CABA™ Continental Automated Buildings Association

What is Li-Fi?

The Evolution of Integrating Li-Fi Technology into Smart Lighting and Control Systems for the Intelligent Building

A CABA WHITE PAPER

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CABA Connected Home Council

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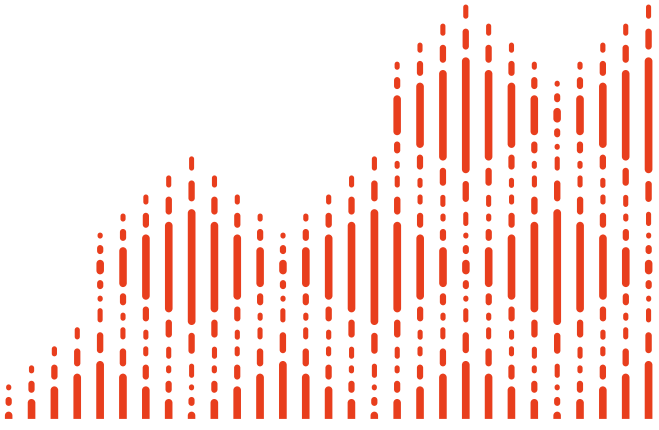

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What is Li-Fi? The Evolution of Integrating Li-Fi Technology into Smart Lighting and Control Systems for the Intelligent Building

A CABA White Paper

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ABOUT CABA

The Continental Automated Buildings Association (CABA) is an international not-for-profit industry association, founded in 1988, and dedicated to the advancement of intelligent home and intelligent building technologies. The organization is supported by an international membership of over 360 organizations involved in the design, manufacture, installation and retailing of products relating to “Internet of Things, M2M, home automation and intelligent buildings”. Public organizations, including utilities and government are also members. CABA's mandate includes providing its members with networking and market research opportunities. CABA also encourages the development of industry standards and protocols, and leads cross-industry initiatives. CABA's collaborative research scope evolved and expanded into the CABA Research Program, which is directed by the CABA Board of Directors. The CABA Research Program's scope includes white papers and multi-client market research in both the Intelligent Buildings and Connected Home sectors. www.caba.org

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Established in 2004, the CABA Connected Home Council initiates and reviews projects that relate to connected home and multiple dwelling unit technologies and applications. Connected homes intelligently access wide area network services such as television and radio programming, data and voice communications, life safety and energy management/control information and distribute them throughout the home for convenient use by consumers. The Council also examines industry opportunities that can accelerate the adoption of new technologies, consumer electronics and broadband services within the burgeoning connected home market. www.caba.org/chc

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WHAT IS LI-FI?

Li-Fi (Light Fidelity) is an optical wireless technology that uses both visible and non-visible light rather than radio frequencies to transmit data. Li-Fi technology uses light sources such as LEDs (Light Emitting Diodes), laser LEDs, infrared, and ultraviolet light frequencies in the electromagnetic spectrum (Figure 1).

