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Smart Lighting Solution

Home automation code camp – Spring 2017

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1. Abstract

This report comes as the result of our group work for Code Camp 2017 in the field of Home Automation.The purpose of our work is to implement automated technologies in a predefined scenario from our daily life, aiming the improvement of at least one of the sustainability pillars. In our case, we are trying to maximize the usage of the natural light and reduce the energy consumption by adjusting automatically the indoor light in a complementary response to the infused sunlight.

2. Motivation

Our scenario is inspired by a specific home automation technology implemented in the upper regions of the North hemisphere where natural light is absent in the winter. By implementing this system in public institutions, it is possible to imitate the sunlight, in order to reduce the negative psychological effects caused by the disruptions of the Circadian rhythm.

Our idea is a moderate version of the above-mentioned solution that considers not only the social factor but also the economic one. Artificial lighting in office buildings typically requires 30% of the total energy consumption of the building, providing a substantialopportunity for energy savings[1].The application of our solution aims to create a more comfortable environment in houses, libraries, offices in terms of light while parallelly improving energy consumption in regions that are located under the subarctic latitudes. Our motivation is to harvest as much as possible sunlight and to complement the remaining amount with artificial one until the optimal level of light for the human eye is reached. In addition, different studies have concluded that natural light has direct impact not only in our health and Circadian rhythm , but also in our performance, learning and creativity[2].(fig.1)

[1]A sensor-less LED dimming system based on daylight harvesting with BIPV systems Seunghwan Yoo,1 Jonghun Kim,1 Cheol-Yong Jang,1 and Hakgeun Jeong1,*
[2]http://www.eco-business.com/opinion/why-natural-light-matters-in-the-workplace

