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Visible Light Communication in a Traffic Controlled Split Intersection

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ACKNOWLEDGEMENTS

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Manuel Augusto Vieira was born in Portugal. He graduated in Electronic and Telecommunication Engineering by Instituto Superior Técnico (IST) of Lisbon from the Technical University of Lisbon. In 2004, he received the Master of Science in Electronic and Computers Engineering by the Superior Technical Institute of Lisbon and in 2012 its PhD by the New University of Lisbon. The title of the thesis was ”Three transducers for one photodetector: essays for optical communication”

Currently he is Professor in Electronics inside the Electronic Telecommunication and Computer Department of ISEL, Lisbon, Portugal and investigator in the M2P group of CTS-UNINOVA.

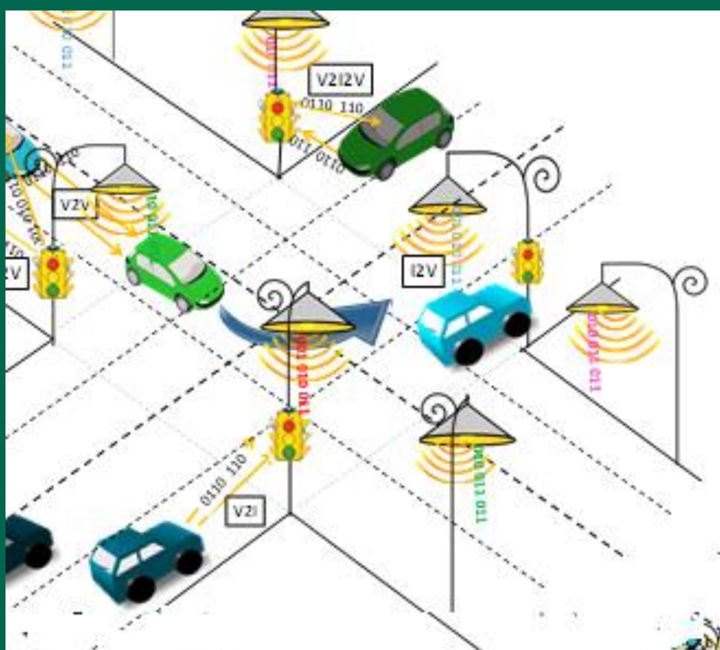
The major research interests are related with traffic control, vehicular communications, operations management, stochastic control, optimization and discrete event dynamic systems, scheduling, inventory control, simulation infinitesimal perturbation analysis, queuing networks.

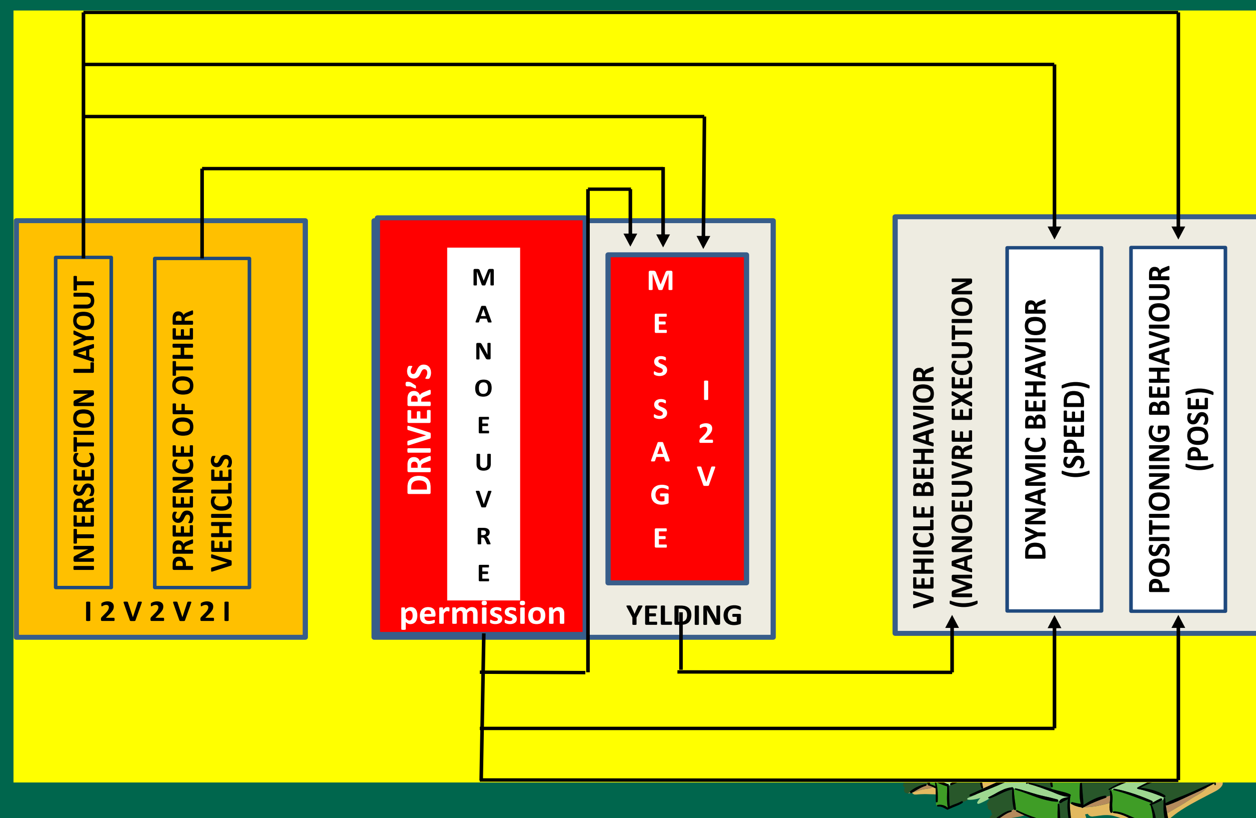
He was director of the traffic department of the City Hall of Lisbon for more than twenty five years.

Authored and co-authored several publications in refereed journals and conferences proceedings. He is an IARIA Fellow since 2020.

Motivation and Objectives

Pose analysis is an important issue to control **driver's behavior** in a crossroad.
Cooperation between multiple **connected vehicles** is possible with the development of vehicular communication
I2V, V2V, V2I, I2V optoelectronic WDM cooperative vehicular system enables direct communication between vehicles, roadside infrastructure, traffic lights control and vulnerable road users (pedestrians, bicyclist, or wheelchair users)





Outline

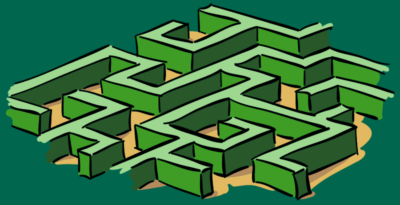
- **State of Art:**
  VLC transmitter and Si/SiC transducers

- **Lighting plan. Graphical representation of the simultaneous localization and mapping**
  Transmitters and Receivers

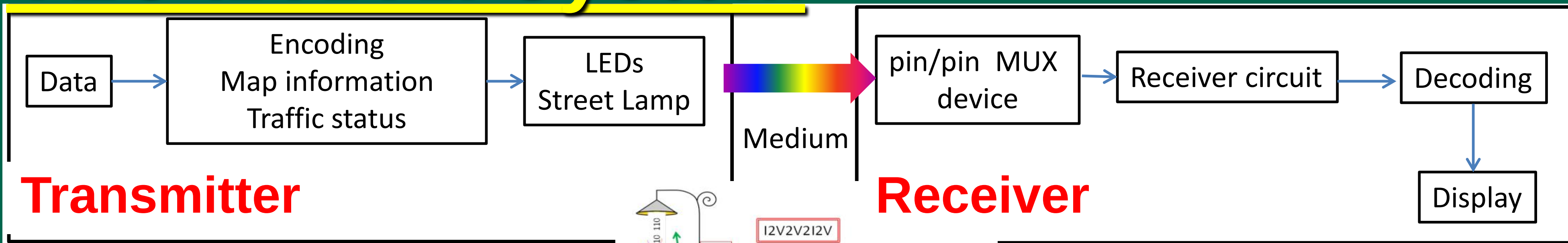
- **I2V, V2V, V2I and I2(V, P, B) communications**
  Cooperative VLC System.

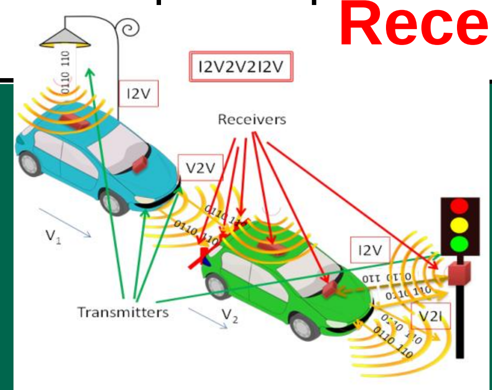
- **Vehicle pose connectivity**
  Evaluation and proof of concept.