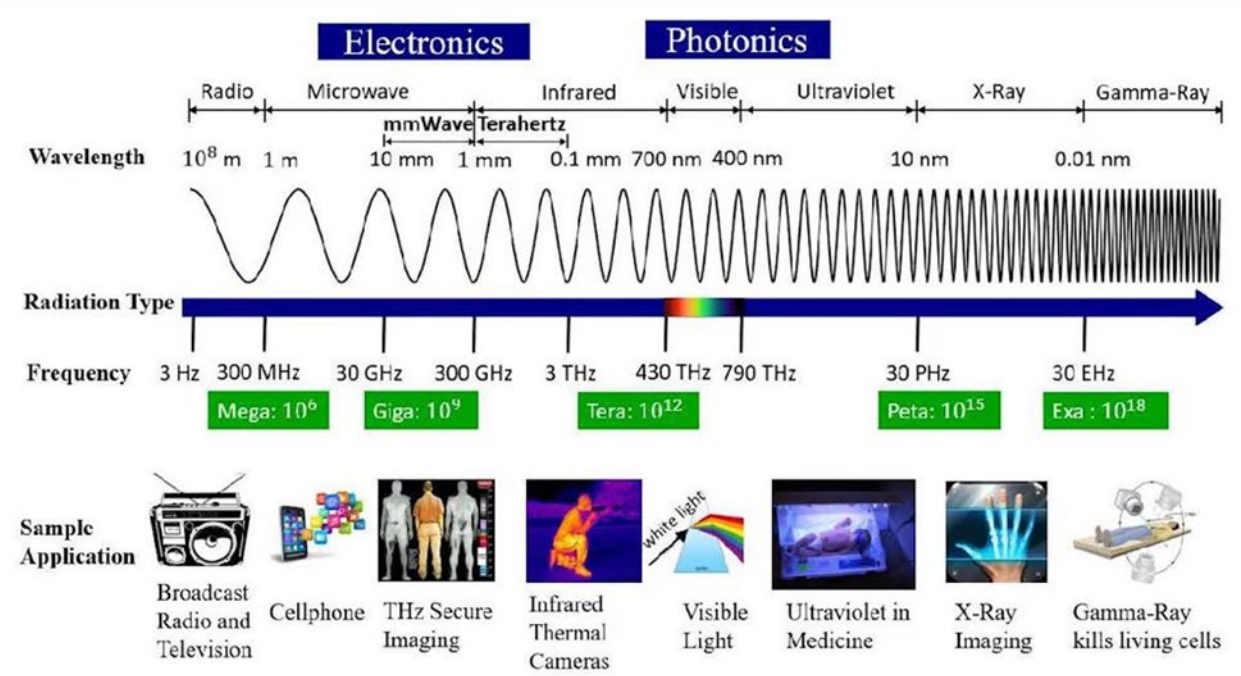

Figure 1 : The Electromagnetic Spectrum

HOW LI-FI WORKS

Li-Fi requires a light source that can be flashed (modulated at a high frequency). This has not been possible with incandescent or fluorescent lamps. The current technology of a LED includes a luminare (a light fixture), which directs and defines the light propagation of the lamp (Figure 2) with a signal-processing light driver technology that modulates lamp light with a message coded in binary (on and off) and illuminates a photo detector. A receiver detects the lamp light, demodulates the binary stream of data, and sends the message to a computer for decoding.

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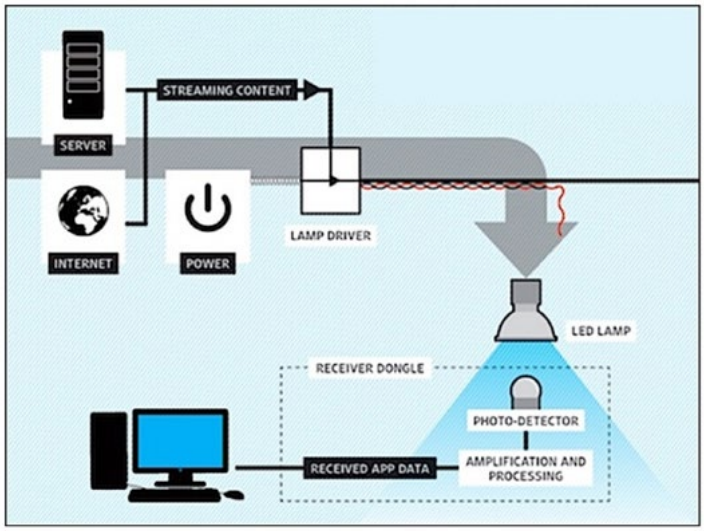
Figure 2 : Li-Fi LED Luminare

This diagram shows the equipment needed: the Li-Fi luminaire (LED light fixture); and the receiver dongle containing a photodetector and demodulator, possibly combined in a USB device suitable for a laptop. In the future, network interface controller (NIC) cards and cell phones could be connected via Li-Fi, alongside Wi-Fi, cellular, near-field communication (NFC), and Bluetooth. To the user, this would make it similar to Wi-Fi connectivity, with the Li-Fi luminaire playing the Wi-Fi access point role.

Luminaires can connect via power lines, coax cabling, phone lines, and optical fiber, allowing for a large variety of network



configurations and applications.

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Figure 3 : Technical Aspects of Li-Fi (credit : pure Li-Fi)

SOURCE: https://cacm.acm.org/news/213948-li-fi-promises-two-way-internet-via-light-waves/fulltext?mobile=false

THE FUNDAMENTAL DIFFERENCE BETWEEN LI-FI AND WI-FI

RF means radio frequency (informally called a "radio wave"). RF is an alternating current that when input to an antenna, causes an electromagnetic field to propagate, which can be used for wireless broadcasting and/or two-way communications.