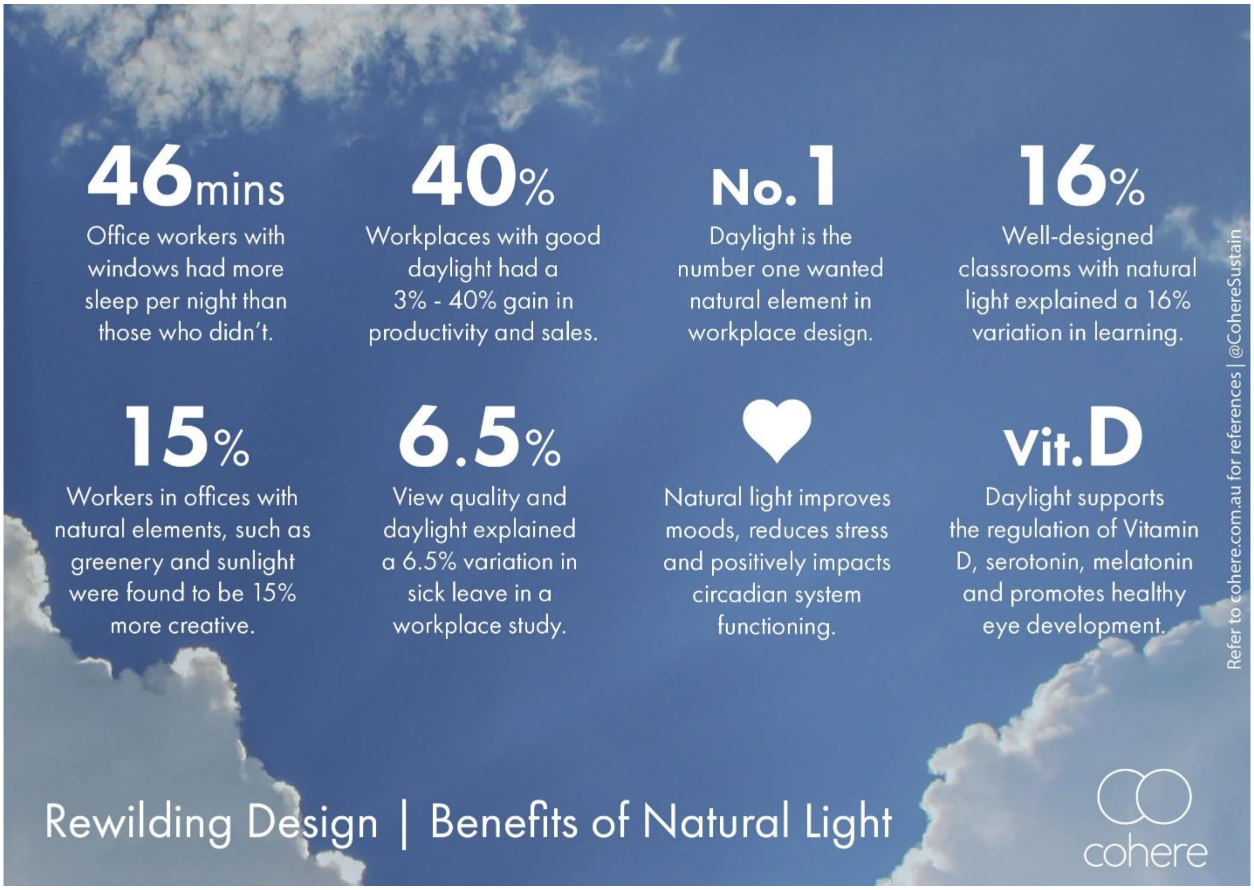


Fig.1 The benefits of natural light.

3. Implementation.

In this section, we will briefly present our scenario, used devices and technologies that we implemented during this CodeCamp.

3.1 Devices and Technologies.

To implement this scenario, we had to choose between a variety of technologies for different devices. We chose to work with the non-standardized FS20 protocol, which determines what devices should be used, their RF communication frequency and the modulation of the signal transmission. In our case, all the devices that we utilized use a non-encrypted AM modulation. The biggest advantage of this technology is the price, which is relatively cheaper than the standardized alternatives. The list of the necessary sensors and receivers is:

1. A Twilight sensor. It has 2 thresholds that divide the light spectrum in 3 parts.
2. A dimmer switch (receiver)
3. A Pyroelectric Motion Detection Sensor.

Used individually these devices are dummy without functionality, so to add the logic to our implementation we used a DHS server. This is a Linux-based device, like a RaspberryPi, but it has a RF module with 2 antennas (2 channels of communication) and a Touchpad UI. DHS comes with FHEM pre-installed, which is an open source management software PERL-based for Home Automation.

