Poster: A VLC Solution for Smart Parking

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ABSTRACT

With the rapid growth of vehicle ownership, parking has become an issue, especially in metropolitan areas – the extra time for check-ins, check-outs and finding available parking spaces not only causes frustration and potential road rage on the driver side, but also increases the traffic congestion, gasoline waste and air pollution in consequence. In order to address these problems, the concept of "smart parking" is put forward. To make a parking lot "smart", we argue that three basic features, namely *Vehicle Identification*, *Parking Space Detection* and *Indoor Localization* are are critical and should be supported by the infrastructure. Herein, we present LightPark, a Visible Light Communication (VLC) solution to realize the vision of "smart parking". Building on top of the visible light backscatter communication primitive, LightPark is able to leverage the lighting infrastructure to perform scalable visible light communication and networking with the batter-free tag devices instrumented on the vehicles and parking spaces to manage the critical information such as identification and real-time location of vehicles, and status of parking spaces in a centralized and low-cost manner.

CCS CONCEPTS

• **Hardware** → **Wireless devices**; • **Computer systems organization** → *Embedded systems*;

KEYWORDS

Visible Light Communication; Backscatter; Smart Parking; Parking Space Detection; Indoor Localization

1 INTRODUCTION

In big cities, parking has become a potential societal problem. People waste a lot of time waiting for check-ins and check-outs, circling around looking for available parking spaces, as well as finding their cars when they forget where they park them. More importantly, these things not only frustrate drivers but can also lead to traffic congestion, gasoline waste, and air pollution.

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Aiming to resolve all these problems, the concept of "smart parking" is put forward in recent years. Imagine when you drive into a parking lot, a parking space will have been reserved for you in advance. The navigation system will give you, or even your autopilot system precise instructions to park your car into that specific parking space. There will be no problem if you forget where you park your car because your smart phone will be able to navigate you back. And you won't have to stop at the entrance or exit anymore because your car will be identified and the parking fee will be charged automatically. To realize the "vision" aforementioned, the following three features appear to be critical:

- **Vehicle Identification**, that is to say the parking lot should be able to identify the vehicles.
- **Parking Space Detection**, which means the parking lot should be able to detect whether a parking space is occupied and keep track of available parking spaces.
- **Indoor Localization**, which requires the parking lot infrastructure to provide vehicles and other smart devices the ability to locate themselves inside the parking lot.

To provide these features in a low-cost and easy-to-maintain manner, we propose LightPark.

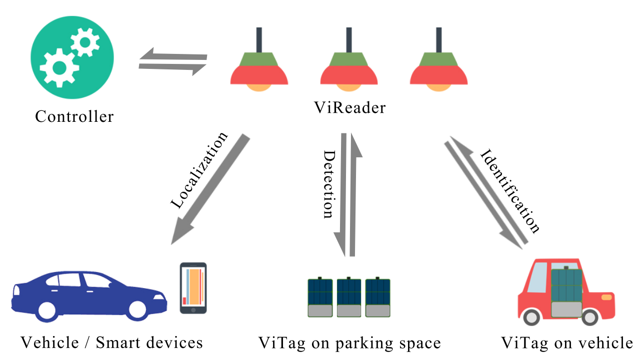

Figure 1: LightPark System Diagram

LightPark is based on a recently emerged technique called PassiveVLC [2, 4]. PassiveVLC is a low power visible light backscatter communication system, consisting of ViReaders and ViTags. ViReaders are LED light sources that can perform bidirectional communication with low-cost battery-free ViTags using visible light as carrier. More details about PassiveVLC can be found in §2.

Since PassiveVLC only specify the communication between one ViReader and one ViTag, a data link layer for it is designed and implemented to enable collaboration of multiple ViReaders and ViTags, making it possible to scale out. Without loss of flexibility, the data link layer is optimized for the needs of LightPark according to the characteristics of PassiveVLC. See §3 for details.

The key idea of LightPark is to replace the lighting facilities in the parking lot with ViReaders, thus lights will not only work for illumination but also act as medium to communicate with users, vehicles and parking spaces, enabling our desired features. §4.1 and §4.2 describe how LightPark supports *Vehicle Identification* and *Parking Space Detection*. We adopt *Epsilon* [3] as a subsystem to support *Indoor Localization*, which is briefly discussed in §4.3. Such system can be integrated into existing illumination infrastructure and be easily deployed.