RF used for communications poses the following challenges:

- The conducted throughput of RF is slowed by the conducting material and the number of connections interposed in the transmission channel.
- An unauthorized person may be able to intercept the RF wireless signals when propagated through the air.
- Additional technology is required to secure the RF wireless network to protect information.
- There is a significant cost to construct an RF infrastructure.
- RF wireless communication performance is affected by physical constructions, climatic conditions, and interference from other wireless devices.

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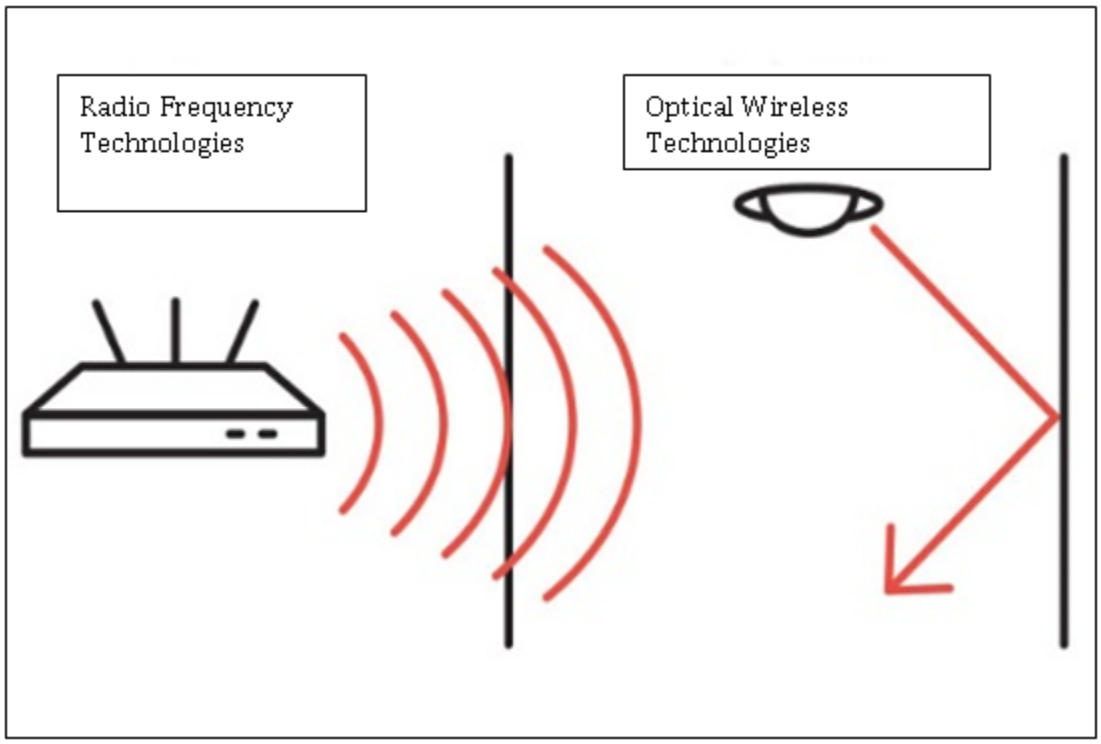

Figure 4 : Spectral Wave Penetration of Signal

This table shows a fundamental difference between radio frequency technologies (RFT) and optical wireless communication technologies (OWT): RFT signals can penetrate various materials, thus enabling broadcast and cellular network communications), while OWT signals stay within the boundaries of physical surroundings that reflect the light, with significant benefit for privacy and security. Li-Fi is complementary to all Wi-Fi technologies.

