Viability of LiFi as the Future of Wireless Communication

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***Abstract* - Advent of Light-Fidelity (LiFi) is considered to be the dawn of a new era in the field of wireless communication. Visible Light Communication (VLC) has been around for over a century; however, after the introduction of LEDs into the VLC, there has been a drastic change in the efficiency of VLC. Not only was it taken seriously but the initial prototypes hinted towards a great opportunity, and as with passing years the VLC achieved spectacular data rates. Recently VLC was turned into a complete communication system with the introduction of layers and protocols and was named as LiFi. This paper focuses on LiFi as a feasible complement to the existing RF based communication. For this purposes, we thoroughly analyzed the difference between VLC and LiFi, the issues in RF based communication that can be addressed by LiFi, the working mechanism of LiFi, its pros and cons and finally we studied the application of LiFi. We concluded that LiFi can prove to be an excellent complement to the existing communication technologies. And if enough research is focused on this technology it can completely replace the RF based communication technology in the years to come.**

Index Terms – Light Fidelity, Visible Light Communication, Optical Wireless Communication, WiFi, Radio Frequency.

I. INTRODUCTION

Communication is one of the core pillars of the modern lifestyle which is entangled with the use of Information and Communication Technology (ICT). Most of the ICT systems work through wireless technologies, which has eliminated the use of cables. This has created an ease in connecting devices to the wireless hotspot easily and has also allowed more devices to be connected to one hotspot simultaneously. 3G, 4G and WiFi are the leading wireless communication technologies that is used to connect devices. The data traffic on wireless networks is increasing with each passing day [1]. More and more devices are being connected to internet. Initially, there were only Desktop Computers, then came the laptops, followed by smart phones and the trend continued and eventually lead to smart TV and hence the concept of Smart homes, smart building and smart cities was introduced. It all pile up into what we call as the Internet of Things (IoT), which is considered to be the next big thing in technology [2]. One of the major hurdle in execution of all this is the inability of the existing Radio Frequency (RF) spectrum in handling the immense amount of data traffic that we anticipate from the IoT [3].

Cisco's Visual Networking Index (VNI) calculated that in 2016 alone the total amount of internet traffic, as known as the IP traffic will be around 1.1 zettabyte (1 zettabyte = 1 trillion gigabytes), which turns out to be a massive 88.4 exabytes per month. The report states that the traffic is expected to increase immensely in the coming five years. By the year 2019, we are looking at a traffic of 2 zettabytes per year. The report further says that in 2016, the overall traffic generated from Wireless devices will bypass the traffic generated from wired devices. Around 53 percent of the global traffic in 2016 will be from wireless devices. The same report cites that two years ago in 2014, the traffic from wireless devices was 46 percent which indicates a massive seven percent increase in just two years. We can expect the wireless traffic to grow further for the years to come [4]. This means a serious potential threat to the exiting RF spectrum. We can reduce the cell size for our RF communication cells in order to allow the usability of the spectrum with the increasing load; however, this is going to be very costly and will come with an immediate threshold in cell size as well as issues like handovers and eventually we will need to look around for a replacement of RF based communication system [5].

Visible Light Communication (VLC) is the foremost contender with the ability to replace the RF based communication system efficiently. VLC is a communication technology which uses the visible light spectrum range from 430 and 770 THz [6]. Tossed by Alexander Graham Bell, the concept of VLC regained attention over a century later after the introduction of Light Emitting Diodes (LED's). Prof. Harald Haas of Edinburgh University proposed the concept of Light-Fidelity (LiFi), a bidirectional, high data rate, full-fledged networking technology which allows transmission of data through the visible light spectrum at very high speed, such that it allows smooth HD video streaming [3]. LiFi is a unique technology that offers all the services of the RF spectrum but in the visible light spectrum.

LiFi has an innate ability to utilize the existing infrastructure of lighting systems around us [7]. Any light source around us, be it an indoor lightening system or a street light can be effectively turned into a LiFi hotspot [8]. This will save us an unfathomable cost and this is one of the reasons why LiFi is being considered as the best potential replacement to the existing RF communication systems.

