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# Experience the modern mode of Wireless Communication

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*Abstract*— **The essential concepts of illumination engineering are now having a absolute amelioration and newer capabilities are being discovered with the smart and efficient LED technology. Researchers are focusing on approaches to optimize the energy consumption in illumination systems through using LEDs, which are about 3 times more energy efficient than conventional light sources. In this paper, it will show how Li-Fi takes VLC further by using light emitting diodes (LEDs) to realize fully networked wireless systems. Li-Fi technology deals with the huge data rate which is in the range of 150 Mbps to 10 Gbps and uses the visible light of electromagnetic spectrum. This paper presents that the Main LED Unit (MLU) is enlarged to the Agent LED (AL) blubs where every LED bulb has its own Li-Fi cloud for the users to access the internet and other services.**

***Keywords*— Illumination systems; solid-state lighting; LED; Data Rate; ON-OFF switching; Li-Fi.**

## I. INTRODUCTION

"Keeping calm and quiet is not necessarily pushing the world forward. And here comes the opposite attitude. Technology brings the excitement; helps look into the future, and make us brave enough to try to shape it". There comes the era of IOT (internet of things) made possible through Li-Fi. In 2011, Professor Harold Haas from the University of Edinburgh in the UK, suggested an idea called "Data through illumination" and coined the mission of Li-Fi as "Pure Li-Fi seeks to resolve the global struggle for diminishing wireless capacity by developing and delivering technology for secure, reliable, high speed communication networks that seamlessly integrate data and lighting utility infrastructures and significantly reduce energy consumption." Due to the increasing demand for wireless data communication, the available radio spectrum below 10 GHz (cm wave communication) is congested and the available radio spectrum has become insufficient. The wireless communication industry has responded to this challenge by considering the radio spectrum above 10 GHz (mm-wave communication).

Li-Fi is alternative of wireless networking that is based on visible light communication (VLC). Li-Fi technology deals with the data rate about the range of 150 Mbps to 10 Gbps and uses the visible light of electromagnetic spectrum. It refers to 5G Visible Light Communication systems using Light Emitting Diodes as a medium to high-speed communication in a similar manner as WI-FI Figure 1. Li-Fi is label of communication in which light is used as a carrier instead of radio frequencies. Li-Fi signals are confined to narrowly focused 'beams' that do not travel through walls which support secure internet access, given that both uplink and downlink channels are 'intercepted'. Li-Fi is fast cheap wireless communication system and is the advanced version of Wi-Fi.

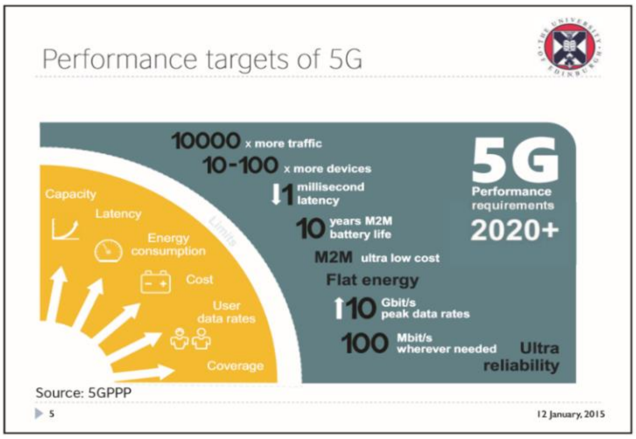



Fig. 1 Performance target of 5G

## II. EVOLUTION OF LIGHTING TECHNOLOGIES

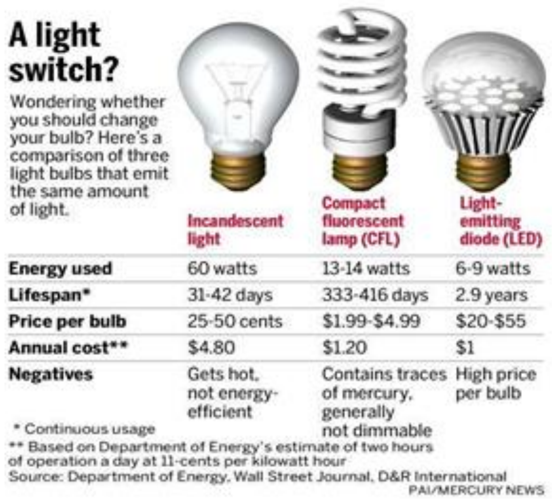
Prof. Asim Kar [1] has very well said that: "The century old gas filled incandescent and fluorescent lighting technology will be gradually flagged off by the successful introduction of

