Keynote Speech

SENSORCOMM 2018
September 16, 2018 to September 20, 2018 - Venice, Italy

# Vehicular communications using V L C: Future trends and applications


**Manuela Vieira**

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Paula Louro

Pedro Vieira




**ACKNOWLEDGEMENTS**

- FCT – ref. UID/EEA/00066/2013
- IPL/2017/EmGraph/ISEL
- IPL/2017/SMART_VeDa/ISEL.

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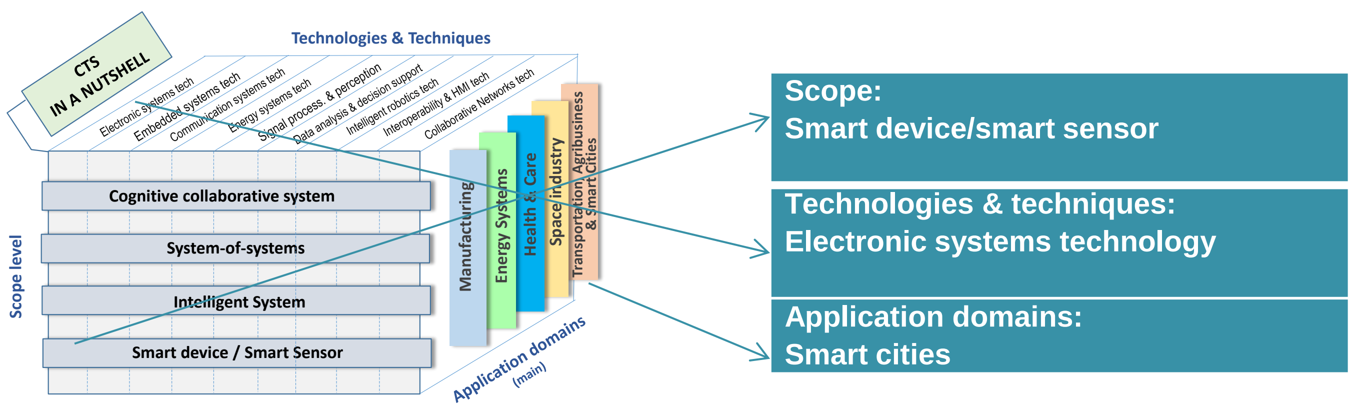
- **Manuela Vieira** was born in Lisbon, Portugal. In 1986 she received the Master of Science in Solid State Physics-Microelectronic and in 1993 the PhD in Semiconductor Materials both from the New University of Lisbon. She is a full professor since 2011 in Electronics inside the Department of Electronics Telecommunication and Computers (ISEL- Portugal) and the head of a Group in Applied Research in Microelectronic Optoelectronic and Sensors-GIAMOS in ISEL and another in Microelectronic, Material and processes-(M2P) in CTS-UNINOVA. She has several scientific papers and 30 years of experience in the field of thin films and devices, her research activities have been mainly related to the development of optical sensors .

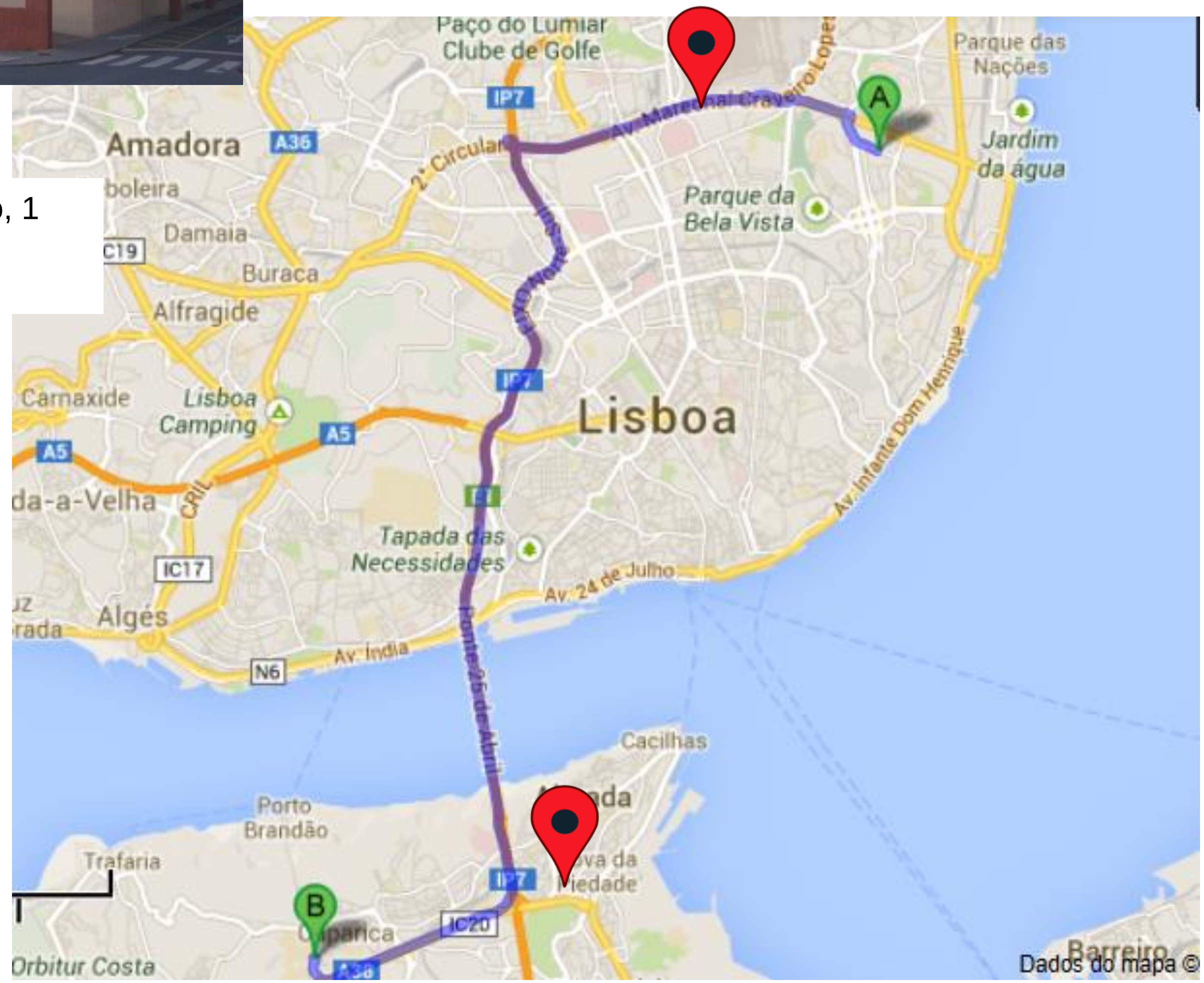
- **Other scientific activities**:
- Referee for international publications such as: Thin Solid Films, Material Research Society, Sensor Magazine, Sensor and Actuators, Material Science Fórum, Solid State Electronics, Vacuum, Applied Surface Science, Sensors and Transducers, Ibersensors, Physica Status Solidi, Sensors, Journal of Nanoscience Nanotechnology, Journal of Sensors, Journal of Signal and Imaging Systems Engineering) Journal of Optical Engineering, Plasmonics, Journal of Luminiscence, etc.
- Referee for several EU projects as part of the Programme Growth "Innovative Products, Processes and Organisation".
- Supervision and co-supervision of Master and PhD students
- Examiner for Master and Doctoral degrees.
- Authored and co-authored more than *350* publications in international journals cited in *"Science Citation Index"*. Presented more than *500* communications at conferences and seminars most of which with publication in journals and proceedings.

# Location

## ISEL-ADEETC

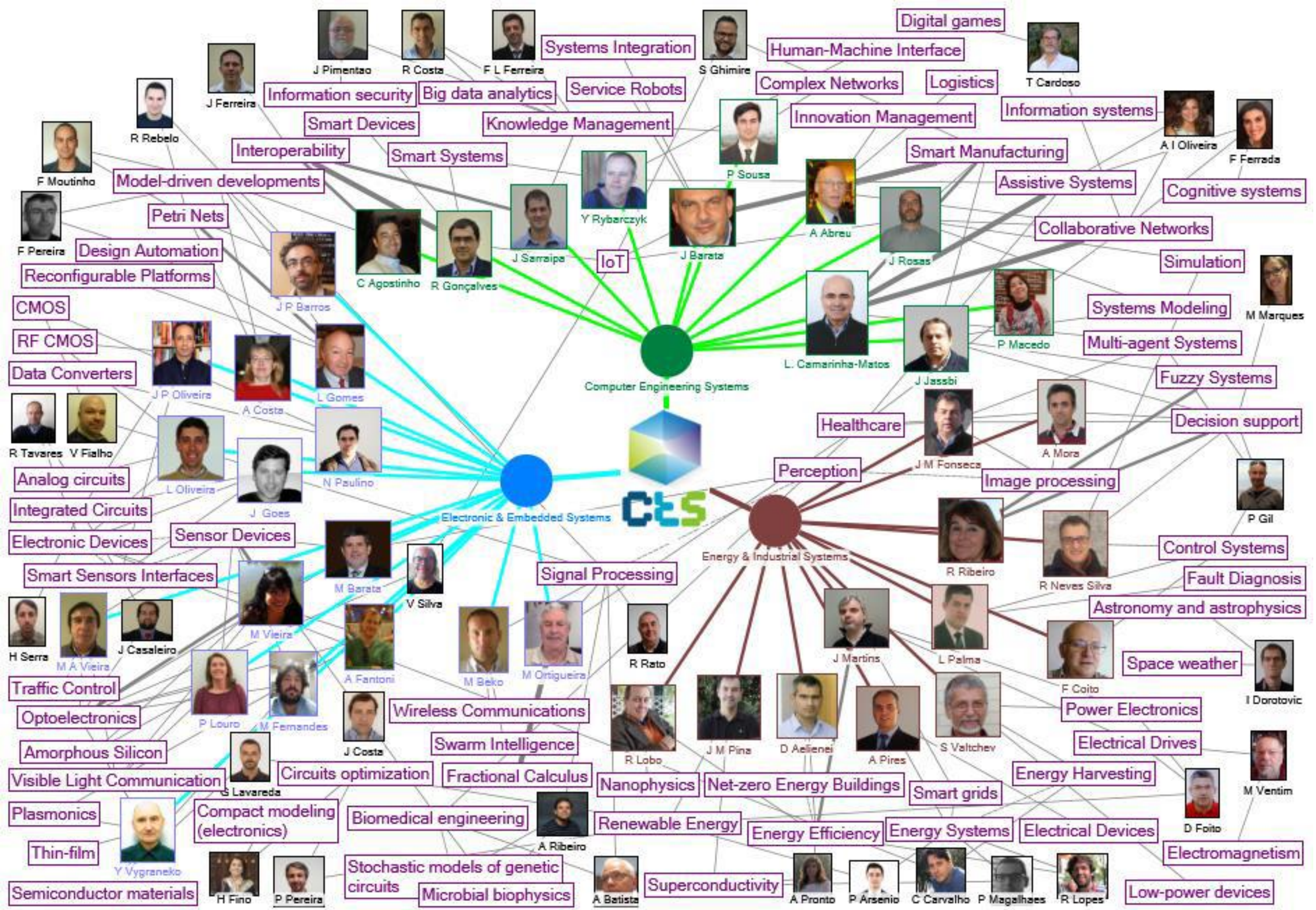
Rua Conselheiro Emídio Navarro, 1
1959-007 Lisboa
Portugal




CTS

## CTS-UNINOVA

FCT Campus
2829-516 Caparica,
Portugal


Computer Engineering Systems
Electronic & Embedded Systems
Energy & Industrial Systems
CTS
Digital games
Systems Integration
Human-Machine Interface
Information security
Big data analytics
Service Robots
Complex Networks
Logistics
Smart Devices
Knowledge Management
Innovation Management
Information systems
Interoperability
Smart Systems
Smart Manufacturing
Model-driven developments
Assistive Systems
Cognitive systems
Petri Nets
Collaborative Networks
Design Automation
IoT
Simulation
Reconfigurable Platforms
Systems Modeling
CMOS
RF CMOS
Multi-agent Systems
Data Converters
Fuzzy Systems
Healthcare
Decision support
Perception
Image processing
Analog circuits
Integrated Circuits
Sensor Devices
Electronic Devices
Control Systems
Smart Sensors Interfaces
Signal Processing
Fault Diagnosis
Astronomy and astrophysics
Space weather
Traffic Control
Optoelectronics
Wireless Communications
Power Electronics
Swarm Intelligence
Electrical Drives
Amorphous Silicon
Circuits optimization
Fractional Calculus
Energy Harvesting
Visible Light Communication
Nanophysics
Net-zero Energy Buildings
Smart grids
Plasmonics
Compact modeling (electronics)
Biomedical engineering
Renewable Energy
Energy Efficiency
Energy Systems
Electrical Devices
Thin-film
Electromagnetism
Stochastic models of genetic circuits
Superconductivity
Semiconductor materials
Microbial biophysics
Low-power devices
J Pimentao
R Costa
F L Ferreira
S Ghimire
T Cardoso
J Ferreira
R Rebelo
F Moutinho
P Sousa
A I Oliveira
F Ferrada
Y Rybarczyk
F Pereira
J Sarraipa
J Barata
A Abreu
J Rosas
C Agostinho
R Gonçalves
J P Barros
M Marques
P Macedo
L. Camarinha-Matos
J Jassbi
J P Oliveira
A Costa
L Gomes
R Tavares
V Fialho
J M Fonseca
A Mora
L Oliveira
J. Goes
N Paulino
P Gil
R Ribeiro
R Neves Silva
M Barata
V Silva
H Serra
M A Vieira
J Casaleiro
M Vieira
A Fantoni
M Beko
M Ortigueira
R Rato
J Martins
L Palma
F Coito
I Dorotovic
P Louro
M Fernandes
J Costa
R Lobo
J M Pina
D Aelenei
A Pires
S Valtchev
M Ventim
G Lavareda
D Foito
Y Vygranenko
A Ribeiro
H Fino
P Pereira
A Batista
A Pronto
P Arsenio
C Carvalho
P Magalhaes
R Lopes

# People (M2P)

- **PhD members (9)**
- Manuela Vieira (Coordinator)
- Alessandro Fantoni
- Guilherme Lavareda
- João Costa
- Manuel Barata
- Manuel Vieira
- Miguel Fernandes
- Paula Louro
- Yuriy Vygranenko

- **PhD students (5)**
- Dora Gonçalves
- João Martins
- Vitor Fialho
- João Mendes
- Vítor Silva

- **MSc students (5)**
- Ricardo Almeida
- João Reis
- Nuno Mendes
- Hugo Leão
- Fábio Cardoso

# Objectives

- Development, optimization and application of semiconductor based devices: image and color sensors, optoelectronic devices, solar cells, optical amplifiers, biosensors, nanostructures and UV and IV detectors, VLC devices.

- Design and modeling of optical devices.

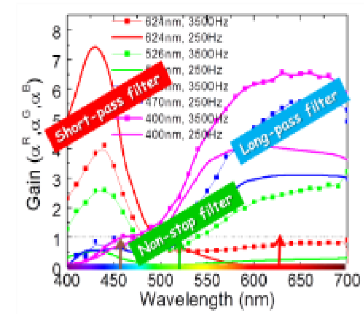
- Electrical and numerical simulation of optical devices.

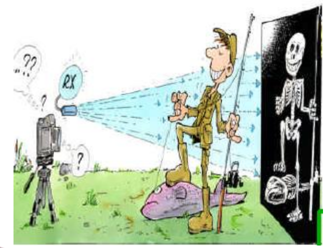
- Integration of different technologies, namely optical sensors, wavelength-division multiplexing, X-ray detectors and full digital medical imaging.

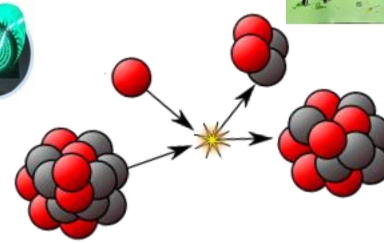
- Optical Communications

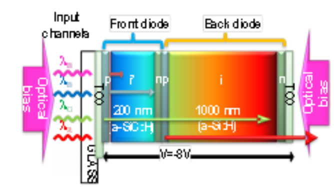
# Main Research Areas

- Applications of semiconductor devices
  - Wavelength Division Multiplexing (WDM)
  - Optical biosensors
  - X-ray flat panel
  - OLEDs
  - Nanodevices

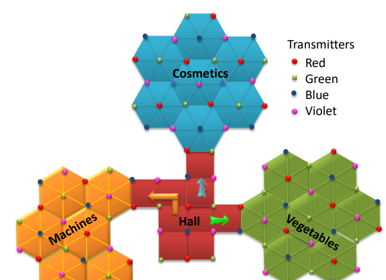


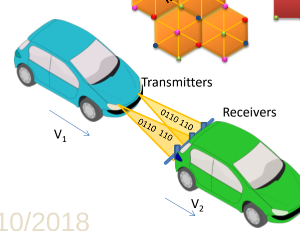







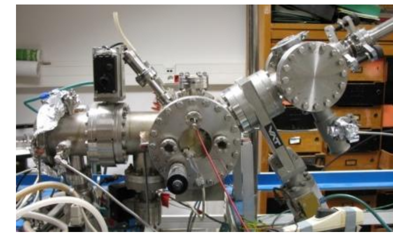

- Visible Light Communications
  - Indoor positioning systems
  - Vehicular Communications



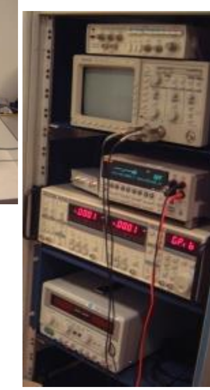



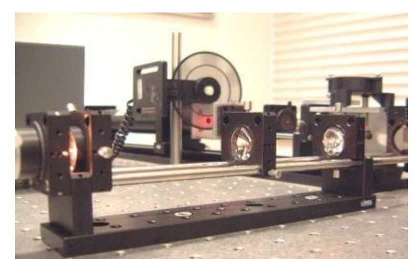
# Facilities

- **Deposition facilities:**
  - Laboratories for support of Semiconductor Thin Film Development using the PECVD (Plasma Enhanced Chemical Decomposition) techniques.
  - Laboratories for support of Electronic, Optoelectronic and Microelectronic Device Processing.



- **Characterization facilities:**
  - UV-VIS-NIR and IR Spectrophotometers (Shimadzu),
  - dark/photo conductivity as a function of temperature;
  - spectral response;
  - Flying Spot Technique-FST;
  - Photothermal Deflection Spectroscopy-PDS;
  - Space Charge Limited Current-SCLC;
  - C(T)/C(V) measurements,
  - Coatings uniformity test-bench,
  - Characterization systems for devices (IV characteristics; annealing test chambers; degradation tests; interface characterization; Electroluminescence) and Solar simulator for small areas.
  - Spectrometers (UV, VIR, NIR, IR) and
  - Optical Characterization Systems (I-V, C-V),
  - Electric Characterization Systems,
  - Material Testing Bench.





# Dissemination


**Abbreviated Journal Title**

APPL PHYS LETT

IEEE T ELECTRON DEV

SENSORS and
TRANSDUCERS

J APPL PHYS

J. NANOSCI. NANOTECH

J. OPTICAL ENG.

J. LUMINISCENCE

…
.

# International Cooperation

- Department of Electrical and Computer Eng., Waterloo, Canada.
- Giga to Nano Electronics Group, Univ. Waterloo, Canada.
- University of  Cagliari, Italy.
- IPE, Stuttgart University, Germany
- Institute of Semiconductor Physics, Ukrainian Academy of Science, Kiev, Ucraine.
- Institute of Physics, Polish Academy of Sciences, Warszawa, Poland.
- Institute of Molecular Physics University, Polish Academy of Sciences, Poland.
- Wurzburg University, Germany.
- Polish Academy of Sciences, Poland.




