MINISTRY OF NATIONAL EDUCATION

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SYSTEMS ENGINEERING DOMAIN

CONTRIBUTIONS REGARDING THE VISIBLE LIGHT DATA COMMUNICATION APPLICABLE IN INDUSTRY

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TABLE OF CONTENTS

SUMMARY

Unexpected progress of science we witness very day, as well as amazing technological discoveries with great impact on daily human activities.

During the last decade, the hunger for wireless fast and secure data communication has become visible since more and more smart devices are locally connected to each other or remotely by internet. Machine to Machine (M2M) communication, is not more a novelty since Internet of Things, smart house, smart cities, smart driving, personal or body area network have exponentially grown lately, all of these, due to local or remotely wireless data communication based on radio frequency (RF) in the electromagnetic spectrum. When all these concepts will be fully integrated in our daily life in the near future, the need for high speed and secure data transmission both indoors and outdoors will demand new mature wireless technologies to support them beside wireless technologies based on RF communication. As Cisco visual networking index data traffic forecasts, by 2022, will be more than 12.3 billion mobile devices connected, exceeding projected population (8 billion) by one and a half times. Even more, with the entire forecast amount of worldwide wireless connected smart devices, the spectrum crunch will soon become reality.

For years already, many alternative technologies have been searched and developed in order to support this exponential growth and hunger for Terra bytes of wireless data communication.

Since most of data traffic takes place indoor, optical wireless communication, due to lately deployments, proved to be a suitable and reliable partner for the wireless data communication based on radio frequency spectrum such as Wi-Fi or cellular.

Optical wireless communication covers both Infrared (IR) and visible light wireless data transmission. Visible Light Communication (VLC) has recently become possible due to continuously worldwide both academic research efforts and business interest in the subject.

LiFi, as one of the optical wireless communication emerging technologies, has been coined by professor Harald Haas on 2011 during a Ted talk. He made an inspired analogy with Wi-Fi and therefore drawing worldwide attention and thus raised interest of both scientific and business communities for intensive research efforts. Although not standardized or fully developed yet at its entire potential, LiFi technology has already been deployed on the academic community for testing, at the end of 2018 and promises to grow exponentially in the near future.

LiFi concept refers to a system embedded into the LED lighting fixture to allow wireless secure and fast data to be piggybacked by illumination and remote communication by internet. Full duplex communication is possible due to download on visible light and upload on infrared spectrum. Multiple mobile users and wireless handoff from one LiFi access point to another is also possible in early deployed LiFi systems.

Since LiFi allows multiple Gigabits transmission, it holds the key to solving challenges faced by spectrum crunch and 5G wireless technology, due to its strengths: uniquely more secure, virtually interference free and more reliable than currently wireless technologies based on radio frequency.

Furthermore, LED lighting is also forecast to replace present illumination light bulbs/lamps (incandescent bulbs, fluorescent or halogen lamps) and spread worldwide due to its obviously advantages (long lifetime - 25,000 to 50,000 hours, high energy conversion efficiency, low heat generation, high tolerance to humidity and high or low temperatures, mercury free, compact size) therefore, the market for LiFi wireless data communication technology will be soon wide open.

Both powerful, free software electronic circuit designing and software solutions covering wide areas for modelling and systems' simulation are online available. They make possible modelling and simulation prior to printed circuit boards (PCB) designing and hardware implementation of various ideas allowing fast designing, testing and laboratory prototyping with low costs.

Advanced technological growth made also possible more sensitive, low cost, off-the-shelf photodiodes (PDs) to become worldwide available and therefore many projects with remarkable various possible implementations of different ideas, in different areas, to turn into reality.

The wireless data communication is growing by the day and due to spectrum crunch, in places where Wi-Fi is overcrowded, limited or forbidden, optical wireless communication is a suitable, alternative technology to be used.

Various areas, such as those where wireless data communication based on radio frequencies is limited (airplanes or health facilities) or forbidden (nuclear power plants or petrochemical industry) as well as different other facilities with overcrowded, high demanding wireless connectivity, are appropriate places for LiFi to be deployed.