LED technology in near future." In Figure 2, comparison of three light bulbs that emit the same amount of light.

1) *Incandescent lamps:* An incandescent light bulb is an electric light with a wire filament heated to a high temperature, by passing an electric current through it, until it glows with visible light (incandescence). It is first introduced in 1879 credited to Edison, developed by using a carbon filament. In 1906, the first tungsten filament is introduced for commercial. The luminous lamp productiveness is only 18lm/W. these lamps produce large amount of heat and a small fraction of input energy appearing as visible light. The incandescent lighting era comes to an end with the upcoming time, wherein these lamps will be stopped being produced or imported in the USA.

2) *Fluorescent lamps:* It is first developed in the 1930s by General Electric with a gradual improvement in lamps technology that have high more brightness and efficiency as compared to the Incandescent lamps. They are highly used in residential and commercial lighting. Luminous lamps productiveness is gradually growing above 100 lm/W.

3) *Solid state light emitters:* Light emitting diodes are semiconductor light sources and produce an effect called as electroluminescent. LED is small in area (<1 mm$^2$) and is an integrated optical component. The quantum efficiency of these devices are good i.e. approx (>0.9) and can operate in low voltages (<3.5V). These devices have high luminous productiveness (~120 lm/W) and can be massively produced at a low cost. LED light can also be used as a communication system and act as an alternative source of radio frequency wireless communication system known as Li-Fi.




| | Incandescent light | Compact fluorescent lamp (CFL) | Light-emitting diode (LED) |
|---|---|---|---|
| Energy used | 60 watts | 13-14 watts | 6-9 watts |
| Lifespan* | 31-42 days | 333-416 days | 2.9 years |
| Price per bulb | 25-50 cents | $1.99-$4.99 | $20-$55 |
| Annual cost** | $4.80 | $1.20 | $1 |
| Negatives | Gets hot, not energy-efficient | Contains traces of mercury, generally not dimmable | High price per bulb |



Fig. 2 Comparison of incandescent light lamps, Fluorescent lamps and LED lamps

In order to have wider applicability of LEDs, scope of improvements in their electro-optical and temperature characteristics, high power generation and color rendering capabilities need to be explored. Automation and multitasking is becoming another prime requirement in modern lighting system design with rising demand for smarter and need-based solutions. The new generation illumination engineering is actually becoming a creative arena, bringing together the expertise of electrical, electronic and optical engineers, scientists and policy makers. The future lighting systems can therefore be envisioned as extremely intelligent and efficient applications, developed through the optimum fusion of illumination, communication, sensing and control engineering concepts [2].

LED lights, in addition to illumination can be used for transmitting information as connected nodes in a communication network. These can either be a visible light based communication (VLC) or navigation system, wherein high-frequency pulsed LED light instead of radio or microwaves are used. In these systems, the intensity of light from LEDs deployed at various applications such as indoor and outdoor lighting, displays, illuminated signs, traffic lights etc are modulated to transmit audio, video and location information [3]. Indoor free-space optical communication links using visible light LEDs have achieved data rates as high as 1 Gbps (in labs). This type of twofold utilization of LED properties for illumination and communications is very attractive for use with automobiles, traffic lights, smart phones etc. Automobile head lamps, tail lamps, dashboard lamps are designed using high brightness LEDs which can be judiciously used by such a communication concept for road safety applications. For example, two side-by-side or back-to-back road vehicles can communicate to each other via their illuminating lamps for exchanging information. Street lamps posts using LEDs also can effectively act as base station towers or repeaters for free-space visible light communication. This technology has great potential for widespread applications in important public places such as city markets, airport terminals, hospital buildings and museums and is biologically safe. Another most modern technology is the combination of VLC with indoor Global Positioning Systems (GPS) which has already been exhibited successfully in Japan in 2010. In VLC based navigation, a user with a GPS system can receive information from traffic lights about accidents or delays ahead. The traffic lights could be updating car drivers with information or streaming video directly from news broadcasts. Street lamp poles can be redesigned to gather and provide information services such as weather, air quality and traffic condition monitoring stations.

