The Twelfth International Conference on Sensor DeviceTechnologies and Applications
SENSORDEVICES 2021
November 14, 2021 to November 18, 2021 - Athens, Greece

Keynote Speech

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Pedro Vieira

Cooperative Self-localization and Wayfinding Services Through Visible Light Communication

- **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.

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OBJECTIVES

CTS - Centre of Technology and Systems

The Centre of Technology and Systems (CTS) aims to develop theoretical and applied research and encourages technology transfer mostly supported by spin offs and deep involvement in international R&D projects. The scientific results are expected to contribute to improve the graduate training in the academia and contribute to the internationalization of the center. Participates in many international projects financed by the European Union, the European Space Agency, industries and also financed by national funds such as FCT and other companies. Also participates in several international actions as joint papers, international events organization, etc.

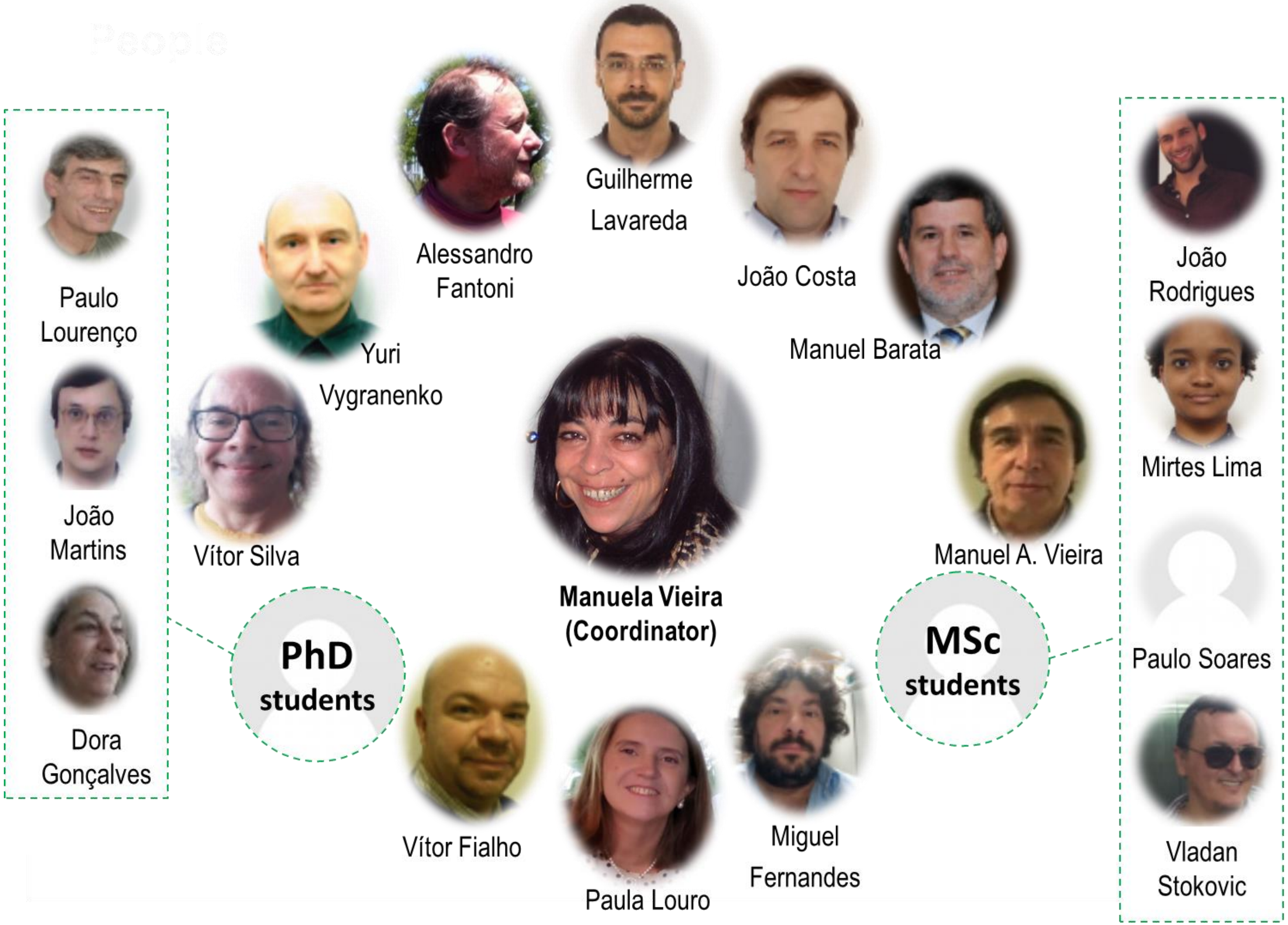
- Development, optimization and application of semiconductor based devices: image and color sensors, optoelectronic devices, solar cells, optical amplifiers, biosensors, VLC devices, nanostructures and UV and IV detectors.
- Design and modeling of optical devices. Photonics.
- Electrical and numerical simulation of optical devices.
- Integration of different technologies, namely optical sensors, wavelength-division multiplexing, Visible Light Communication, X-ray detectors and full digital medical imaging.

CTS

M2P Research group

PEOPLE (M2P)

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



Investment in R&D is part of the solution to exit from the economic crises

Running projects applications

The three priorities of H2020

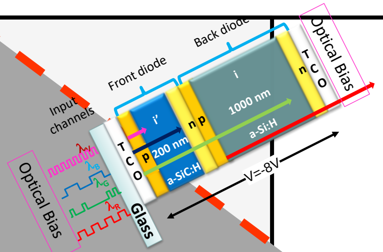
1. "Excellent science"
2. "Industrial leadership"
3. "Societal challenges"

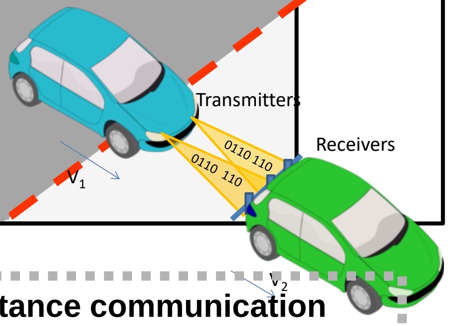
Optical biosensor

Large area

X-ray flat detector

WDM based optical communication system area





FRET based prototype to detect fluorescence of the excited fluorophores when glucose is present, allowing to monitor its level.

