# Study on Multi-Users Interference in Vehicle to Vehicle Visible Light Communications

Emmanuel Plascencia, Oyunchimeg Shagdar, Hongyu Guan and Luc Chassagne

Emmanuel Plascencia

Institut VEDECOM | Laboratoire d'Ingénierie des Systèmes de Versailles University of Versailles

luis-emmanuel.plascencia@vedecom.fr

version 01/10/2020

# PRESENTER'S PROFILE

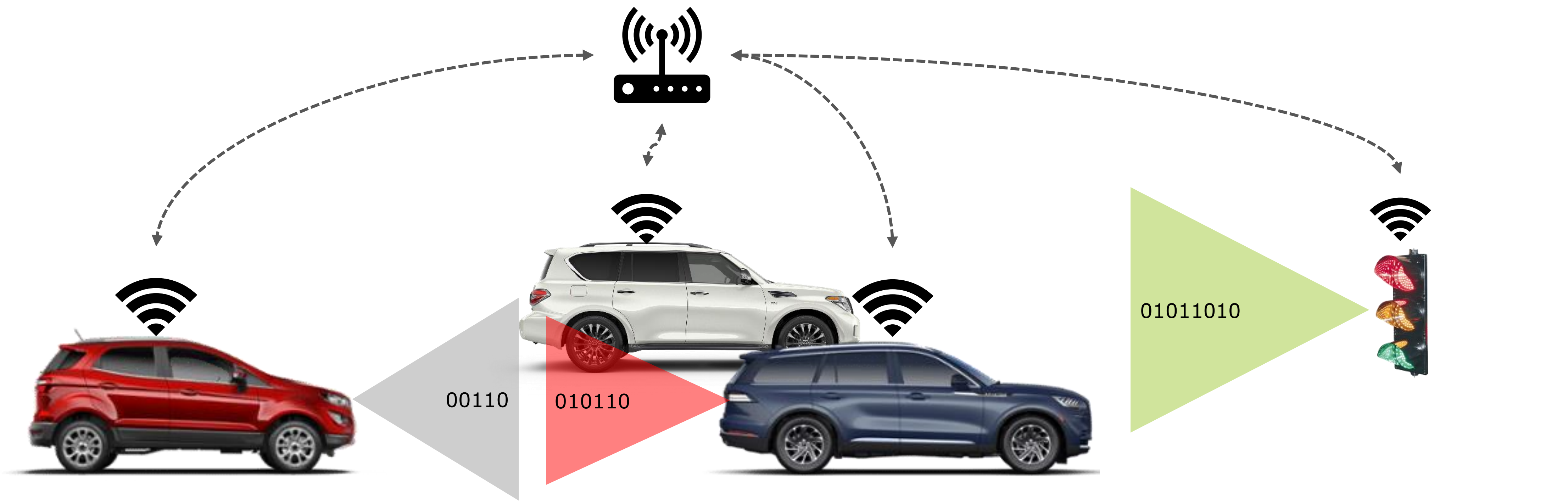


**Emmanuel Plascencia**

He obtained his bachelor's degree in Electronic Engineering from the Technological Institute of León, Mexico in 2016, and a master's degree in Applied Sciences in medical physics and instrumentation from the University of Guanajuato, Mexico in 2018. He is a 2nd-year Ph.D. student at the University of Versailles in codirection with the Vedecom Institute in France. His thesis research includes Visible Light Communication for vehicle platoons, as well as the Physical layer (PHY) and Medium Access Control (MAC) for VLC technology.