✓ Production of semiconductor devices,
✓ Characterization of materials and devices,
✓ Joint publications.

# Vehicular communications using V L C: Future trends and applications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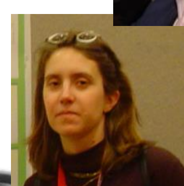
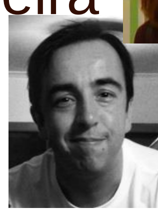
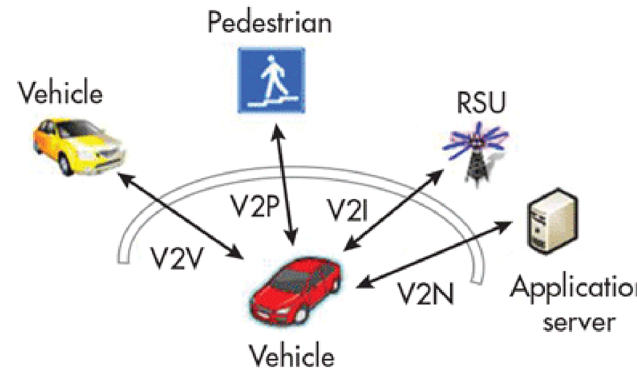
Manuel A. Vieira

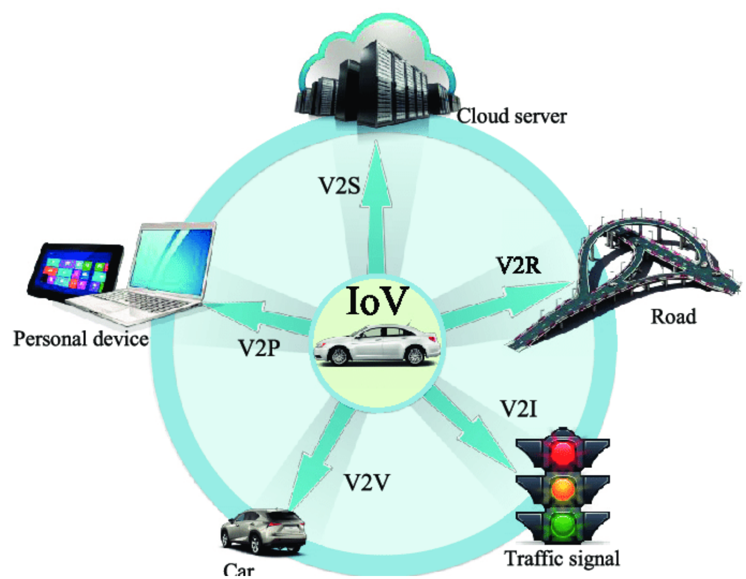
Paula Louro

Pedro Vieira

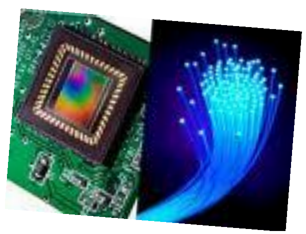




# NOBEL in Physics 2009

**TWO REVOLUTIONARY OPTICAL TECHNOLOGIES**



George E. Smith

Charles K. Kao

Willard S. Boyle

"The Nobel Prize in Physics 2009 honors three scientists, who have played important roles in shaping the modern information technology, with one half to **Charles K. Kao** and with **Willard S. Boyle** and **George E. Smith** sharing the other half."

# GLOBAL INTERNET GROWTH AND TRENDS

**Wi-Fi will begin to become limited**

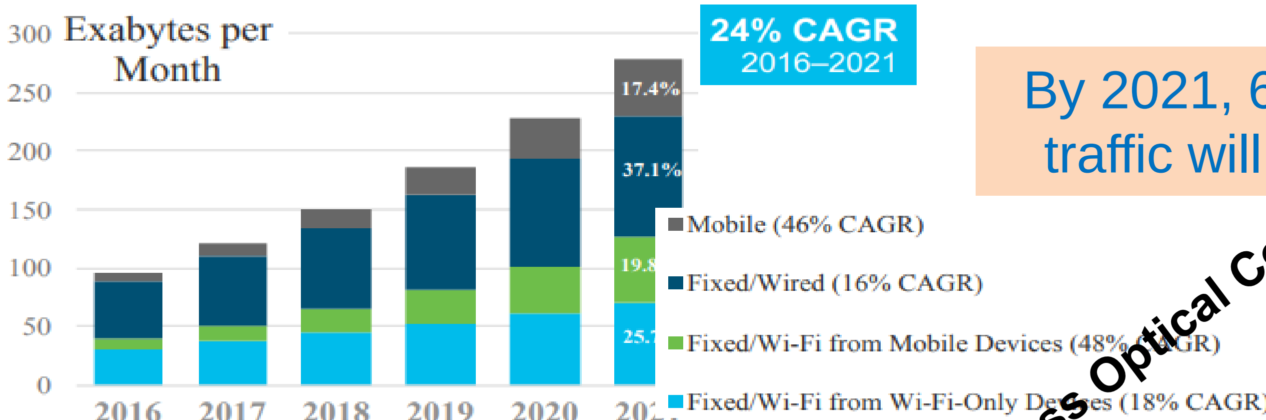
By 2021

| | More Internet Users | More Devices & Connections | Faster Broadband Speeds | More Video Viewing |
|---|---|---|---|---|
| 2016 | 3.3 Billion | 17.1 Billion | 27.5 Mbps | 73% of Traffic |
| 2021 | **4.6 Billion** | **27.1 Billion** | **53.0 Mbps** | **82% of Traffic** |

Data traffic

CAGR - Compound annual growth rate

Source: Cisco VNI Global IP Traffic Forecast, 2016-2021

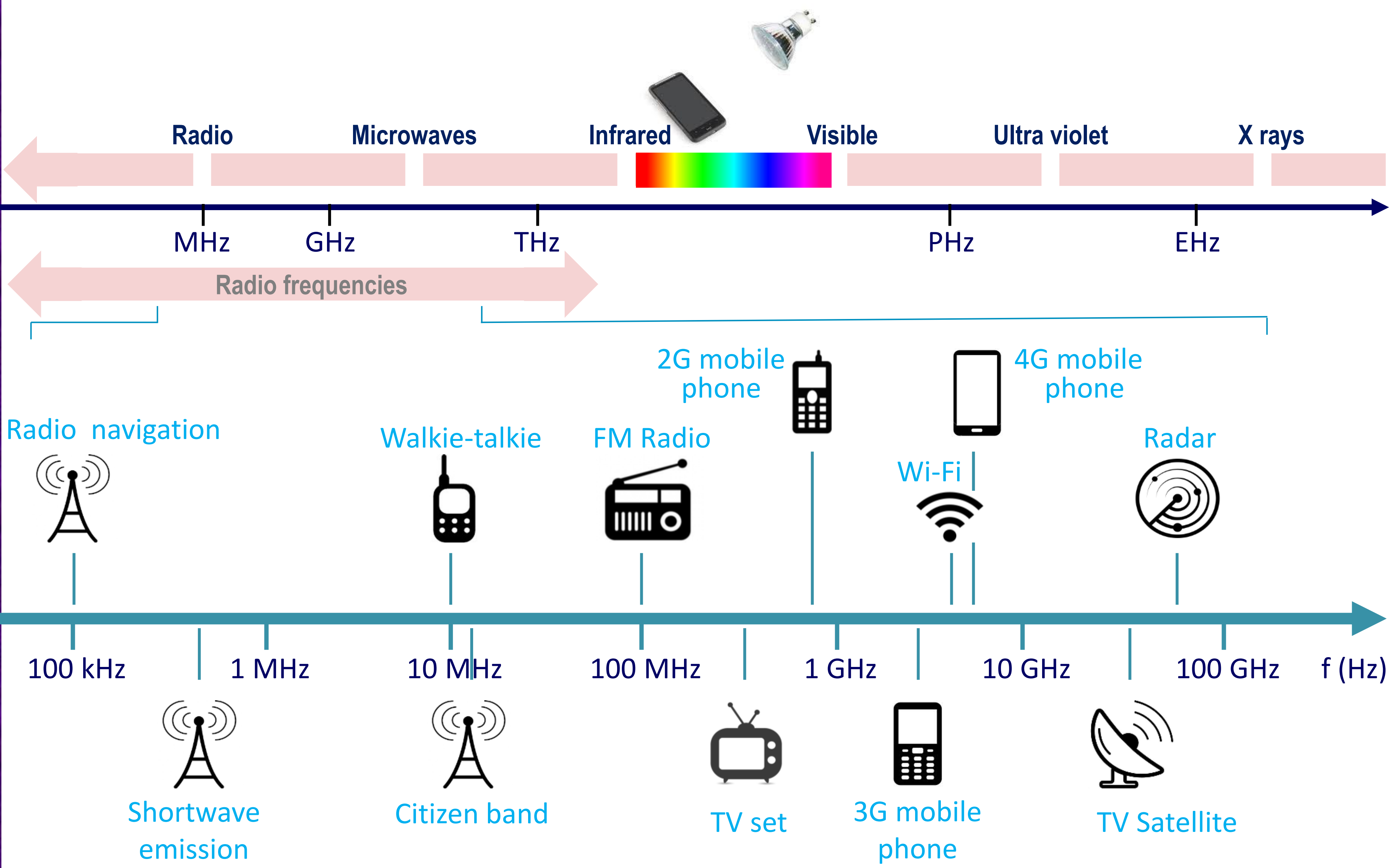


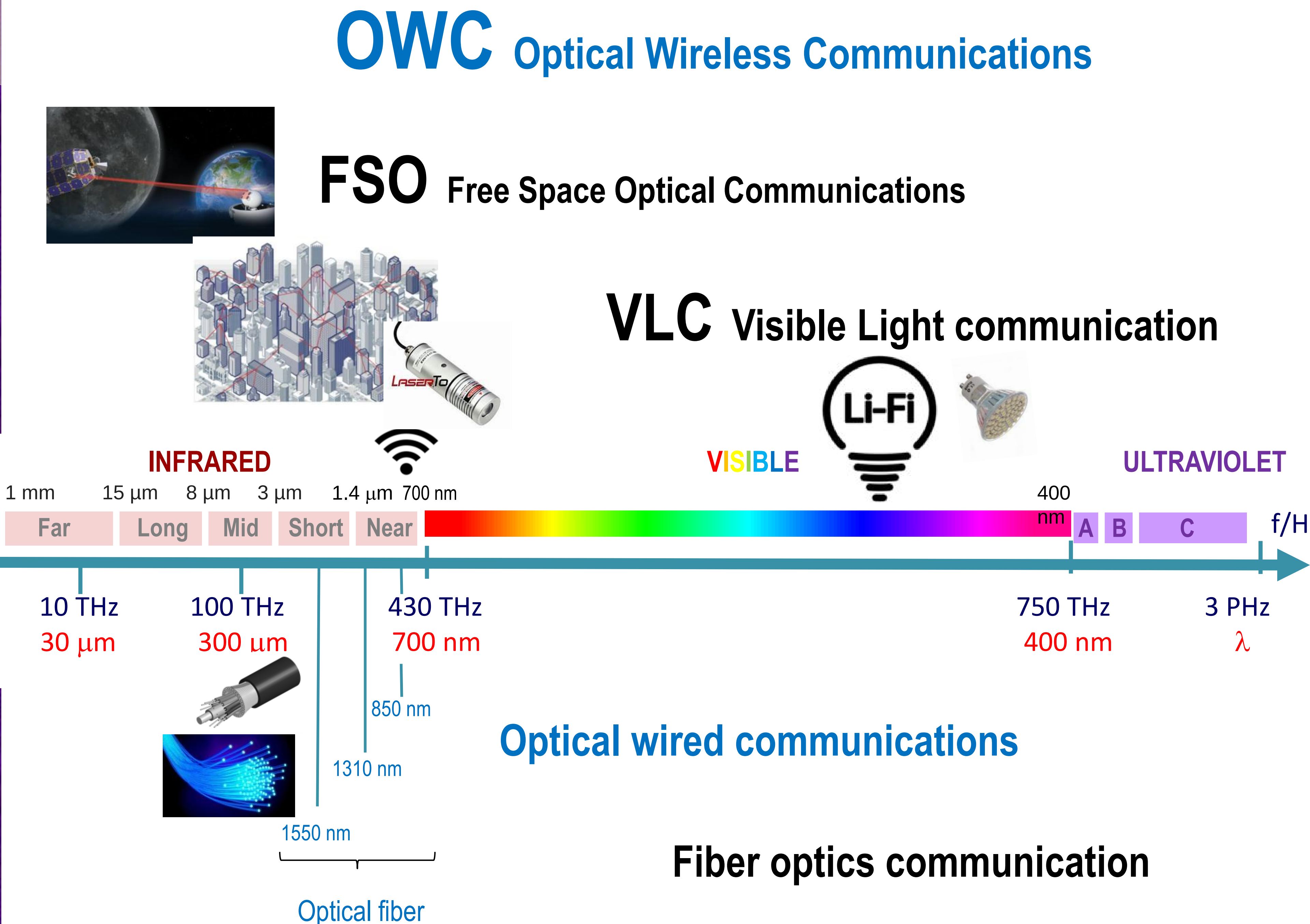

By 2021, 63% of total IP traffic will be wireless *

**Wireless Optical Communications**

* Wireless traffic includes Wi-Fi and mobile

# COMMUNICATION SPECTRUM

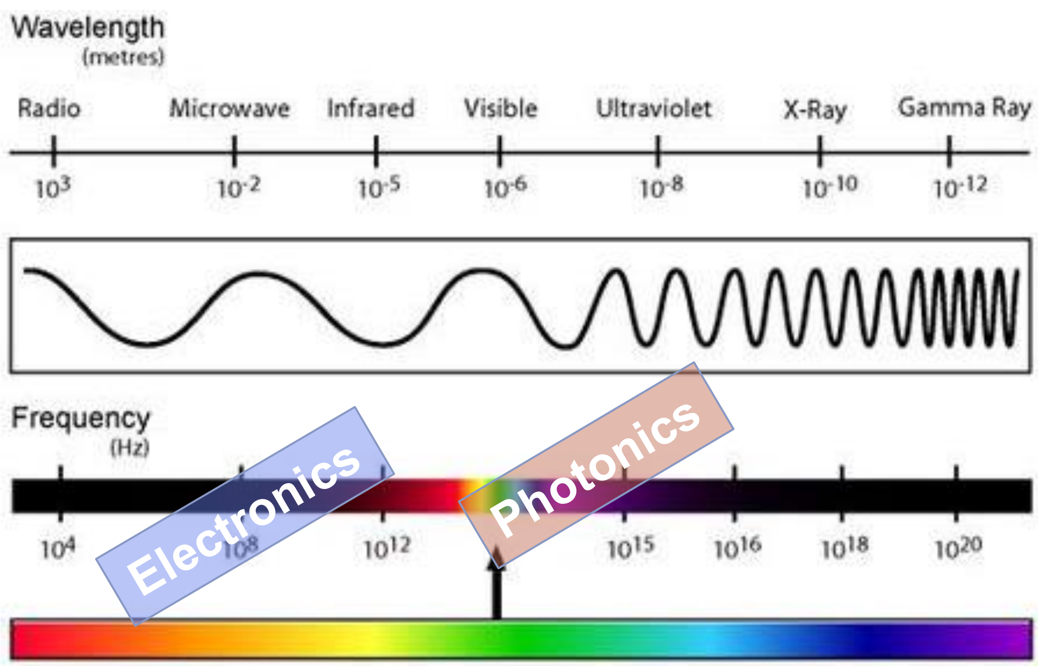




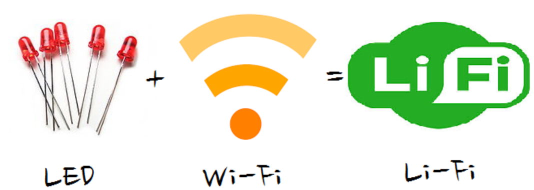
OWC Optical Wireless Communications
FSO Free Space Optical Communications
VLC Visible Light communication
LaserTo
Li-Fi
INFRARED
VISIBLE
ULTRAVIOLET
1 mm
15 µm
8 µm
3 µm
1.4 µm
700 nm
400 nm
Far
Long
Mid
Short
Near
A
B
C
f/H
10 THz
30 µm
100 THz
300 µm
430 THz
700 nm
750 THz
400 nm
3 PHz
λ
850 nm
1310 nm
1550 nm
Optical fiber
Optical wired communications
Fiber optics communication

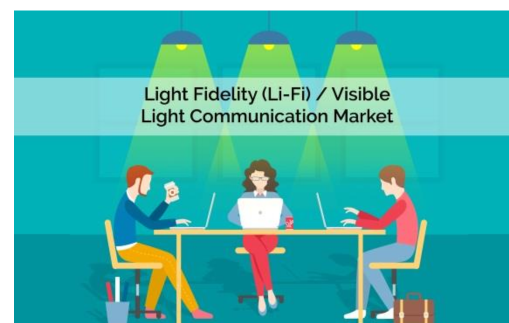
MOTIVATION

# VLC – Visible Light Communication







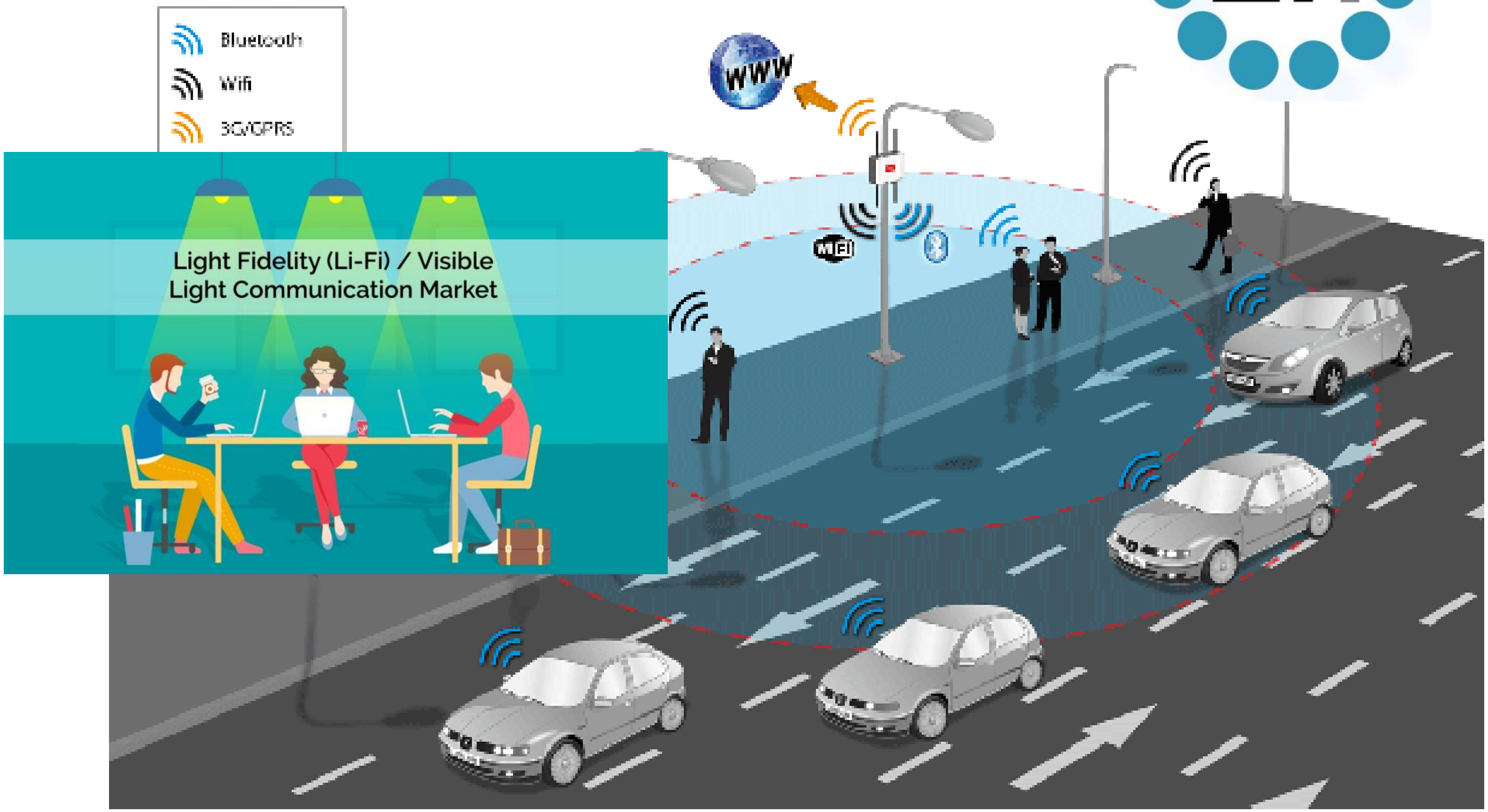




- increased bandwidth
- free and non-regulated spectrum
- line of sight technology (1 – 100 m)
- negligible power
- inexpensive (use of already existing lighting infra-structures)

