Designing of Cell Coverage in Light Fidelity

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***Abstract*—The trend of communication has changed and the internet user demands to have higher data rate and secure communication link. Wireless-Fidelity (Wi-Fi) that uses radio waves for communication has been used as an internet access methodology for many years. Now a new concept of wireless communication is introduced that uses visible light for communication and is known as the Light-Fidelity (Li-Fi). Li-Fi attracted the researchers for its vast advantages over Wi-Fi. Wi-Fi is now an integral part of everyday life. In near future, due to scarcity of spectrum, it would be quite difficult to accommodate new users in limited spectrum of Wi-Fi. To overcome this, Li-Fi is a good option because of its infinite spectrum range, as it uses the visible range of the spectrum. Many researchers discussed that Li-Fi is secure when compared to Wi-Fi. But is it really secure enough? Can anybody access hotspot of Li-Fi? Or is there a need to develop a technique that is used to block the unauthorized access? In this research work, a cellular concept is introduced for the Li-Fi usage in order to increase the security. This research presents a flexible and adjustable cell structure that enhances the security of Li-Fi. The coverage area is shown by utilizing the geometrical structure of the cone and the area of the cone can be controlled. A mechanical system is also installed on the roof to control the coverage area of a Li-Fi by moving LED bulb slightly up and down. A mathematical expression for the proposed coverage area of the cell is provided, which is formed on the ground level by a beam of light originating from the source of light. The adjustable and controlled structure provides security benefits to the owner. Finally, the research is backed by its simulation in Matlab.**

Keywords*—Light-Fidelity (Li-Fi); Wireless-Fidelity (Wi-Fi); communication technology; light emitting diode (LED)

I. Introduction

Light has been utilized as a communication medium for many years and still light has a very vital role in the field of communication. For making signals of smoke on a cloud, fire was used in the past. But in the 19th century the light bulb was invented by Thomas Alva Edison that introduced new options to use light for communication [1]. After the invention of electric bulb another invention for optical communication to visualize signals was signal lamp. It was used along with Morse's code to relay message to the onlooker.

In year 1880 Graham Bell implemented the idea for utilization of light as a communication medium, when he invented the photo phone. Working of photo-phone depends upon a beam of light in which voice signal is super imposed. A mirror was used to focus sunlight and then apply voice pressure on a mechanism that causes the mirror to vibrate. At receiving end the detector detects the vibrating beam and decodes it reverse to the voice indicator, the same method was implemented inside phone in the occurrence of electric signals. However, Graham Bell did not give any idea for point to point transmission of light and couldn't produce a carrier frequency. Also photo-phone, made by Bell, was affected by the obstacles in nature such as rain, fog, and noise [2].

Light's use as a medium of communication progressed again when light emitting diode (LED) was invented. Visible light communication (VLC) uses white LED for transmission of data and flickering of LED generates a signal in the form of digital pulses. The frequency of LED flickering is very high, thus human eye perceives this light as constant and stable. Due to this flickering of LED, the signal is modulated by using binary codes in order to turn the communication off-on. This encoded signal is used for transmission of data in optical wireless communication (OWC) [3].

Li-Fi got much attention after August, 2011 in technology, entertainment, design (TED) global conference where Professor Harald, commonly known as the father of Li-Fi, introduce Li-Fi to the audience in a very dramatic and magical way. He presented the idea that how an LED bulb can communicate along with its ordinary working of illumination. With the help of LED bulb he stopped the high definition (HD) video on screen and then played it again by obstructing light of the lamp. It made a very astonishing impact on the audience as well as the researchers from the whole world [4].

Li-Fi communication is more secure than Wi-Fi in a sense that a user can access the Li-Fi access point only when he is in the line-of-sight (LoS). In the non-line-of-sight (NLoS) situation, a user cannot receive light from the source and hence cannot use the internet from the Li-Fi access point. Unlike Li-Fi, a user can access the Wi-Fi access point in the communication range weather he is in LoS or NLoS. This is one of the strongest issues that provide motivation for a coverage based Li-Fi communication channel model. The proposed research work provides an adjustable coverage cell size to accommodate the desired number of users in the region of interest.

A lot of work has been done in the field of Li-Fi. The researchers from all over the world are doing research in this area. Because of the vast advantages of Li-Fi over Wi-Fi, it got much attention, especially for its speed that is undefeatable. But there is no work found on the cellular side of Li-Fi and it is totally a new concept. The Wi-Fi signals cannot be controlled and limited to some specific point; a user cannot restrict the Wi-Fi signal due to its open nature. An unauthorized user or intruder can intervene with the Wi-Fi signals. On the other hand Li-Fi uses light as a signal that can be restricted and a user can control it not to cross some point. So Li-Fi can be secured by designing a cell for it. This novel research area is quite challenging.

The objectives of this research work are to design cell coverage for the users of Li-Fi such that users can access the Li-Fi hotspot more securely and communication could be speedier.

There is no doubt on the importance of the cell in the cellular network. The mobile networks become more efficient and effective through the use of cell. By imagining the cells in the cellular network, the goal is to introduce the cellular concept in the Li-Fi. In this paper, we designed three types of cells on the basis of number of users and we explored the number of users to be accommodated in each cell.

Paper is divided into following sections. Previous work for and Li-Fi is discussed in Section II. Proposed method to model curve shapes, surfaces, two dimensions (2D) and three dimension (3D) structures is presented in Section III. Mathematical derivation for cell coverage of Li-Fi is carried out in Section IV where we also analyzed the achieved data, and retrieved simulation results in Matlab are discussed in detail. Finally, the paper is concluded and future work is highlighted in Section V.

II. Literature Review

As the trends are changing, communication has become vital like oxygen for humans. So it must be accurate, secure, cheaper and faster. Yesterday's light was introduced to visualize the objects, but today's light is effective tool using for communication. Li-Fi is a term used for Light Fidelity.

