LiFi: Conceptions, Misconceptions and Opportunities

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Abstract *In this talk we will first explain what Light-Fidelity (LiFi) is and highlight the key differences to visible light communication (VLC). We will discuss misconceptions and illustrate the potential impact this technology can have across a number of existing and emerging industries.*

LiFi Conceptions

It is forecast that by 2020, we will generate 44 zettabytes of data. This amounts to nearly as many bits on the planet as stars in the universe. A vast amount of this data will be generated by machines. In this context, it is forecast that by 2020, there will be 80 billion Internet-of-Things (IoT) devices. Take a wind turbine for example. A wind turbine currently already creates 10 terabytes of data per day. A lot of this digital data is transmitted from a source to a receiver across large distances, and this end-to-end communication very often involves a wireless link. In the past, resources to achieve wireless connectivity have been taken from the radio frequency (RF) spectrum. These are the electromagnetic frequencies of up to 300 GHz. The generally accepted exponential increase in data volumes during the next decade will make it increasingly difficult to provide enough RF resources. At this point it is helpful to recognize that the electromagnetic spectrum is much larger. There are 300 THz (1000 times the 300 GHz RF spectrum!) unused bandwidth available at higher frequencies in the visible light spectrum. These resources can be used for data communication which has been successfully demonstrated for decades in fibre optic communication using coherent light communication links enabled by lasers.

With the advent of the high brightness light emitting diode (LED), which produces incoherent light, it is logical to consider the light spectrum for pervasive wireless communication which can be achieved with LiFi, a technology first coined in[2]. LiFi extends the concept of visible light communication (VLC) to achieve high speed, secure, bi-directional and fully networked wireless communications[3], and this is illustrated in Fig. 1. It is important to note that LiFi supports user mobility and multiuser access. The key advantages of a LiFi wireless networking layer are: i) three orders of magnitude enhanced data densities; ii) unique properties to enhance physical layer security; iii) three order of magnitude improvements in energy efficiency; iv) use in intrinsically safe environments such as petrochemical plants and oil platforms where RF is often banned; v) with the

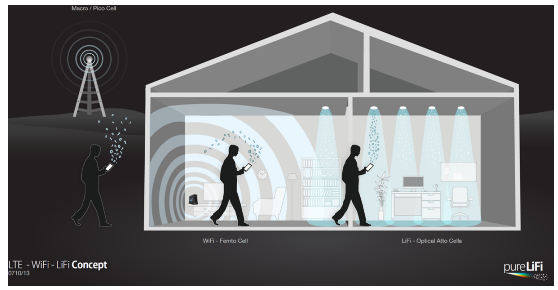

Fig. 1: LiFi is an additional wireless networking layer complementing existing heterogeneous RF networking technologies such as Long Term Evolution (LTE), and Wireless-Fidelity (WiFi). In LiFi every LED light source acts as an access point (AP) for bi-directional networked wireless multiuser communication indoors, but also outdoors. The high density of light sources is exploited to achieve orders of magnitude improvements in data density. Since light does not propagate through opaque walls and objects, physical layer security is enhanced massively. (Photo courtesy of pureLiFi).

advent of power over ethernet (PoE) and its use in lighting, there exists the opportunity to piggyback on existing data network infrastructures for the required backhaul connections between the light sources with its integrated LiFi modem and the Internet.

LiFi Misconceptions

Misconceptions about LiFi can be addressed as follows:

"LiFi is a line-of-sight (LoS) technology" This perhaps is the greatest misconception. By using an orthogonal frequency division multiplexing (OFDM)-type intensity modulation (IM)/direct detection (DD) modulation scheme[1], the data rate scales with the achieved signal-to-noise ratio (SNR)[4]. In a typical office room environment where the minimum level of illumination for reading purposes is 500 lux, the SNR at table height is between 40 dB and 60 dB. This means higher order digital modulation schemes can be used in conjunction with OFDM to harness the available channel capacity. By using adaptive modulation and coding (AMC) it is possible to transmit data at SNRs as low as -6 dB. This means signal blockages between 46 dB - 66 dB can be tolerated. Fig. 2 illustrates a video transmission to the laptop in the foreground over a distance of about 3 m

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Fig. 2: LiFi video transmission in a strictly non-line-of-sight (NLoS) scenario. A LiFi AP in the background directly connects to an off-the-shelf LED light fixture. The LED lamp streams a video to a LiFi modem in the foreground which is connected via a universal serial bus (USB) connection to the laptop positioned at the front.

where the LED light fixture is pointing towards a white wall in the opposite direction to the location of the receiver. Therefore, there is no direct LoS component reaching the receiver in the foreground, but the video is successfully received.

"LiFi does not work in sunlight conditions" Sunlight constitutes a constant interfering signal outside the bandwidth used for data modulation. LiFi operates at frequencies typically greater than 1 MHz. Therefore, the constant sunlight is simply filtered out, and has no impact on the bit error ratio (BER) performance as long as the receiver is not saturated. This has been shown in experimental studies with commercial LiFi equipment from pureLiFi. Saturation can be avoided by using automatic gain control algorithms. So on the contrary, we assert that sunlight is hugely beneficial as it enables solar cell based LiFi receivers where the solar cell acts as data receiver device, and at the same time harvests sunlight as energy[6].

"Lights cannot be dimmed" There are advanced modulation techniques such as enhanced unipolar OFDM (eU-OFDM)[5] which enable the operation of LiFi close to the turn-on voltage (ToV) of the LED which means that the lights can be operated at very low light output levels while maintaining high data rates.

"The lights flicker" The lowest frequency at which the lights are modulated is in the region of 1 MHz. The refresh rate of computer screens is about 100 Hz. This means the 'flicker-rate' of a LiFi light bulb is 10,000 higher than that of a computer screen. This means there is no perceived flicker.

"LiFi is for downlink only" A key advantage is that LiFi can be combined with LED illumination. This, however, does not mean that both functionalities always have to be used together. Both functions can easily be separated (please see the comment on dimming). As a result, LiFi can also be used very effectively for uplink communication where lighting is not required. The infrared spectrum, therefore, lends itself perfectly for the uplink. We have conducted an experiment where we sent data at a speed of 1.1 Gbps over a distance of 10 m with an LED of merely 4.5 mW optical output power.

LiFi Opportunities

LiFi is a disruptive technology that is poised to impact a large number of industries. LiFi can unlock the IoT, drive Industry 4.0 applications, enable light as a service (LaaS) in the lighting industry, contribute to the $5^{\rm th}$ generation of cellular systems (5G) and beyond, 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, and offer new solutions to close the digital divide.

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 the LED lightbulb will serve thousands of applications and will be an integral part of the emerging smart cities, smart homes and the IoT, and LaaS will be a dominating theme in the lighting industry which will drive the required new business models when LED lamps last 20 and more years. 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.

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