2 BACKGROUD: PASSIVEVLC

PassiveVLC is a bidirectional communication system using visible light as its carrier. The system uses modified LED lights called ViReader to work as base stations, and the corresponding mobile devices are called ViTag, which are credit card size, battery-free tags built for IoT applications.

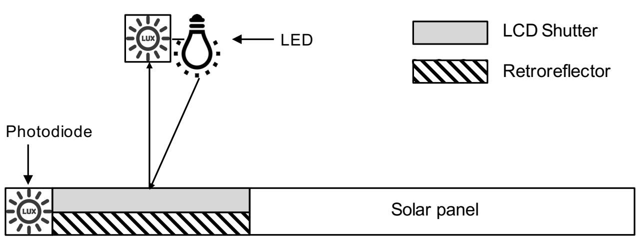

Figure 2: PassiveVLC design illustration.

Current communication systems for IoT applications are commonly based on RF techniques, *e.g.*, BLE and NB-IoT, *etc.*, while PassiveVLC shows another approach to achieve low-power, low-cost and practical networking and sensing. At a high level, PassiveVLC works as follows. For the downlink, the LED in ViReader switches on and off, turning the illuminating light into a communication carrier. The light signals are then picked up by the light sensor on the ViTag and decoded therein. For the uplink, the same carrier is leveraged via reflection. The ViTag uses a special material called retroreflector to concentrate and reflect the light from the lighting source and further carries information bits by toggling an LCD shutter. The modulated reflected light carrier is then picked up by a photodiode on the ViReader and further demodulated and decoded. PassiveVLC reported a maximum of 5*kbps* speed for downlink and 1*kbps* for uplink.

Meanwhile, such visible light link has another unique feature that it only performs line-of-sight communication. This feature, which is commonly treated as bad for communication, turns out to be critical to enable *Parking Space Detection*. *Indoor Localization* can also benifit from it to achieve higher accuracy.

3 SCALING OUT PASSIVEVLC

3.1 Logic Link Control

The Logic Link sublayer specifies communication mode, ID space, packet format and error control for the system. As the name suggests, ViTags perform passive communication, which means that ViTags will never actively send packets but respond to packets sent by ViReaders. The ViReader is able to unicast to a specific ViTag by ID, and broadcast to all ViTags within its work range.

Given the uplink speed being much slower than the downlink speed, we aim to reduce uplink packet overhead as much as possible. By taking advantage of the passive communication mode and offloading overheads to downlink packets, we manage to completely remove the header for uplink packets. Another trick that makes it possible is to XOR-encrypt the uplink packet with downlink checksum, so that only the sender can decode the uplink packet. As a result, our uplink packet consists of payload and CRC checksum only. The downlink packet is pretty ordinary, consisting of header, payload and CRC checksum.

3.2 Tag Discovery

The tag discovery protocol is responsible for discovering and identifying nearby ViTags within the range of a ViReader. The basic idea is to broadcast a query and let each ViTag respond its ID. The problem is that collision happens when multiple ViTags respond at the same time, in which case reader will not receive any useful information. To resolve these collisions, we adopt a binary tree based method. Compared to the slotted-ALOHA method used in EPC Gen 2[1] RFIDs, our method expects less uplink time.

3.3 Muliple Access of ViReaders

If two ViReaders' work ranges intersect, we say these two ViReaders interfere with each other. If they send at the same time, ViTags in their common coverage may not be able to decode the packet. Therefore, two ViReaders interfering with each other shouldn't be permitted to send at the same time. A MAC protocol for ViReaders is needed. Since the coverage of lights are relatively stable, and their position rarely change once installed, we can assume that the interference map is available in advance.

In our use case, the work load will be heavy as we frequently update the status of each parking space. Besides, concurrent sending for multiple ViReaders that do not interfere with each other should be allowed and utilized to gain better efficiency, since coverage of each light is relatively small.

With these properties taken into consideration, we come up with a centralized turn-taking Media Access Control protocol. In each turn, the centralized controller selects a set of pending ViReaders that do not interfere with each other, and permits them to send. It won't proceed to the next turn until all responses are received. The selection is done in a greedy manner, from the least recently sent ViReader to the most recently sent one, to guarantee fairness.

