Technical Feasibility of Visible Light Communication Systems for Low Bitrate Smart Cities and the Industry 4.0 Applications

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***Abstract*—Visible Light Communication (VLC) is a growing technology in the context of new telecommunication systems. It uses the visible and infrared spectrum to communicate data to light sensitive equipment. Thus it enables Light Emitting Diodes (LEDs) lamps to have the dual role of illuminating and communicating. This means of communication is very much studied and commercialized for indoor applications. However, with the popularization of smart city applications in urban areas as well as in industries, it appears that the VLC technology could be relevant in those environments too. In order to measure its feasibility of deployment, this work proposes tools, including an innovative smoke model and the use of advanced modulation schemes, to simulate the coverage of a VLC communication in order to estimate its theoretical feasibility as well as a set of prototypes that demonstrate the technical feasibility of this technology.**

***Index Terms*—Visible Light Communication, smoke, fog, WDM, Li-Fi, Industry 4.0, Smart Cities, Prototypes, UFMC**

I. Introduction

The development of technologies that use cellular Radio Frequency (RF) networks to transmit information wirelessly has increased dramatically over the last decade. These technologies include mobile phones, tablets, connected gadgets and the Internet of Things (IoT). The simultaneous use of all these devices quickly saturates the available RF bandwidth. It is then important to find alternative connectivity like in the case of this work, Visible Light Communication (VLC), to avoid the shortage of wireless connectivity. VLC is part of the Optical Wireless Communication (OWC) technology family which uses the visible, ultraviolet and infrared light bands of the electromagnetic spectrum to transmit information. After a literature review on the potential of VLC in outdoor and industrial environments, it was brought to our attention that there is no universal answer as to its usefulness in those sectors. Therefore, the aim of this thesis is to demonstrate the feasibility or infeasibility of VLC in these two relevant environments. To this end, simulation tools and prototypes have been developed with the main objective of studying the major constraints encountered in these environments. This extended abstract presents the guiding questions of the thesis followed by a statement of contribution that highlights the novelties of this work in terms of simulation tools and prototypes.

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II. Research questions of the thesis

The first part of the thesis focuses on the comprehension of the technology, its optimisation and the exploration of its capabilities. The second one focuses on the practical outcomes that can be deduced from the thorough study. Taking both aspects into account, the thesis replies to the questions below:

- What are the founding technical blocks that allow to understand and evaluate the limits of the system? This question is then subdivided in two.
  - How to optimize/improve the VLC system by studying the outdoor transmission channel and mitigating its effects on the optical communication? For this purpose, a channel simulator was developed to include the impacts of the amount of particles in the air on an optical communication.
  - Which new signal processing techniques can be proposed to increase its performance? Can innovative systems be designed from the conclusions drawn? To this end, the simulator is capable of studying different kind of signal processing modulation schemes. It turns out that UFMC (Universal Filtered Multi-Carrier) performs better than the classical OFDM (Orthogonal Frequency Division Multiplexing).
- How to exploit what exists today as commercial equipment and off-the-shelves products to build real-life applications that reply to real constraints? In that scope, a range of prototypes coupling different pairs of emitter/receiver have been developed.

III. Statement of contribution

The thesis aims at achieving the objectives of the Wal-e-Cities project, that funded this thesis, through a scientific research rigour [1]. As the project is an R&D project about telecommunication technology, the core research was undertaken through a telecommunication engineering approach by first studying the communication channel and then a point-to-point communication. Afterwards, prototypes were implemented and studied. This section details the replies to the different research questions.

A. Study of the transmission channel

The transmission channel is the space between the emitter and the receiver. To characterize at best the VLC system, the phenomena that can occur between the light wave and the space surrounding it, a simulator has been developed using open-source tools. The simulator includes the characteristics of the emitter, the receiver as well as the overall space configuration such as the presence or absence of walls in the studied space. Compared to simulators described in the scientific literature, key improvements have been added. In place of only using theoretical Lambertian assumption, the simulator also enables the use of any LED lighting taken from actual optical power measurements (freely available from constructors), making it closer to reality as possible. The outdoor environment has been thoroughly explored thanks to different weather condition models. A novel smoke model has been issued from the combustion literature, adapted and added in the simulator in the scope of the thesis. Combined with other models, they allow to estimate the attenuation the optical signal undergoes from the emitter to the receiver. The description of the scenario around the LEDs is as flexible as possible in terms of the distribution of wall reflection properties. In conclusion, this tool allows the end-user to theoretically study the communication coverage of a VLC system for smart city and industrial scenarios. Finally, some concrete reference scenarios have been developed in the thesis [2][3].

B. Performance study

On the performance study side, this thesis aims to optimize point-to-point transmission, namely by wisely chosing the modulation scheme. A modulation scheme is a process by which the signal is transformed into a waveform suitable for the transmission channel. Three different schemes have been explored in this thesis. They follow the evolution of VLC standards from the oldest version (OOK: On-Off-Keying), via the lastest one (OFDM: Orthogonal Frequency Division Multiplexing), towards an innovative proposition in the VLC domain (UFMC: Universal Filtered MultiCarrier). The challenge of OFDM and UFMC, when they are used with an optical source in general, and a VLC source in particular, is the necessity of adapting the signal processing to their requirements that are different from RF (Radio Frequency) communications. As one of the results of this work, the relative spectral efficiency highlights a gain of 16% and a 5 dB SNR (Signal to Noise Ratio) gain for a VLC-UFMC communication scheme compared to a VLC-OFDM one, showing the potential of this new waveform. All those developed simulators enable the researcher to estimate the theoretical performances of a VLC system in both smart city or industrial scenarios previously to any effective implementation.

C. Prototyping

The "Development" axis of the Wal-e-Cities R&D project focused on the design and study of low-cost prototypes that combine different types of LED transmitters and optical receivers. The thesis addresses the fundamental question of the technical feasibility of deploying this kind of technology in smart cities and smart industry environments. The first smart city prototype is the demonstration of the Wavelength-Division Multiplexing (WDM) capabilities of a tri-colour LED (Red, Green and Blue). This prototype enables the sending of three simultaneous streams of data while keeping the overall light white. The second one presents a system that uses a camera as a receiver using the Optical Camera Communication (OCC) principle [4]. This enables the triggering of stored contents on the end-device. Regarding the industrial prototypes, a small scale robot arm controlled thanks to a VLC link has been developed as well as an Automated Guided Vehicle (AGV) [5].

IV. Conclusion

The main contribution of this thesis is a set of tools that can assess the theoretical feasibility of deploying VLC in constrained environments and the development of different low-cost prototypes. It is also important to conclude that this study shows that VLC is emerging as a relevant technology for smart city and industrial applications in he coming years.

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