Comparison of RF Wireless and Optical Wireless Technologies

Feature	Li-Fi	Wi-Fi
Technology	Light Fidelity – also called Optical Wireless Communications	Wireless Fidelity
Means of operation	Li-Fi transmits data using light with the help of a light driver/access point	Wi-Fi transmits data using radio waves with the help of a Wi-Fi access point

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Interference	Does not have any electromagnetic interference (EMI) issues	Will have interference issues from nearby access points
Technology and standards	Present LED, Laser LED, IrDA, and/or Ultraviolet devices	WLAN 802.11a/b/g/n/ac/ad/ax/ay compliant devices
Applications	Li-Fi is typically used to access the internet on portable devices like smartphones, tablets, or laptops, Li-Fi may be used to connect to an access point, which in turn provides Internet access. Li-Fi is an optical wireless connection that connects the Li-Fi enabled device for access to the network	Wi-Fi is typically used to access the internet on portable devices like smartphones, tablets, or laptops, in actuality, Wi-Fi connects to a router for internet access
Advantages/Benefits	Enhanced complementary wireless infrastructures by providing an additional layer of small cells ('attocells' and 'multi-cells') enabling very high peak data rates (10 Gbps) The enabling of the Internet-of-Things (100 times more devices)	Proven technology
Privacy/Security	Li-Fi does not pass through walls	RF signals pass through walls and therefore need additional techniques to achieve secure data transfer
Data transfer speed	<100 Mb/s	<100 Mb/s
Frequency of operation	10,000 times the spectrum of RF	2.4 GHz, 5 GHz, and 60 GHz

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Data density	Works in a highly dense environment	Works in less dense environments due to interference issues
Coverage distance	Varies depending upon Li-Fi standard	Varies upon Wi-Fi standards
System components	LED fixture composed of lamp driver LED bulb (lamp) and photo detector makes up a complete Li-Fi system. Devices or connected stations require Li-Fi hardware installed and/or connected to device for connectivity	Requires wireless access point/router Devices or connected stations require RF hardware installed and/or connected to device for connectivity

FEATURE COMPARISON LI-FI VS WI-FI – https://www.rfwireless-world.com/Terminology/LiFi-vs-WiFi.html

Li-Fi and Wi-Fi IEEE/ ITU Standards and Link Speed

Li-Fi IEEE and ITU Protocol Standards			
802.15.7	**802.15.13**	**802.11bb™**	**ITU-T G.9991**
Visible Light Communication (VLC) refers to short-range optical wireless communication using visible light spectrum from 380 to 780 nm.	Standard for Multi-Gigabit per Second Optical Wireless Communications (OWC).	Standard to define one medium access control (MAC) and several physical layer (PHY) specifications for light-based wireless connectivity for fixed, portable, and moving stations within a local area network	ITU-T G.9991 specifies the system architecture, physical (PHY) layer and data link layer (DLL) for high-speed indoor optical wireless communication transceiver using visible light.

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Speed			
Enabled by recent advances in LED technology, IEEE 802.15.7 supports high-data-rate visible light communication up to 96 Mb/s (Megabits per second) by fast modulation of optical light sources which may be dimmed during their operation.	The standard is capable of delivering data rates up to 10 Gb/s (Gigabits per second) at distances in the range of 200 meters unrestricted line of sight. It is designed for point-to-point and point-to-multipoint communications in both non-coordinated and coordinated topologies.	Uplink/Downlink within a band of 380-5000 nm All PHY modes of operation must achieve a minimum single-link throughput of 10 Mb/s and at least one mode of operation that achieves single-link throughput of at least 5 Gb/s, as measured at the MAC data service access point (SAP), Interoperability among solid state light sources with different modulation bandwidths	224 Gb/s under lab conditions, albeit usually over very short distances (a handful of meters) and across a limited field of view.
Wi-Fi IEEE Protocol Standards			
802.11ac (Wi-Fi 5)	**802.11ad (Wi-Gig)**	**802.11ax (Wi-Fi 6)**	**802.11ay**
Supports up to eight antennas and supports beamforming, which detects the locations of connected devices and increases	802.11ad is a multi-gigabit Wi-Fi technology that allows downloading and sharing 4K videos in seconds as well as sync photo albums and access cloud content in	Wi-Fi 6 also known as “AX Wi-Fi" or "802.11ax Wi-Fi” builds and improves on the current 802.11ac Wi-Fi standard.	Where 802.11ad uses a maximum of 2.16 GHz bandwidth, 802.11ay bonds four of those channels together for a maximum bandwidth of 8.64 GHz. MIMO is