Fig. 2 Twilight Sensor

Fig. 3 Dimmer Switch

Fig. 4 PIR Sensor

Fig. 5 DHS server

3.2 System architecture & behavior.

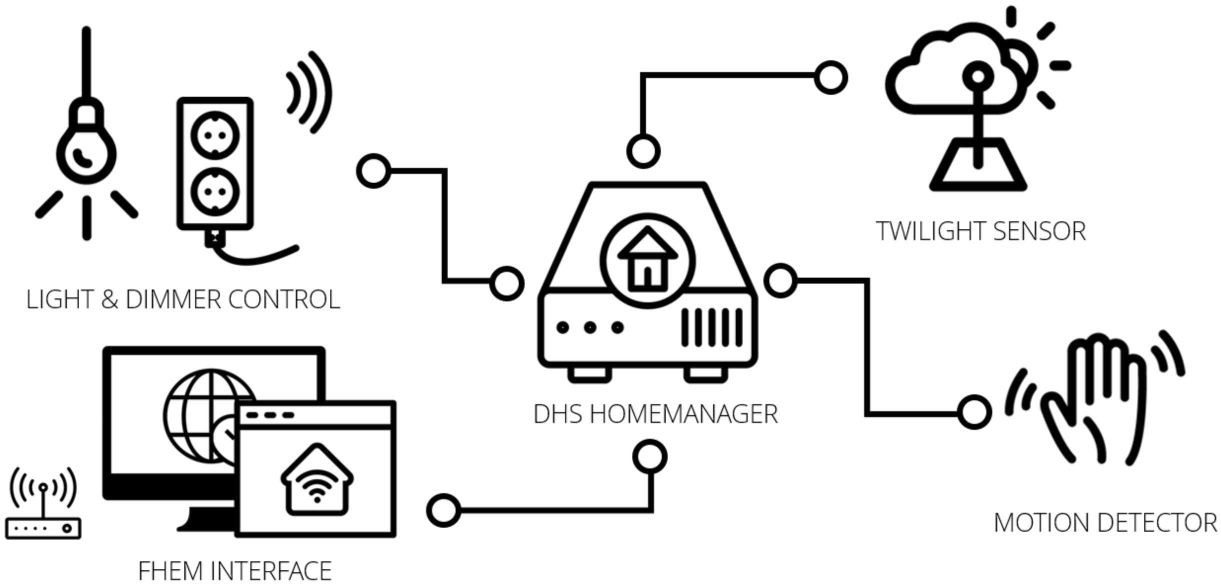


Fig. 6 System Diagram

The behavior of our system is determined by the light intensity captured by Twilight sensor and the occupancy of the indoor environment. The output is reflected on brightness of the lightning system. In more details, as long as nobody is inside all lights are turned off. The moment that motion is detected the lights are turned on and the brightness is adjusted based on the outside light measurements. At this point we have 3 cases (fig.7):

- The measured outdoor illuminance falls under the high bright segment, so our lights will be dimmed by 18% (this value is used for testing purposes).
- The measured outdoor illuminance falls under the mid-bright segment, so our lights will be dimmed by 50%.
- The measured outdoor illuminance falls under the low-bright segment, so our lights brightness will be 100%.

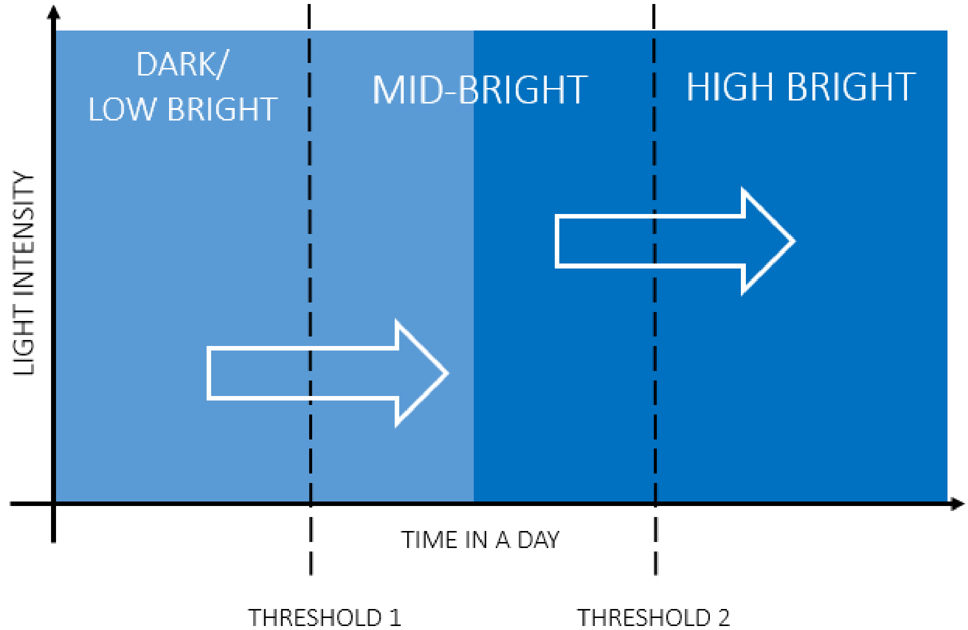


Fig. 7 Twilight sensor threshold settings

4. Benefits.

For our calculations, we took into consideration an office (or any other public space) with 30 light bulbs. We created 2 scenarios, a normal one and a scenario after the implementation of our solution. The price electricity is the one offered by Helen Company for basic electricity in Finland. The Carbon footprint calculation was done by using an online calculator. In the table 1 we briefly describe these two scenarios.

