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Integration of Li-Fi System in street lights – A future for easy internet access.

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Abstract

A functional Li-Fi real-time testbed implemented on FPGAs is presented. The setup evaluates the performance of our design in a downlink scenario where the transmitter is embedded on the streetlights and a mobile phone's camera is used as receiver, therefore achieving the goal of lighting and communicating simultaneously. To validate the design, simulations of the whole system are performed. Where simulations of the channel between streetlight and mobile device show the scope of the reflection in an outdoor environment. The measurements are carried out to characterize the modulator, in particular the FPGA resources and latency due to the encoder blocks. In addition the feasibility of the communication function in presence of the ambient light is verified.

Introduction

Whether you're using wireless internet in a coffee shop, stealing it from the guy next door, or competing for bandwidth at a conference, you've probably gotten frustrated at the slow speeds you face when more than one device is tapped into the network. As more and more people and their many devices access wireless internet, clogged airwaves are going to make it increasingly difficult to latch onto a reliable signal. But radio waves are just one part of the spectrum that can carry our data. What if we could use other waves to surf the internet? One German physicist DRHarald Haas, has come up with a solution he calls "Data Through Illumination"—taking the fiber out of fiber optics by sending data through an LED light bulb that varies in intensity faster than the human eye can follow. It's the same idea behind infrared remote controls, but far more powerful. Haas says his invention, which he calls D-Light, can produce data rates faster than 10 megabits per second, which is speedier than your average broadband connection. He envisions a future where data for laptops, smart phones, and tablets is transmitted through the light in a room. And security would be a snap—if you can't see the light, you can't access the data.

Introduction to Li-Fi

In simple terms, Li-Fi can be thought of as a light-based Wi-Fi. That is, it uses light instead of radio waves to transmit information. And instead of Wi-Fi modems, Li-Fi would use transceiver-fitted LED lamps that can light a room as well as transmit and receive information. Since simple light bulbs are used, there can technically be any number of access points. This technology uses a part of the electromagnetic spectrum that is still not greatly utilized- The Visible Spectrum. Light is in fact very much part of our lives for millions and millions of years and does not have any major ill effect. Moreover there is 10,000 times more space available in this spectrum and just counting on the bulbs in use, it also multiplies to 10,000 times more availability as an infrastructure, globally. It is possible to encode data in the light by varying the rate at which the LEDs flicker on and off to give different strings of 1s and 0s. The LED intensity is modulated so rapidly that human eyes cannot notice, so the output appears constant. More sophisticated techniques could dramatically increase VLC data rates. Teams at the University of Oxford and the University of Edinburgh are focusing on parallel data transmission using arrays of LEDs, where each LED transmits a different data stream. Other groups are using mixtures of red, green and blue LEDs to alter the light's frequency, with each frequency encoding a different data channel. **Li-Fi**, as it has been dubbed, has already achieved blisteringly high speeds in the lab. Researchers at the Heinrich Hertz Institute in Berlin, Germany, have reached data rates of over 500 megabytes per second using a standard white-light LED. Haas has set up a spin-off firm to sell a consumer VLC transmitter that is due for launch next year. It is capable of transmitting data at 100 MB/s - faster than most UK broadband connections.

History

Harald Haas, a professor at the University of Edinburgh who began his research in the field in 2004, gave a debut demonstration of what he called a Li-Fi prototype at the TED Global conference in Edinburgh on 12th July 2011. He used a table lamp with an LED bulb to transmit a video of blooming flowers that was then projected onto a screen behind him. During the event he periodically blocked the light from lamp to prove that the lamp was indeed the source of incoming data [2]. At TED Global, Haas demonstrated a data rate of transmission of around 10Mbps comparable to a fairly good UK broadband connection. Two months later he achieved 123Mbps [2][8][10].

Description of Smart City

Cities have quite an impact in the economic development of a country, being the "platform" where many people live and work, where services are provided to citizens in a wide range of ways, and where local government officials have a close contact with citizens [1] [2]. It is only natural then that ICT (Information and Communication Technologies) plays an increasing role in the life of both people and private and public entities that are part of a city. The concept of Smart Cities is gaining increasingly high importance as a means of making available all the services and applications enabled by ICT to citizens, companies and authorities that are part of a city's system. It aims to increase citizens' quality of life and improve the efficiency and quality of the services provided by governing entities and businesses. This perspective requires an integrated vision of a city and of its infrastructures, in all its components, and extends beyond the mere "digitalization" of information and communication: it has to incorporate a number of dimensions that are not related to technology, e.g., the social and political ones.

A clear definition of smart cities should have two important factors, that is the city's desired functions and purposes, where functions refers to appearance and operation of the city, and purposes to required benefits promised by a smart city model.