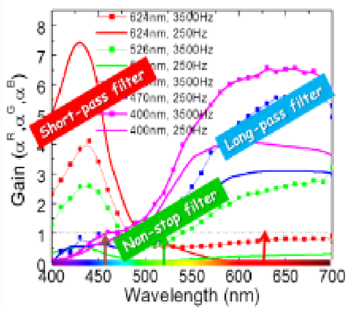
The use of Laser Scanned Photodiode (LSP) sensor is proposed for medical applications

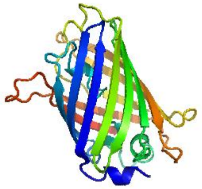
Short distance communication Systems. Digital city auto industry, medical sector and in-house communication

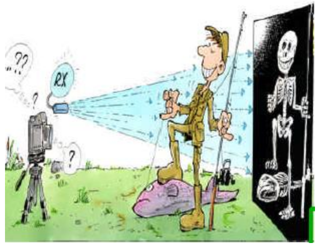
- Information and communication technologies
- Nanotechnologies
- Advanced materials
- Biotechnology
- Health
- Green and integrated transport
- Resource efficiency

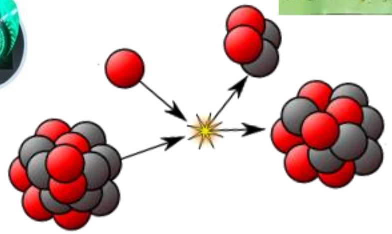
Main Research Areas

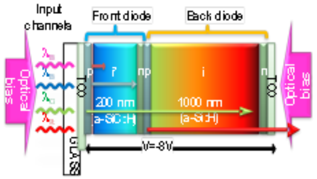
- Applications of semiconductor devices
  - Wavelength Division Multiplexing (WDM)
  - Optical biosensors
  - X-ray flat panel
  - OLEDs
  - Nanodevices



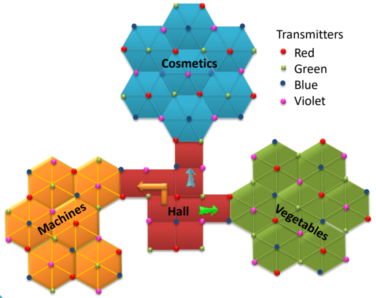


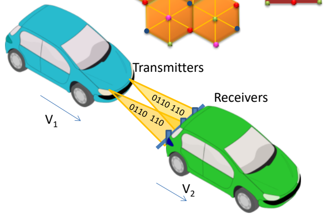






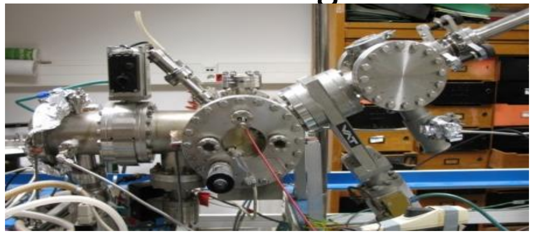
- Visible Light Communications
  - Indoor positioning systems
  - Vehicular Communications



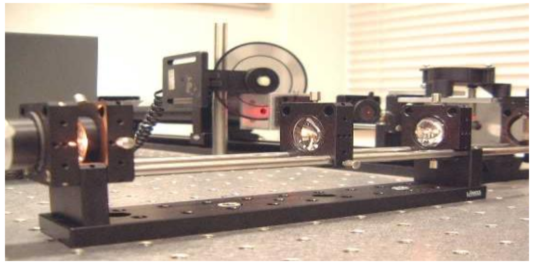


Facilities

- **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.



PUBLICATIONS

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

…
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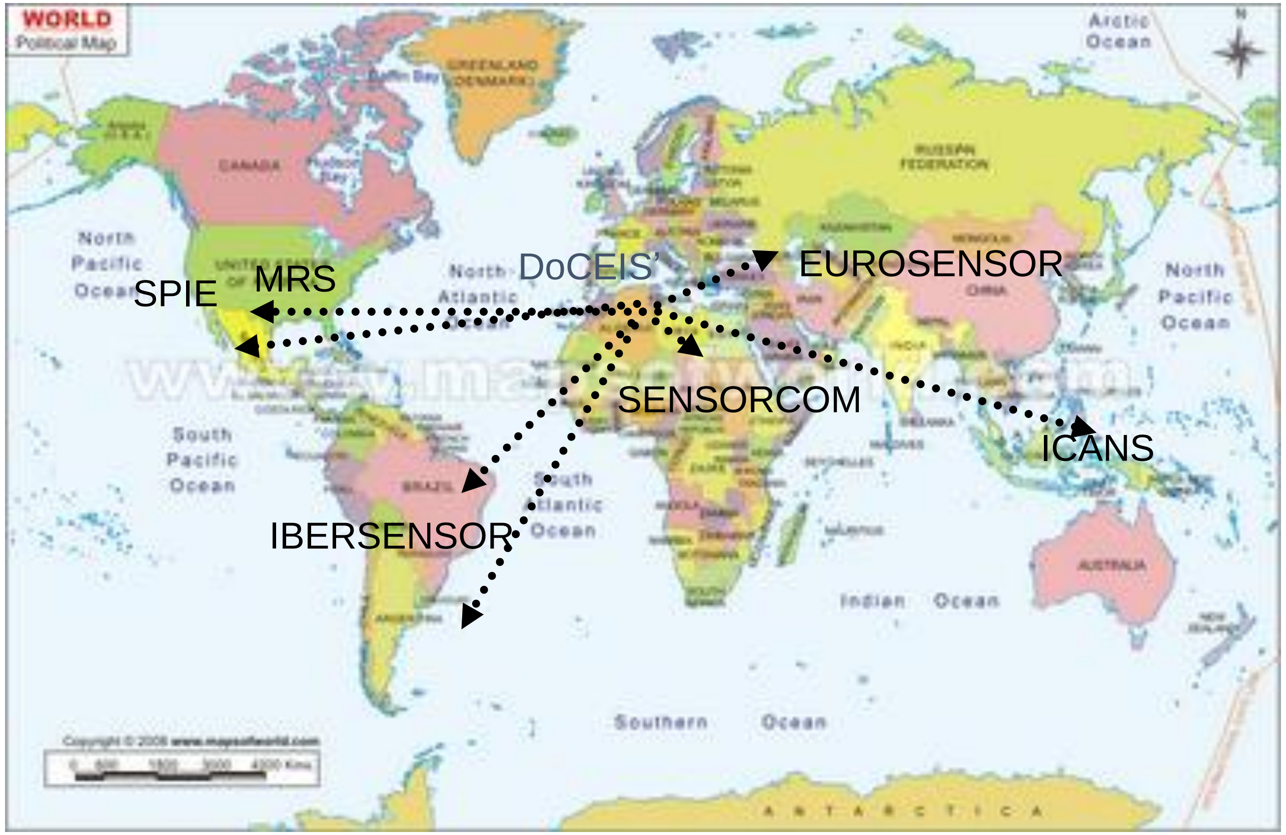
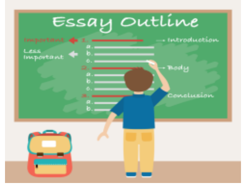


International Cooperation

- 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.



