Platoon Control Using VLC: A Feasibility Study.

Mohammad Abualhoul, Mohamed Marouf, Oyunchimeg Shagdar, Fawzi Nashashibi

Platoon Control Using VLC: A Feasibility Study

Mohammad Y. Abualhoul, Mohamed Marouf, Oyunchimeg Shagdar

IMARA research team, INRIA, Paris-Rocquencourt
{mohammad.abu_alhoul, mohamed.marouf, oyunchimeg.shagdar, fawzi.nashashibi}@inria.fr

***Abstract*— The major benefits of driving vehicles in controlled close formations such as platoons are that of increasing traffic fluidity and reducing air pollution. While vehicle-to-vehicle (V2V) communications is requisite for platooning stability, the existing radio communications technologies (e.g., the IEEE 802.11p) suffer from poor performance in highly dense road scenarios, which are exactly to be created by platooning. This paper studies the applicability of visible light communications (VLC) system for information exchange between the platoon members. A complete VLC model is built enabling precise calculations of Bit-Error-Rate (BER) affected by inter-vehicle distance, background noise, incidence angle and receiver electrical bandwidth. Based on our analytical model, the optical parameters suiting platooning application are defined. Finally, a SIMULINK model is developed to study the performances of a platooning longitudinal and lateral control, where VLC is used for V2V information exchange. Our study demonstrates the feasibility of VLC-based platooning control even in the presence of optical noise at significant levels and up to a certain road curvature.**

I. INTRODUCTION

Nowadays, the requirements for the solution of road traffic problems such as accidents, roads congestion and the accompanying environmental pollution have exponentially increased. Both ordinary roads and highways are becoming more jammed every year due to increased usage of automobiles. Automatically controlled vehicles in platoon, whose inter-vehicle distance can be reduced down to 2 meters [1], will efficiently reduce the traffic jam by increasing the roads throughput.

In this paper, we develop a complete VLC channel and noise model taking account of background noise, incidence angle and receiver electrical bandwidth. Considering OOK (On-off Keying) modulation method, we calculated BER for varying inter-vehicle distance. Finally, using a SIMULINK, we simulate the impact of VLC on a platooning performance controlled under longitudinal and lateral control, considering the use of the vehicles' lightning system for inter-vehicle communications providing stable platooning.

II. PLATOONING CONTROL USING VLC

Continual LOS between the rear LED and the receiver for channel modeling analysis is assumed, indicating that the platooned vehicles are free from any obstruction. For platoon model simplicity, and after following the analysis in [2] for optical channel DC gain and noise effect modelling , we approximate the kinematics of Ackerman steering mechanism of the vehicle to be a bicycle model as depicted in Fig. 1, which has the same instantaneous centre of rotation (ICR), where δ, l and θ are respectively the steer angle, wheelbase and the orientation. The studied model shows half-duplex link between two vehicles in the platooning queue, with BER = 10^{-6} as the performance requirement for stable communication link. All the simulation parameters are tabulated in Table I.

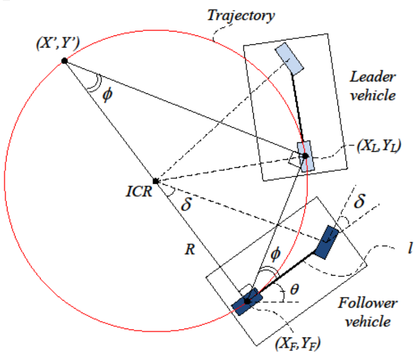

Fig. 1 Circle trajectory going from the follower vehicles position (X_F ;Y_F) to the leader vehicles position (X_L;Y_L) with a constant steer angle.

III. PERFORMANCE EVALUATION

We determine the system performance through the BER plot for different incidence angle, electrical bandwidth and day time noise in order to determine the feasibility of platooning control using VLC. Our simulation results as depicted in Fig. 2, show that it is feasible to achieve up to 7 meters Line-of-Sight (LOS) communication range even in the presence of optical noise at significant levels and with up to 40 degree of road curvature.

