Li-Fi : A Framework for Future IT Environment

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Abstract: *The emergence of the new paradigm of computing in the cloud computing architecture has made it necessary to overcome the inherent limitations of cloud computing, such as location awareness, scalability, energy efficiency, mobility, bandwidth bottlenecks, and latency delay. To address these issues, this paper proposes an efficient hybrid cloud architecture framework coupled with Li-Fi communication for a human-centric IoT network. It also introduces the architecture of the local cloud to reduce the latency delay and bandwidth cost and to improve efficiency, security, reliability and availability. This paper attempts to clarify the difference between visible light communication (VLC) and light-fidelity (LiFi). In particular, it will show how LiFi takes VLC further by using light emitting diodes (LEDs) to realise fully networked wireless systems. Finally, the paper discusses the communication modulation schemes in the Li-Fi technique and presents scenarios involving the application of the proposed model in the real world. In this paper we will first explain what Light-Fidelity (LiFi) is and argue that it is a 5th Generation (5G) technology. Peak transmission speeds of 8 Gbps from a single light source have been demonstrated, and complete cellular networks based on LiFi have been created. We will discuss numerous misconceptions and illustrate the potential impact this technology can have across a number of existing and emerging industries. We also discuss new applications which LiFi can unlock in the future.*

Keywords: **LEDs, LiFi, Transmission Speed, Networks, CAGR, MTC, IMC, VLC**

1. Introduction

LiFi is a wireless communication technology that uses the infrared and visible light spectrum for high speed data communication. LiFi, first coined in [1] extends the concept of visible light communication (VLC) to achieve high speed, secure, bi-directional and fully networked wireless communications [2]. It is important to note that LiFi supports user mobility and multi user access. The size of the infrared and visible light spectrum together is approximately 2600 times the size of the entire radio frequency spectrum of 300 GHz (see Fig. 1). It is shown that the compound annual growth rate (CAGR) of wireless traffic has been 60% during the last 10 years. If this growth is sustained for the next 20 years, which is a reasonable assumption due to the advent of Internet-of-Things (IoT) and machine type communication (MTC), this would mean a demand of 12,000 times the current bandwidth assuming the same spectrum efficiency. As an example, the industrial, scientific and medical (ISM) RF band in the 5.4 GHz region is about 500 MHz, and this is primarily used by wireless fidelity (WiFi). This bandwidth is already becoming saturated, which is one reason for the introduction of Wireless Gigabit Alliance (WiGig). WiGig uses the unlicensed spectrum between 57 GHz–66 GHz, i.e., a maximum bandwidth of 9 GHz. In 20 years from now, the bandwidth demand for future wireless systems would however, be 12,000 × 500 MHz which results in a demand for 6 THz of bandwidth. The entire RF spectrum is only 0.3 THz. This means a 20 times shortfall compared to the entire RF spectrum, and a 667 times shortfall compared to the currently allocated bandwidth for WiGig. In comparison, the 6 THz of bandwidth is only 0.8% of the entire IR and visible light spectrum.

One could argue that a more aggressive spatial reuse of frequency resources could be adopted to overcome this looming spectrum crunch. This approach has been used very successfully in the past and has led to the 'small cell concept'. In fact, it has been the major contributor towards the improvements of data rates. The cell sizes in cellular communication have dramatically shrunk. The cell radius in early 2 G systems was 35 km, in 3G systems 5 km, in 4G systems 100 m, and in 5G probably about 25 m in order to reuse the available RF spectrum more efficiently and to achieve higher data densities. However, further reductions in cell sizes are more difficult to achieve due to the high infrastructure cost for the backhaul and fronthaul data links which connect these distributed access points to the core network. Moreover, with a smaller cell size the likelihood of line-of-sight between an interfering base station and a user terminal increases. The resulting interference can significantly diminish data rates and may cause a major problem in cellular networks [4]. Therefore, WiFi access points have been mounted under the seats in stadia to use the human body as an attenuator for the RF signals and to avoid line-of-sight interference links. Clearly, this is not a viable solution for office and home deployments. For these reasons, it is conceivable that the contributions for the future mobile data traffic growth will stem from more spectrum rather than spatial reuse. In particular, the optical resources are very attractive as they are plentiful as shown in Fig. 1 and they are license-free.