II. REVIEW OF EXISTING LITERATURE

The concept of LiFi was initially tossed in 2012 by Prof. Haas in a TED video in the most simplistic way through a real-time demonstration of LiFi to play a high-quality video. Haas, is thus considered as the 'Father of LiFi' and he has been part of an in-depth research on LiFi ever since. In paper [3], Prof. Harald Hass et al. has thoroughly clarified the basic difference between common VLC and Prof. Haas' brainchild, Light-Fidelity. The paper focuses on elucidating the major facts which makes LiFi, as the future of VLC and its technical aspects. The paper explains the entire LiFi communication model including the concept of optical attocells. Prof. Haas has also talked about the current research work in progress in the modulation, interference mitigation and other relevant fields. The researchers have also focused on how the ubiquitous luminaries turn into attocells for LiFi hence resulting in an enhanced wireless capacity and opening a new window to not only materialize the concept of Internet of Things (IoT), but also fulfilling the major Key Performing Indicators (KPIs) of the 5G technology. The research also encompasses the interoperability of LiFi and Wireless Fidelity (WiFi) using attocells to demonstrate its practicality.

In paper [7], 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 Internet of things (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. LiFi, an improved version of VLC, that works using the Light Emitting Diodes (LED's) and LiFi Attocells is thoroughly studied in this paper.

Researchers has surveyed the fundamental technologies indispensable for the realization of LiFi in paper [9]. 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 LiFi models, multiple user-access, allocation of resources and interference management. The paper also suggested some future improvements in LiFi.

Paper [10] has a thorough review of the LiFi technology and is inspired by the role of LiFi as a possible solution to the problem of slow bitrate in WiFi communication at crowded places with multiple communication devices. The research is concentrated on the built and working of LiFi networks. The author has also compared the performance of LiFi with traditional wireless technologies.

Paper [11],[12],[13] shed light over the use of VLC and LiFi as the future of the communication. The papers study the technology in details from individual perspectives and comes to a conclusion that LiFi does have a potential to overcome the upcoming demands like shrinking RF spectrum and growing data traffic.

Paper [14] 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 Internet of Things (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 LiFi is the foremost contender to be considered in this regard. The paper describes the core characteristics of WiFi and LiFi 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. Paper [15] follows the same track as [14] and study the LiFi-WiFi Hybrid networks and mainly focuses on the handover and mobility related issues in the optical attocells.

In paper [16] the authors have studied the limitation of VLC through LED's. VLC via LEDs has an innate limitation i-e the trade-off among bandwidth and optical efficiency. The paper suggests off-the-shelf Laser Diodes (LDs) as the possible solution to this alternate. The research has an in-depth study of the communication competence of the LDs with practical illumination restraints. The paper concludes that the optical wireless communication can touch a speed as high as 100gbps at standard ambient illumination.

III. VLC VS. LIFI

Before we study LiFi and its comparison to the traditional RF based communication systems, we need to understand the basic differences between the traditional VLC and the modern concept of LiFi.

A. A Complete Wireless Communication System

LiFi is a complete VLC based communication model for networking [3] as shown in figure 1. VLC uses LEDs for transmission of data. VLC uses Intensity modulation (IM) and other mod by increasing and decreasing the intensity in order to transmit bits of data. Photodiodes are used at the receiver's end in order to detect the signals. Principle of Direct Detection is used to receive the signal. VLC has essentially remained a point-to-point communication method. The earlier IEEE standard IEEE 802.15.7 is based on the same. However, with the arrival of LiFi the standard is to be amended now. LiFi, unlike the traditional VLC is a bi-directional communication for multi-users and allows point-to-multipoint and multipoint-to-point communication.

