Implementation Invisible Light Communication

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Abstract— Visible light communication (VLC) is becoming an alternative choice for next-generation wireless technology by offering low cost, unregulated bandwidth and ubiquitous infrastructures support. This technology is envisioned to be used in a wide range of applications both indoor as well as outdoor. Visible Light Communication (VLC) uses light emitting diodes (LEDs), for the dual role of illumination and data transmission. With this leading edge technology, data including video and audio, internet traffic etc. can be transmitted at high speeds using LED light. Using LEDs is helping to drive this technology in the form of Visible Light Communication (VLC). By enabling wireless communication among vehicles and also with the traffic infrastructure, the safety and efficiency of the transportation can be substantially increased. Considering the numerous advantages of the VLC technology encouraged the study of its appropriateness for the envisioned automotive applications, as an alternative and/or a complement for the traditional radio frequency based communications. In order to conduct this research, a low-cost VLC system for automotive application was developed. The proposed system aims to ensure a highly robust communication between a LED-based VLC emitter and an on-vehicle VLC receiver.

Key words: VLC (Visible Light Communication), LED (Light Emitting Diode) IT'S (Intelligent Transportation System)

I. INTRODUCTION

Nowadays, a lot of researchers are working on the development of light-emitting diode (LED) lighting system. The LED lighting system can achieve lower power consumption and has a longer life-time. Meanwhile, the development of the Solid State Lighting (SSL) devices, especially of Light-Emitting-Diodes (LEDs), had a huge growth. Nowadays, LEDs are highly reliable, energy efficient and have a life-time that exceeds by far the classical light sources. Considering the numerous advantages, LEDs began to be used in more and more lighting applications and it is considered that, in the near future, they will completely replace the traditional lighting sources. Beside these remarkable characteristics, LEDs are capable of rapid switching, which enables them to be used not only for lighting but also for communication.

Visible Light Communication (VLC) represents a new communication technology that uses energy efficient solid-state LEDs for both lighting and wireless data transmission. VLC uses the visible light (380-780 THz) as a communication medium, which offers huge bandwidths free of charge, it is not limited by any law and it is safe to human body, allowing for high power transmissions. VLC has the potential to provide low-price high-speed wireless data communication. Even if VLC is a new technology, it had a fast development, which is a proof of its huge potential.

The architecture of VLC system: A VLC system mainly consists of a VLC transmitter that modulates the light produced by LEDs and a VLC receiver based on a photosensitive element (photodiode) that is used to extract the modulated signal from the light. The transmitter and the receiver are physically separated from each other, but connected through the VLC channel. For VLC systems, the line-of-sight (LoS) is a mandatory condition. A schematic of a VLC system is illustrated in Figure 1.

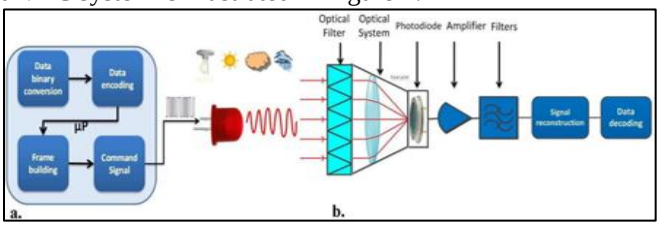

Fig. 1: Architecture of a VLC system: a. Emitter; b. Receiver

A. The VLC Emitter

A VLC emitter is a device that transforms data into messages that can be sent over the free space optical medium by using visible light. The purpose of the VLC emitter is to emit light and to transmit data at the same time. The core component of the VLC emitter is the encoder which converts the data into a modulated message. The encoder commands the switching of the LEDs according to the binary data and to the imposed data rate.

B. The VLC Receiver

The VLC receiver is used to extract the data from the modulated light beam. It transforms the light into an electrical signal that will be demodulated and decoded by the embedded decoder module. Depending on the required performances and the cost constraints, the decoder can be a microcontroller. Generally, the VLC receivers are based on photosensitive elements which have high bandwidth and offer the possibility of high-speed communications.

