. Wearable computers, gadgets integrated into everyday objects, and sensors strategically placed across our surroundings are all examples of ubiquitous computing, and it not only involves devices but also, it concerns the infrastructure that is distributed to assist those devices to be connected [3].

By definition, According to [4] Ubiquitous means "Seeming to be everywhere or in several places at the same times" while computing is formally defined as "the use or operation of computers" on the other hand the word Compute as a verb exposes as "reckon or calculate (a figure or amount)".

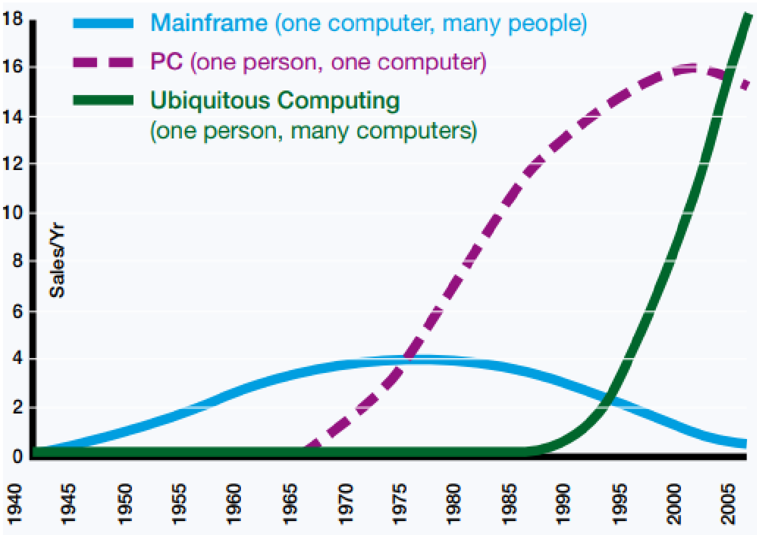


**Fig. 1 Graph conceptually portraying three eras of modern computing [13]**

A professor from Tokyo University, a veteran of ubiquitous computing, and one of the japans' famous computer architects, Ken Sakamura, showed the advantage of UbiComp by saying, "When sensors detected a breeze outside, the windows opened. When they detected rain, the windows closed and the air-conditioning was switched on" [5]. The interaction between human activities and technological advancements is the benchmark of UbiComp and it speculates how those affiliations affect daily life. Enormously modern computing went throughout many different epochs as figure 1 enacted.

The concept of Ubiquitous computing aroused only in the last era which was defined as that one individual being able to use more computing devices. Concurrently the usage of different computing devices and a variety of applications demonstrates and influences human daily activities. Additionally, by manipulating that view we can conceptualize that one technology at a time can be used in more variant applications. In [3, 6] productivity and life quality will increase by the time a world in which computers outnumber human beings comes. As a result, during that period human to computer ratio was expected to be a hundred/thousand to one. Conveniently, this is the era of ubiquitous computing, which is supposed to be in and beyond the 2020s [7, 8].

There is not only one computational device we contact in our daily life but numerous different ones, like mobile phones and personal computers, which are the most growing human-made technology ever. Simply, if we take an instance for mobile phones, in 2022, of the 7.93 Billion current human population, 91.54% of them use mobile cell phones. This number will be estimated to increase in 2025 up to 7.94 mobile users as appeared in figure 2. A surplus of mobile connections over the current human population, a 2.64 Billion additional mobile connections [9], resulted in high demand for a network infrastructure with a promised bandwidth, and environment-friendly attributes.

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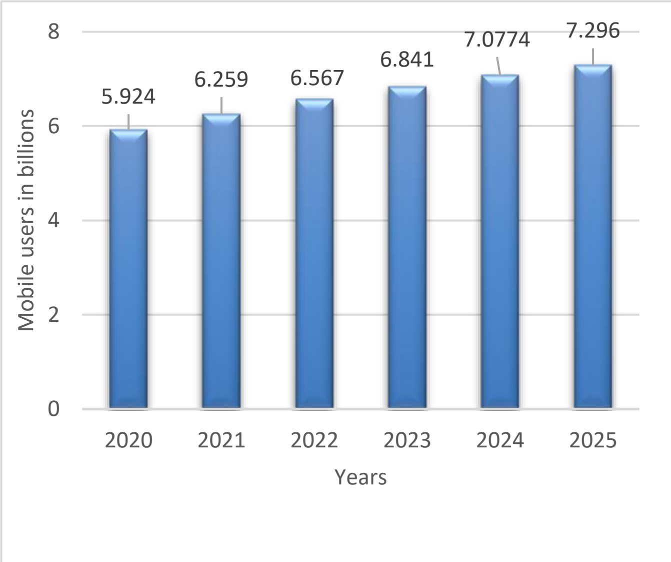


