Visible Light Communication Challenges in the Frame of Smart Cities

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ABSTRACT
Visible Light Communication (VLC) is the family of telecommunication technologies that uses the visible range of the electromagnetic spectrum to send data. This technology mainly uses Light Emitting Diodes (LEDs) to simultaneously illuminate and send data. Furthermore, thanks to the adoption of LED lighting by cities and for car lights, VLC is about to bring a lot of interconnectivity possibilities among devices in the city, making this latter smarter. Even though outdoor VLC is still in the research phase, the main promising applications foreseen by this technology are urban Li-Fi (Light Fidelity), VLC-IoT (Internet of Things) and V2X (Vehicle to Vehicle or Vehicle to Infrastructure). VLC-IoT is envisioned as a streetlight communicating with the surrounding urban furniture or a streetlight sending location-based content to a visitor located under its light beam. V2X is intended to communicate with each other and/or with the street infrastructure. In this way, VLC could reply to the lack of connectivity in some places and relieve the RF spectrum. This work outlines and surveys the current state of Visible Light Communication in outdoor environments, its main challenges, the most promising outdoor applications and the still ongoing standardisation efforts in the context of Smart Cities.
Keywords: visible light communication, smart cities, VLC-IoT, V2V, V2I, Li-Fi.

1. INTRODUCTION

Over the past few years, Smart Cities have been trending all over the world. Headlines put forward cities with smart transportation, smart waste management, smart energy, smart government systems. But a Smart City is not limited to that [1]. It is an ecosystem that uses data collected from its citizens and its environment to make their lives better and optimize the resources of the city to reduce its ecological footprint. This is possible thanks to technology and the digitalization of many services.

One of the many challenges that a smart city faces is the urban connectivity for its inhabitants as well as for sensors spread in the city that collect relevant information. The RF (Radio Frequency) spectrum as we know is getting more and more crowded on the grounds of the increasing number of connected devices in the streets either for IoT (Internet of Things) purpose or a person having several connected objects. The RF spectrum is a limited and regulated resource so new alternatives of connectivity must be found.

Among the existing telecommunication technologies, the family of Optical Wireless Communication (OWC) technology is gaining increasing interest in the fields of research and business [2]. OWC encompasses the communication technologies that use ultraviolet (UV), visible light (VL) and infrared (IR) spectrum ranges of the electromagnetic spectrum to send information. UV communication (UVC) is not considered as a potential for smart city use cases as it can damage the skin of citizens. VL communication (VLC), which covers the 400 to 750 nm range, has an attractive spectrum enhancement factor of 1230 times the current 300 GHz [3] wide RF spectrum band. This makes VLC technology very attractive for telecommunication solutions [4]. Most VLC systems use LEDs (Light Emitting Diodes) as their optical frontend and the introduction of LED lighting in the cities makes this technology relevant [5]. IR communication is often used alongside VLC for the uplink communication in bidirectional systems. Free Space Optics is another use case where IR lasers are used for long distance communication [6]. The most famous application using VLC is Li-Fi (Light Fidelity) [7] which is the equivalent of Wi-Fi (Wireless Fidelity) but using visible or infrared light to communicate as opposed to wireless electromagnetic waves. Within the different categories of OWC, VLC is the most promising technology for smart cities.

This trend about VLC is visible in the academic publication records. As an illustration, Fig. 1 is a bar chart that represents the cumulated number of citations using the keywords: *Visible Light Communication*, *infrared communication*, *Li-Fi*, *Free Space Optics* and *Optical Wireless Communication*.

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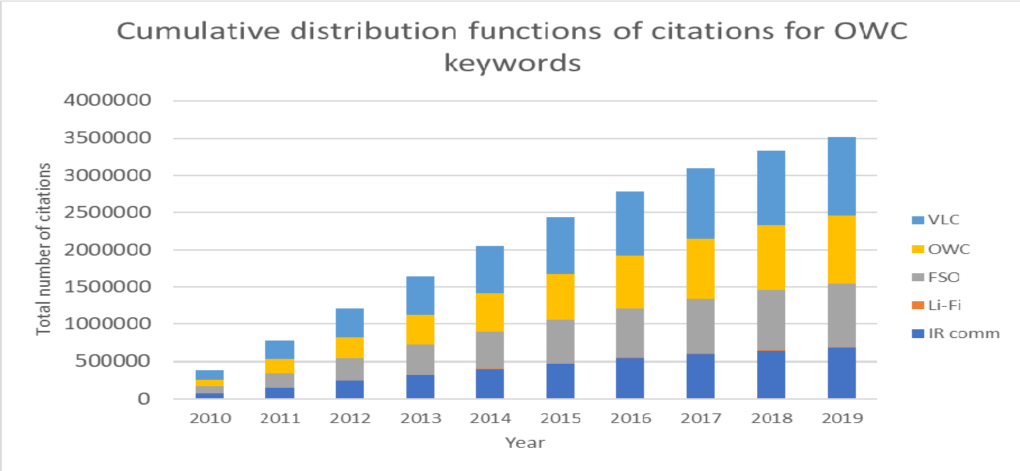

Figure 1. Cumulated number of citations of OWC keywords.