Smart city in simple can be defined as "a city which utilizes smart factors such as Information and Communication Technology to increase the city's growth and also strengthen the city functions, promising citizens' wellness."

Li-Fi Enabled Street Lights

The concept of Smart City has attracted a lot of interest in recent years; even though, it was coined at the beginning of 90s. A Smart City is known as a city committed to the environment, whose infrastructures are equipped with the most advanced and innovative technological solutions from the Information and Communications Technology area so as to satisfy the challenges of the cities in terms of energy sustainability (e.g., water, gas, electricity) to the social demand for vast real time information (about parking, public transport, weather, ATMs) and to the emergence of the Future Internet related technologies, such a wearable computing, mobile devices, cloud computing or the Internet of Things (IoT) [2].

Many of technological solutions are based on the usage of Wi-Fi by Smartphone's, which are increasing the continuous demand for higher data rates. In order to tackle this problem, network operators are forced to deploy new technologies like the future 5G. As the RF spectrum is getting scarcer, the push for more bandwidth is driving wireless technologies in alternative spectrum bands into the networking field. Besides, supplying cities with wireless radio frequency networks is limited by the concern from the general public on the exposure to the electromagnetic fields, which is increasing nowadays. For instance, the 2010 Euro barometer study reveals that 70% of the European citizens believe that mobile phone base stations could have some negative effects on their health, which hinders the progress in these technologies [3].

In order to deal with the limited RF spectrum and social concern, Optical Wireless Communication (OWC) systems are getting an important attention both from the research community and the industry because of their numerous potential advantages, in particular, the usage of the freely available visible light spectrum in Visible Light Communication (VLC) systems. Recently due to the widespread use of Light Emitting Diode (LEDs) in streetlights and the fact that these devices are the key element of optical systems, the design of technologies jointly performing the two functions lighting and communicating is made possible. In this case, the incorporation of VLC technology into LED bulb drive circuits provides the opportunity of applying the same visible light energy used for illumination and for communication too. In the context of a home networking environment, Power Line Communication (PLC) is used to distribute high-speed data. PLC combined with VLC may benefit from the main infrastructure for backhaul and allow wireless connection between devices and the Internet.

For this application, where LEDs are used as internet access points, VLC technology is known as LiFi (Light Fidelity). This term was coined firstly by Edinburgh University's Prof. Harald Haas in 2011. Many experts claim that LiFi represents the future of mobile internet thanks to its reduced costs and greater efficiency, becoming an alternative to WiFi as a basic technology for the IoT . In this framework, the goal is to implement a LiFi system to validate its use in a scenario with streetlights. It focuses on a downlink system formed by the streetlight as a transmitter and a mobile phone camera as a receiver. The streetlights receive data via PLC and modulate the information to be sent by light pulses through the LED bulb. The modulator functionality is the one to be designed and tested within the work presented here. In turn, streetlights forward the data received by the optical link to the mobile user terminal which receives through a photodiode integrated in a camera. For the uplink, LiFi is integrated with existing technologies as Bluetooth, ZigBee or Wi-Fi. Thanks to the infrastructure of streetlight that cities possess, they reach full connectivity and are able to interconnect other devices with each other such as traffic and vehicles lights or ATMs. The envisaged scenario is shown in Figure 1[2]

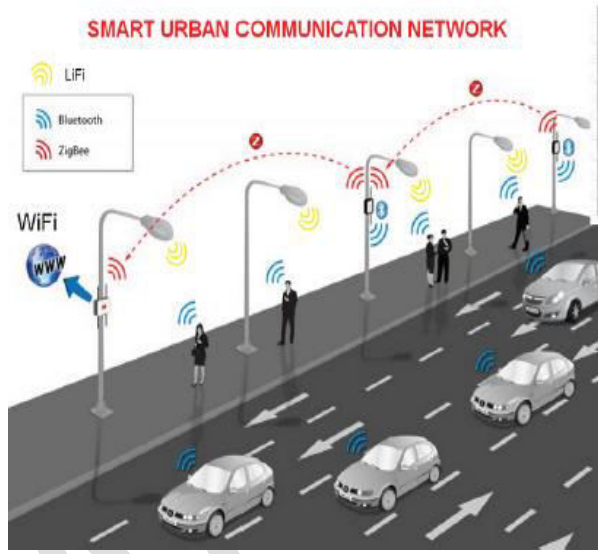

Figure 1 Li-Fi Network in SmartCity

In summary, the current work focuses on the following contributions:

- The design and implementation on Field Programmable Gate Array (FPGAs) of the modulator.
- Simulations of the channel between streetlight and mobile device.
- The definition of the testbed for testing LiFi in the streetlights.

