ALLSENSORS 2021 - The Sixth International Conference on Advances in Sensors, Actuators, Metering and Sensing, July 18, 2021 - July 22, 2021

Propagation Model Using White LEDs in a Visible Light Communication Link

P. Louro, M. Vieira, M. A. Vieira, P. Vieira

plouro@deetc.isel.ipl.pt

Lisbon, PORTUGAL

Acknowledgements: UIDB/00066/2020 | IPL/2020/GEO-LOC/ISEL

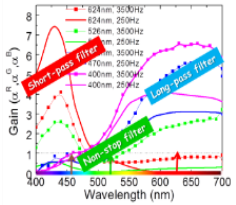
SHORT RESUME OF THE PRESENTER

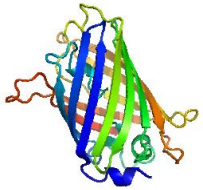
Paula Louro

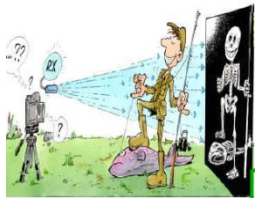
Paula Louro received the Ph.D. degree in Electrotechnical and Computers engineering from Universidade Nova de Lisboa, Portugal, in 2007 and habilitation in the same university in 2015. She is full professor at the Electronics, Telecommunication and Computer department of Instituto Superior de Engenharia de Lisboa (ISEL), Portugal, where she lectures Electronics and Optoelectronics courses of 1st and 2nd cycle. Her main research interests are in the field of thin-film electronics based on amorphous semiconductors for the development of optoelectronic devices in applications ranging from optical communication to biosensors. Recently she has headed several national research projects in the field of visible light communication using tri-chromatic LEDs. She is author and co-author of more than 150 publications in international journals and in proceedings of international conferences.

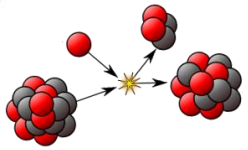
TOPICS OF RESEARCH INTEREST

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

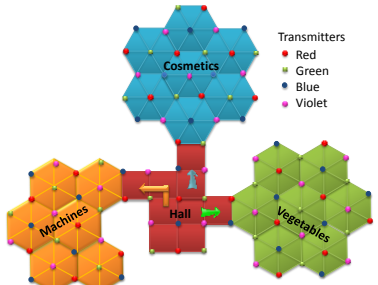


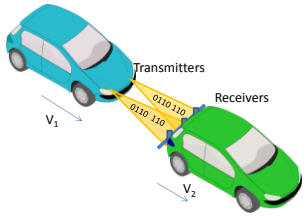






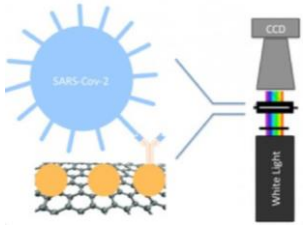
- Visible Light Communication
  - Indoor Positioning Systems
  - Vehicular Communications



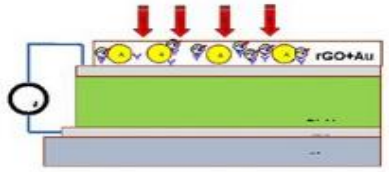


CURRENT PROJECTS

GEO-LOC
“Indoor and Outdoor Geo-Localization and Navigation by Visible Light Communication”
IDI&CA program, 5th Edition, 2020-2021



AGE-SPReS
“Arrayed Graphene Enhanced Surface Plasmon Resonance for Sensing Applications“
IDI&CA program, 5th Edition, 2020-2021



PhotoAKI
“Photonic Biosensor for point of care and Early Diagnostics of Acute Kidney Injury”
LISBOA-01-0145-FEDER-031311, 2018-2021

OUTLINE

- **Introduction**
- **Design of the Geo-Location VLC system**
  - Generic model
  - VLC Transmitters
  - VLC Receivers
  - Data frames
- **Results and discussion**
  - Proposed scenario
  - Coding of VLC transmitters
  - Decoding of the VLC received signal
- **Conclusions**

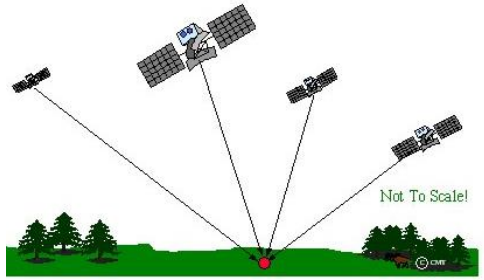
MOTIVATION

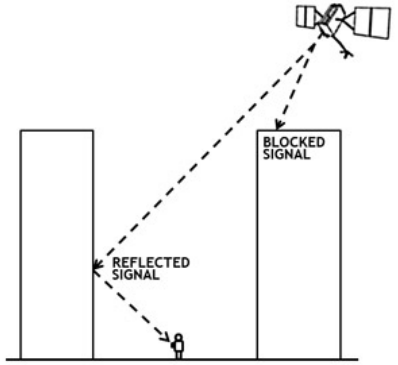
- Improve the **efficiency** of an automated warehouse which translates into direct savings
- Automated solutions can enlarge the human element in certain tasks, removing health and safety risks and limitations
- Use of **autonomous guided vehicles** to remove goods from racks of and carry them to the packaging station
- Navigation along pre-defined routes
- Use of **VLC** to support navigation and positioning of the vehicles

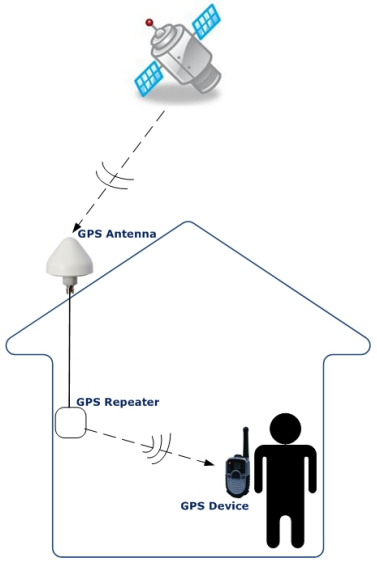
EFFICIENT WAREHOUSING

NAVIGATION SYSTEMS

GPS – GLOBAL POSITIONING SYSTEMS





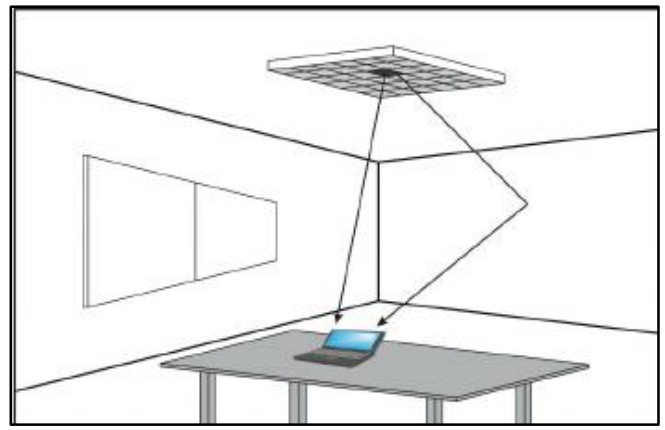


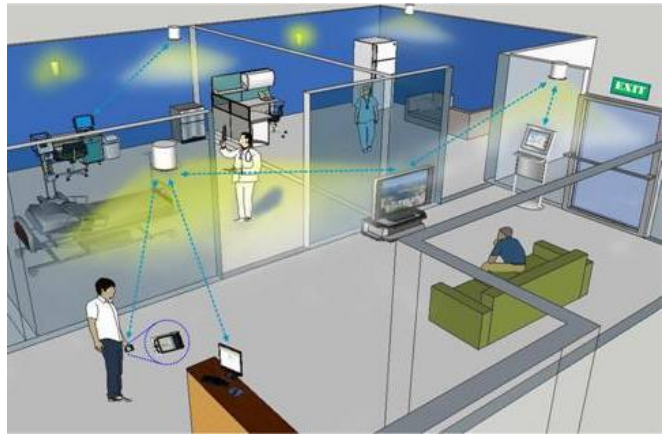
INDOOR POSITIONING SYSTEMS

RADIO	OPTICAL	MAGNETIC	ACOUSTIC
UWB (Ultra-wideband)	Video camera	Magnetic strength	Ultrasound
Bluetooth (e.g. Beacons)	Lidar (Light Detection and Ranging)		
UHF RFID	Infrared light pulses		
Wi-Fi (Wireless Fidelity)	VLC (Visible light communications)		