Data were collected on *Google Scholar* starting from the beginning of 2010, one year before the invention of Li-Fi, until the end of 2019. It can be observed in Fig. 1 that in one decade, the papers with one or more of these keywords have grown at a fast rate. Furthermore, VLC on its own, is steadily increasing in interest by representing a fair fraction of citations making it the most teeming of activity, and so, a promising technology.

Another *Google Scholar* search of the number of citations including the keywords *smart city* and *visible light communication* enabled the computation of the proportion of papers dealing with VLC including "Smart City" in the paper. It turns out that 5% of the papers with VLC included the words *Smart City*. This figure supports the need to encourage outdoor VLC research in the scope of Smart Cities.

This paper presents the promising VLC technologies that can be considered in Smart Cities. Section 2 presents more deeply each application followed by the presentation of a generic VLC system in section 3. VLC technology faces many challenges. The main ones are listed in section 4 which precedes the conclusion.

2. SMART CITY VLC APPLICATIONS

An overlook of a hypothetic smart city street, like in Fig. 2, shows the main VLC applications. There are 3 main categories of VLC application:

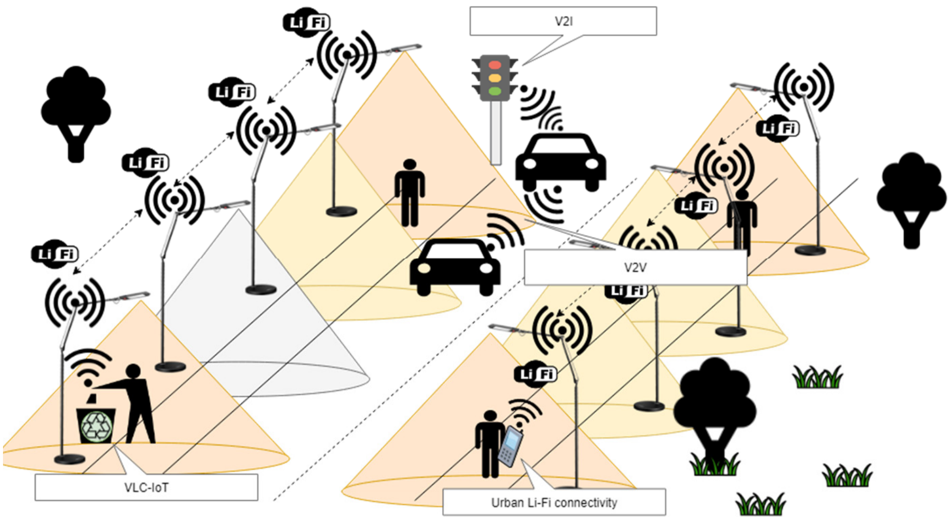

Figure 2. Hypothetic smart city street using VLC technologies.

- **<u>V2X communication</u>**: V2X refers either to V2I (Vehicle-to-infrastructure) [8] or to V2V (Vehicle-to-Vehicle) [9]. V2I can be a LED traffic light sending an information to the incoming car when it is about to turn red or green. The incoming car then relays the information to the car behind it and starts therefore a communication chain from car to car. This would also make it possible to regulate the speed of cars in congested road conditions.
- **<u>VLC-IoT</u>**: Street furniture can communicate with their surroundings thanks to the visible light of streetlights for downlink communication and are using infrared light for uplink communication. A decoupled communication network can be created to offload the RF networks. This network can be dedicated to low data rate IoT applications with sensors spread across the city. The example in Fig.2 is

a bin equipped with an infrared LED that can send information when it is nearly full to the streetlight. The streetlight can then rely the information back to a central unit.

- **Urban Li-Fi connectivity**: Li-Fi is the most promising VLC application as it is a high data rate communication use case. Products are already available for indoor settings using visible light or infrared light. As part of a Smart City solution, some streetlights can be equipped with Li-Fi drivers to offer high data rate connectivity to end users. Figure 2 depicts this example with an end user using its smartphone under a *Li-Fi* enabled light. The key challenge to make this use case possible is either making the camera sensors more sensitive to light variations or adding a photosensor on new smartphone generations.

3. VLC GENERIC SYSTEM

VLC systems show like any telecommunication system 3 main parts: the emitter, the channel and the receiver.