B. Mobility

VLC is a mere cable replacement and work as a unidirectional communication technique. LiFi on the other hand uses 'Optical Attocells' which allow smooth communication through handover just like the RF communication cells [18]. In order to allow free mobility optical attocells are used which results in a new layer in our existing Heterogeneous Networks (HetNets) [7]. Since an entire new layers is introduced, hence there is a need to make relevant changes in each of the other layers and protocols to adjust.

C. Security

Light does not pass through opaque objects normally which allows the LiFi to be limited to a certain specific area [9],[19]. This also give us an easy way to manage the Co-Channel Interference (CCI) which otherwise exists at physical layer.

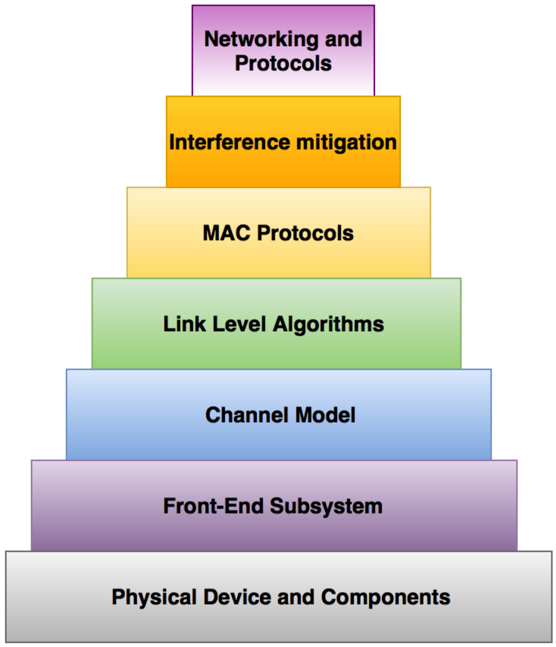

Fig. 1 Block Diagram of a LiFi Communication System

IV. LIMITATIONS OF RF BASED COMMUNICATION TECHNOLOGIES

Wireless technologies that work through the RF spectrum has multiple limitations which is hampering the global move towards an all-out smart lifestyle. Once we figure out those issues, we will be able to check whether LiFi can replace the RF based communication technologies in future.

A. Capacity

One of the major issues of the RF spectrum communication is the bandwidth capacity. The RF spectrum is though good enough to handle a massive traffic, but given that the data traffic is increasing several folds with each passing year, the capacity has started to turn into a bottleneck for all the communication. Most of the downlink communication in future would need much more capacity than RF spectrum can handle. Any future technology that has to replace or work in complement to the RF based communication should have a broader capacity.

B. Data Rate

Data rate is one of the fundamental requirements of the modern communication systems. RF communication provides a high data rate, but the increasing demand and the upcoming technological advances like IoT require even higher data rates which requires a very high data rate [20]. Any upcoming technology must have a higher data rates than the contemporary RF based communication systems.

C. Security

Security is yet another important issue faced in the RF communications. Security at the physical layer is considered as a serious bottleneck. The RF signals easily pass through walls and other obstacles which is why it is impossible to control the reach of signals to unwanted locations [21]. Any future technology proposed must be able to have the ability to work in a Non Line-of-Sight (NLOS) and yet have the ability to control its reach.

D. Cost

All RF communication comes at a cost. Although the prices of RF infrastructure are dropping; however, as the demand is increasing at a very high pace, meeting the required demands would need a heavy amount. Any future replacement has to be cost-effective while meeting the increasing demand.

E. Ecological effects

RF signals are said to have an adverse effect on human lives. The closer we are to the RF source, the more we are vulnerable to its effects. Similarly, higher the intensity of the source, the more it would affect human and other living organization. With the increase in the data traffic, we will need more and more RF communication devices which means more exposure to these RF signals, hence leads us to search for a communication technology that is absolutely safe regardless of its intensity and excessive use.

Feature	RF based WiFi	LiFi
Data rate (Theoretical)	1 – 2100 Mbps	224 Gbps
Data rate (Practical)	54 – 500 Mbps	10-35 Gbps
Range	20 – 100 Meters	10 Meters
Frequency Band	2.4/5GHZ	430-770 THz

Fig. 2 Table showing technical Comparison of LiFi and WiFi.