# INTRODUCTION

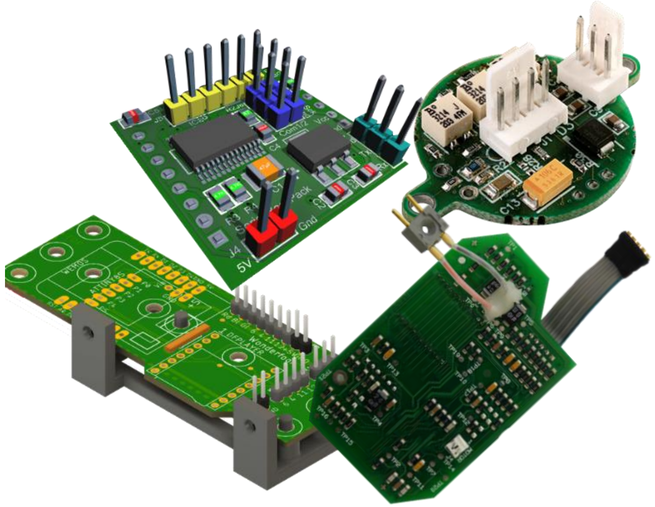





Visible Light Communications (VLC) can play an important role in the Cooperative Intelligent Transport Systems (C-ITS) by enabling vehicles to communicate with nearby vehicles (V2V) and infrastructure (V2I) by offering virtually unlimited and unregulated spectrum.

# EXISTING EFFORTS ON VLC & MOTIVATION OF THE WORK





Physical Layer (PHY)

Huge number of efforts

- Coding techniques
  - Manchester coding
  - Miller coding
  - Color shifting
  - …
- Filtering stages
  - Pre-equalization Tx
  - Post-equalization Rx
  - Logarithmic Amplifications
  - RGB arrangements
  - …

Medium Access Control (MAC)

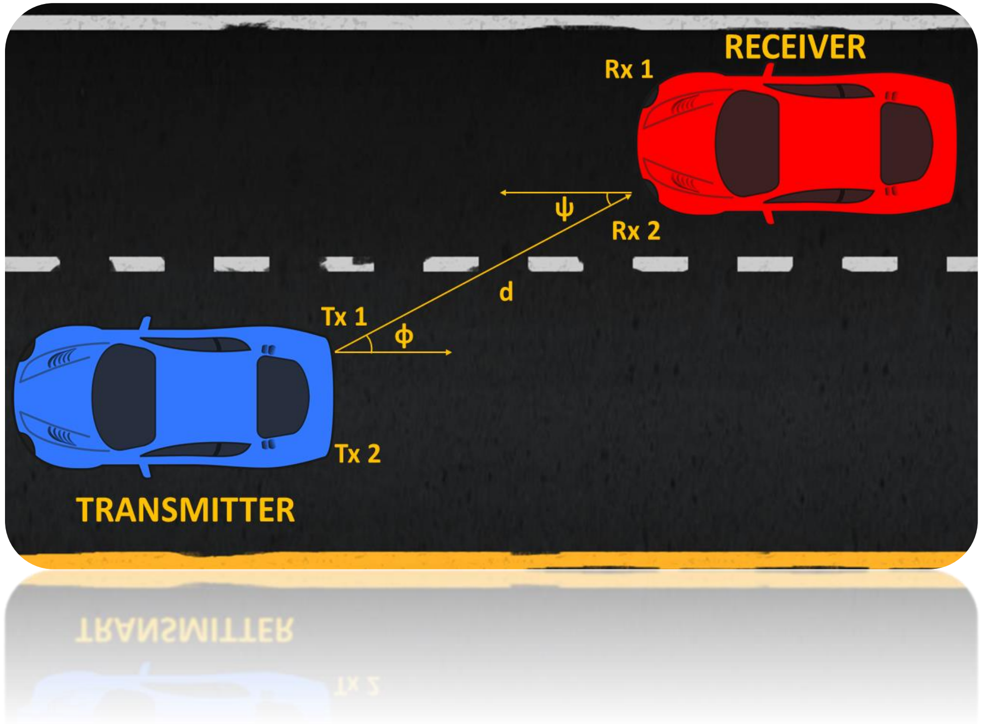
Very limited number of efforts

- CSMA/CA (802.15.7/r1) – Carrier sensing is challenging in VLC (directional half-duplex link)
- ALOHA

**Is Multi-Users Interference (MUI) being problematic in VLC?**
**→ Do we need MAC?**

# MODELING IMPACT OF VLC MULTI-USERS INTERFERENCE

## VLC channel Model




Angular distribution (Tx)

$$R_o(\phi) = \begin{cases} \frac{(m_i+1)}{2\pi} Cos^{m_i}(\phi) & \phi \in [\frac{-\pi}{2}, \frac{\pi}{2}] \\ 0 & \phi \geq \frac{\pi}{2} \end{cases}$$

