Communicating through visible light: internet of things perspective

'A sensitive plant in a garden grew, And the young winds fed it with silver dew, And it opened its fan-like leaves to the light, And closed them beneath the kisses of night.'

–Percy Bysshe Shelley,
The Sensitive Plant, 1820.

Truly said as the poet has embarked on the existence of the light around us from the beginning of origin to the uncertain but grand ending; light is present in every aspect of life be it human, plant, animal, solar system or intergalactic region. Technically light is an electromagnetic radiation within a certain portion of the available electromagnetic spectrum. The word 'visible' refers to the portion of wavelengths which is visible to the human eye and is responsible for the sense of sight[1]. Visible light is positioned between the infrared and the ultraviolet having wavelengths in the 400–700 nm range, i.e. frequency range 430–750 THz. Although the Sun is the ordinary and natural source of visible light, researchers have been able to develop its digital alterative such as light emitting diode (LED). This is a semiconductor device capable of very fast switching between ON (1) and OFF (0) states, and which emits energy in the form of visible light when a suitable voltage is applied to the leads resulting in electron–hole recombination.

How did it start? Visible light has been used as the medium of wireless photonic communication since the 1880s, when Alexander Graham Bell invented the 'photophone' that transmitted speech on modulated sunlight over several hundred metres. Due to inappropriateness in related technology, visible light communication (VLC) has been ignored for more than a century, but has recently begun in 2003 at Nakagawa Laboratory, Keio University, Japan. Multiple LEDs have been used to transmit digital data through visible light. Since then, there have been numerous research activities focused on VLC, notably in 2006, when researchers proposed a technique to combine power line communication (PLC) and white-light LED to provide broadband access for indoor applications[2]. This research has shown the huge capability of VLC that may be used as the ultimate communication technology in the near future. Gradually, in 2010, researchers from Heinrich Hertz Institute, Berlin, Germany have demonstrated successful transmission of data at 500 Mbit/s with a white LED over a distance of 5 m (16 ft)[3]. IEEE Wireless Personal Area Networks (WPAN) Working Group[4] has recently standardized VLC as 802.15.7. In 2011, Herald Haas (University of Edinburgh, UK) has demonstrated high-definition video transmission from a standard LED lamp following a novel technology, Li-Fi (light fidelity). Recently, VLC-based indoor positioning system has been deployed that could unlock the US$ 5 billion 'indoor location market' in the coming years[5]. Giustiniano *et al.*[6] have recently implemented a cost-efficient and low-complexity toy system which requires one LED as an optical front-end. Variants of LED such as organic (OLED) and RGB LED have been used as optical transceivers to build up VLC communication links ranging between 10 and 300 Mbit/s up to a distance of 25 feet (ref. 7). In May 2015, Philips used VLC to deliver location-aware services to shoppers' smart phones in a hypermarket in France[8]. Lack of test bed has always restricted the scientific community to carry out in-depth VLC-based research. An open source VLC platform has been recently demonstrated in the Summer Topical Meeting Series held in Spain[9]; the source code and design blueprints are available at http://www.openvlc.org. VLC-based systems can be used in hospitals, traffic control, elderly-care homes, warehouses, retail shops, open offices and defence.

Now the important question is how this technology can be leveraged into connecting everything around us? Literally, 'thing' can be termed as any physical and environmental parameter that we can feel or whose behaviour can be comprehended; starting from pen, paper, pencil, to car, mobile phones, to our living room. If we consider digital equipment, including smart phones and other sensor-enabled gadgets, their number is going to increase up to 4.9 billion by 2020 (ref. 10), when every citizen around the globe would use gadgets to get connected to the internet. We know that the internet is a collective framework of various topological networks such as LAN, MAN, WAN, etc. The objective of this note is to conceptualize the fact of obvious conglomeration of things to the internet, which is known as 'internet of things', or 'IoT' in short. Now that we have got IoT[11–24] and VLC together, it further motivates us to get associated with each and every object in our periphery in a seamless and eco-friendly manner. Despite tremendous usage of current radio spectrum (ranging from 1 Hz to 3 THz) in every aspects of human livelihood, VLC seems to be the right alternative, due to its fundamental characteristics like capacity, efficiency, availability and security. In a public talk, Haas has mentioned the reasons in a lucid manner[14]. Let us have a quick discussion of these. Capacity – the way we transmit wireless data is by using electromagnetic waves, in particular radio waves; and radio waves are limited, scarce, expensive and we only have a certain range of them. Due to these limitations, we are unable to cope with the demand of wireless data transmissions and the number of bytes and data which are transmitted every month; we are simply running out of spectrum. With regard to efficiency, around 1.4 million radio base stations are installed in the world that consume huge amount of energy not just for transmitting data, but to also get cooled. The efficiency of such a base station is just 5%. The next issue is availability. For instance, while travelling on airplanes, in hospitals, or any other remote or restricted locations (e.g. public talks) where we are compelled to switch off our digital devices (mobile phones), there is lack of coherence with communication media. Lastly, security – where any person can intercept our radio data by decrypting them as radio waves that can travel through the wall or any barrier. For instance, a person sitting in a closed room sending some message from his mobile phone can be easily intercepted by an intruder, if he knows the decoding pattern of the wave. All these factors are gradually facilitating the usage of VLC for communication, especially in wireless mode. The next question is why is VLC better than radio waves? The answers are as follow. Light has the maximum known speed and hence it can carry almost infinite amount of information throughout the communication channel. Visible light is safe to use; there is no need of licensing due to its availability everywhere, and it is secure to use as the person who is transmitting information using VLC can switch-off for a while so that an hacker cannot pass through it.