4 FEATURE DESCRIPTION

4.1 Vehicle Identification

Vehicle Identification requires a ViTag to be installed on each vehicle, usually on the front window by design. With these ViTags

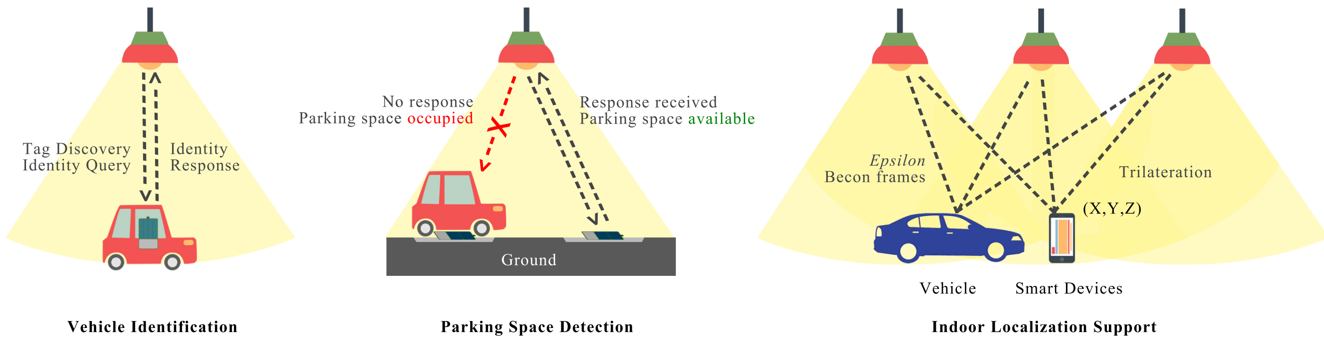

Figure 3: Illustration of LightPark features.

carrying vehicle identity information installed, *Vehicle Identification* is straight forward. The ViReader that needs to perform *Vehicle Identification* (e.g. the ones at the entrance or exit) simply runs tag discovery protocol and communicate with the discovered ViTags to obtain the corresponding vehicle identities.

4.2 Parking Space Detection

For *Parking Space Detection*, we have a ViTag installed onto the middle of each parking space.

Leveraging the fact that light travels in straight lines, we can indicate the occupancy of a parking space by reachability of the corresponding ViTag installed on it. Considering a ViTag within the work range of a ViReader, the ViReader should be able to get response from the ViTag if the corresponding parking space is available; otherwise if the parking space is occupied, the line-of-sight path between the ViReader and ViTag will be blocked, then the ViReader thus will never receive response from the ViTag.

For the parking-lot-wide detection, the solution is polling. At system start-up, each ViReader in the system runs tag discovery protocol to discover all the ViTags (representing parking spaces) it can manage. Then, once a ViReader is permitted to send according to Link Layer MAC (and there is no other packet pending to send on this ViReader), it sends to one of the ViTag within its work range to update the status of the corresponding parking space according to response. If there is more than one ViTag to choose from, the ViReader chooses the one that least recently got its status updated, for fairness.

4.3 Localization

Visible light based indoor localization has been well-studied in recent years. Among many works, *Epsilon* [3] provides a simple but powerful way for accurate localization. We adopt *Epsilon* as a subsystem of LightPark to support indoor localization. Note that in our system, in most of the time a ViReader is sending nothing but an empty carrier signal, due to asymmetric uplink/downlink rates and Media Access Control for ViReaders. We utilize these "wasted" time frames to send location beacons.

5 PRELIMINARY RESULTS

So far, we've built a prototype with 4 parking spaces and 2 ViReaders using the original PassiveVLC hardware for concept demonstration, shown in Fig. 4. We run the prototype under different configurations

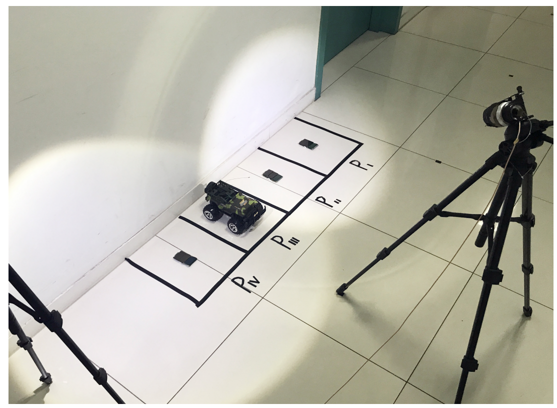

Figure 4: LightPark prototype

Configuration	Period
1 ViReader	0.45 s
2 ViReaders with interference	0.45 s
2 ViReaders without interference, each covering 2 parking spaces	0.23 s
2 ViReaders without interference, covering 1 and 3 parking spaces respectively	0.28 s

Table 1: Measurement result of average status update period under different configurations.

and measure the average status update period for all parking spaces. The results are shown in Tab. 1.

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