Research Statement: Vehicular Visible Light Communications

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***Abstract*—Lighting modules based on Light Emitting Diodes (LEDs) have become increasingly popular in the automotive industry, consequently Visible Light Communication (VLC) has emerged as a serious candidate for Inter-Vehicle Communication (IVC). As a new technology, VLC has a lot of intrinsic advantages, but the technology is too immature for us to conclude. It has a huge unlicensed spectrum which if combined with existing RF-based communication technologies provides inter-spectrum heterogeneity and opens up the path for various vehicular networking applications. However, there are lots of open questions to be addressed before we can discuss potential application scenarios. For one, the need for a sound Vehicular VLC (V-VLC) simulation model is evident in the community. To develop one such, I plan to investigate the channel properties of V-VLC via multiple empirical studies and iteratively reflect the gained insights to the model. Modeling the effects of mobility, interference, shadowing and environmental factors are some of the goals. The end result should be a simulation model which will support inter-spectrum heterogeneity and will enable the study of higher level topics, such as the coexistence of VLC and RF technologies, the quest for V-VLC's killer application, etc.**

I. Introduction

Intelligent Transportation Systems (ITSs) refer to a range of ICT solutions which aim to address transportation issues in different environments. As far as vehicular transportation on roads is concerned, Inter-Vehicle Communication (IVC) is the main facilitator of ITS application. The majority of proposed ITS applications until now are based on WLAN-like ad-hoc communication (e.g., Dedicated Short Range Communication (DSRC)), cellular communication (e.g. LTE), or a combination of both, known as heterogeneous vehicular networks. The aforementioned access technologies utilize the Radio Frequency (RF) bands of the electromagnetic spectrum. However, with the looming RF spectrum crisis [1], and the development of cheap and affordable Light Emitting Diodes (LEDs) Visible Light Communication (VLC) has emerged as a potential candidate for IVC. The advantages of VLC are manifold:

- The visible and near infrared spectrum together have a *huge unlicensed bandwidth* of nearly 670 THz, about ten thousand times the size of the RF spectrum. Since the VLC spectrum is unlicensed the usage of VLC bands is practically free of charge.
- LED-based light modules are becoming increasingly popular in the automotive industry. Such optical front-ends enable Vehicular VLC (V-VLC) and are relatively *cheap*.
- VLC's directional nature makes for *secure* communication since any interception of the communication link cannot go unnoticed.

However, VLC also has its shortcomings, for example:

- It is an emerging technology and inherently *immature*.
- In outdoor environment, where most of vehicle-to-vehicle communication is to take place, VLC is *susceptible to ambient light and weather conditions*. These have nontrivial implications on the communication channel.

From the communication perspective, there is a general consensus that LED-based light modules, (e.g., headlight and taillight), should be used as transmitters for a V-VLC system. Whereas, on the receiving end we can utilize either Photodiodes (PDs) or camera image sensors.

If the combination of ad-hoc and cellular technologies gives us intra-spectrum heterogeneity in the RF band, with the addition of VLC into the mix we get inter-spectrum heterogeneity for vehicular networks. One of the main challenges of such heterogeneous communication systems is finding out the use cases where a particular communication technology excels compared to others, and using it for that specific purpose. In that sense, I would like to investigate the applicability of VLC in the context of IVC and find out what would be the best application scenario for it, having in mind the distinct properties of the VLC waves. Moreover, if VLC is to be deployed in a vehicle with wireless communication capabilities, it is interesting to investigate whether applications running on different communication channels can coexist. And if so, how can they complement each other.

Given the current stage of development, the deployment of front-ends which enable V-VLC is prohibitively tedious beyond the scope of a few vehicles in order to conduct research. As an alternative, we can use simulation tools. However, the majority of vehicular networking simulators assume DSRC as the underlying communication technology, and do not provide support for VLC. In that regard, at the moment I am working on a simulation tool which can simulate vehicular nodes with dual communication interfaces, namely, DSRC and VLC. My plan is to incrementally improve this VLC simulation model by investigating the behavior of the VLC channel through real-world experiments. Once I have a credible simulation tool I can test the feasibility of VLC for various ITS applications even in large scale.