New developments in inorganic and organic materials and nanostructure devices have created a wide range of LED applications and finally pushed LEDs into the realm of large area general purpose illumination with the white LED technology. These new classes of LEDs have high brightness, suitable colour temperature and high colour rendering qualities to emulate natural light and are on their way to supplant fluorescent and incandescent light sources in near future. Apart from this, LEDs offer good colour control, dimming capability, short switching response times and compactness. Further, they are environment friendly with no mercury content, emit no UV or IR radiation and can withstand strong vibrations.

## III. Li-Fi versus VLC

Prof. Harald Hass [4] as well said that: VLC uses LEDs to transmit data wirelessly by using intensity modulation (IM). At the receiver the signal is detected by a photodiode (PD) and by using the principle of direct detection (DD). VLC has been conceived as a point-to-point data communication technique - essentially as a cable replacement. This has led to early VLC standardization activities as part of IEEE 802.15.7 [5]. This standard, however, is currently being revised to include Li-Fi. Li-Fi in contrast describes a complete wireless networking system.

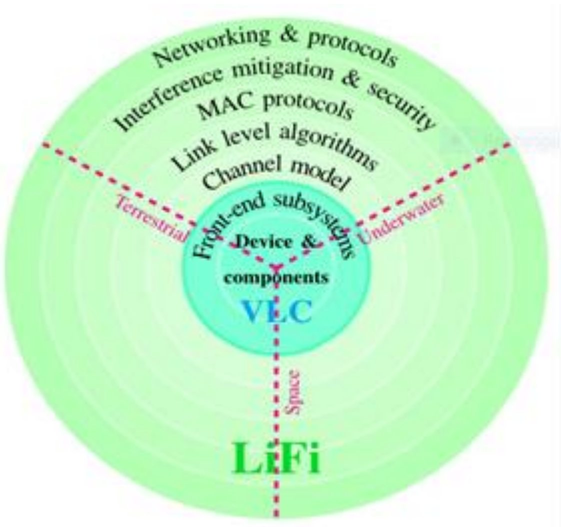



Fig. 3 The principal building blocks of Li-Fi and its application areas

This includes bi-directional multiuser communication, i.e. point-to-multipoint and multipoint-to-point communication. Li-Fi also involves multiple access points forming a wireless network of very small optical attocells with seamless handover. This means that Li-Fi enables full user mobility, and therefore forms a new layer within the existing heterogeneous wireless networks. The fact that LEDs are natural beam-formers enables local containment of Li-Fi signals, and because of the blockage of the signals by opaque walls, CCI can effectively be managed and physical layer security can be enhanced.

## IV. MODULATION TECHNIQUES FOR LI-FI

In order to actually send out data via LED, like any multimedia data, it is necessary to modulate these into a carrier signal. This carrier signal consists of light pulses sent out in short intervals. Digital modulation techniques generally used for Li-Fi are summarized, and some special issues and requirements are discussed. In principle, Li-Fi also relies on electromagnetic radiation for information transmission. Therefore, typically used modulation techniques in RF communication can also be applied to Li-Fi with necessary modifications. Moreover, due to the use of visible light for wireless communication, Li-Fi also provides a number of unique and specific modulation formats.