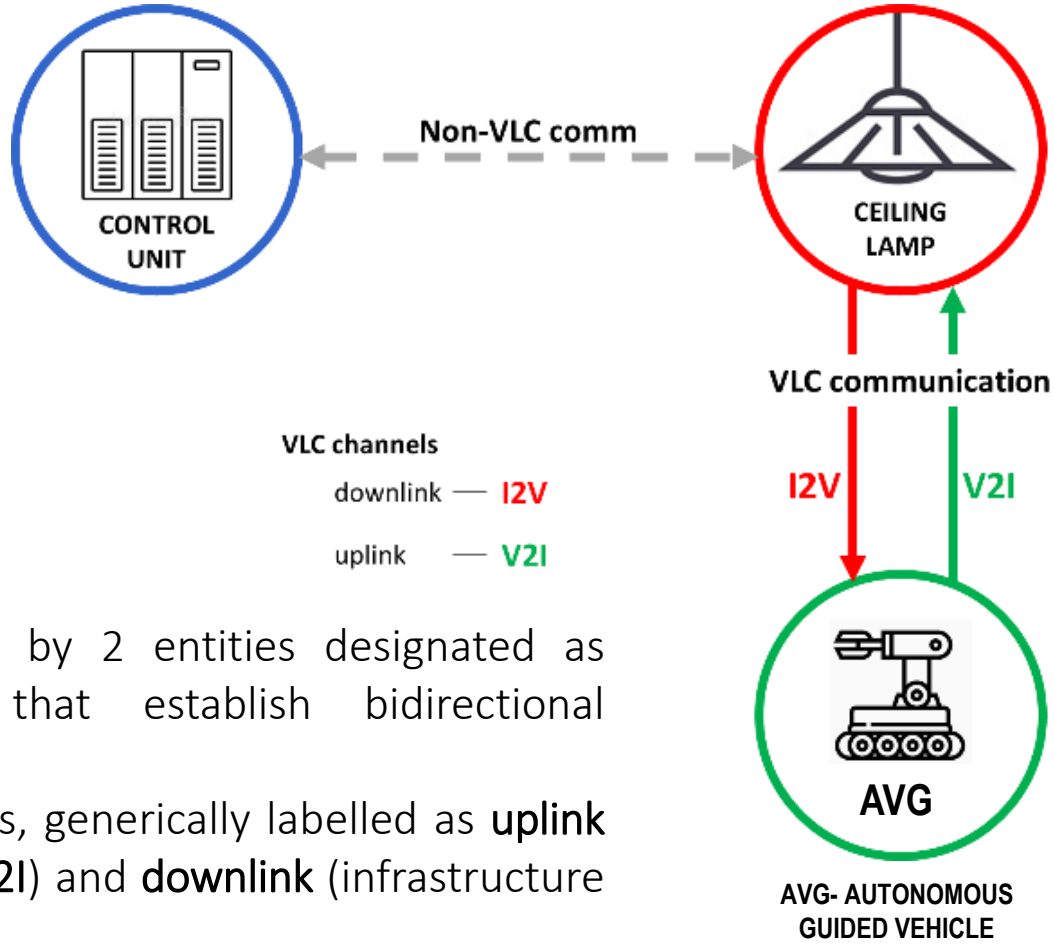
VISIBLE LIGHT COMMUNICATION

- Provides lighting and communication services
- Free and non-regulated spectrum
- Harmless to the human health
- No EM interference
- Use of installed infrastructure
- Increased bandwidth
- Negligible power
- Inexpensive
- Security
- Can be used in many applications
- Able to provide spatial location and navigation services



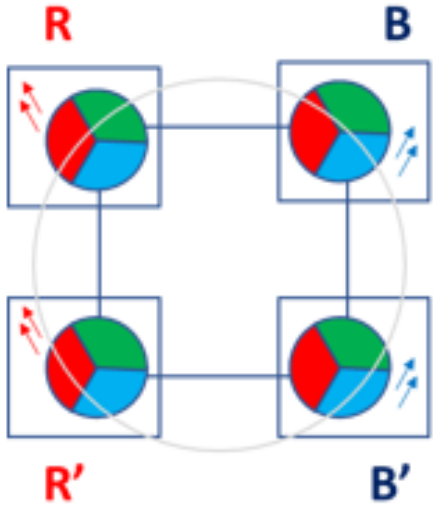


GENERIC GEO-LOCATION VLC MODEL

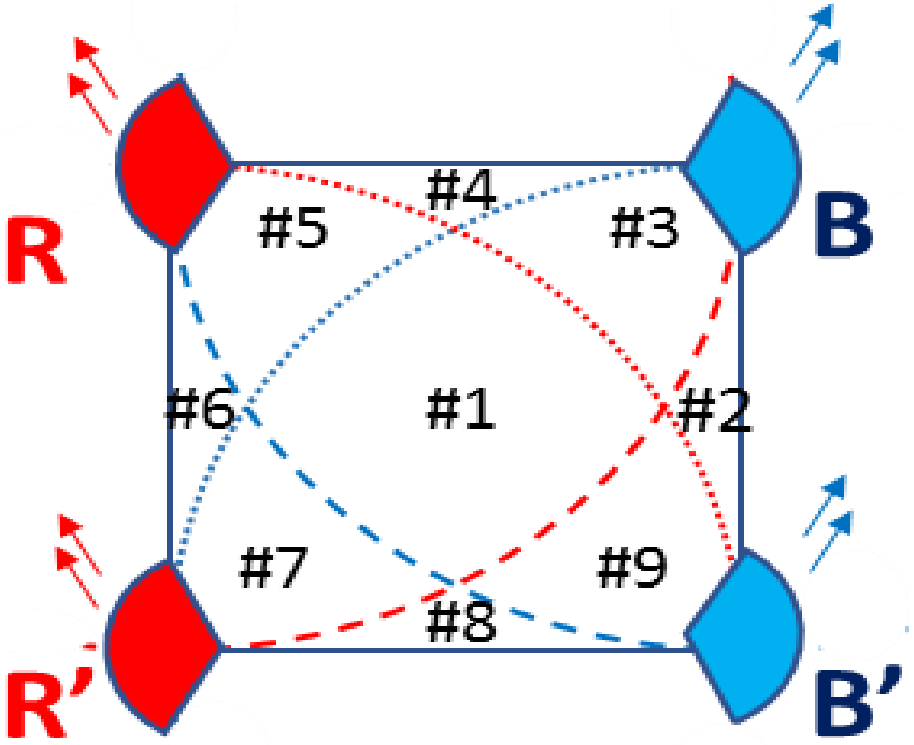


- The VLC system is composed by 2 entities designated as **infrastructure** and **vehicle**, that establish bidirectional communication between them.
- These communications channels, generically labelled as **uplink** (vehicle to the infrastructure, **V2I**) and **downlink** (infrastructure to the vehicle, **I2V**).

