Enhancing Vehicle-to-Vehicle Communication Security: Unique Identification via Optical Camera Communications

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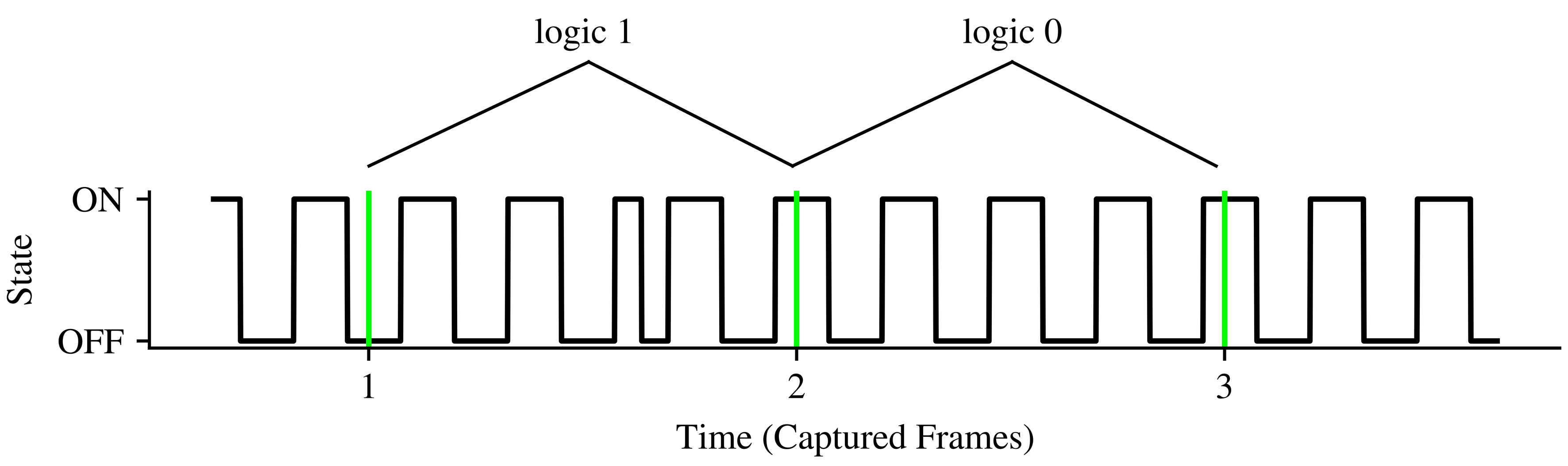
INTRODUCTION

Over recent years, the use of advanced driver assistance systems (ADAS) and semi-automated driving has expanded in consumer markets. However, for the more complex applications envisioned within intelligent transportation systems (ITS), relying solely on on-board sensors is insufficient. Modern vehicles will be or even already are able to communicate with each other and their environment. If multiple vehicles are following each other on the highway, they can utilize vehicle-to-vehicle (V2V) communication to build a platoon. Sensing the environment and the distance to the vehicle in front using radar, lidar or ultrasonic sensors introduces a significant delay, constraining the smallest safe distance within platoon members. This delay can be substantially diminished by interconnecting the vehicles via low-latency radio frequency (RF) communication. This reduction in delay not only boosts traffic safety but also allows vehicles to maintain a closer proximity, thereby elevating the road capacity utilization, decreasing energy consumption, and mitigating emissions.

Of course, one of the key aspects of V2V communication is to verify the identity of the communication partner to ensure your car genuinely connects to the car in front while driving in a platoon. Mismatching communication, regardless of whether it happened unintentionally or was caused by a malicious third party, might lead to fatal incidents and must be prevented. Our research proposes a mechanism to verify the identity of the preceding car on the road by utilizing optical camera communications (OCC) as an out-of-band channel.