Wi-Fi vs Li-Fi

# Visible Light Communication

Li-Fi is a Visible Light Communications (VLC) system



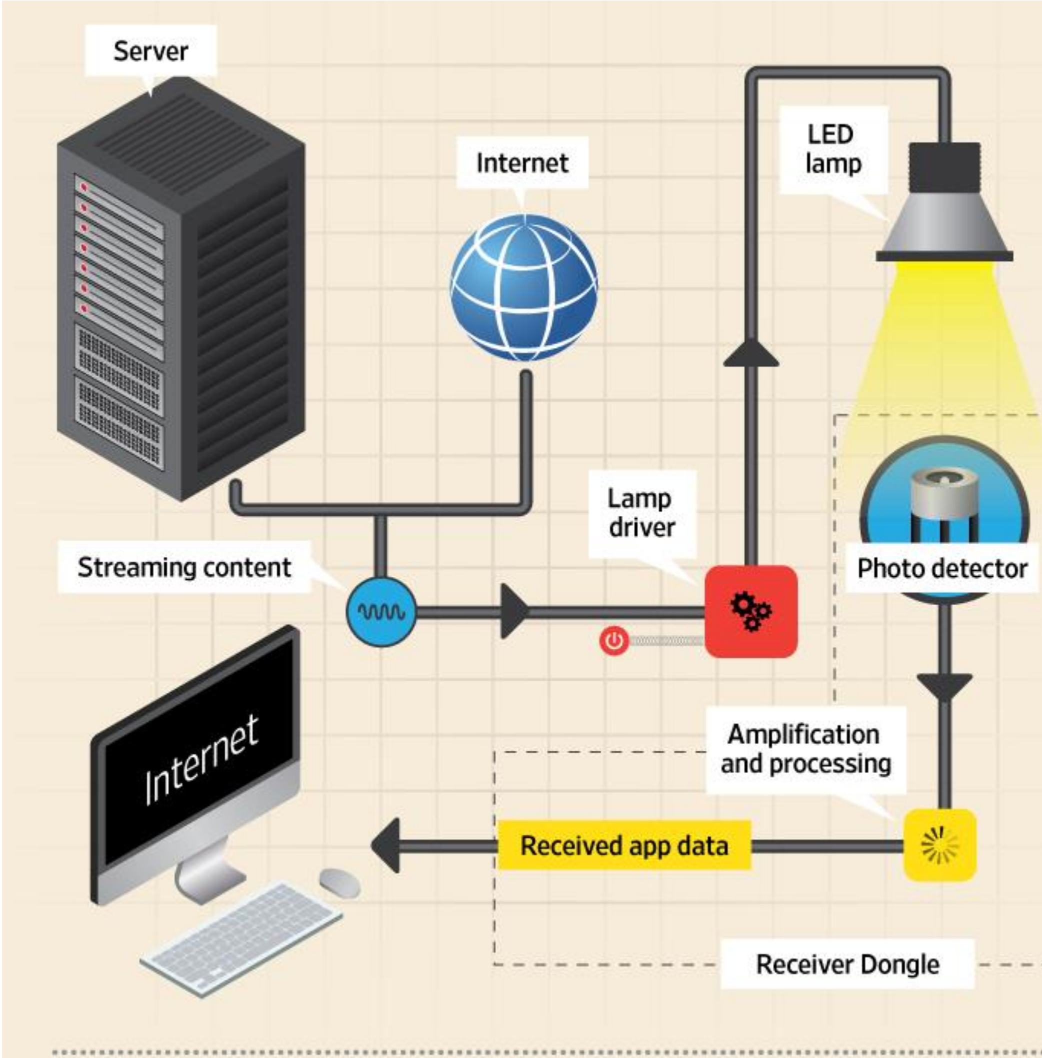

**Li-Fi and Wi-Fi** are quite similar as both transmit data electromagnetically

# INTEGRATION


- The term Li-Fi was coined by Professor **Harald Haas** in 2011. Haas envisioned light bulbs that could act as wireless routers.

Li-Fi signals cannot pass through walls, so in order to enjoy full connectivity, capable LED bulbs will need to be placed throughout the home.

Li-Fi and Wi-Fi are quite similar as both transmit data electromagnetically. However, Wi-Fi uses radio waves, while Li-Fi runs on visible light waves.

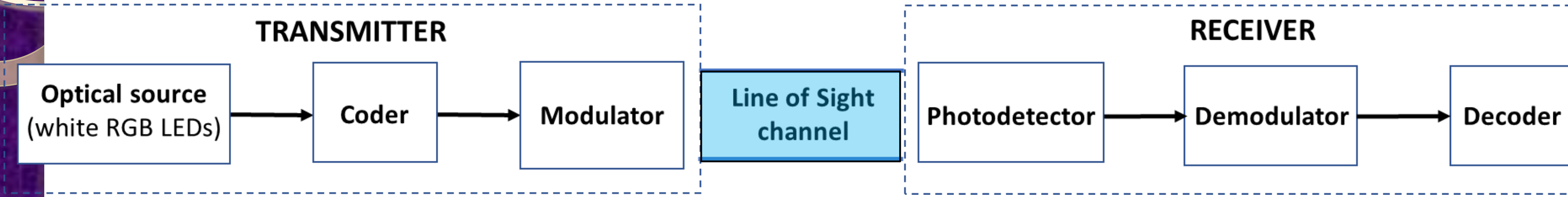


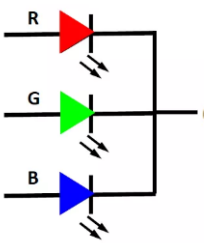


- Data is fed into an LED light bulb (with signal processing technology), it then sends data (embedded in its beam) at rapid speeds to the photo-detector (photodiode).

- The tiny changes in the rapid dimming of LED bulbs is then converted by the 'receiver' into electrical signal.

# Indoor scenario of infrastructure-to-device communication.

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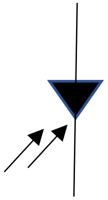
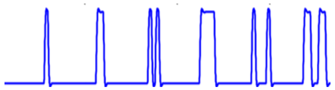
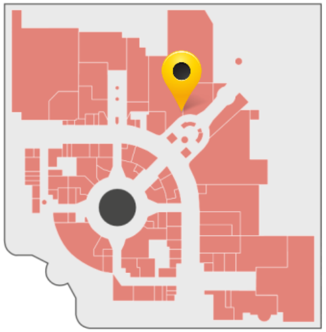


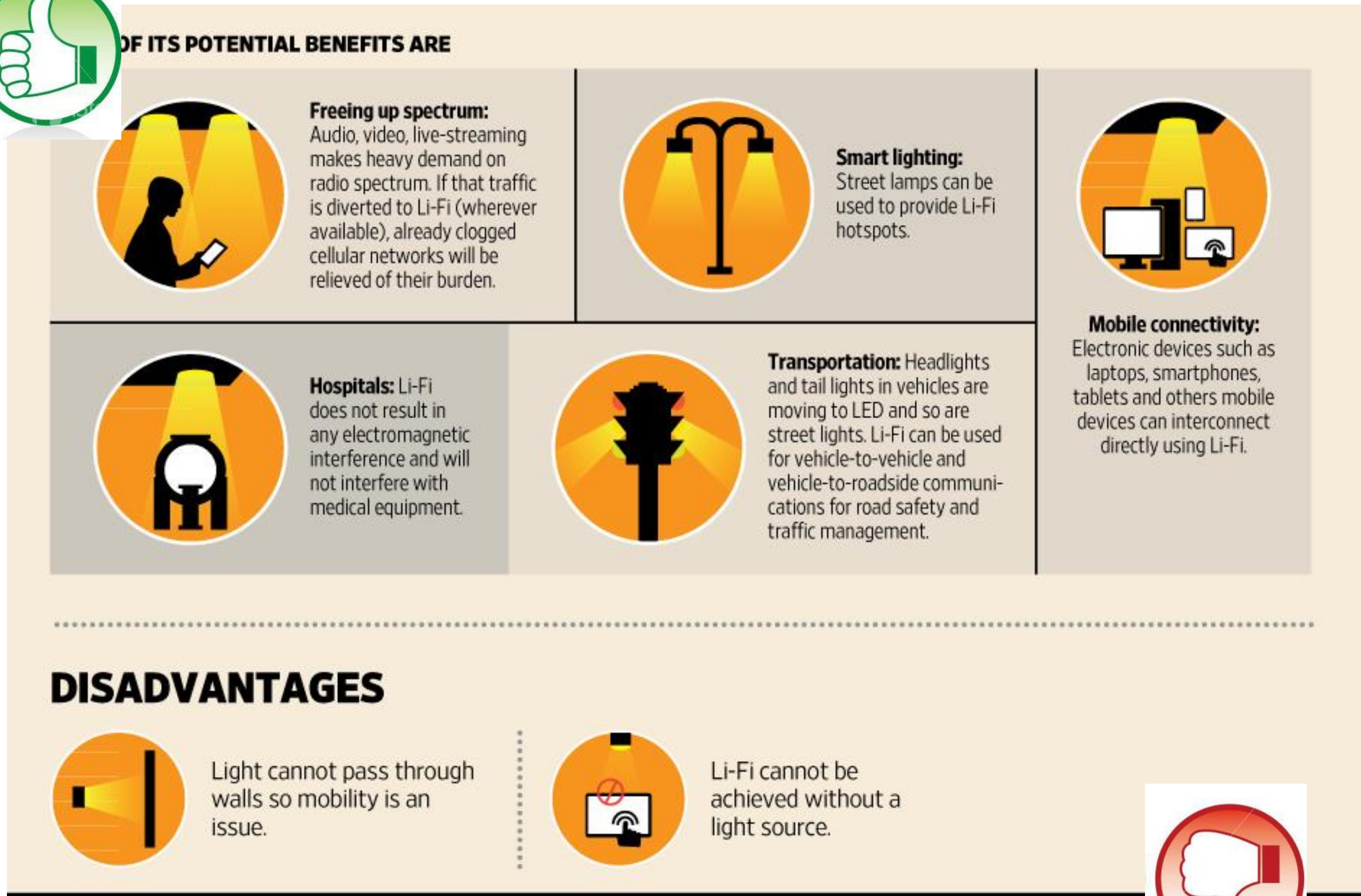




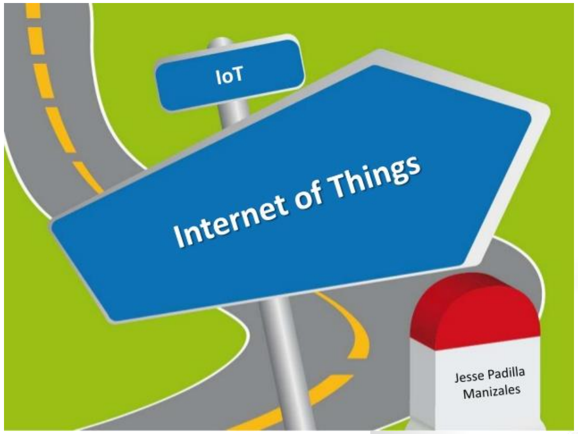
- room illumination
- position/navigation
- data transmission

VLC SYSTEM

# ADVANTAGES/ DISAVANTAGES



# The Internet of Things



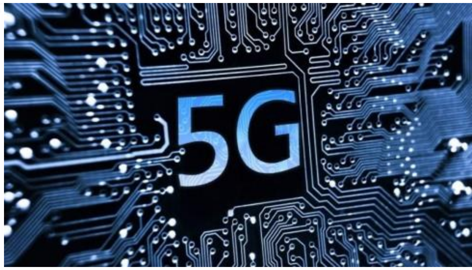


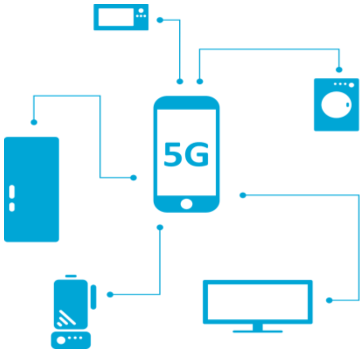
connecting any device with an on and off switch to the Internet (and/or to each other)

The integration of IoT devices and Li-Fi will provide a wealth of opportunities. For example, shop owners could transmit data to multiple customers' phones quickly, securely and remotely.


**Speed**
**Latency**
**Capacity**

| 1G | 2G | 3G | 4G | 5G |
|---|---|---|---|---|
| 1981 | 1992 | 2001 | 2010 | 2020(?) |
| 2 Kbps | 64 Kbps | 2 Mbps | 100 Mbps | 10 Gbps |
| Basic voice service using analog protocols | Designed primarily for voice using the digital standards (GSM/CDMA) | First mobile broadband utilizing IP protocols (WCDMA / CDMA2000) | True mobile broadband on a unified standard (LTE) | 'Tactile Internet' with service-aware devices and fiber-like speeds |

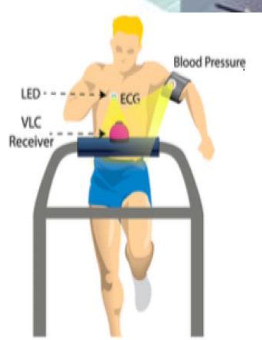



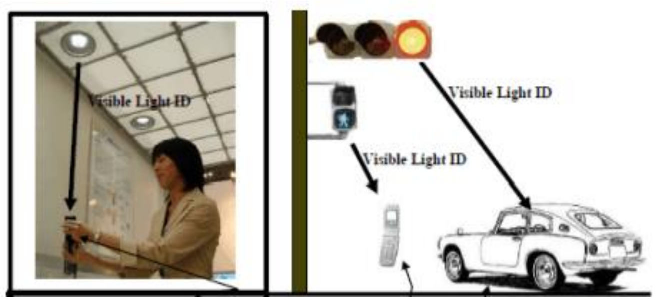

5G will drive the future networked society

5G is expected to use various technologies such as LTE (Long Term Evolution), WiFi, Ultra Wide Band (UWB) and VLC to ensure permanent coverage of the communication network without any interruption of service.

MOTIVATION

# VLC – Visible Light Communication


**Indoors environments**

- Light atmospheric absorption
- shadows
- light dispersion
- influence of other light sources

- Internet service distribution
- Navigation techniques

3 Gbps

APPLICATION

# Visible Light Communication Technology for Fine-grained Indoor Localization


**M. Vieira**
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P. Louro
A. Fantoni
P. Vieira

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FCT FACULDADE DE CIÊNCIAS E TECNOLOGIA UNIVERSIDADE NOVA DE LISBOA

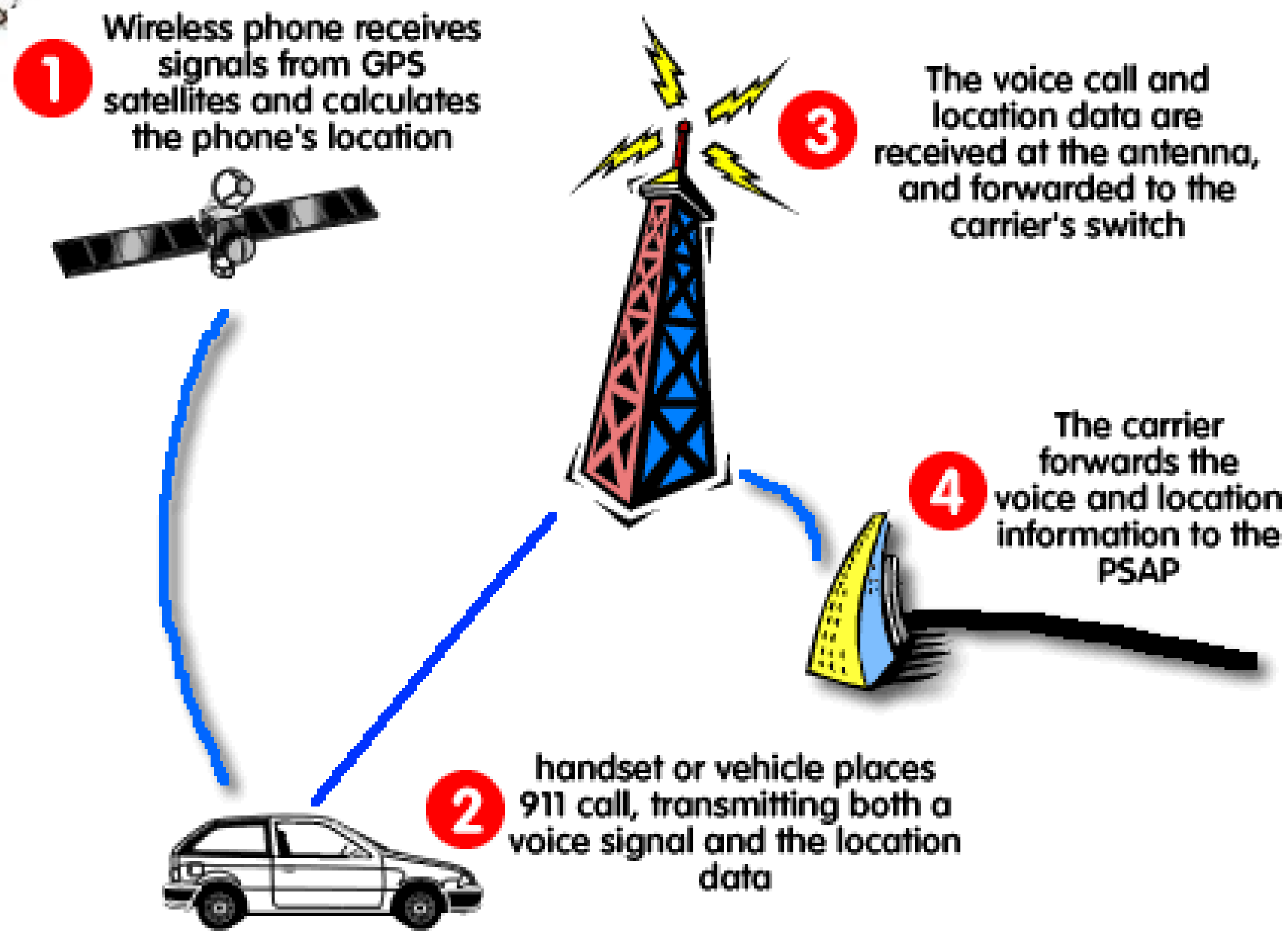



**ACKNOWLEDGEMENTS**

- FCT – ref. UID/EEA/00066/2013
- IPL/2016/VLC_MIMO/ISEL
- IPL/2017/SMART_VeDa/ISEL.