Khandal et al. described in their paper, cell coverage will be controlled by using VLC. Li-Fi is much effective than Wi-Fi because of its speed and privacy. Visible spectrum is used in VLC so it means that LoS communication will be applicable in VLC [5]. Li-Fi is 100 times faster than Wi-Fi and its speed is more than one GBPS. It can work those places where Wi-Fi cannot be applicable. It can be used in airlines, undersea exploration, theaters in operation, etc. The LED bulb is used as a transmitter and a photo detector diode is used as receiver along with light driver in Li-Fi system. Every light bulb can behave like a Wi-Fi access point in the near future [6].

It seems an idea of Li-Fi is little older than August 2011 where Professor Harald from university of Edinburg introduced Li-Fi. In real, Li-Fi emerged in 2006, and a lot of patents written by researchers in the year followed by 2006 inclusive. Li-Fi captivated the sight of researchers, companies and countries to focus on this new era in technology. Fig. 1 shows the companies and organization focused on activities of patent filing on Li-Fi before 2011.

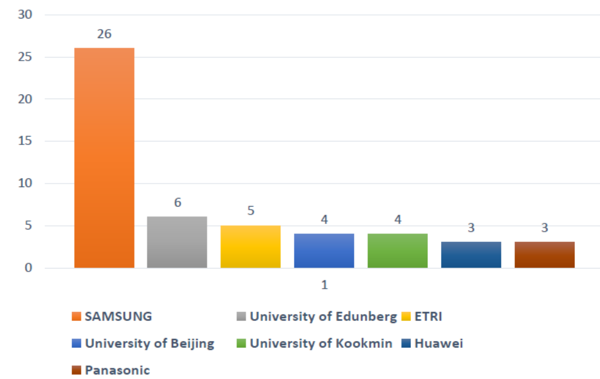

Fig. 1. Li-Fi patents by companies before 2011.

Aside from the research area, some of the world most famous countries that paid attention to convert LED bulb into Li-Fi access point in the past are shown in Fig. 2. The South Korea is the leading country with the most number of patents than any other country. The comparison relating to the number of patents written per year from 2006 to 2015 is shown in Fig. 3. The number of patents are increased gradually from only 3 patents in 2006 to highest 39 patents in 2013 and 34 patents in 2014. Only 8 patents written in 2015 do not mean that Li-Fi does not attract researchers, but it takes time for the patents to release usually 1 to 2 years. These figures were taken in 2016 so many of the patents that were written in 2015, not completely published. The point is that the gradual increase in the number of patents clearly shows the importance of Li-Fi in the sight of researchers [7].

Researchers and inventors of Li-Fi were doing research and writing patents before the publicly announced of Li-Fi in 2011. The first research on Li-Fi is written by Prof. Mr. Harald Haas in the early days of 2006, states of all top five researchers are coincidentally working for Samsung [8], see Fig. 4. Li-Fi is expected to become a world huge industry estimated 113 billion dollars in 2022 due to its unique characteristics and advantages.

According to a CISCO survey about existing spectrum usability that is about 80% of spectrum has been utilized. Currently Wi-Fi is deployed within universities, hotels, offices, buildings, cafes, homes, airports and provides connectivity of ten to hundred meters distant. The very rapid growth in radio frequency spectrum utilization made it very dense and there exists insufficiency of available frequencies. So people start pondering upon VLC communication because it is free from spectrum scarcity.

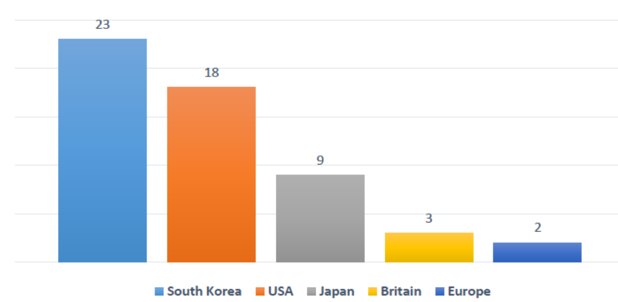

Fig. 2. Li-Fi patents by countries before 2011.

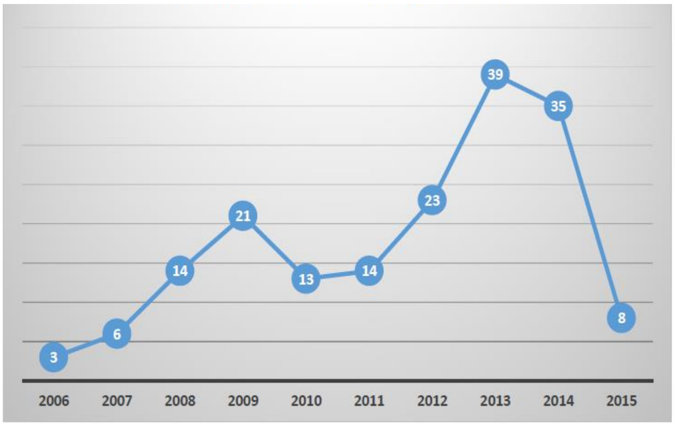

Fig. 3. Number of patents per year.

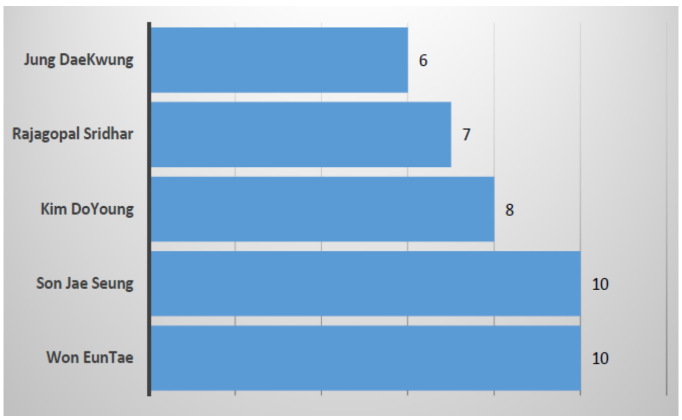

Fig. 4. Top Li-Fi inventors before 2011.