**Fig. 2 Number of Mobile cell Phone Users 2020 – 2025 [30]**

***1. Vision of Ubiquitous Computing***

Figure 1 is depicted how far contemporary computers have progressed over several distinct epochs. The term "ubiquitous computing" was coined fairly recently, and it was defined as "one person, many computers." This is a fundamental component of human behaviors, demonstrating that one individual can use several computing devices and applications at the same time. We can also imagine that one technology at a time can be used in a variety of applications. UbiComp's benchmark is the interaction between human activities and technological improvements, and it speculates on how those linkages affect human daily life.

By glancing at a novel three UbiComp applications [10] that were investigated by Xerox PARC, the first one expresses the true invisibility of machines or applications, which shows the integration of different self-supporting applications to each other for creating new ones. The second idea was to leverage Multi-User Dungeon (MUD) technology to create so-called "virtual communities." The use of cooperation to specify information filtering was the third innovative technique.

**Fig. 3 inch-scale ParcTab palm [13]**

Classically, illumination and communication are separate and independent sectors in our study, which had been utilized differently. Thus, VLC allows for creating a comfortable environment by fusing those applications and bringing them into line with the pioneer of ubiquitous computing's vision as "the coming age of calm technology" [7]. Ubiquitous Computing devices and their applications are the "whole main point" for the usability of this concept, and that is the reason are referred the applications of VLC [10]. Besides, this precisely explicates where the VLC interrelates with ubiquitous computing.

Concisely, ubiquitous computing's vision can be summarized in this quote from its pioneer "The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it." [11].

***2. Early Inventions in PARC***

After the foundation of Xerox Palo Alto Research Centre in 1970, it became one of the initiators of the informative research and studies of Ubiquitous Computing in the 1980s. It was where Mark Weiser worked and coined the term Ubiquitous Computing in 1988 [12, 13]. Mark Weiser stated in [10], that this phenomenon (Ubiquitous Computing) also can be used in terms of computer science or from the Telecommunications perspective. By that, we can say telecommunication or networking technology is the center of UbiCom. Without a fast and reliable networking infrastructure, Ubiquitous Computing is not lingering towards an advancement at all but can fade conceptually.

Therefore, this offers an opportunity that the potentiality of VLC over those existing wireless network technology helps to a great extent for the accessibility of more modern ubiquitous computing devices. On the other hand, UbiComp shifts the focus in at least four areas when it comes to communication networking [10]:

- Wireless media access,
- Wide-bandwidth range,
- Real-time capabilities for multimedia over standard networks, and
- Packet routing.

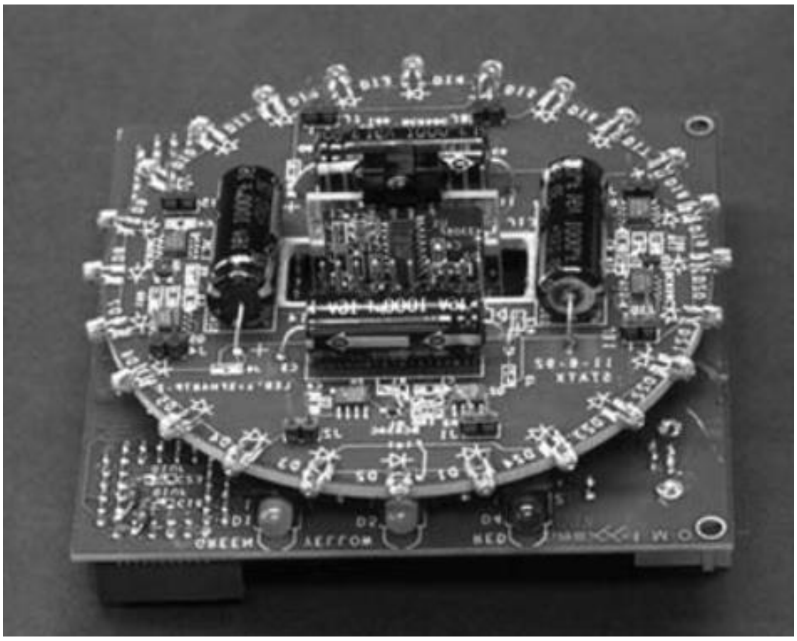

**Fig. 4 each room in the Ubiquitous Computing environment had such an infrared transceiver base station mounted in the ceiling [13]**

PARC categorized their projects as traditional metric-based system characteristics and table 1 summarized their outcome. That categorization resulted to become an easy and efficient way to integrate engineered devices that are practicable and workable for human interaction. The integration of those diverse technologies gives us the idea that VLC is very important to reach such an extent with the Ubiquitous computing's vision. An inch-scaled ParcTab palm computer (figure 3), is one of the devices that were used for communicating using an infrared signal with an infrared transceiver base station (figure 4) hanging from the ceiling of the room to provide good coverage [13].