VLC TRANSMITTERS

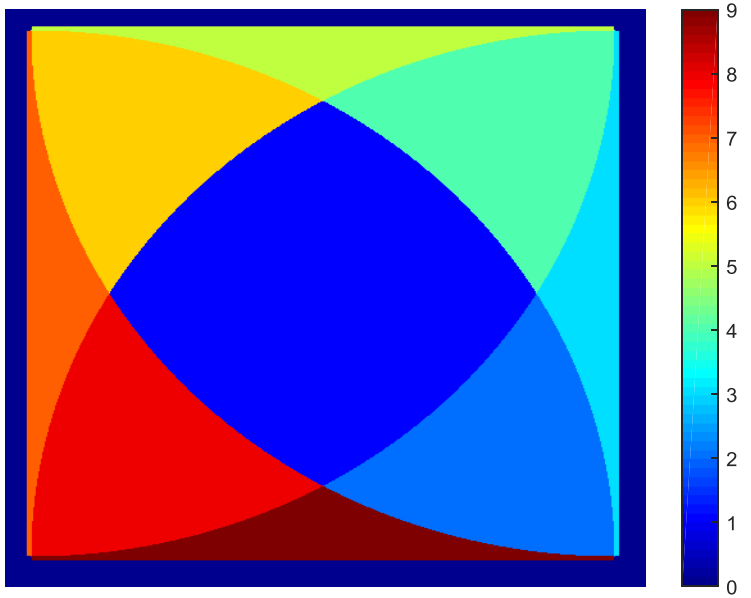


UNIT NAVIGATION CELL



#1 – R+R'+B+B'
#2 – B+B'
#3 – R+B+B'
#4 – R+B
#5 – R+B+R'
#6 – R+R'
#7 – R+R'+B'
#8 – R'+B'
#9 – R'+B'+B

FOOTPRINT MAP

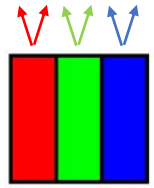


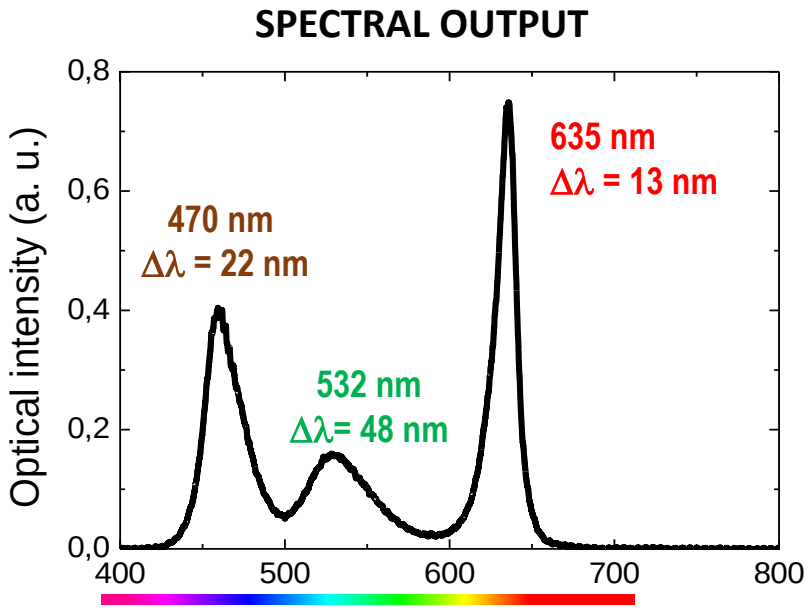
RGB WHITE LEDS

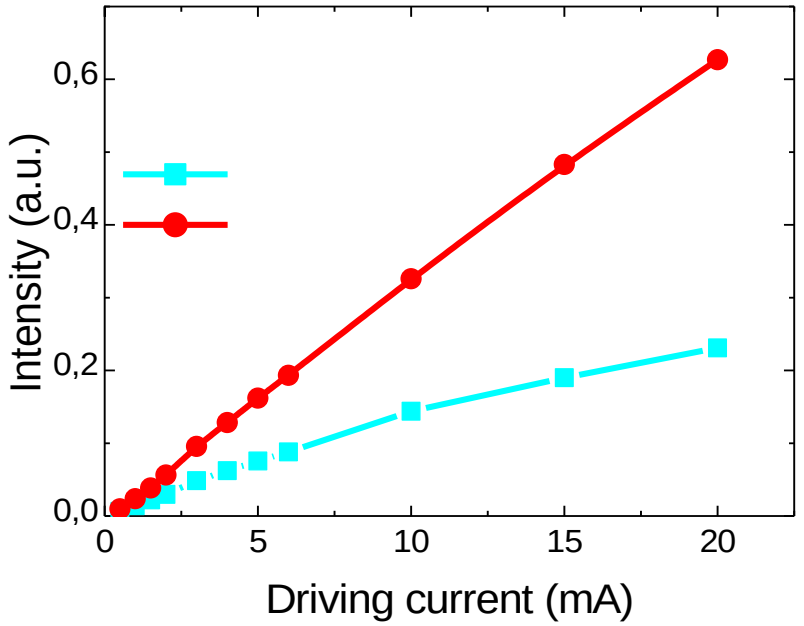
Luminous int.	Illuminance	Luminous flux	Power	Power
mcd	(lx)	(lumen)	(mW)	(dB)
550	1375	0,1375	1,375	-28,6
850	2125	0,2125	2,125	-26,7
320	800	0,08	0,8	-31,0

Dominant wavelength	Spectral linewidth	Half view angle	Forward voltage
(nm)	(nm)	(º)	(V)
619-624	24	120	2
520-540	38		3.2
460-480	28		3.2

Average values
@ 25°C, 20 mA

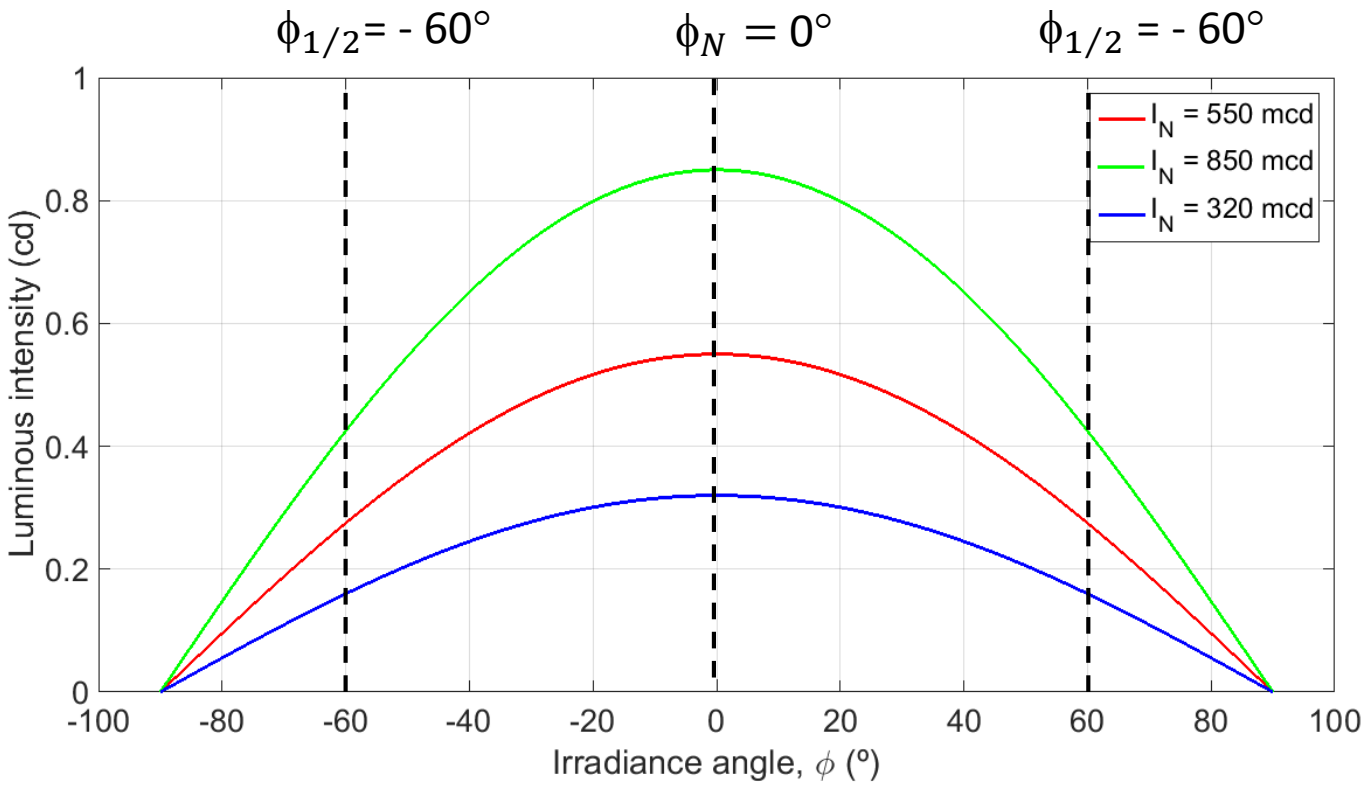






- The magnitude and width of each RGB peaks are optimized for the white.
- The green component is lowest because the human eye has a maximum sensitivity at 550 nm.
- Half viewing angle ≅ 60º

LED MODEL



LAMBERTIAN DISTRIBUTION

$$I(\phi) = I_N \cos^m(\phi)$$

$$m = -\frac{\ln(2)}{\ln(\cos(\phi_{1/2}))}$$

$\phi_{1/2} = \pm 60° \rightarrow$ m = 1

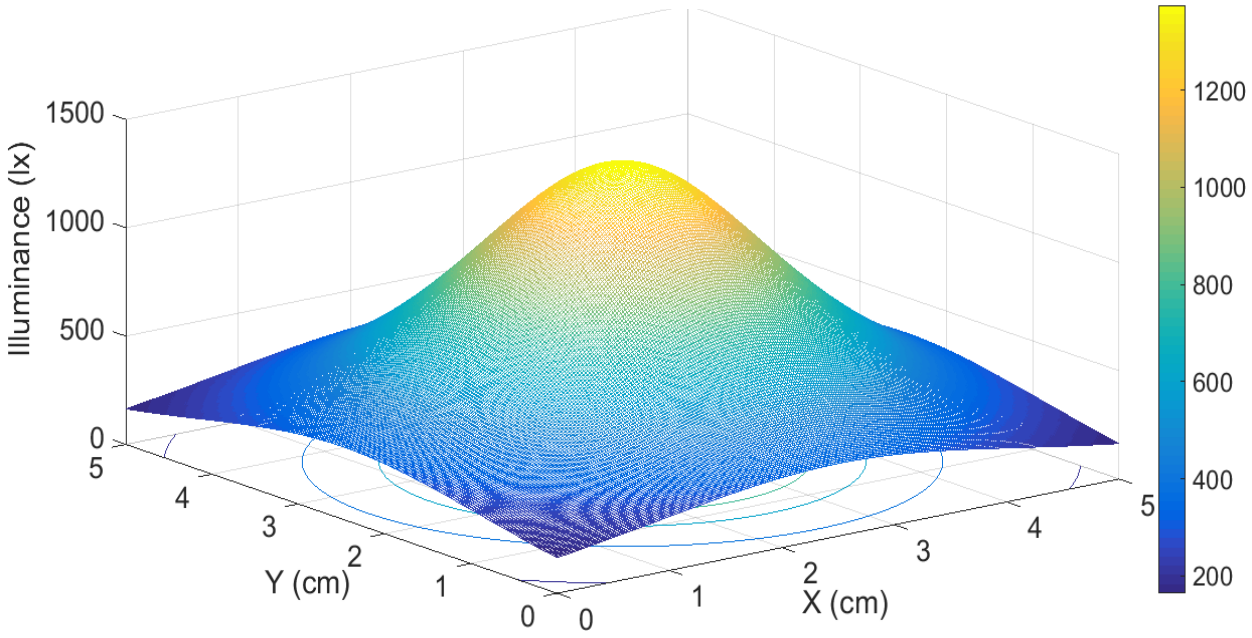
- The luminous intensity varies with the direction
- Exhibits a maximum at the axial direction (0°) and half of the maximum at $\phi_{1/2} = \pm 60°$

