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Li-Fi Technology: Principle, Future Scope, Challenges and Applications

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Abstract Within a couple of decades we have headed from large and heavy devices used for voice communication alone to small and compact smart devices those are capable of handling multitasking operations as well as browsing through high-speed internet and HD video streaming. The stark difference among the previous generations and now is the rate of flow of data. If we want to expand our capabilities we need to proportionately increase the data rate keeping further exponential growth in the future too. This thesis investigates a heterogeneous network that comprises a Li-Fi and a Wi-Fi wireless fidelity network. Two tiers of miniature attocells of Li-Fi that use the visible light spectrum are used, resulting in a significant boost in wireless network's data transmission in the indoor environment. The frequency bands of LiFi and Wi-Fi do not overlap, as they belong to completely different spectrum. Unlike Wi-Fi access points (APs), Li-Fi access points (APs) cover a smaller area where even a minor client movement can result in multiple handoffs between Li-Fi attocells, impairing system performance.. As the span of handover decreases, however, the Li-Fi data rate increases with the increased bandwidth of the Li-Fi AP that is serving the client. Additionally, a comprehensive comparison between LiFi and Wi-Fi has been elaborated.

Keywords: *heterogeneous network, Li-Fi, Wi-Fi, handover, attocells, CCI, mobility, data rate*

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1. Introduction

The high demanding evolution of multimedia wireless devices in recent years has motivated the engineers to explore the millimeter wave frequency band for multiple gigabit wireless communication. Recent advancement in antenna technology, RF CMOS process and highly mobile baseband signal processing algorithms helping millimeter wave wireless communication practical. The multi gigabit per second high data rate of millimeter wave wireless communication system has led to various applications in many important areas like WPAN, WLAN, and backhaul for cellular system. The frequency spectrum consists of 28 GHz, 38 GHz, 45 GHz, and 60 GHz and even beyond 100 GHz. The ZTE communications special issue of will present some major research and development in gigabit millimeter wave wireless communication.

The key motivation is that Li-Fi is a green communication as it reuses the existing lighting infrastructure for communication and this leading to a clean radiation free communication which might be helpful in Digital India initiative taken by our government in parallel to the use of renewable clean energy in communication. It is helping to transmit information in rapid subtle changes of light intensity which is unnoticeable to the human eye. A key point for encouraging to the optical wireless communication with hybrid heterogeneous network system across the whole worldwide with many nation giving center of attraction to their investment in this radiation free and license free source of internet service providers for eliminating the traffic buffer because RF electromagnetic spectrum is limited and to avoid the congestion of the traffic.

2. Li-Fi and VLC

The growth of data demanding multi-media mobile devices has reached its saturated capacity resulting in the congestion of radio spectral band. Li-Fi expertise may be used having 300 THz spectrum band, license free and untouched optical band for wireless communication can be an alternative to this congestion [1]. The merit of Li-Fi is its ability of not causing interloping to RF as it uses different frequency [2]. It allows heterogeneous network combining HetNet configuration.

In indoor environment, heterogeneous network leads to improvement of the system data rate and QoS [5]. As Li-Fi is not affecting RF system, the sum data rate is higher in

heterogeneous network rather than in separate Li-Fi and RF system.

In hybrid heterogeneous network, efficient and fair load balancing is an obstacle due to atto size of Li-Fi service area. Recent work considers the resource allocation to be static [4] but in practical scenario, clients may be moving and mobility factor acts. Hence, when client movement is considered, the clients experience handover between Li-Fi attocells.

There are two types of handover coming into picture:

i. Flat handover- This handover taking place between Li-Fi attocells.
ii. Vertical handover- This handover taking place between Li-Fi and Wi-Fi service area.

Handover results in exchange of information between clients and central unit (CU) and there may be delays depending on the complexity of the algorithms [8] and transmission losses may also occur during handover. In orthodox RF system handover takes place in lower signal to noise ratio (SNR) but in hybrid heterogeneous network, the issue of stability is considered as a handover may prompt further handover.