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**Table 1: PARC UbiComp project Scope**

| Scale | Definition | Embarked Devices |
|---|---|---|
| Yard | Large & Immovable | ParcTab (as a pocketbook or wallet) |
| Foot | Hold in hand but can't be with the person all the time | ParcPad (pen-based notebook or e-book reader) |
| Inch | Fit inside pockets and then go unnoticed by doing other unrelated everyday chores. | Liveaboard |

Historical similarities lie on that the third era of modern computing (as Ubiquitous Computing), in which its concept emerged in the 1990s as shown in figure 1, as well as that also, the modern evolution of VLC research started at Keio University specifically in Nakagawa Laboratory, Japan in 2003 [14].

## III. OVERVIEW OF VISIBLE LIGHT COMMUNICATION

Optical communication is a part of the communication methods used to convey information by using light whether it's visible or invisible to human eyes. Figure 5 shows the Electromagnetic (EM) spectrum. In the EM spectrum, the light portion is approximately between 100 -10,000 nm of wavelength [15], as figure 6 illustrates that specific optical parts of the EM spectrum are among:

1) Ultra violate (100 nm – 400 nm)
2) Visible light (380 nm – 770 nm)
3) Infrared (770 nm – 10 000 nm)

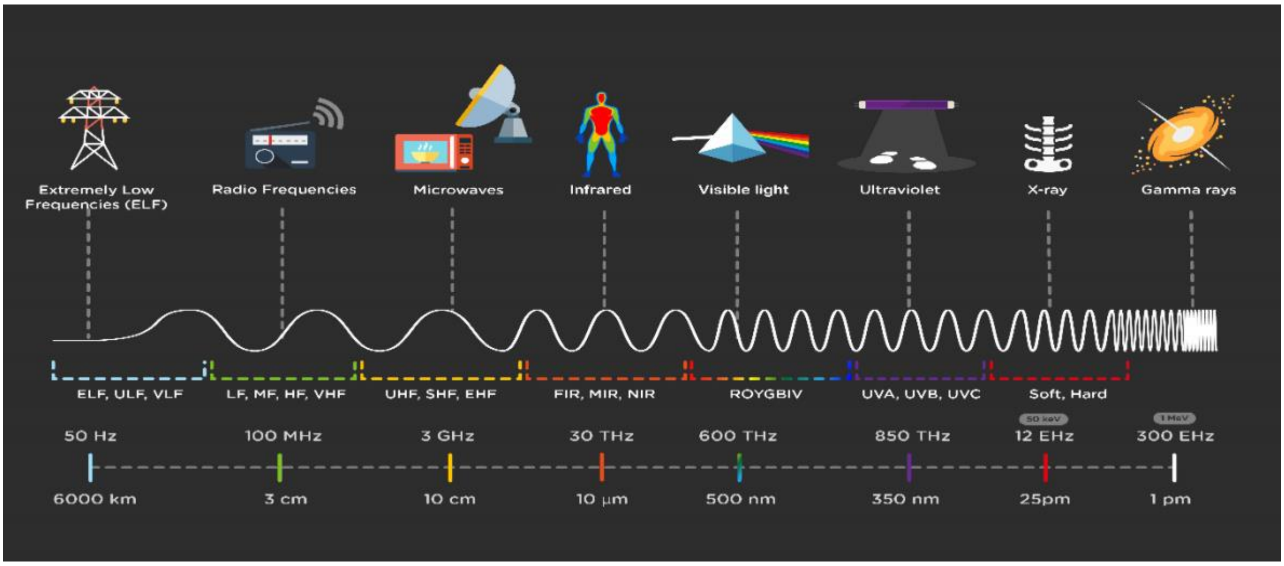


**Fig. 5 EM Spectrum [38]**

There seem to be problems due to an overcrowded spectrum of technologies based on copper/coaxial cable & RF communications, a limited data rate, costly licensing, security challenges, as well as a huge installation cost, and connectivity which are the multiple points that Optical Wireless Communication (OWC) is preferred over that similar types of communications [16]. This does not mean that OWC doesn't undergo any problems which limit its potentiality, to explain the simple limitation that OWC has, let's take a real-life example for the Sun, the Sunrays directly come from the Sun to our environment, so by any chance, if those rays are blocked by an un-transparent object, they are susceptible and can be blocked and as well be attenuated, and the amount of that attenuation depends on the characteristics and configuration of that opaque.