Photodiode area (Rx)

$$A_{eff}(\psi) = \begin{cases} A_r Cos(\psi) & 0 \leq \psi \leq \frac{\pi}{2} \\ 0 & \psi > \frac{\pi}{2} \end{cases}$$

$$H(\phi,\psi) = \begin{cases} \frac{A_r(m_i+1)}{2\pi d^2} Cos^{m_i}(\phi) Cos(\psi) & 0 \leq \psi \leq \psi_c \\ 0 & elsewhere \end{cases}$$

The receiver power $P_r$, is hence

$$P_r = H(\phi,\psi) P_t = \frac{H_0(\phi,\psi)}{d^2}$$

$$H_0(\phi,\psi) = \begin{cases} \frac{A_r(m_i+1)P_t}{2\pi} Cos^{m_i}(\phi) Cos(\psi) & 0 \leq \psi \leq \psi_c \\ 0 & elsewhere \end{cases}$$

# MODELING IMPACT OF VLC MULTI-USERS INTERFERENCE

## Impact of MUI

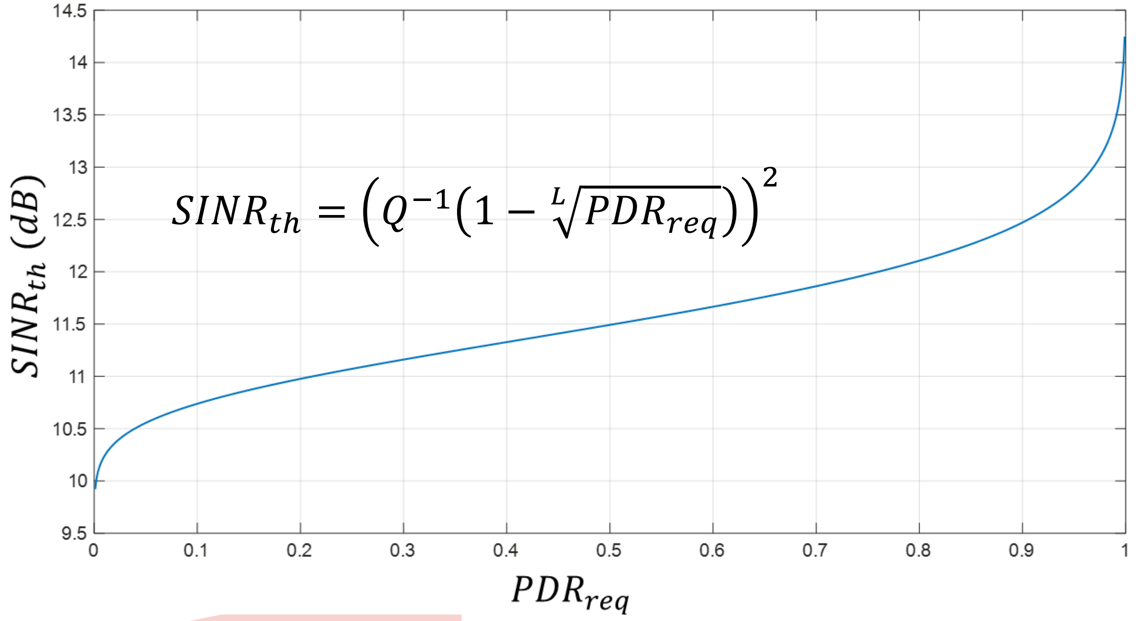
Packet Delivery Ratio (PDR) depends on the Bit-Error Rate (BER) and the packet size (L). BER is a function of Signal to Interference plus Noise Ratio (SI