Li-Fi uses optical part of the spectrum instead of the radio part of the spectrum that is used by Wi-Fi. This new spectrum is ten thousand times greater in size than radio spectrum [9]. The operating frequency on which Li-Fi operates is in terahertz while Wi-Fi is operated at 2.4GHz usually except for some standard that uses 5GHz and 60GHz frequency band.

The frequency spectrum consists of many regions on the basis of characteristics of frequency. These regions include infrared rays, X-rays, radio region, microwaves, ultra violet rays, gamma rays and visible light region. Among these regions anyone can be used for upcoming technology but VIBGYOR portion is chosen because it does not encompass harmful effects on the human body. VIBGYOR region that is visible to human eye comprises of seven colors that combine to make a white light, see Fig. 5. The wavelength of these colors ranging from 390nm to 700nm. As frequency is reciprocal of wavelengths, so in frequency terms that are vicinity of 770 terahertz greatest for violet to 430 terahertz smallest for red [10], see Table I.

Security of Li-Fi is much better than Wi-Fi. Light can never penetrate through walls and communication can be easily established within the room without any security flaws because no one can hack or decode the signals of Li-Fi. A person cannot use the Li-Fi hotspot without the permission of owner [11].

There is no method available to restrict the Wi-Fi signal. So the signal of Wi-Fi transmits away from the service providers so any unauthorized user or intruder can interrupt the Wi-Fi signal and hackers can hack important or confidential information by applying some easy decryption methods [12]. The only way to provide security in Wi-Fi is to pursue wireless intrusion prevention system (WIPS) and follow the security measures describe by WIPS.

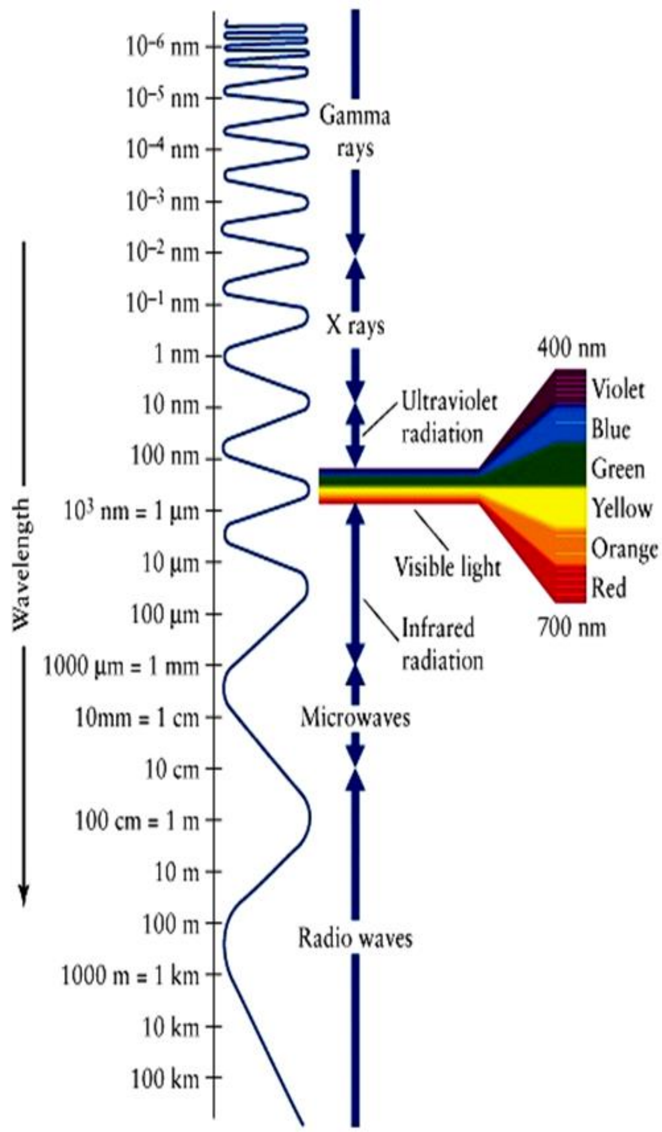

Fig. 5. Full electromagnetic spectrum.

TABLE I. VIBGYOR FREQUENCIES AND WAVELENGTHS

COLOR	WAVELENGTH (nm)	FREQUENCY (THz)
Violet	400.0 – 440.0	680.0–789.0
Indigo	440.0 – 460.0	668.0–680.0
Blue	460.0 – 500.0	606.0–668.0
Green	500.0 – 570.0	526.0–606.0
Yellow	570.0 – 590.0	508.0–526.0
Orange	590.0 – 620.0	484.0–508.0
Red	620.0 – 720.0	400.0–484.0

TABLE II. SPEED COMPARISON OF WIRED, WI-FI AND LI-FI

Technology	Speed
Wired	***Speed (Gbps)***
Fire Wire	0.80
USB 3.0	5.0
Thunderbolt	2*10.0
Wireless (Current)	***Speed (MBPS)***
WI-FI-IEEE 802.11n	150.0
Bluetooth	3.0
IrDA	4.0
Wireless(Future)	***Speed (GBPS)***
WiGig	2.0
Giga-IR	1.0
Li-Fi	>10.0

A. Li-Fi Advantages

There are lots of advantages Li-Fi has over Wi-Fi. Li-Fi is faster than Wi-Fi, speed in the order of 500MBPS. Wi-Fi uses radio waves that have to bear disturbances and others hazardous while Li-Fi uses the light which is robust to disturbances. In February 2015, the researchers at Oxford University acquired a record breaking speed of 224GBPS with Li-Fi. With this pace twenty HD movies can be downloaded in one second. Though these results were experimental and are not achieved practically, but still considering data transfer rate Li-Fi has a potential to thrash Wi-Fi [13]. Table II shows the speed comparison of technologies.