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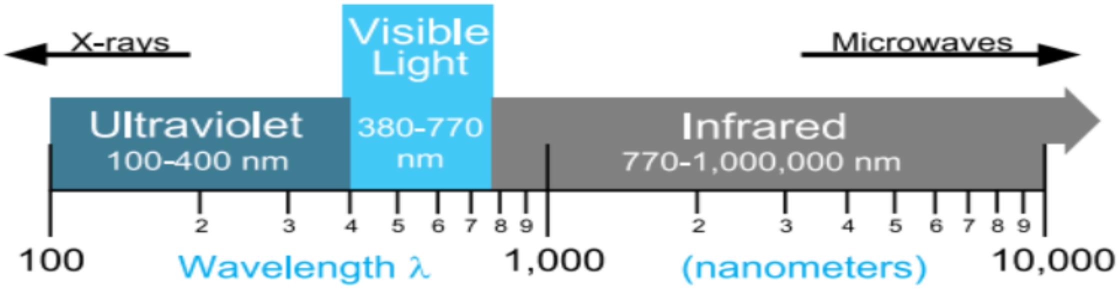


**Fig. 6 Optical portion of the electromagnetic spectrum [15]**

Concretely, RF and VLC have different similarities, table 2 shows the comparison between both of them.

**Table 2: comparison of VLC and RF [18]**

| Property | | VLC | RF |
|---|---|---|---|
| **Bandwidth** | | Unlimited | Regulatory |
| **Electromagnetic Interference** | | No | High |
| **Line of Sight** | | Yes | No |
| **Standard** | | Beginning (1G-VLC) | Matured |
| **Hazard** | | No | Yes |
| **Mobile to mobile** | ***Visibility (Security)*** | Yes | No |
| | ***Power Consumption*** | Relatively low | Medium |
| | ***Distance*** | Short | Medium |
| **Infra to Mobile** | ***Visibility (Security)*** | Yes | No |
| | ***Infra*** | LED illumination | Access Point |
| | ***Mobility*** | Limited | Yes |
| | | | |
| | ***Coverage*** | Narrow | Wide |

Furthermore, the OWC beams do not penetrate through opaque objects, but rather bounce off most of the components that can be found for instance inside our rooms, like walls and ceiling [17]. In [16] it was mentioned some advantages of the OWC over RF, and are included:

1) Unregulated bandwidth.
2) As there is no regulation on the optical portion of the spectrum, tariffs are not necessary.
3) For the side of security, what you see is what you are using, no eavesdrops, etc.
4) Frequency reuse of neighboring cells is applicable.
5) Cheap and light-sized components.
6) Unlikely inter-channel interference.
7) Easily infrastructural installation.
8) No radiation risk to the environment & personal well-being.
9) Energy-saving benefits.
10) Optical communication is not susceptible to the interference of electromagnetics.

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As a transmitter, Light Emitting and Laser Diodes, abbreviated as (LEDs) and (LDs) respectively are mostly used, while also, on the side of the receiver Positive-Intrinsic-Negative diode (PIN) and avalanche photodiode (APD) are most preferred for OWC systems [16, 19]. Figure 7 shows VLC physical layer model.