As a channel for high-speed data transfer, Optical Wireless Communication (OWC) uses light from LEDs. The visible light communication method uses a fast switching of current, too fast for the human eye to notice. Though Li-Fi LEDs must remain on to transmit data, the light they emit could be dimmed to emit enough light to support data transmission while still being not noticeable to humans. It is confined to a shorter range due to its inability to penetrate walls, and hence immune from hacking.[5] Tried to mark the distinction with visible light communication (VLC) and light fidelity (Li-Fi). Li-Fi advances VLC by using LEDs to make the wireless system fully networked. Li-Fi attocells enhances wireless capacity by providing condition to support Internet-of-Things and thus contributing to fifth generation of the wireless system and beyond. This clearly illustrates all the major areas of research for hybrid Li-Fi/Wi-Fi components. There is no longer theoretical discussion here, but real-world implementation is underway [6].

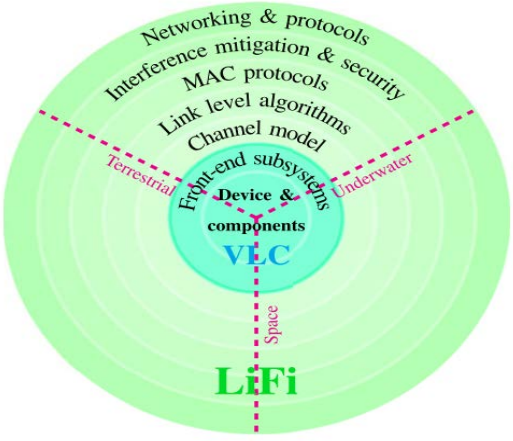

Figure 1. Building blocks of Li-Fi [5]

VLC uses LEDs to transmit data using intensity modulation (IM). At the end of the reception, the signal is received by the photodiode (PD) using the direct detection system (DD). VLC acts as a point-to-point data communication system-like cable switch. This has led to VLC evaluation activities as part of IEEE802.15.7 [6]. This standard is updated to include Li-Fi as it defines a complete wireless communication system that combines multi-client communication with bi-directional. Li-Fi also incorporates multiple access points that form a wireless network of the smallest atocell visible through transmission. This means that Li-Fi allows clients to move and build a new layer within a variety of wireless networks. Since LEDs are not natural beam makers and therefore allow for local content of Li-Fi signals due to blocking of signals by light walls, integrated channel interference can be effectively managed and physical layer protection can be increased.

3. Need of Heterogeneous Networks

In the field of optical wireless communication sector in these days one of the major concerns is day by day increasing more data demand but the availability of RF spectrum band are not enough as it is reaching to its saturated capacity leading to congestion of the traffic. While thinking about the future availability of RF spectrum band, we have to think about the alternative spectrum band. So, it is very important to use visible light spectrum band as it is of 300THz band capacity and is license free as well to fill the requirement of the increasing data demand. [10]

In order to rigging the current day's data crisis, it is necessary to use hybrid heterogeneous network as the band is visible so it is essential to deploy Li-Fi network which has the ability of not causing the interloping to RF as it uses different electromagnetic interloping. Hence visible light is used for data transmission as it is lavishly available on earth and free to everyone without any requirement of license. [4]

Visible light communication system has to be networked such that harvesting of this band is done into our suitability and properly utilize it efficiently. Thus, hybrid heterogeneous network is considered and distributed in attocells with LED based space light system for indoor local area network (LAN) communication. This networking system has the merit over traditional RF based systems from improved isolation between outdoor and indoor system, the size and cost of receivers and transmitters, RF licensing laws and by combining the visible light and RF spectrum into the same system.

All the other indoor visible light based networks are connected to the outdoor RF based network or the indoor system can be isolated or standalone service provider even though it is networked with the centered RF system that depends on the utility, fairness, location of load area, availability of the access point nearby it. Thus where the availability RF access point data is very difficult or dangerous light based access point can be used to supply the data to those untouched areas within their attocells only such that the security issue is curbed but when mobility factor comes into existence it is necessary to optimize the system such that the handover and load balancing is done accurately. [4]

The most important advantages of visible light is that it does not cause interloping to the RF system and hence can

be operated easily in the hybrid heterogeneous network. Another advantage of visible light is that it is license free with high data rate and capacity. The basic difference is that Wi-Fi uses radio frequency to transmit data and Li-Fi uses light to transmit data in each small attocells with several merits like working across high bandwidth, working in areas susceptible to radiations and interloping and offering high transmission speed.