Table 1

Normal lighting scenario	Automated lighting scenario
- 9 hours/day in 100% brightness - 5 days/week - 30 bulbs of 40 W each. - Electricityprice:0.0579 euro/kWh (Helen company) - CO_2 emission in Finland(default): 0.225 kgCO_2/kWh - We assume that we are using conventional light bulbs , rather than LED	- 6 hours/day in 20% brightness (during the morning) - 3 hours/day in 50% brightness (during the afternoon) - 5 days/week - 30 bulbs of 40 W each. - Electricityprice:0.0579 euro/kWh (Helen company) - CO_2 emission in Finland(default): 0.225 kgCO_2/kWh - We assume that we are using conventional light bulbs , rather than LED

The annual consumption for both scenarios depicted in Table 2.

Table 2		
Calculations	Normal lighting scenario	Automated lighting scenario
Annual electricity consumption (kWh)	2592	907.2
Cost(euro/kWh)	150,0768	52,52688
Carbon footprint (kgCO2/kWh)	1390	490

5. Limitations.

Our project faced several limitations in different domains. First of all our time to get familiar and develop it was limited in just 4 days. Secondly, we worked in the same environment with four other groups that were using also similar or identical technologies, a fact that created interference problems in our RF connectivity. Finally, we used a Twilight sensor which has only 2 thresholds and is used to detect only the rise and sunset of the sun, rather than giving gradient information of the illuminance. This fact limited our project in only 3 modes of working (18 % dimming, 50% and 100%), rather than a more granulated curve of operating.

6. Vision

It is obvious now that future belongs to Home automation and Internet of Things. Since technology is all here, big ideas are limited only by imagination. Our actual implementation is facing a lot of limitations that affect its performance and usability, so when it comes to turn this idea in a Business Plan we can see that it is almost impossible if we also keep in mind the usage of LED lights. Nevertheless, ourscenario is the first step of a project that can be fully developed in more innovative and economic versions.

Let’s consider the following futuristic scenario. You enter in an indoor environment with multiple smart light bulbs that adjust their brightness individually, based on the information they gather from the light sensor of your smart device (smartphone, smartphone or other wearables) and their distance from the window. In this way, the artificial light becomes a gradient continuation of the natural illuminance.

Another interesting scenario published in a research paper by the Korean Institute of Energy Research[1] "A sensor-less LED dimming system based on daylight harvesting with BIPV systems"proposes an innovative solution where Building integrated Photovoltaic panels are used not only to generate electricity for the lighting system, but also based on the amount of energy produced in a certain time we can calculate illuminance outside. Using this information and the distance from the window of each bulb we can adjust our indoor lighting system in a proper level for each light bulb individually (Fig.8).