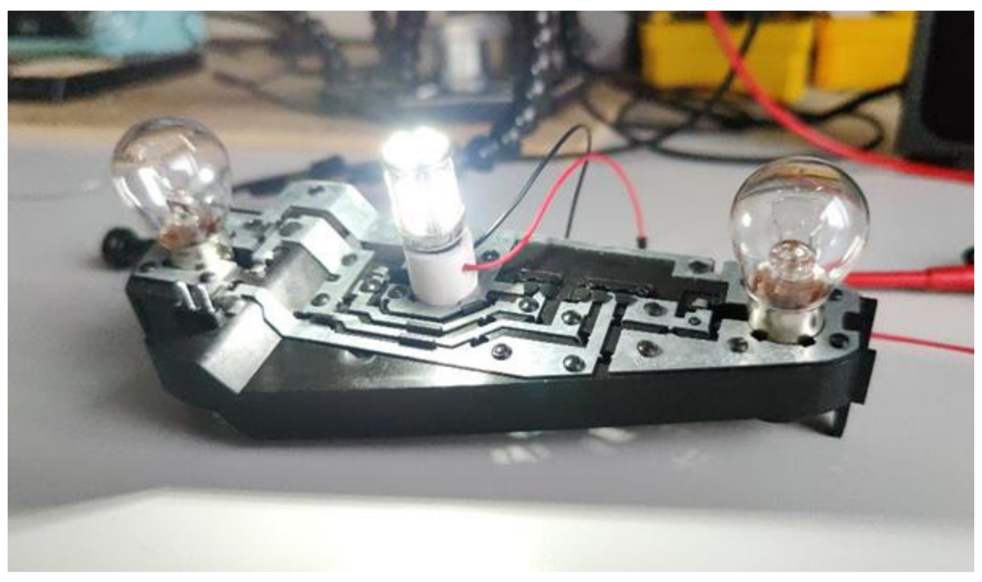
METHODOLOGY

V2V-OCC can be implemented by modulating the taillights of a car to transmit a signal. The front-facing camera of the following car can receive the message. This communication method uses undersampled differential phase-shift on-off keying (UDPSOOK) with a carrier frequency above the critical flicker threshold, ensuring the taillight flicker remains imperceptible to the human eye. A camera using short exposure time is able to capture the distinct states of the modulated taillights.

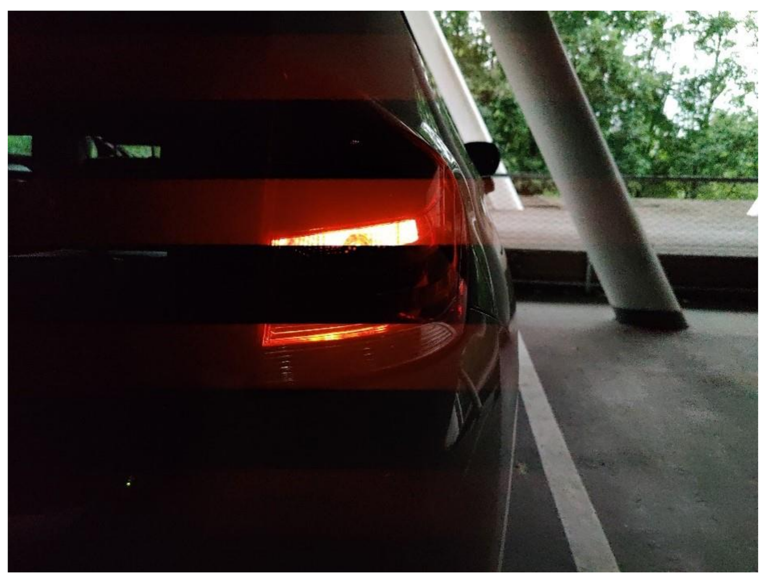


UDPSOOK modulation signal.

The limitation of UDPSOOK modulation, however, is its low throughput. It allows transmission of only a single bit per frame captured by the camera for each light source modulated. This throughput level is insufficient to convey safety-critical traffic information. But where V2V-OCC distinguishes itself is in image-based traceability. The data transmitted is visible in the camera footage along with the transmitting vehicle, allowing to associate each message with its origin. Using V2V-OCC as an out-of-band channel to transmit a verification key allows for confirmation of the communication partner's identity in the primary, low-latency RF channel. With this method, we ensure secure and reliable information exchange, strengthening the integrity of the main V2V communication channel.



V2V-OCC transmitter prototype.

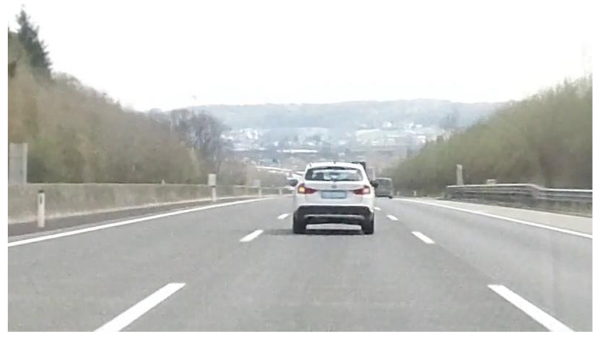


Rolling shutter effect.

EXPERIMENT

The developed prototype was subjected to rigorous testing in real-world conditions, conducted across selected public roads within the regions of Hagenberg and Linz. This test drive period covered approx. 800 km and encountered a comprehensive range of environmental conditions.

Sunny.



Partly cloudy.

Cloudy.

Light rain.

Medium rain.