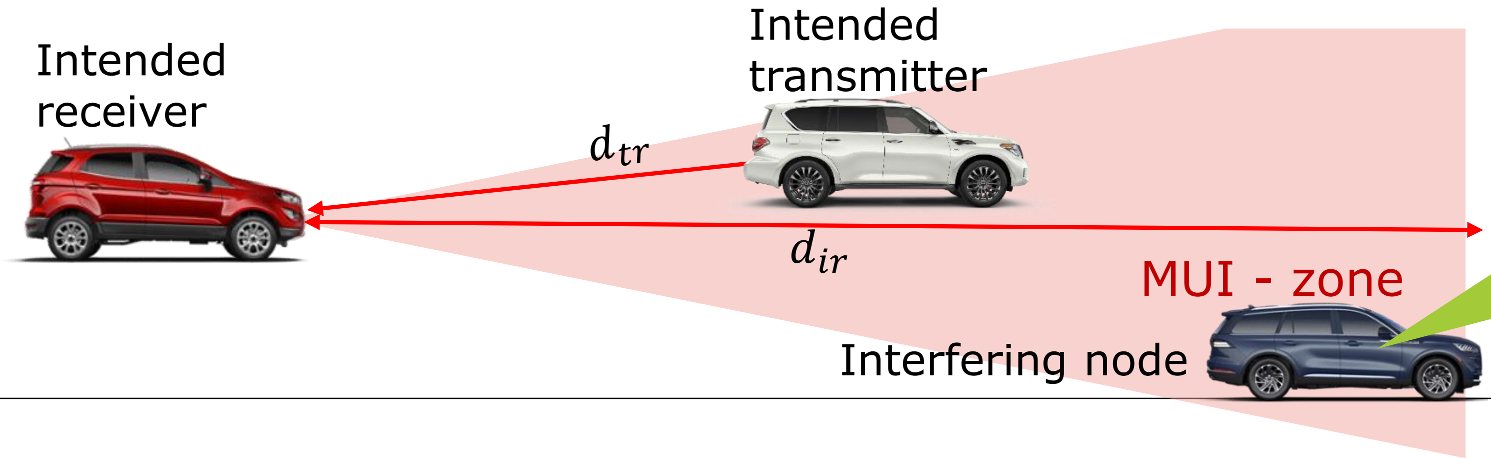
$$\text{PDR} = (1 - BER)^L \qquad BER = Q\left(\sqrt{SINR}\right) = Q\left(\sqrt{\frac{P_r}{MUI+N}}\right)$$

SINR requirement ($SINR_{th}$ : *minimum required SINR*)