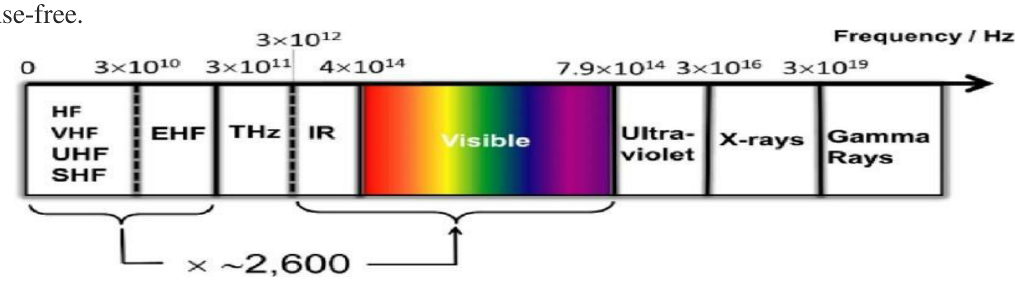

Figure 1: The radio frequency (RF) spectrum is only a fraction of the entire electromagnetic spectrum. The visible light spectrum and the infrared (IR) spectrum are unregulated, and offer 780 THz of bandwidth.

These resources can be used for data communication which is successfully demonstrated for decades in fibre-optic communication using light amplification by stimulated emission of radiation (lasers). With the widespread adoption of high brightness light emitting diodes (LEDs) an opportunity has arisen to use the visible light spectrum for pervasive wireless networking.Traditionally, a VLC system has been conceived as a single point-to-point wireless communication link between a LED light source and a receiver which is equipped with a photo detection device such as a photo detector (PD). The achievable data rate depends on the digital modulation technology used as well as the lighting technology.

Most commercial LEDs are composed of a blue high brightness LED with a phosphorous coating that converts blue light into yellow. When blue light and yellow light are combined, this turns into white light. This is the most cost-efficient way to produce white light today, but the phosphor color converting material slows down the frequency response, i.e., higher frequencies are heavily attenuated. Consequently, the bandwidth of this type of LED is merely in the region of 2 MHz. With a blue filter at the receiver to remove the slow yellow components it, however, is possible to achieve data rates in the region of 1 Gbps with these devices. More advanced red, green and blue (RGB) LEDs enable data rates up to 5 Gbps as white light is produced by mixing the base colors instead of using a color converting chemical. Record transmission speeds with a single micro LED of 8 Gbps have been demonstrated [5], and it was shown that 100 Gbps are feasible with laser-based lighting [6].Wireless technology has reformed the current work environment. With the advantages of WiFi, it also has certain limitations as wireless technology has notorious difficulty in making peace with its sworn enemy: the walls. However, it seems that some of these gaps could be resolved with Li-Fi technology. Li-Fi technology is a two-way, high-speed, wireless technology that uses the spectrum of light to provide a user experience similar to that of traditional wireless systems. The advantages of the Li-Fi technique are summarized below.

Energy efficiency

Li-Fi works based on visible light communication technology using LED bulbs. Many indoor premises already have LED bulbs for lighting purposes; the same source of light can be used as a means of communication to transmit data. It is possible to adjust Li-Fi bulbs so that the light is barely visible to the human eye, when there is no need for light.

Availability

The internet can be everywhere, wherever there is a light source. The transmission of high-speed data could be available everywhere because LED bulbs can now be almost found anywhere in the indoor premises.

Security

Unlike WiFi, Li-Fi works by using a very unique system, and it cannot be hacked because light cannot penetrate opaque and solid structures. It is only available to users in a room, while remaining inaccessible to anyone outside the workstation.

Speed

Li-Fi is unbelievably quick, i.e. it is capable of achieving a speed of 1 Gbps in a normal environment and 100 Gbps in a laboratory environment. Li-Fi is 100 times faster than Wi-Fi.

Safety

Unlike infrared, there is no danger to the health from visible light in illumination conditions. Li-Fi illumination conditions meet the safety standards for the skin and eyes, making it safe to use in any environment or situation.