VLC safely could be used in aircrafts without affecting aircrafts signals. Li-Fi can be integrated into medical devices with no side effects to patients and in hospitals as this technology doesn't deal with radio waves, so it can merely be used in all such places where Bluetooth, infrared, Wi-Fi and internet are broadly in use. Wi-Fi does not work under water, but Li-Fi can effortlessly be deployed in water and undersea working can be performed with ease [14].

Millions of bulbs in the world can be replaced with LED, in order to transmit data along with illumination. Li-Fi is much secured than Wi-Fi as it won't penetrate through walls. For controlling traffics on highways, motorways, the vehicles can be integrated with LED and can be used to avoid accidents. Every lamp on the street would be used as an access point. The deficiency in radio spectrum can also be addressed using Li-Fi. LED consumes very less power and high patience to humidity [5].

B. Li-Fi Limitations

Even though, there are many advantages, Li-Fi is not widely deployed yet because it requires the source and destination to be in the LoS. If the photo detector is blocked or the receiver is blocked the signal cannot be destined. If there is an external source of light, that can also disturb Li-Fi signal. Li-Fi is good for indoor communication unless and until there is no other source of light or ambient light. For working Li-Fi needs a direct LoS and distance from the LED bulb is also needed to be defined because light intensity decreases with distance from the source [9].

C. LI-FI Application

Li-Fi can prove itself in areas where other technologies along with Wi-Fi either could not be deployed or failed to provide higher data rates. Such applications include underwater, power plant, airplanes, and hospitals, especially in operation theaters where other technologies can be harmful for patients. Other applications include medical science, aircrafts, learning purposes and in avoiding accidents on the roads. Li-Fi can be used in any emergency situation like flood, earthquake, and nuclear plants or where security cannot be compromised, thermal plants and in all sensitive locations [3].

Due to increase in demand the spectrum of electromagnetic is near to fill so solution of this problem is to introduce an alternate to overcome this situation. Spectrum of visible light has a very large bandwidth that enables many users to fulfill their requirements. It is also cost effective as it is licensed free and also has a large number of applications.

White LED is an important part of VLC because it works as a source in OWC. When multiple parallel lights have been installed within the room, then interference between the lights and reflection of lights are considerable. The spectrum of visible light ranging from 380 nm to 780 nm is followed the range of personal area network (PAN). But VLC sends data by using different intensity modulated optical sources, like LED and laser diode which are faster than the persistence of vision of the human eye [15].

Data rate of LED is much higher than any other visible light such as incandescent bulb and fluorescent tube. LED consumes very low power, but provides longer life time, which is easy to control and also has high luminance. LEDs are operated as an optical transceiver which can be used for communication purpose [16].

VLC can work only in those places where light is present so communication can be more secure than radio frequency (RF). VLC can be used under water where RF couldn't throw the signals. Aero plane is operated in RF so that hotspot which is operated in RF become reasons for interference, but if VLC is used for communications there will be no interference.

Yingshu discussed a framework that is based upon algorithms to solve the coverage area problems of wireless sensor network (WSNs). This algorithm has very low time for complexity than all the previous algorithms. Also, it prolongs the network life and saves energy by not covering the area where coverage is not needed [17].

To avoid interference a femtocell has been discussed for indoor wireless environment, a femto cell is a cellular base station consumes low power and is very small in size and it is used for home and office. Femto cells control the convergence plan between service providers and users. It is useful for both user and service provider also because it fills the gaps and eliminates the loss of energy [18].

A research has been published in CISCO Systems Inc. that every person in the world is going to use mobile data that shows that there is a large number of increase in the mobile web applications and mobile videos. This research is named as the visual network index (VNI), which estimates that in next few years usage of mobile data may increase from 90 thousand terabytes to 3,600 thousand terabytes in each month. After 5 years, this factor may increase to 40 or in case more than hundred percent cumulative annual growth rate (CAGR). This will become a huge growth in mobile data, mobile videos will cover sixty six percent, PCs, tablet, networking equipment, laptops, and mobile devices may be used seventy percent of it. A data is further share between these devices within the buildings, offices and classrooms. So one can guess the amount of data which will be shared or transferred in communication. Because transfer rate for data in VLC is very high, so these challenges can be catered in the future [19].

The reason of using LED instead of Laser diode is that LEDs is not harmful for eye of human and light of LEDs is less penetrating than laser diode. Spectrally, modulated techniques are used to achieve high speed communication that is based upon high rise times of LEDs [20].

Initially, the communication between end terminals took place via a very high tall tower with huge transmitting power. There was no idea of the frequency-reuse and cell splitting. After it became popular in the market, it was necessary to increase the spectrum bandwidth to increase the number of channels in the given coverage area. First of all, the existing bandwidth which was 30 kHz is split into three 10 kHz, narrow bands and increased the capacity in terms of customer by three times. American mobile phone system (AMPS) was fully analog and manual dialing system. To increase the system capacity, a cellular concept was introduced [22]-[24].

In cellular mobile communication system, the allocated spectrum is insufficient to provide services to the large number of subscribers. While the goal of cellular communication is to increase capacity, increase coverage within the same limiting spectrum. The reuse of frequency concept is introduced in a cell after a suitable distance among cell to avoid interference between same cells [21], [25].

Cells with the identical alphabets in Fig. 6 using the same frequencies with frequency reuse pattern 7. That means same frequency is to be allocated to every seventh cell. To increase capacity and coverage some other techniques were introduced such as sectored antennas, umbrella cells, small cell sizes or micro cells, and channel assignment strategies etc. In each cell two types of channel assignment strategy are used. First one is fixed channel assignment and second one is a dynamic channel assignment. In the first one, pre-defined numbers of channels are allocated in the cells while in the latter one; channels are assigned on demand of the active customers [21].