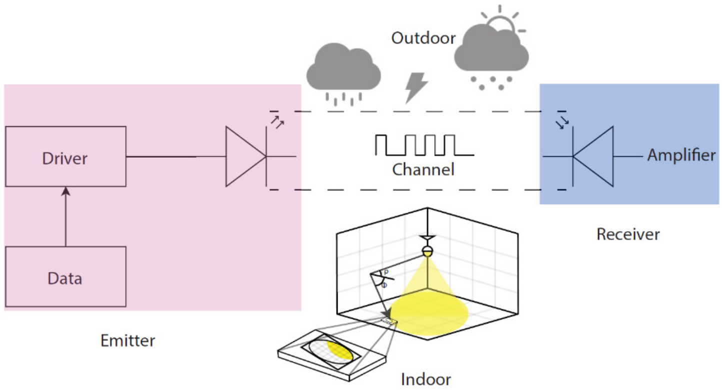

Figure 3. Generic VLC system.

- **The emitter**: it is usually a hardware capable of converting the data into either a digital or an analog electric signal to drive the LED [4]. Any off-the-shelf LED can be used as the optical frontend.
- **The channel**: Depending on the environment, different phenomena impact the communication channel and attenuate the optical signal. In VLC, the system can either be deployed indoor or outdoor. The main source of indoor optical attenuation is the distance between the emitter and the receiver as well as the reflection of the optical signal on any obstacle in the room. Outdoor, sunlight and artificial lighting can increase the noise level at the receiver side [10]. Furthermore, some weather conditions such has fog and rain can attenuate the optical signal [11].
- **The receiver**: There are 3 types of receivers in VLC systems. The most common solution is a photodiode that converts the optical signal into an electric signal to be decoded in a hardware [4]. Another solution is using the camera of the smartphone to decode the optical signal thanks to the rolling shutter technique [12]. The last decoding method is for outdoor VLC communication and it is based on solar panels [13].

4. OUTDOOR VLC CHALLENGES

A large number of achievements have been carried out in indoor Visible Light Communications this past decade. Companies are starting to make VLC or Li-Fi products available on the market. However, this activity is still a niche market and outdoor applications are not yet popular. In order to make it available on the mass market, VLC products face some challenges. There are technical challenges linked to the VLC system itself but also marketing challenges. The technical challenges include the necessity to have a secure [14] flicker-free [15] system, always keeping a Line-of-Sight between the emitter and the receiver, also being robust against variable weather conditions. The second set of challenges is related to marketing. For now, companies and most research work focus their energy on indoor applications. Market research highlighted the larger customer base including private companies and schools for indoor products. Most products available include a LED, IR or VL emitter and a USB receiver that needs to be plugged onto the receiving end-device. This limits the use of Li-Fi on smartphones and tablets and thus slowing down the deployment of urban Li-Fi. In order, for this latter application to work, phone manufacturers should add a high data-rate photodetector or make Li-Fi compliant phone cases affordable. Thus Li-Fi product manufacturers should work together with the lighting and phone industries. The lack of a unique standard also hinders the development of VLC applications. Figure 4 is a timeline showing the existing and upcoming VLC standards. Most of them focus on indoor high data rate communication. Only IEEE 802.15.7 [16][17] gives some guidelines for outdoor low data rate applications. This makes it difficult to choose one as the basis of Li-Fi compliant smartphones and end-devices developments.

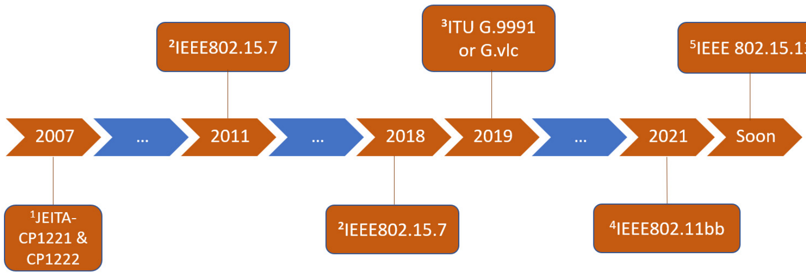

Figure 4 Timeline of the existing VLC standards.

[1]Japan Electronics and Information Technology Industries Association; [2]IEEE Standard for Local and Metropolitan Area Networks – Part 15:7: Short-range Optical Wireless Communications;[3]High speed indoor visible light communication transceiver – System architecture, physical layer and data link layer specification; [4]IEEE 802.11 Light Communication. Integration of Li-Fi in IEEE 802.11 LAN protocol; [5]Multi-gigabit/s Optical Wireless Communications for industrial environments.

5. CONCLUSIONS

In this paper, outdoor Visible Light Communication is presented as a good candidate to relieve the crowded RF spectrum in Smart Cities. Indeed, by using the visible and infrared spectrum ranges to send information, a decoupled optical network can be created. Several promising applications include the use of VLC for IoT use cases, Vehicle-to-Infrastructure/Vehicle communication and high data rate Li-Fi to complement the Wi-Fi offer in the streets. On the downside, there is much work to be done to build robust outdoor applications and some marketing challenges to overcome before deploying it massively. On the bright side, this technology is relevant as more and more lights in the streets are being replaced by LEDs. Our future Smart Cities will be living labs with different types of technology serving the citizens and the welfare of the city.

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