Ease of deployment in existing infrastructure

With the addition of relatively simple and inexpensive front-end components running on the baseband, Li-Fi can be deployed in the existing lighting infrastructure. Due to the symbiotic relationship with energy-saving LED bulb lighting, Li-Fi transmitters are widely deployed.

Cost

The installed LED light bulbs could be used to transmit information directly to the destination without having to run close to a mile of cable. Indoor premises can remain connected to each other by using a point-to-point network, without using additional cables from one access point to another.

Challenges of the existing cloud computing architecture

For real-time applications in cloud computing, design, implementation, and operations present a number of challenges. In terms of real-time applications, and the need to improve the services of a specific domain, data is dynamically analyzed to obtain new information that can be used to provide services. In the traditional cloud computing system, the time taken to analyze data in real time and make decisions is usually very long and can greatly reduce the efficiency and benefits of applications. The following challenges must be met in cloud computing in order to design, implement, and deliver services for real-time applications.

Event transfer in real-time

Whether as filtered events or raw events, all current events must be transferred in real time. All transferred events are also preprocessed before being transferred to the main control unit. The traditional cloud is good if the amount of events generated is not too huge. However, due to the rapid increase in demand for IoT devices and the ever-increasing volume of IoT data, the current cloud architecture is unable to provide services for real-time applications due to the limitations of network resources, bandwidth, and high latency delay.

Bandwidth and performance cost

Organizations can reduce the cost of acquiring, managing and maintaining the system by switching to the cloud; however, they may need to spend more on the network bandwidth. Usually, there is no problem processing a small amount of data for a small application; however, for data-intensive applications, the cost can be high. The complex and intensive data transmitted and received across the network to the traditional cloud require sufficient bandwidth to avoid waiting times and delays.

Security and compliance

In many organizations there may be data or applications with which they never feel comfortable enough to allow them out of their sight. We need to pay special attention to this problem because demand is so important and because the traditional architecture of the cloud is not sufficiently capable of providing the necessary security measures at present.

Availability and reliability

As with security, availability and reliability are an issue for cloud service providers. When the integration of IoT and cloud is adopted for critical applications, reliability problems typically arise in the context of intelligent mobility; vehicles are often in motion; and vehicular networks and communication are often intermittent or less reliable. There are a number of issues related to the failure of a device or devices that are not always accessible when applications are deployed in resource-constrained environments [7, 8, 9].

Integration with existing infrastructure

It is an essential characteristic to maximize the value of cloud services, and this needs to be addressed. For many IT departments, this challenge already exists within their organizations in the form of Bring Your Own Device (BYOD) and IT. In addition, a well-integrated environment can provide better services compared to the incremental gains resulting from the introduction of discrete cloud services within an organization.

2. Existing Research

Even though the IoT and Cloud are two different domains that have evolved rapidly and independently of each other, their characteristics are often complementary. Generally, to obtain advantages in specific application scenarios, complementarity characteristics are the main reason cited by many researchers in integrating the IoT and Cloud [10,11,12]. To manage things more dynamically and distribute them in the IoT-Cloud, the scope of cloud computing must be extended by introducing the middle layer to reduce the complexity of the cloud. In the multi-cloud environment, new challenges have emerged with regard to the collection, processing, and transmission of information [1].IoT devices do not allow the processing of complex data on site due to the limitations of energy and processing resources. Generally, collected data is transmitted to the nodes of the upper layer, which has more computational resources and the ability to aggregate and process collected data. However, scalability and low latency are difficult to achieve without the proper infrastructure. For the real-time analysis of data, sensor-centric applications, energy efficiency, complex event management, and scalability, the architecture must be properly designed [1, 12].Currently, Software Defined Networking (SDN) has become one of the most attractive technologies in network research. It involves the separation of the data plane and the control plane, and the programmability of the network. By leveraging the strength of SDN, Nguyen et al. [19] proposed an architecture designed to enable enterprise networks to easily and flexibly troubleshoot the virtual local area network. Gilani et al. [20] introduced the network selection approach for mobility management using SDN and network function virtualization.