Working principle of Li-Fi

The working of Li-Fi is based on VLC, which uses visible light for data transmission. The visible light spectrum has wider range of hundreds of THz of free bandwidth, which is 10,000 times more than RF spectrum up to 30GHz. It uses LED to generate data stream which is connected to the internet or cellular system. As per the data stream the LED flickers at high rate which is not recognized by human eye [5].

The flickering of LED is regulated by voltage regulator and level shifter circuit. At the receiver side of the system photo detector is used. This photo detector senses light and converts into the respected pulses. These pulses are then amplified and processed to achieve the original data stream. The distance achieved by system depends only on the potential of the light source that is LED lamp. The one among the major advantage of Li-Fi is the merging of illumination with wireless communication provides a measurable reduction in both infrastructure complexity and energy consumption [8].

LI-FI Source LED

As LED is more commonly used source for room lighting, it is also used in Li-Fi as a data source more sophisticatedly and efficiently to generate data streams. As compare to the IR LED which generate a single data stream with 10-20 kbps speed, these LED's generates a thousands of data streams spreading all over the room where the light can reach with a very fast rate. The potential of these LED's can be increased by using some Luminaire Design Optimization techniques. Recently the R & D centre of pure VLC has achieved 3.5Gbps of data rate from a single color micro LED operating at 5mW with a 1m distance and 1.1Gbps of data rate at 10m at 5mW . So it can be concluded that by using three colors RGB LED's the data rates of more than 10Gbps can be achieved.

Uplink

For a complete Li-Fi communication system, full duplex communication is required, that is an uplink connection from mobile terminals to the optical AP has to be provided. This can be achieved by using the infrared (IR) transmission, where the mobile terminals can send data using infrared frequency and optical AP receives it to respond [6]. The first commercially available full duplex Li-Fi modem using IR light has been announced by pure Li-Fi.

LI-FI receiver photodiode

The photodiode is used as a Li-Fi receiver to sense the data stream. The Avalanche photodiodes are used to make better receivers. At Haas's recent talk on "My Li-Fi Revolution" at Tam Dalyell prize lecture he shown the first receiver chip for Li-Fi with integrated Avalanche photodiodes on CMOS created by his team at the Li-Fi R&D centre. The 7.8 –square–mm IC houses 49 photodiodes which is around 13% of length of single Wi-Fi antenna. At the IEEE Photonics Conference in October, Li-Fi consortium showed off the progress of combining both emitters and photodiodes to detect light using available red, green and blue LED's. By doing that the system could both send and receive data at aggregate rates of 110 Mbps [5].

Overview

Li-Fi PHY Layer overview

The physical (PHY) and the medium access control (MAC) layers for LiFi are specified in IEEE 802.15.7 standard. Both the PHY and MAC layers are defined to achieve high data rates in audio and video transmission, while the illumination function is not affected. As specified in the standard, there are three different types of PHY with various combinations of digital modulation and coding schemes. The data rates are from 11.67kb kb/s to 266.6 kb/s for the PHY I and from 1.25 Mb/s to 96 Mb/s for PHY II. For streetlights, the best option is the PHY I because it is optimized for outdoor scenarios. However, the PHY II is considered to be implemented too in this work. The modulation schemes used are on-off-keying (OOK) and variable pulse position modulation (VPPM). Reed Solomon (RS) and Convolutional encoders are proposed by the standard to correct channel errors and improve the link reliability. On the other hand, to avoid burst errors, an interleaver is included. Manchester and 4B6B encoders are the two types of RLL encoders which are used for 200 kHz and 400 kHz clock rates, respectively, to balance the DC level of the output. The standard does not include a specification for the buffers between blocks, but they are necessary to make data conversion between serial and parallel data flow, for example between RS and interleaver. Also, the implementation is not described in the standard [9].

System Design and Simulation

The development of this project started with simulations in MATLAB of a reference LiFi modulator and demodulator according to the specifications of for PHY I-II operating modes. The study of the model in MATLAB serves as a benchmark for subsequent implementation in FPGA for streetlights.

Simulation of LiFi PHY layer

First, the system viability is tested. To do this, each of the blocks that make up the Li-Fi transmitter and receiver are programmed in MATLAB:RS and convolutional encoder, interleaver, Manchester and 4B6B encoding; while in the receptor, the Viterbi algorithm is performed first and then blocks transmission coders are undone. In Figure 2 it is shown the block diagram [6].