### A. *Single-Carrier Modulation (SCM)*

Single carrier modulation techniques include on-off keying (OOK), pulse position modulation (PPM) and pulse amplitude modulation (PAM) in Li-Fi technology. We have studied SCM technology in wireless infrared communication systems. OOK key is a simplest modulation technique of amplitude shift keying (ASK). It represents digital data as the presence and absence of a carrier wave i.e. presence of carrier for a specific duration represents a binary one, while its absence for the same duration represents a binary zero. By its very nature that OOK transmits data by sequentially turning on and off the LED, it can inherently provide dimming support. It is analogous to unipolar encoding line code. OOK dimming can be achieved by two process first is by refining the ON/OFF level and second is by applying symbol compensation. Dimming through refining the ON/OFF levels of the LED can maintain the same data rate; however, the reliable communication range would decrease at low dimming levels. On the other hand, dimming by symbol compensation can be achieved by inserting additional ON/OFF pulses, whose duration is determined by the desired dimming level. As the maximum data rate is achieved with a 50% dimming level assuming equal number of 1 and 0 s on average, increasing or decreasing the brightness of the LED would cause the data rate to decrease.

Compared with OOK, PPM is more power-efficient but has a lower spectral efficiency. A variant of PPM, termed variable pulse position modulation (VPPM) [6], can provide dimming support by changing the width of signal pulses, according to a specified brightness level. Therefore, VPPM can be viewed as a combination of PPM and pulse width modulation (PWM). A novel SCM scheme, termed optical spatial modulation [7], which relies on the principle of spatial modulation, proves to be both power- and bandwidth-efficient for indoor optical wireless communication. As a variant of quadrature amplitude modulation (QAM) for single carrier systems, carrier-less amplitude and phase modulation [8] uses two orthogonal signals, in place of the real and imaginary parts of the QAM

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signaling format, for spectrum-efficient signal transmission in Li-Fi networks.

### B. *Multi-Carrier Modulation Techniques*

As the required data rate increases in Li-Fi networks, SCM schemes such as OOK, PPM and PAM start to suffer from unwanted effects, such as non-linear signal distortion at the LED front-end and inter-symbol interference caused by the frequency selectivity in dispersive optical wireless channels. Therefore, for high-speed optical wireless communication, efforts are drawn to multi-carrier modulation (MCM). Compared with SCM, MCM is more bandwidth-efficient but less energy-efficient. One and perhaps the most common realization of MCM in Li-Fi networks is OFDM. Where parallel data streams are transmitted simultaneously through a collection of orthogonal subcarriers and complex equalization can be omitted.

If the number of orthogonal subcarriers is chosen so that the bandwidth of the modulated signal is smaller than the coherence bandwidth of the optical channel, each sub-channel can be considered as a flat fading channel. The use of OFDM allows for further adaptive bit and power loading techniques on each subcarrier so that enhanced system performance can be achieved. An OFDM modulator can be implemented by an inverse discrete Fourier transform block, which can be efficiently, realized using the inverse fast Fourier transform (IFFT), followed by a digital-to-analogue converter (DAC). As a result, the OFDM generated signal is complex and bipolar by nature. In order to fit the IM/DD requirement imposed by commercially available LEDs, necessary modifications to the conventional OFDM techniques are required for Li-Fi.

As the light intensity cannot be negative, the Li-Fi signal needs to be unipolar. There are many methods to obtain a unipolar time-domain signal. DCO-OFDM [9] uses a positive direct current (DC) bias for unipolar signal generation. This method brings an increase in the total electrical power consumption, but without further loss in spectral efficiency. Asymmetrically clipped optical OFDM(ACO-OFDM)[10] is another type of optical OFDM scheme where, as well as imposing Hermitian symmetry, only the odd subcarriers are used for data transmission and the even subcarriers are set to zero. Therefore, the spectral efficiency of ACO-OFDM is further halved. Since only a small DC bias is required in ACO-OFDM, it is more energy-efficient than DCO-OFDM. Asymmetrically clipped direct current biased OFDM (ADO-OFDM) is a combination of DCO-OFDM and ACO-OFDM, where the DCO-OFDM scheme is used on the even subcarriers and the ACO-OFDM scheme is used on the odd subcarriers. In certain scenarios, it is shown that ADO-OFDM outperforms both DCO-OFDM and ACO-OFDM in terms of power-efficiency.