$$\frac{P_r}{MUI + N} \geq SINR_{th}$$

$$P_i(d_{ir}) \geq \frac{P_r(d_{tr})}{SINR_{th}} - N$$



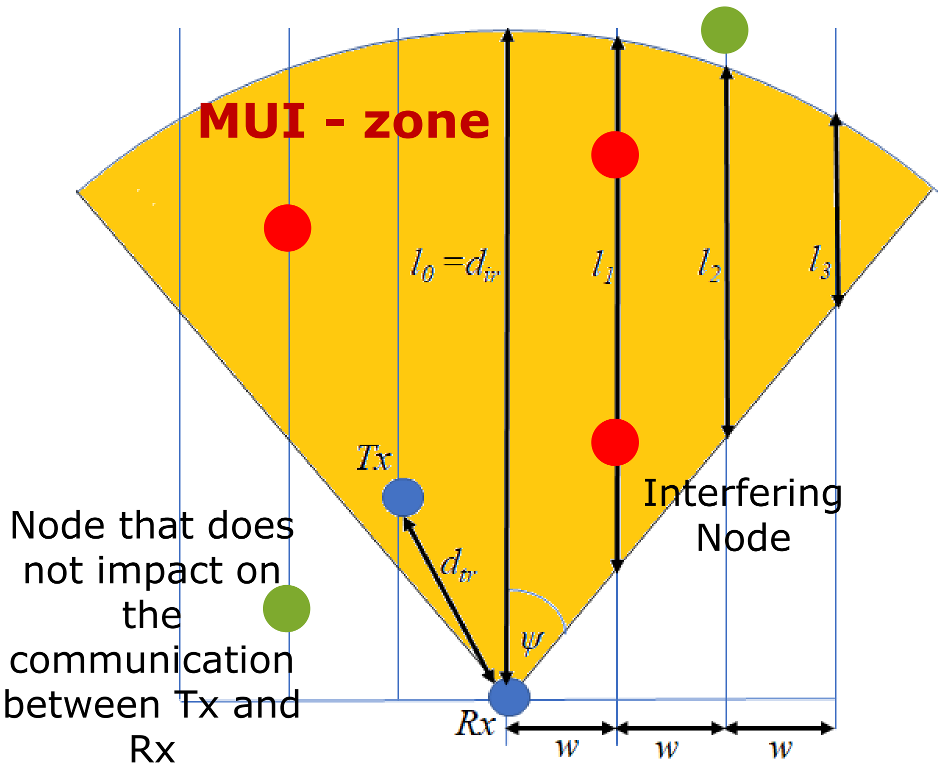

MUI-zone ($d_{ir}$):
Simultaneous transmission from a node in the MUI-zone results in a failure for the communication between the intended transmitter and receiver.

# SUCCESS PROBABILITY WITH PRESENCE OF MUI

## Impact of MUI

Relation between Tx and RX distance ($d_{tr}$) and the MUI zone on a multi-lane ($l_0, l_1, l_2, l_n \dots$)

$$d_{ri} = d_{tr}\sqrt{SINR_{th}}$$




Road length in MUI-zone:

$$l = d_{ir} + \sum_{k=1}^{n_l} l_k + \sum_{k=1}^{n_r} l_k$$

The probability of finding $i$ vehicles in the MUI zone

$$P(i,l) = \frac{(\beta l)^i \, e^{-\beta l}}{i!}$$

Communication success probability

$$P_s = \sum_{i=0}^{\infty} P(i,l)(1-\tau)^i$$

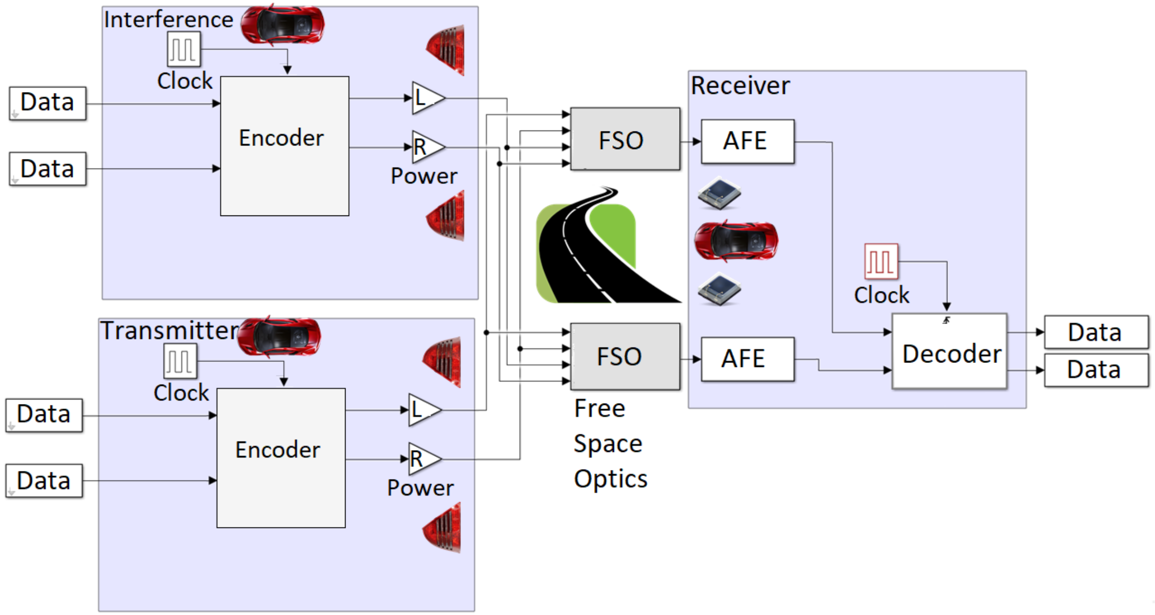
Where $\tau$ is the channel access probability: function of transmission time ($T_{tx}$) and message generation interval ($T_{interval}$)