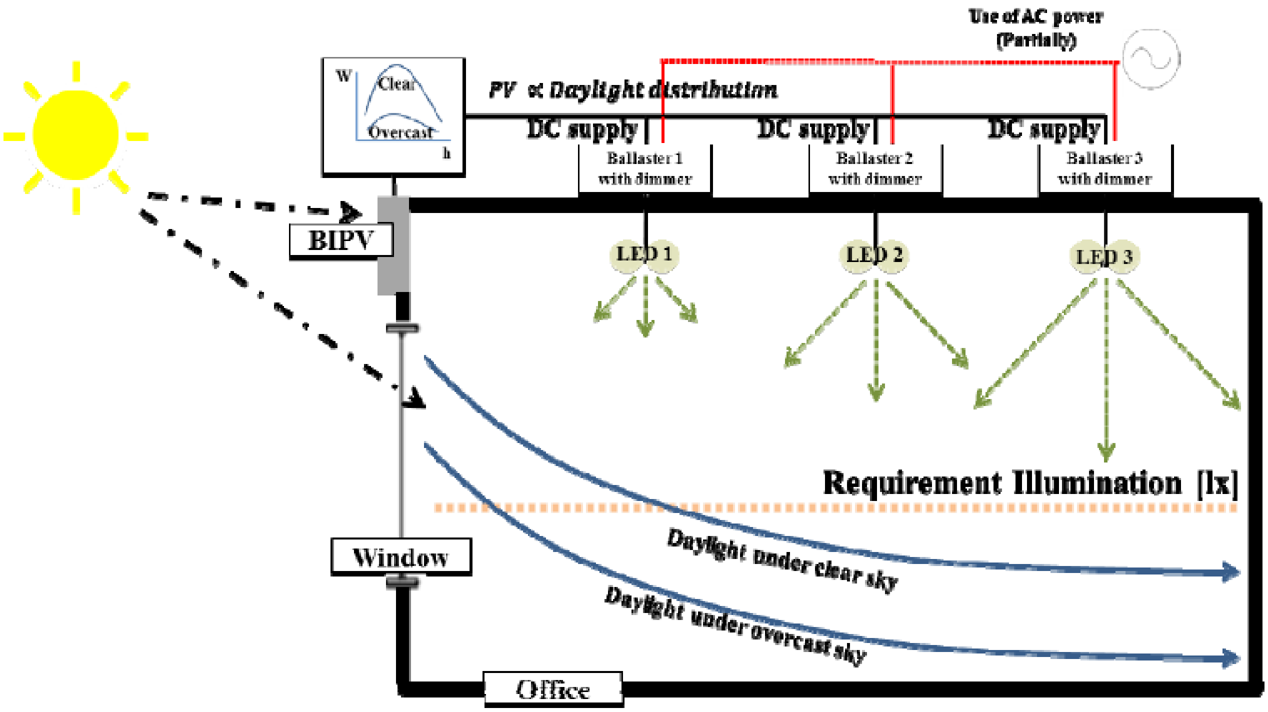


Fig. 8 Proposed solution by Korean Institute of Energy Research.

7. ZigBee Protocol.

ZigBee is a low-cost, low-power, wireless mesh network standard targeted at the wide development of long battery life devices in wireless control and monitoring applications. The ZigBee network layer natively supports both star and tree networks, and generic mesh networking. Every network must have one coordinator device, tasked with its creation, the control of its parameters and basic maintenance. Within star networks, the coordinator must be the central node. Both trees and meshes allow the use of ZigBee routers to extend communication at the network level.

7.1 ZigBee statistics.

ZigBee builds on the physical layer and media access control defined in IEEE standard 802.15.4 for low-rate WPANs.

	Band	Coverage	Date rate	Of channel(s)
2.4 GHz	**ISM**	**Worldwide**	**250 kbps**	**16**
868 MHz		**Europe**	**20 kbps**	**1**
915 MHz	**ISM**	**Americas**	**40 kbps**	**10**

7.2 ZigBee protocol stack.

ZigBee protocol stack is illustrated in the figure below (fig. 9):