## V. LI-FI SPECIFIC MODULATION TECHNIQUES

Li-Fi transmitter is used as a wireless transmission and also for illumination. Different coloured LEDs like Blue LEDs with yellow phosphorus coating or by colour mixing through colored LEDs can be used for Li-Fi transmitter. Luminaries equipped with multi-colored LEDs can provide further possibilities for signal modulation and detection in Li-Fi systems. Color shift keying (CSK) is an IM scheme outlined in IEEE 802.15.7, where signals are encoded into colour intensities emitted by red, green and blue (RGB) LEDs. In CSK modulation techniques, constant average perceived colours maintained by incoming bits are mapped on to the instantaneous chromaticties of the coloured LEDs. The advantages of CSK over conventional IM schemes are twofold. Firstly, since a constant luminous flux is guaranteed, there would be no flicker effect over all frequencies. Secondly, the constant luminous flux implies a nearly constant LED driving current, which reduces the possible inrush current at signal modulation, and thus improves LED reliability.

TABLE I
QUALITATIVE COMPARISON OF POPULAR MODULATION SCHEME

| **Modu-lation** | **Spectral Efficien-cy** | **Power Effici-ency** | **System Comple -xity** | **Comment** |
|---|---|---|---|---|
| OOK | High | Low | Low | Prone to flickering |
| PPM | Low | High | Moderat e | Complex transceiver structure |
| PAM | Moderate | Low | Low | Non linearity in LED's luminosity |
| CAP | High | High | Moderat e | Lower cost than OFDM |
| GSSK | High | Low | Low | Requires limited receiver mobility |
| OFD-M | High | Moder ate | High | Non linearity for higher PAPR |
| CSK | Moderate | low | High | Require feedback mechanism |

## VI. COMPARISON WITH OTHER WIRELESSS MEDIA

Balaram Ghosal presented that [11]: Li-Fi is acquired this name due to the similarity to Wi-Fi, only using light instead of radio frequency. So this technology can easily be used in the places where Bluetooth, infrared, Wi-Fi cannot be used. Wi-Fi is very good for general wireless coverage area within building; but many simultaneous users in one place lead to lesser speed. Li-Fi is ideal for high density wireless data coverage in confined area. Moreover no one has to pay to use the radio bandwidth, as light is open to use anywhere. In Li-Fi many different colors light may be used to communicate secured data, the advantage is you are doing Internet as well you enlighten and decorate your place. The comparative technicalities of the existing and proposed wireless media are enlisted below considering Wi-Fi, Bluetooth, Infrared and proposed Li-Fi communication.

## VII. ARCHITECTURE OF LI-FI

Li-Fi Technology is another milestone in the history of Wireless Communication and refers to 5G visible light communication technology. Li-Fi technology deals with the huge data rate which is in the range of 150 Mbps to 10 Gbps and uses the visible light of electromagnetic spectrum. There is some theoretically suggested architecture for Li-Fi.

In this, we present idea of Main LED Unit (MLU) and Agent LED (AL) [12]. MLU is extended to ALs which covers a wide area in terms of light. Also presents the idea and technique that how to increase the data rate (R) by increasing or decreasing some parameters. Here it can be concluded that data rate is inversely proportional to the size of LED. In Li-Fi, data rate can be increased by increasing the number of LEDs and also increasing the ON-OFF switching of LED bulb.

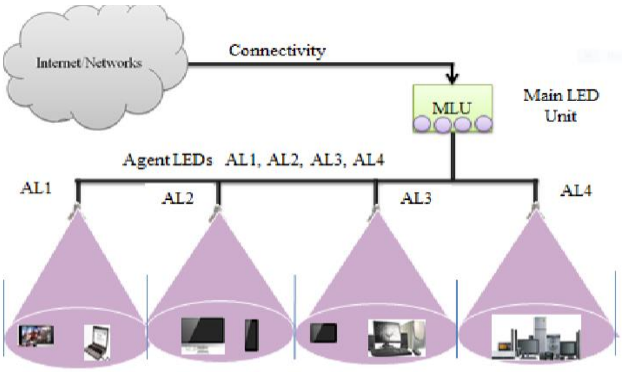


Fig. 4 Novel Architecture of Li-Fi

The size of normal LED bulb can be reduced to micro-LED which handles millions of alterations in light intensity per second and hence faster the ON-OFF switching and so capable of transmitting large amount of data at high speed. Micro-LED is capable to transmit data 1000 times faster than normal LED with faster ON-OFF switching.