MOTIVATION

# GPS How it works????



MOTIVATION

# VLC: Visible Light Communication

- Dual operation: light + comm
- Infrastructure advantage
- Increased bandwidth
- Free and non-regulated spectrum
- Negligible power
- Inexpensive
- Security
- Harmless to human health
- No **EM** interference

- Line of sight technology (LoS)
  - Distance: 1 – 100 m
  - Obstructions
  - Atmospheric absorption
  - Shadows
  - Light dispersion
  - Influence of other light sources

**INDOOR USE**

# OUTLINE

## ✓ MOTIVATION

- VLC – Transmission of data using light
- Multilayered a-SiC:H heterostructures as optical filters

## ✓ SYSTEM DESIGN

- The cellular topologies
- The emitters
- The OOK modulation scheme
- The VLC receiver

## ✓ RESULTS AND DISCUSSION

- Coding/decoding techniques
- Cellular VLC System evaluation

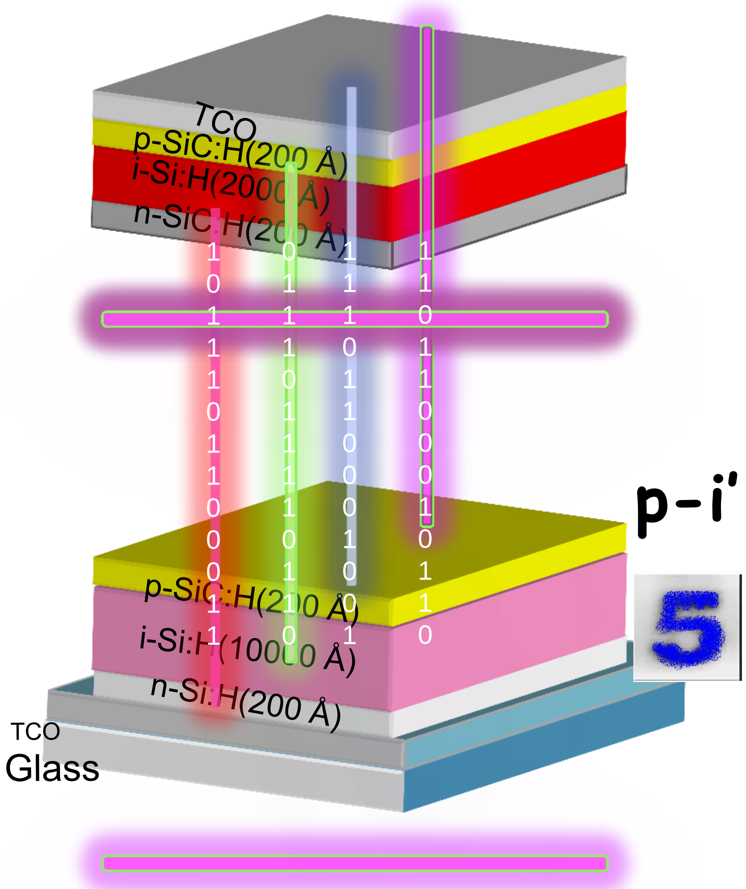
## ✓ APPLICATION

- Navigation data bits
- I2V Vehicular communication

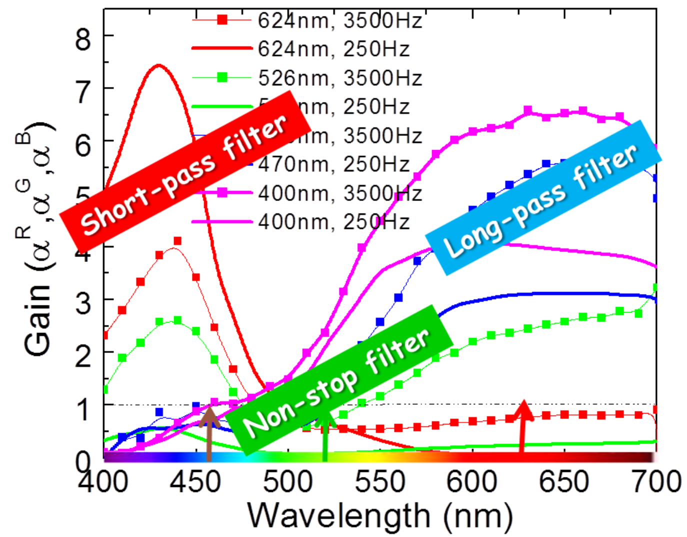
## ✓ CONCLUSIONS/FUTURE WORK

# a-Si/SiC Photodiodes

- **Coder/decoder device $I_R$/RGBV/UV channels; 30kbps**




p-i'-n p-i-n



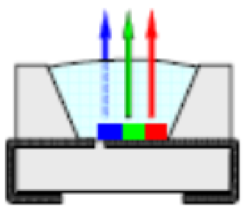

- Light-to-dark sensitivity depends on the *carbon concentration*
- Color recognition depends *on the applied bias*
- Light filtering depends on the *bias wavelength and side*
- WDM device *RGB* channels; *6000*bps

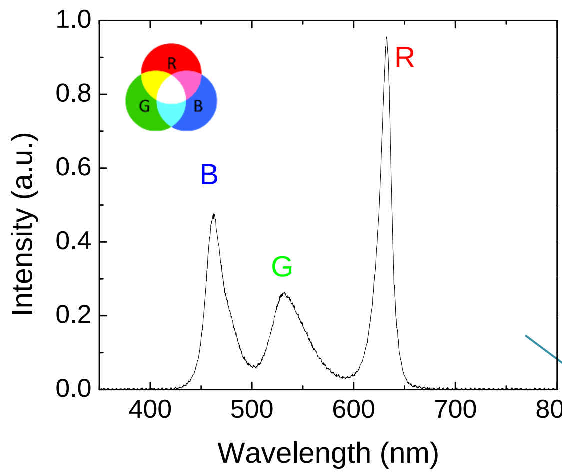
VLC receiver

# SYSTEM DESIGN

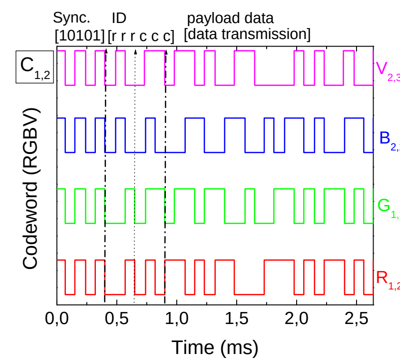
- The system is a self-positioning system in which the measuring unit is mobile.
- This unit receives the signals from several transmitters in known locations, and has the capability to compute its location based on the measured signals.

## Transmitter

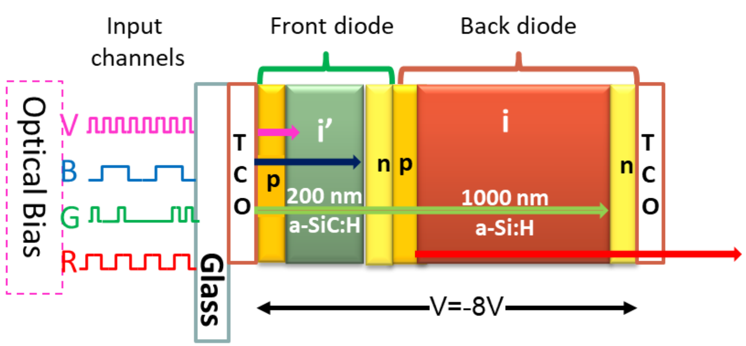





- Red, Green and Blue white LED



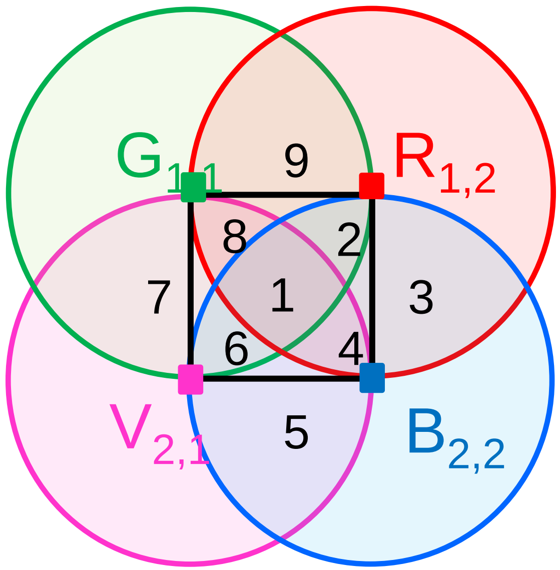

## Receiver

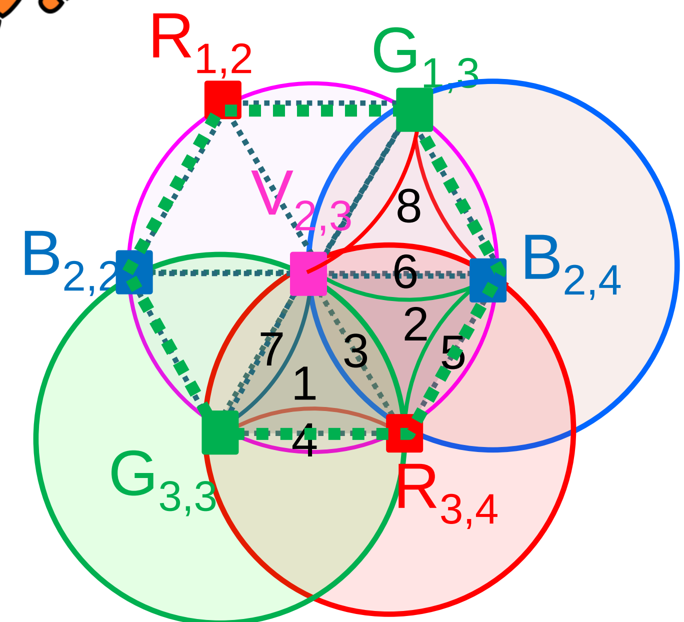



- p-i'(a-SiC:H)-n/p-i(a-Si:H)-n heterostructure produced by PECVD.

EMITTERS

## Footprint regions




Four-code assignment for the LEDs

### Square

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

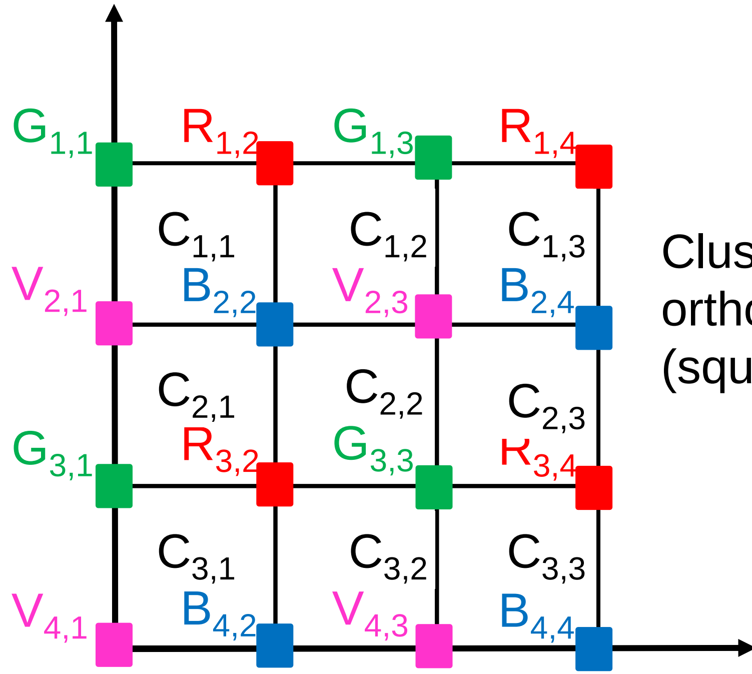
### Diamond

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

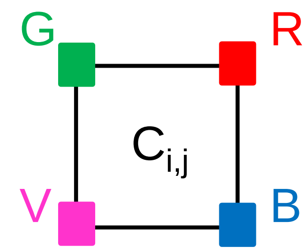
## Unit cell fine-grained lighting topology .

| Footprint regions | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| Square topology | RGBV | RGB | RB | RBV | BV | GBV | GV | RGV | RG |
| Diamond topology | RGV | RBV | RGBV | RGBV | RGBV | RGBV | RGBV | GBV | - |

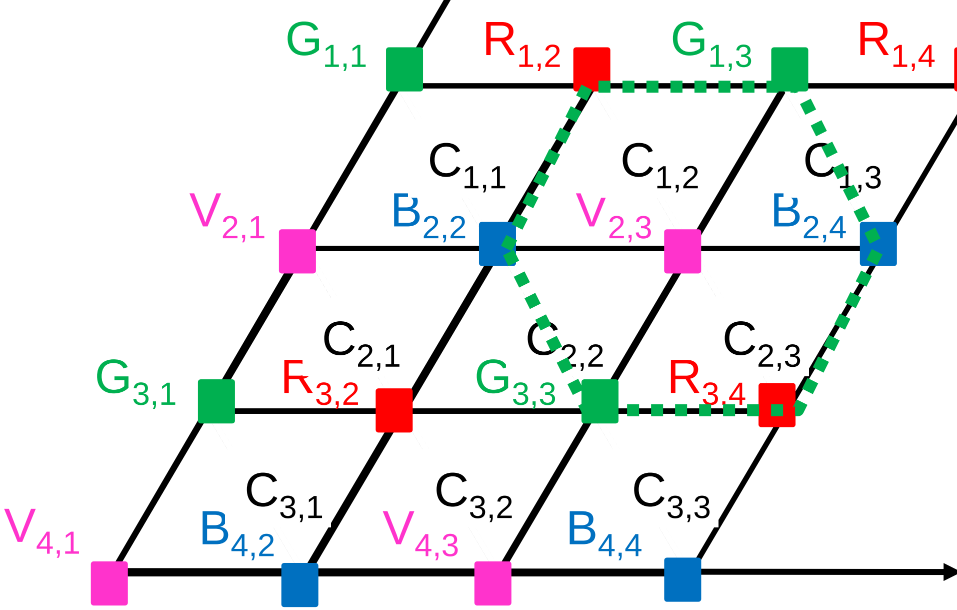
# CELLULAR TOPOLOGY

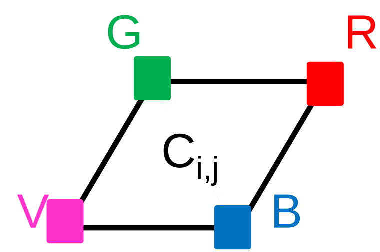



Clusters of cell in an orthogonal topology (square).



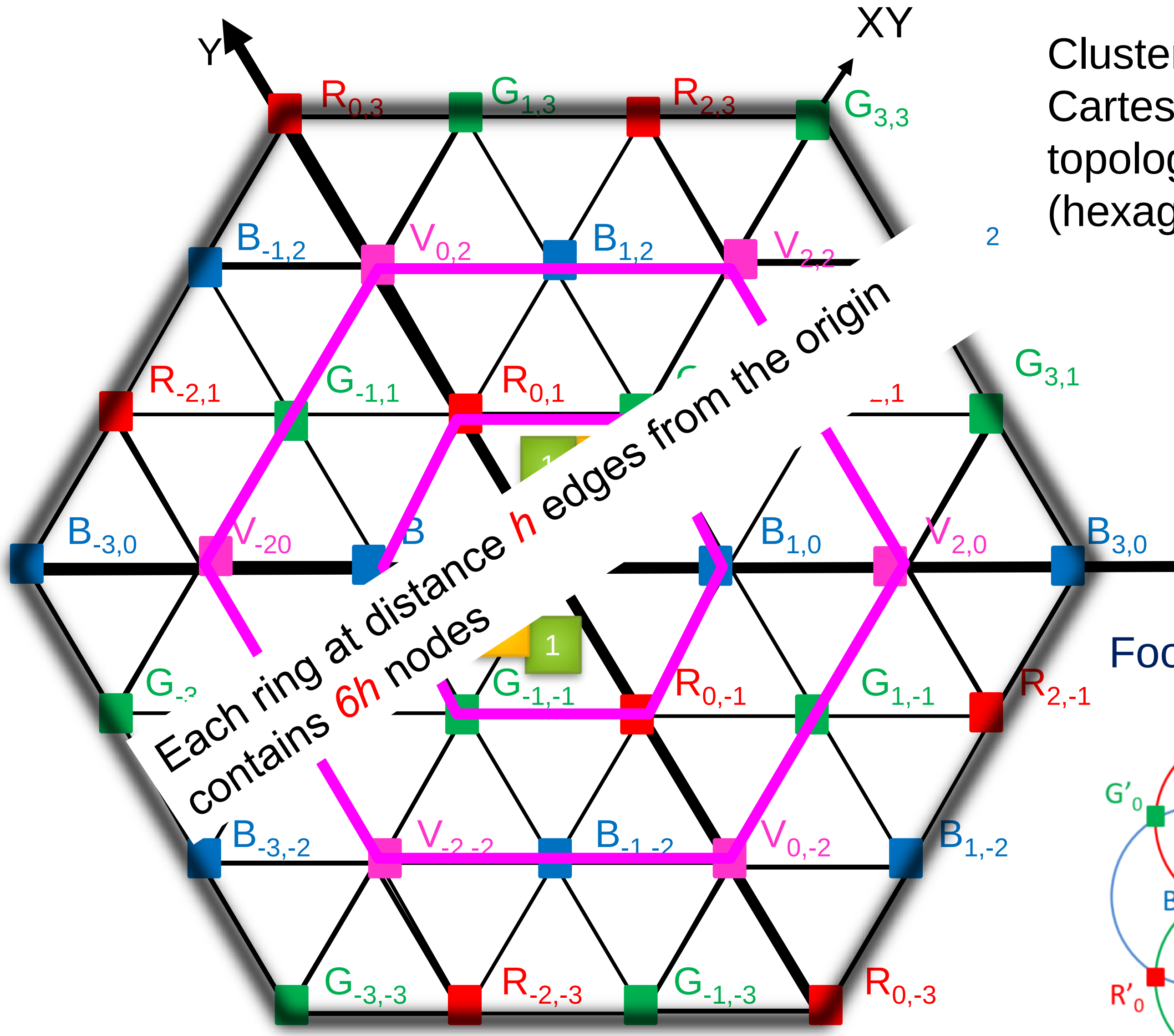

- Each node, $X_{i,j}$, carries its own color, X, (RGBV) as well as its ID position in the network.



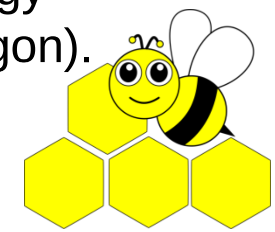




Cluster of cells in no-orthogonal topology (diamond).

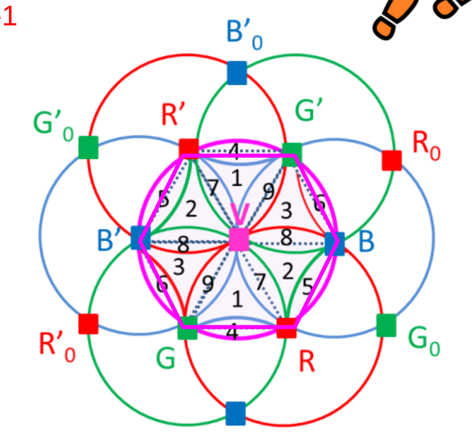
# HEXAGONAL TOPOLOGY




Cluster of cells in 60º Cartesian coordinates topology (hexagon).