II. State of the Art

Many publications in the literature have addressed the topic of VLC in the context of vehicular networking. Uysal et al. [2] do mathematical modeling of empirically measured low and high beam patterns of tungsten halogen headlights which are selected based on vehicle sale numbers. Besides the Line Of Sight (LOS) component of the VLC link, their model also considers the Non LOS (NLOS) components reflected by the pavement, and the effect of pavement's built material and weather conditions on this reflectance. While Uysal et al. [2] use an analytical model to characterize the VLC channel, Lee et al. [3] base their study of the VLC channel on simulation tools. They use a commercial tool to model the low beam of an LED headlight and to construct the simulation scenarios. Then, the results obtained from these scenarios are fed into another simulation tool which uses backward optic ray tracing to obtain VLC channel's impulse response. Tomas et al. [4] present a VLC transceiver model for the JiST/SWANS simulator. In their work the physical layer is based on a simplistic analytical path loss model, whereas they adopt the IEEE 802.11 MAC as the MAC layer. There are a few publications which use heterogeneous simulation, combining DSRC with VLC. For example, Segata et al. [5] consider using VLC alongside DSRC for a real vehicular application, such as platooning. However, the used VLC model is purely probabilistic and abstracts many of the real channel properties. Similarly, Yu et al. [6] compare DSRC and VLC but they do not disclose any details about the simulation tool or model they use.

The current state of the art clearly points out that we are in the early stages of understanding how the V-VLC channel behaves. Although simulation has been used as a methodology for investigating V-VLC, there are significant deficiencies on that front. It is not only the lack of detailed channel modeling which is missing, but also the choice of simulation tools is questionable. Many works in literature simulate vehicular networks solely focusing on the communication perspective, thus completely omitting the effects of the vehicular road traffic on the communication channel. This is extremely important in the case of VLC – because of its directional nature the slightest changes in the mobility of the vehicles might affect the communication. Looking at the upper layers, various studies have improvised the MAC layer, oftentimes adopting oversimplified medium access schemes [4], [7], [8]. The IEEE 802.15.7 [9] standard specifies PHY and MAC mainly for indoor VLC but it does not address V-VLC yet.

III. Open Questions and Contributions

As part of my research I want to follow an iterative bottom up approach. Starting from the physical layer, via empirical measurements, I want to get better insights on the behavior of the V-VLC channel. Here, the challenges are manifold. For example, despite the availability of LED-based light modules in vehicles, they are meant only for lightning and not dual purpose: lightning and communication. Moreover, there might be vendor-dependent variations in the design of the light modules resulting in different beam patterns. Under such conditions coming up with a generic channel model for headlights and taillights is indeed an interesting research question. With respect to the channel conditions, I also want to investigate the effects of mobility, weather and other environmental factors on it. From each of the empirical measurements I will be able to collect data, which can be used to develop a sound V-VLC channel model. My goal is to initially complete the ongoing simulation model which will be supporting DSRC and VLC and iteratively refine it based on the new insights. This simulation model will enable us to investigate topics from the upper layers. For instance, I want to address the topic of medium access for V-VLC considering the dynamic nature of the vehicular environment and potential issues arising from it.

Finally, in the application layer I will look for the ideal vehicular networking application which can exploit V-VLC. This can be either platooning, or a cooperative awareness application. In the upper layers, the idea is to enable the coexistence of DSRC and VLC, and utilize them such that they complement each other. Particularly interesting questions might be network offloading and balancing strategies from DSRC to VLC, creation of overlay topology using VLC as backbone, and content buffering assuming that the V-VLC channel is highly dynamic but the data rates are very high over short time periods.

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