A VLC can be used in homes for monitoring appliances with cameras. Cameras have recent exchange data with other embedded devices at a rate less than one KBPS, which is insignificant. A VLC can give high downstream speed and better performance for communicating indoors in homes, schools, universities, organizations, etc. This process requires very low power and can be initiated in ten milliseconds [26].

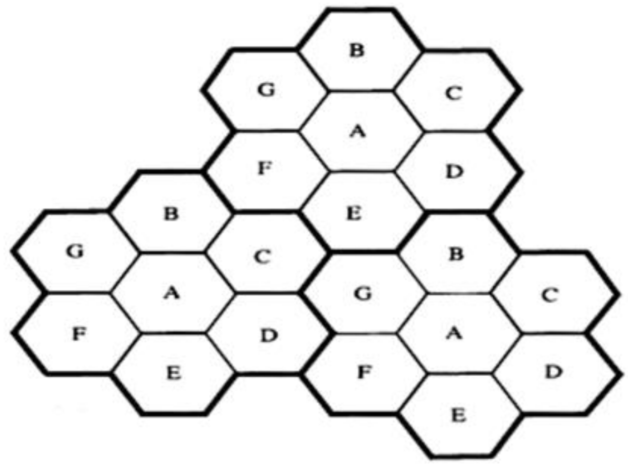

Fig. 6. Frequency reuse.

III. Proposed Method

In this research work, geometric modeling approach is chosen to address cellular coverage area of Li-Fi. Geometric modeling is applied mathematical concepts and approaches to model curve shapes, surfaces, two dimensions (2D) and three dimension (3D) structures. It clearly states simple mathematical equations and to combine them to make more complex models [27].

A cellular concept for Li-Fi usage along with a flexible and adjustable cell structure enhances its security while utilizing geometry of cone. There are three main units of communication; transmitter, receiver and medium and other subunits are used for driving these main units.

In VLC, LED lamp acts as transmitter which transmits light signals in the form of pulses and pulses on-off is generated due to flickering of the LED lamp. The lamp driver is further connected to these parallel connected LEDs. Power is provided to the transmitter unit after rectification. The data that is transmitted by lamp driver is further gone through medium and form a conical shape at the base of floor. This data signal is received by the photo sensing device called photo detector. Photo detector is acted as receiver along with the processing and amplification units. After the signal is processed and amplified by the amplifier unit, it relays data to the destination devices, see Fig. 7.

When light start to travel, the beam of light become scattered or spread out as light travels on more distance. A cone is formed when the beam of light from the source through a small hole is thrown on a flat surface. This conical form made of light is supposed to be called as cell or coverage area for Li-Fi. The area of a cell is to be controlled by adjusting the distance of light source from the small hole or slit. A mechanical system is to be installed above the slit in the ceiling holding LED bulb, which is used to control the distance by moving LED up and down according to the requirement of number of users to be accommodated in the cell.

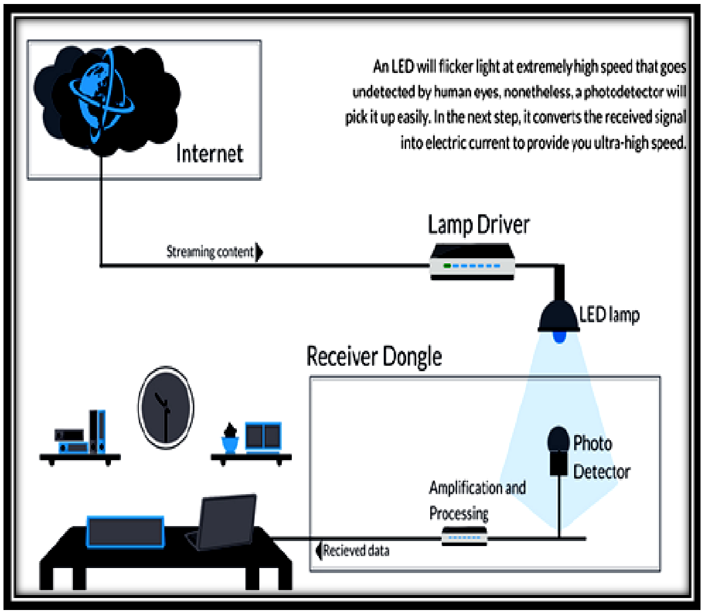

Fig. 7. Working of VLC.

Fig. 8. Small cell area.

A wide hole with diameter "d" is created in the ceiling through which light can easily pass. By changing the distance between the hole and LED bulb, the area of a cell can be controlled, which in turn can control the number of users who can access or connect with the hotspot of Li-Fi. The cell size dynamically adjusts to accommodate more users by mechanically decreasing the separation between LED and slit. We design three categories for conical cell with respect to coverage. Each category will have different number of users on the basis of mathematical and theoretical calculations.

A. *Small Conical Cell*

This section describes the formation of small cell size using the proposed conical beam of light from the LED towards the users on the ground. To achieve this, the distance between LED bulb and the hole in the ceiling is kept large enough through the mechanical system. Due to this large gap between the LED bulb and hole in the ceiling resultantly the beam of light went pass through the hole with a narrow beam. This narrow beam forms a cone with a small conical area which will cover a small circular region on the ground that covers lowest number of users and can be labeled as small cell, see Fig. 8.

A small conical area is covered on the ground because the angle of incident light 'a' through the slit with diameter 'd' on the ceiling is very small.

A cone has two right angle triangles and both triangles are congruent with each other so the single triangle is taken which has three angles (a,b,c) and right angle 'b' is 90 degrees and the sum of these angles must be 180 degrees. So if the incident angle 'a' has a minimum value, then scattered angle 'c' will be maximized and when scattered angle 'c' has maximum value then the cell will cover a small area. When the coverage area is smaller than minimum number of users can connect with the hotspot.