LED ILLUMINANCE

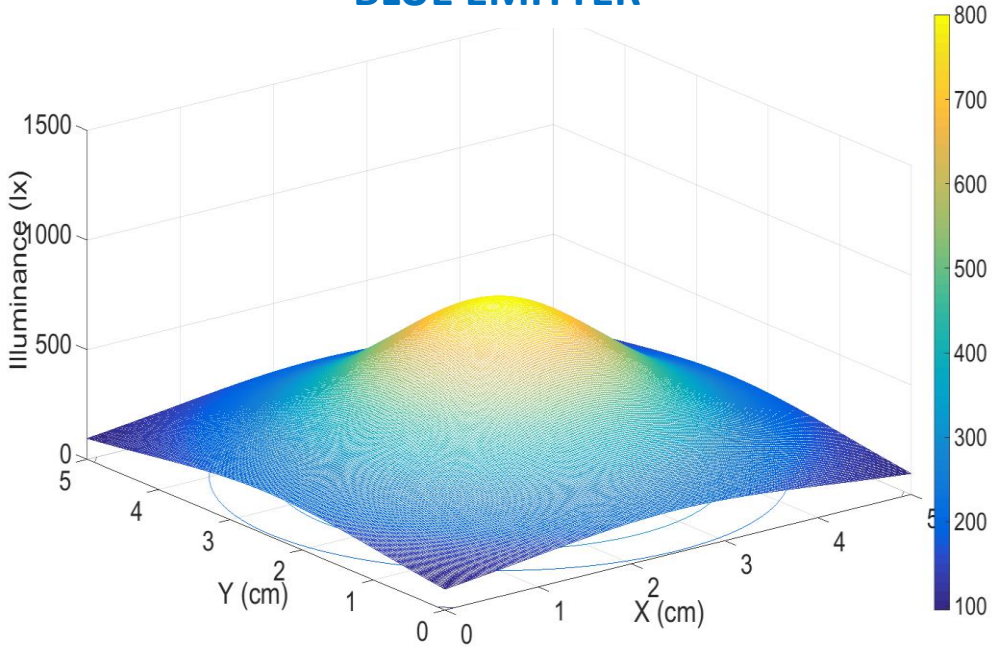
Simulation at lab prototype scale

$$E_{hor}(x, y, z) = \frac{I_N \cos^m(\phi)}{D_{t-r}^2 \cos(\theta)}$$

RED EMITTER



BLUE EMITTER

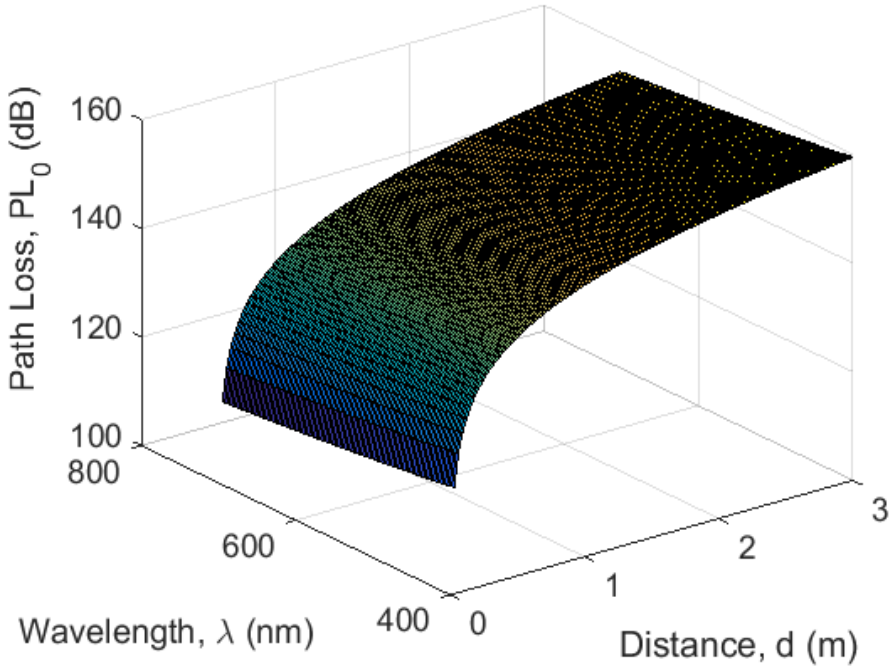


- The wide field of view provides light energy scattering in all directions
- Uniform distribution of illuminance in all directions

PATH LOSS

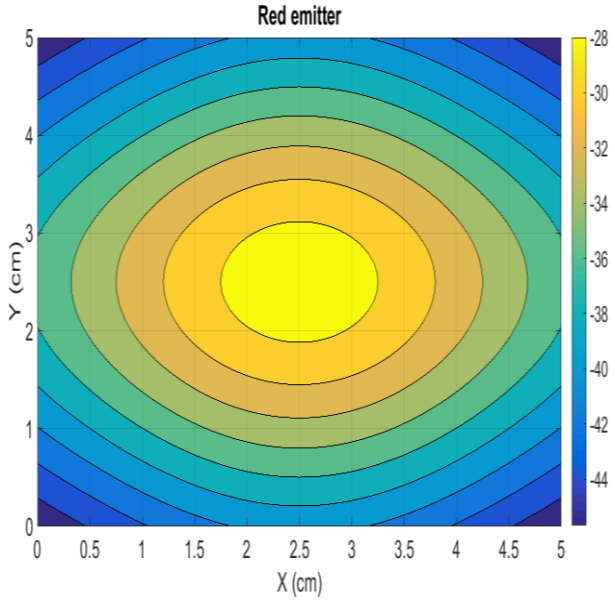
Friis model

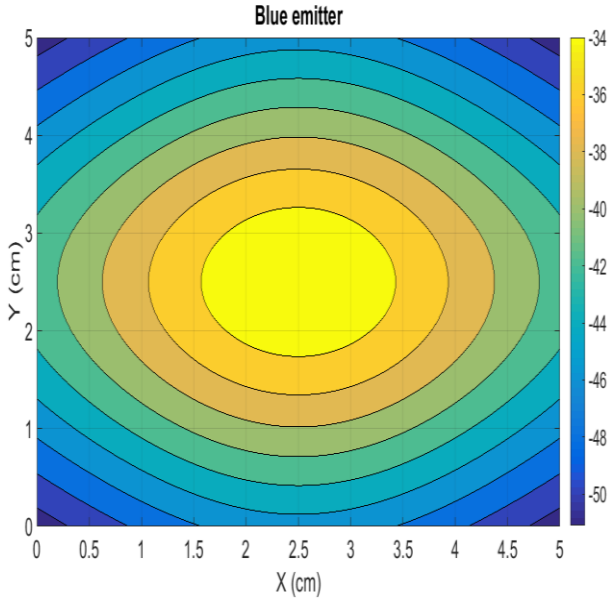
$$PL_0 = 10\log_{10}\left(\frac{4\pi d}{\lambda}\right)^2 = 20\log_{10} 4\pi + 20\log_{10} d - 20\log_{10}\lambda$$



- Influence of wavelength: very reduced (variation < 3%) due to very narrow dynamical range of the visible spectrum.
- Most important factor: distance between the emitter and the receiver. (attenuation ~ 30% in the analyzed range).