- The idea for novel architecture of Li-Fi technology which is based on the MLU, AL and Li-Fi cloud. The MLU is extended to the ALs where every AL has their own Li-Fi cloud to provide internet and other services connectivity through light.
- The dimensions of the LED lamp can be of two types; one is Placement and Positioning (PP) dimension and second is the Internal Structure Design (ISD) dimension.
- The PP dimension further divided into two parts: fixed position and movable position.
- In Fixed Position, the LED lamp or bulb is fixed inside the room or building or any other place as shown in figure 2. The position is adjusted in such a way that it can cover the maximum area with high intensity of light. The LED lamp or bulb can be fixed on walls and ceiling of the room or building. The user can access the services and applications of Li-Fi technology in a fixed area where the LED lamp light can reach.

TABLE II
COMARISON OF LI-FI WITH OTHER WIRELESS SYSTEMS

| **Parameters** | **Li-Fi** | **Wi-Fi** | **Blue-tooth** | **IrDa** |
|---|---|---|---|---|
| Speed | >1Gbps | 150Mbps | 3Mbps | 4Mbps |
| Data Intensity | High | Low | Low | Low |
| Security | High | Medium | Low | High |
| Power usage | Low | Medium | Low | Low |
| Ecological Impact | Low | High | Low | Low |
| Cost of material | High | Medium | Low | Medium |
| Market maturity | Newest (2011) | Old (1990) | New (1998) | Old (1917) |

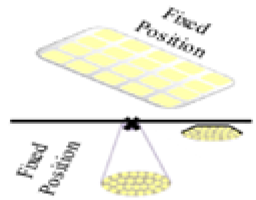


Fig. 5 Fixed position of LED Lamps

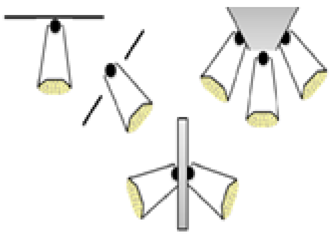

Fig. 6 Movable position of LED Lamps

- In Movable Position, the LED lamp is adjusted in such a position that it can move with some specific angle and user can access the services of Li-Fi with low mobility. This type LED can be used widely because the lamp is moved around a fixed position, as shown in figure 3. The LED lamp or bulb is mounted on the walls and ceiling of the room and the direction can be changed according to the movement of the Li-Fi users. If there is a wide angle of movement of the lamp then it can cover the large area as compared to fixed position.

*A. Data Rate versus Size of LED*

The variations in data rate (R) with the size of LEDs are very critical in the Li-Fi technology. Different data rates can be achieved with different sizes of LEDs. The size of normal LED bulb can be reduced to micro-LED which handles millions of alterations in light intensity. A micro LED light bulb to transmit 3.5 Gbps and the data rate of more than 10 Gbps is possible. The tiny micro LED bulbs allow the stream of light to be beamed in parallel and transmitting huge amount of data in terms of Gbps. The microchip LED bulb can generate data rates up to 150 Mbps with single bulb which provide fast internet connectivity and services. Here it can be concluded that data rate (R) is inversely proportional to the size of LED ($S_{LED}$). The LEDs are of different sizes e.g. 5mm, 3mm, 1.8mm, 1mm, 1 m and 1nm LED. The maximum data rate can be achieved with 1 mm and 1nm LED which is considered to be a pixel in size.