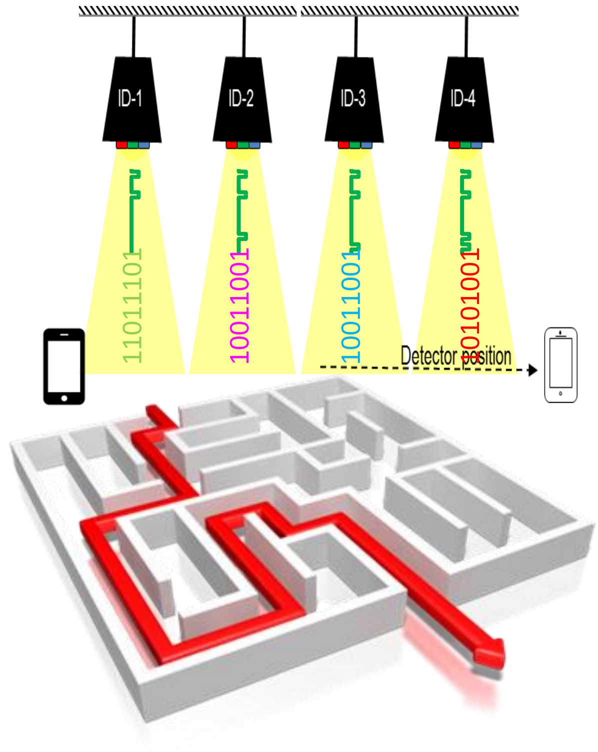


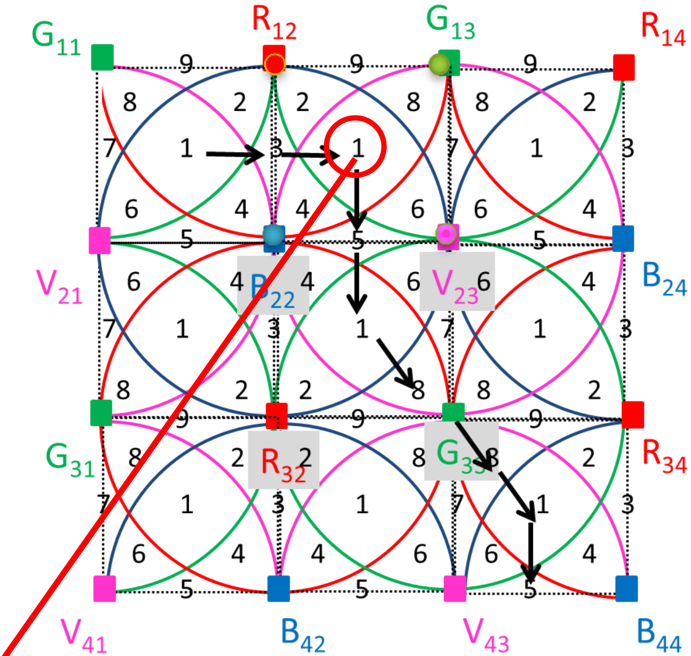
Footprint regions



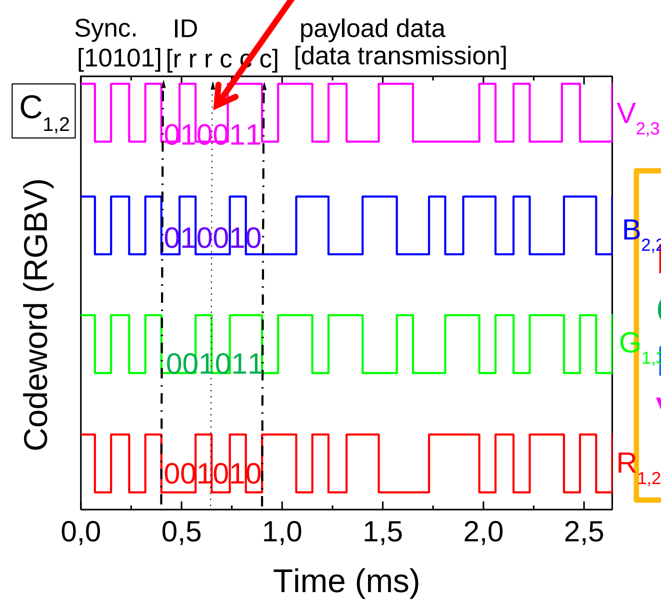

| Footprint regions | P#1 | P#2 | P#3 | P#4 | P#5 | P#6 | P#7 | P#8 | P#9 |
|---|---|---|---|---|---|---|---|---|---|
| Hexagon topology | RGV<br>R'G'V | RBV<br>R'B'V | G'BV<br>GB'V | RGB$_0$V<br>R'G'B'$_0$V | RG$_0$BV<br>R' G'$_0$B'V | R$_0$G'BV<br>R'$_0$GB'V | RGBV<br>R'G'B'V | RG'BV<br>R'GB'V | RGB'V<br>RGB'V |

# FINE-GRAINED




- The input of the aided navigation system is the MUX signal, and the output is the system state estimated at each time step (Δt).



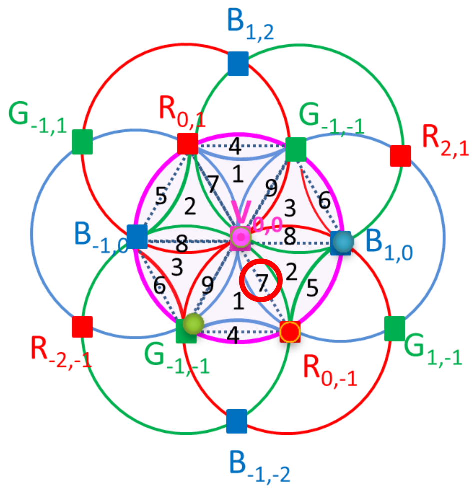

ID: $C_{1,2}$, #P1

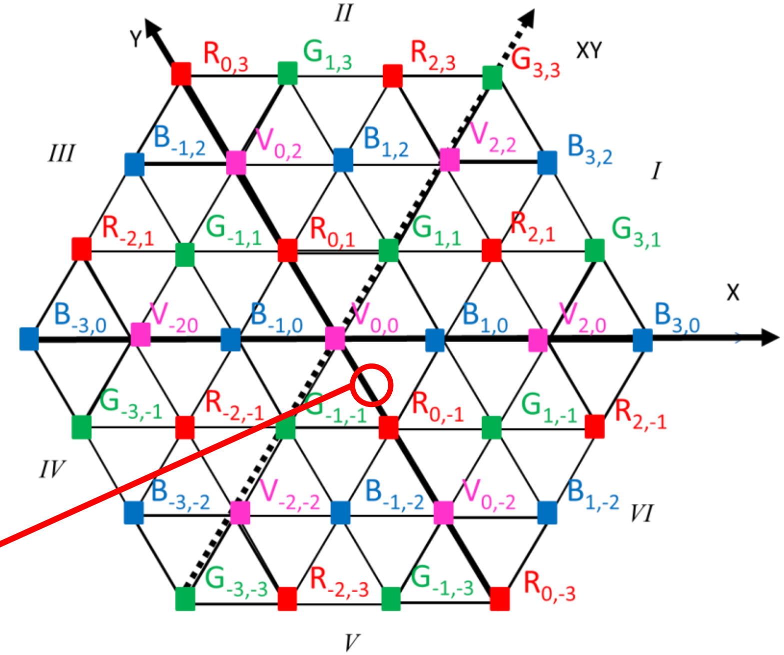
$R_{12}$ [10101 001 010…]

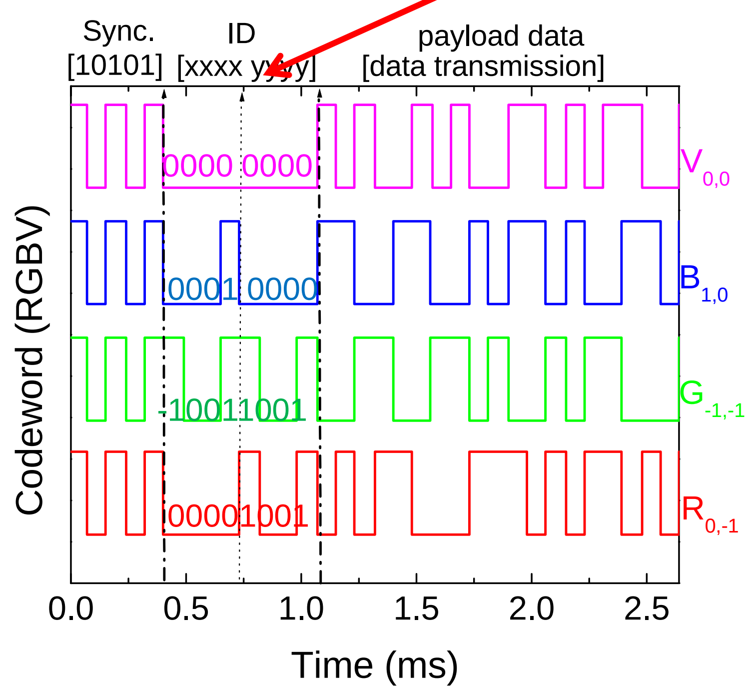
$G_{13}$ [10101 001 011…]

$B_{22}$ [10101 010 010…]

$V_{23}$ [10101 010 011…]




$R_{0,-1}$ [10101 0000 1001…]
$G_{-1,-1}$ [10101 1001 1001…]
$B_{1,02}$ [10101 0001 0000…]
$V_{0,0}$ [10101 0000 0000…]

Sign and magnitude representation:
4 BITS
1st BIT : **0** for *positive* and 1 for *negative*
Next 3 BITS : magnitude

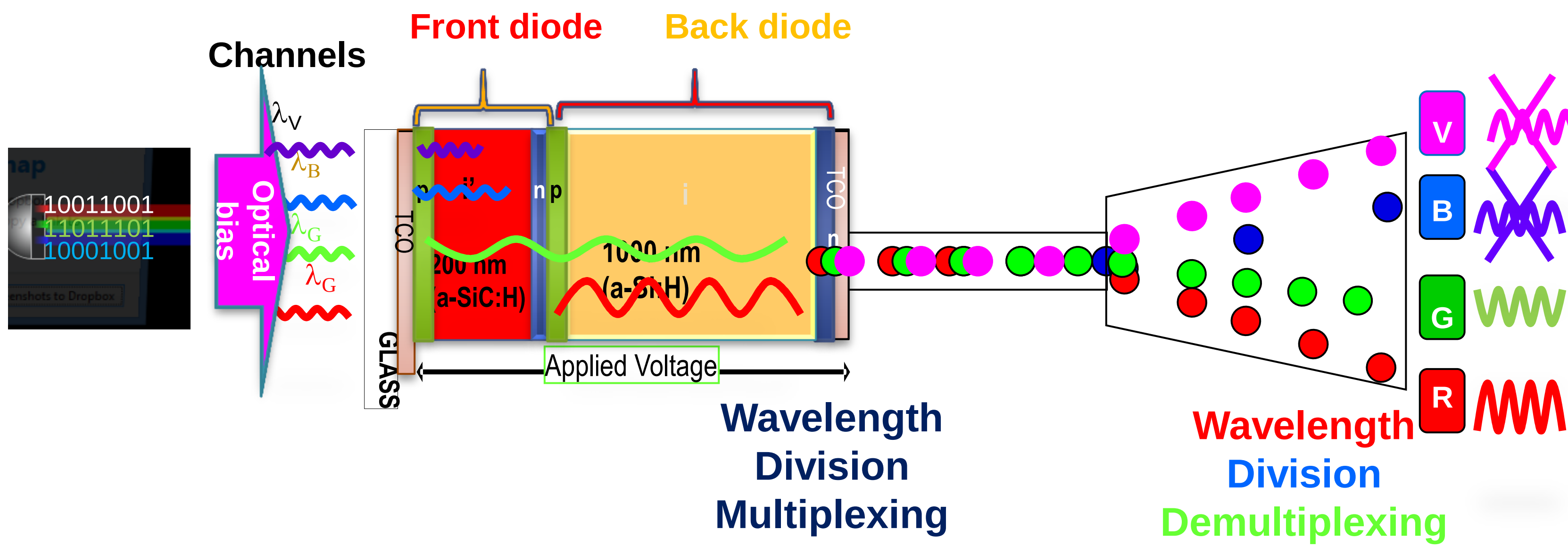
SYSTEM OPERATION

# Transmitter / Receiver of VLC

LED
ID data transmit with fast blinking

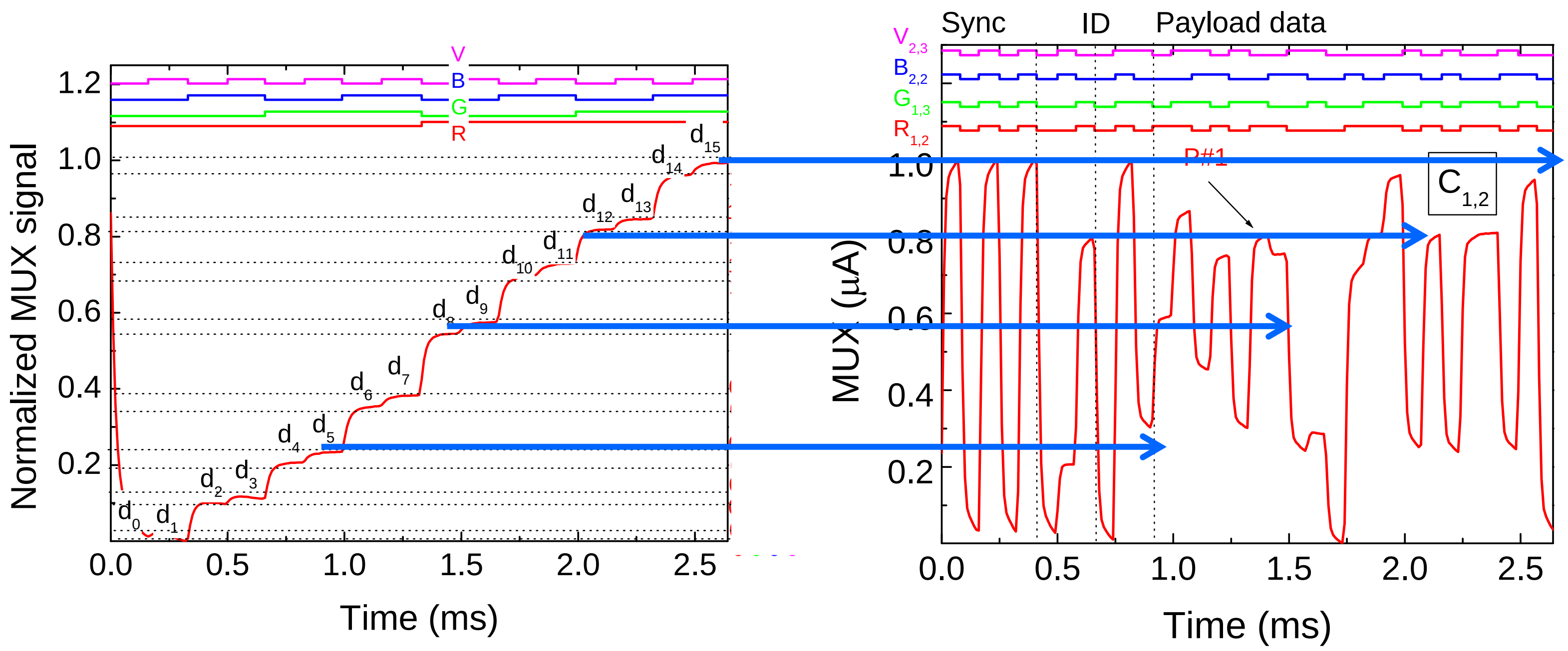
Coder/decoder device

Bit decode




- The device acts as an active filter, under irradiation.
- The gain is higher than the unity for wavelengths above 500 nm and lower for wavelengths below, resulting in an amplification of the **green** and **red** spectral ranges and quenching of the **violet**/**blue** ones.
- As the wavelength increases, the signal strongly increases. This nonlinearity is the main idea for the decoding of the MUX signal at the receiver.

# DECODING ALGORITHM



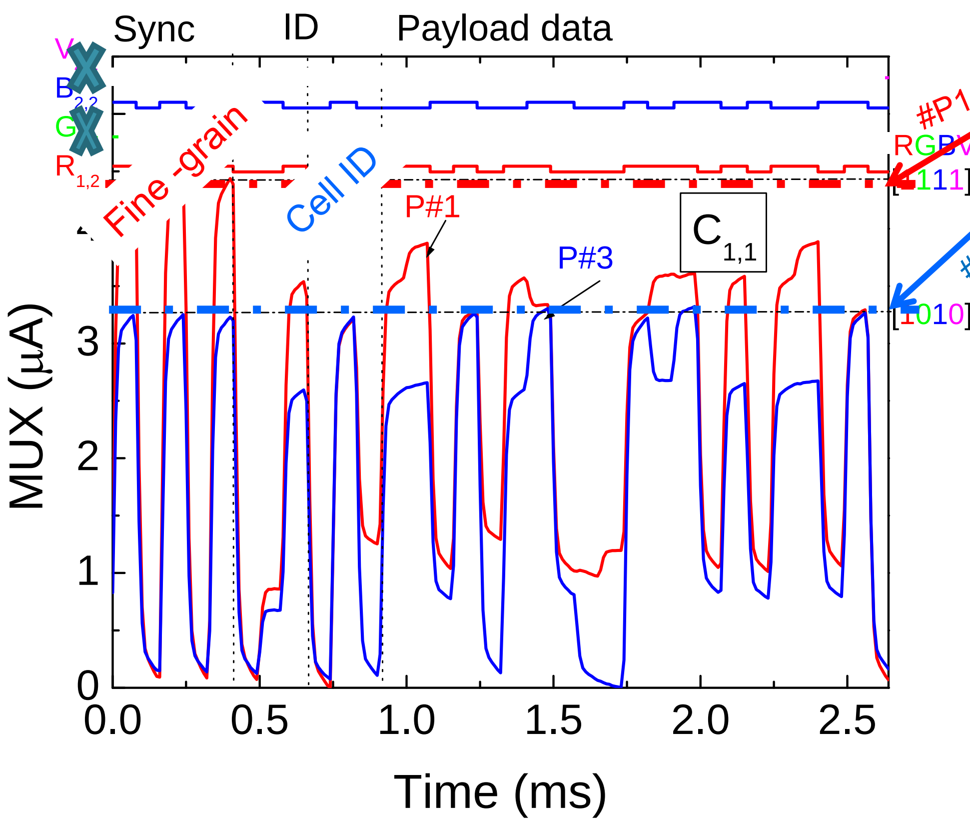

- $2^4$ ordered levels pondered by their optical gains are detected and correspond to all the possible combinations of the *on/off* states.

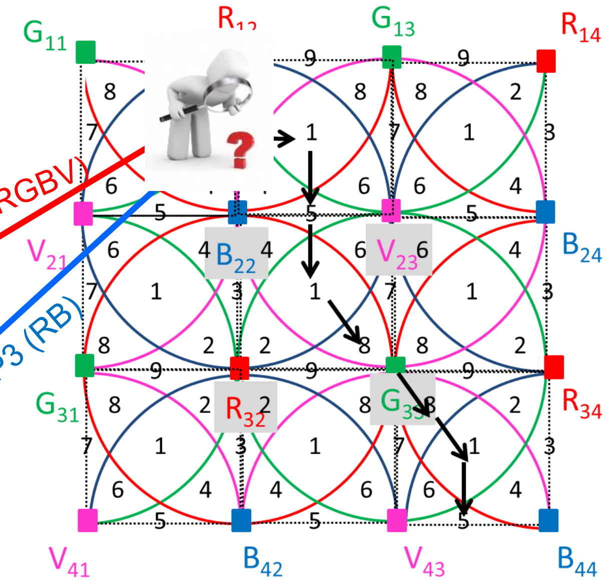
- By assigning each output level to a 4-digit binary code (weighted by the optical gain of the each channel), $[X_R, X_G, X_B, X_V]$, with X=1 if the channel is *on* and X=0 if it is *off*, the signal can be decoded.

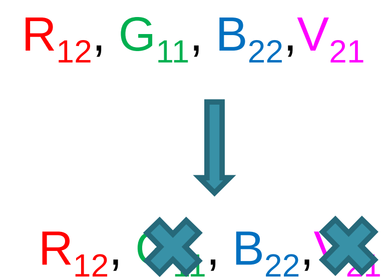
- Comparing the calibrated levels with the different generation levels in the same frame of time, a simple algorithm was used to perform 1-to-32 demultiplexer function and to decode the multiplex signals.