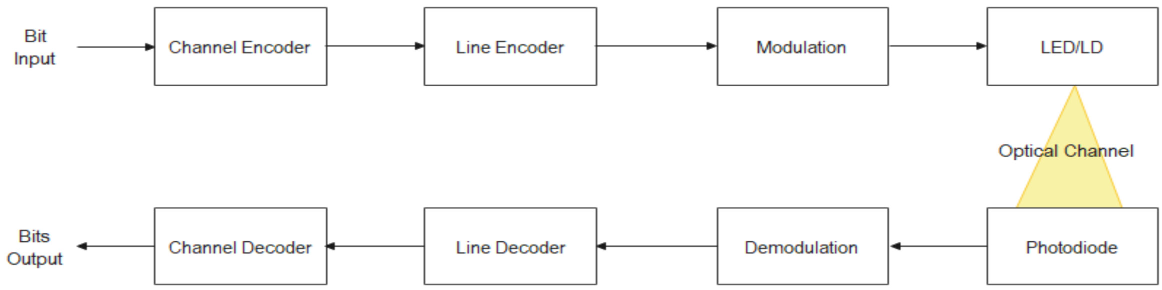


**Fig. 7 VLC's typical physical layer model [19].**

Additionally, the VLC is part of OWC, visible to the human eyes. Simply, the visible optical wave, like every other wave, has certain parameters [20], and one of those parameters can be named the wavelength of the wave. The wavelength is always symbolled as the Greek word lambda (λ) and states the distance between two corresponding and consecutive points on the wave, like crests or troughs. Another parameter is the wave's frequency the amount/number of waves that are passing through a fixed point at a specific time. Frequency shows the scale of energy that the wave carries (Frequency ∝ Energy), the higher the frequency means the higher the energy. So if we need to get the maximum and minimum frequency of the visible light portion of the EM spectrum, we can use the following equation which states that Frequency is inversely proportional to the wavelength of the wave [21, 20], meaning if the frequency increases the wavelength decreases and vice versa.

$$F(v) = \frac{C}{\lambda} \quad in\ (Hz) \tag{1}$$

Moreover, the bandwidth of the Visible light portion of the EM spectrum is the difference between the upper and lower frequencies [22].

$$Bandwidth = F_2 - F_1 \tag{2}$$

Table 3 shows both the bandwidth and frequency of the VLC portion. The bandwidth of the Visible Light portion is approximately equal to 360.7THz while the RF portion is much less. Optimistically Visible light communication beats RF communication in terms of bandwidth. Strongly, in terms of applications, VLC seems to be more effective than RF for visible light ID networks, healthcare facility robots, undersea telecommunication, transportation communications networks, and informational exhibiting signboards *[19]*. Those applications are one of the fundamentals that Ubiquitous Computing focuses on; and for those applications, VLC overpowers RF communications.

**Table 3: Frequency and wavelength of the visible light portion of the EM spectrum**

| **SPEED (constant) ($\approx 3 \times 10^8 m/s$)** | **Maximum** | **Minimum** |
|---|---|---|
| **Wavelength** | 700 $nm$ | 380 nm |
| **Frequency** | 428.3 THz | 789 THz |

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## IV. DISCUSSION

We are referring to some ubiquitous computing issues that are primarily concerned with the augmented capability of visible light communications; we are not only fascinated with UbiComp devices, but also with how VLC supports the devices in satisfying the UbiComp concept's requirements. As we previously mentioned, ubiquitous computing technologies provide calm and feasible applicability to human activities, which means that it is a comfortable and highly utilizable technology that can be found everywhere around us, whether it is in indoor or outdoor environments. Reasonably, there are some motives [23] which simplify that VLC is one of the great inventions for the UbiComp era, those motivates are included:

- Visible light communication is in the unregulated spectrum internationally.
- Visible light LEDs are widely used everywhere around.
- Image sensors like the camera of the phone can be used as receivers, this is motivated by the excessive usage of mobile phones.
- LEDs in-which is used for transmitting and sometimes receiving light packets of data are cost-effective and affordable for their potential in comparison with Compact Fluorescent (CFL) and incandescent lamps [24].

The need for light from the sun's natural rays to the beams of artificial light sources in our daily lives motivates the cumulative capability of this technology. This also decreases to an extent, the dependent on highly sophisticated communication technology in our life, those certain applications include the need to use lighting and communications differently but contrarily came up with the usage of both the illumination and communications at the same time by providing an infrastructure that facilitates to merge devices that were classically independent on their owns specifications.

Intimately, in this modern age, technology is obsessed with our daily activities. Phones, computers, and also other electronic gadgets are almost necessitating a high bandwidth and cheap network that connects those various technological gadgets that surely can be spotted around us. Also, as people live in a very busy world, it is intolerable to depend on slow and unreliable network connections.

Interestingly, the potentiality of VLC over RF-based networks shows a magnitude solution that increases the dependence on ubiquitous computing systems. Moreover, both the communication and lighting (illumination) were used individually in different ways conventionally, however, VLC clears the way for simultaneous usage. The merging of both communication devices and light devices simultaneously to provide data transmission alongside illumination of surroundings proves the true invisibility of applications [10]. Consequently, that shows VLC is described itself as ubiquitous [18].