B. *Medium Conical Cell*

This section describes the formation of medium sized cell when the distance between the hole in the ceiling and LED bulb is moderate; neither large nor small gap. Due to this moderate gap, a medium sized cone is formed on the ground at the receiver end. The base of the cone covered circular area between the small sized and large sized cell and consequentially provides an accommodation for more number of users as compared to small sized cell.

The moderate conical area of cell can be covered by the light because of the incident angle of light 'a' is less scattered than one in the case of the small cell area and distance between LED bulb and slit opens hole 'h1' is also kept less than in case of small sized cell. So if the incident angle 'a' becomes almost equal to the scattered angle 'c' that is nearly 45 degrees, then the cell will cover medium area and when the coverage area will be medium then more numbers of users can connect with hotspots as shown in Fig. 9.

C. *Large Conical Cell*

When the distance between the hole in the ceiling and the LED bulb is kept almost zero, it covers a large area that is formed on the surface of the floor. Due to no gap between them the beam of light went pass straight toward and scattered more enough to reach the receivers and makes a wider cone shaped form from ceiling to the receiver, see Fig. 10.

Very large conical area of cell can be covered by the light that is 'hi' is equal to zero, and the incident angle of light 'a' through slit will spread more having large diameter. So if incident angle 'a' is maximum then scattered angle 'c' is minimized and then the cell will cover a very large area. Ultimately, maximum numbers of user can connect to the hotspot of Li-Fi.

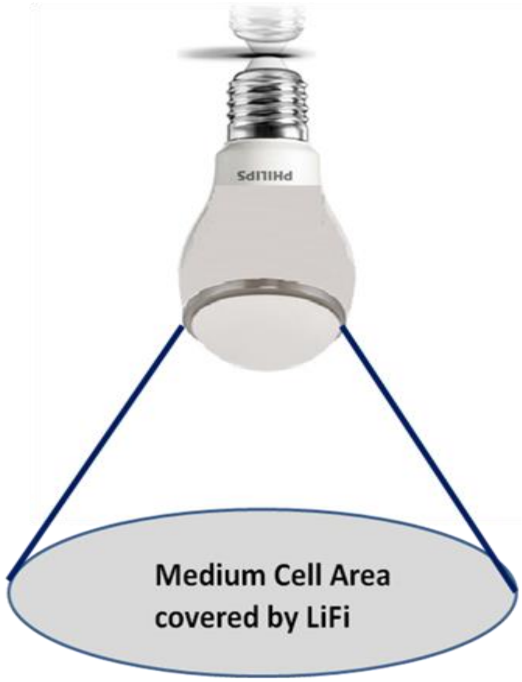

Fig. 9. Medium cell area.

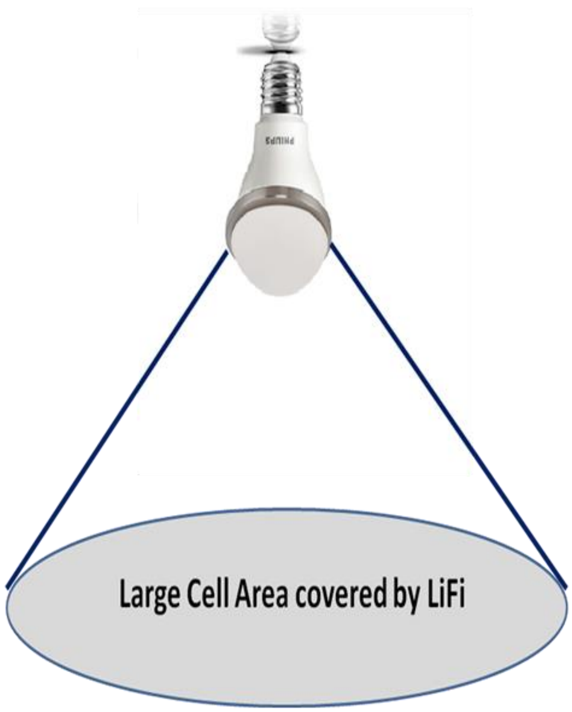

Fig. 10. Large cell area.

IV. Results and Discussion

In this section, the mathematical derivation for cell coverage of Li-Fi is carried out. The equations from the cone with the help of mathematical theorems, formulas and trigonometric identities are derived. Using these equations area of the cone is calculated for all three cell sizes and estimates the number of users that can exist in a small area, medium area and large area.

A. *Layout of Geometry of Cone*

By drawing a vertical on the cone the two right angled triangles are formed, see Fig. 11. As these two triangles are congruent to each other so focused on just one and find a solution by applying trigonometric function.

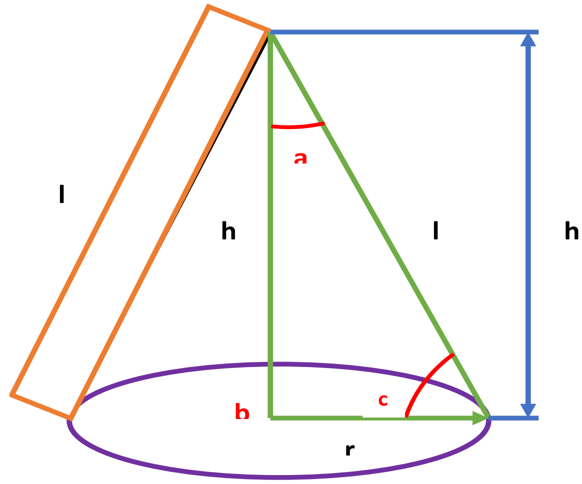

Fig. 11. Geometry of cone.