# CELLULAR VLC SYSTEM EVALUATION

- For each transition between an initial location and a final one, two code words are generated, the initial (*i*) and the final (*f*). If the receiver stays under the same region they should be the same, if it moves away they are different.

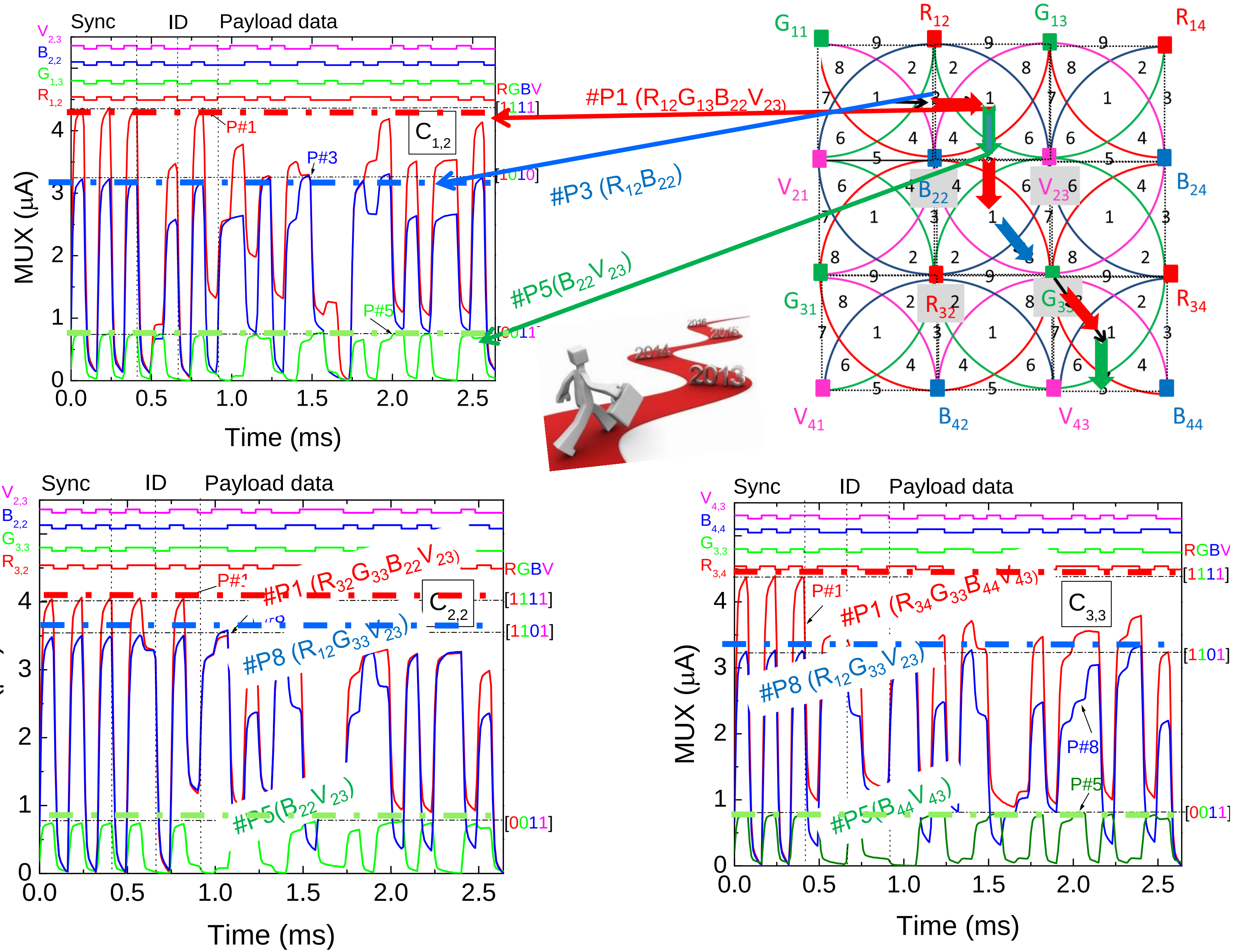


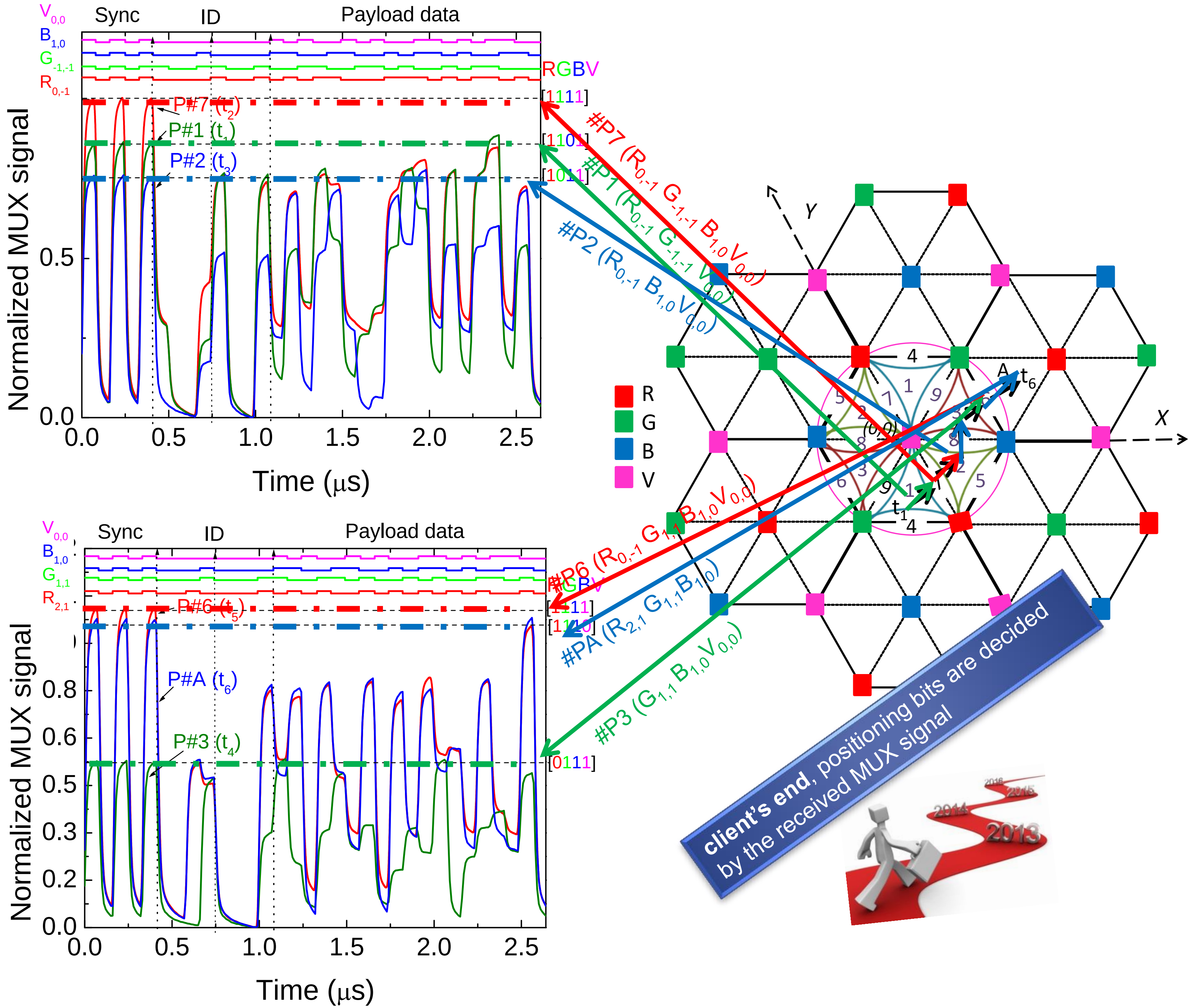

- The device's position (ID position) during the receiving process will be given by the highest detected level, the level where all the *n* (n=1, 2, 3, 4) channels are simultaneously on.

# NAVIGATION DATA BITS

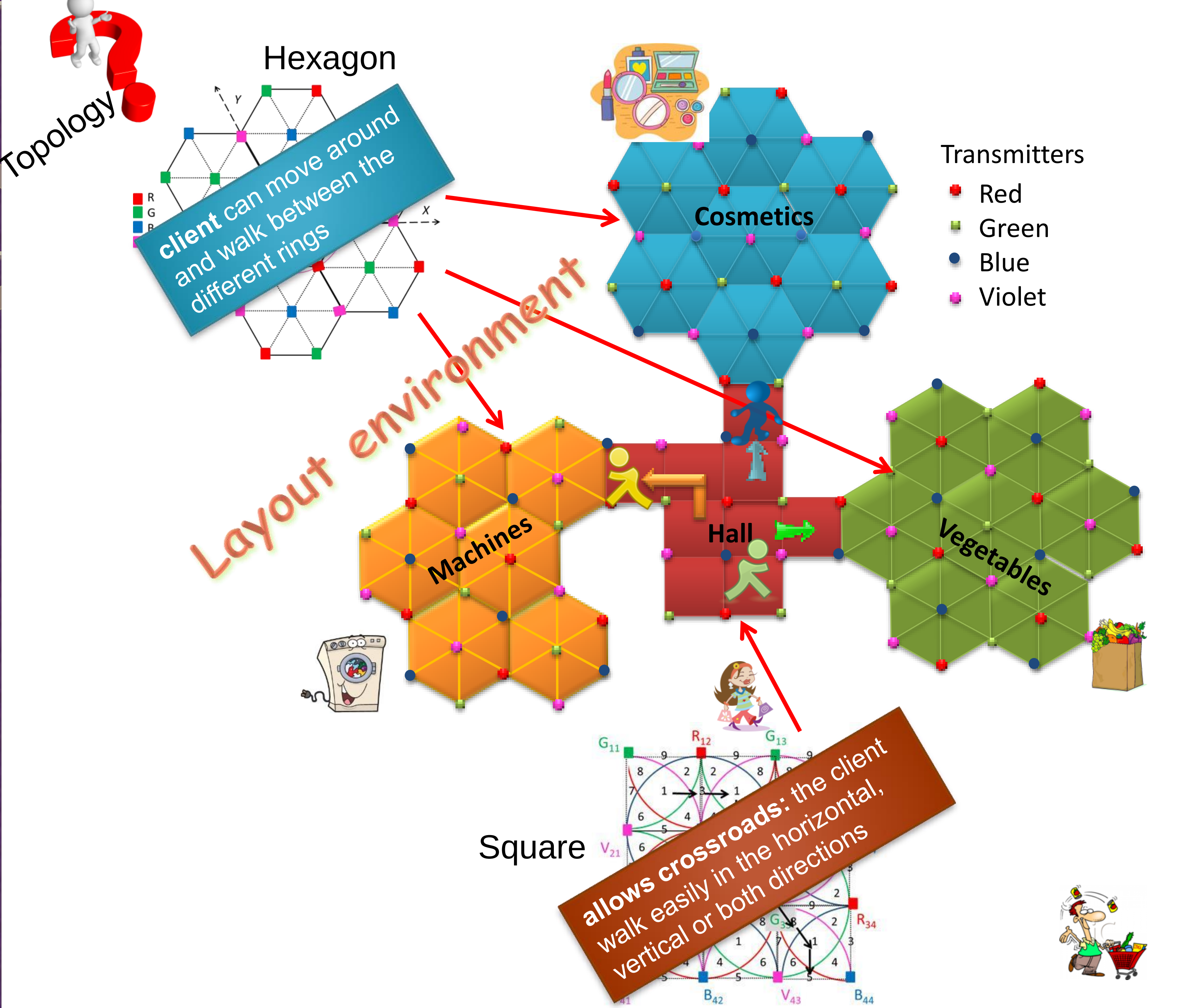



- As the receiver moves between generated point regions, the received information pattern changes. The transition actions are correlated by calculating the ID position codes in successive instants.

# LED-BASED NAVIGATION SYSTEM

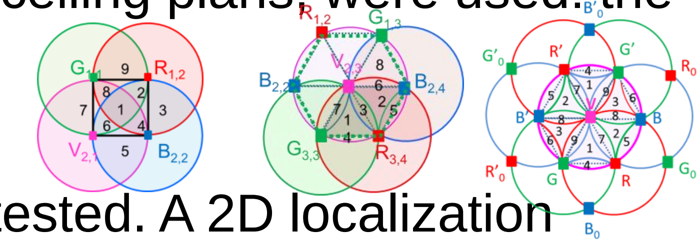


# INDOOR LOCALIZATION

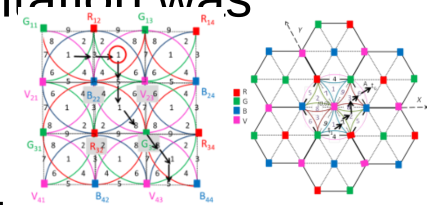


# CONCLUSIONS

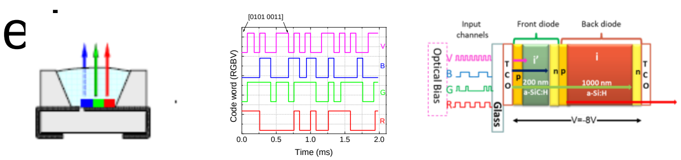
- A coupled data transmission and indoor positioning was presented. To transmit the data, an On-Off Keying code was used. Two cellular topologies, for the ceiling plans, were used: the square and the hexagon.



- Fine-grained indoor localization was tested. A 2D localization design, demonstrated by a prototype implementation was developed.



- A detailed analysis of the characteristics of various components within the VLC system were discussed.

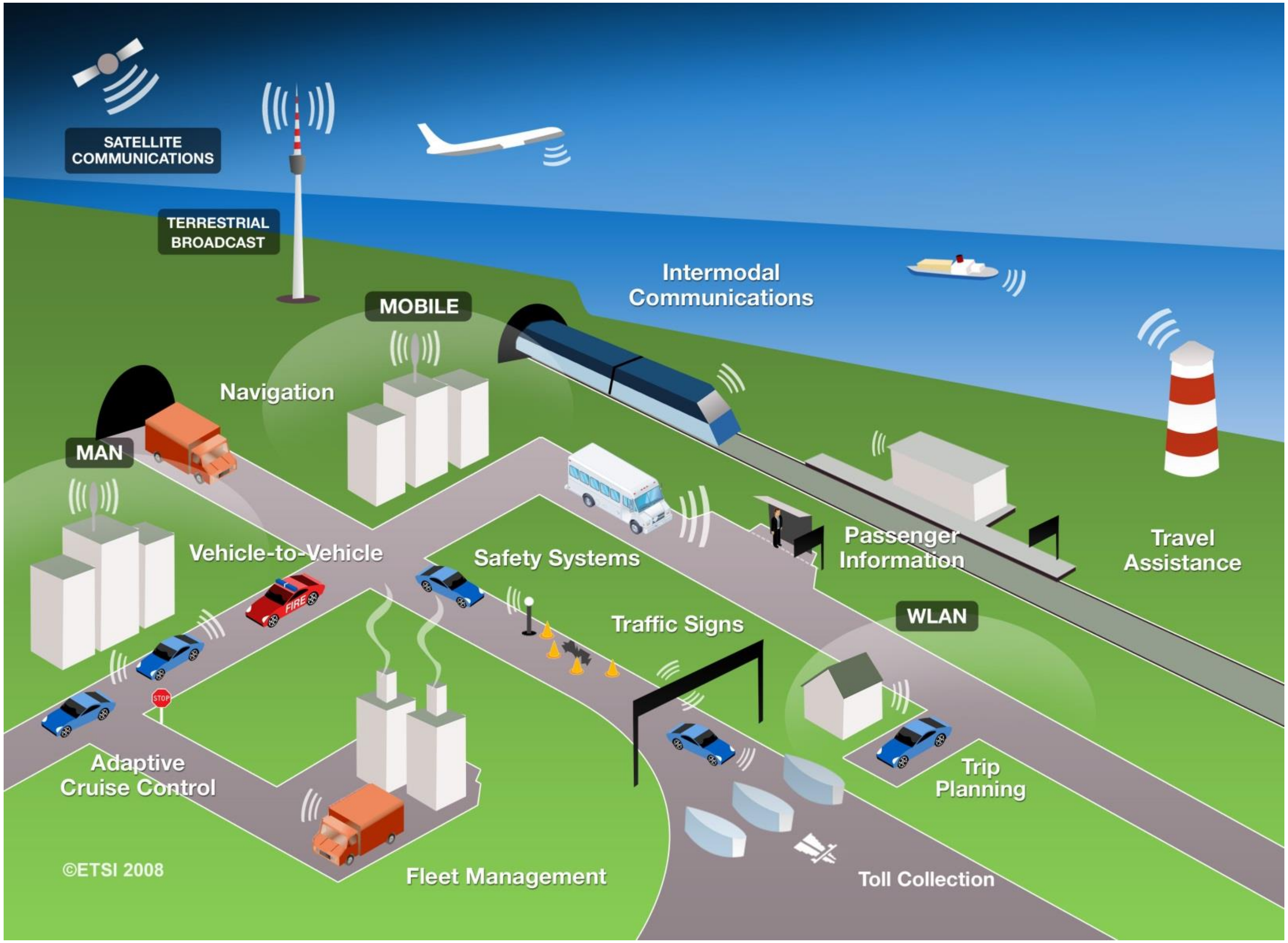


- Results showed that is possible not only to determine the position of a mobile target inside the unit cell but also in the network and concomitantly to infer the travel direction along the time.

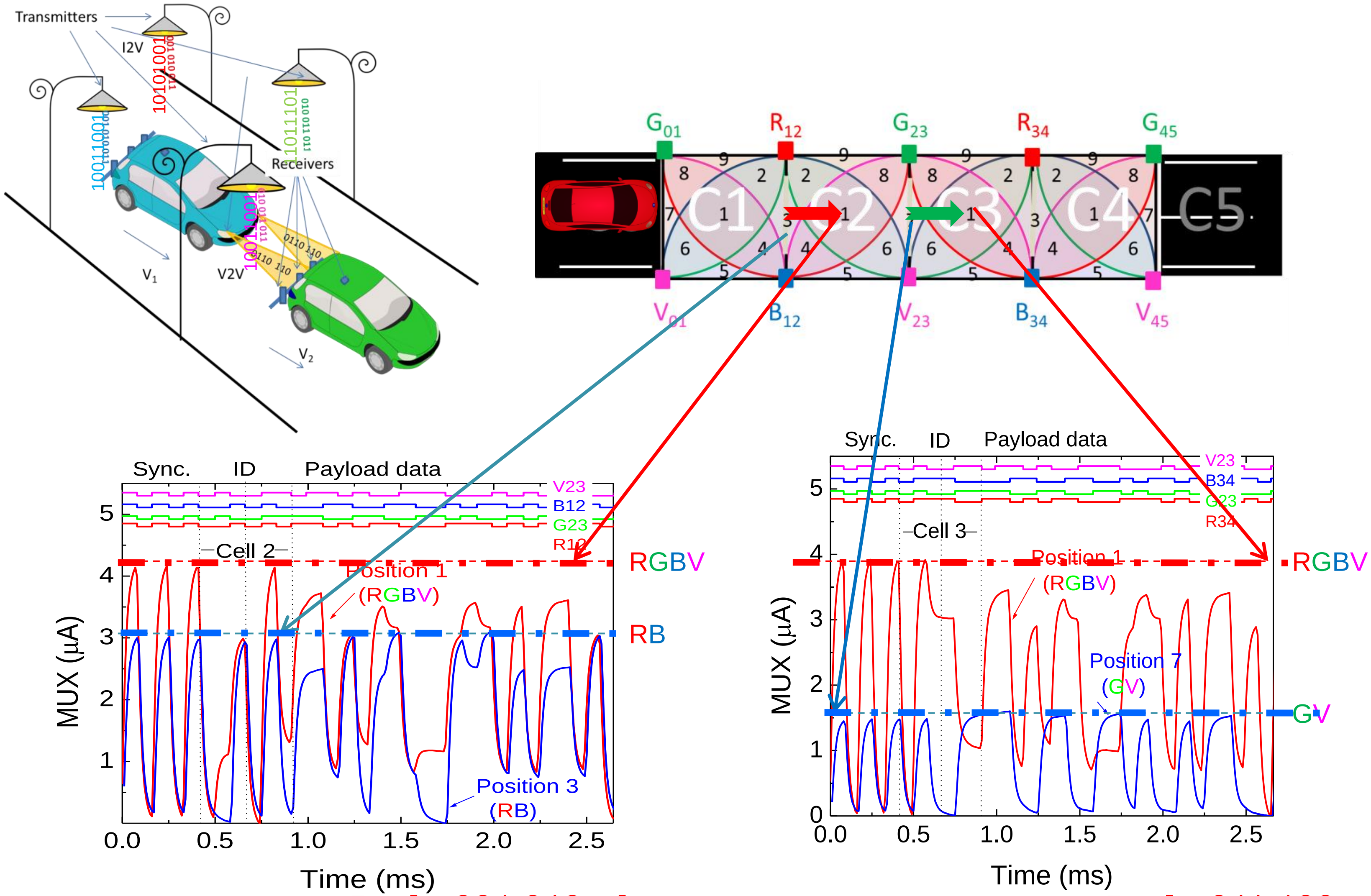
- For future work, by using multiple emitters and receivers, the transmission data rate through parallelized spatial multiplexing can be improved.