- **Conclusions and Recommendations.**



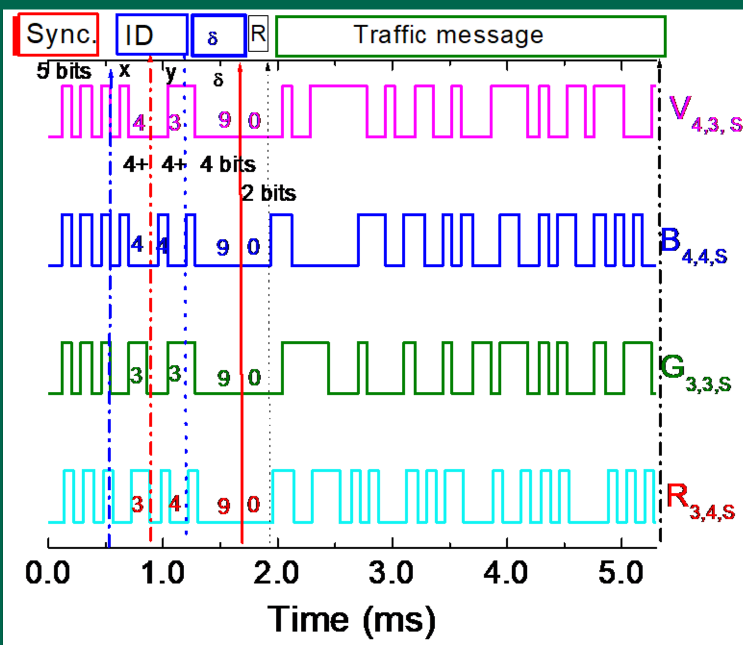
VLC I2V2V2I System

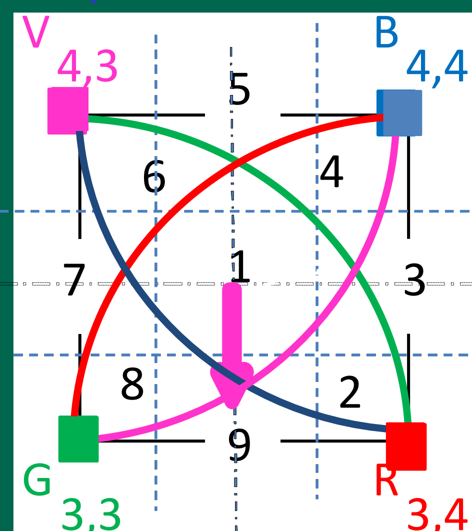


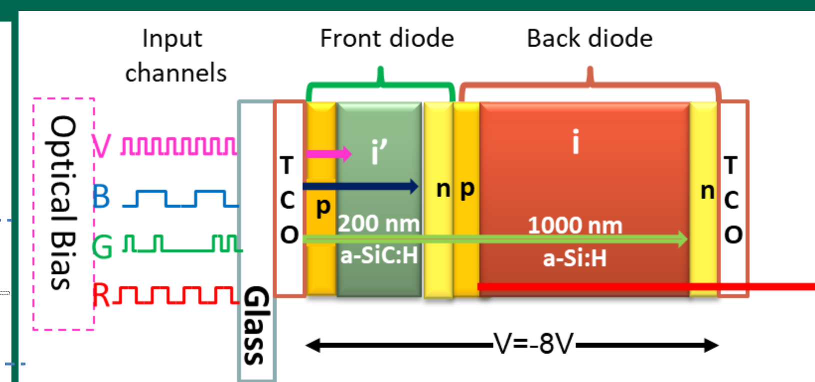


I2V : the street lamp sends a message to the SiC receiver, located at the rooftop.

V2V2I: the information is resent to a leader vehicle or the signal controller using the headlights as transmitters (request distance)







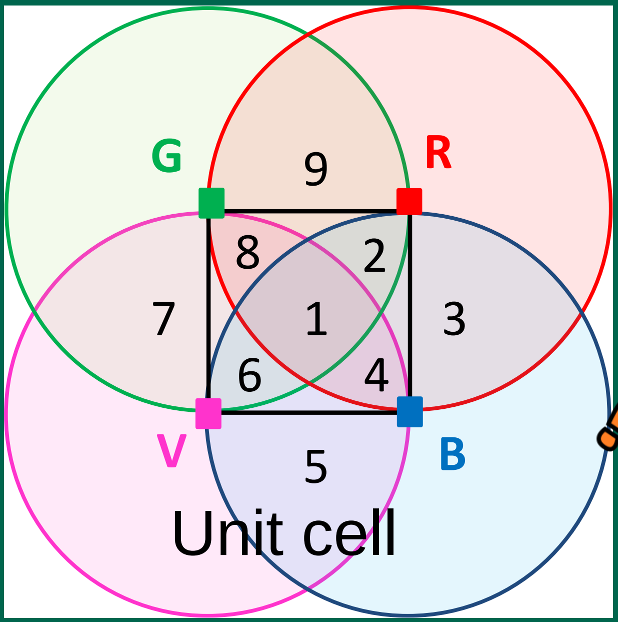
p-i'(a-SiC:H)-n/p-i(a-Si:H)-n heterostructure produced by PECVD with light filtering properties.

Frame structure representation.

The message begins with 5 synchronization bits

The rest of the frame consists of 8 ID´s bits and 4 steering angle´s bits (eight steering angles along the cardinal points) coded with the same number of the footprints in the unit cell, data bits and stop bit. If the message is diffused by the IM transmitter, a pattern [0000]) follows this identification, if it is a request (R) a pattern [00] is used.

Lighting plan

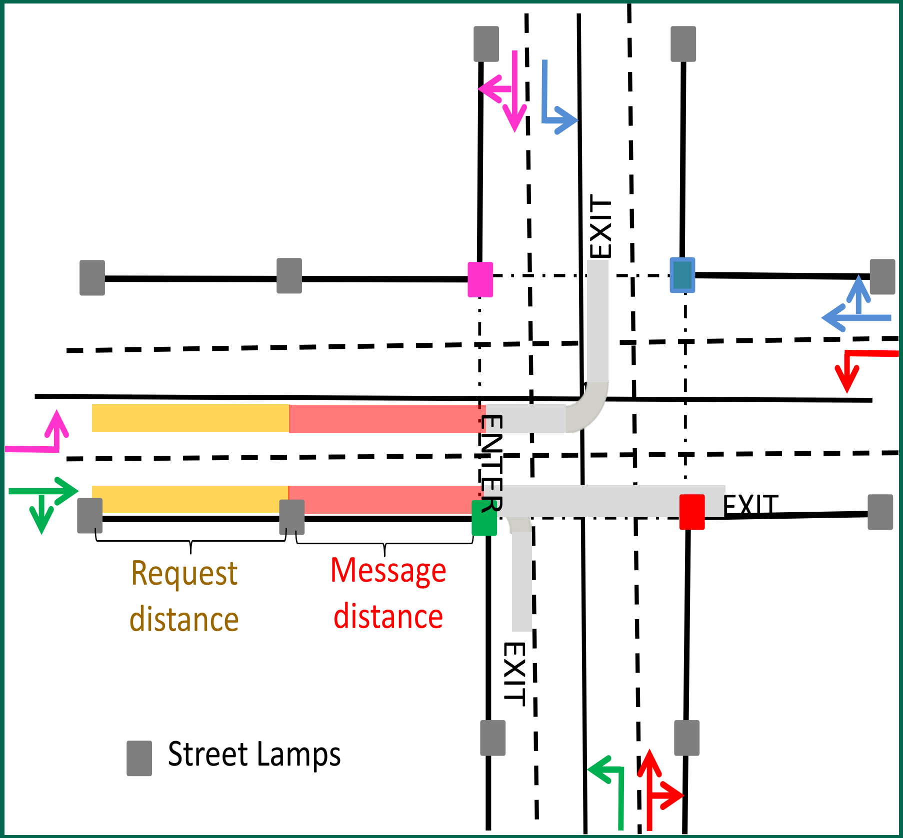


- Four modulated LEDs (RGBV) located
- at the corners of a **square grid**.

footprint regions	#1	#2	#3	#4	#5	#6	#7	#8	#9
Overlap	RGBV	RGB	RB	RBV	BV	GBV	GV	RGV	RG

Concept of request/response

for the management of a trajectory in a two-way-two-way traffic lights controlled crossroad, using Visible Light Communication.