RECEIVED POWER



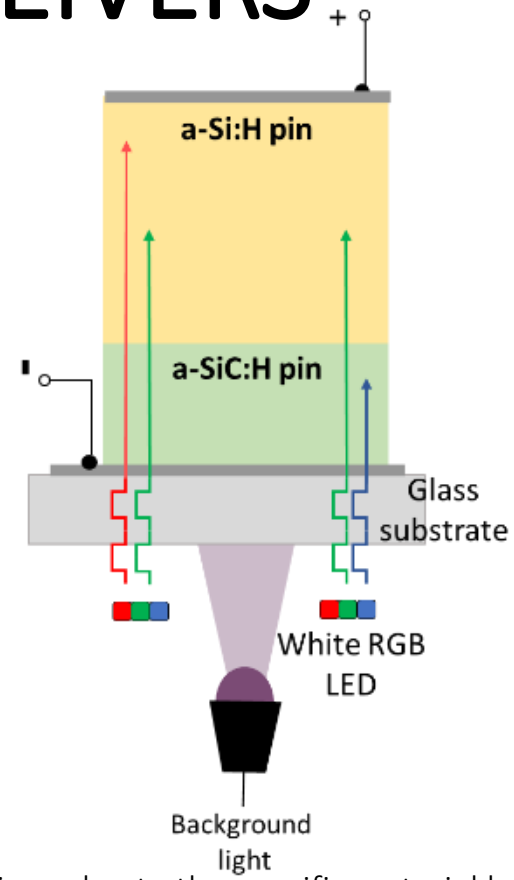


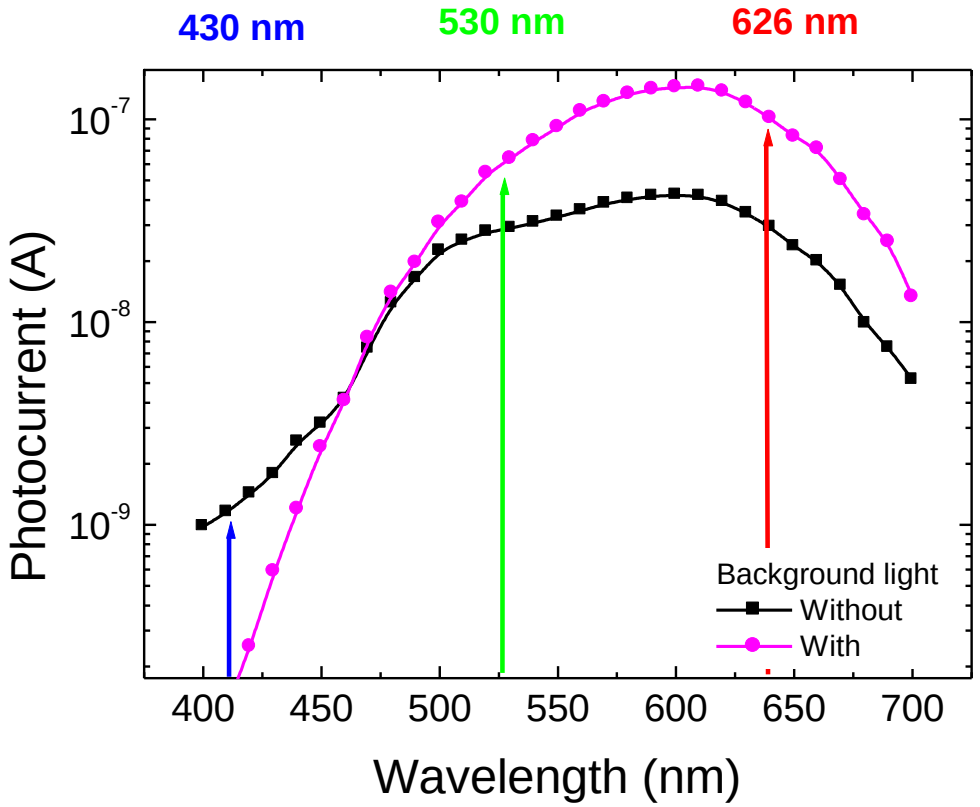
CHANNEL GAIN

$$P_R = P_T \times G$$

$$G = \frac{(m+1)A}{2\pi D_{t-r}^2} I_N \cos^m(\phi) \cos(\theta)$$

VLC RECEIVERS





- Different absorption mechanisms due to the specific material bandgaps of the intrinsic layers.
- High absorption of short wavelength light in the front photodiode (a-SiC:H).
- High absorption of the long wavelengths in the back photodiode (a-Si:H).
- Intermediate wavelengths are absorbed by both photodiodes.
- The use of steady state light as background light enhances the electrical field of the front a-SiC:H photodiode and amplifies the generated photocurrent signal produced under long wavelength light incidence.

DATA FRAMES

11011101

11011101

I2V

SoT (4 bits)	TYPE (4 bits)	GEO-LOCATION (16 bits)	MESSAGE (36 bits)	EoT (4 bits)

GEO-LOCATION block

CELL ID (8 bits)	POSITION (8 bits)
R & B: X X X 0 Y Y Y 0	1 1 1 1 0 0 0 0
R' & B': X X X 0 Y Y Y 0	1 1 0 0 1 1 0 0

X X X: Line | Y Y Y: Column

MESSAGE block (Request mode, TYPE = 0000)

DESTINATION Line x column (8 bits)	RACK Position # items (4 bits + 4 bits)	ROUTE (4 + 4 bits)	ADD INFO (16 bits)
___0___0	___0____	____ ____	________________
___0___0	___0____	____ ____	________________

MESSAGE block (Standard mode, TYPE = 0011)

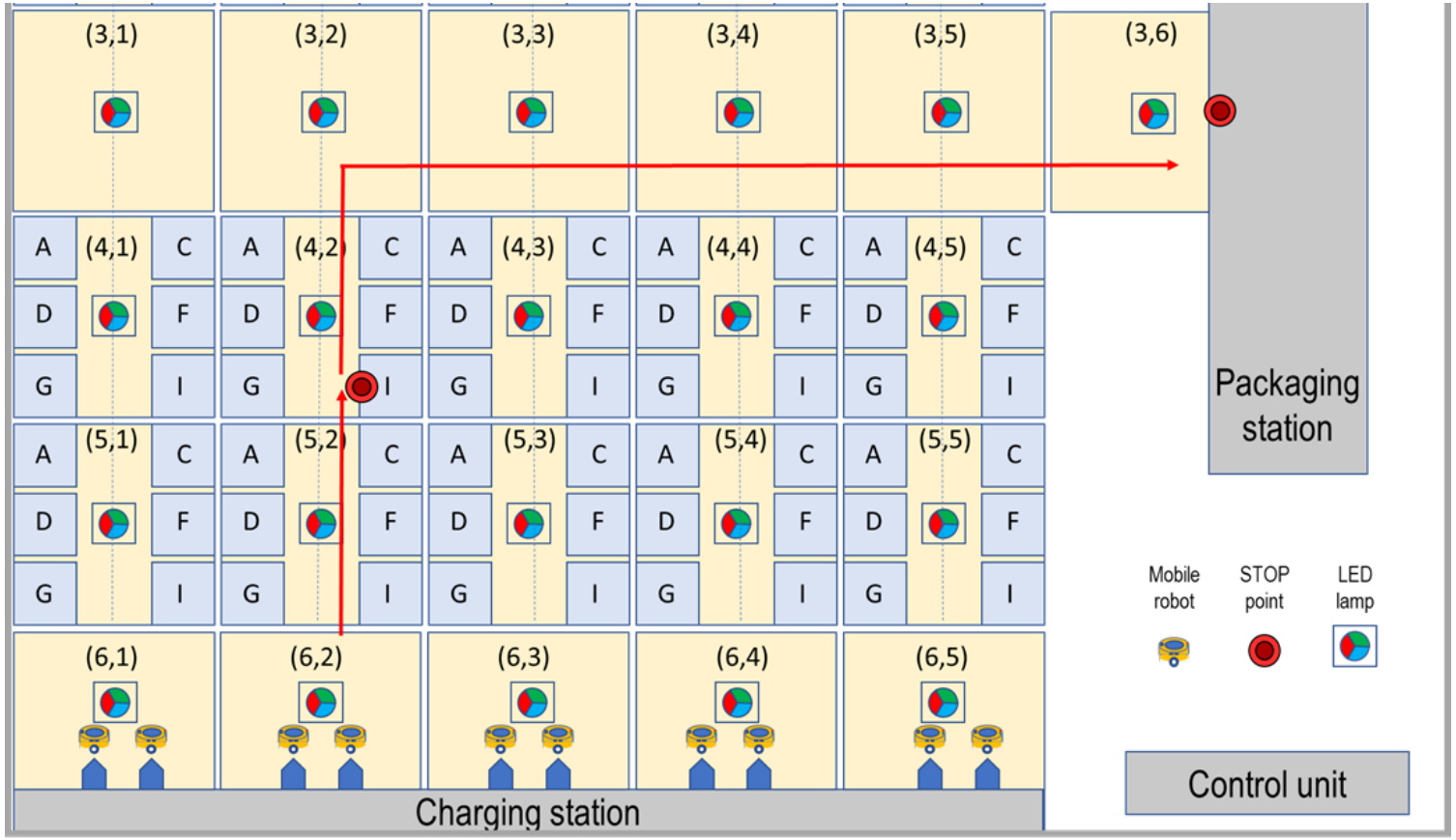
NULL (24 bits)	ADD INFO (16 bits)
000000000000000000000000	________________
000000000000000000000000	________________

11011101

V2I

SoT (4 bits)	TYPE (4 bits)	IDENTIFICATION (16 bits)	MESSAGE (36 bits)	EoT (4 bits)