$$\tau = \frac{T_{tx}}{T_{interval}}$$

# PERFORMANCE EVALUATION: VLC SUCCESS PROBABILITY

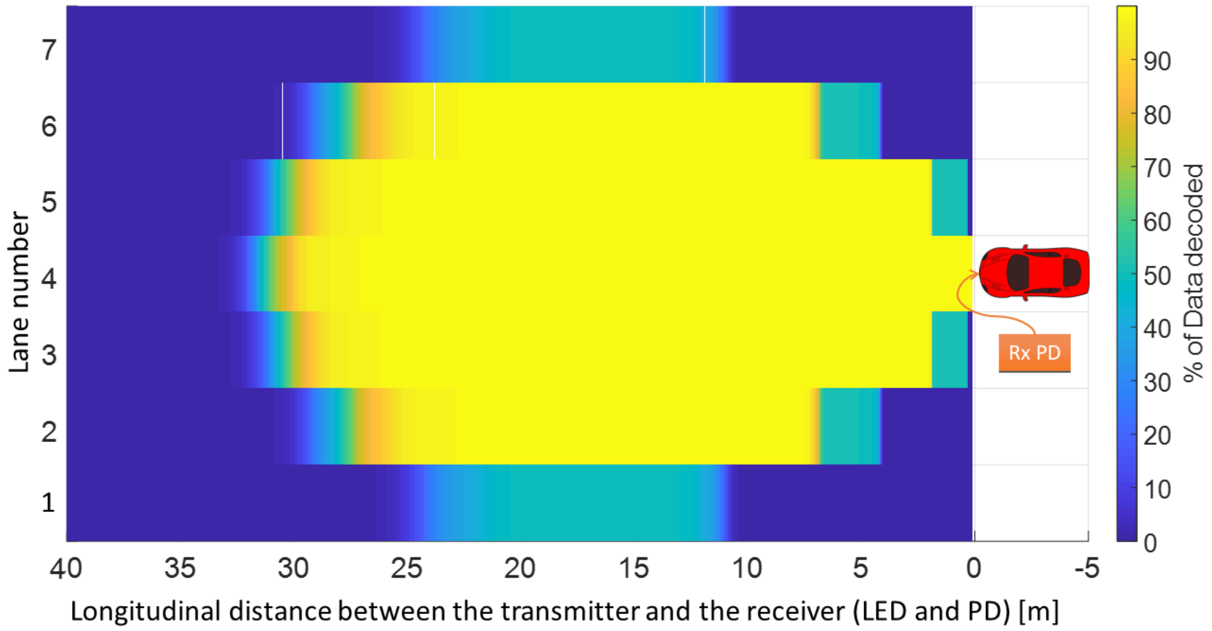
## MATLAB parameters + Simulink Model

| Parameter | Value |
|---|---|
| PD reference | S6967 Hamamatsu |
| $A_{eff}$ | 100mm x 100mm |
| PD efficiency | 0,5(A/W) |
| FoV ($\psi$) | 55° |
| PD capacitance | 1,2 $\mu F/m^2$ |
| Transmission frequency | 500 KHz |
| Transmission power | 1 Watt (Car taillight) |
| Transmitter Semi-angle ($\phi_{\frac{1}{2}}$) | 20° |
| Inter-PD separation distance | 1,2 meters |
| Road lane width | 2,5 meters |
| Data size (L) | 1000 Bytes |