Generatedd join footprints

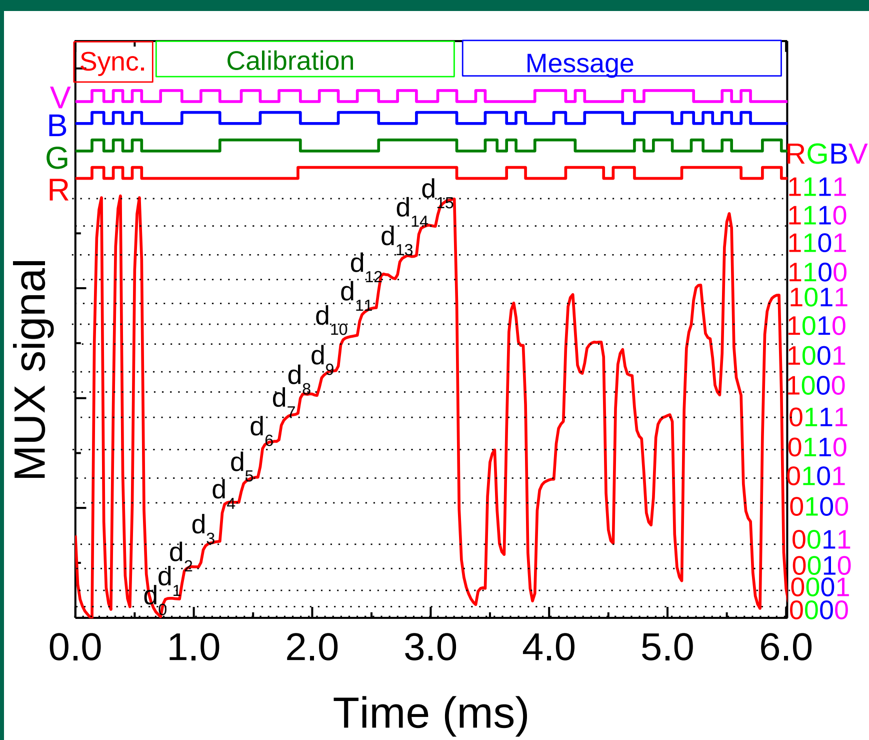
Data collected from connected vehicles provides a much more complete picture of the traffic states near an intersection

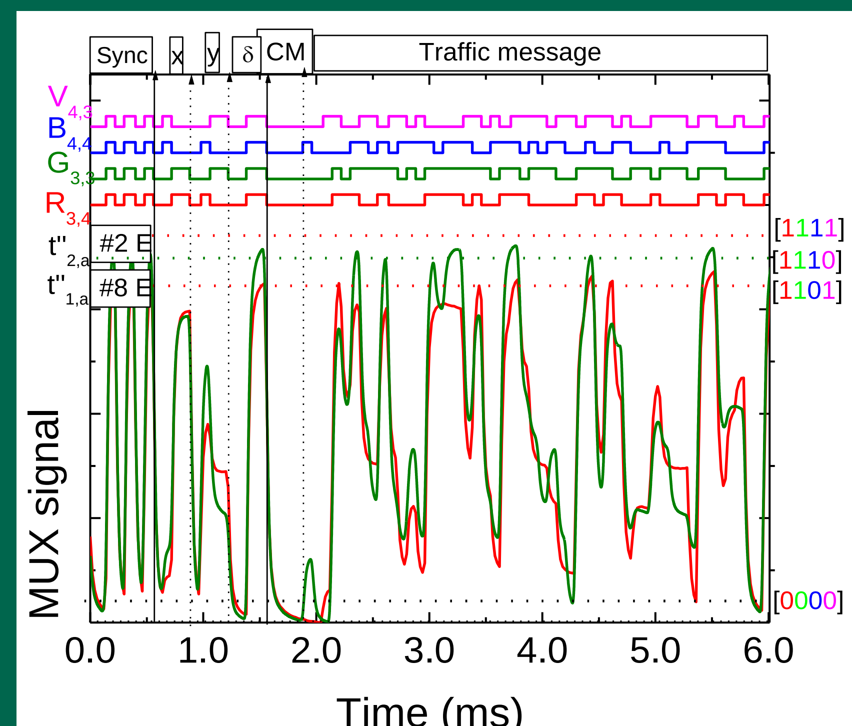
Promising benefits expected from safety and mobility improvements at the road network

MUX/DEMUX techniques

The information about the emitters that are being modulated is crucial to determine the pose of the receiver relative to the lighting/communication infrastructure. The calibration of the receiver supplies an additional tool to enhance the decoding task.

MUX/DEMUX response signals received by vehicle *a* , crossing the intersection ($C_{4,3}$) with poses #8E and #2E.
On the top the received information is decoded





- The output presents 2^4 ordered levels each one related with ***RGBV*** bit sequences

Connected Vehicles Model

Graphical representation of the simultaneous localization and mapping problem

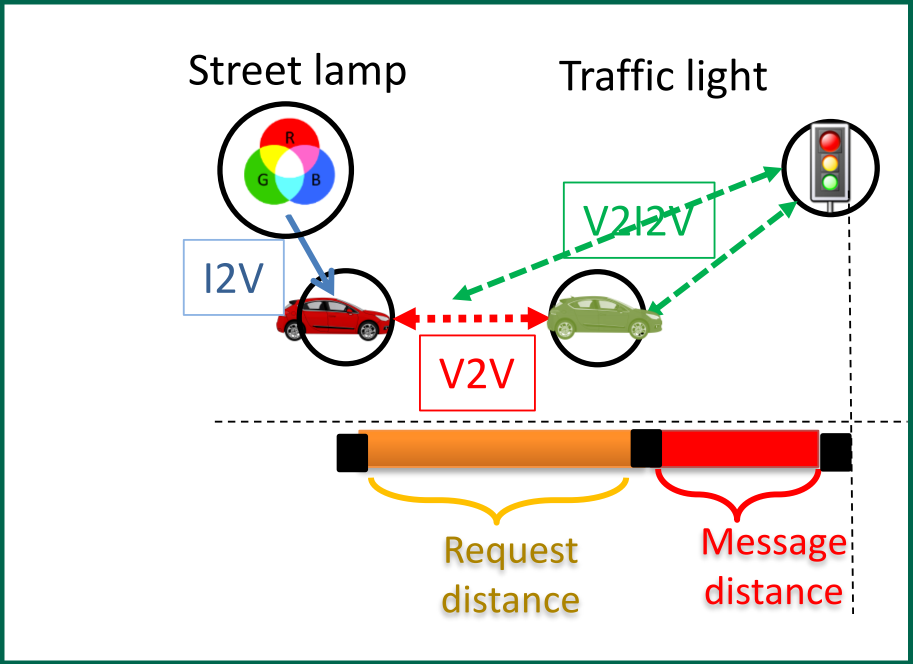
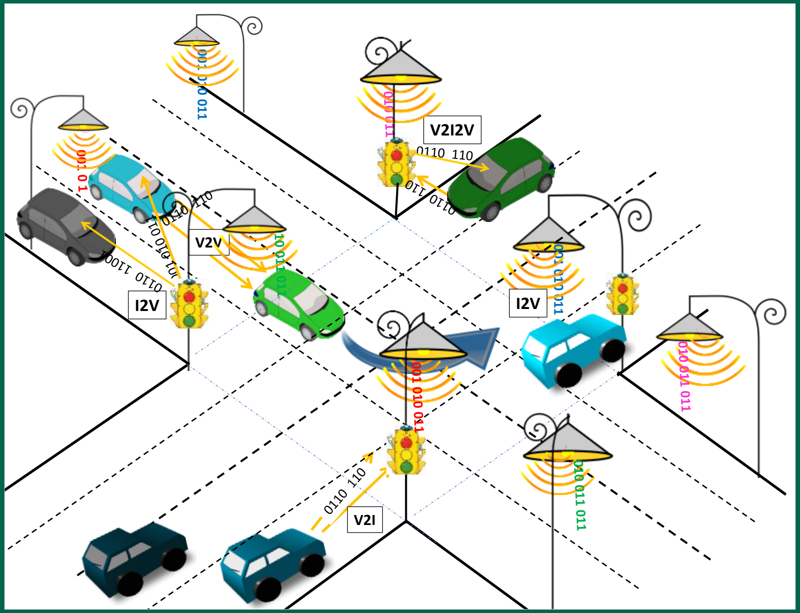


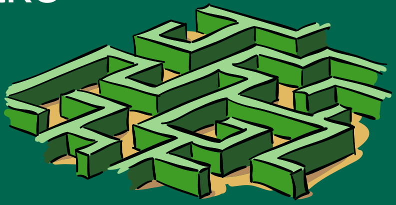
Illustration of the proposed communication scenario:

✓Connected vehicles communication in a crossroad.

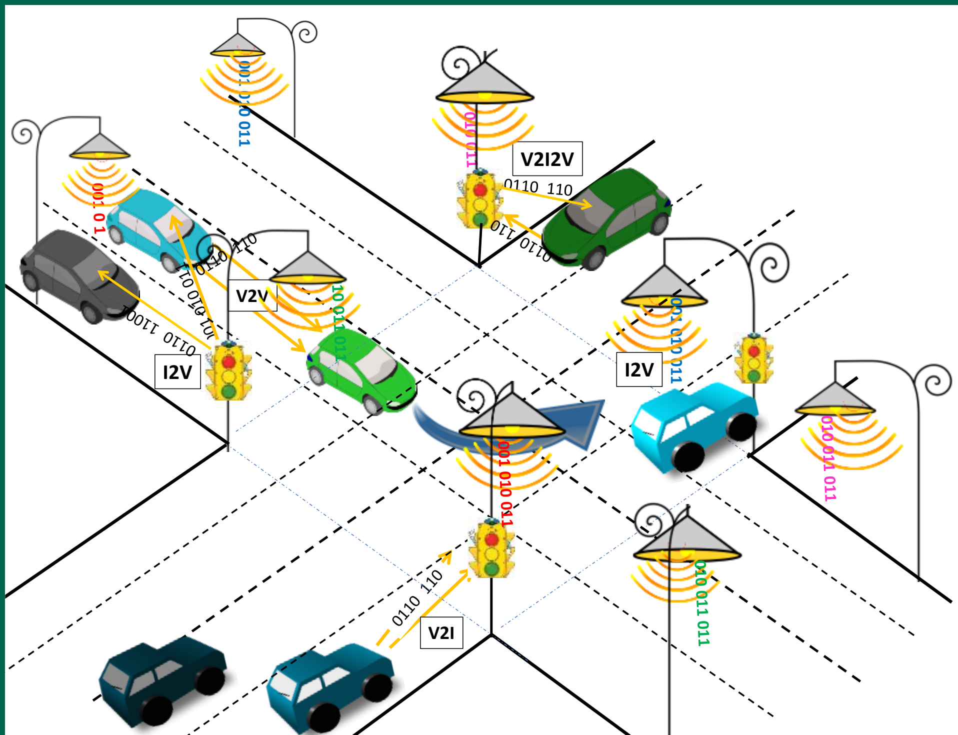


Until recently…

- ✓ (V2V) communication was limited to brake lights, turn signals;
- ✓ (V2I) was restricted to point detection (loop detectors).