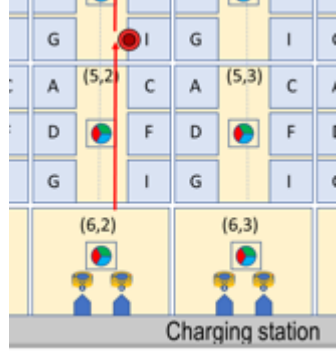
PROPOSED SCENARIO



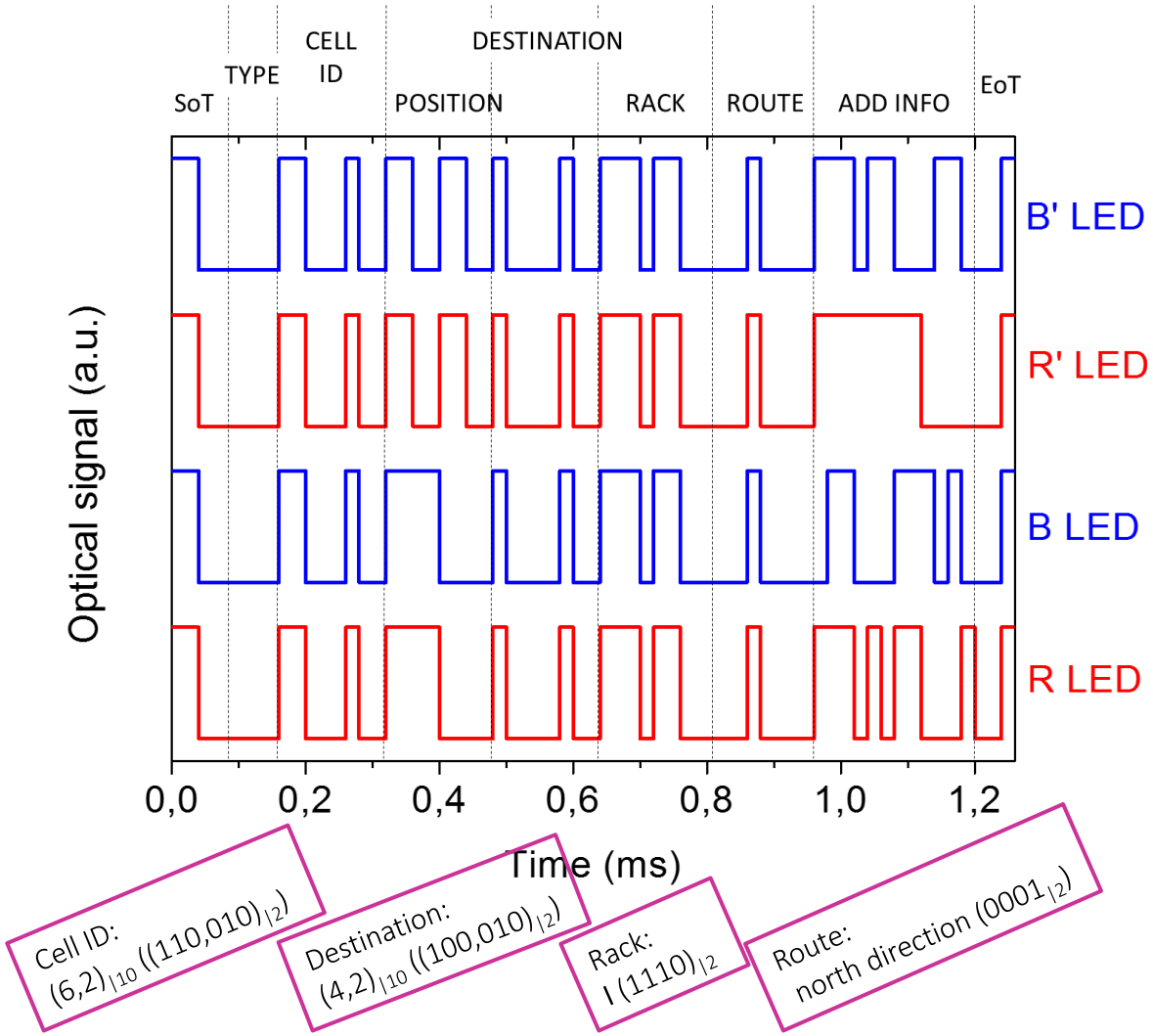
- Warehouse with 5 corridors with racks on both left and right sides.
- The indoor space is lightened using LED lamps that establish the navigation cell in a squared geometry.
- In this example there are 30 LED lamps - 30 navigation cells,
- Numbering of the cells - matrix

CODED EMITTER SIGNALS

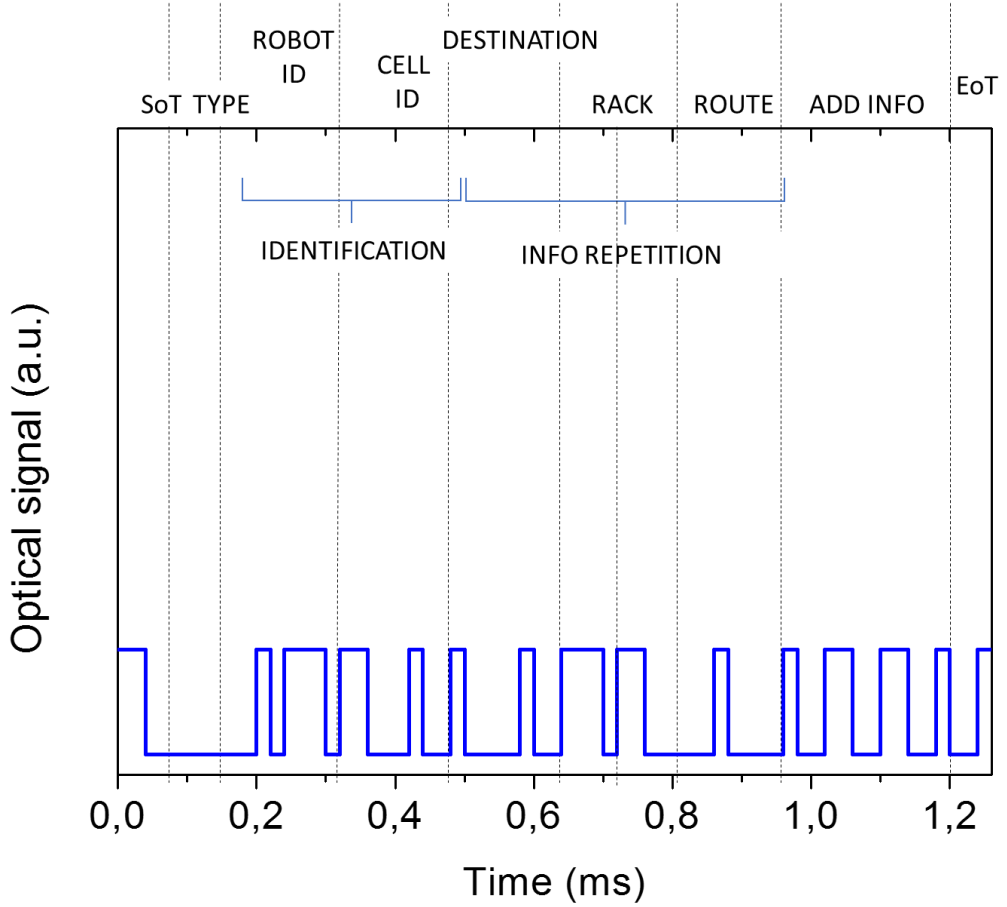
Vehicle received a request!



