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An experimental evaluation and prototyping for visible light communication☆

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A B S T R A C T

As the research community is moving toward 5G technology, it is important to keep up this growth by developing new technologies and mechanisms that fulfill its requirements such as spectrum availability, wireless connectivity and coverage. Visible Light Communication (VLC) has been proposed as an efficient way of utilizing the visible wireless spectrum for proving lightning and carrying information utilizing the highly available visible spectrum. In this paper, an experimental evaluation and prototyping are presented utilizing off-the-shelf electronic components and the Telecommunications Instructional Modelling System (TIMS), which is a flexible modelling and prototyping technique widely used for building communication systems. The proposed prototypes are supported by a survey that was conducted among engineering students to get their feedback in regards to VLC, TIMS and 5G technologies. The aim of this paper is to provide the means to pave the way toward educating the students and new technology adopters concerning VLC along with facilitating its deployment.

1. Introduction

Technology has been rapidly advancing in many different directions that are exceeding the human imagination and expectation. When researchers, for example, started to discuss the idea of Vehicle-to-Vehicle (V2V) and Machine-to-Machine (M2M) communication long time ago, it looked as pure imaginary scenarios that will never be applied. That is not anymore true, especially when the U.S. Department of Transportation has been actively engaged in standardizing this technology [1], and has recently unveiled its requirements for US car manufacturers to include the Dedicated Short-Range Communications (DSRC) modules in their future cars. As such, with 5G-technology advancement, people should expect to have their home appliances and many other devices capable of communicating and interacting with the Internet for a variety of useful and innovative applications, which are expected to take place in the near future. The authors in [2,3] referred to the major challenges currently facing the wireless communications infrastructure in the telecommunication industry, that are

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very essential to address in order to actualize 5G technology implementation. These challenges can be mitigated by using the visible light communication. The first one is capacity. The radio frequency spectrum is currently bearing the entire load when it comes to commercial and non-commercial wireless transmission systems, which have made it extremely scarce and expensive. With the exponential increase in data consumption and the rapid advancements achieved in multimedia quality on mobile devices, the radio frequency spectrum is set to hit a roadblock in the near future. Therefore, applications' providers cannot rely solely on this part of the electromagnetic spectrum for wireless communication in the future. A quick look at the remaining part of the spectrum shows that waves in the ultraviolet range and beyond are too dangerous to humans for any commercial wireless data transmission usage. The Infrared spectrum is also not a viable solution as there are regulations limiting the maximum power that can be used due to its harmful effects on the human eye. This leaves the visible light spectrum as the only safe and feasible solution to the radio frequency spectrum's capacity problem, which offers 10,000 times more capacity than the radio frequency spectrum [4].

The second problem encountered in wireless communications is the efficiency. Currently, base stations are some of the most inefficient components in wireless communications. These stations require significant amounts of power to cool down, Light Emitting Diodes (LED) lamps and long-range lasers, on the other hand, are commercially famous for the cost savings offered due to their economic power consumption. Accessibility is yet another aspect, in which the radio frequency spectrum has shortcomings. Airplanes and hospitals are only few places where radio frequency devices' usage is not recommended since it may interfere with other critical devices or communication systems, especially when operates on the freely available Industrial Scientific Medical (ISM) frequency band. Visible light, however, does not face these problems, as it does not cause any interference with other electromagnetic fields generated by radio frequency devices. Lastly, the issue of security has always been a concern for radio frequency communication. Since radio waves spread in a largely uncontrolled manner, they are prone to eavesdropping when not properly secured. Radio waves also penetrate walls and other materials, making them hard to contain within a specific area. Although this can be considered a feature, it can also be seen as a disadvantage when considering confidential communication. For these reasons, most highly secure connections are usually carried through wired infrastructure to avoid this problem. Light waves have completely different properties when it comes to wave spread and penetration as they cannot pass through opaque materials, which restrict its range to regions where a VLC access point can be reached. This feature can be highly desirable in office rooms or meeting halls, where the wireless data transmission needs to remain within a confined area.

Given the above unique features, VLC has facilitated several indoor and outdoor applications that can totally either substitute the RF based solutions or complete its usage by providing extra bandwidth and coverage. Furthermore, the established robust infrastructure of radio frequency communication simply cannot be neglected. Therefore, the visible light communication should mostly be considered as a supporting technology, which may ease part of the load currently placed on the radio frequency spectrum. One of the areas where visible light communication can emerge as a key technology is the development of 5th generation mobile networks, or simply, 5G networks. As 5G networks are estimated to rollout sometime around 2020, visible light communication will be further matured by then and an opportunity to create devices that can use a hybrid system of visible light and radio waves to achieve the desired high data rates, without putting any heavy burden on the suffocating radio frequency spectrum, can be realized. The properties of visible light communication also allow for certain specific applications, which were difficult to achieve through radio frequency communication to have safe and disturbance-free visible light communication links. Underwater communication can also be a strong point for visible light communication as short radio waves cannot penetrate significant distances underwater. Visible light communication Line-of-Sight (LOS) links can have very interesting applications since their radiation spread can be easily controlled and lasers can replace streams of wires in certain infrastructure. Further, indoor positioning is another application, which takes advantage of the narrow and specific spread of a visible light communication access point [5]. A popular example for this application is the indoor positioning in departmental stores where ceiling LED arrays, which are placed a few meters apart throughout the store, can quickly and efficiently guide the user through their mobile devices on which directions to take in order to reach a certain product or department. The same principle can be implemented in museums, large conventions and any other large indoor areas. Another potential and interesting application is within the automotive industry, namely, vehicular visible light communication, which sometimes is referred to V^2LC and as the name suggests, allows vehicles to communicate with other vehicles or infrastructure such as traffic lights, road signs or even the roads themselves [6].

Most modern cars employ LED headlights and taillights, which can be easily used as transmitters, while image sensors can be used as receivers. Collision avoidance among cars forced braking on red lights and in-cabin announcements of warnings can all be potential features of V^2LC. The applications of visible light communication are numerous [7] whereas with the recent burst in interest surrounding the technology, the field has witnessed a spike in research and innovation. Hence, this paper provides a simple yet efficient prototype of this technology that can be used and integrated in educational institutes' laboratories and facilities.

The rest of the paper is organized as follows: Section 2 presents the literature review. Section 3 describes the basic VLC theoretical and mathematical background. Section 4 demonstrates the proposed TIMS VLC prototypes. Section 5 presents another prototype that is based on off-the-shelf electronic components. Section 6 discusses the conducted survey on the field of VLC, TIMS and 5G technologies. Finally, Section 7 concludes the paper and proposes future works.