C. The VLC Channel

The two main components of VLC are interconnected through the free space optical communication channel. As the visible light is an electromagnetic radiation, similar to all electromagnetic radiations, its intensity decreases with the square root of the distance as it passes through the communication channel, making the signal that arrives at the receiver to be very low.

D. Intelligent Transportation System in VLC

ITS ads value to the transportation system by offering real-time access to traffic information. ITS continuously gathers information, analyze it and distributes it to increase efficiency. The gathered data is used in order to automatically adapt the transportation system to different traffic situations. Large geographical distribution of the intelligent

infrastructure is also required so that the system is able to gather more data and to be able to distribute it efficiently. At the same time, a major challenge for the ITS, is to keep the implementation cost as low as possible but without affecting its reliability. ITS is concerned by three major issues: safety, congestion and environment. The safety of the transportation system can be improved by increasing vehicle awareness. The benefits of adding intelligence to the transportation system are the efficient monitoring and management of the traffic which will help reduce congestion and provide optimized alternative routes depending on the traffic situation. Increasing the efficiency of the transportation system will help save time, money and will reduce pollution. But, the most important benefit of the ITS will be the millions of saved lives. The primary beneficiaries of the ITS are the travelers that will travel in safety and will use optimized travel routes but also the transportation companies and the industry.

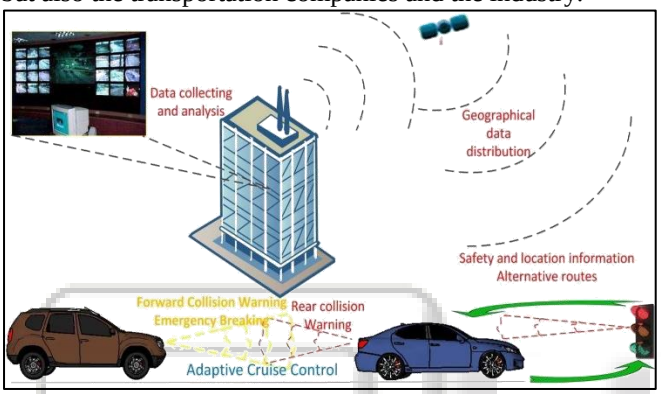

Fig. 2: ITS architecture including the three major components.

IT'S has three major components connected together by wireless and/or wire communication technologies. The three components are:

- The intelligent vehicles;
- The intelligent infrastructure;
- The traffic center.

Intelligent vehicles equipped with on board equipment for wireless communication are connected together and to the intelligent infrastructure forming a Vehicular Ad-hoc Network (VANET). The intelligent infrastructure also uses wireless communication technologies to communicate with the intelligent vehicles and wired communications to connect with the traffic center and for interconnections. The intelligent infrastructure is basically the connection between the intelligent vehicles and the traffic center.

II. The Potential Usage of VLC in ITS

The main advantages of VLC usage in automotive applications are represented by the low complexity, reduced implementation cost and the ubiquitous character. All these characteristics can facilitate a rapid and wide market penetration, which represents a strong considerate (argument) in the favor of VLC.

LEDs are highly reliable, energy efficient and have a life-time that exceeds by far the classical light sources. These unique features made the car manufacturers to think of replacing the classical halogen lamps by LED lighting systems. The efficiency of the LEDs made them being used also for LED-based traffic lights. This new generation of traffic lights is becoming more and more popular and is beginning to be used on extended scale. The main advantages of these traffic lights are: low maintenance cost, long life and low energy consumption but also the better visibility.

In this context, one can see that LED-based lighting will be part of the transportation system, being integrated in vehicles and also in the infrastructure. The large geographical area in which LEDs lighting will be used, combined with VLC technology will allow ITS to gather data from a widespread area and can enable the distribution of high quality communications. These additional functions will be possible without affecting in any way the primary goal which is signaling or lighting. The success of the ITS is largely dependent on its penetration. Insufficient penetration means insufficient data collection and distribution. If it is to think of RF solutions for the ITS, this will not be possible for a long time ahead because in order the system to be effective it is needed that all intersection and streets to be equipped with RF units, which implies huge implementation cost.