OUTLINE

✓ MOTIVATION

- VLC – Transmission of data using visible light
- Self-localization , position and orientation

✓ SYSTEM DESIGN

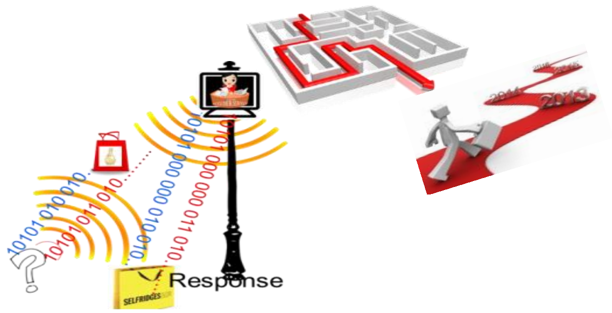
- Wayfinding concepts
- VLC dynamic navigation system
  (position and route control)
- Building infrastructure (3D model)

✓ CODING/DECODING TECHNIQUES

- Communication protocol by VLC
- Decoding techniques

✓ ROUTE EVALUATION

- Fine Grained Localization and travel direction
- Bi-directional Communication and wayfinding services

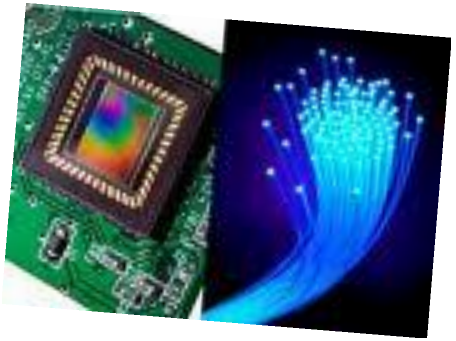


✓ CONCLUSIONS/FUTURE WORK

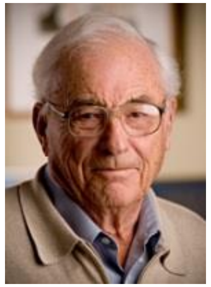
LEDs for Lighting

NOBEL in Physics 2009

TWO REVOLUTIONARY OPTICAL TECHNOLOGIES



Charles K. Kao



Willard S. Boyle

George E. Smith

"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

Key Digital Transformers

By 2021

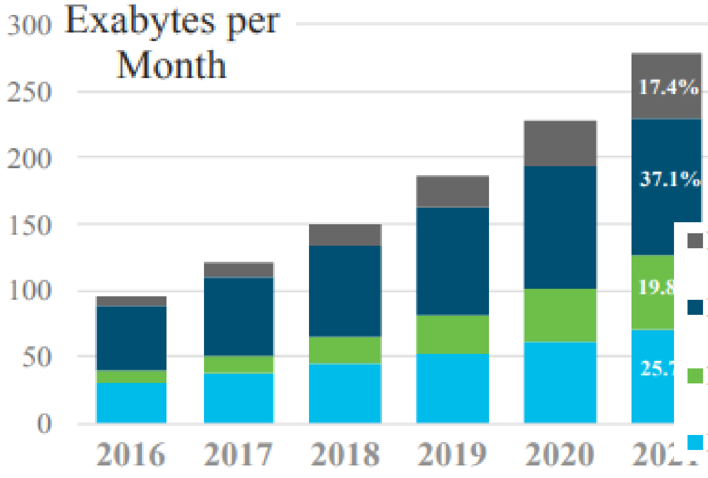
Wi-Fi will begin to become limited

	More Internet Users	More Devices & Connections	FasterBroadband 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