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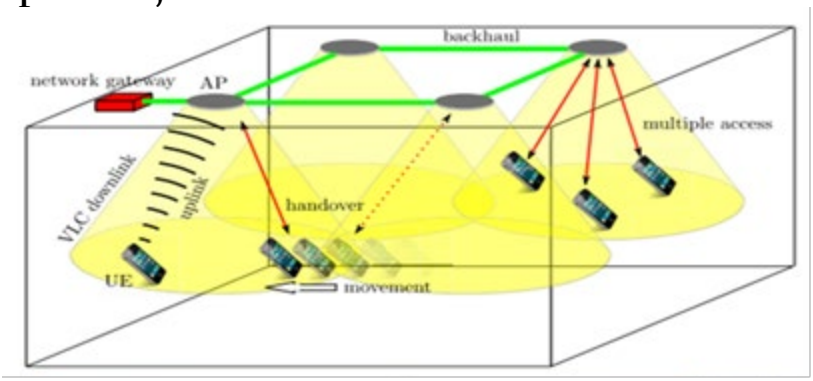
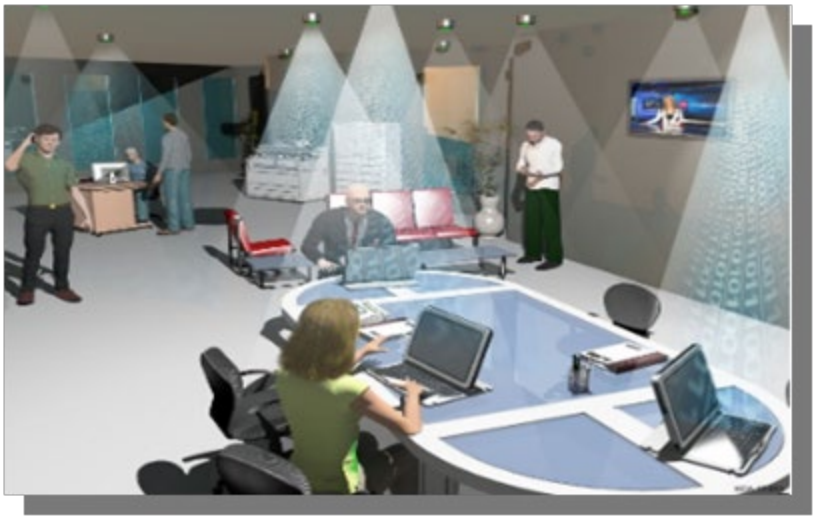
strength to those locations.	near real time. It complements the efficiency of 802.11ac by supporting ultra-high-speed zones.		also added with a maximum of 4 streams. The link-rate per stream is 44Gbit/s, and with four streams this goes up to 176Gbit/s.
Speed			
Theoretically up to 7 Gbps but currently at 1.3 Gbps	Up to 7 Gbps – this throughput can only be achieved when device is within 3.3m of the access point	1 to 10 Gbps at distances of up to 120m	1 to 20 Gbps at distances of up to 100m

As illustrated below, Li-Fi could enable data for laptops, smart phones, and tablets to be transmitted through the LED lighting in





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a room using light emitting diodes pulsing at extremely high speeds, undetectable to the human eye. Security is established through direct light transmission; therefore, no computer outside the amplified light network can access the data or other networked appliances.

Figure 5 : Conceptual Depiction of a Complete Network

A complete Li-Fi network includes downlink, uplink, and backhaul connections. In addition, the system should provide a handover function, mobility support, and multiple access capabilities.

Benefits of Li-Fi

- Efficiency
- Availability
- Security
- EMI is non-existent
- Optical Navigation – Indoor positioning
- Optical Navigation – Free Space Optical
- Safety
- Low latency

Disadvantages of Li-Fi

- Limitations: Li-Fi offers a limited range. While this may prove useful for security, it also creates disadvantages. Physical barriers limit its operational scope. In order to increase its scope, lamps or bulbs must be strategically placed in various rooms. In contrast, single Wi-Fi routers have wider, longer ranges, making them an ideal selection for public networks.
- Interference: Li-Fi signals are susceptible to light interferences, including sunlight. Receivers may have a difficult time to process signals when other sources of light are present. Moreover, because LED lamps must remain on to function, they can further contribute to light pollution, especially if set at higher brightness levels to compensate for possible interference.

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- Infrastructure: Theoretically speaking, deploying Li-Fi systems are inexpensive because they only make use of LED lamps. In reality, the installation of Li-Fi systems can become expensive due to the lack of infrastructure. Additionally, due to its limited range, several Li-Fi routers will need to be installed for greater connectivity. This means incurring additional purchase and installation costs. In contrast, a small home will only require a single Wi-Fi router.