As that communication technologies are one of the key requirements in the Ubiquitous Computing applications [25], VLC applications which include using newly innovating Visible light Ad hoc networks [26], and recently the in-very-demanding applications of Internet of Things (IoT) [27] are almost conceivable and practicable for providing calm and easily relevant applications by utilizing the Ubiquitous Computing theory. VLC shows how enough it is for our needs of calm technology. VLC networks are modern up-to-date technology [13], and we can say that it is our demand in technology. Also, we can mention that VLC is one of the most advantageous technologies that assist to deliver different applications for better and calm daily human activities. Besides that, as any specific wireless communication network has to accommodate multiple different high-speed devices, the VLC network is regarded as a state-of-art network for ubiquitous computing.

Furthermore, in the matter of transmission and reception of light signals, it was explored and proved in [28, 24] that LEDs (in solid-state lighting) which are used mostly as a transmitter [19], are good for energy-saving technology, regarding its potentiality. For example, figure 8 illustrates the comparison of different lighting technologies. The figure depicts that LED lamps have a longer lifetime than Compact Fluorescent (CFL) and incandescent lamps. Following that, the United States Department of Energy's (DOE) Research and Development Solid-State Lighting Plan beyond 2030 brought up, that LED technology annually offers the potential to save 261 terawatt-hours (TWh) [29].

We mentioned in the first subsection that mobile cell phones statistically surpass the current human population while also mobile cell phone connections have increased by 2.64 billion connections over the world population [30]. This gives the idea that most of the time, mobile users are at home or in at least an indoor environment. Environmental lighting which positively increases human performance and health [31] is one of the fundamental necessities of the indoor environment.

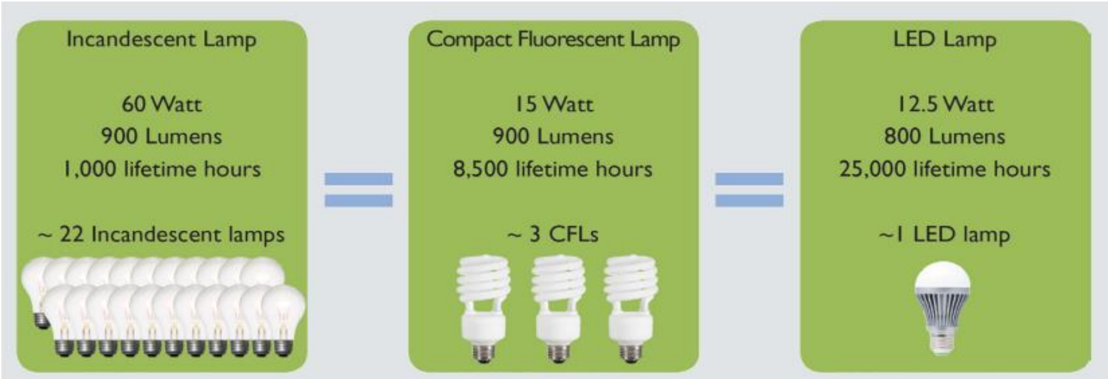


**Fig. 8 Approximate number of lamps required to achieve 20 Million Lumen-Hours Equivalency [39]**

Instrumental Activities of Daily Livings (IADLS) [32], which includes Healthcare, are on the radar of ubiquitous computing, which is also influenced by the Internet of Things (IoT). Smart sensing units and wireless devices are used to integrate the real environment with decision-making and computing capacities in IoT system services. The services of this environment bring advantages to multimedia, communication networks, information access, business, healthcare, and other applications for residential and industrial consumers [33]. If we take healthcare as an example, which is one of the Activities of Daily Living (ADL) [34], people can measure their health status by using wearable technology including smartphones [35]. As we referred before, VLC overpowers RF technology in terms of electromagnetic interference (EMI) [18]. Therefore, when it comes to the healthcare sector, VLC is more suitable and preferable.

On the other hand, in the traditional ubiquitous computing applications, locating people in indoor workplaces was one of the very early applications of Ubiquitous Computing [10] and the indoor Global Position System (GPS) is one of the leading noteworthy applications of it [36]. Thus, for indoor VLC, there is no need for home routers instead of that, LED lamps are enough, promoting that VLC is a state-of-art for indoor locating system [37].

## V. CONCLUSION

Basically, we examined the comparison of RF-based communications and VLC roles in this review while concerning the UbiComp concept. We referred to the benefits of VLC concerning governmental regulations and tariffs which are negligible compared to RF-based regulations. Additionally for true invisibility of applications, VLC provides data communication alongside illumination or lighting on surroundings which itself can be defined as ubiquitous. We showed the potentiality of VLC and the outperformance of VLC components, especially the light-emitting diodes (LEDs). We mentioned excessive usage of mobile cell phones as online connections and predominantly the increase of mobile phone users stimulates technologically a social change which created a need for high speed, reliable and calm technology.