To study the platoon control using VLC, two scenarios were built in SIMULINK, describing two trajectories properties and representing communication success and failure.

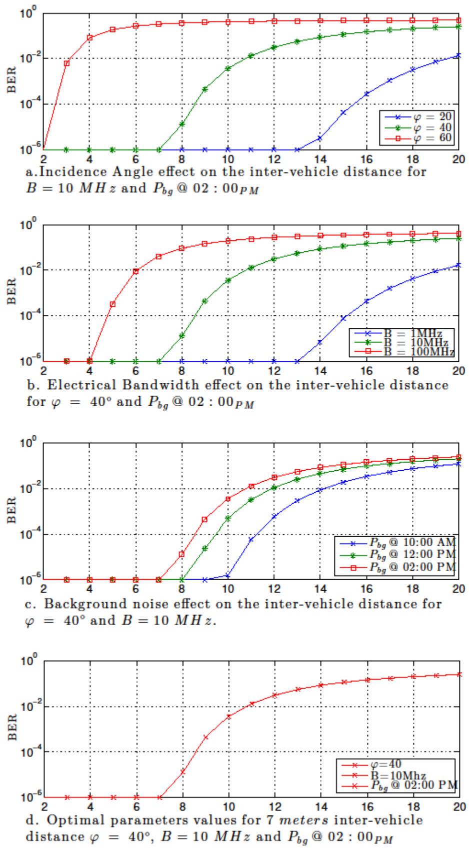

Figure 2. Performance of the optical wireless channel for the three main parameters as a function of BER and the platoon inter-vehicle distance

In the first scenario, incidence and irradiance angles are continuously less than the 40 degree limit all along the trajectory path, allowing the queued vehicles to maintain the FOV and BER strict requirement, while the second scenario taking into account the communication link limits, and is expressed by sending stop (communication failure) signal to any vehicle located just after the link disconnection. Simulations also show that the proposed lateral controller has a good performance with less processing time compared to other more sophisticated controllers. The maximum lateral error, which is the maximum spacing between the trajectory of the head vehicle and the tail vehicle, found to be less than 20 cm considering the parameters tabulated in Table I.

TABLE I
SIMULATION MODEL PARAMETERS

Parameter	Value
Inter-vehicle reference distance	2 m
Filter Transmission coefficient	1
Incidence/Irradiance Angle	40^o
Photo Diode Responitivity	0.56
Semi Angle at Half Power	60^o
Receiver Field of View	60^o
Detector Physical Area	1 cm^2
Output Optical Power	170 mw
Electrical Bandwidth	10 Mhz
Ambient Noise Power	12 μw
Maximum Steer Angle	30^o
Wheelbase	2 m

IV. CONCLUSIONS

In this paper, we have investigated analytical model; suggesting employing the vehicles commercial rear lights as a reliable communication link. Furthermore, the main parameters that have significant effects on the outdoor VLC system performance and suiting platooning application were defined. The variation of these parameters such as incidence angle, receiver electrical bandwidth and day time noise were investigated and compared for different inter-vehicle distances. The simulation of the studied model shows that a BER of 10^{-6} which is equivalent to SNR around 14.6 dB is achievable for separation distance up to 7 meters between the platooned vehicles.

We also implemented a Matlab/SIMULINK based platoon model with a longitudinal and a lateral controller for each vehicle considering the VLC model limitations.

REFERENCES

[1] W. B. Dunbar and D. S. Caveney, "Distributed Receding Horizon Control of Vehicle Platoons: Stability and String Stability," IEEE Transactions on Automatic Control, vol. 57, no. 3, pp. 620–633, 2012.
[2] I. E. Lee, M. L. Sim, and F. W. L. Kung, "Performance enhancement of outdoor visible-light communication system using selective combining receiver," IET Optoelectronics, vol. 3, no. 1, pp. 30–39, 2009.