SOURCE : https://lifi.co/

Li-Fi Applications

- Portable devices
- Mobile Backhaul/Fronthaul
- Medical
- Submarines/underwater communications
- Transportation
- Space/planetary applications
- Factory manufacturing cells
- Li-Fi enabled Intelligent Clothing
- Community Centers
- In-Theater Battlefield Secure Communication
- Hospitals
- Schools
- Intelligent Li-Fi Enabled Streetlights
- Intelligent Li-Fi enabled Signage

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- Automotive (see diagram below – V2V, V2I)

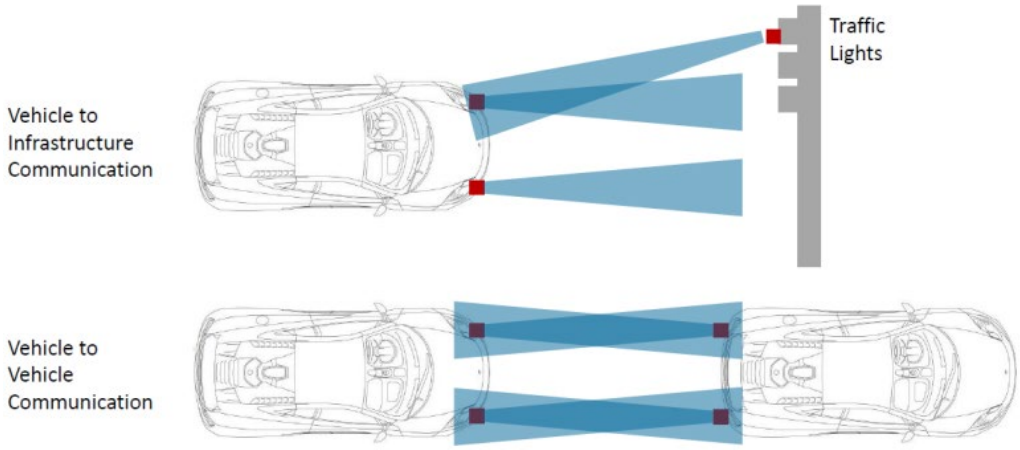

Figure 6 : Li-Fi Automotive Applications

THE MARKET FOR LI-FI

Li-Fi Market size forecast according to a research report by Global Market Insights, Inc. is anticipated to reach USD 75.5 billion by 2023.

Considering the components, light fidelity (Li-Fi) market is mainly divided into LED, Microcontroller, Photodetector. – source: https://gminsights.wordpress.com/2017/04/07/light-fidelity-lifi-market/

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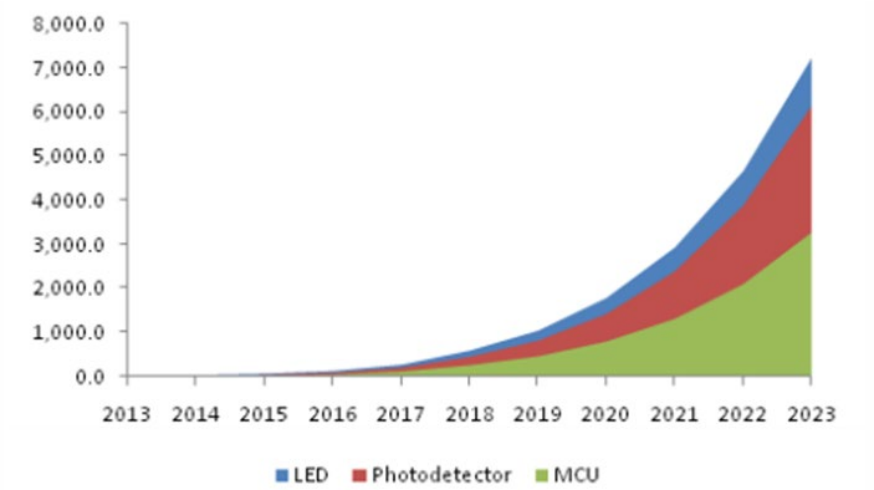

Figure 7 : U.S. Li-Fi Market Size, by Component, 2013-2023 (USD Million)

SUMMARY

Li-Fi is a complementary wireless technology to existing wireless technologies. Over time the expense of manufacturing, implementing, and supporting Li-Fi technologies will become affordable as does any "new" technology that enters the market.