We also addressed the vision of ubiquitous computing and its historical aspects. We defined that network technology is the center of this still-evolving concept. Ubiquitous Computing interrelates to the ADL while facilitating how those activities are performing. We glanced that by using VLC as intermediate network infrastructure, there are no other access points or home routers for internet usage but instead that LED and its subordinate components are enough to provide both data communication and illumination simultaneously. As that energy-saving is fundamental for this highly sophisticated technology, LEDs displayed positive promises for future perspectives over CFL and incandescent. We named the reasons that LEDs outperformed other available sources for our daily life usage in terms of energy consumption and lamp lifetime.

## REFERENCES

[1] M. Bellis, "Alexander Graham Bell's Photophone Was an Invention Ahead of Its Time," 07 March 2019. [Online]. Available: https://www.thoughtco.com/alexander-graham-bells-photophone-1992318. [Accessed 2020].

[2] A. Greenfield, Everyware: The Dawning Age of Ubiquitous Computing, Berkeley: New Riders, 2006.

[3] R. Siagri, "Pervasive Computers and the GRID: the Birth of a Computational Exoskeleton for Augmented Reality," in Proceedings of the 6th joint meeting of the European software engineering conference and the ACM SIGSOFT symposium on The foundations of software engineering - ESEC-FSE '07, Dubrovnik, Croatia, 2007.

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[4] A. S. Hornby, D. Lea, and J. Brad, Oxford Advanced Learner's Dictionary, 10th ed., Oxford: Oxford University Press, 2020.

[5] J. Krikke, "T-Engine: Japan's Ubiquitous Computing Architecture Is Ready for Prime Time.," IEEE Pervasive Computing, vol. 4, no. 2, pp. 4-9, 2005.

[6] D. Tennenhouse, "Proactive Computing," Communications of the ACM, vol. 43, no. 5, pp. 43-50, May 2000.

[7] M. Weiser and J. S. Brown, "The Coming Age of Calm Technology," in Beyond Calculation, New York, Springer New York, 1997, pp. 75-85.

[8] J. S. Winter, "Emerging Policy Problems Related to Ubiquitous Computing: Negotiating Stakeholders' Visions of the Future," Knowledge, Technology & Policy, vol. 21, no. 4, pp. 191-203, 2008.

[9] BankMyCell, "How Many Smartphones are in the World," Bank My Cell, 1 April 2022. [Online]. Available: Source: https://www.bankmycell.com/blog/how-many-phones-are-in-the-world. [Accessed 28 April 2022].

[10] M. Weiser, "Some Computer Issues in Ubiquitous Computing," Communications in ACM, vol. 36, no. 7, pp. 75-84, July 1993.

[11] M. Weiser, "The Computer for the 21st Century," Scientific American, pp. 94-104, September 1991.

[12] PARC, "PARC hIstory," Xerox Palo Alto Research Center, 20 June 2018. [Online]. Available: https://www.parc .com/about-parc/parc-history/. [Accessed 01 March 2022].

[13] J. Krumm, ubiquitous computing fundamentals, J. Krumm, Ed., Redmond, Washington: CRC Press, 2010, p. 410.

[14] O. Ergul, E. Dinc, and O. B. Akan, "Communicate to illuminate: State-of-the-art and research challenges for visible light communications," Physical Communication, vol. 17, pp. 72-85, December 2015.

[15] A. Ryer, Light Measurement Handbook, Newburyport, MA: International Light, 1998.

[16] Z. Ghassemlooy, W. Popoola, and S. Rajbhandari, Optical Wireless Communications: System and Channel Modelling with MATLAB, NewYork: CRC Press, 2013.

[17] R. Ramirez-Iniguez, S. M. Idrus, and Z. Sun, Optical wireless communications: IR For wireless connectivity, NewYork: CRC Press, 2008.

[18] IEEE, "Visible Light Communication (Tutorial)," 17 March 2008. [Online]. Available: https://www.ieee802.org/ 802_tutorials/2008-03/15-08-0114-02-0000-VLC_Tutorial_MCO_Samsung-VLCC-Oxford_2008-03-17.pdf. [Accessed January 2021].

[19] L. U. Khan, "Visible Light Communication: Applications, Architecture, Standardization, and Research.," Digital Communication Networks, vol. 3, no. 2, pp. 78-88, May 2017.