I2V link in request mode

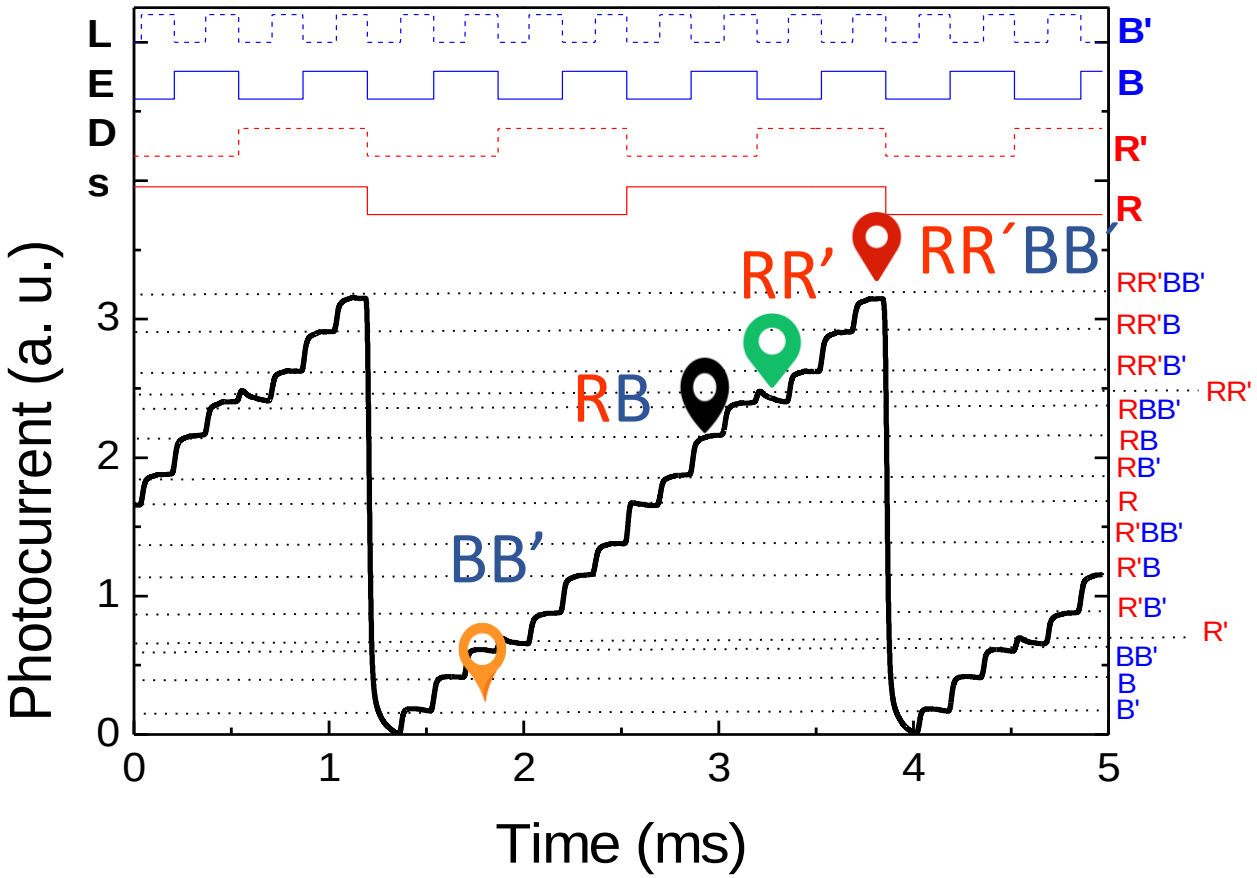


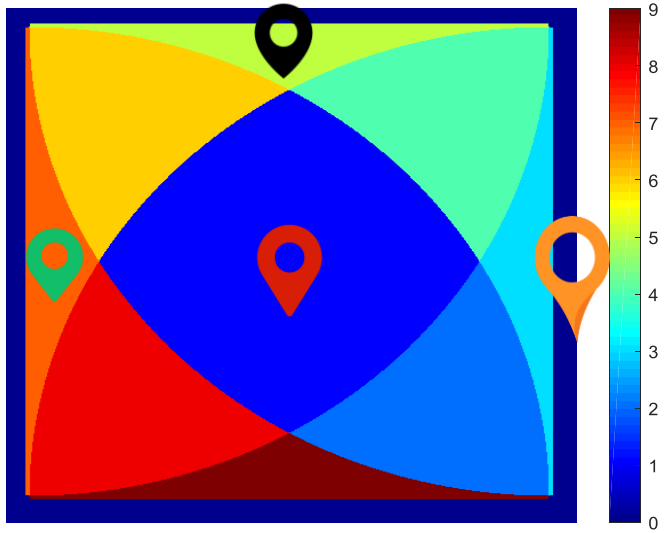
V2I link in acknowledge mode

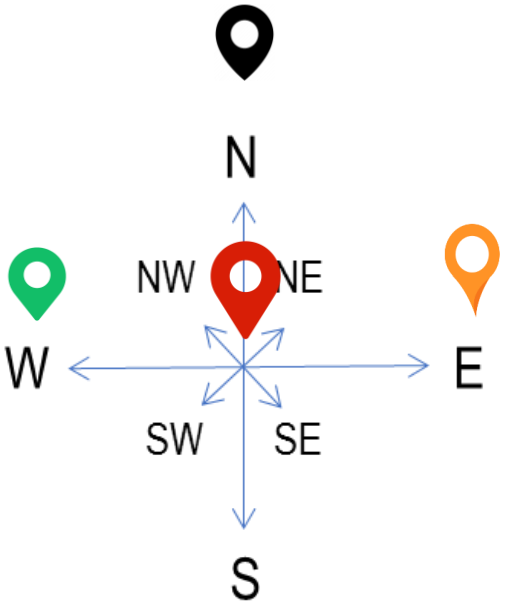


- The vehicle transmits its own identifier and retransmits the information received from the infrastructure in request mode.
- This can in future be used to detect any decoding error.

DECODING STRATEGY – I2V

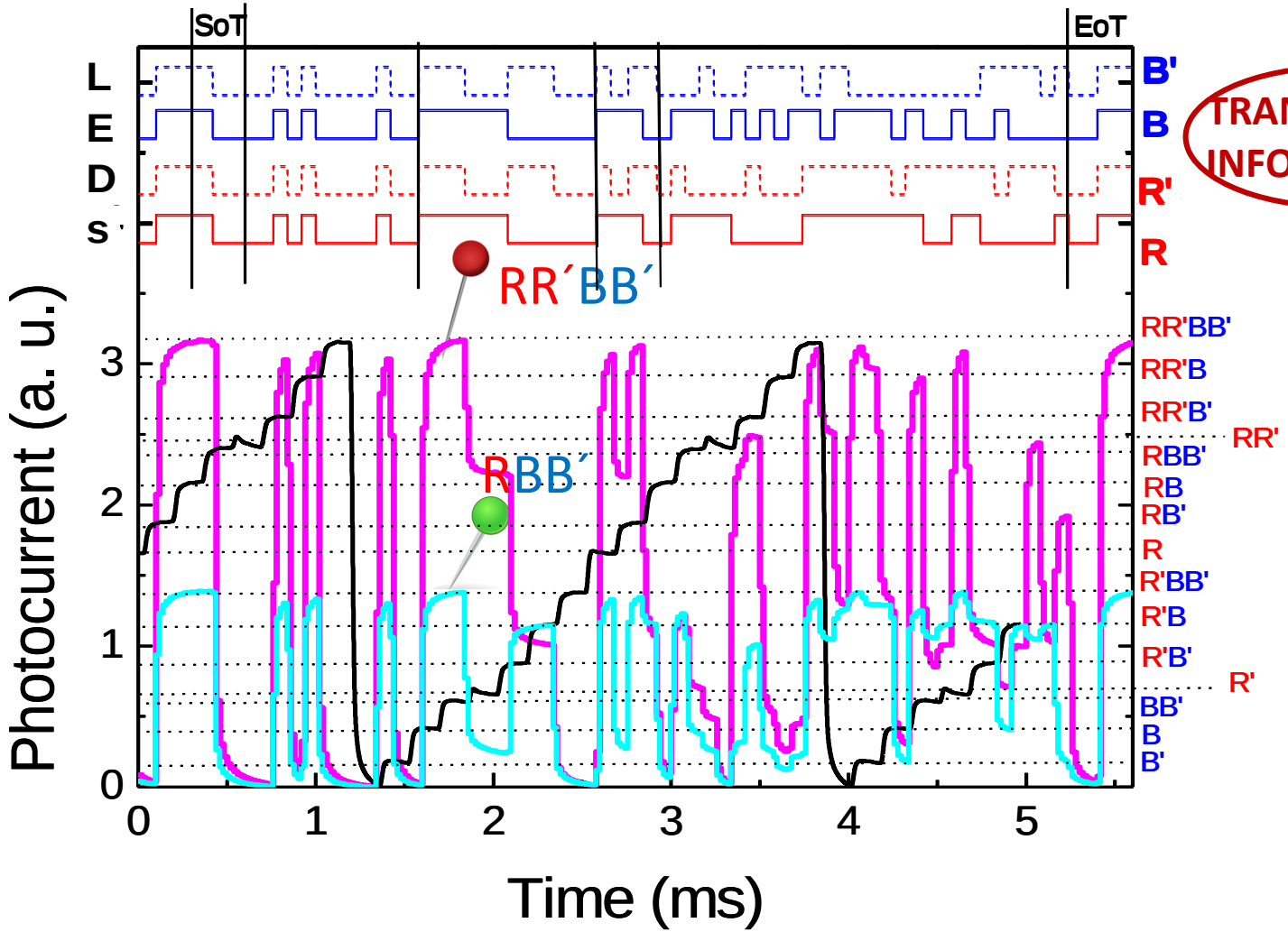




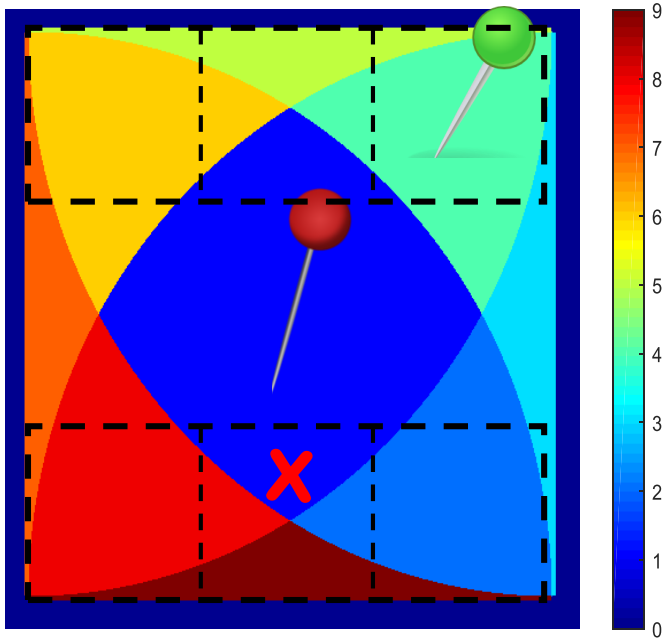


- Simultaneous modulation of **4** emitters
- The resultant optical signal is a combination of 4, 3, 2 or 1 optical signals → **16** possible photocurrent levels

