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Light Fidelity: Wireless Communication using Light

LiFi is a form of wireless communications that uses the spectrum of visible light instead of the conventional spectrum of radio frequencies (RF). The huge amount of visible light spectrum allows LiFi systems to ensure high-data-rate communication links, complement short-range RF transmission, and potentially alleviate the RF spectrum congestion. In addition, the visible light spectrum is unregulated and does not require licenses. It has to be ensured, however, that LiFi systems do not present any health hazards and that they are properly installed so as not to create any electromagnetic interference. In this article, we give an overview of the LiFi technology, discuss its benefits and challenges, and summarize research and standardization activities in the field, including commercially available products.

Ivica Stevanovic, Licences and Frequency Management

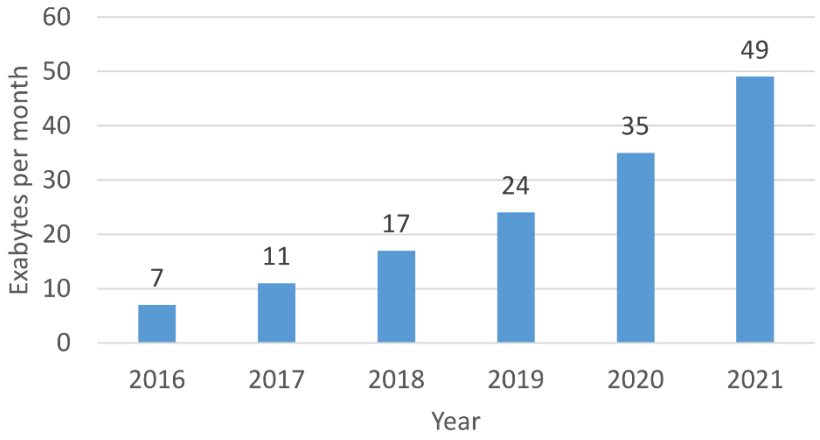
The term LiFi denotes «light fidelity» and it is a form of bidirectional, networked, mobile, and high-speed wireless communications closely equivalent to Wireless Fidelity (WiFi). Unlike WiFi, the LiFi technology uses visible light spectrum instead of the increasingly congested radio frequency (RF) spectrum. Similarly to WiFi, this technology allows connection of different web-enabled devices such as computers, printers, smart TVs, smart phones, etc. to internet; provides the inter-connection of WiFi enabled things such as refrigerators, watches, cameras, etc. in Internet of Things (IoT); and makes off-loading from cellular networks possible, addressing this way capacity needs for mobile broadband connections.

LiFi works in complement with existing and emerging wireless systems (source: pureLiFi).

The Reasons behind LiFi

According to Cisco predictions, global mobile data traffic is expected to grow to 49 Exabytes (1 million Terabytes) per month by 2021, which amounts to a sevenfold increase over 2016. The demand for

broadband wireless data access is constantly increasing and the radio frequency spectrum, that is limited and for the most part licensed, is becoming progressively more congested. Potential bandwidth of visible light (400 THz to 780 THz) is thousand times wider than the conventional RF and microwave bandwidth (3 kHz to 300 GHz). A huge amount of unregulated spectrum is available to complement short-range wireless transmission and potentially alleviate the RF spectrum congestion.



Mobile data traffic predictions until 2021 (source: Cisco).

How Does LiFi Function?

A typical LiFi system consists of a light source (transmitter) and a light detector (receiver). On the transmitter side, information data (streaming content) is introduced to the light source by changing its intensity (modulation) in a way that cannot be perceived by human eye. On the receiver side, the light detector detects these tiny changes in the light amplitude and extracts them into an electrical signal (demodulation) to recover the transmitted data to a user's PC or mobile device.

For most indoor applications, light emitting diodes (LEDs) are the favored light sources due to their low cost and energy efficiency. They are replacing incandescent bulbs as the primary source of illumination in residential and public environments and by as early as 2018, the majority of new energy efficient lighting installations are expected to be LED-based. For higher speeds or longer distances, laser diodes appear to be a better choice.

Benefits and Advantages of LiFi

Recently, communication by visible light has been gaining popularity as a complement to RF communications due to the following advantageous features:

- **Spatial Reuse**: Since visible light does not penetrate through building walls and can be directed to the desired working area, LiFi can exhibit a higher degree of spatial reuse of the spectrum than it is the case with RF communications.
- **Security:** With the confinement property of visible light, there are well-defined coverage zones that enhance communication security by preventing eavesdropping from outside of a room or building.
- **Electromagnetic Interference (EMI):** Visible light intrinsically does not create EMI, which allows its safe use in airplanes and hospitals, and especially in hazardous industrial zones, such as power/nuclear generation or oil and gas drilling. However, LED luminaires need to be correctly installed so as not to produce any EMI, as shown by recent measurements from EBU.
- **Safety:** There are in principle no health hazards of visible light. Some studies have shown health concerns relating to flicker that may induce biological human response (photosensitive epilepsy). In addition, glare of certain blue-rich LED designs is thought to have psychological effects such as disrupting people's sleep patterns and harming nocturnal animals.