V. COMPARISON BETWEEN LIFI AND RF COMMUNICATION

LiFi came into market as a replacement or a complement of RF based Wireless Fidelity (WiFi). This is a huge thing to claim given that RF based communication models are ubiquitous around the world and for many years, there has been no challenge. In order to accept LiFi as a valid replacement, we studied whether LiFi has the potential to compete with RF based networking technologies like WiFi. We found that LiFi can actually work as an efficient replacement. Here are some of the major features we researched.

A. Data Rate

WiFi can provide around 150Mbps of speed by transmission in RF spectrum. LiFi, on the other hand, works in Visible Light spectrum and has so far achieved the speed of over 1Gbps [22]. In some experiments, the LiFi has achieved a speed of well over 100Gbps in certain controlled environments [23].

B. Range

WiFi signals cannot be contained easily to a certain physical boundary [21]. While it is looked upon as a security issues in sensitive environment, it is regarded as a positive feature because it enhances the range of the service. LiFi on the other hand uses visible spectrum and since light does not pass through opaque objects, it comes with a very limited range [3].

C. Spectrum Capacity

WiFi works through RF spectrum which has a comparatively smaller spectrum. Visible Light Spectrum on the other hand is roughly 10,000 times larger than the RF spectrum, which means we have equally larger potential for expansion in terms of parallel communication [10].

D. Security

WiFi can be compromised, mainly because of its ability to reach unwanted locations without any hurdles. This leaves WiFi severely prone to security breaches [21]. LiFi with its ability of containment remains way much safer than its counterparts.

E. Infrastructure and cost

An expansion of WiFi to meet the growing demand is going to require us to modify and bring around way more WiFi based equipment to connect devices around. This is going to be one costly affair that we have to face in the years to come. The use of LiFi can eliminate the need of investment on more and more devices and infrastructures. Any traditional electricity bulk can be turned easily into a LiFi hotspot, which will create a small attocell around it, hence allow communication within that cell. Since LiFi is proposed to be implemented over the preexisting infrastructure, it will slash down the enormous costs expected to meet the rising demand for reliable communication technique [3].

F. Market Maturity

WiFi is abundantly utilized throughout the world and has been around for several years hence possesses a high market maturity. LiFi being a latest technology lag behind in this, and being a new technology is yet to go through a lot of phases before it matches the WiFi in its market maturity [24].

VI. Working Mechanism of LiFi

The basic principle of LiFi can be understood if we study the On-Off Keying (OOK) technique for VLC [3]. It is the most basic form of modulation technique which can help us understand the core working mechanism of the LiFi. In OOK, if an LED is ‘On’ it can be considered as ‘1’ and if it is ‘Off’, it can be considered as a ‘0’. Due to the ability of LEDs to quickly turn on and off multiple times in a very brief moment of time, it gives us a great opportunity to use it to transmit data. Theoretically, it would result in a flickering light; however, since the flickering is too fast, it become impossible for the naked eye to notice the flickering and hence, we observe a constant light from the source while transferring our data. The photodiode at the receiver’s end can read the flickering and transmit it ahead to the digital signal processor.

There are several modulation techniques used in LiFi including Single-Carrier Modulation (SCM), which include OOK, Pulse Amplitude Modulation (PAM) and Pulse Position Modulation (PPM). The SCM despite its energy efficient nature, has some major issues like non-linear signal distortion and Inter-Symbol Interference (ISI) [3]. To address the issues faced by SCM, Multi-Carrier Modulation (MCM) was introduced. MCM is comparatively bandwidth efficient but consume more energy than SCM. The common form of MCM that is used in LiFi is Orthogonal Frequency-Division Multiplexing (OFDM) [25]. Certain specific modulation techniques have also been proposed for LiFi including Color Shift Keying (CSK) which has become part of the IEEE 802.15.7. There are two modulation techniques namely Metameric Modulation (MM) and Color Intensity Modulation (CIM) based on CSK which works for both orthogonal as well as non-orthogonal channels [26],[27].