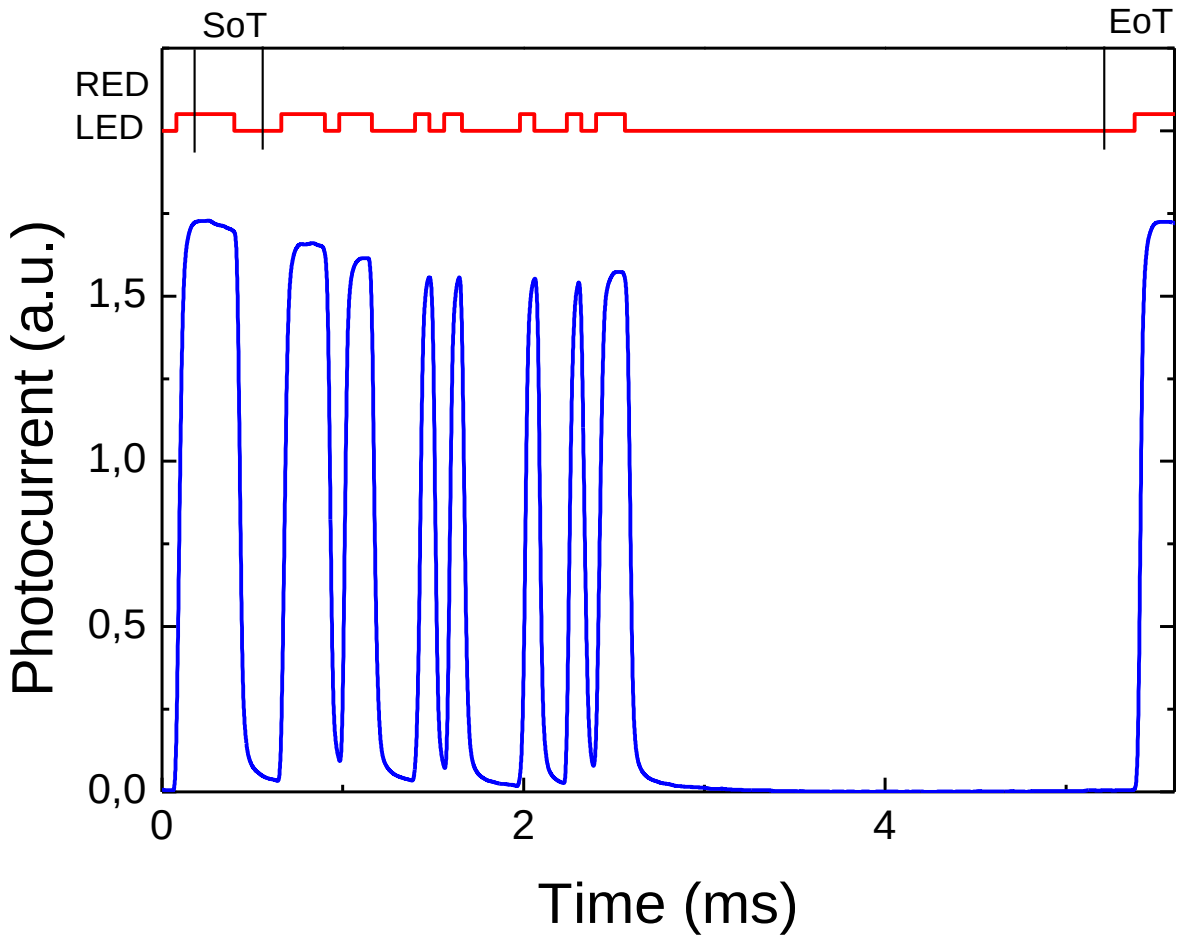
I2V LINK



TRANSMITTED INFORMATION



V2I LINK



- ✓ Only one emitter is used
- ✓ The signal detected by the photodetector is due to a single excitation.
- ✓ The identification of the transmitted bits is immediate.
- ✓ There is no need the demultiplex the photocurrent signal

CONCLUSIONS & FUTURE WORK

Transmitter

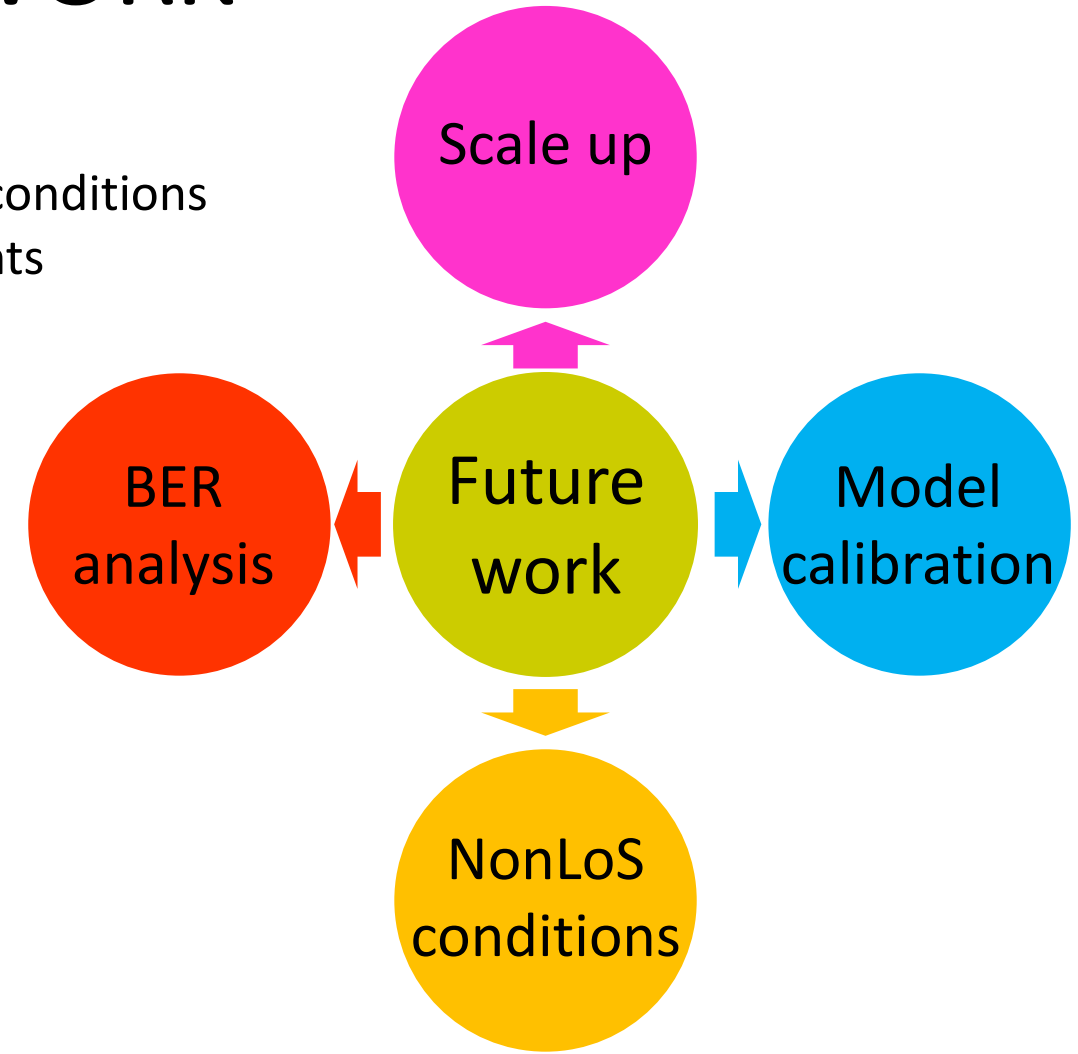
- Simulation of the propagation model in LoS conditions
- Definition of the coverage areas and footprints

Coding

- Use of 64 bits word
- Syncronization of frames

Receiver

- Calibration data
- Footprints – photocurrent signal



Thank you for your attention!

plouro@deetc.isel.ipl.pt

Acknowledgements

UIDB/00066/2020
IPL/2020/GEO-LOC/ISEL