3. LiFiNetworking

Fig. 2 illustrates the concept of a LiFiattocell network. The room is lit by several light fixtures, which provide illumination. Each light is driven by a LiFi modem or a LiFi chip and, therefore, also serves as an optical base station or access point (AP). The optical base stations are connected to the core network by high speed backhaul connections. The light fixtures also have an integrated infrared detector to receive signals from the terminals. The illuminating lights are modulated at high rates. The resulting high frequency flickers which are much higher than the refresh rate of a computer monitor are not visible to the occupants of the room. Power and data can be provided to each light fixture using a number of different techniques, including PoE and power-line communication (PLC) [9], [10]. An optical uplink is implemented by using a transmitter on the user equipment (UE), often using an IR source (so it is invisible to the user). Each of these light fixtures, which at the same time act as wireless LiFiAPs, create an extremely small cell, an optical attocell [11]. Because light is spatially confined, it is possible in LiFi to take the 'small cell concept' to a new level by creating ultra-small cells with radii less than 5 m while exploiting the huge additional unlicensed spectrum in the optical domain. The balance of light fixtures that contain APs and those that provide only illumination is determined by the requirement of the network, but potentially all light fixtures can contain APs. Compared to a single AP wireless hot-spot system, such cellular systems can cover a much larger area and allow multiple UEs to be connected simultaneously [12]. In cellular networks, dense spatial reuse of the wireless transmission resources is used to achieve very high data density - bits per second per square meter (bps/m^2). Consequently, the links using the same channel in adjacent cells interfere with each other, which is known as co-channel interference (CCI) [13]. Fig. 2.illustrates CCI in an optical attocell network.

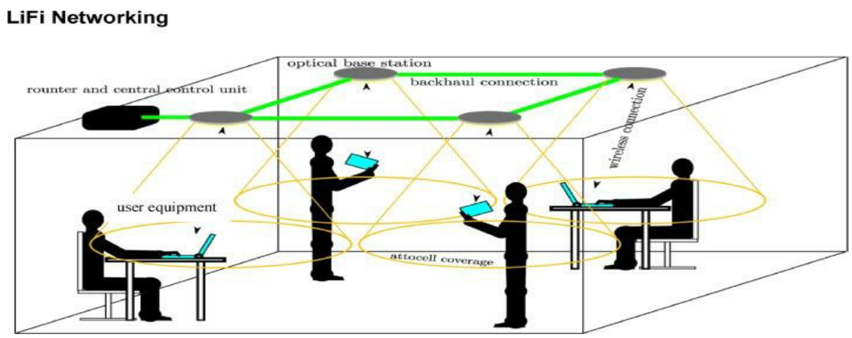

Figure 2: The concept of LiFiattocell networks applied to indoor wireless networking.

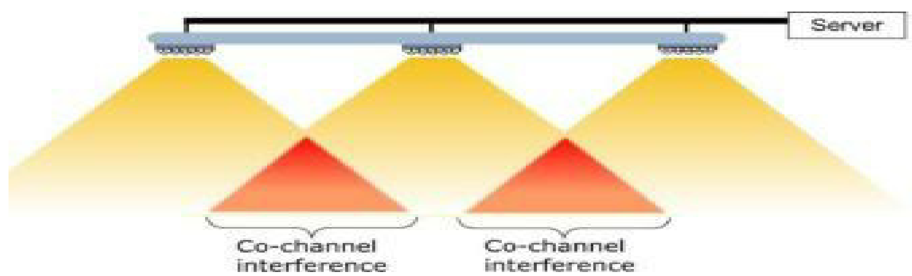

Figure3: CCI occurs in the region where the same light spectrum of neighboring APs overlaps, and when these APs use the same modulation bandwidth for data encoding.