We can improve the performance of the LiFi by allowing parallel communication through the use of the multiple diodes or an array of diodes [10]. Similarly, we can use variation of LEDs, i.e. Red, Green and Blue LEDs to transmit the signals [9],[10]. So far scientists have achieved a theoretical data rate of over 100 Gbps. Similarly, LiFi can work in more than one medium unlike WiFi which only works in air, LiFi also works underwater [28].

Apart from light-based transmission, the LiFi is a complete communication and networking system with its own structure, layers and protocols. In the core of the system are the physical components i-e Gallium-Nitride (GaN) based LEDs to transmit the signal, a single-photon avalanche diode (SPAD) to receive the signal. The physical layers are placed in an optical front-end with analogue circuitry to smoothly run the LEDs and convert the received signals from Photodiodes into useful data. Link level Algorithms are utilized in order to form the signals in such a way that we get maximum throughput. Since we lack any negative signal in Intensity-Modulation (IM) technique, we need to come up with new algorithms as the Shannon model cannot be theoretically applied in the given case [3].

One of the purpose of LiFi is to ensure multi-user communication, for this purpose new Medium Access Control (MAC) protocols, needs to be introduced keeping the unique physical layer of LiFi in consideration. To improve the overall efficiency of the system, interference diminution is required. Finally, the optical attocell needs to be embedded in a software based networks.

VII. Benefits of LiFi

LiFi has multiple advantages over the common RF based communication. Here we will summarize some of them.

A. Bandwidth Utility

There is around 300 THz of unused bandwidth that is in the visible light spectrum in the range of 430–770 THz.

B. High Signal-to-Noise Ratio (SNR)

While colored LEDs are very bright and the average distance between a LiFi hotspot and the receiver is very moderate, which is why the signal received at the receiver is of very high-intensity. It results in a much higher SNR than the RF based communication [9].

C. Beam Confinement

Due to the inability of the light to pass through opaque objects, the LiFi based communication model gets an edge in terms of security. Only devices within visible range can be connected to LiFi, thus eliminating the risk of any foreign intrusion into the network [9].

D. Cost Efficient

As a practical technology with an intention of spreading globally to meet the growing demands of increasing data traffic, one of the most prominent feature of LiFi is its cost efficiency. LiFi has the ability to be embedded into the existing lighting infrastructure. The only two additional devices required are LEDs and PDs which comes at a very low cost [9].

E. Electro-Magnetic Interference (EMI)

LiFi is so far the only modern communication technology that is completely free from the Electro-Magnetic Interference [29].

F. Health

LiFi uses LEDs at normal intensity. It has been noted that at normal intensity, the LEDs does not cause any sort of harm to the human body [9],[29].

G. Multipath Interference

Due to the use of PD, which are larger than the wavelength of the transmitted signal there is a spatial diversity, which helps in elimination of multipath from the signal at the receiver's end.

H. IoT

LiFi make use of small autonomous cells called attocells. Attocells are comparatively smaller than traditional cellphone cells and the WiFi cells. This allows LiFi to be able to connect to a staggering number of items simultaneously without any problem. This paves the way for IoT to be materialized [30].

I. Speed

LiFi has attained a speed of well over 100 Gbps making it one of the fastest sources of communication known to us [23]. This will realize the long standing dream of IoT and improve general user experience in terms of data rate.

J. Green Technology

LiFi is classified as a green alternate to the existing technologies [10],[11]. It does not need much amount of energy to power a basic LED. Since, LiFi is expected to be embedded into the existing infrastructure, it will not create any further demand for extra power and will not require any extra electricity. LiFi can be safely considered as a technology which is greener and safer than its counter-parts [12],[13].

VIII. Applications of LiFi

LiFi has been tested for multiple practical implementations and several prototypes have been used in multiple applications like vehicle-to-vehicle communication, Internet of Things (IoT) and others. Apart from these individual applications, LiFi is going to revolutionize the very concept of the wireless communication.