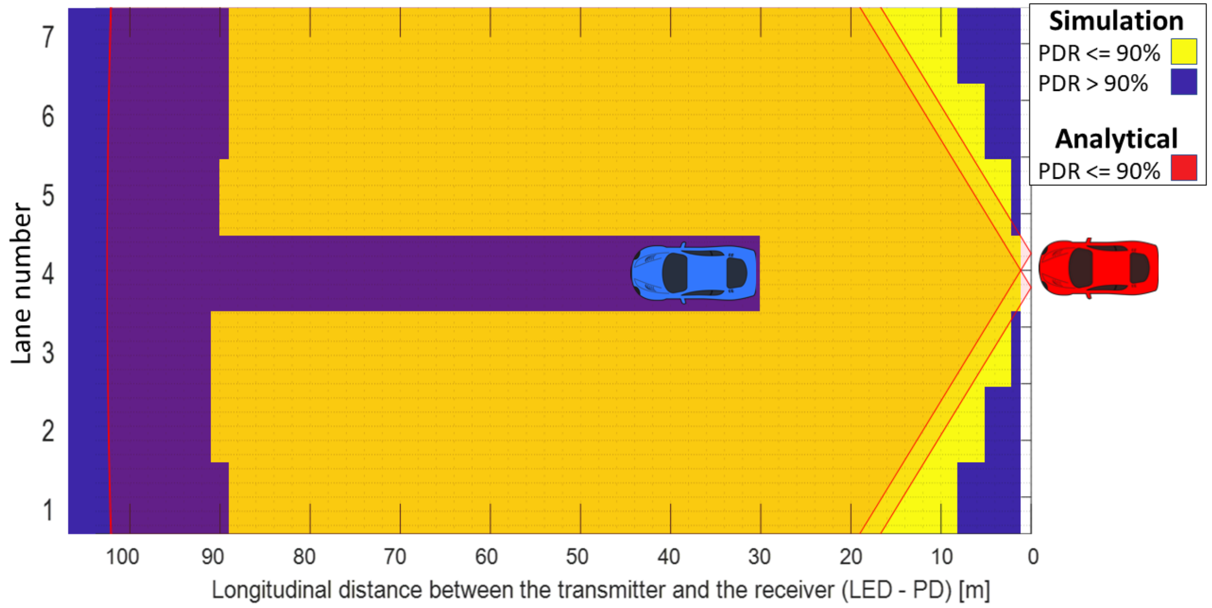


# PERFORMANCE EVALUATION: VLC COMMUNICATION RANGE & MUI ZONE VALIDATION

## Results



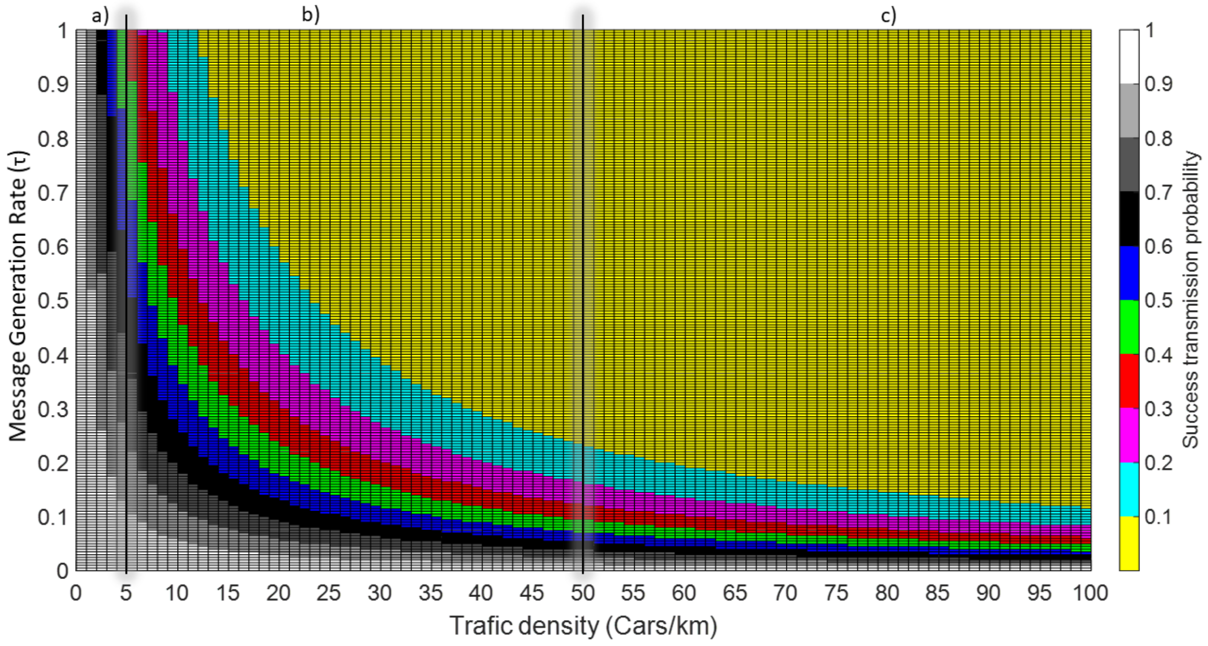

VLC communication range on a 7-lanes road.