[20] D. Fleisch and L. Kinnaman, A Student's Guide to Waves, Cambridge, UK: Cambridge University Press, 2015.

[21] "Electromagnetic Transitions," in Quantum Physics of Light and Matter: A Modern Introduction to Photons, Atoms and Many-Body Systems, Springer International, 2014, pp. 51-80.

[22] A. Z. Dodd, "Carrier Networks," in The Essential Guide to Telecommunication, 5th ed., Indiana, Prentice-Hall Press, 2012, pp. 165-214.

[23] S. Haruyama, "Visible Light Communications," in 36th European Conference and Exhibition on Optical Communication, Torino, Italy, 2010.

[24] N. Luewarasirikul, "A Study of Electrical Energy Saving in Office," Procedia - Social and Behavioral Sciences, vol. 197, pp. 1203-1208, July 2015.

[25] J. Sen, "Ubiquitous Computing: Potentials and Challenges," Proceedings of the International Conference on Trends & Advances in Computation & Engineering (TRACE), p. 1323–1346, 26 February 2010.

[26] N. Cen, J. Jagannath, S. Moretti, Z. Guan, and T. Melodia, "LANET: Visible-Light ad hoc networks," Elsevier, pp. 107-123, 19 April 2018.

[27] K. Kadam and M. R. Dhage, "Visible Light Communication for IoT," 2nd International Conference on Applied and Theoretical Computing and Communication Technology (iCATccT), pp. 275-278, 2016.

[28] M. H. Crawford, "LEDs for Solid-State Lighting: Performance, Challenges and Recent Advances," IEEE Journal of Selected Topics in Quantum Electronics, vol. 15, no. 4, pp. 1028-1040, 2009.

[29] EERE Building Technologies Office, "Solid-state Lighting R&D plan," 2016. [Online]. Available: https://www.energy.gov/sites/default/files/2018/09/f56/ssl_rd-plan_jun2016.pdf. [Accessed 19 March 2022].

[30] S. O'Dea, "Forecast number of mobile users worldwide from 2020 to 2025 (in billions)," Statista, 12 July 2021. [Online].Available:https://www.statista.com/statistics/218984/number-of-global-mobile-users-since-2010/. [Accessed 28 April 2022].

[31] L. Bellia, F. Bisegna, and G. Spada, "Lighting in indoor environments: Visual and non-visual effects of light sources with different spectral power distributions.," Build And Environment, vol. 46, no. 10, pp. 1984-1992, October 2011.

[32] H. J. Guo and A. Sapra, "Instrumental Activity of Daily Living.," StatPearks, 21 November 2021. [Online]. Available: https://www.ncbi.nlm.nih.gov/books/NBK553126/. [Accessed 1 May 2022].

[33] V. Suma, "Wearable IoT based Distributed Framework for Ubiquitous Computing," Ubiquitous Computing and Communication Technologies, vol. 03, no. 01, pp. 23-32, 3 May 2021.

[34] R. J. Kaptain, T. Helle, A.-H. Patomella, U. M. Weinreich and A. Kottorp, "New Insights into Activities of Daily Living Performance in Chronic Obstructive Pulmonary Disease," International Journal of Chronic Obstructive Pulmonary Disease., vol. 16, pp. 1-12, January 2021.

[35] Y. Chen, X. Qin, J. Wang, C. Yu, and W. Gao, "FedHealth: A Federated Transfer Learning Framework for Wearable Healthcare.," IEEE Intelligent Systems, vol. 35, no. 4, pp. 83-93, 1 July 2020.

[36] J. Luo, L. Fan, and H. Li, "Indoor Positioning Systems Based on Visible Light Communication: State of the Art," IEEE Communications Surveys & Tutorials, vol. 19, no. 4, pp. 2871-2893, 2017.

[37] M. T. Zia, "Visible Light Communication Based Indoor Positioning System," TEM Journal, vol. 9, no. 1, pp. 30-36, 28 February 2020.

[38] M. McEntee and E. Ekpo, "Life, Health and Radiation," Coursera [MOOC], 02 November 2017. [Online]. Available: https://www.coursera.org/learn/life-health-radiation. [Accessed 12 October 2020].

[39] EERE Building Technologies Office, "Life-Cycle Assessment of Energy and Environmental Impacts of LED Lighting Products," 2013. [Online]. Available: https://www1.eere.energy.gov/buildings/publications/pdfs/ssl/lca_factsheet_apr2013.pdf. [Accessed 19 March 2022].