

Towards cost-effective use of Li-Fi in Smart Buildings

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Abstract— Light Fidelity (Li-Fi) is an advanced form of Visible Light Communication (VLC) which makes use of the latest Light Emitting Diodes (LEDs). A Digital Signal Processor is used to spatially modulate the light coming out of the LEDs through rapid intensity variation which is undetected by the human eyes. One of the most prominent features of Li-Fi is its ability to work in environments where Wireless Fidelity (Wi-Fi) and other Radio Frequency (RF) based communication are considered unsafe, dangerous or otherwise unwanted. In this research, we study the use of Li-Fi and check its feasibility of working in a sensitive environment like intelligence departments, hospitals, Universities, smart homes and buildings. The research focuses on an improvement of communication systems throughout entire smart buildings, making them safer and ensuring uninterrupted transmission. The paper also proposes a business model covering different aspects of innovation, market survey, industry impact and financial benefits achieved by the use of Li-Fi in place of Wi-Fi.

Keywords— Wi-Fi, Li-Fi, Communication, Business model

I. INTRODUCTION

Wireless communication is at the core of the modern lifestyle and is one of the basic pillars of the Information and communication technology. Much work has been done in order to improve the performance of the wireless communication systems. 3G and 4G are the most common standards today for mobile communication throughout the world. There is a very high data traffic on these networks and is constantly expanding. The currently used wireless networks are very slow, links us with internet if multiple nodes are connected such as usage of enlarge internet, number of devices and the fixed available bandwidth for transmission of data [1]. But the waves have a little bandwidth available for transmission of data. Li-Fi can solve these problems of data transmission by sending data via LED bulb with taking fiber out of fiber optics which varies faster intensity than human eye. From the infrared, Li-Fi has a various wavelength and frequencies range via visible and down to ultraviolet spectrum.

The most important activity is moving data from one place to another. For accommodating building's residents, the smart buildings must be adapted as shown in figure 1. It is desirable for the smart buildings to get the locations of every occupant and then providing a services of location based, in order to improve user experience and achieve improved comfort as like health monitoring, navigation, logistics, intelligent car parking, and shopping assistance [2]. For example, the technology Internet of Things (IoT) that connects every item for sale via wireless internet in a smart shopping mall.

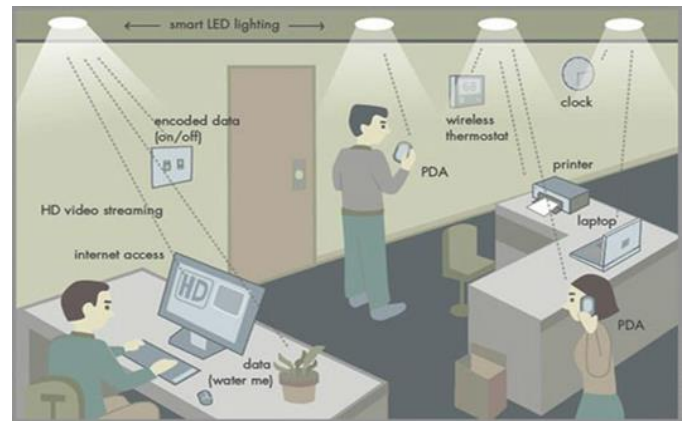


Figure 1: Working on Li-Fi in a traditional office [3]

In 2015, the mobile data traffic remained almost 3.7 Exabyte per month, the value is expected to spike up to 30.7 Exabyte (EB) per month by 2020. Around 67% of all the mobile communication will be done through “Smart” connections by 2020 [4]. Traditional Wireless Communication systems are though ubiquitous, they are expected to reach a certain virtual threshold which will act as a bottleneck for the growth of mobile communication. The radio frequency spectrum is about to be saturated and there is an imminent need to figure out a technology which can not only replace the modern wireless communication technologies but is also able to work in parallel as a hybrid system [5].

Figure 2 shows the electromagnetic spectrum as well as the visible spectrum which is used by Li-Fi. In 2011, Prof.