Cooperative VLC System Evaluation

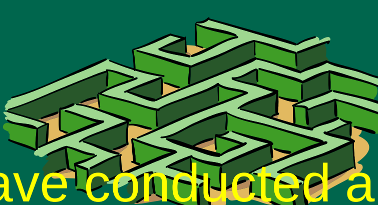


7 different scenarios:

Request poses
Message poses
Platoon poses
Enter poses
Conflicting poses
Exit pose
Exclusive Pedestrian Phasing

Operational procedure:

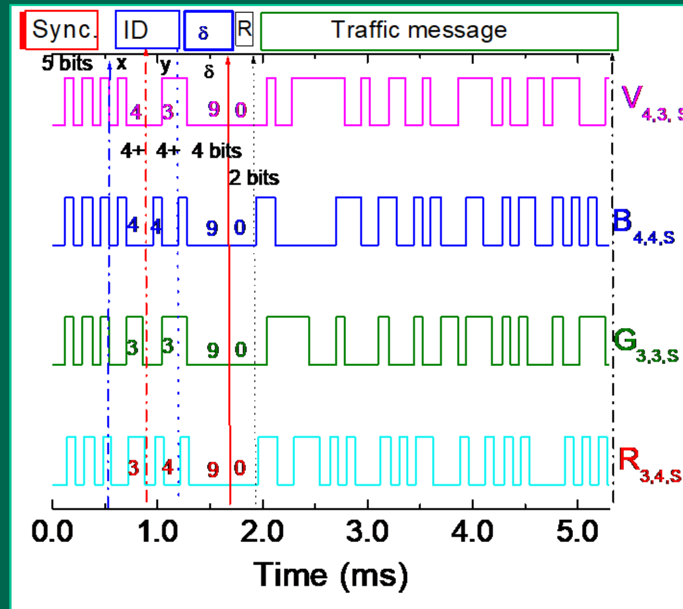
- Each vehicle receives two different messages: **I2V** and **V2V** coming from the streetlight and from the follow vehicle;
- Compare them and infers the **drive distance** and the **relative speed**.
- Send the information to a next car (V2V2V) or to an infrastructure (V2V2I).
- Connected vehicles receive response messages (I2V).

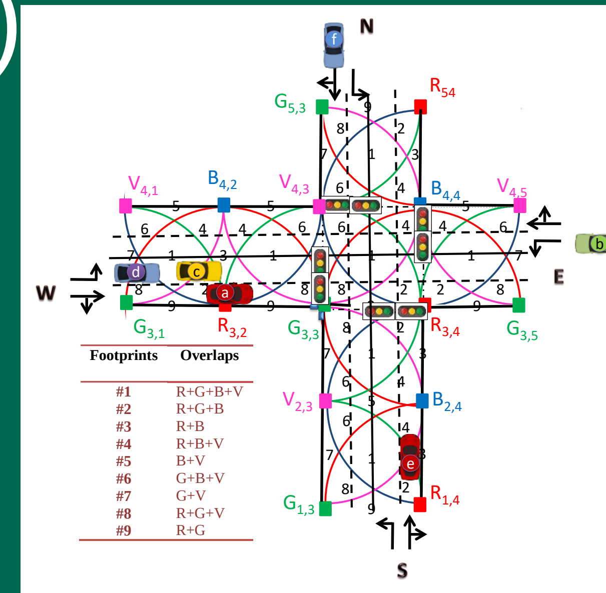


In order to verify the system operability and efficiency we have conducted an extensive set of measurements

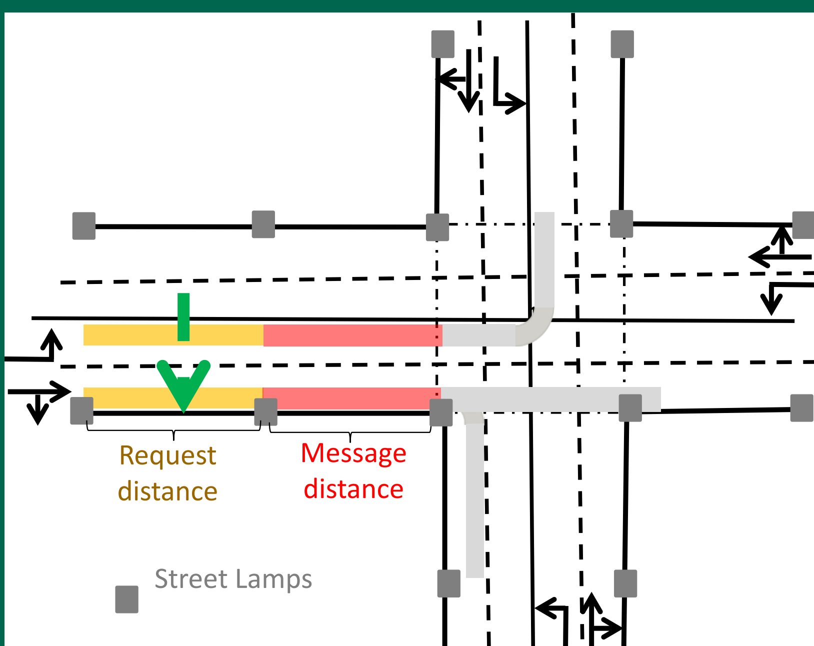
Scenario 1: Request poses (q)

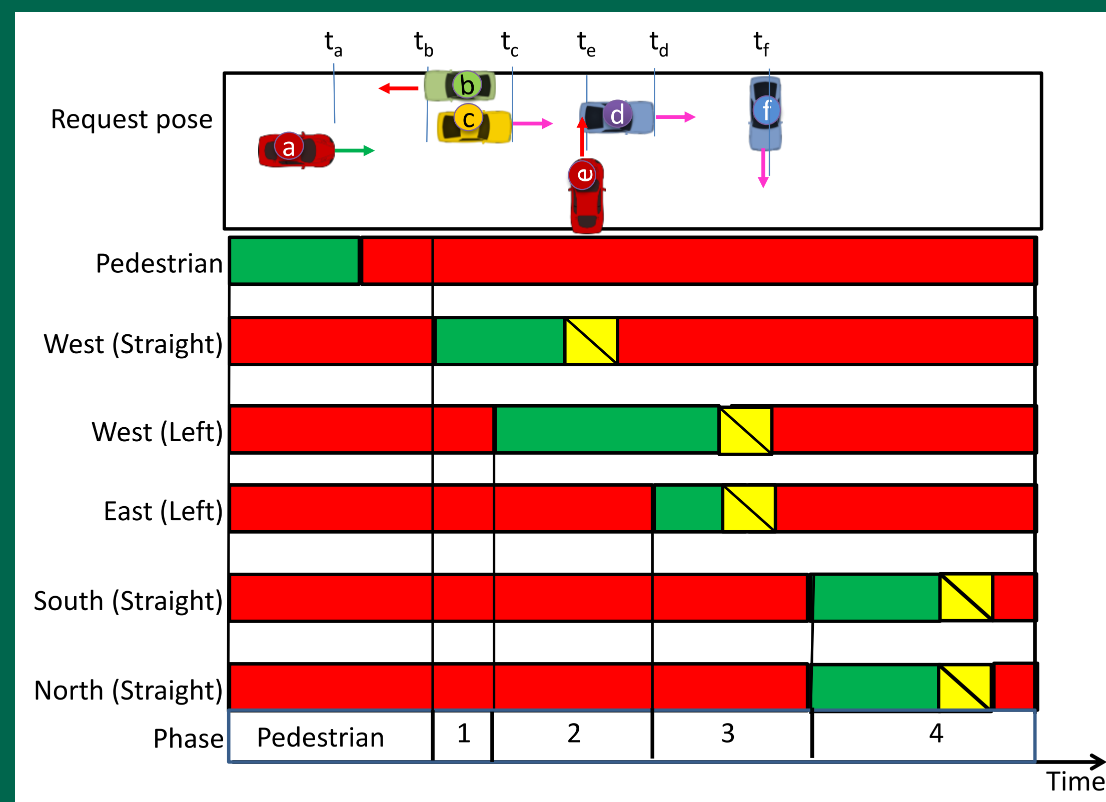
- Vehicles "a,b,c,d,e,f" send the request poses to the infrastructure (V2I) and inform the signal controller that these vehicles desire service (often called "demand" for service).