24% CAGR
2016–2021



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

Wireless Optical Communications

* Wireless traffic includes Wi-Fi and mobile

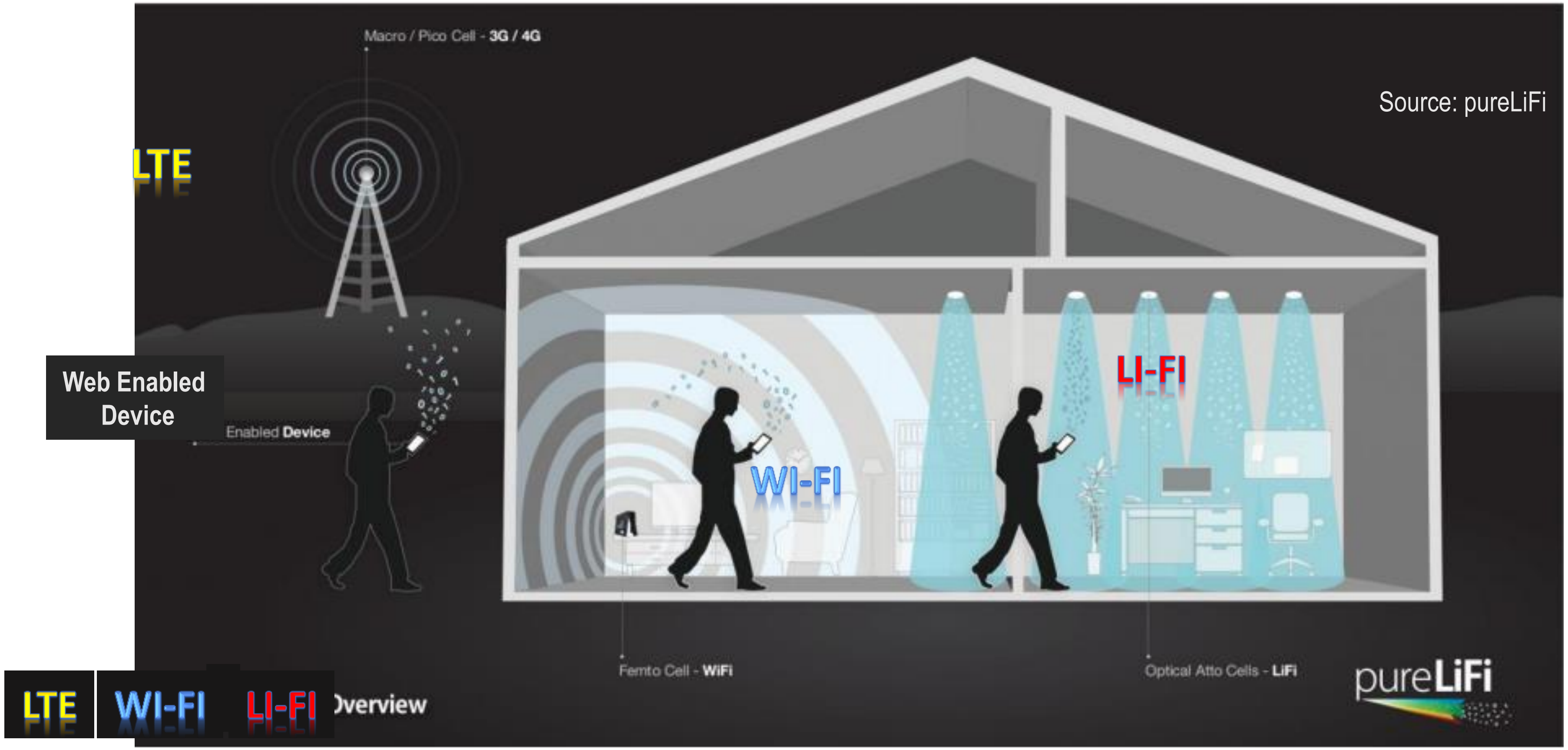
FUTURE GENERATIONS OF TELECOMM NETWORKS

European Commission

Speed
Latency
Capacity

- **IoT (Internet of Things)**
- **VR (Virtual Reality)**
- **AR (Augmented Reality)**
- **Holograms**

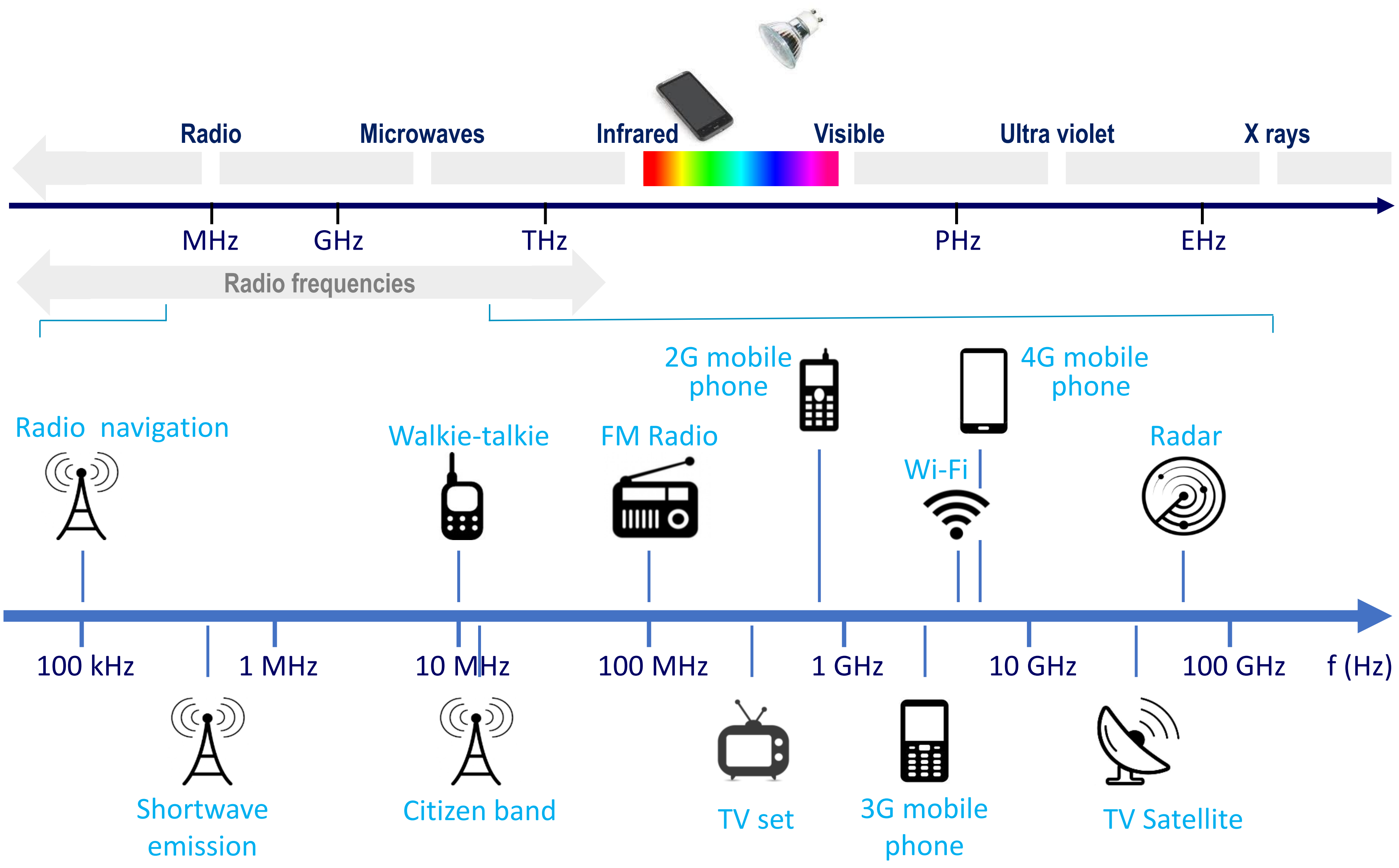
TECHNOLOGY INTEGRATION



- 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.