In the last few years this technology is actively being developed by several organizations across the globe. The advance research in the field of optical wireless communication and visible light communication have greatly helpful for engineers to develop such a hybrid heterogeneous network that can be combined with each other such that they can provide high capacity with high data rate for fulfilling the high data demand of the traffic in their respective coverage area.

For every country day by day internet clients are increasing therefore using the hybrid network will be useful as it will help to serve this billions clients in the coming future. This can done by configuring center Wi-Fi interconnected with all the APs of the attocells. This hybrid network due to its high installation cost and low power of LED based Li-Fi system can hardly participate in the competitive telecommunication markets as a main internet source of multimedia data demand.

Scientists are constantly trying to improve in the field of development of Li-Fi devices for increasing the capacity of the data clients. That will definitely help to make the internet services as in the habit for use in daily life as prime new source fast data service on a wider range basis than present day conditions. However even though they are serving the demand but that are leading to the congestion of the data. Thus, to resolve that it is essential to deploy hybrid heterogeneous network to serve in multiple coverage area.

4. Li-Fi and Wi-Fi Coupled Connected Devices

i. Connected devices require a reliable source of low energy consuming source to establish a entangled communication network among eachother. 5G had its own limitations and 6G comes with its own complexities. LiFi holds the middle ground for these various devices and applications.

ii. With passage of subsequent time we have seen significant rise in data which would eventually put lot of strain in the existing model of Wi-Fi network giving rise to interferences and other unprecedented errors. As mentioned previously, in order to cater to the demands of the connected devices we can push forward a couple arrangement of Wi-Fi and LiFi ecosystem; primarily LiFi would act as a complimentary to Wi-Fi. These days, IoT and IoE devices require low powered smart sensors. Data speed is not the bigger issue here; however we need a reliable system to transmit smaller data packets with more emphasis on reliability instead of speed. But eventually when the industry grows we would require both reliability and speed combined. Therefore we need to foresee this situation and build our infrastructure accordingly.

iii. The left hand side of the Fig 4, labeled as 'Things in IoT' we could use a matrix array of sensors, actuators and other peripheral equipments to establish a communication network based ecosystem which would communicate in real time basis.

iv. In the real world scenario, the sensors can read the environmental parameters like temperature, humidity, intensity of sun/light and return values of status as feedback in real time basis. In most of the times, the input is given only via physical parameters but then we can also create convert non physical readable files for specific data which cannot be physically quantified to specific data and can be equally treated as a input signal for the sensor. These peripherals are connected to Wi-Fi in a enabled field connector gateway. The primary function of the gate-way is to establish communication and inter-connect the functionalities using a distributed cloud based service.

v. Taking actuator as an example from industrial application which would has enormous distinct data points to establish from the device but still, we can compare that analogy with a sensor. They are used to flip states from ON to OFF or 0 to 1 either electromagnetically or mathematical logic.

vi. The building units of the device includes intelligent devices like Smartphone, computers, portable devices, new AI enabled high end chip based systems etc. The applications and equipments are employed in order to take care of complex situations where humans cannot multi-task such variety of data that require processing of simultaneous real-time operations. The fundamental task of the IoT gateway is to convert the physical field protocols to cloud protocols by establishing communication between the sensors and the distributed network used.

vii. Message Queue Telemetry Transport (MQTT) enables the integration of connectivity between applications and interface middle-wares; also the networks and communications to facilitate subscribe/publish architecture, within which a publisher, a broker and a end user (subscriber) are the 3 pillars. Apart from MQTT, we have Hypertext Transfer Protocol (HTTP) which finds its acceptance in IoT based applications where reliability, latency and bandwidth are not primary concerns. We can use LiFi in the downlink side of the system.