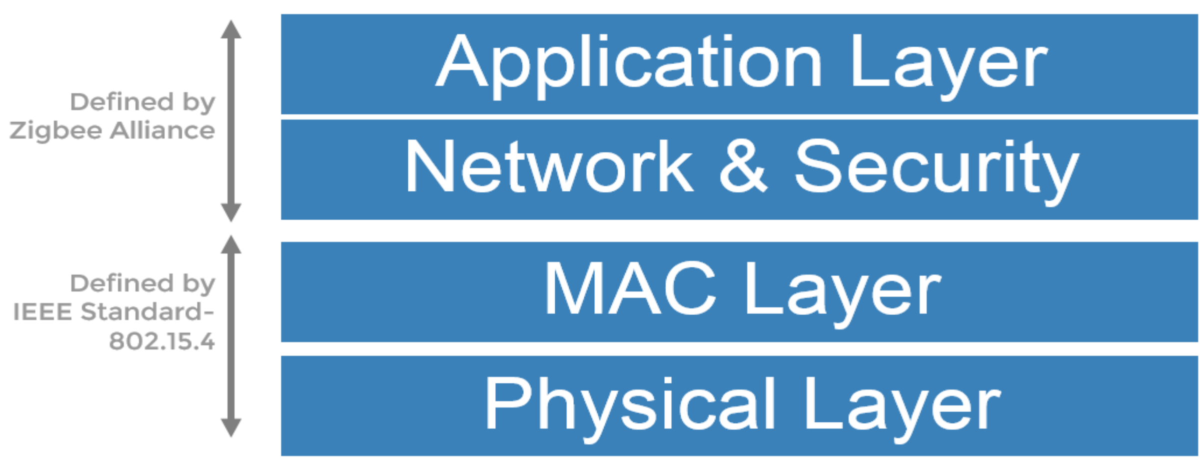


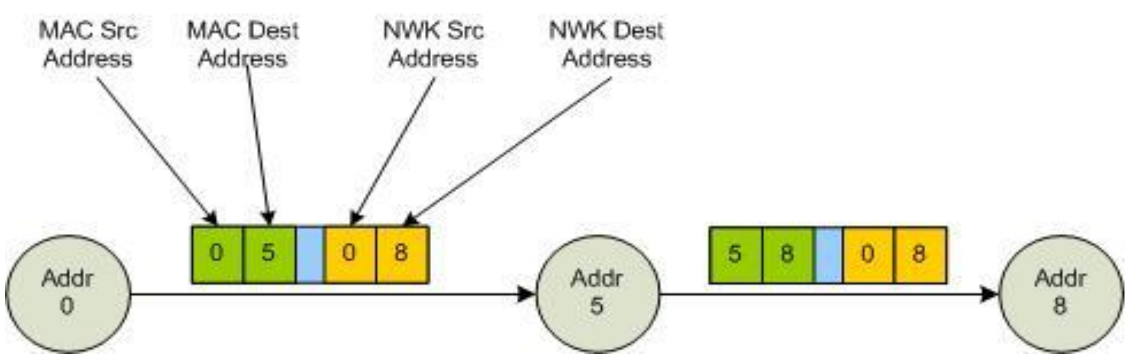
Fig. 9 ZigBee protocol stack illustration

1. The application layer: highest-level layer defined by the specification and is the effective interface of the ZigBee system to its end users. The application layer consists of three parts: the Application Sub-layer (APS), the Application Framework (AF), and the endpoints. The Application Sub-layer interfaces the ZigBee application layer to the ZigBee networking layer and it provides a common set of data transport services to all the endpoints;
2. The network & security layer: enables the correct use of the MAC sublayer and provide a suitable interface for use by the next upper layer and provides 128 bit AES encryption key for communication on PAN(Personal Area Network);
3. MAC layer: used by ZigBee devices to establish connection to the PAN by exchanging system information;
4. Physical layer: ZigBee builds on this layer and media access control defined in IEEE standard 802.15.4 for low-rate WPANs.

7.3 ZigBee Stack Architecture Addressing

- Every device has a unique 64 bit MAC address;
- Upon association, every device receives a unique 16 bit network address;
- Only the 16 bit network address is used to route packets within the network;
- Devices retain their 16 bit address if they disconnect from the network, however, if they leave the network, the 16 bit address is re-assigned.

On the transmit side, the Application Sub Layer (APS) sends data down to the network layer via a data request. Once inside the data request, the network header is filled out and then the address is examined. There are two sets of addresses in each ZigBee frame: the 802.15.4 source/destination addresses and the ZigBee network source/destination addresses. The MAC actually has a 64-bit address:



7.4 Why ZigBee?

There are many advantages of using this technology, for instance, it is an open standard, cheap, can be used globally, secure, very long battery life, supports large number of nodes, easy to deploy, reliable and self healing. Also it has few drawbacks, for example, the interference with the other devices and slow market expansion.

8. Li-Fi technology.

8.1 What is Li-Fi?

Li-Fi basically known as "Light Fidelity". Li-Fi is a wireless optical network technology protocol that uses light-emitting diodes (LEDs) for data transmission. With LIFI is possible to encode the data into the light by varying the rate at which the LED's flicker ON and OFF which is too quickly to be noticed by the human eye.