COMMUNICATION SPECTRUM



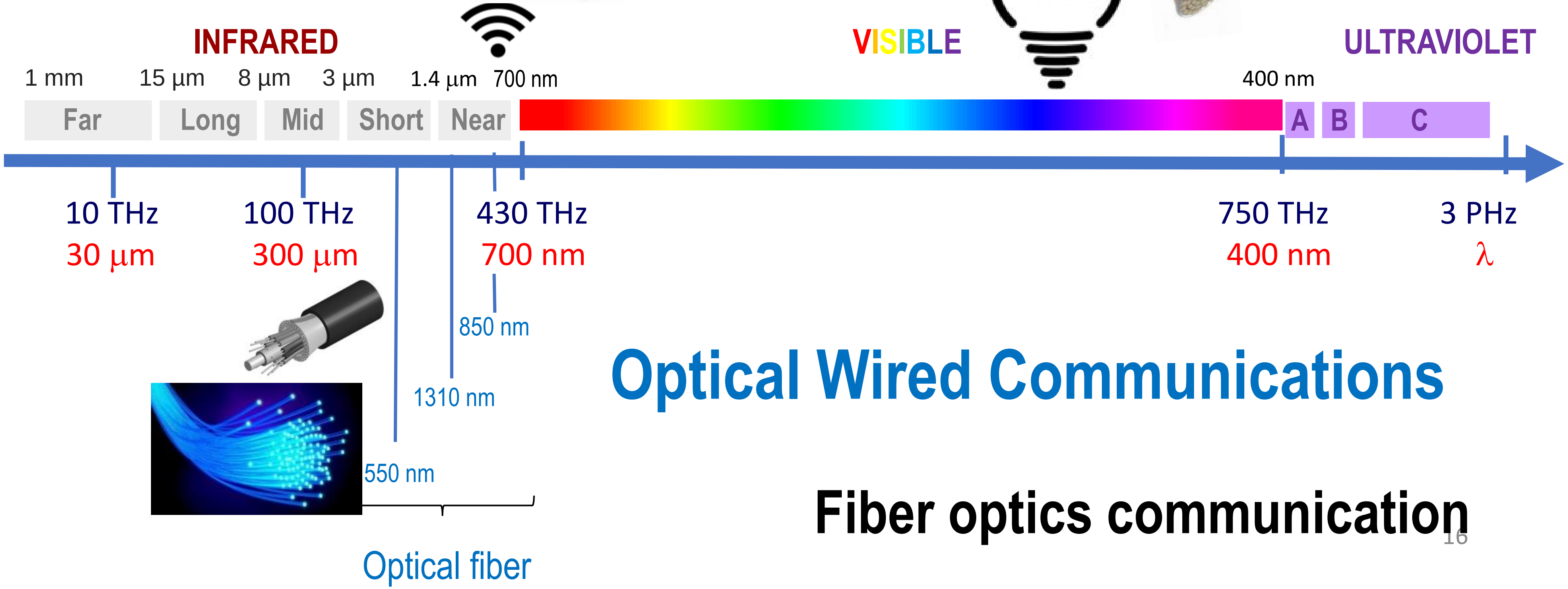
Adapted from “Física 11”, C. Fiolhais et al

OPTICAL COMMUNICATIONS

OWC Optical Wireless Communications

FSO Free Space Optical Communications

VLC Visible Light communication

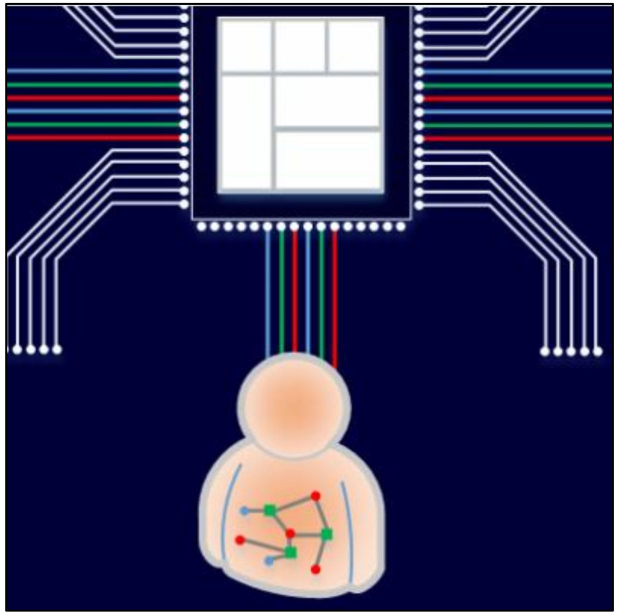


Optical Wired Communications

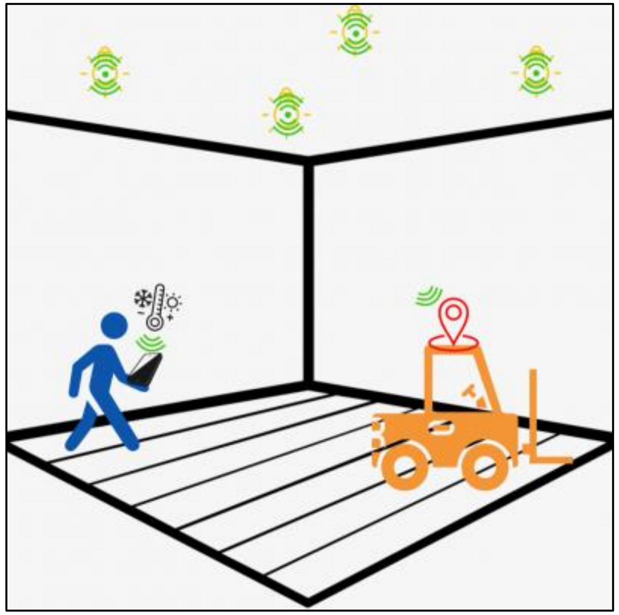
Fiber optics communication

OPTICAL WIRELESS COMMUNICATION (OWC)

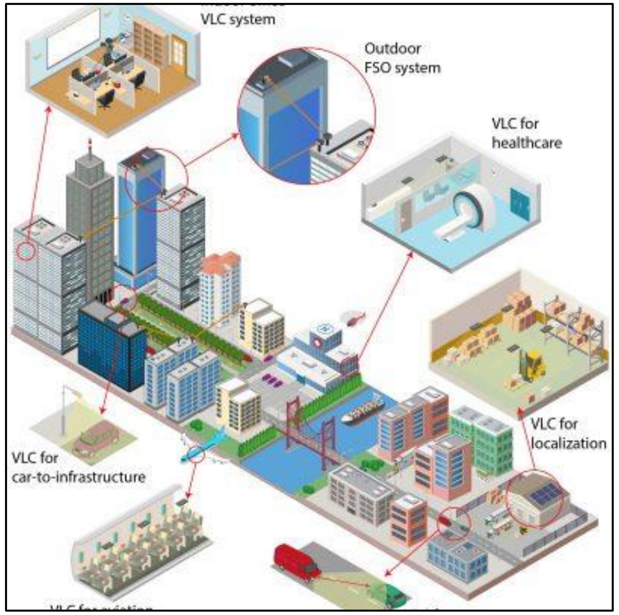
ULTRA SHORT RANGE	SHORT RANGE	MEDIUM RANGE	LONG RANGE
sub-meter range	few meters	few meters to few kilometers	many kilometers