Harald Haas of Edinburgh University proposed the idea of Li-Fi [1]. It is an advanced form of VLC which makes use of the latest LEDs. A digital signal processor is used to spatially modulate the light coming out of the LEDs through rapid intensity variation which is undetected by the human eyes. The light is received at the receiver end by a

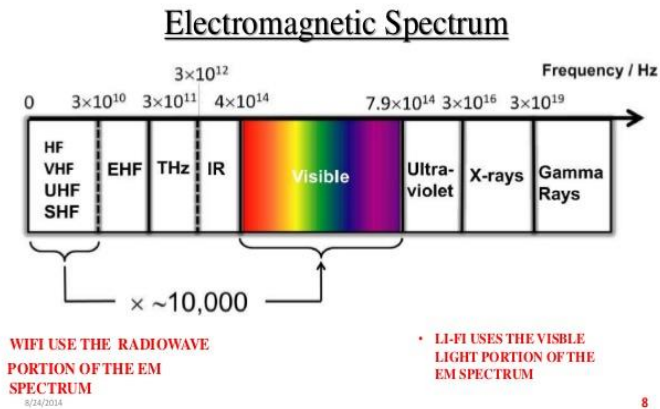


Figure 2: Visible Spectrum used by Li-Fi

photo-diode which decodes the frequent variations in the intensity of the light into bits and then turn them into a constant stream of data. While the Visible Light Communication has been in the public for quite a long time, it had been pretty much a virtual concept. However, with the advent of LEDs and their successful use in transmitting data through Light in the form of Li-Fi has opened a whole new world for us. Li-Fi has been lab tested and several prototypes have been successfully experimented with, in order to achieve a practically usable data rate. So far, Li-Fi has successfully achieved data rate which can not only match Wi-Fi but also overcome its deficits [5].

The shift from radio spectrum towards the visible light spectrum will solve a lot of the problems that the current communication technology is facing. Bandwidth is one of the major issues in the latest technologies, with the latest move into visible light spectrum; we have a 10,000 times larger bandwidth awaiting our services. Similarly, since lighting system is already everywhere, we do not have to invest a lot into a new infrastructure [6]. Li-Fi uses Attocells for communication which is not only smaller in size and enhances the usability, but also gives us an opportunity to allow the IoT to be practically implemented. One of the most prominent features of Li-Fi is said to be its ability to work in environments where RF based communication are considered unsafe, dangerous or otherwise unwanted. In this research, we study the use of Li-Fi and check its feasibility of working in a sensitive environment like government intelligence & other departments, hospital, universities shopping malls in short all smart homes and buildings [7].

II. LITERATURE REVIEW

In paper [1], Prof. Harald Haas has thoroughly clarified the basic difference between VLC and Prof. Haas' brainchild, Li-Fi. The paper focused on elucidating the major facts which makes Li-Fi, as the future of VLC due to the smart use of LEDs. The researchers have focused on how the ubiquitous luminaries turn into auto cells for Li-Fi hence resulting in an enhanced wireless capacity and opening a new window to not only materialize the concept of IoT but also fulfilling the major Key Performing Indicators (KPIs) of the 5G technology. The research also encompasses the interoperability of Li-Fi and Wi-Fi using auto cells to demonstrate its practicality.

Paper [2] proposes a novel VLC system for an enhanced control of the automated delivery robots in hospital (smart building). The research studied the traditional mobile robot systems that only concentrates on location accuracy and operational abilities; however, open management of safety hazards remain unchecked e.g. to stop them from going to an unauthorized and restricted area. Sensors have been introduced by the researchers in order to achieve the desired goals. Visible Light Communication through LEDs i.e. Li-Fi has been chosen for this technology. The Li-Fi creates a mini in-house positioning system by replacing several lights at specific spots in the hospital premises. The researchers have developed HOSPI, a hospital specific transportation robot, which makes an efficient use of VLC technology. Using VLC, the proposed robot will overcome the outdated localization techniques and ensure a better level of security for the robots. The paper is backed with theoretical and practical data of the subject in a real environment to check its feasibility.

Authors of paper [3] propose a solution to the constant interruption of the RF technology with the hospital equipment and their potential threat to humans. The paper proposes a method of transmitting the ElectroEncephaloGraphy (EEG) biomedical signals through Visible Light Communication. The method involves LOS based VLC with On-Off Keying non-return-to-zero modulation using Red, Green and Blue LEDs simultaneously with matching photodiodes at the receiver's end. Multiple experiments have been performed and it concludes that VLC based system is reliable and accurate.