# VEHICULAR VLC: ROAD-TO-VEHICLE

APPLICATION



# I2V COMMUNICATION




$R_{12}$ [...001 010...]
$B_{12}$ [...001 010...]

→

$R_{12}$ [...001 010...]
$G_{23}$ [...010 011...]
$B_{12}$ [...001 010...]
$V_{23}$ [...010 011...]

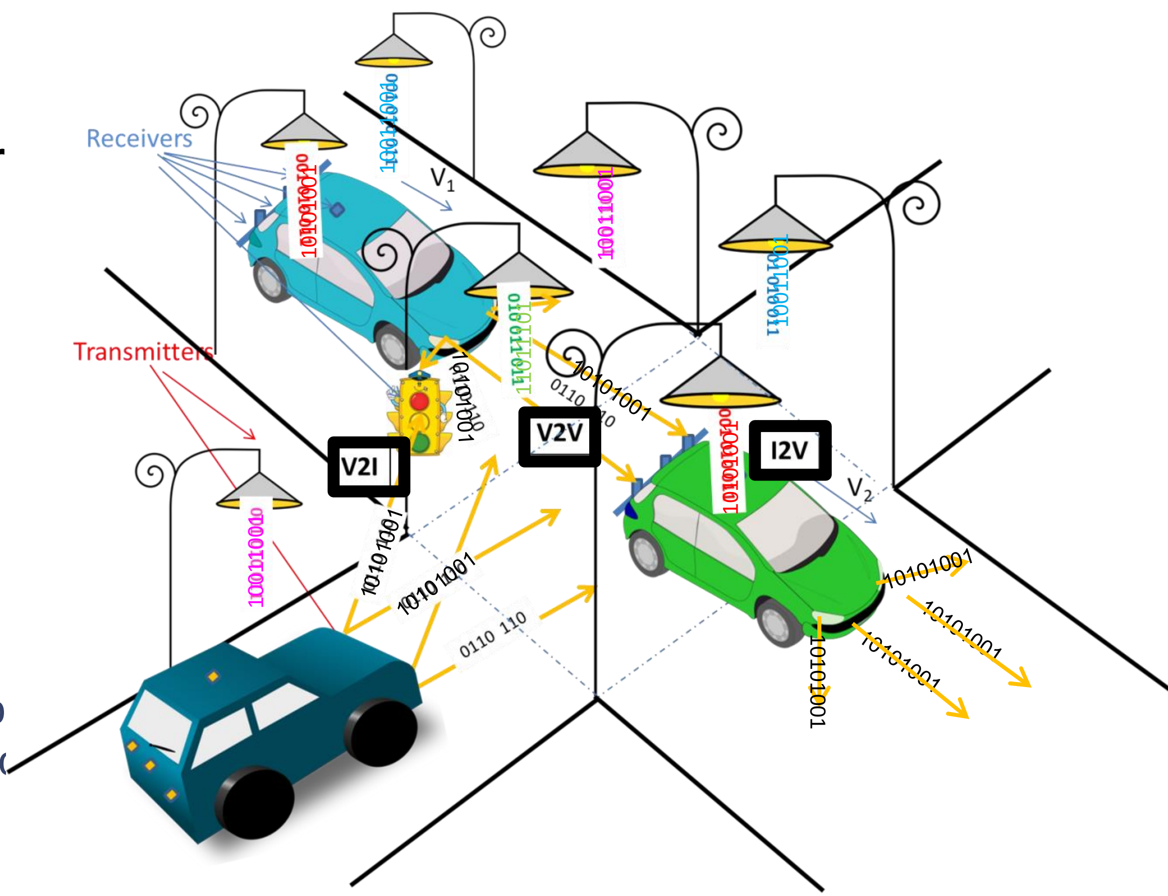
$G_{23}$ [...010 011...]
$V_{23}$ [...010 011...]

→

$R_{34}$ [...011 100...]
$G_{23}$ [...010 011...]
$B_{34}$ [...011 100...]
$V_{23}$ [...010 011...]

- Each decoded message carries the node address of the transmitter

## Generic model for cooperative vehicular communications




### Until recently…

- (V2V) communication limited to brake lights, signals;
- (V2I) was restricted to detection (loop detect

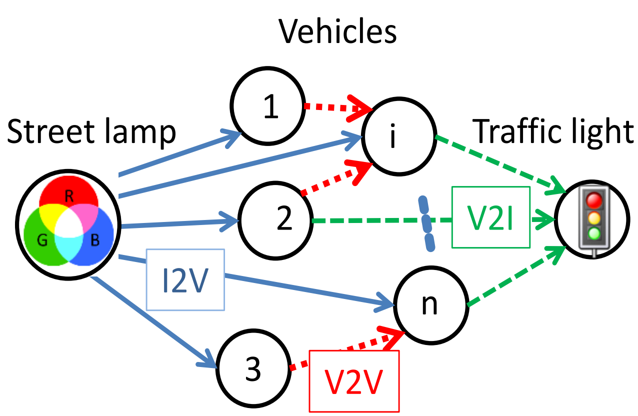
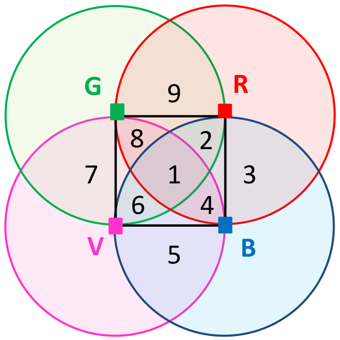



**Illustration of the proposed I2V2V2I communication scenario:**
Connected vehicles communication in a crossroad.

# LIGHTING PLAN

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

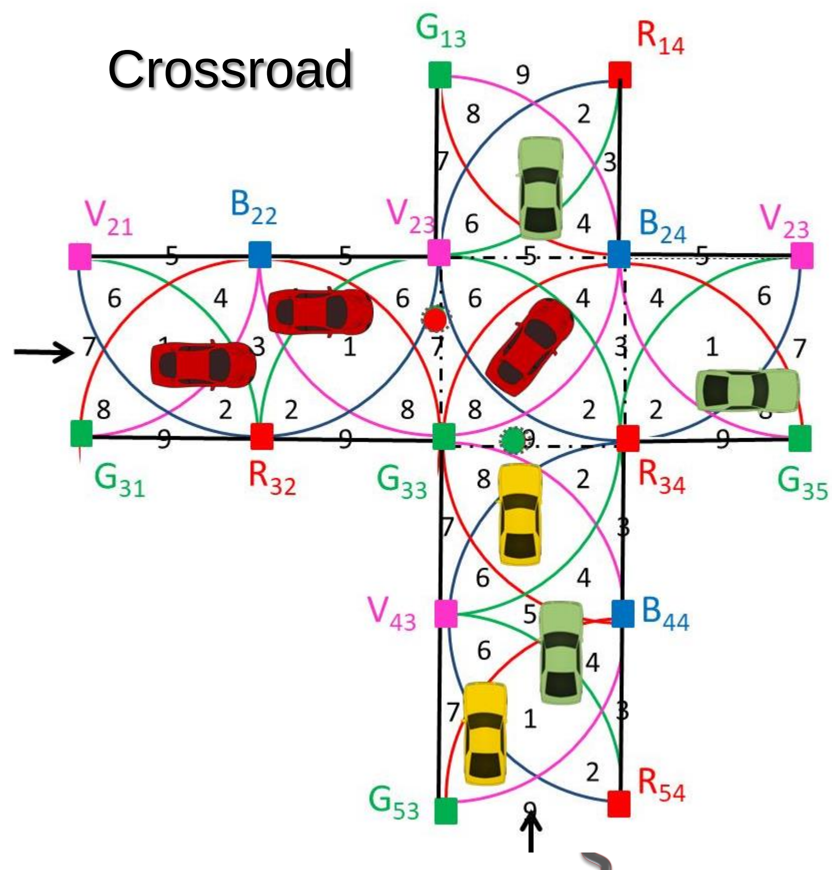



Unit cell

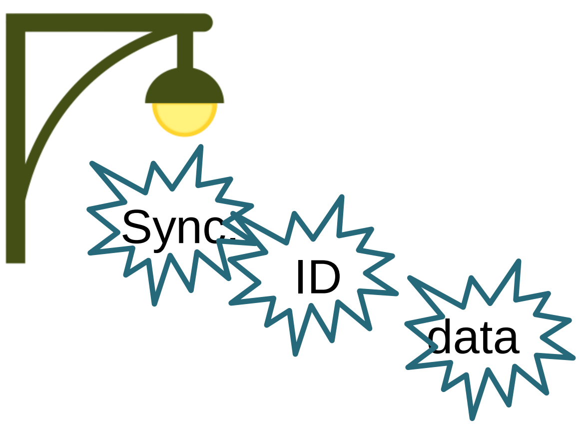
Generated joint footprints

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

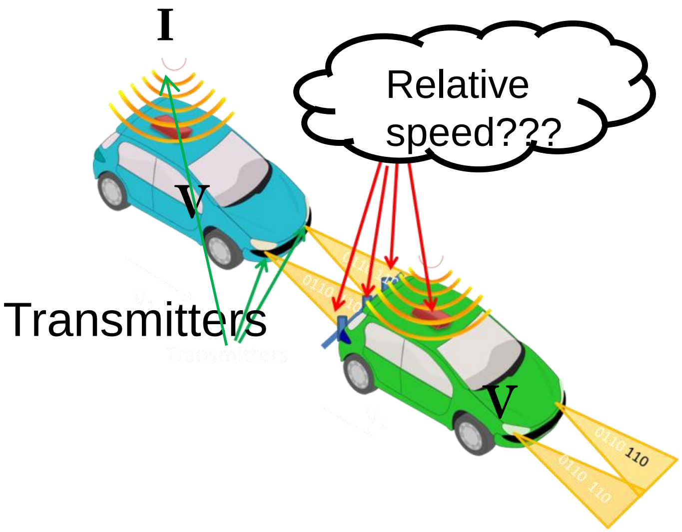
Crossroad



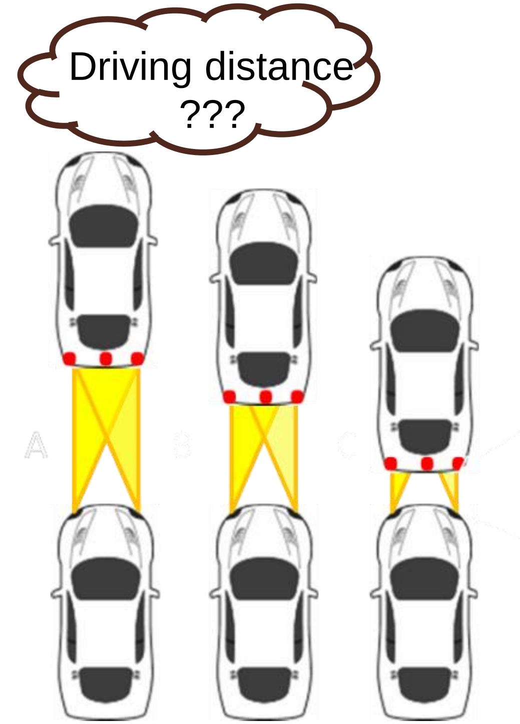

✓ **Promising benefits expected from safety and mobility improvements at the road network**



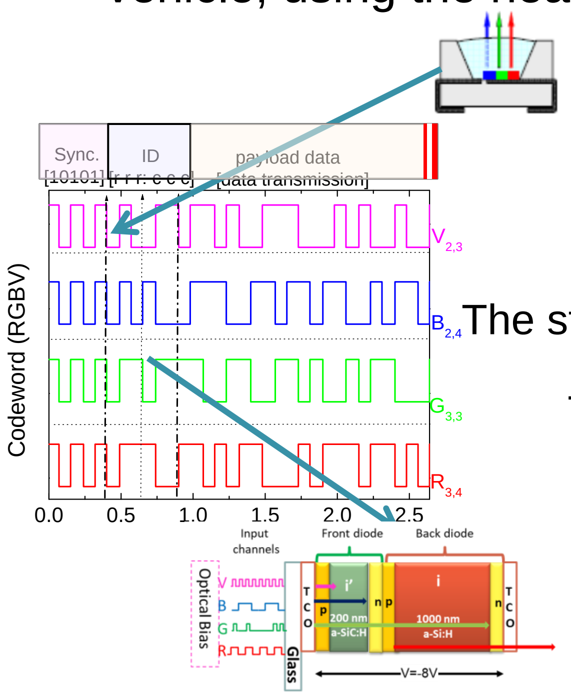
# I2V2V system design




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




**V2V**: the information is resent to a leader vehicle, using the headlights as transmitters



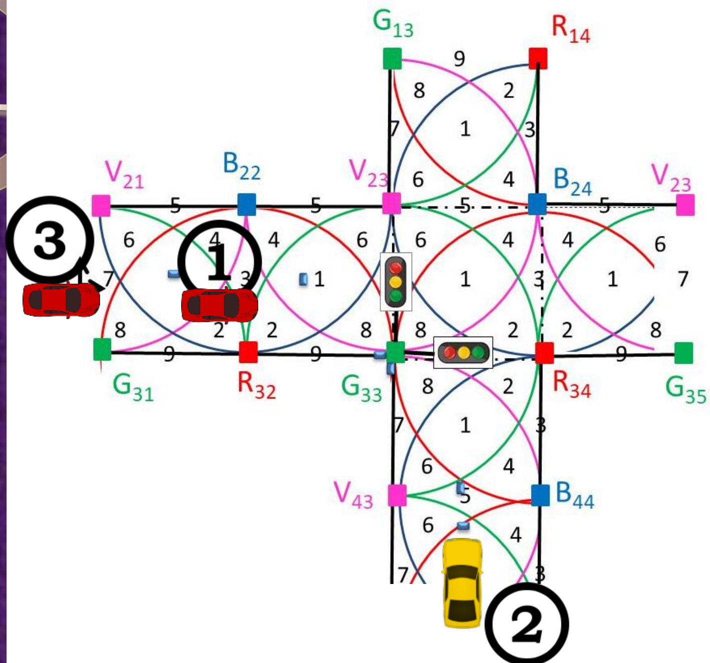

The structure of the frame is a classical one

The message begins with 5 synchronization bits

The rest of the frame consists of 6 ID´s bits,
The payload data bits and a stop bit.

# Cooperative VLC System Evaluation

## Generalized view of the architecture




**Three different scenarios:**

Scenario 1 I 2 V 2 V 2 I

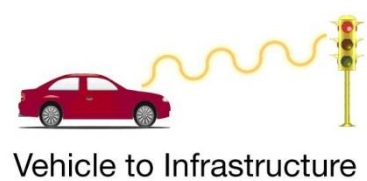
Scenario 2 I 2 V 2 I

Scenario 3 I 2 V 2 V 2 I

## Operational procedure:

Each vehicle receives two different messages:

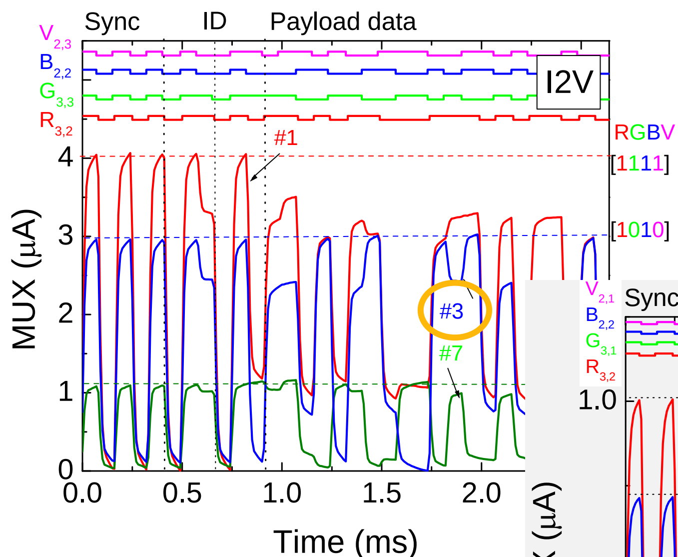
- **I2V** and **V2V** coming from the streetlight and from the follow vehicle;
- Compare them and infers the **drive distance** and the **relative speed**.
- Send the information to a next car (**V2V2V**) or to an infrastructure (**V2V2I**).