III. Advantages of VLC

A. High Bandwidth

The RF(Radio Frequency) communications come with an available spectrum of 300 GHz, which is used for different types of applications such as: AM and FM radio broadcasting, television broadcasting, GSM, military applications or satellite communications. The Industrial, Scientific and Medical (ISM) band offers unlicensed access but the available bandwidth is limited. But VLC takes full advantage of the usage of the visible light spectrum which is between 380 and 780 THz, adding 400 THz off available bandwidth for the wireless communication.

B. Safe for the Human Health

The usage of the visible light as a carrier for the data enables VLC to be completely safe for the human health. Being safe to human health enables the possibility of high power transmissions which is another advantage of VLC.

C. Unrestricted Technology

RF communication can cause malfunctions of the high precision electronic equipment as the one found in hospitals or in aircrafts and for this reason, such places are RF restricted. On the other hand, besides being safe for the human body, VLC is safe also for the high precision electronic equipment, enabling its usage in such places.

D. Security

Unlike RF waves, the light cannot penetrate through walls, providing VLC with high security against eavesdropping. In VLC, one can basically see the data and ensure the security of the data simply by closing the door, making VLC suitable in military applications or in areas of high security.

E. Low Cost Implementation

Compared with other wireless technologies, VLC comes at a lower price thanks to some of its characteristics. Since no cost for a license is implied, the implementation cost is significantly reduced. A second advantage that helps VLC reducing the implementation cost of such systems is its ubiquitous nature. The third aspect which enables VLC to reduce the implementation cost is its reduced complexity.

F. Green Wireless Communication Technology

While the Earth's population is increasing and the human society is developing, the natural resource consumption the natural resource consumption and the pollution can be significantly reduced by decreasing the energy consumption. Artificial lighting, commonly provided by electric lights, represents a significant percent of the energy consumption. , VLC is also a green wireless communication technology. VLC is green firstly because it does not use additional power for the communication. The same light which is used for illuminating or signaling is used for carrying the data.

IV. Limitations in VLC

A. Stringent LoS Condition

Generally, LoS maximizes the power efficiency and minimizes multipath distortion. In some of the cases the mandatory LoS condition can be considered as an advantage because the interferences from other receivers are limited and the communication security is enhanced. However, there are other applications where this issue is considered as a strong disadvantage. Non-LoS communications are considered to be more reliable, flexible and robust. The mandatory LoS condition has a negative effect on mobility and, in some areas, it represents VLC's greatest disadvantage because an object interposed between emitter and received can block the communication, unless an alternate route is available.

B. Limited Transmission Range

When considering the transmission range, VLC cannot compete with RF communications. Even if the VLC transmission range can be increased by optimizing the emitter and receiver parameters, VLC communication range is still significantly shorter than RF communication range. On the emitter's side, the communication range can be increased by increasing the transmission power or by using a more directive light beam. On the receiver's side, the range can be increased by using different techniques for Signal to Noise Ratio (SNR) Enhancement, such as narrow Field of View (FOV) receiver, optical lens or different filtering techniques.

C. Susceptibility to Interferences

Another disadvantage of the VLC is its susceptibility to interferences. VLC is likely to be affected by other illuminating devices such as incandescent or fluorescent light sources. Generally, these light sources produce low frequency noise which can be removed with a high pass filter. Besides the artificial light sources, in outdoor applications, the sunlight represents a very strong perturbing factor. The sun produces unpopulated light which introduces a strong DC component that can be removed with capacitive DC filters. However, high intensity optical noise can saturate the receiver, blocking the communication.

V. Applications

A. Underwater Communications

Unlike RF communications which are not able to provide under water communications, VLC can be used in this environment. In this case, VLC can provide short range communications which can enable divers to communicate with each other or with the base station.

B. Creating Smart Places

VLC could be also used to create smart places as in museums, by providing geo-localized information. This way, the information about the exhibits can be provided to users' smart phones or tablets by using the indoor light. The usage of VLC in a museum is illustrated in Figure 3.