8.2 How it works?

Flicking an LED on and off at extreme speeds (imperceptible) can be used to write and transmit things in binary code. The constant current of electricity supplied to an LED light bulb can be varied up and down at extremely high speed invisible to human eye.
The photo-detector is responsible for receiving the light signal and a signal processing element to convert data into streamable content. The data fed into an LED light bulb are sent at high speed to photo-detector/photodiode to be converted into electrical signal.

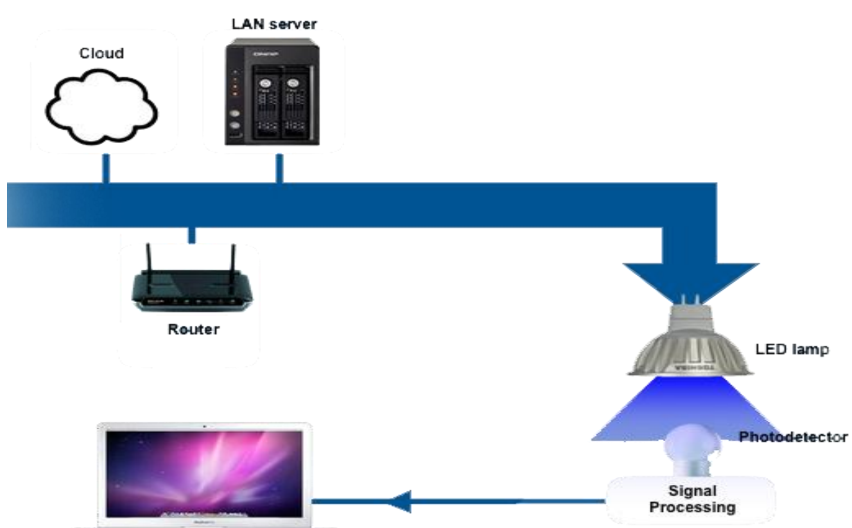


Fig. 10 working principle of Li-Fi

The data coming from the internet and LAN server is used for the modulation. The photodetector picks up the signal, convert it into data stream and send it to the client.
The clients could use their own LEDs output for the communication. Li-Fi is bidirectional technology.

8.3 Layers and modulation.

The Li-Fi communication protocol is established by the IEEE, defines the (physical layer) and MAC layer for compatible solutions and to deliver enough data rates to transmit audio, video and multimedia services. The MAC layer allows creating the link with the other layers as in case of the TCP/IP protocol.

The three physical layers are used for different transmission rate for various real-time applications as per user requirement. Reed-Solomen codes can be used for forward error correction.

The modulation formats recognized for PHY I and PHY II are On-Off Keying (OOK) and Variable Pulse Position Modulation (VPPM). The Manchester coding used for the PHY I and PHY II layers includes the clock inside the transmitted data by representing a logic 0 with an OOK symbol "01" and a logic 1 with an OOK symbol "10", all with a DC component. The DC component avoids light extinction in case of an extended run of logic 0's.

Table 3

Physical layer name	Transmission rate	Applications
PHY-I	11.6 kb/s to 267.6 kb/s	Outdoor and low data rate applications.
PHY-II	1.25 Mb/s to 96 Mb/s	Indoor operation with moderate data rates.
PHY-III	12 Mb/s to 96 Mb/s	The applications where RGB sources and detectors are available.

8.4 Advantages.

Li-Fi is secure since the light cannot pass through walls, and this means less interference between devices. Moreover, it offers high data transmission rates up to 10Gbps. Also there is no harmful radiation for living beings in Li-Fi.
Li-Fi is unlike the RF communication, it is very useful in electromagnetic sensitive areas such as aircraft cabins, hospitals, nuclear power plants. Compared to Wi-Fi, there is no need to license Li-Fi when using transciever-fitted lamps, it is cheaper and has less ecological impact.
Despite the high cost of installation, the cost of manufacturing and maintenance are much cheaper.