From the geometry of the cone, the equations can be drawn using basic mathematical concepts. The right angled triangle is shown in the Fig. 12 and for any arbitrary triangle the interior angle sums equals to 180^{o} degrees, see (1). The very familiar trigonometric functions sine (Sin), cosine (Cos) and tangent (Tan), can be used to solve the sides of a cone.

$$a+b+c=180° \quad (1)$$

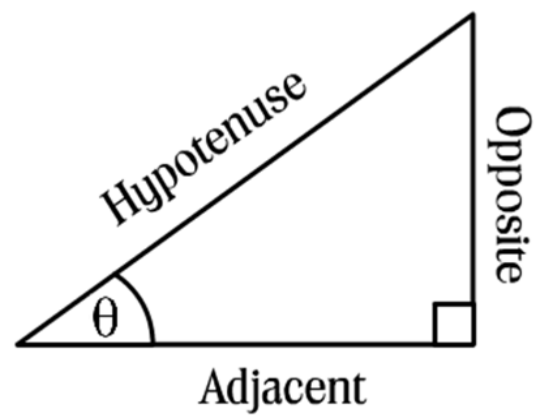

Fig. 12. Right angle triangle.

By applying (1) sine and tangent is calculated by (2) and (3).

$$\sin\theta = H/1 \quad (2)$$

$$\tan\theta = H/r \quad (3)$$

Where H is a sum of the heights from the floor to the roof, ho (constant) and LED bulb height h1 from roof slit. The height h1 can be varied only if the separation between LED bulb and slit is increased or decreased, depending on the requirements of coverage. So H is calculated by (4):

H=ho+h1 (4)

Now for right circular cone, let say cone area A is the sum of the curved surface area of cone Al and circular surface area of cone Ac. Lateral surface area of the cone or curved part area of the cone is given by (5).

Al = π r l (5)

Where r is the radius at the cone bottom and l is the lateral height of the cone.

The circular part area is simply the circle at the bottom with radius r is given by (6).

Ac = π r2 (6)

Hence the total area of cone A, the (6) can be written as (7).

A = Ac + Al (7)

The incident angle 'a' is controlled by the gap h1 between LED bulb and slit and the diameter 'd' of slit is fixed by (8).

Θ = arctan (d/2 * h1) (8)

The incident angle 'a', scatter angle 'c' and right angle 'b' relation is given by (9).

Φ = 90-θ (9)

ho is the constant height from floor to roof slit, and h1 is controlled by mechanism, when both ho and h1 is known then length 'l' and base 'r' can be found easily by arranging (2) and (3) into (10) and (11).

l =H / sinθ (10)

r = H / tanθ (11)

When the values of 'l' and 'r' has been evaluated then by putting these values in (5) and (6), the lateral surface area of cone Al and area of circular part of cone Ac can be found. After inserting all the values in (7), total area of cone A can be inquired, number of users to be adjusted in the circular part of the cone Ac by rearranging (7) into (12).

Ac = A – Al (12)

B. Data Analysis

Few of the terms in these calculations are constant such as height of floor ho, right angle in all cases, and some of the terms are specifically constant in each case that are height of LED bulb from slit h1, angle θ and angle φ. Values of heights and angels for all three cases are elaborated in Tables III and IV, respectively.

TABLE III. VALUES OF HEIGHTS FOR THREE CASES

Cases	Height (h_o)	Height (h_1)	Height (H)
Small	10	1	11
Medium	10	0.5	10.5
Large	10	0	10

TABLE IV. VALUES OF ANGLES FOR THREE CASES

Cases	Angle (a)	Angle (b)	Angle (c)
Small	30	90	60
Medium	45	90	45
Large	60	90	30

The standard designated area per person in buildings is 0.6 square meters. As feet square unit are used in our calculation so converting 0.6 square meters to square feet, will get 6.45 square feet. If the user is working by having a laptop on the desk or working in an office or laboratory, then this reserved space can be increased from 6.45 square feet. It is better to use 10 square foot area for each user that is almost equal to 1 meter square space for better utilization of cell area and coverage, see (13).

No. of users = Ac /10 (13)

To extend our equation for 'n' number of cells because there can be more LED bulb fitted into the room in order to fill up the gaps. So (13) becomes (14).

$$\text{no of users in "n" cells} = \sum_{i=1}^{n} \frac{A_{C_i}}{10}$$
$$\text{no of users in "n" cells} = \frac{1}{10} \sum_{i=1}^{n} A_{C_i} \quad (14)$$

The values utilizing from Tables III and IV are applied to the calculations and final results are presented in Table V.

TABLE V. NUMBER OF USERS FOR THREE CASES

Cases	Radius(r) feet	Cone Area (A) ft^2	Circular Area (Ac) ft^2	No. of Users
Small	6.35	380	126.7	13
Medium	10.5	834.6	346.4	35
Large	17.3	1483.5	940	94

From the Table VI, conclusion can be drawn that if scattered angle 'c' is less than 30 degrees, then the result will be a large sized cell. Similarly, if scattered angle 'c' is greater than 30 degrees and less than or equal to 50 degrees, the results show it will be a medium sized cell. Finally, if the scattered angle is greater than 50 degrees results in small sized cell. The number of users with respect to cell size is clarified in the Fig. 13. The maximum users in small cell are almost 13, covering each user a space of 10 square feet.

TABLE VI. SCATTERED AND INCIDENT ANGLE FOR THREE SIZED CELL

Cell Types	Scattered Angle 'c' (degrees)	Incident Angle 'a' (degrees)
Small Cell	$\Theta > 50$	$\Theta \leq 30$
Medium Cell	$30 < \Theta \leq 50$	$30 < \Theta \leq 50$
Large Cell	$\Theta \leq 30$	$\Theta > 50$

The conclusion can be drawn on the basis of incident angle 'a' as well. If the incident angle 'a' is greater than the scattered angle 'c' will be smaller, so greater the value of incident angle 'a' results in large sized cell that can cover large areas with more number of users in large halls. Similarly, if incident angle ‘a’ is small then the scattered angle ‘c’ will be large, so smaller the incident angle results in small sized cell for a small portion of the building.