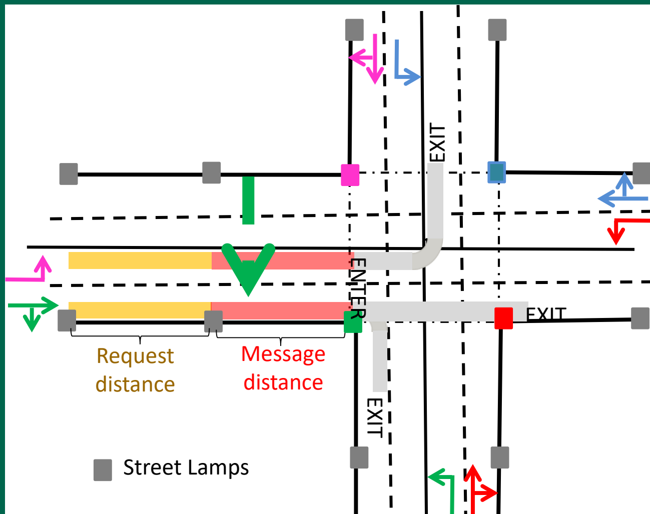


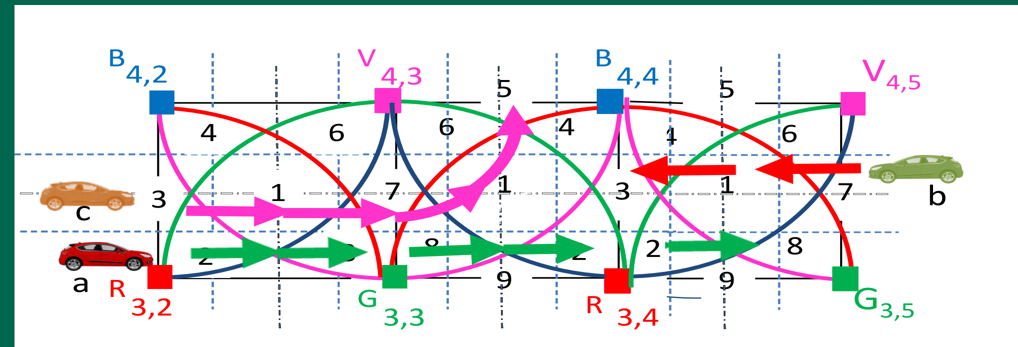
Phasing of traffic flows



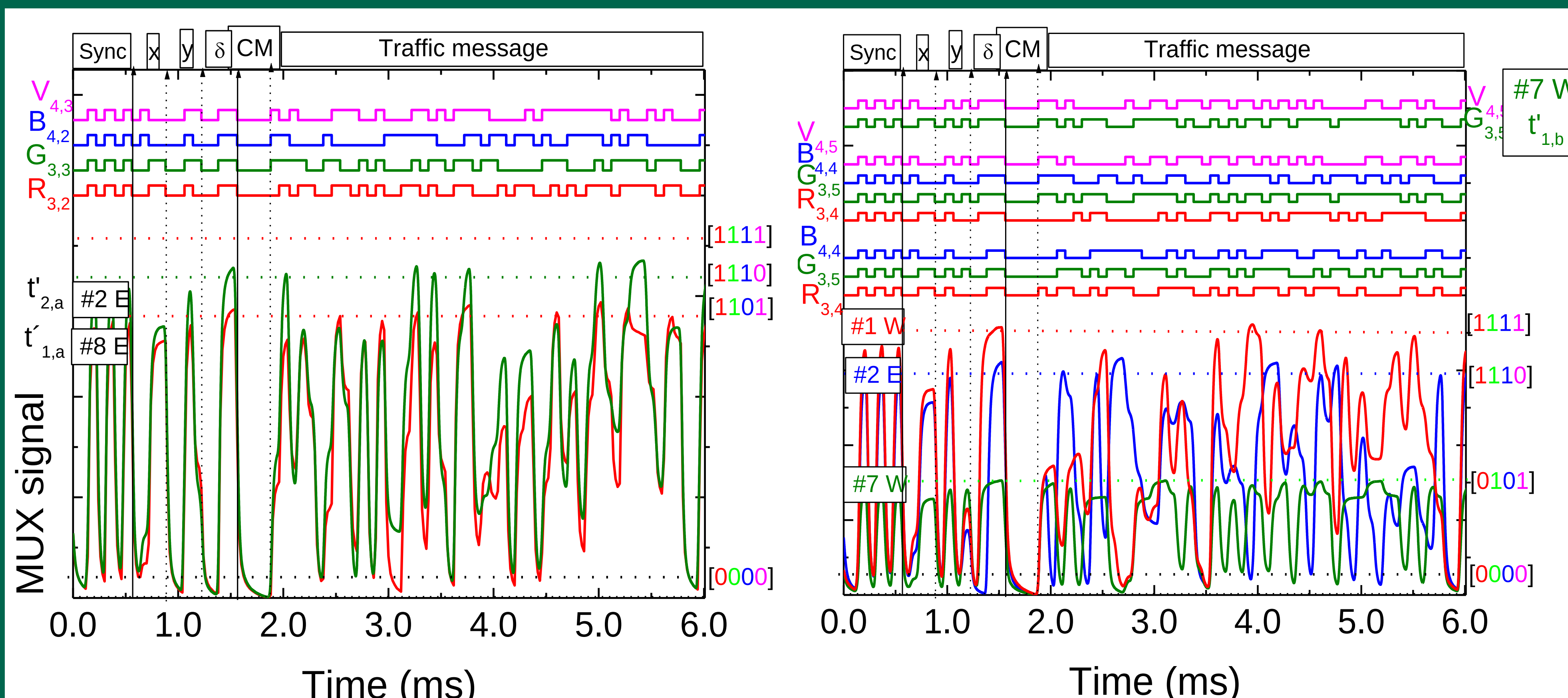


Scenario 2: Message poses (q´) Phase1

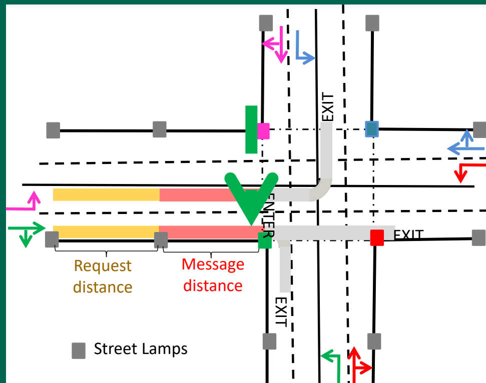




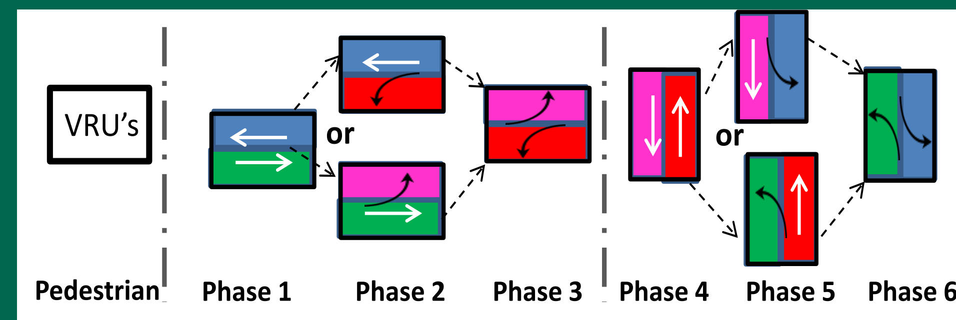
Responding permission (I2V) to vehicles "a" t'_a, "b" t'_b to cross the intersection



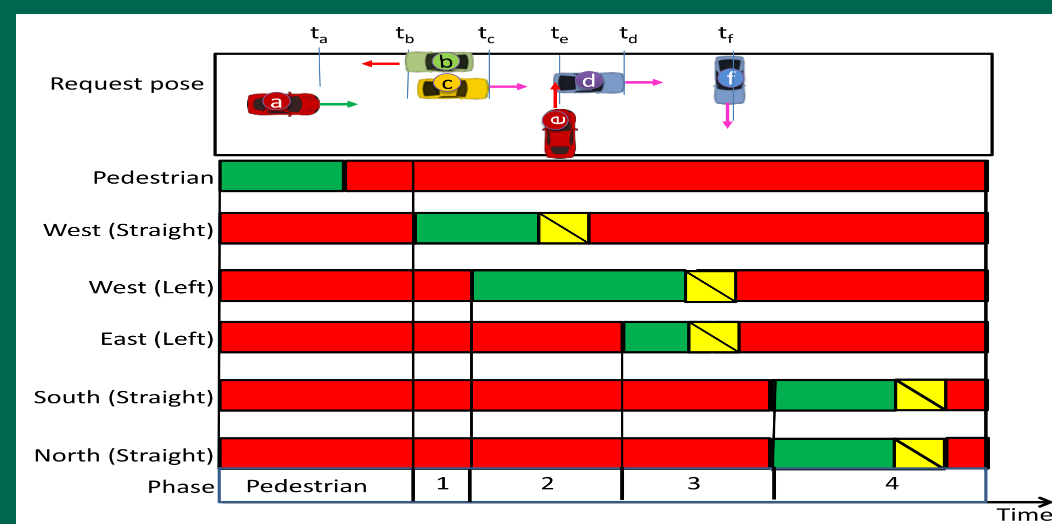
Scenario 3: Capacity, Platoon poses (q´)



A first-come-first-serve approach could be realized by accelerating or decelerating the vehicles such that they arrive at the intersection when gaps in the conflicting traffic flows and pedestrians have been created.