Paper [4] is based on the application of Li-Fi in RF sensitive environments. The paper focuses on the Li-Fi as a new healthier, greener and cheaper replacement of the traditional Wi-Fi technologies. The paper focuses on how Li-Fi is an emerging technology from the field of VLC. The paper studies the role of Li-Fi in Radio Frequency sensitive environments like hospitals and airplanes where the use of Wi-Fi can cause potential damage.

In paper [8], the authors have studied the concept of communication at frequencies higher than 10 Ghz. The paper states that due to the increasing bandwidth utility and introduction of the IoT, the spectrum below the 10 Ghz is becoming insufficient to fulfill the increasing demand. Hence the concept of VLC became the next best contender to resolve the issue. Li-Fi, an improved version of VLC that works using

the LED and Li-Fi Attocells is thoroughly studied in this paper.

Paper [9] focuses on the concept of Wireless HetNets amid the growing wireless capacity demand due to the skyrocketing increase in utilization of channel capacity with the rise of smart devices and IoT. The paper states that most of the data is consumed in indoor environments, which is why the idea of using the gigabit small-cells looks practical. VLC, specifically the Li-Fi is the foremost contender to be considered in this regard. The paper describes the core characteristics of Wi-Fi and Li-Fi and discusses their interoperability. The paper then round off all the possible research challenges in this field in an attempt to devise a VLC HetNet Prototype.

Researchers have surveyed the fundamental technologies indispensable for the realization of Li-Fi in paper [10]. The research has been conducted in order to come up with cutting edge details on each of these aspects like VLC modulation techniques, optical MIMO, spatial modulation, optical wireless channel model, OFDM concept in VLC, hybrid Li-Fi models, multiple user-access, allocation of resources and interference management. The paper also suggested some future improvements in Li-Fi.

III. MOTIVATION

Li-Fi is unique form of communication in terms of its insensitivity towards Electro-magnetic signals. Li-Fi is safe to use in planes and other such sensitive environments. Wi-Fi and all types of RF communication are considered non reliable in smart buildings like big government departments as they are totally dependent on electricity availability as well as router performance. Also Wi-Fi working in one floor may not produce promising signals in the same building having some distant office. Also Wi-Fi signals are more prone to intruders attacking or Wi-Fi signal catchers.

They also pose a potential threat to general unhealthiness for humans. Since all the communication systems of the world are mainly based on the RF spectrum, there has been no possible solution to bypass these issues. With Li-Fi in the view, we now have a potential solution to the problems as we can utilize the Li-Fi in smart building particularly in Govt office and get rid of the RF related issues without hampering and compromising on our communication systems. In fact, it will improve the communication systems throughout the smart buildings, make them safer and ensure that the transmission is uninterrupted.

IV. AIMS AND OBJECTIVES

The aim of this research is to study the efficiency of LED based VLC systems and check its feasibility in sensitive

environments like government buildings and particularly in smart buildings. Govt buildings being very sensitive areas with a lot of sensitive equipment faces a potential threat from the use of RF signals. The introduction of Li-Fi technology in smart building communication systems will bring about a revolution and help us move towards a safer, cheaper and greener solution. The objective of the proposed business model will be addressing different aspects of innovation, market survey, industry impact and financial benefits achieved by the use of Li-Fi in place of Wi-Fi. The deployment of Li-Fi in place of Wi-Fi will prove to be more efficient not only in terms of monetary benefits but health concerns which are considerable in terms of RF communications. Also for communication systems, the use of Li-Fi will prove to be more effective and the speed will largely enhance with respect to Wi-Fi.

V. BUSINESS MODELING AND ANALYSIS

Here we use the framework and definitions by Chesbrough & Rosenbloom for building analysis and modeling [11]. Our focus will be on the valuable propositions such as value chain, the firm organization, and the competitive strategy of the operator and in the value network the position of the firm.

Actors, Relations (between actors) and Business roles with functionality were three main components where the organization of position and value chain of different companies using network model were discussed in [12]. Their focus in this paper was on network deployment for smart building, public access and office buildings for cases investigated. The two main key aspects for configuration of business roles and business modeling were:

- i) the access services were restricted to available public users or for own users
- ii) which smart building was there that operates and deploys the indoor network

The business modeling and cost analysis aspects in our analysis are related as; for enhancing network capacity, the production cost is lower and Li-Fi is localized to the high demand areas only with the indoor deployment. e.g No expensive marts or tower. It must be controlled. For ensuring the lower cost level, other different types of costs like transmission or maintenance and installation associated with infrastructure should be controlled. For re-using existing infrastructure, competence, company staff and for cooperating with facility companies and owners are another ways for reducing or controlling these costs. Furthermore no need to pay to the site leases, if the network is deployed for internal use in the premises of the customer. Figure 3 shows a smart building using a Li-Fi environment getting solar light as its energy to run.