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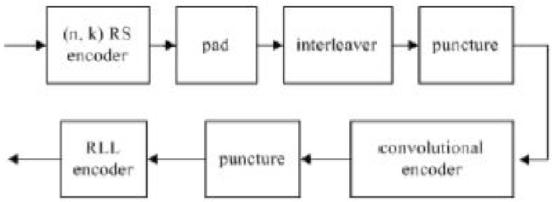

Figure 2 Reference modulator diagram for PHY Layer

The results according the bit error rate (BER) are shown in the Figure 3 for AWGN (Additive White Gaussian Noise).As shown, the operating mode, that has the lowest data rate according to presents the best performance because of the high protection. SNR=10 dB is chosen to illustrate the effect on an image transmission using our simulated Li-Fi system. In Figure 4 the quality of the image clearly shows the effect of coding. Also, if a SNR = 15 dB is chosen, a level of BER and image quality are acceptable for all modes of operation.

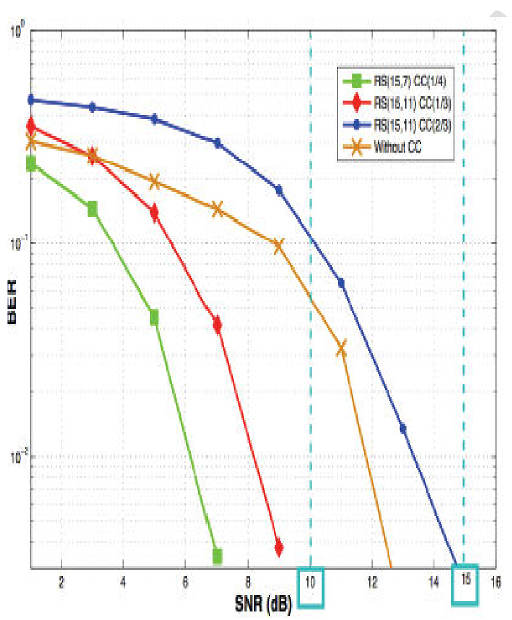

Figure 3 Performance

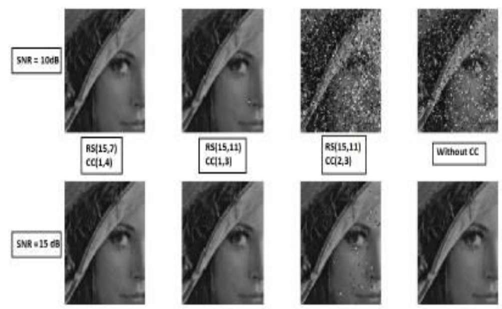

Figure 4 .Image transmission using Li-Fi syste

Prototype Description

The LiFi prototype system is based on an Software Defined Radio (SDR) approach. FPGAs boards have been used to implement the communication module in both the streetlight and the user equipment. The goal is to validate the communication function using this prototype in a scenario with streetlights. The prototype is divided into two subsystems: hardware and software subsystem. Figure 5 shows the overall setup of the proposed testbed for the LiFi prototype.

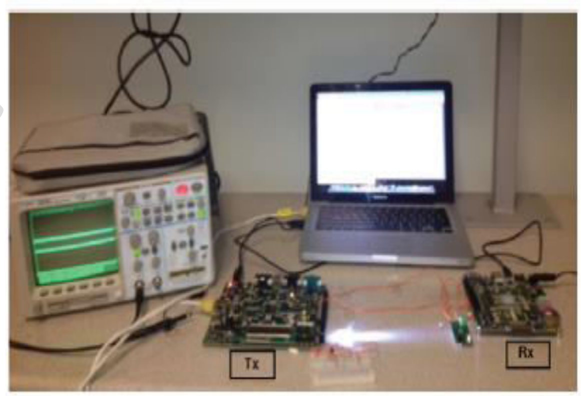

Figure 5Testbed for Li-Fi prototype system

Hardware

The transmitter and receiver designs have been implemented on two separate FPGAs. The FPGA used in the receiver has a larger memory, in order to store the performance measurements done at this end. The transmitter front-end, the streetlight, is constituted by the Development Kit Board of Digilent, equipped with a Spartan 3E-xc3s500E FPGA, acting as the LiFi modulator. It also includes the LED driver circuit and a commercial high power

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white LED as the light emitting source. The data stream received from PLC is delivered via an Ethernet port to the FPGA and encoded as shown in Fig. 2, then the modulated signal is fed to the LED driver circuit, which acts in switching mode, varying the current of the streetlight LED.