How should a VLC system be designed? According to Harbers *et al.* the building blocks of a VLC system may be framed by: (i) LED-based light source; (ii) constant voltage supply using an integrated DC–DC LED driver with dimming capability, and (iii) integrated thermal and electrical sensors[25]. Due to its proficiency in low-range communication, the system can also use bluetooth low energy (BTLE) module for hyper local connectivity. Figure 1 demonstrates the structural design of VLC system that can be formulated as the core component of communication in IoT domain. Internal heat sink holds the overall skeletal structure comprising antenna for wireless communication, LED driver board and sensor board. Microcontroller controls the whole process, while the system is powered by a steady DC power source.

The VLC incorporated IoT, in its simplest form can be defined as the integration of physical assets with sensors, control networks and intelligent software, where VLC modules is ready to get deployed in all layers of connectivity attached with the physical devices.

What kinds of managerial and business values could be obtained from VLC-IoT? When VLC is allowed to get merged with the concept of IoT, the underlying business values that originate from the system could be visualized as data analytics, remote access, distributed management, collaboration, high speed, exact accuracy of intelligence, capture and transfer of knowledge.

The question now is how can VLC communicate in a network? In a demonstration[9] held in 2015, an Open VLC system has been disseminated where physical and data link layer of network stack are built into the VLC Linux driver. The system is based on BeagleBone Black (BBB)[26], a cost-effective, user-friendly single board computer. The protocol stack is shown in Figure 2, where an LED is connected at the VLC physical layer, and transceives from and to the upper and lower layers as an example. The open approach allows contributors coming from different fields such as localization, optical, networking and wearable computing communities, while helping them with the valuable experiences of their specific domains to build a general-purpose platform for research.

How can VLC be associated with IoT? Figure 3 illustrates the conceptual framework where VLC modules are attached with *n* number of 'things'. Things such as physical and sensory elements fetch data from environmental events and process through LED-enabled VLC modules. The VLC modules are placed in the vicinity of the master node-gateway which is responsible for further transmission of information towards the available network facilities that may be equipped with VLC and related facilities. The information is then forwarded to the cloud servers through internet, where the fetched information is permanently stored. A multitude of applications such as real-time monitoring of environment, cattle-gazing imagery, traffic video, watering plants in fields, etc. are leveraged from the underlying infrastructure. Here, we can find the complete representation of VLC modules to interact with the existing network using the internet, resulting in the actual implementation of IoT.

What research problems in VLC-based IoT need to be solved? Giustiniano *et al.*[9] have appropriately mentioned three major research challenges in this regard: (i) Physical layer design: where few advancements are required that should include matched filtering, time-error recovery, and efficient modulations techniques. High performance signal sampling and association with multiple input multiple output (MIMO) methodologies

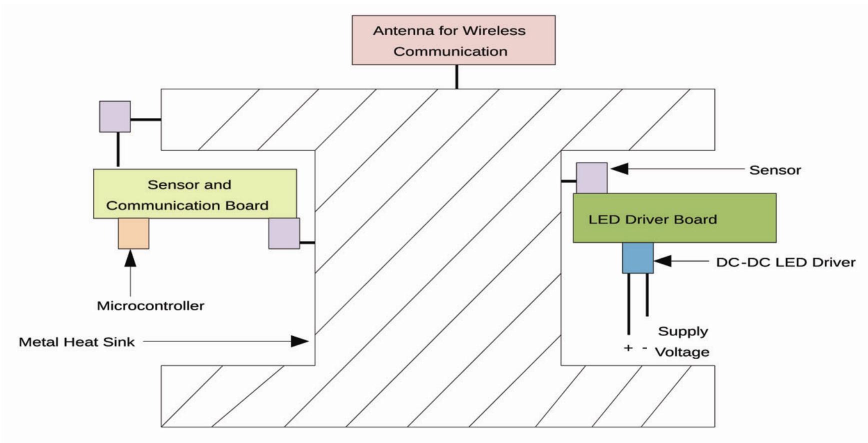

Figure 1. Visible light communication module.