viii. A light source (LED bulb for example) driver is used where we need the downlink of the data stream. The data is converted into readable binary format using OFDM or PWM method of modulation. The required data input is channeled into the light source driver which controls the source. The light signal undulations are recorded by the photo-detector and the signal is transferred to the signal conditioning unit. Here, the signal is read and amplified and fed into the end application after being passed through the processing unit. [7]

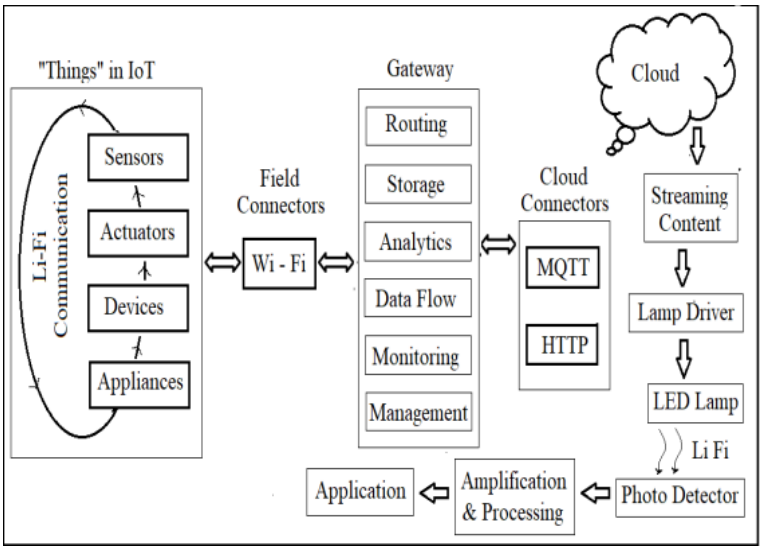

Figure 2. Li-Fi and Wi-Fi combined system design [7]

5. Crucial Applications of LiFi

LiFi can be treated something as a complimentary for Wi-Fi. Also when worked together it can become a force multiplier as it provides internet faster than a conventional Wi-Fi. In this section we highlight the prime domains where LiFi can deliver more neat performance than a traditional Wi-Fi:

i. **Natural Disasters:** During any natural calamity like Tsunami, earthquake, cyclone, tornado etc. the existing service towers can get damaged and face all sorts of glitch to perform their usual tasks. Here, LiFi enabled LED devices which are installed in street light towers can be useful. Given the scenario that street lights are available in every regular interval within the vicinity. Therefore, the coverage could be kept operational even during such emergencies.

ii. **Aviation:** During landing and takeoff the crew members announce to the passengers to turn off or put the mobile device in flight mode to avoid interference. But if we use LiFi then such a situation can be compensated fairly.

iii. **Medical:** In the wards where critical patients are taken care of; as a precautionary measure the Wi-Fi is not allowed to avoid in anticipated adverse effects due to radiation on patient's health parameter. Chances are there that the signal could well interfere with the medical equipments. In the age when we speak of robotics based medical treatment methods; in such a scenario LiFi can be adopted as a game changer.

iv. **Military:** Conventional equipments are can be blocked via electronic warfare based jammers. But if we need localized operations then communication using LiFi can be helpful. Also, since the signals would not trespass the walls of the room hence we can have naturally secure connection which would be difficult to intercept and exploit valuable intelligence remotely.

v. **Underwater survey:** There is no scope of use of Wi-Fi underwater. However, as a limited role capability LiFi can be used to perform untathered exploration operations. [3]

6. Advantages of Li-Fi

i. The main advantage which runs in favor of LiFi based communication is its ability to make available high data rate. Carrying out the system usage in the visible light frequency range translates into higher frequency; that creates room for potentially broader bandwidth and as a consequence a higher data rate. According to studies, visible light frequency band is expected to be ten thousand times more accommodating than conventional radio band. Expectations are already there to attain gigahertz range.

ii. As anticipated, the user requirement of data has risen exponentially and hence demand for higher and higher bandwidth has become more vital. Spectrum scarcity is a issue that needs to be addressed. Significant amount of available radio frequency range has been fully utilized and it is becoming stringent make space to accommodate more range. Another problem is situation of licensing in order to operate a RF range based communication system. Good news is that visible light band can be locally used and such problem is not encountered with this spectrum. Making use of this frequency band can effectively address this problem.