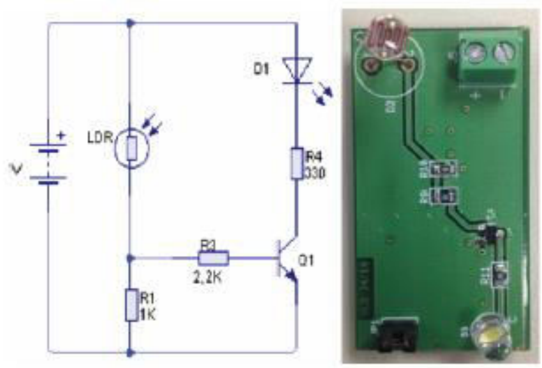

Figure 6 Setup and prototype receiver

The receiver front-end, at the phone's camera, consists of the Altys platform equipped with a Spartan 6-xc6slx16 FPGA. An external circuit, shown in Figure 6 has been designed and implemented to capture the signal using an LDR (light-dependent resistor). The digital signal is delivered to demodulator FPGA to reverse the flow in Fig. 3. Also, the FPGA generates the clock signal in both Tx and Rx. The hardware description is depicted in Figure 7 [7][8].

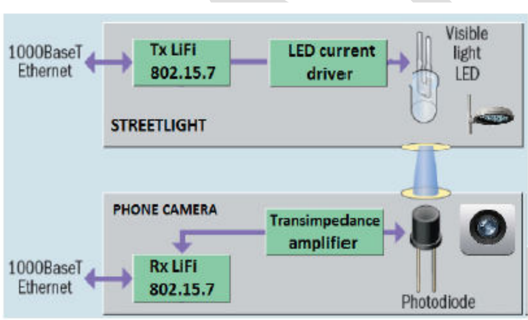

Fig 7 Diagram of the Li-Fi Hardware Architecture

Software

The software subsystem is responsible to implement the functions of each block represented in Fig.5.1 in VHDL on FPGA. The Xilinx ISE Design Suite 14.7 tool is used. To simulate each implemented block, iSim Simulator integrated in Xilinx ISE tool and is used. The data stream is delivered to FPGA, to that end, the Xilinx libraries are used to setup the LAN83C185 10/100/1000 ETH PHY port of the FPGA and to acquire the data to be encoded that allow us to use fewer FPGA resources. Also, memory blocks as buffers have been implemented using Xilinx libraries, in particular, to reduce the period of latency which is defined as the time is taken to deliver the first frame to encode to the RS block

Applications of Li-Fi

There are many applications for Li-Fi. These include [2][7][8]:

- **RF Spectrum Relief**: Excess capacity demands of cellular networks can be off-loaded to Li-Fi networks where available. This is especially effective on the downlink where bottlenecks tend to occur.
- **Smart Lighting**: Any private or public lighting including street lamps can be used to provide Li-Fi hotspots and the same communications and sensor infrastructure can be used to monitor and control lighting and data.
- **Mobile Connectivity**: Laptops, smart phones, tablets and other mobile devices can interconnect directly using Li-Fi. Short range links give very high data rates and also provides security.
- **Hazardous Environments**: Li-Fi provides a safe alternative to electromagnetic interference from radio frequency communications in environments such as mines and petrochemical plants.
- **Hospital & Healthcare**: Li-Fi emits no electromagnetic interference and so does not interfere with medical instruments, nor is it interfered with by MRI scanners.
- **Aviation**: Li-Fi can be used to reduce weight and cabling and add flexibility to seating layouts in aircraft passenger cabins where LED lights are already deployed. In-flight entertainment (IFE) systems can also be supported and integrated with passengers' own mobile devices.
- **Underwater Communications**: Due to strong signal absorption in water, RF use is impractical. Acoustic waves have extremely low bandwidth and disturb marine life. Li-Fi provides a solution for short-range communications.

- **Vehicles & Transportation**: LED headlights and tail-lights are being introduced. Street lamps, signage and traffic signals are also moving to LED. This can be used for vehicle-to-vehicle and vehicle-to-roadside communications. This can be applied for road safety and traffic management.
- **RF Avoidance**: Some people claim they are hypersensitive to radio frequencies and are looking for an alternative. Li-Fi is a good solution to this problem.
- **Location Based Services (LBS)**: Highly accurate location-specific information services such as advertising and navigation that enables the recipient to receive appropriate, pertinent information in a timely manner and location.
- **Toys**: Many toys incorporate LED lights and these can be used to enable extremely low-cost communication between interactive toys.

Conclusion

All the operating modes of the physical layer according to the specifications of the IEEE 802.15.7 standard are implemented. This development is based on FPGAs. Besides, the prototype includes a circuit, to capture the received signal, which has been design. The testbed is proposed for a scenario with streetlights, for which the results have been validated. The transmitter and the channel have been tested. The effect of the ambient light has been observed.

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