For years already, intense research efforts have been made to set up systems based on optical wireless communication, in different domains, such as:

- Indoor data wireless communication;
- Indoor positioning systems and navigation (for example in museums and supermarkets);
- VLC between smart personal or medical devices, equipment or various other devices (as toys, for example);
- In home and embedded into office or home appliances;
- Smart lighting;
- Vehicle to vehicle communication and traffic lights;
- Underwater VLC and so on.

More and more international well-known companies run projects aiming to add to the core function of illumination, wireless data communication in order to solve challenges for highly demanding, secure and high-speed wireless connectivity.

Chanel impulse response, channel modelling, signal modulation or electronic board with microcontrollers embedded, integrates various theoretical concepts already demonstrated with mathematical models. Most of the major VLC projects worldwide, have also shifted from theoretical demonstration of high speed, longer communication distance, improved signal to noise ratio (SNR) to hardware and software development and prototyping.

The VLC technology promises to provide, in the near future, a safer, faster and greener data wireless communication system. When LiFi technology will be mature enough and financial accessible, we can expect that each light source (LED bulb) to be used as a LiFi access point (AP), meaning where will be a LED light we can expect to have data communication, as well.

As fast this technology develops, within a few years, we expect to see both VLC and LiFi in addition with other wireless complementary technologies to create a new ubiquitous wireless communication platform. Under this forthcoming integration, every device large enough to include a LED, a transmitter driver and a light sensor can be connected and powered by these optical wireless technologies.

Regarding the VLC's technology, an up-to-date scientific literature review, state of the art, as well as an exhaustive blueprint of the VLC system are covered in this present work.

A general model of the optical wireless channel, especially VLC setups (line of sight or not line of sight, diffuse or direct topologies) together with VLC channel modelling, as well as light propagation topologies have been detailed presented in this work.

The optical wireless channel models are classified as deterministic and stochastic geometry based models. The deterministic approach, recursive, iterative, ceiling bounce, DUSTIN and ray tracing geometry based deterministic models (GBDM), as well as diverse recursive approach evaluates the channel impulse response CIR $h(t)$) taking into consideration multiple-bounces (more than two reflections) both in wireless IR and VLC channels. Geometry based stochastic models (such as spherical or Carruthers model) as well as non-geometry based stochastic models such as Monte Carlo or modified Monte Carlo algorithms are used to describe the light's behaviour indoors. Root Mean Square (RMS) Delay Spread (DS) and optical path loss are, also, the two characteristics mathematically described here for the optical wireless channel.

The electrical setup (both oTx and oRx drivers), the topology for an efficient VLC system as well as modulation techniques (both single carrier and multi carriers) have been analysed and exhaustive investigated.

The author of this work also proposes an underground positioning and monitoring system (UP&MS) with VLC embedded. Detailed presentation of the system as well as modelling, simulation and designing of the VLC system along with the communication channel modelling in underground environments are also extensive introduced with this work.

Beside stimulation of the entire electronic system (oTx and oRx) with microcontroller, optical description of the lenses and filter embedded in both optical transmitter (oTx) and optical receiver (oRx) are exhaustive presented with mathematical backgrounds and software based simulation for a proper an accurate choice in a Line of Sight (LOS) topology and field of view optical setup (FOV).

Software application used for simulation are Every Circuit, Multisim, MatLab, Simulink, Proteus and Phet. Results after simulation allow a fast, low cost and reliable prototyping of the entire VLC system.

The VLC system prototyped with microprocessor has been also developed (both hardware and software) and laboratory tests were run in order to send wireless data through light. Data sent consist in a EAN-8 code that is uniquely related to each miner's cap lamp, compulsory to be used entire time when a person is underground.

The UP&MS proposed with this work consists in a oTx module with the VLC embedded as the miner's cap lamp that continuously send, piggybacked by illumination, wireless data aka its own lamp ID. The lamp ID is uniquely identified underground being directly linked with the person wearing the lamp the entire time when he/she is underground. This is the way that also each person's position underground is uniquely identified and known at the mine surface in the surveillance room, on a real time basis.