The move from point to point links to full wireless networks based on light poses several challenges. Within each cell, there can be several users and therefore multiple access schemes are required. The provision of an uplink can also require a different approach from the downlink. This is because low energy consumption is required in the portable device, and an uplink visible light source on the device is likely to be distracting to the user. Therefore, the use of the infrared spectrum seems most appropriate for the uplink. In addition, modulation techniques for a high-speed uplink have to be spectrum efficient and power efficient at the same time. Two recently developed modulation techniques that achieve this are enhanced unipolar OFDM (eU OFDM) [14], or spectral and energy efficient (SEE OFDM) [15]. Advanced CCI mitigation techniques [16] often require that these multiple LiFi APs are operated by means of a centralized control mechanism such as 'resource schedulers' within the controller of a software defined network (SDN) [17]. The main tasks of the 'resource scheduler' are to adaptively allocate signal power, frequency, time and wavelength resources. Typically, there are trade-offs between signaling overhead, computational complexity, user data rates, aggregate data rates and user fairness, and the optimum selection of respective CCI mitigation and resource scheduling techniques depend on actual use cases and system constraints [18], [19]. Other functions of the central controller include achieving multi-user access, and the process of handover from cell to cell when terminals move. Handover plays an important role in LiFi networks. For example, the handover controller has to ensure that connectivity is maintained when users leave a room, or the premises. Therefore, there might be situations when there is no LiFi coverage. In these scenarios to avoid loss of connectivity we utilize the fact that LiFi is complementary to RF networks. To this end, there have been studies on hybrid LiFi/RF networks, and the three key findings are: (i) LiFi networks will significantly improve services quality to mobile users, (ii) service delivery can be uninterrupted, and (iii) WiFi networks significantly benefit from LiFi networks. The latter is because well-designed load balancing will ensure that WiFi networks suffer less from inefficient traffic overheads caused by constant re-transmissions which happen when two or multiple terminals are in contention.

LiFiattocell networks have many advantages over incumbent technologies. Firstly, unlike omnidirectional RF antennas radiating signals in all directions, a LED light source typically radiates optical power directionally because of the way it is constructed. Therefore, the radiation of the visible light signals is naturally confined within a limited region. In contrast, RF mm-wave systems require complicated and expensive antenna beamforming techniques to achieve the same objective. Secondly, LiFiattocell networks can be implemented by modifying existing lighting systems. Any LiFiattocell network can provide extra wireless capacity without interference to RF networks that may already exist. LiFiattocell networks, therefore, have the potential to augment 5G cellular systems in a cost-effective manner.

A unique feature of LiFi is that it combines illumination and data communication by using the same device to transmit data and to provide lighting. Fig. 4(a) depicts a simple room scenario with two lights. Fig. 4(b) shows the resulting illuminance at desk level of 0.75 m. In the particular example, the lights are placed such that within the plane at desk height, 90% of the area achieves an illuminance of 400 lx based on a given illumination requirement. Fig. 4(c) depicts the resulting signal-to-interference-plus-noise ratio (SINR). The region where the light cones overlap is subject to strong CCI, and the SINR drops significantly. It is interesting to note that the SINR can vary by about 30 dB within a few centimeters. This example also highlights that the peak SINR can be in region of 50 dB which is two to three orders of magnitude higher than the peak SINR in RF based wireless systems. The achievable data rate strongly depends on the location of the receiver and also on the field of view (FoV) of the receiver.