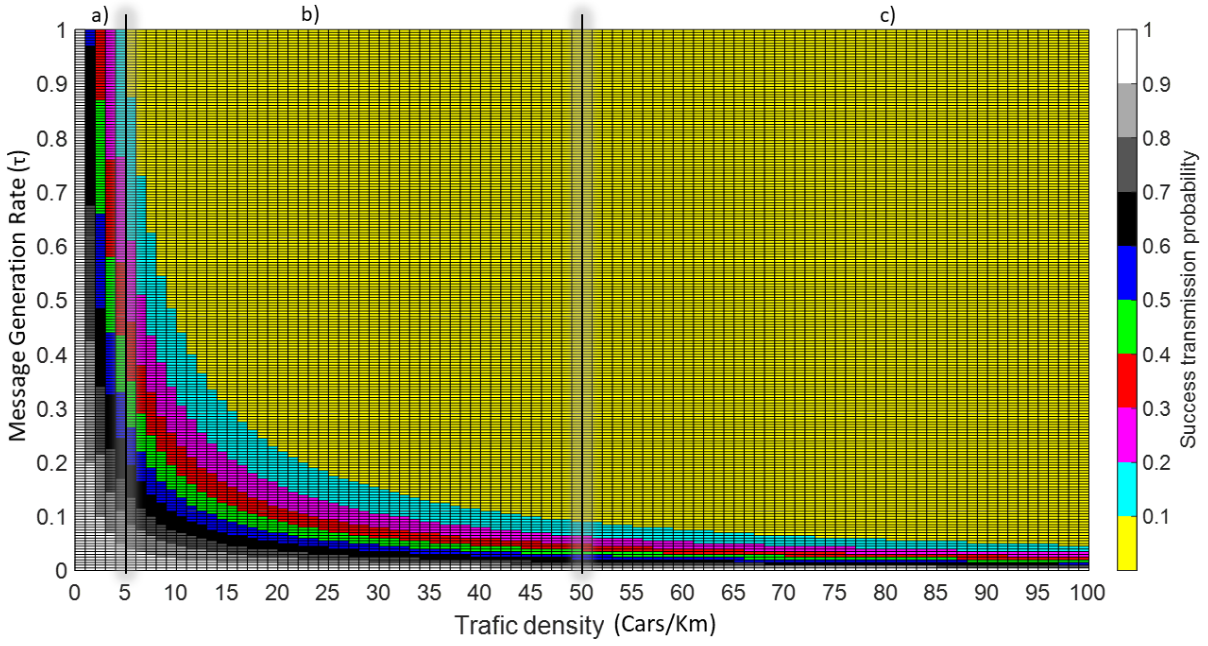

MUI zone for 90% of PDR requirement. Blue and yellow zones are simulation results, Red transparent area is the results of the analytical model.

# PERFORMANCE EVALUATION: PROBABILITY TO GET VEHICLES IN MUI-ZONE & SUCCESSFUL TRANSMISSION

## Results




PDR performances of VLC in 3-lanes highway scenario ( $l$ = 203m).
a) Low Density - maximum 1 vehicles on the road
b) Medium Density - maximum 10 vehicles on the road
c) High Density - maximum 20 vehicles on the road.




PDR performances of VLC in 7-lanes highway scenario ( $l$ = 529m).
a) Low Density - maximum 2 vehicles on the road
b) Medium Density - maximum 26 vehicles on the road
c) High Density - maximum 53 vehicles on the road.

# CONCLUSION AND FUTURE WORK



- Development of an analytical model
  - Determining multi-user interference zone
  - VLC success probability for Poisson distributed road traffic.
- The Simulink simulation results confirm the correctness of the analytical model on MUI zone.
  - Even with low traffic densities and low message generation rates, the vehicles in the MUI zone can significantly degrade the PDR performance of the target VLC communication
  - An inherent necessity of a MAC protocol for V2V communications.


Future work:

- Improvement of the theoretical model by considering shadowing effect by bodies of vehicles.
- Conduct study on MAC that is aware of the presences of vehicles in the MUI zones.

# Thank you for your attention

## Together to accelerate the mobility of tomorrow !