Miner's cap lamp ID is received by the oRx embedded into the already setup illumination network. oRx modules with VLC embedded are integrated in access points that add, to the information received, its own ID representing its own position on the main gallery, data and time of the optical signal (data) received from the lamp, into an Ethernet frame type II.

Throughout the access points, data are send to the mine surface (over an Ethernet network with dedicated equipment) into a specialized surveillance room with a server and a wide screen for a real time monitoring of the personnel position underground.

A comprehensive analyse has been done prior to prototype development of the system. The VLC system must be explosion proof and certified ATEX in order to meet the highest safety standards. Explosion hazard, as it is in coal mines, for example, involves the use of special lighting to avoid accidents because here, due to high firedamp or high level of methane concentration, atmosphere is favourable to explosion.

During tests, data acquired during communication into the prototyped gallery (dimensioned 1:6.25) serve as a base of a detailed analyse of the signal send in order to determine the improvements necessary to be done on the Access Points positioned on the illumination network close to the working room where light behaviour has to be carefully modelled due to light scattering and absorption caused by the tiny particles of coal and rocks into the air.

Since the author applied for a patent at the State Office for Inventions and Trademarks (OSIM) in Romania, a cost estimation considers to be necessary for the entire VLC setup underground that comes to fill a research gap in order to fulfil the product's life cycle for the system proposed.

Summary of research contribution and further enhancements, are, as follows:

- A chronological literature review of the OWC and its state-of the art;
- A detailed blueprint of a VLC setup with LED's and PD's key characteristics emphasized and discussed with mathematical backgrounds explained;
- CIR and channel description for different possible VLC topologies;
- Detailed description of optical setup for both oTx and oRx;
- Detailed description of the electrical setup for both oTx and oRx;
- Single carrier and multiple carrier modulation with theoretical description for suitable VLC system;
- Simulation of the electronic setup (with support of Every Circuit, Multisim, ISIS Proteus and Arduino software) for both oTx and oRx;
- Simulation of the optical setup for both oTx and oRx (with the support of Phet online application, mathematical models and Simulink application);
- CIR simulation and optical distribution into the main gallery underground of three possible scenarios with the support of MatLab software;
- UP&MS description and analyses of a proper VLC system suitable in high explosive risk environments with ATEX requirements;
- VLC hardware prototyping of the electronic boards with microprocessors for both oTx and oRx;
- Detailed description of the miner's cap lamp ID associated with an EAN-8 code with a checksum algorithm for a correct identification of data sent;
- Ethernet frame type II general description and data payload specification;
- Software implementation for both oTx and oRx for miner's cap lamp ID communication to the oRx with AP embedded on the illumination network;
- Laboratory model of the underground main gallery geometry (scale 1 : 6.25) with data communication setup;
- Data acquisition from both oTx and oRx with support of oscilloscope with the aim of identifying the proper system in order to develop the best mathematical model that describes a suitable optical wireless communication in a polluted environment, filled with tiny suspended particles of coal and rock close to the working space;
- Cost estimation of the VLC system underground as part of the UP&MS described.

Possible different improvements on the VLC setup proposed can be done both on the oTx and oRx from the point of view of electronic and optical system, as well.

More advanced digital signal processing (DSP) boards with performant microcontrollers and multi-carrier modulation techniques can be used, as well.

An improved design of both optical setups at the oTx (suitable, sensitive lenses) as well as at the oRx (suitable lenses and high quality filters) can be used in order to support more LEDs and more PIN PDs respectively, in order to increase the optical power sent by LED and received by PDs.

The solution presented can be upgraded using an optical fiber network mounted on the ceiling along the main galleries to form an Internet of Things network (IoT).

Based on the research, there can be taken into consideration further tests, in laboratory conditions, in order to achieve and analyse data with a higher degree of noise, that still support a proper functionality of the UP&MS even in rough conditions with severe optical attenuation.

Additional data acquired can be a base for further investigations in order to determine the optical attenuation of the environment (and its correlated extinction coefficient) with the purpose of determine the VLC system functionality in polluted environment, as close to the working space, underground, is.

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