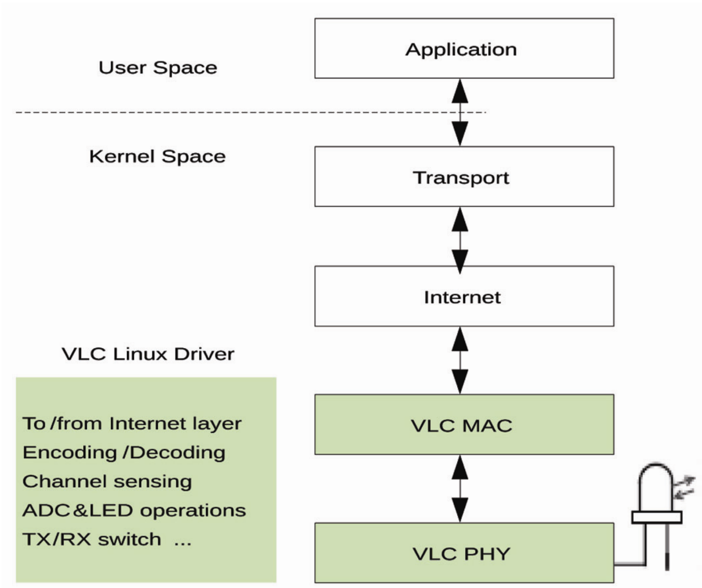

Figure 2. Communication stack of VLC in an embedded Linux operating system.

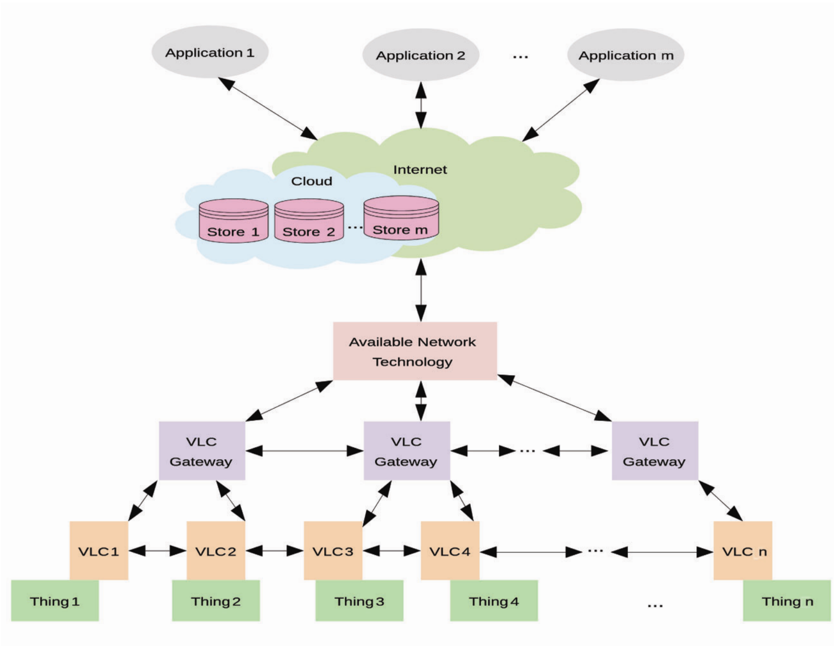

Figure 3. Internet of things (IoT)-enabled VLC framework.

may resolve the present physical restrictions. (ii) Integration of VLC with radio frequencies: this direction of research would provide backward compatibility with concurrent embedded systems, thus creating a collaboration with IoT. Binding of blind-spot visible light and radio communication will give flexibility of the embedded boards so as to allow plug-in supported integration of sensors resulting in transmission through radio-based internet and/or via high-power LED to end-users in the environment. (iii) Implementing VLC in IoT user space: implementation of physical and media access control layers in different communication protocols (e.g. ZigBee, Wi-Fi, etc.) would streamline the testing and deployment issues related to modifications of existing and new protocols using available software packages (e.g. Matlab, LabView) to furnish efficient IoT user space.

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