A. Health Sector

LiFi can safely be used in places where RF communication is either not possible or is not allowed due to the fear of the EMI adversely affecting some sensitive medical equipment. Lifi is the solution to ensure smooth communication even at places like hospital and other health related institutes [29].

B. Aircraft Utility

Airlines do not permit the use of cellphones because of their ability to create EMI. LiFi eliminates this problem, as LiFi does not induce EMI. Hence, it is absolutely safe for use in airplanes for communication purposes [12].

C. In Densely Crowded Areas

The traditional WiFi proves to be have very limited utility in dense urban areas. With a dense crowd around, a WiFi hotspot usually shows its limitation. LiFi on the other hand can solve this problem by offering parallel communication through the LiFi microcells, the attocells [14].

D. Vehicular Communication

LiFi ensures a smooth vehicle-to-vehicle communication in an effort to reduce the risk of accidents and ensure smooth traffic flow. In future, the traffic lights can be turned into LiFi hotspots, such that they can directly communicate with the vehicles, hence improved the flow of traffic [17].

E. Underwater Communication

RF based communication system does not work efficiently underwater. LiFi can be used to communicate underwater [28].

F. Military Installations and Sensitive Areas

LiFi has a potential to be used in military, security apparatuses and other sensitive areas; however, this opportunity has not been researched much. As the technology matures, LiFi can be expected to become a great source of communication for military purposes by providing it with low-powered communication with high security and improved efficiency [12].

IX. Limitations of LiFi

Undoubtedly LiFi is a great source of communication and will bring about a revolution in the field of communication. However, there are some limitations faced by LiFi which may prove to be a hurdle in the growth of this technology. Here are some of the prominent limitations of this technology.

1) Opaque objects including walls and other hard obstacles are impenetrable for visible light. This limits the range of the LiFi to a great extent, hence the receiver has to be placed somewhere under the light. If the receiver is placed in the shadow, it will either slow down the data rate or stop working altogether [28].

2) In order for Lifi to work, the light must be on. In indoor locations like homes, where light has to be turned off during the day time or during at night, LiFi will stop working. Efforts have been made to ensure that LiFi remain working even at dim lights, however, the light has to stay on. This can be considered as a sort of drawback [28].

3) The LiFi systems that are ready to be rolled out to public are limited to downlink only due to hardware and infrastructure limitations. Hence, we would still need to have a WiFi around us for the uplink.

4) Initial cost of VLC systems, especially LiFi is high [13]. The LiFi may be able to work on off the shelf LED lights; however, for better transmission we would eventually

need to get specialized LEDs which are able to be compatible with the modulation circuitry.

5) LiFi cannot be used outdoors and highly-illuminated places as smoothly as the WiFi can be used. This can prove to be a serious drawback in the times to come unless it is addressed on time [13].

6) LiFi which is said to be a safe-to-use technology for communication in the airplanes [12], the external light from windows during the day time can prove to be a hurdle.

X. CONCLUSION

LiFi is one of the staggering inventions of the recent years and it rightfully attained a spot as one of the best inventions of 2011 by Times Magazine. It is the most feasible solution to the upcoming spectrum shortage and can help in materializing the concept of IoT. LiFi, based on its abilities that we have researched so far, can prove to be a perfect complement to the existing RF based communication system, specially the WiFi. It can easily fulfill the ever increasing downlink capacity requirement and can prove to be a feasible solution to the anticipated spectrum crisis. While LiFi, being in its infancy is showing its ability to easily replace the downlink communication, can easily replace the entire RF based communication in future if proper research work is focused and resources allocated to this technology. LiFi is a new technology and there is a lot of work required to be done in this technology in order to address its drawbacks and limitations. There is a huge margin for research work on the modulation techniques, interference mitigation methods, LiFi-WiFi HetNet performance, Trade-off between light dimming and data rate, multiplex schemes and LiFi-RF network protocols.

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