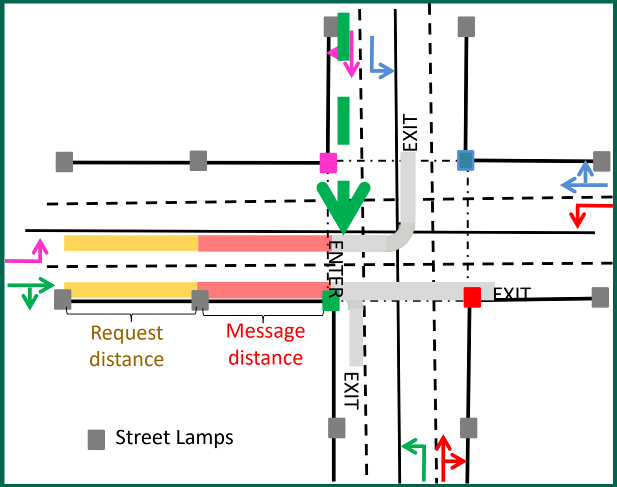


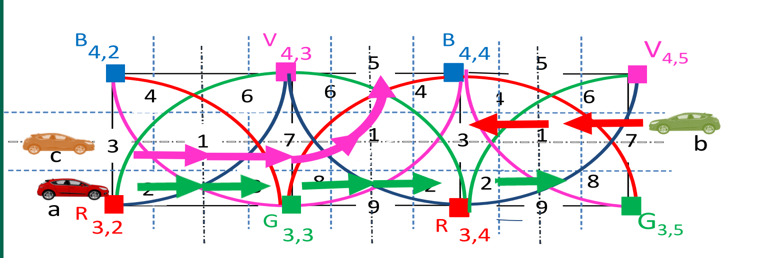
However, a one-by-one service policy at high vehicle arrival rates is not efficient.
From the **capacity** point of view it is more **efficient**, **if Vehicle c is given access** (q´) at t'_c **before Vehicle b**, at t'_b to the intersection **and Vehicle d is given access** (q´) at t'_d **before Vehicle e**, at t'_e then, **forming a west left turn of set of vehicles (violet platoon poses)** before giving way to the fourth phase (north and south conflicting flows)

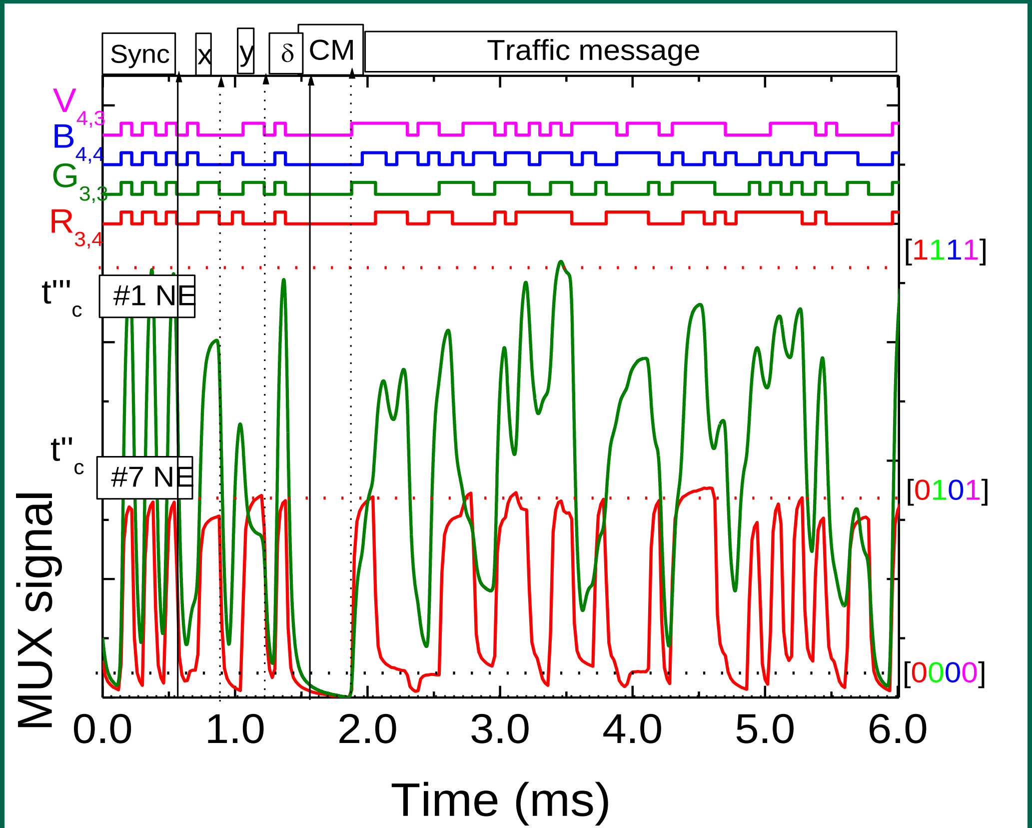


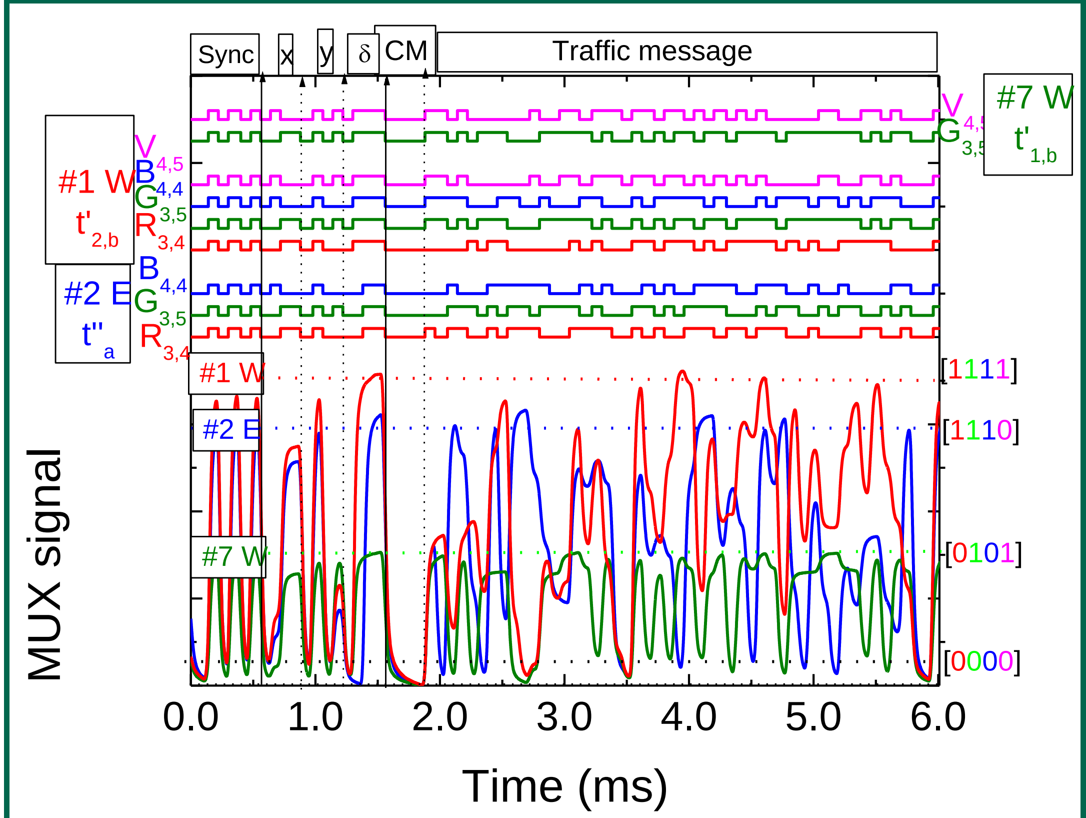
Scenario 4: Enter poses (q´´) Phase 2

At the heart of the command and control is the Intersection Manager (IM). It shares sensing information “Enter Poses “of the vehicles “a” t''_a, “c” t''_c.
This allows vehicle “a“ **to “see”!** *vehicle “c“* improving driving safety.