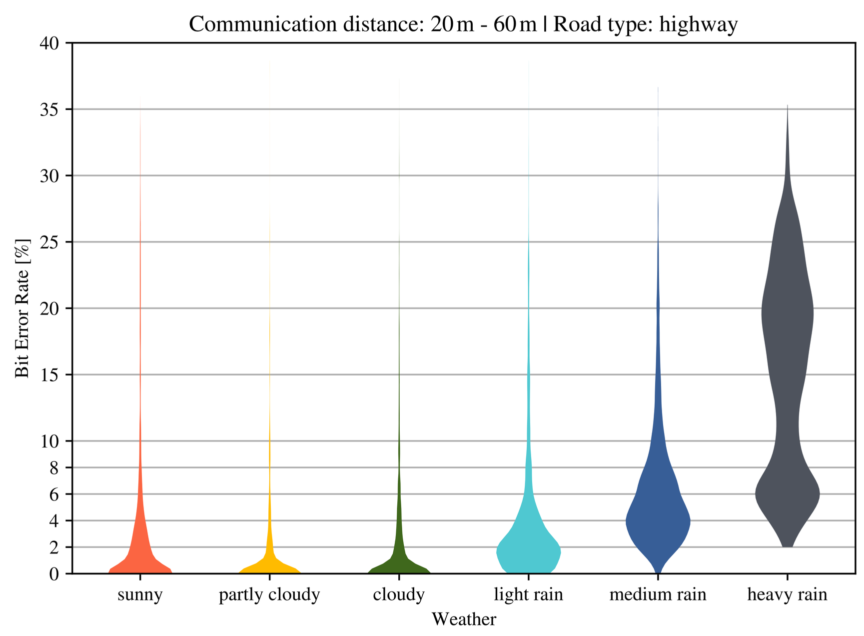
Heavy rain.

EVALUATION

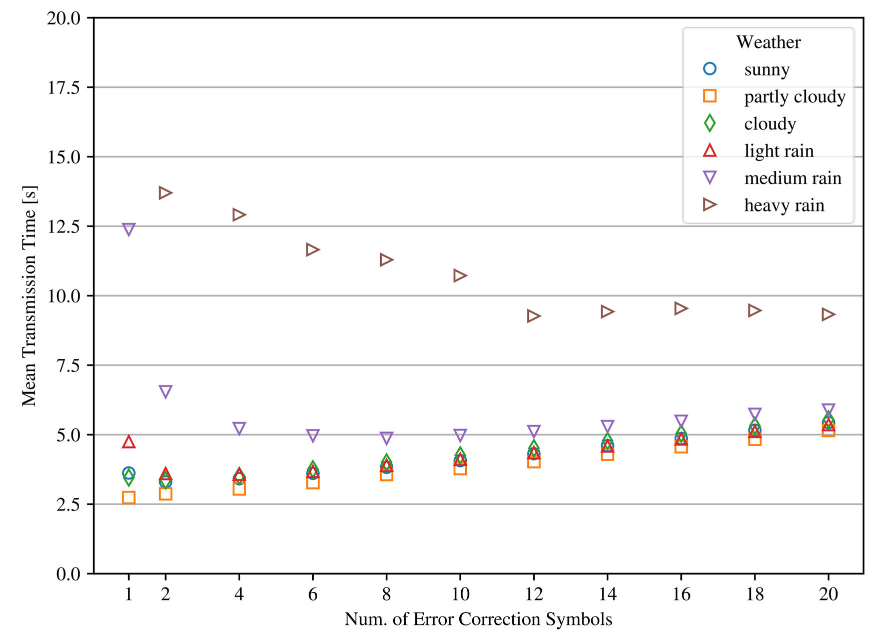
The performance of the V2V-OCC prototype was found to be optimal in dry, non-glaring sunlight conditions wherein the taillights' states could be distinctly identified, and the front vehicle precisely tracked. Under these conditions, the mean bit error rate (BER) stays beneath 1.7%.

However, wet conditions present a higher challenge for signal reception. Factors such as rain droplets on the windshield, spray swirled up by preceding vehicles, and windshield wipers intermittently blocking the modulated taillights are causing bit errors. Depending upon the intensity of rainfall, the BER ranges from 2.8% during light rain to 6% and 15% during medium and heavy rain, respectively.

Additionally, the duration required to successfully transmit a 128-bit verification key via V2V-OCC was evaluated, the primary factor for the platoon verification time. By incorporating redundancy for Reed-Solomon error correction, we managed to maintain the mean verification time beneath 5 seconds across all conditions, the only exception being heavy rainfall.



BER distribution.



Platoon verification time.

PUBLICATIONS

- Michael Plattner and Gerald Ostermayer. “Filtering Specular Reflections by Merging Stereo Images”. In: Scandinavian Conference on Image Analysis. Springer. 2019, pp. 164–172.
- Michael Plattner and Gerald Ostermayer. “A Visible Light Vehicle-to-Vehicle Communication System Using Modulated Taillights”. In: The Twelfth International Conference on Adaptive and Self-Adaptive Systems and Applications. IARIA XPS Press. 2020.
- Michael Plattner and Gerald Ostermayer. “Undersampled Differential Phase Shift On–Off Keying for Visible Light Vehicle-to-Vehicle Communication”. In: Applied Sciences 11.5 (2021), p. 2195.
- Michael Plattner and Gerald Ostermayer. “Camera-based Vehicle-to-Vehicle Visible Light Communication – A Software-Only Solution for Vehicle Manufacturers”. In: Proceedings of the 32nd international conference on computer communication and networks (ICCCN). IEEE. 2023.
- Michael Plattner and Gerald Ostermayer. “A Camera-based Vehicular Visible Light Communication System using Modulated Taillights in Public Road Scenarios”. In: Vehicular Communications (2023).

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