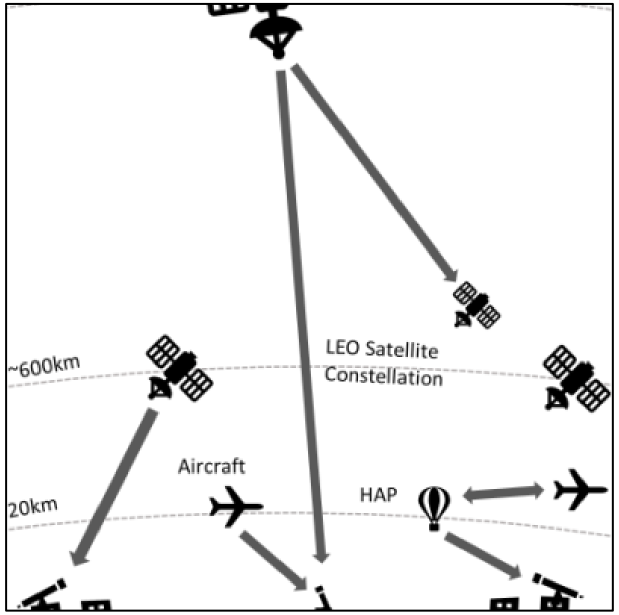
FSO



VLC

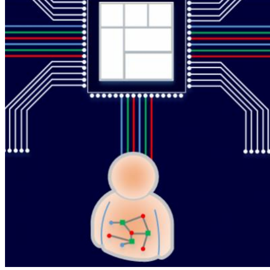


VLC



FSO

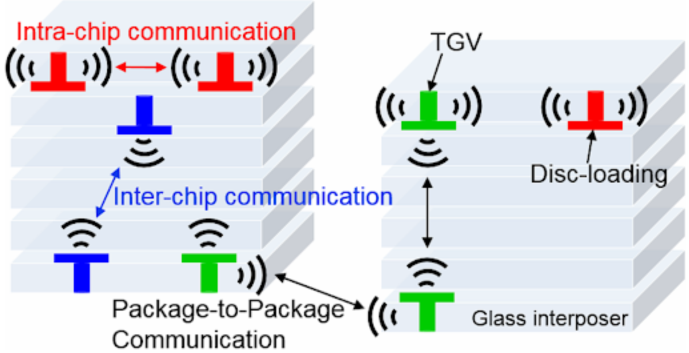
ULTRA SHORT RANGE OWC



Device communication for ultra-high-speed links and **sub-meter** applications. These entail inter and intra-chip communications, high performance computing systems, as well as device to device communications in hyper dense IoT scenarios, such as wireless body-area networks with medical application.

Intra- and inter-chip communication

PHOTONIC CHIP

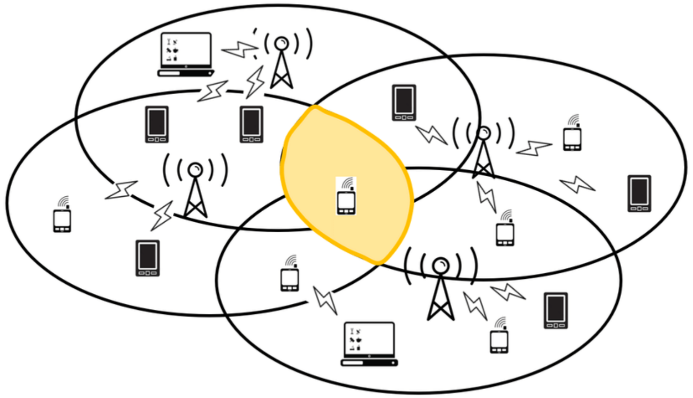


- In IC and PCB designs **FSO** offers high speed with low energy consumption per bit, compared to metal contacts.
- Optical devices: multiple quantum wells, modulators/Detector and VCSELs.
- In Interchip connectivity **FSO** offers reduced EMI, higher capacity, design flexibility and mitigation of routing and switching issues.

High performance computing platforms (HCP)

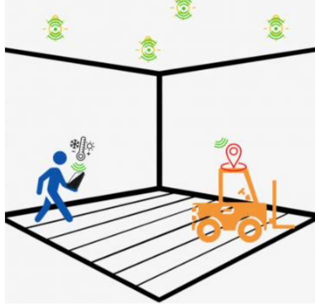
- **FSO** can be used in HCP platforms: servers, distributed computing systems, etc.

Device-to-device (D2D) communication in hyperdense IoT scenarios



- Connections between smart objects with sensing/actuating and communication capabilities

SHORT RANGE OWC

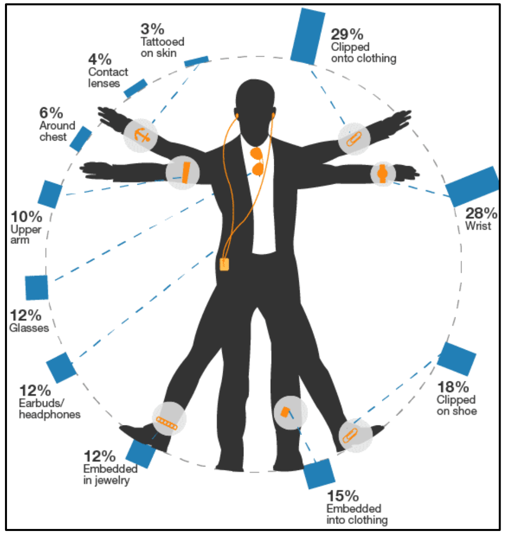


Links up to a few meters: The deployment of intensity modulated artificial optical sources, such as LEDs, enables infrastructures and sensors to communicate with mobile entities, resulting in ubiquitous indoor location-based services, together with wireless communication capacity.

Li-Fi

- **VLC** uses the current day ubiquitous presence of LED lamps

Wearables

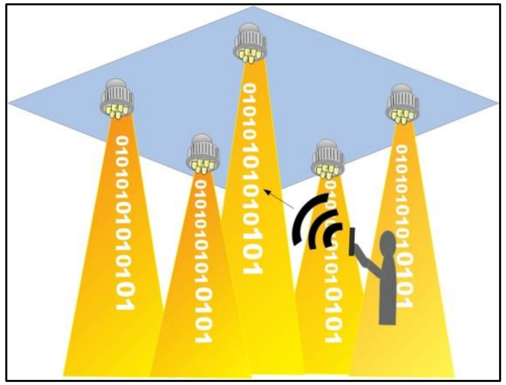


- Current advancements in OLED technology enable the integration of **VLC** transceivers into wearable gadgets and clothing

Short range IoT

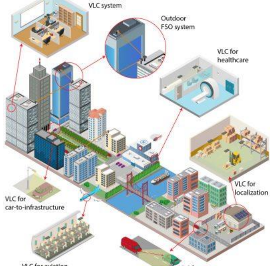
- Smart spaces and buildings
- Smart manufacturing: autonomous machine to machine (M2M) links