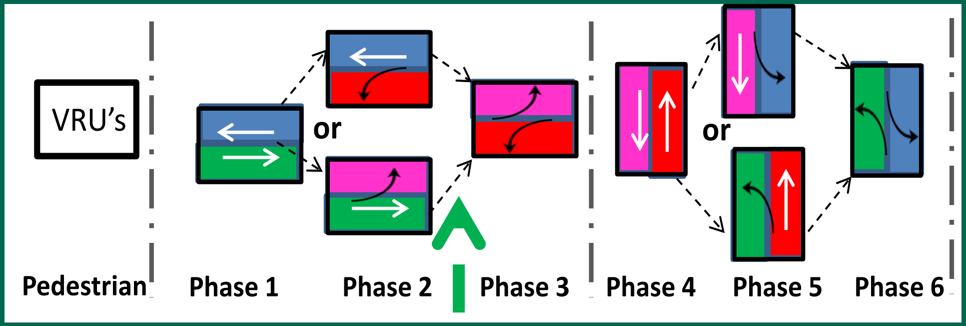


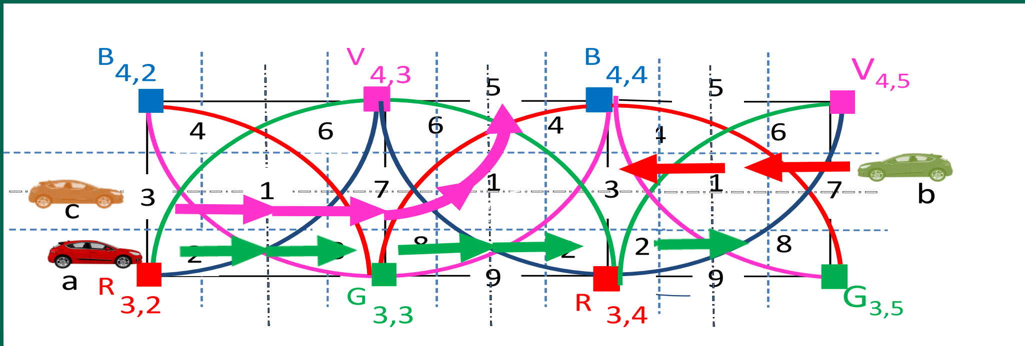




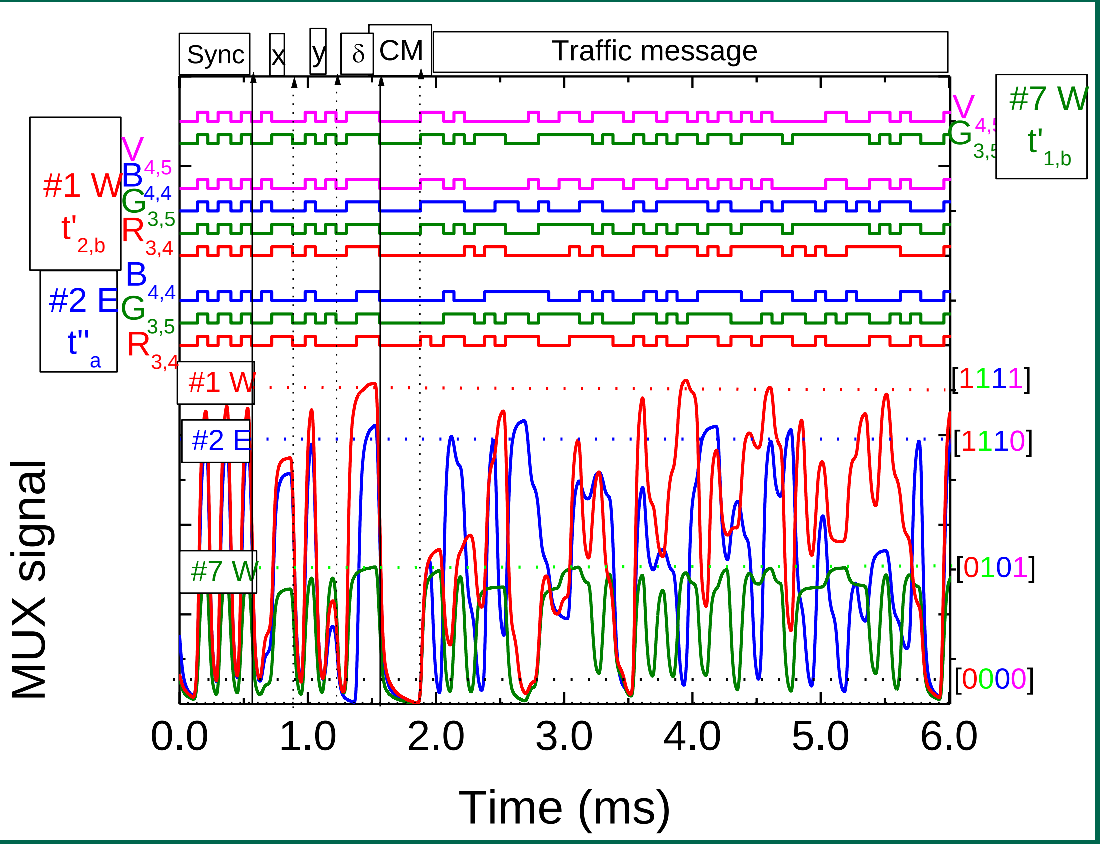


Scenario 5: Conflicting vehicles





Phase 2 ends,
Phase 3 begins

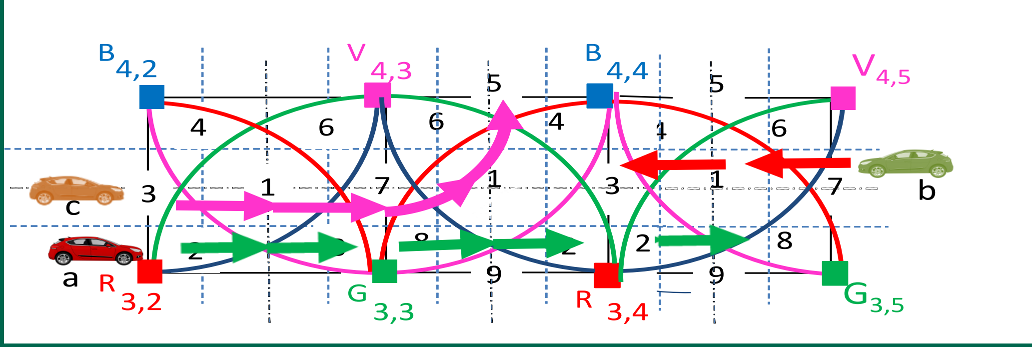


Vehicle *b* approaches the intersection after having asked permission to cross it and only receives authorization when the vehicle *a* has left the intersection (end of Phase 2).

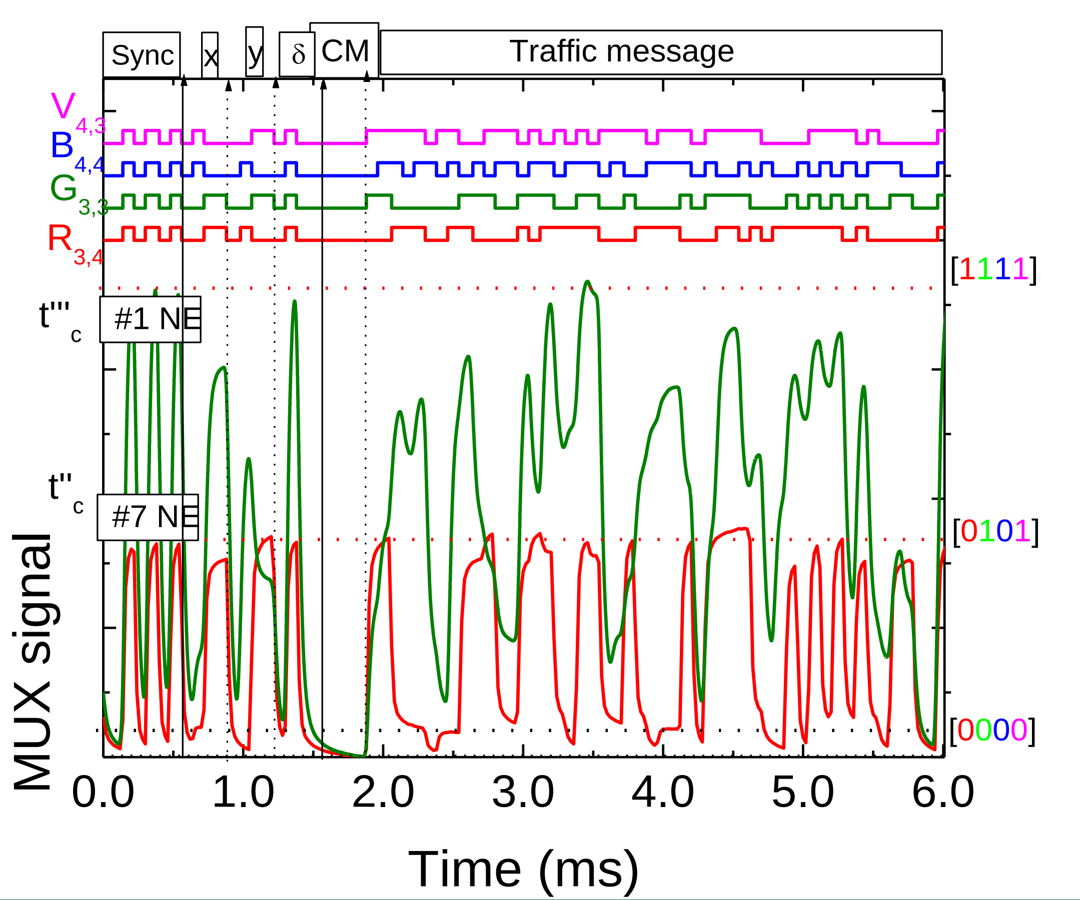
Then, Phase 3 begins with vehicle *b* heading to the intersection (W) (**pose red**) while vehicle *a* follows its destination towards E (**pose green**).