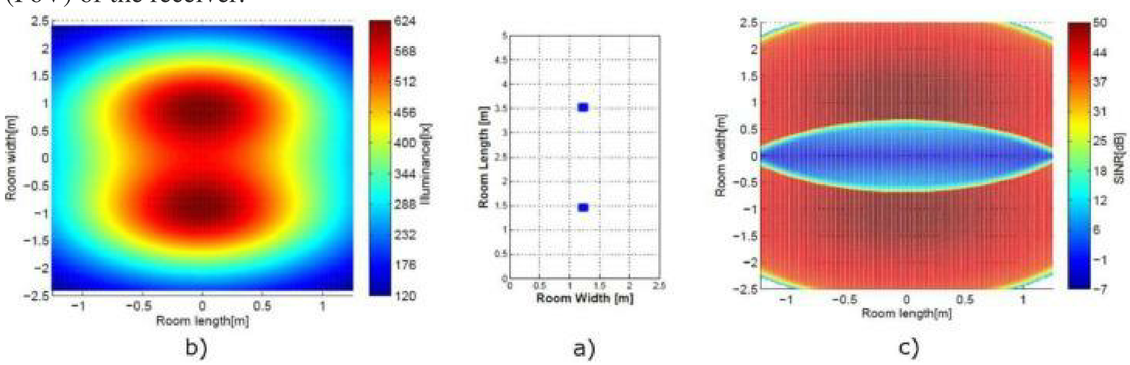

Figure 4: A room of size 2.5 m × 5 m is equipped with two LiFi luminaires installed at 3 m height pointing vertically downwards. The LiFi luminaires are illustrated by two blue squares in subplot (a). Both luminaires use the same visible light spectrum to transmit independent information. Vertically upwards pointing receivers at 0.75 m desk height are assumed. The illuminance at desk height is illustrated in subplot (b). The resulting SINR assuming a receiver FoV of 45° is depicted in subplot (c). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Interference mitigation techniques are required to ensure that within the region of strong CCI, a mobile station can also achieve high SINR, and this is a non-trivial problem which involves signal processing such as successive interference cancellation.

4. Design architecture overview

The proposed architecture is grouped into three different layers: public cloud, private cloud, and infrastructure layers. The public cloud layer is traditional cloud computing, which is used to provide long-term pattern recognition, massive data analysis, large-scale event detection, and so on. Here, the local cloud node is considered a private cloud in the private cloud layer that is deployed at the edge of the network; and the infrastructure layer is the physical layer which consists of data producers and consumers. In this model, we propose to use the Li-Fi communication medium to communicate between IoT devices and local cloud nodes. As the speed of Li-Fi is much faster than the RF communication medium, the traditional cloud cannot provide the service at a high speed. Even though there is a high-speed communication medium at the edge of the network, it will remain useless until and unless our server provides high-speed services. To meet this challenge, this paper introduces the concept of the local cloud in the model architecture. Every organization will have its own local cloud, i.e. a private cloud, to provide the necessary services, and the local cloud will be connected to the public cloud via the internet.

5. Case Study of the Proposed Model and Discussion

Smart Transportation System

To reduce congestion and increase the efficiency of urban transport systems, a smart city must facilitate intelligent transport optimization solutions. A report by the Center for Economics and Business Research predicts that in the UK economy the total cumulative cost of congestion is estimated to reach £307 billion by 2030; and over a similar period, the annual cost of congestion anticipated would rise by 63% to £21.4 billion. This increase is largely attributable to increased demand for road travel due to population growth and higher per capita GDP, as the British economy continues to strengthen. Due to the search for parking places by drivers, 30% of traffic congestion is caused in urban areas, resulting in the release of incalculable carbon dioxide emissions in city environments. In addition, poorly managed parking has reduced the number of visitors to urban centers, resulting in lower revenues for local businesses.

These problems could be addressed by installing sensors and cameras at LED traffic lights and street lamps and by using the proposed architecture to provide connectivity, make decisions, and provide real-time optimization solutions.

Smart Parking (Case 1)

Figure 5 illustrates the use case of smart parking using the proposed model. Using the proposed model, it is possible to provide information on the provision of parking, rates, and regulations etc. to drivers in real time via the Li-Fi communication medium between the street lamp and the smart car. Users can also be provided with information about non-parking areas, maps, loading areas, overtaking areas, and payment. This will result in lower fuel costs, less congestion, and less time spent looking for parking spaces in urban areas.

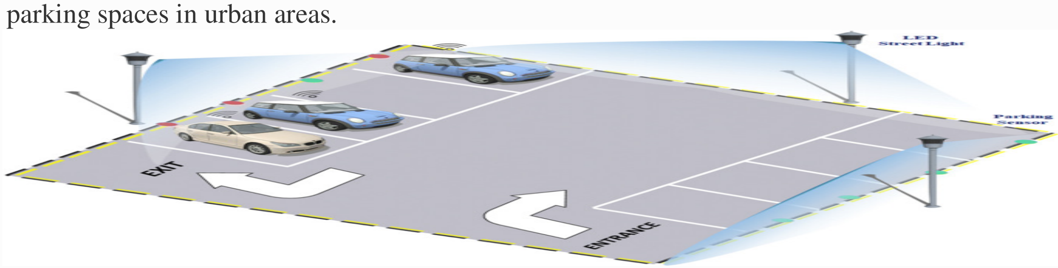

Figure5 : Use-case of smart parking using proposed model

Smart Traffic Lght (Case 2)

Using the proposed model, traffic optimization solutions can be provided by installing sensors and cameras at LED traffic lights. Figure 6 illustrates a case of smart traffic light scenario use cases. Using the proposed model, smart traffic lights can collect information in real time via installed cameras and sensors, analyze the data, and help users to make real-time decisions. It can provide live traffic conditions and optimal route suggestions to drivers using the digital signage system to avoid congested areas. It can also use the collected data to analyze and make future transport planning decisions. This will not only reduce congestion, pollution, fuel costs, and travel times but will also increase traffic visibility and improve road safety.