Localization



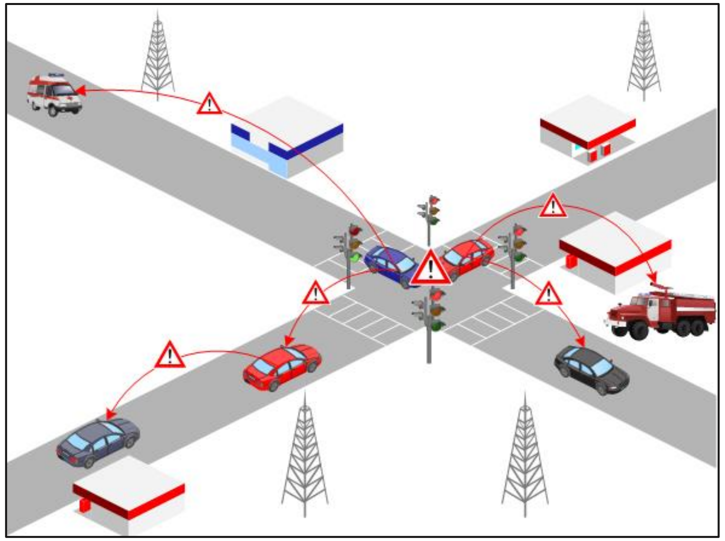
- Location based services provided by **VLC** using LED lamps

MEDIUM RANGE OWC



Typical range of few meters to few kilometers . VLC-based solutions for smart-cities and intelligent transportation systems, first- and last-mile access and backhaul/fronthaul wireless networks, hybrid FSO/RFadaptive wireless connections, and underwater communications for sensor networks

Vehicular networking (VN)



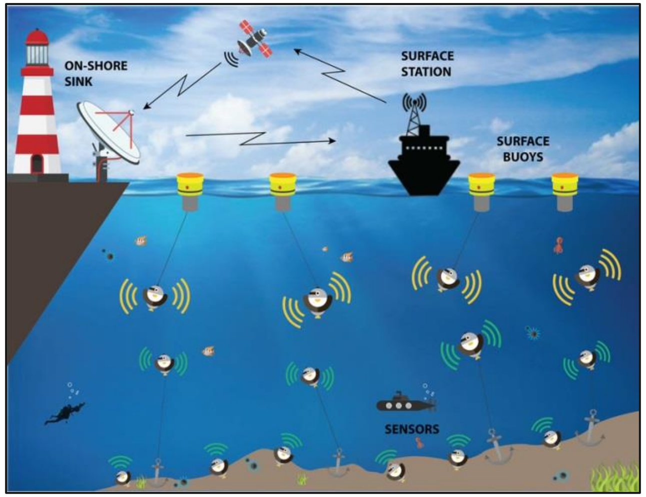
- Wide use of LEDs for vehicle, traffic and street lights
- **VLC** emerges as a natural solution
- VLC-based VNs: V2V, V2I, I2V links

- Additional noise sources due to background radiations, roads and visibility-limiting weather conditions

PtP WA links

- Outdooor PtP terrestrial **FSO** links as a solution for first and last mile access WNs.
- Typical applications: high speed trains, low altitude drones, data centre networks,

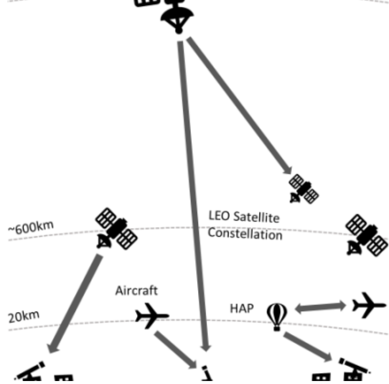
Under Water (UW) communications



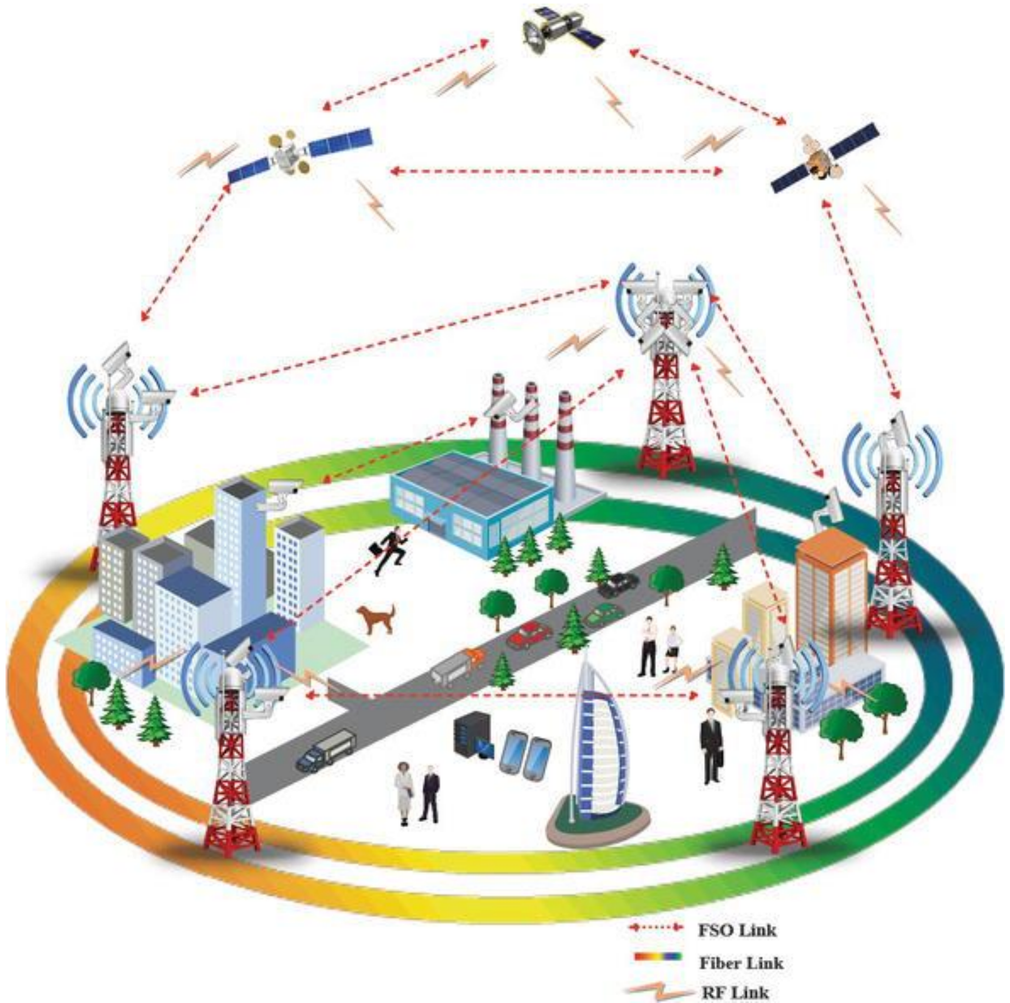
- **VLC** enables high data rates, low latency and high energy efficiency (outperforms acoustic and RF communication)
- Applications: environmental monitoring, UW exploration, port security, disaster prevention