Fig. 3: VLC usage in a Museum

C. Li-Fi

One of the most important applications envisioned for VLC is providing of Light-Fidelity or "optical Wi-Fi". Thanks to the huge available bandwidth, VLC could enable high speed internet connections from the ceiling lamp. Li-Fi is favored in this case by the fact that the distances involved are just of few meters, equivalent to the distance between ceiling and office.

In this area, VLC is considered to be able to provide multi Gb/s connections. As illustrated in Figure 4, the data coming from the internet is transformed by a Li-Fi router into a signal which is applied to the light source. The light source will switch on and off at frequencies unperceivable by the human according to the data to send. The receiver transforms the light signal into numerical data which will be delivered to the mobile terminal. Concerning the upload, it is performed using an infrared link.

Fig. 4: VLC usage for wireless internet (Li-Fi).

The fast evolution and the huge potential of the Li-Fi technology contributed to the foundation of the Li-Fi Consortium in 2011. The organization brings together the leading companies and research institutions from the optical communication technology and aims at contributing to the development of the technology.

D. Indoor Localization

In addition to Li-Fi, VLC can provide very efficient indoor localization. By determining the received signal strength or the time of flight and by using the triangulation technique, VLC is able to provide localization at centimeter accuracy. In this type of applications VLC is very convenient since the classical GPS is not able to work inside buildings. Such a scenario where VLC is used for indoor localization is

proposed in and illustrated in Figure 5. The indoor localization is also possible by providing the ID of the lamp, which includes its coordinates.

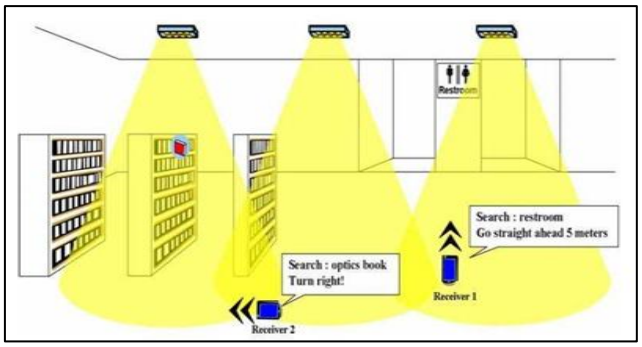

Fig. 5: VLC usage for indoor localization

E. Provide Wireless Communication in RF Restricted Areas

Due to its nature, VLC can be safely used to provide wireless communications in areas where RF communications are restricted. For example, due to the risk they pose, the usage of RF communications in hospitals and in health care units are restricted, especially in operating theatres and around MR (magnetic resonance) scanners. However, in such places the information exchange is possible by using a VLC system as the one presented in. Aviation is a restricted area for RF communications. VLC can be also used in hazardous environments where there is a risk of explosions, such as in mines, chemical plants or oil rigs. In all these areas where RF communications are restricted due to the risk they pose, VLC can be successfully used, not mentioning that the communication capability is a complement to the already existing lighting systems.

Fig. 6: VLC usage inside a plane

F. Transportation

The intelligent transportation system (ITS) is a particular area where VLC could be very useful. An important segment of both the academia and the industry considers that VLC could be Used in ITS to enable vehicle-to-vehicle (V2V) and/or infrastructure-to-vehicle communication (I2V). In ITS, VLC has the advantage that LEDs lighting systems already began to be integrated in traffic infrastructures and in the vehicle lighting systems. A scenario of using VLC for traffic applications is illustrated in Figure 7. A security vehicle can proceed on a damaged car and communicate about the situation around the accident area. One car receives the data and relays the information on its line. This information can be transmitted to the front car with the headlights and also to the followers with the red back-lights. Data are thus propagated on the motorway. Furthermore cars on the same line can also communicate with each-other about their mechanical state, like speed, acceleration, braking action or other data to enhance the traffic and its security.