Figure6: Use-case of smart traffic light using proposed model

To compare the proposed model with other approaches, a qualitative analysis of the proposed architecture was conducted using state-of-the-art approaches. Parametric qualitative performance metrics include scalability, distributed, flexibility, programmability and easy configurability of the network, and a secure high speed network service to meet the requirements of the future sustainable IoT network.

Market Disruption Potential

LiFi is a disruptive technology that is poised to impact many industries. LiFi is a fundamental 5G technology. It can unlock the IoT, drive Industry 4.0 applications, light-as-a-service (LaaS) in the lighting industry, enable new intelligent transport systems, enhance road safety when there are more and more driverless cars, create new cyber secure wireless networks, enable new ways of health monitoring of aging societies, offer new solutions to close the digital divide, and enable very high-speed wireless connectivity in future datacenters. LiFi will have a catalytic effect for the merger of two major industries: i) the wireless communications industry and ii) the lighting industry. In 25 years from now, we argue that the LED light bulb will serve thousands of applications and will be an integral part of the emerging smart cities, smart homes and the IoT. LaaS will be a dominating theme in the lighting industry, which will drive the required new business models when LED lamps last 20 years or more. LaaS in combination with LiFi will, therefore, provide a business model driven 'pull' for the lighting industry to enter what has traditionally been a wireless communications market. In the wireless industry, LiFi has the potential to create a paradigm shift by moving from cm-wave communication to nm-wave communication – see Fig.7. It is, therefore, conceivable that the wireless industry and the lighting industry will merge into one. An important prerequisite for the large-scale adoption of LiFi technology is the availability of standards. In this context, efforts have started in IEEE 802.15.7, IEEE 802.11 as well as ITU-R to standardize LiFi technology.

Cellular Generations	Paradigm Shifts	Service pull	Impact
1G → 2G	Analogue to digital	Mobile telephony	Revolution
2G → 3G	Small cell concept	Mobile Internet	Evolution
3G → 4G			
4G → 5G	*RF to Light*	*LaaS, IoT and MTC*	*Revolution*

Figure 7: The transition from cm-wave to mm-wave is already happening in 5G. LiFi will take this paradigm shift to a radically new level.

6. Conclusion

In this paper we have shown that there has been a clear trend in wireless communications to use ever higher frequencies. This is a consequence of the limited availability of RF spectrum in the lower frequency bands of an exponential growth in wireless data traffic that we have been witnessing at the same time during the last decade. This growth will continue. It is, therefore, inevitable that other spectrum than the RF spectrum must be used for future wireless communication systems. We, therefore, forecast a paradigm shift in wireless communications when moving from mm-wave communication to nm-wave communication which consequently involves light – i.e., LiFi. There has been significant research in physical layer technologies for LiFi during the past 15 years and data rates have increased from a few Mbps in around 2002 to 8 Gbps from a single LED in 2016. In the last five years there has been increasing research in LiFi networking techniques such as multi user access, interference mitigation and mobility support, and in parallel LiFi products have entered the market which have enabled wireless networking with light. Therefore, LiFi has become a reality and this technology is here to stay for a long time.

The integration of the IoT and cloud computing represents a new IT paradigm of next generation cloud computing in a sustainable IoT network. This integration will open up new and exciting solutions and a direction for organization and academic research. This study proposed a layered hybrid cloud computing architecture for a human-centric IoT network. IT used a Li-Fi communication scheme to reduce bandwidth costs and latency delay.

In future work, we will extend our proposed model and introduce an energy harvesting technique to build green cloud computing for the future internet.

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