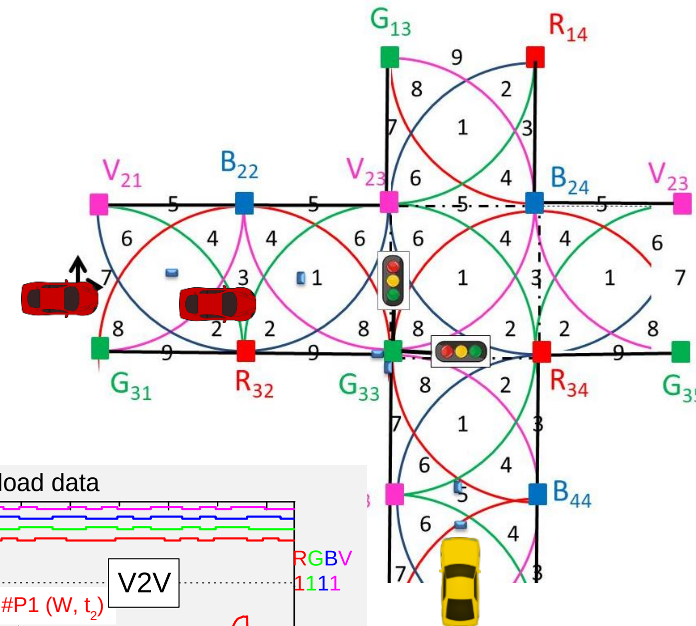


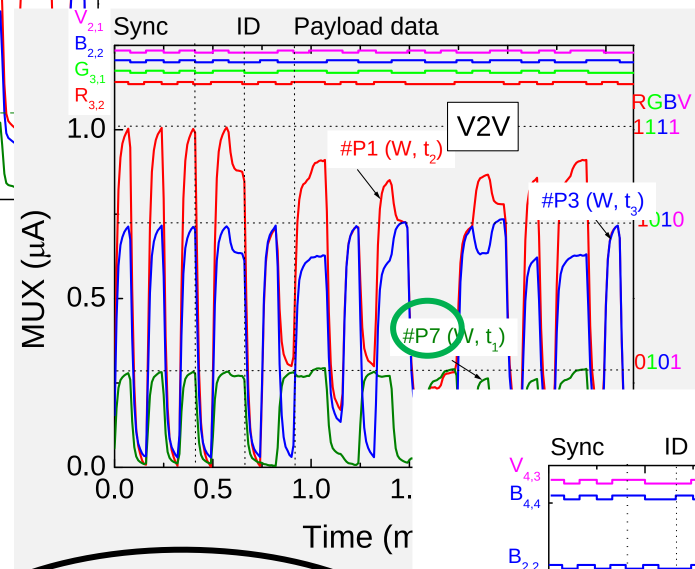

In order to verify the system operability and efficiency we have conducted an extensive set of measurements

# Scenario 1: I2V2V2I

①



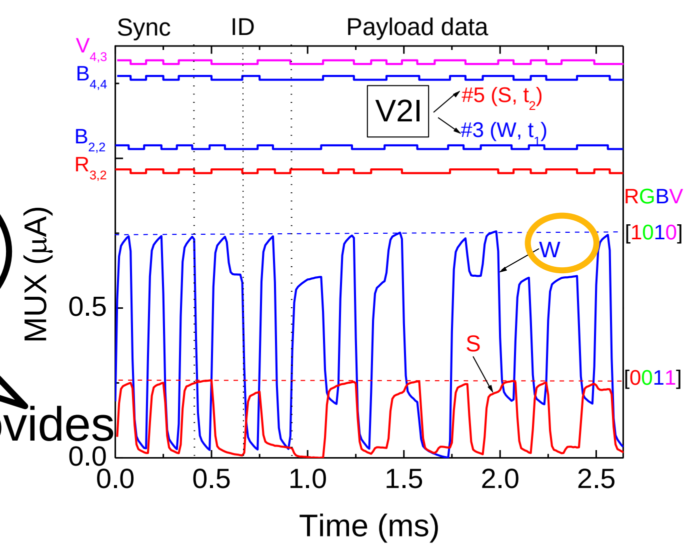




- Vehicle 1 sends the request message to the infrastructure (V2I) and informs the signal controller that this vehicle desires service (often called "demand" for service).

Request time: $t_1$

$\Delta t = ....$

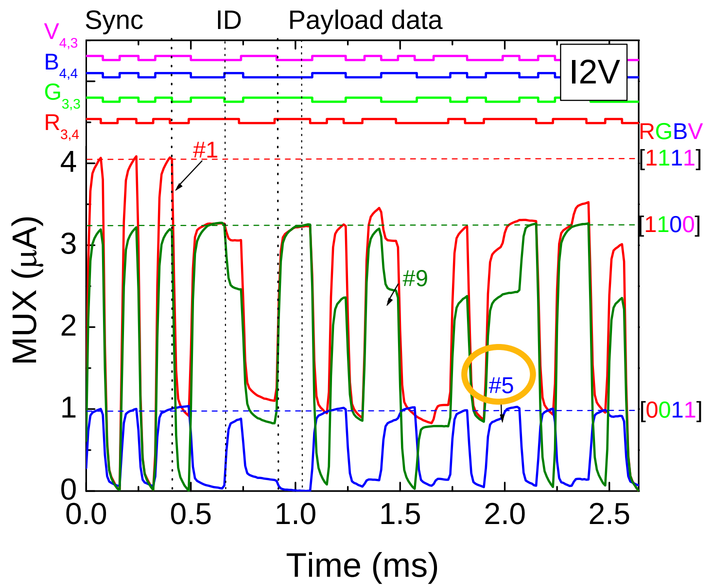
$\Delta v = ....$




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

# Scenario 2: I2V2I

②



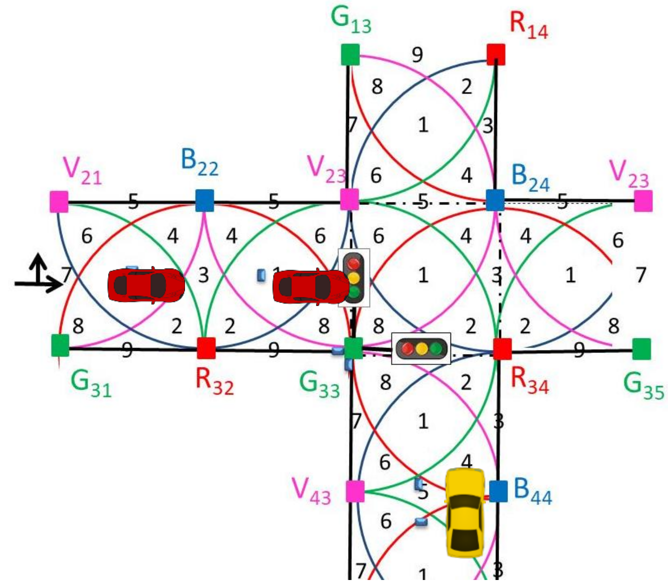

•I2V MUX signal received by a rooftop receiver moving in the S direction when the vehicle 2 is located #5

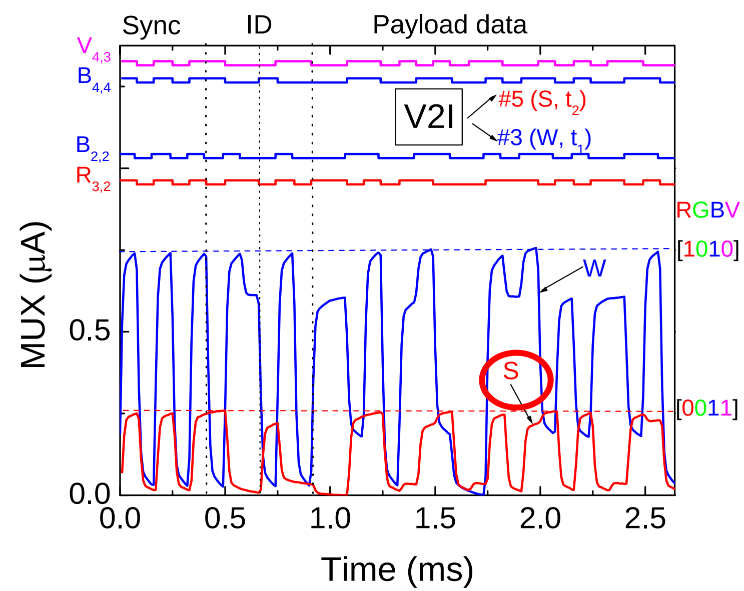
Request time: $t_2$

$\Delta t = \ldots.$

$\Delta v = \ldots.$

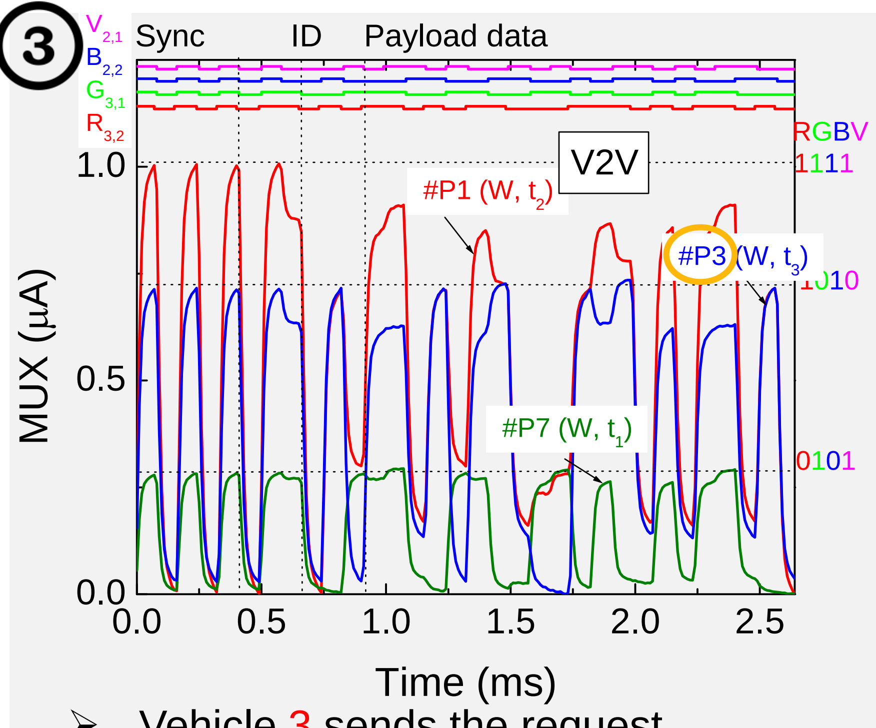
- Vehicle 2 sends the request message to the infrastructure (V2I) ) and informs the signal controller that this vehicle desires service.



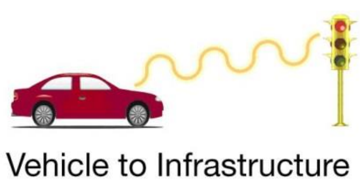




•V2I communication from vehicle 2 to the infrastructure

# Scenario 3: I2V2V2I




- Vehicle 3 sends the request message to the infrastructure (V2I) and to the leader (V2V)

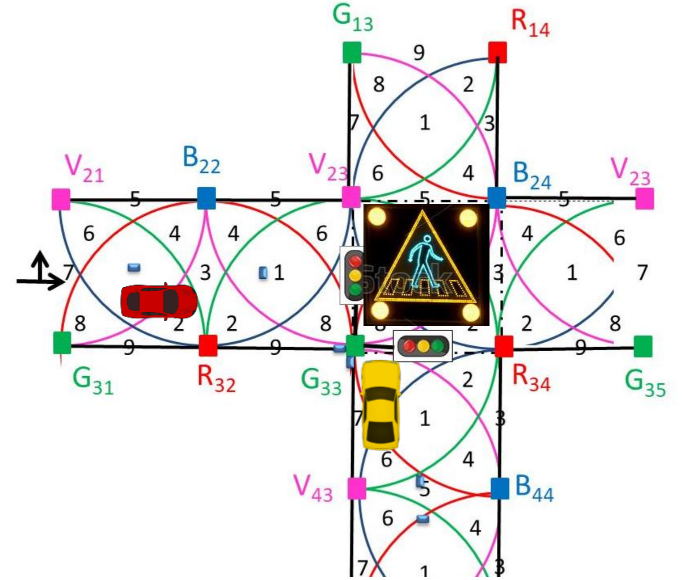



Request time: $t_3$

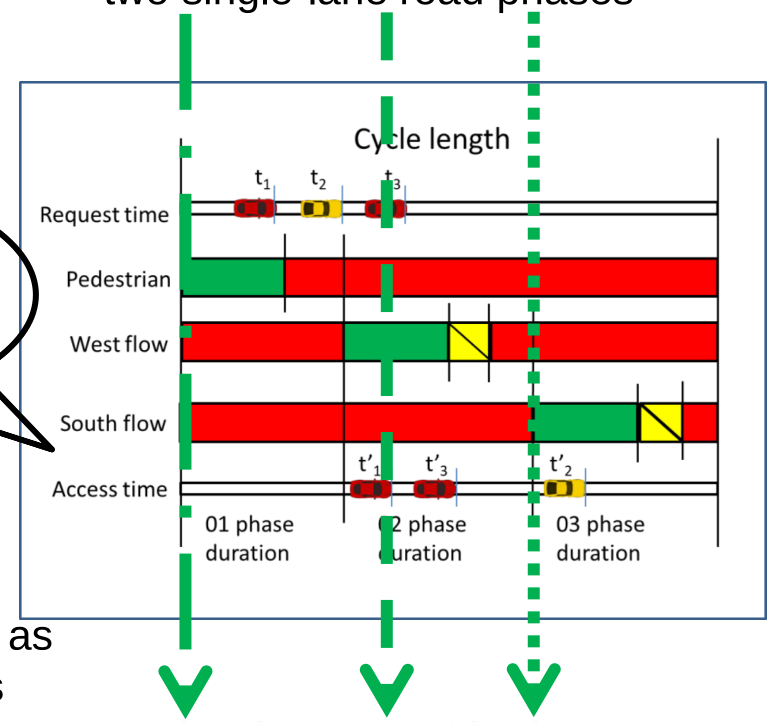
$\Delta t = \ldots$ $\Delta v = \ldots.$

From a capacity point of view is more efficient, if Vehicle 3 is given access before Vehicle 2

**Vehicle's intersection access time** is defined as the time at which the head of the vehicle enters the intersection area




Pedestrian-only stage (01 phase) two single-lane road phases

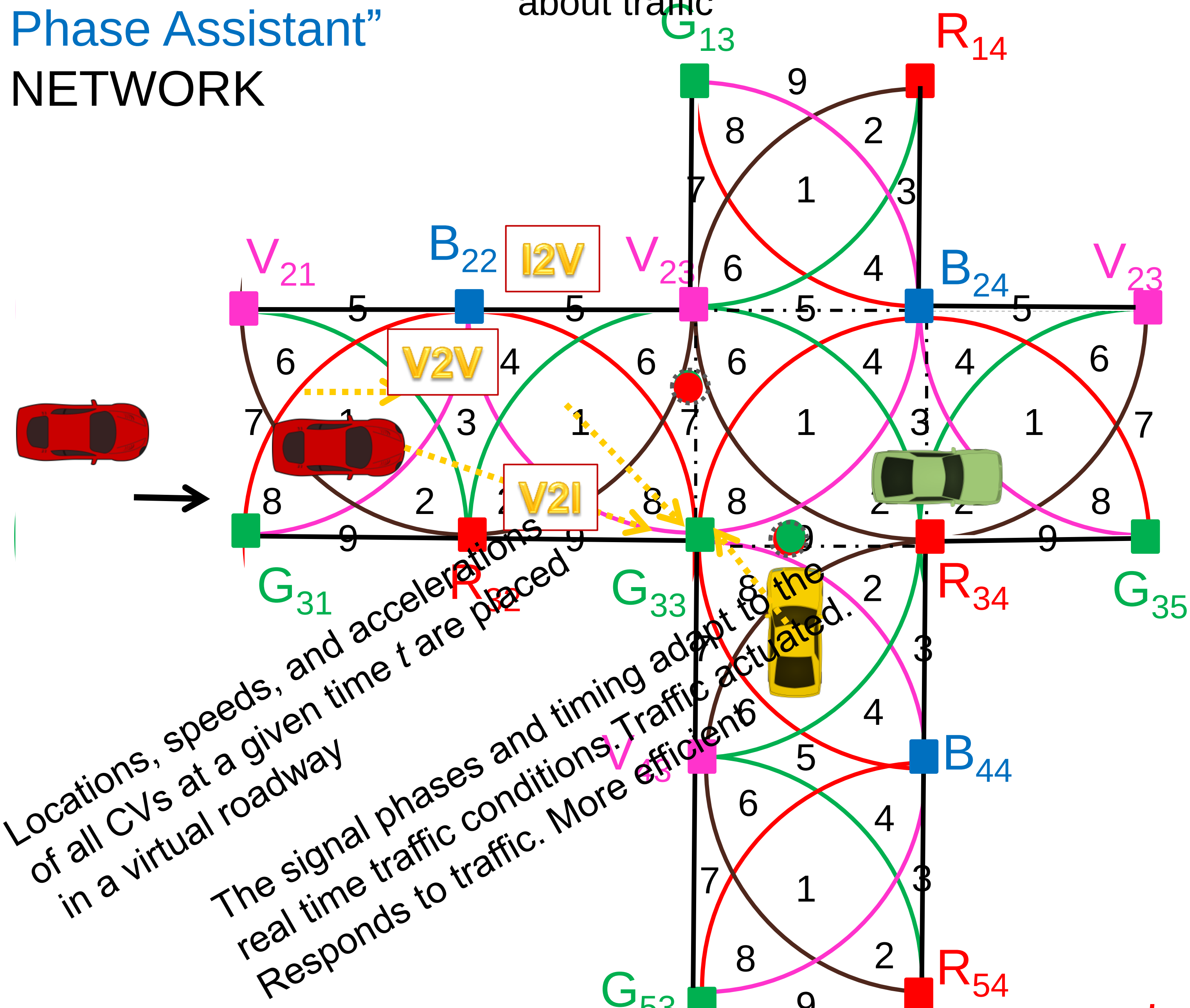



*Phasing of traffic flows*

Virtual road network: I2V2V2I

Traffic Light
Phase Assistant”
NETWORK

Information flow towards the traffic light: Improvement of control by precise information about traffic



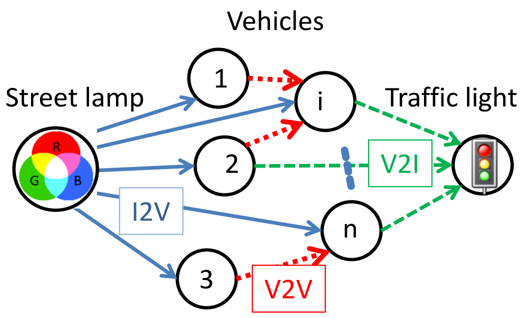

Locations, speeds, and accelerations of all CVs at a given time *t* are placed in a virtual roadway

The signal phases and timing adapt to the real time traffic conditions. Traffic actuated. Responds to traffic. More efficient.

# Conclusions

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

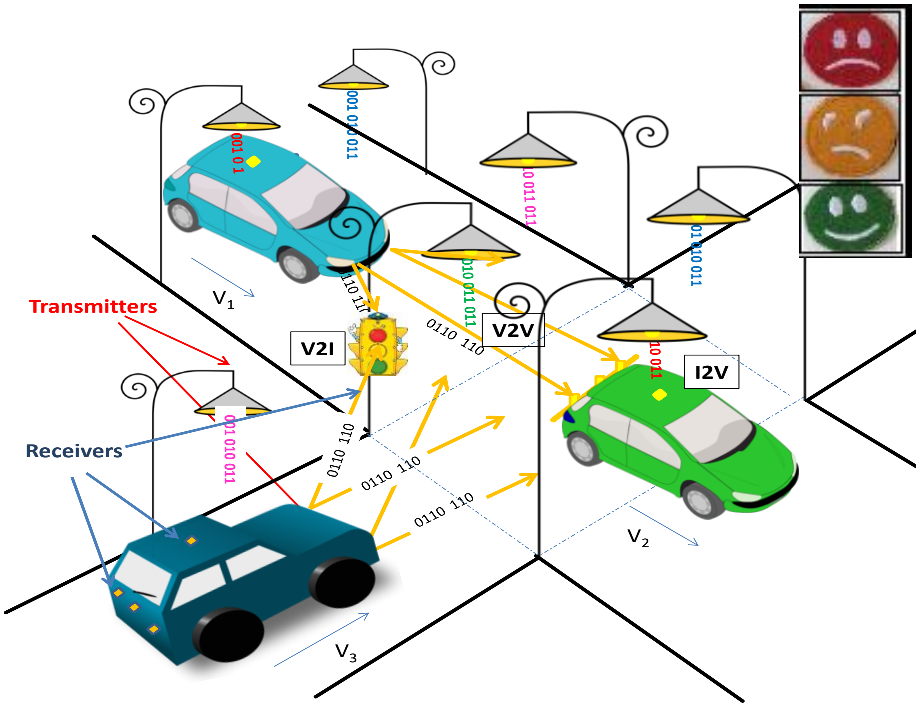
- Connected vehicles information from the netw vehicular interaction (V2V) and infrastructure (V analyzed.




- A generic model of cooperative transmissions for vehicular communications services is established.

- The experimental results, confirmed that the proposed cooperative VLC architecture is **appropriate** for the **control and management of a traffic** light controlled crossroad network.

- **Two-level optimization**: phase sequence and duration.



Thanks for your attention

A group of experienced and young researchers covering the areas of materials and devices processing; materials and devices characterization and optimization, well supported by the physics modelling of the devices and the corresponding software for information extraction

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