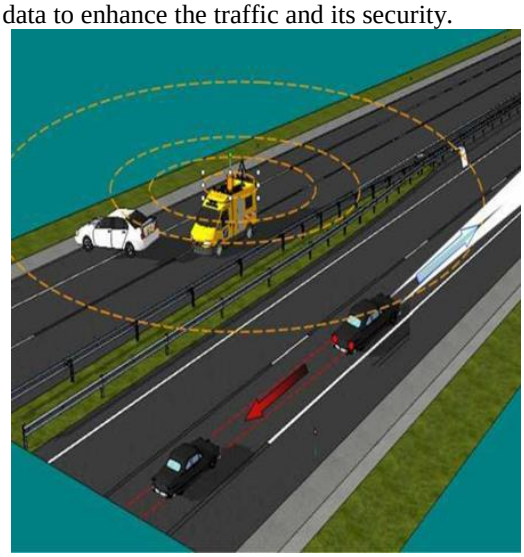

Fig. 7: Illustrations VLC usage in for data exchange in automotive applications.

VI. FUTURE SCOPE

The communication range: One of the most important issues that should be improved is the communication range. In this case, the problem is that the power of the signal and consequently the SNR drops significantly when the communication range increases. Increasing the receiver gain is a suitable solution but still, it has its limits, meaning that additional measurements should be taken.

The developed prototype is based on a single photosensitive element used for the entire visible light spectrum, from 380 to 780 nm. Its spectral sensitivity gets higher as the wavelength increases. This fact resulted in a shorter communication range for the green light compared to the red light. An efficient way to increase the communication range would be to design a receiver that uses an array of photo detectors, each of them dedicated to a specific wavelength (e.g. red, yellow, green). This way, the additional light corresponding to the other colors is filtered using an optical filter, leaving just the wavelength containing the data signal. The SNR level can be thus significantly enhanced and the communication range increased.

A. Mobility

In order to improve the SNR, the effect of the background noise is usually reduced by narrowing the receiver field of view. Even if it is helpful concerning the SNR improvement, it has a downside: the signal reception angle reduces the mobility. However, for the usage in vehicular communications, VLC has also to fully comply with the mobility of the vehicles. Furthermore, in the case of the proposed VLC system the experimental evaluation was performed with the emitter and the receiver relatively aligned. However, for real situations, the traffic light is set at a height between 2.5 and 5 meters above the road. This is for sure a serious issue that again, will significantly influence the performances of the system, limiting the service area.

B. Li-Fi

The Li-Fi technology can be used for various purposes, it matters the data transmission through LEDs thus all the screens which illuminate light can be served as a platform for data communication. The screen of the mobile phone, television, bulbs can act as a source of light. On the other hand, the receiving platform, the photo detector can be replaced by a camera in mobile phone for scanning and retrieving data. Its other applications are Li-Fi for desktops, smartcard Li-Fi, Li-Fi for schools, hospitals, Li-Fi in cities, smart guides, museums, hotels, fairgrounds, events indoor and LBS(Location-based Services), access control and identification crisis, malls, airport and dangerous environments like thermal power plants.

Li-Fi can be used at the place of Wi-Fi for internet connection to all devices. It is also very useful for communication between two devices for data transfer and other type of connections. It's provides the very fast speed for internet access and streaming purpose and also very fast and secure data transfer between the devices. So the Li-Fi Technology is very useful for general use like at the place of Wi-Fi and Other wireless technologies for data transmission or internet access.

VII. CONCLUSION

Even if VLC is an early stage technology, it has numerous advantages and a huge potential of development. This potential has been partially explored regarding the VLC usage for indoor applications. In this context, the main contribution of this thesis is the development, the Implementation and the experimental evaluation of a VLC system aimed for outdoor low-data rate applications. Consequently, the VLC emitter is developed to be representative for two cases. In the first one, the VLC emitter is based on a vehicle tail light. The applicability of such a system is in vehicle to vehicle communications. For the second case, the VLC emitter is based on a commercial LED traffic light. This choice was made in order to prove, how easily any LED lighting or signalling device can become a road side broadcasting unit. The usefulness of such a system is to increase the vehicle awareness. The VLC receiver is the most important part of a VLC system. Its performances are the ones that determine the overall system performances.

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