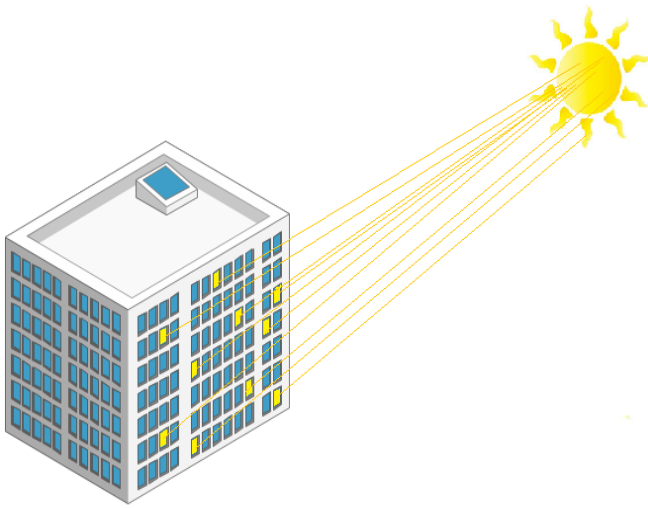


Figure 3: Office buildings scenario used in Li-Fi

VI. SCENARIO DESCRIPTION

With office buildings to be covered with Li-Fi, we will consider an area covered with smart buildings. For provisioning of wireless data services, the facility owner wants to investigate in smart buildings. We will do comparison with operations and cost of networks having “small scale” indoor Li-Fi solutions and “large scale” outdoor base stations. We here assume that everything is deployed from start and that there is no other infrastructure that will be re-used. In the 1 km² area, there are 10 five floor smart office buildings each with 1000 persons each. Demand for broadband access, the monthly total demand access is 5 Giga byte per user. The two levels of “relative wireless usage” are 10% and 50 % and 20% of the total monthly usage will be done for dimensioning of the wireless networks.

VII. IMPACT OF WALL ATTENUATION FOR LI-FI DEPLOYMENT

For wooden walls in rural areas, the wall attenuation varies from 5 dB and in urban areas is to 25 dB for concrete or brick walls. Normally in buildings, between the rooms the walls have a few dB attenuation. We use Okumura-Hata propagation model for estimating the loss for an urban Wi-Fi. In [13] assume the wall attenuation W (dB), K as a constant, R (km) to be the maximum cell range and $a(h)$, a correction for height h of the mobile antenna, so the loss of propagation can be then expressed as followed

$$L = K + 35.2 \log(R) + W - a(h) \dots\dots\dots(1)$$

If here we assume an antenna for the mobile receiver to be 1.5 m above ground and with 30 m height for the Wi-Fi then for a frequency of 2.1 GHz, $K = 136$. While h is about 1.5 m for

ground floor and for the third floor which can be about 10 m; then $a(h)$ is about 5 dB.

VIII. IMPACT OF PROPAGATION AND WALL ATTENUATION FOR LI-FI

For the propagation loss L (dB), the criteria for free space propagation inside a room we are considered employ the well-known formula as:

$$L = K + 20 \log D \dots\dots\dots(2)$$

D is the distance between the Li-Fi and the devices. $K = 32.4 + 20 \log(f)$. $K = 98.84$ for $f = 2.1$ GHz. We have to take into account outside the room wall floor attenuation F and attenuation W . We have to add the floor and wall losses to the free space loss above, where the signals have to penetrate which are proportional to the number of walls n and floors m . The equation now reads:

$$L = 98.8 + 20 \log D + nW + mF \dots\dots\dots(3)$$

At a distance D of 50 m

$$L = 72 + nW + mF \dots\dots\dots(4)$$

When the outer wall attenuation (15 dB) is taken into account this figure is much smaller (round about 60-70 dB) than the propagation loss from the Wi-Fi. Here this implies that a very low power could be used for the Li-Fi then about 10 - 100 microwatt is needed from the Li-Fi for giving the same input power to mobile receiver, if the transmitted power from the Wi-Fi is 100 watt. The maximum allowed power from the Li-Fi is 100m watt which gave large possibilities for adjusting the Li-Fi power to achieve low risk for interference and required performance.