Alexander Graham Bell (who developed the Photophone in 1880) and Dr. Harald Haas (who coined the term Li-Fi in 2011) deserve a high degree of appreciation for their scientific work and invention in bringing the technology of optical wireless communications to the world.

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GLOSSARY

Access Point (AP)
Access Point (AP) is a device, such as a wireless router (either Wi-Fi or Li-Fi), that allows wireless devices to connect to a network. Most access points have built-in routers, while others must be connected to a router in order to provide network access.

Amplitude-shift keying (ASK)
Amplitude-shift keying (ASK) is a form of amplitude modulation that represents digital data as variations in the amplitude of a carrier wave. In an ASK system, the binary symbol 1 is represented by transmitting a fixed-amplitude carrier wave and fixed frequency for a bit duration of T seconds.

Attocell
A cellular Li-Fi network as an attocell network as the cell sizes are smaller than in a typical radio frequency (RF) femtocell network potentially unlocking very high area spectral efficiencies.

Binary
Binary (or base-2) a numeric system that only uses two digits — 0 and 1. Computers operate in binary, meaning they store data and perform calculations using only zeros and ones. ... In fact, any integer can be represented in binary. Below is a list of several decimal (or "base-10") numbers represented in binary. Binary related to Li-Fi and LED: The LED is turned on and off at speeds in Terahertz.

Binary Phase-shift keying (BPSK)
Binary Phase-shift keying (BPSK) is a digital modulation scheme that conveys data by changing, or modulating, two different phases of a reference signal (the carrier wave). The constellation points chosen are usually positioned with uniform angular spacing around a circle.

Li-Fi
Li-Fi (abbreviation for light fidelity) is wireless light-based communication technology that uses light instead of radio waves to deliver data. ... In other words, data is converted to light signals and transmitted by an LED light bulb that sends the data at rapid speeds to the photo-detector.

Li-Fi-multicell
Li-Fi-multicell is the first-ever smart interference orchestrator. It can enhance existing solutions by supporting user's mobility within a network of light sources to ensure optimal data rates among users. It automatically detects all situations of interference and optimizes data transmission rates for each peripheral.

Light Emitting Diode (LED)
Light Emitting Diode (LED) a light-emitting diode (a semiconductor diode which glows when a voltage is applied).

Luminare
Luminare a complete lighting unit consisting of a lamp or lamps together with the parts designed to distribute the light, to position and protect the lamps, and to connect the lamps to the power.

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Microcontroller Unit (MCU)

Microcontroller Unit (MCU) is a small computer on a single metal-oxide semiconductor (MOS) integrated circuit chip. In modern terminology, it is similar to, but less sophisticated than, a system on a chip (SoC); a SoC may include a microcontroller as one of its components.

OCC (Optical Camera Communications)

OCC – Optical camera communications delivers data from light source(s) to a camera. The existing infrastructure should be an advantage for market acceptance of OCC since artificial lights including LEDs and cameras are prevalent where humans live.

On-off keying (OOK)

On-off keying (OOK) denotes the simplest form of amplitude-shift keying (ASK) modulation that represents digital data as the presence or absence of a carrier wave.

Optical wireless communications (OWC)

Optical wireless communications (OWC) is a form of optical communication in which unguided visible, infrared (IR), or ultraviolet (UV) light is used to carry a signal.

Phase-shift keying (PSK)

Phase-shift keying (PSK) is a digital modulation process which conveys data by changing (modulating) the phase of a constant frequency reference signal (the carrier wave). The modulation is accomplished by varying the sine and cosine inputs at a precise time.

Photodetector

Photodetector a device that detects or responds to incident light by using the electrical effect of individual photons.

Photon

Photon is a type of elementary particle. It is the quantum of the electromagnetic field including electromagnetic radiation such as light and radio waves, and the force carrier for the electromagnetic force (even when static via virtual particles).

Visible light

Visible light is a form of electromagnetic (EM) radiation, as are radio waves, infrared radiation, ultraviolet radiation, X-rays and microwaves. Generally, visible light is defined as the wavelengths that are visible to most human eyes. This broad range of wavelengths is known as the electromagnetic spectrum.

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