$$R \alpha 1/S_{LED} \qquad \ldots\ldots (1)$$

*B. Data Rate versus Number of LEDs*

The data rate can be increased with the increasing number of LEDs. The number of LEDs ($N_{LED}$) can be according to the available space inside the lamp. The number of LEDs can be adjusted so that it can achieve the maximum bit rate (bps).

$$R \alpha N_{LED} \qquad \ldots\ldots (2)$$

*C. Data Rate versus On-Off LEDs*

The ON-OFF switching of LED light bulb can create binary data of 1s and 0s e.g. 1 for ON and 0 for OFF. The micro-LED handles millions of alterations in light intensity per second and faster the ON-OFF switching, transmitting large amount of data at high speed. The ON-OFF switching of LED bulb is at a very high speed so that the human eye cannot detect the alterations. Micro-LED is capable to transmit data 1000 times faster than normal LED with faster ON-OFF switching, transmitting large amount of data at high speed.

Data is transmitted in form 0s and 1s.It is necessary to have very low switching time for transfer a large amount of data. The ON-OFF is increased by using the OFDM which enables the micro LED to handle millions of changes in light intensity per second. Here it can be concluded that the data rate (R) is directly proportional to the ON-OFF ($O_{LED}$) switching of LED.

$$R \alpha O_{LED} \qquad \ldots\ldots (3)$$

*D. R versus $S_{LED}$ , $N_{LED}$, $O_{LED}$*

The relation of data rate (R) from the above given parameters of Li-Fi technology.

$$R \alpha 1/S_{LED} \qquad \ldots\ldots (4)$$

$$R \alpha N_{LED} \qquad \ldots\ldots (5)$$

$$R \alpha O_{LED} \qquad \ldots\ldots (6)$$

Combining of above equations of data rate;

$$R \alpha N_{LED}.O_{LED}/S_{LED} \qquad \ldots\ldots (7)$$

## VII. APPLICATIONS OF LI-FI

*E. Security*

In a meeting room environment, each user or group of users directly competes for access to bandwidth. The net result is that the more connections there are, the slower the download speeds are for all the Wi-Fi case. By contrast, in the case of Li-Fi, with its greater number of available access points, each pool of light provides full channel data rates with fewer simultaneous users. The overall net benefit to each user is up to 1000 time's greater speeds. In addition, and in contrast to radio waves, the light does not pass through the walls. Therefore, with minimal precautions to avoid leakage from windows, etc., security is fundamentally enhanced as compared with Wi-Fi.

*F. Cellular communication*

In external urban environments, the use of Li-Fi enabled street lamps would provide a network of internet access points. In cellular communication, the distance between radio base stations has come down to about 200-500 metres. So, instead of deploying new radio base stations in our cities, street lamps could provide both, illumination during night, and high speed data communication 24/7. Surprisingly, even when the lights are off as perceived by the eye, full data communication rates are still possible. There is also an additional cost benefit as installing new radio base stations usually comes with large cost – for installation and site lease.

*G. EMI sensitive environments*

On aircraft, Li-Fi enabled lighting will allow high data rate connectivity for each passenger. It will allow connectivity at all times, without creating electromagnetic interference (EMI) with sensitive radio equipment on the flight deck. The reduction in cabling requirement also means a lighter aircraft.

*H. Underwater communication*

Radio waves are quickly absorbed in water, preventing underwater radio communications, but light can penetrate for large distances. Therefore, Li-Fi can enable communication from diver to diver, diver to mini-sub, diver to drilling rig, etc.

*I. Safety environments*

In explosion hazard environments, the use of electrical equipment, including mobile phones, is generally greatly restricted. The use of Li-Fi to pass data will simplify the configuration of data networks in such environments, and can enable new systems to enhance security in these environments.

### J. Intelligent transportation systems

Car headlights and tail lights are steadily being replaced with LED versions. This offers the prospect of car-to-car communication over Li-Fi, allowing development of anti-collision systems and exchange of information on driving conditions between vehicles. Traffic lights already use LED lighting, so that there is also the prospect offered of city wide traffic management systems. This would enable car systems to download information from the network and have real time information on optimal routes to take and update the network regarding conditions recently experienced by individual vehicles.

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