A. Estimate of Cost

For the Li-Fi solutions, from a WLAN deployment project we use several hundred access points and data running over a couple of years. The deployment of one access point on average is 100 \$ which roughly equal shares (20-30%) for the cost components:

- Access point equipment
- Solar Energy
- Controller
- Planning, installation, documentation
- Management system

IX. ANALYSIS OF DEMAND

In our example we have 10,000 office workers in the area, where each with a total 5 Giga byte data usage per month. We get the following estimates of usage for one user are described below:

- Usage per day: ~ 250 MB
- Per busy hour 63 - 125 MB (for 2 to 4 busy hours per day)
- Per busy hour 0.5 – 1.0 Giga byte

During the busy hours, converting this to average bit rate we get 139 – 278 kbps. This means that for all the 10000 workers, a total of 1.39 – 2.78 Giga byte per seconds for the total data is used. Let us use as an estimate of the total demand 2.0 Gigabyte per second (Gbps). We need this to be carried over wireless connections and the share for the analysis that can be assumed. For the “wireless usage”, a “low level” estimate is 10 % resulting in 200 Mbps and a “high level” estimate is 50 % which would mean 1 Gbps.

X. COMPARISON BETWEEN WI-FI AND LI-FI SOLUTIONS

By the user demand, we will use dimensioning for the Wi-Fi solutions based on the capacity described. For the Li-Fi solutions we will use three different approaches such as:

1. Capacity:

Where the deployed capacity will match the user demand as for Wi-Fi.

2. Coverage:

For each floor in the office building, in order to ensure coverage a specified number of access points were allocated.

3. User oriented:

To each access point a number of users are allocated (demand does not matter)

A. Capacity approach

It is straight forward to estimate the number of required Li-Fi options, base station sites and access points considering that each Wi-Fi and Li-Fi has the capacity of 2Mbps

Total Demand (Mbps)	Wi-Fi solution		Li-Fi solution	
	No sites	Cost	No access points	Cost
200 (low level)	34	\$	100	100 PKR
1000 (high level)	167	\$	500	500 PKR

Table 1: Investment cost comparison

Table 1 shows an investment cost comparison for the number of base station sites and Li-Fi that meet the two levels of estimated user demand. Using the Wi-Fi the result shows that for the Li-Fi solution the investments solution were much

smaller. We assume that there is no wall attenuation in this “ideal” analysis and that the Li-Fi could provide the coverage which was needed. The operational costs should also be included for a complete analysis.

B. Coverage and user oriented approach

In table 2 with 4 or 8 access points per floor and 4 or 8 users per access point, we illustrate the cost for Li-Fi networks dimensioned. Different levels of “over provisioning” are achieved with these coverage and user oriented approaches but still the Li-Fi solutions are much expensive than Wi-Fi solutions. Furthermore an added value of the “over provisioning” is considered by in the form of access with guaranteed bit rates.

	No. APs	Cost	Capacity
Coverage approach			
4 AP per floor	200	200 \$	400 Mbps
8 AP per floor	400	400 \$	800 Mbps
User oriented approach			
8 users per AP	1250	1.25 k\$	2500 Mbps
4 users per AP	2500	2.50 k\$	

Table 2: The investment costs and deployed capacity for Li-Fi

XI. CONCLUSION

Wi-Fi and all types of RF communication are considered non reliable in smart buildings as they are totally dependent on electricity availability as well as router performance. It may not produce promising results in the same building having distant offices. Also Wi-Fi signals are more prone to intruders. The Li-Fi capability solution is for providing services when data rates, security and capacity need increases. We have also shown that we can also introduce offers with guaranteed data rate and availability using Li-Fi although it is costly in addition when using the Wi-Fi. There is even an over provisioning which made it able for deploying more development with higher data rates. This is possible for Wi-Fi to a certain degree but near the site only; thus in spectrum utilization, Li-Fi showed an improved efficiency in results. For private use in homes, Li-Fi has more advantages for consumer whereas Wi-Fi based home station was limited especially that we have to pay for extra equipment. Wireless extensions WLAN based broadband connections will be available at low cost for many years; but eventually be superseded by Li-Fi. Their main advantages will be in public use and within hotels, conference centers, smart buildings and enterprises etc.

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