- **Complexity:** Because LiFi is a non-coherent mode of communication, the front-end components of both transmitter and receiver are relatively simple and inexpensive devices.
- **Existing Infrastructure:** LiFi can be implemented into the existing lighting infrastructure with the addition of a few relatively simple and low-cost front-end components.
- **Energy Efficiency:** LiFi is combined with LED illumination. Since LEDs are energy efficient and highly controllable light sources, LiFi belongs to an eco-friendly green communication technology.

Challenges and Limitations of LiFi

Despite having inherent advantages compared to RF communication systems, LiFi still faces numerous challenges and limitations. A non-exhaustive list of these shortcomings is given in what follows.

- **Coverage and Shadowing:** Visible light sources have a limited transmission range and they require direct line-of-sight between the transmitter and the receiver to achieve high data rates. With an object or human blocking the line-of-sight, the received optical power degrades resulting in severe data rate reductions and even a loss of signal.
- **Uplink:** LiFi with illumination has predominantly broadcast characteristics and is inherently suitable for downlink. A visible light uplink would be inefficient for portable devices, which run on low power. To address this challenge, other types of communication have been proposed and used (infrared or RF).
- **Light Interference:** Other artificial and natural light sources create interference, increase the noise levels at the photo detector, and may even cause the receiver saturation.
- **Lights-off Mode:** LiFi applications based on LED lighting are more attractive in environments where the lights are always switched on (in industrial setting, public transport, or medical areas). Some low data-rate transmission can be achieved with LEDs emitting only a small amount of light so that human eyes perceive it as the lights being switched off.
- **Backhaul Integration:** LEDs need to be connected to internet and their deployment is very dense. The cost of implementing wired infrastructure (such as Ethernet, fiber, etc.) to each LED can, therefore, be very high.
- **Commercialization:** Two different industries need to work together: the lighting manufacturers, who need to make appropriate modifications to their lamp and fixture designs, and the mobile device manufacturers, who need to install high-speed photodiode transceivers in their devices.

Data Rates of LiFi

The LiFi technology has a potential of providing a high-data-rate connection to internet. Additionally, it can also support low data-rate device-to-device communication links. One of the highest data rates is achieved by the University of Oxford, UK, whose researchers setup bidirectional links with 224 Gbps operating over distances of 3 m using high-end technology in laboratory conditions. One movie file in HD quality is about 1.5 GB large. Several of those movies could be downloaded using LiFi within one second.

Researchers from Fraunhofer Heinrich Hertz Institute in Berlin, Germany, have recently demonstrated a prototype entirely based on commercially available low-cost hardware, reaching bidirectional links with 200 Mbps at a working distance of 2 m between the ceiling and the desktop. On the other hand, Disney Research in Zürich has demonstrated a device-to-device communication system called En-Lighting, which uses LED light bulbs enhanced with photo diodes and microcontrollers to support low-data-rate (up to 600 bps) communication for Internet of Things.

There are also many prototypes and some products already available on the market ensuring relatively good data rates for internet connection. One example is Orès LiFi, a fully industrialized LiFi system that enables a complete wireless network with bidirectional rates of up to 42 Mbps and a handover functionality that allows users to keep a stable connection as they move from one luminaire to another. The system is being developed and marketed jointly by pureLiFi (a start-up company of Edinburgh University) and Lucibel (a French company that specializes in the design of lighting solutions based on the LED technology).

Standardization Activities

The Institute of Electrical and Electronics Engineers (IEEE) is working on standardization of the LiFi technology by updating the standard IEEE 802.15.7 that accommodates communication via infrared, visible, and near ultraviolet light. The final version of the standard is expected near the end of 2017.

In November 2016, IEEE has also formed a Topic Interest Group (TIG) to start activities of LiFi standardization and its integration within the IEEE wireless LAN standard 802.11.
International Telecommunication Union (ITU) SG15 started studying indoor high-speed visual light communications systems (100 Mbps to 1 Gbps), including general characteristics, wavelength band plan, architecture, interfaces, and protocols. The work is in an early stage.

Additionally, SG1, WP1A of the ITU has started working on a report on spectrum management in visible light communications.

Outlook

According to a new market research report published by Markets and Markets in 2015, LiFi technology is expected to reach a market value of 8.5 Billion USD by 2020. Nowadays, there are several products and many product prototypes, which are in their final stages before appearing on the market. The technology is promising and many major key players are considering it: Microsoft is implementing the Lucibel and pureLiFi's solution at its innovation center in France and NASA recently announced plans to study LiFi's potential use aboard spacecraft to improve safety, comfort, and quality of life for future astronauts.

The LiFi technology uses unregulated spectrum of visible light that does not need licensing. On the other hand, it has to be ensured, that the LiFi systems do not pose any health hazards and that they are correctly installed so that they do not create any EMI. The LiFi technology does offer numerous benefits, however, there are still some important challenges that must be overcome before it becomes a ubiquitous part of everyday wireless communications.