iii. The legacy radio communication systems get heated rapidly due to high energy consumption and hence require even more energy to maintain a cooling system to cool the base stations or the access points. However, LEDs consume less energy and does not require any such cooling system unlike any legacy system. Also, it delivers illumination.

iv. In situation where privacy is a concern; the light waves cannot trespass the solid walls and hence the communication channel can be kept isolated and confined around the source of signal only and will be difficult for the hackers to break in from a remote location.

v. Traditional systems face glitches created due to multi-path propagation. The transmitted signal with respect to the reflected signal can be sometimes be at anti-phase which would nullify the summation

and could decline the signal. The light signals do not cancel eachother; they complement and enhance eachother.

vi. A traditional radio-receiver communication system is complicated since it requires synchronous-demodulation circuit with a receiver system like an antenna. Even a Wi-Fi system requires a RF circuit to establish communication network. However, LiFi is much simpler. It is etched around a direct-modulation and de-modulation ecosystem; a source of light for source as a transmitter and a photo-detector as the receiver end. [10]

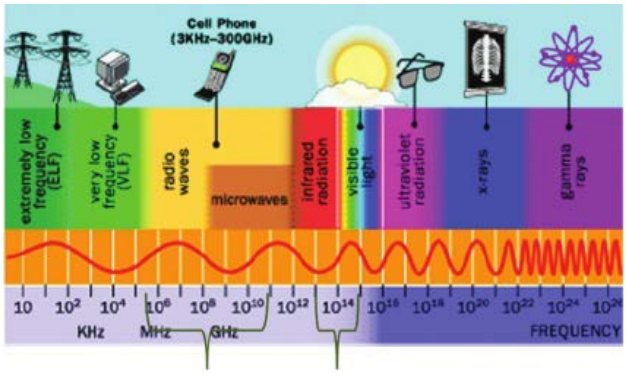

Figure 3. Frequency spectrum of visible light [10]

7. Expected Challenges for Li-Fi

With all the marvelous heights that can be achieved with the help of LiFi, there are some challenges which need to be addressed. Some fundamental challenges that require definite attention are:

i. External source of light can create noise signals and create glitch with the original signal.

ii. Flickering is the most fundamental challenge that requires attention. LEDs are expected to have ON/OFF operations and these two operations are required to be performed with synchronization in order to get both the illumination as well as communication. When a stream of packets of data is communicated the LED does ON/OFF and hence the coverage illumination gets affected. Also, frequent fluctuations can affect human eye vision in long run.

iii. LiFi finds its potential usage in localized environment because light cannot surpass through the walls of a room or any opaque object. Even the intensity is affected in a translucent medium. Till this situation is taken care of; wide area adoption of LiFi remains uncertain.

iv. A clean visible line of sight is essential for proper communication via LiFi. So if we don't get proper line of sight that system cannot be harnessed to its full capability. [3]

8. Conclusion

LiFi can be best harnessed when coupled with the Wi-Fi network. Even though they have different throughputs and exercise with independently different spectrum they display correlation. A calculated combining of the Wi-Fi and LiFi can be a force multiplier which can upgrade the local coverage with reliable and high data rates which are in demand both at present and future. Given the nature of the advancements in the connected devices technologies we can safely assume that LiFi would be a enabler of these demands.

With all its benefits, with the current concepts available the system cannot be used for long distances. The system is easily affected by any opaque obstacle whether indoor or outdoor. One major drawback of the system would be inefficient uplink capability because it is not feasible to transmit the light based signals from User Data to Access Port.

LiFi is in itself at niche among other wireless communication methods. It uses visible range of light frequencies. Unlike traditional antennas, LiFi use a system of light sources, gateways and photo-detectors. As mentioned earlier, the light frequency band is ten thousand times broader than any conventional radio frequency band and hence LiFi can accommodate more. Also, we can get rid of issues related to licensing. Plus, we this system provides natural security feature from remote hackers.

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