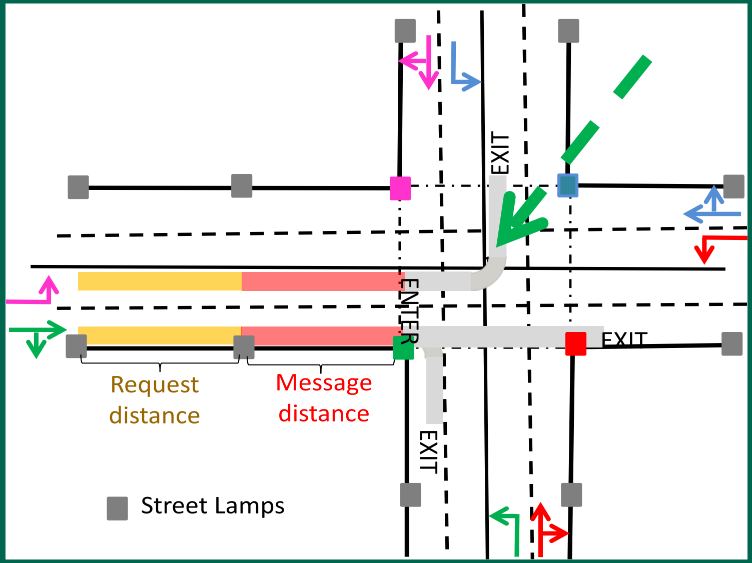
Potential motion conflicts between future "a", "b" trajectories can be detected in advance and should be resolved in time.

Scenario 6: Exit pose (q´´´)



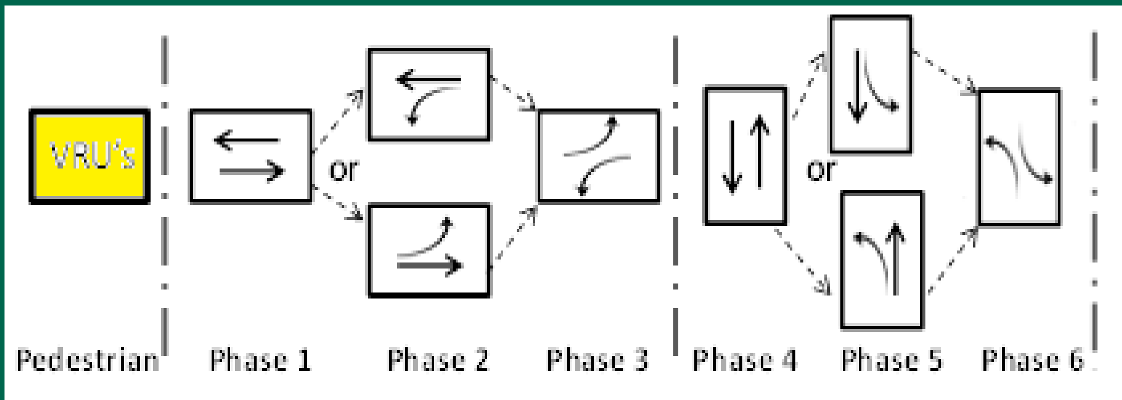
Exit Position of the vehicle “c”
from the W flow

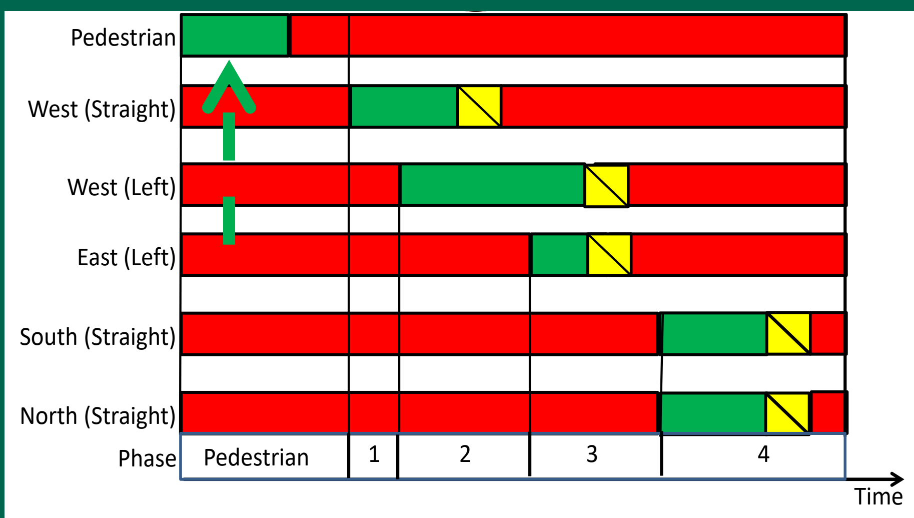


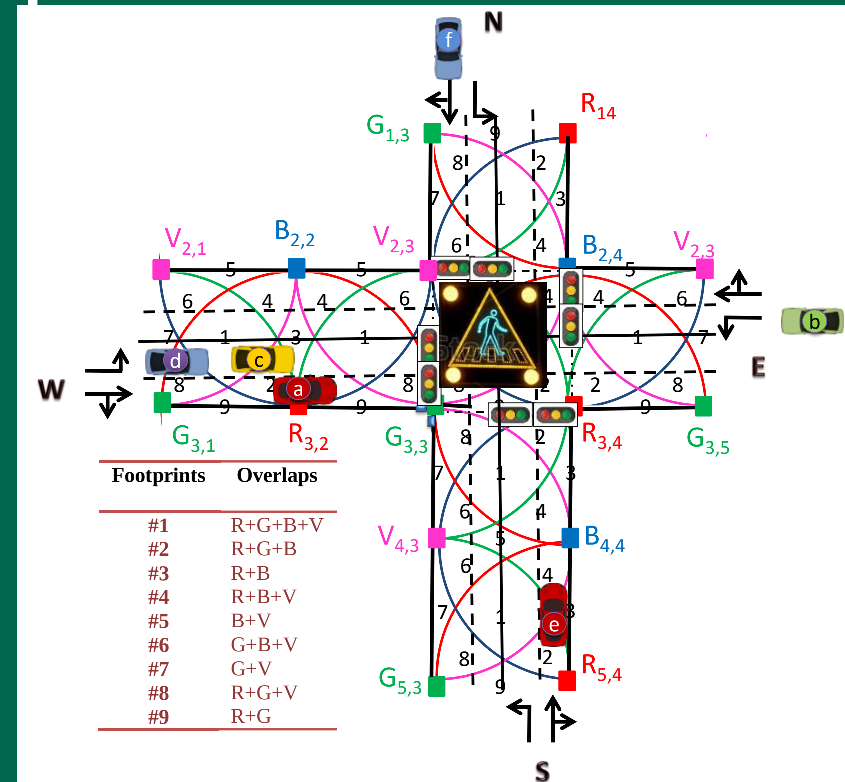


The traffic-actuated controller uses vehicle request/respond message information, **“exit poses”** to generate phase durations appropriate to accommodate the demand on each cycle

Scenario 7: "No" request poses







I2vru´s communication allows direct monitoring:

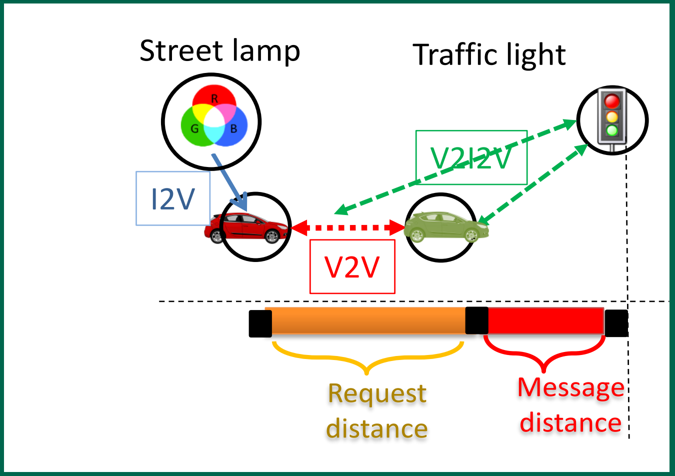
- Vulnerable road user crossing requests
- Controller message to nomadic road user´s devices

Exclusive Pedestrian Phasing

When vehicles will be stopped on all approaches to an intersection

Pedestrians are given a WALK indication

Conclusions and Recommendations



- Light-activated pi'n/pin a-SiC:H devices combines the demultiplexing operation with the simultaneous photodetection and self amplification.

- Connected vehicles information from the network (I2V), vehicular interaction (V2V) and infrastructure (V2I) and (I2V) is analyzed.

- A Graphical representation of the simultaneous localization and mapping problem is established

- The experimental results, confirmed that the proposed cooperative VLC architecture improve the efficacy of Human-Car interaction systems and is **appropriate** for the **management and monitoring of a traffic** light controlled **two-way-two-way** crossroad.

- **Three-level optimization**:
  Redesign phasing duration and vehicle pose connectivity.