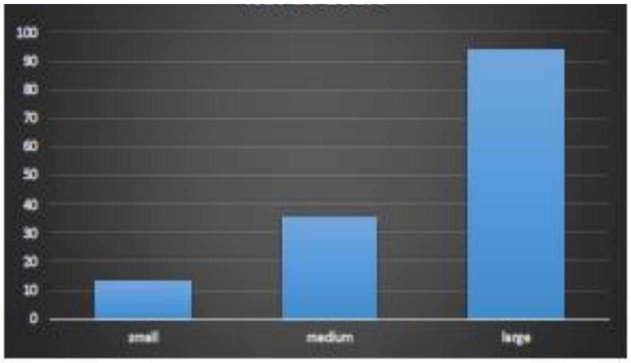

Fig. 13. Number of users for three cells sizes.

C. Simulation Results in Matlab

When the distance between the light source and the slit is zero, then maximum coverage area is achieved, as the distance from the slit increases coverage area at ground decreases. The comparison is shown in Fig. 14.

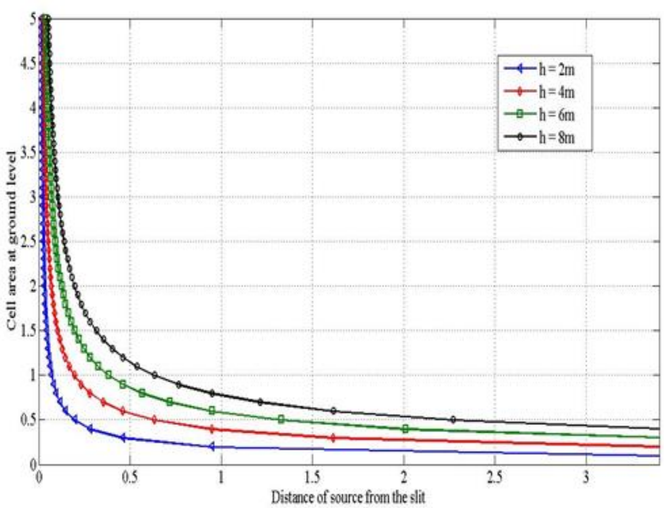

Fig. 14. Distance of source from slit and circular cell area at ground.

By analyzing the results against the height of the building and for different values of h1, it is observed that coverage area at ground level has a maximum value of high-rise building and the cell area decreases with the decrease in the building height.

The proposed model is also analyzed for the different building heights with respect to angle of incidence. With the increase in building heights will increase circular cell size at the base of the ground due to increase in distance between source LED and ground, see Fig. 15. The light beam spreads for larger distances results in large circular cell formed at ground level. The cell size increases for increasing heights of the buildings. It means spreading of beam is directly proportional to the height of the roof, increase in the height of roof results in more spreading of the beam and finally achieves a large circular area at the base of the floor.

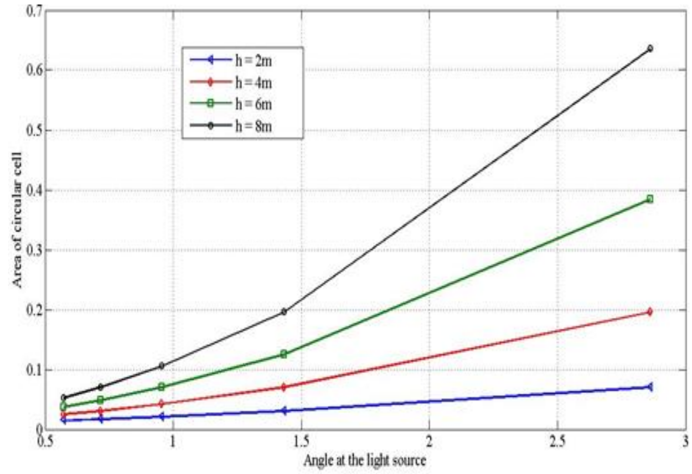

Fig. 15. Circular cell areas for different building heights and incident angles.

V. Conclusion

The basic principle and source using VLC is the radiation in the visible spectrum region which has not been for wireless communications till the introduction of VLC. The reason for using visible light for communication is its wider bandwidth and is not in the use of any other communication system as a source. Another main factor using VLC is that spectrum is licensed-free and anyone can use it anywhere without huge investment in spectrum license. In daily life, visible light is used for different purposes like reading, writing, working in homes, playing, street lights, in operation theaters, etc. In all these activities, Li-Fi access points can be used for internet using these light sources. Li-Fi is now used under the communication rules of VLC and implemented using IEEE 802.15.7 Standard.

The Li-Fi is an internet transmission source similar to Wi-Fi that communicates signals, data, picture, video and live streaming data using LED light source instead of radio waves as a transmitter and a photo detector for a purpose of receiver. The data is traveled wirelessly with the speed of light faster optical fiber communications.

Li-Fi will replace Wi-Fi in the near future as it is more economical wireless communication internet access point. Li-Fi is a very secure communication access point because it is used in the LoS situation. Only those users can access the Li-Fi point when light from the Li-Fi point falls on their devices, that’s why Li-Fi is more secure than Wi-Fi.

We proposed a model for secure communication which enables to optimize the cell coverage according to the number of users in the area of interest. The proposed scheme made hotspot more secure and can be used to block an unauthorized access. Our idea provides a controlled coverage of cell that is used to enhance the security of Li-Fi. The coverage area is shown by cone shape and area of the cone can be controlled by many factors. A mechanical system is also installed on the roof to control the coverage area of a Li-Fi. Area of the cone is categorized in three forms small, medium and large. Every form has different values for different factors. This provides more security to Li-Fi because the number of users in connection is controllable now.

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