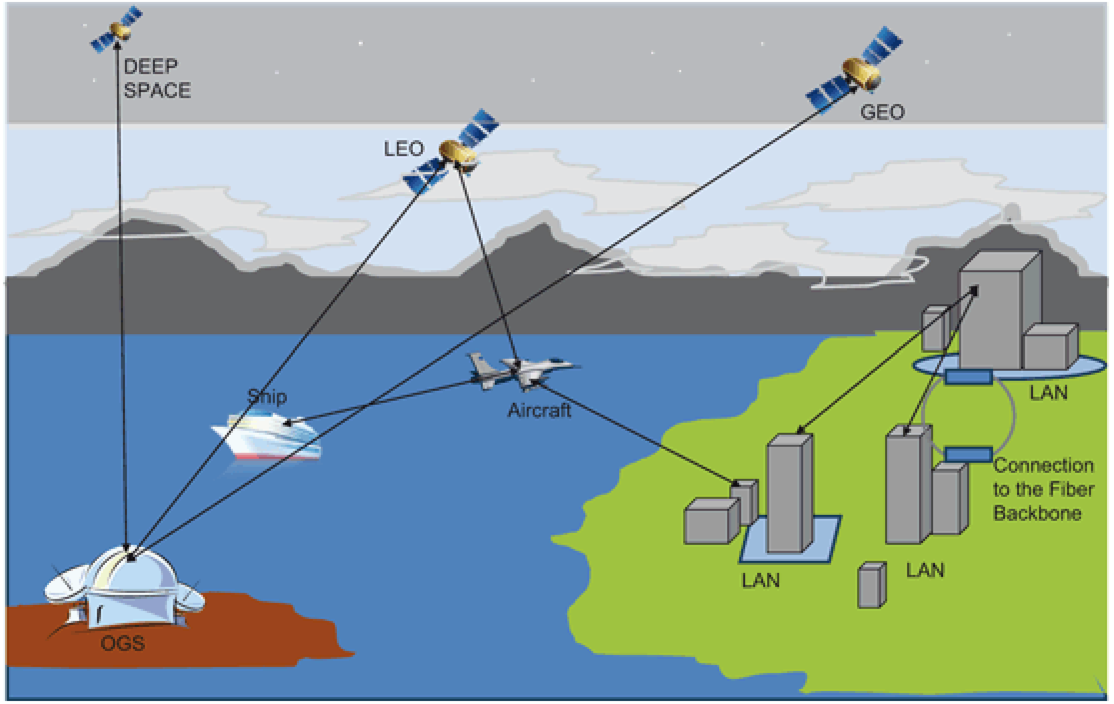
- Challenges: strong signal attenuation of the aquatic channel and the LoS requirement.

LONG RANGE OWC

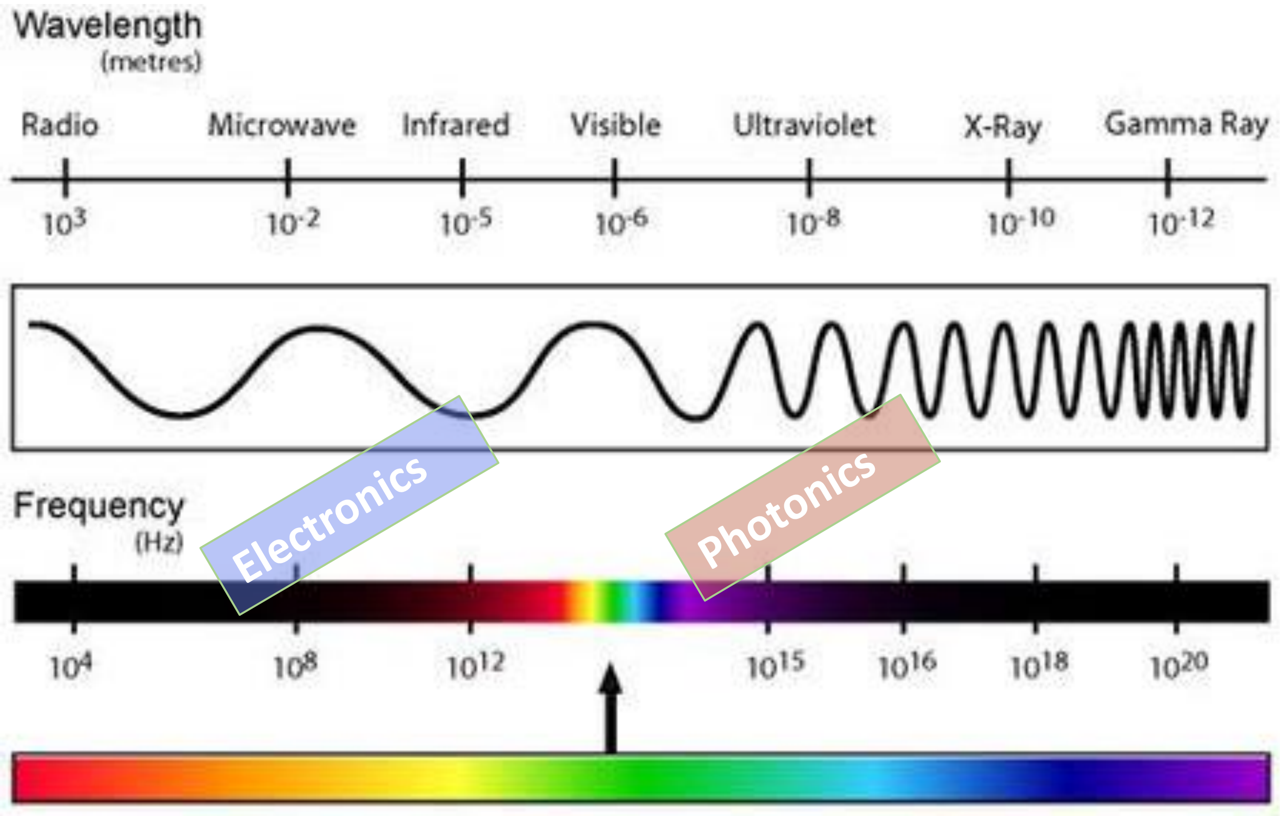


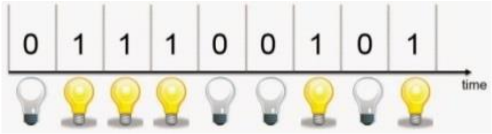
Typical **range of many kilometers**. Airborne and satellite FSO links for deployment in the backhaul/fronthaul wireless networks infrastructure and long-range non-LoS ultra violet links, space-to-ground optical data links, inter-satellite communication links, ground-to-air and air-to-air links, and long-range ultraviolet transmissions.

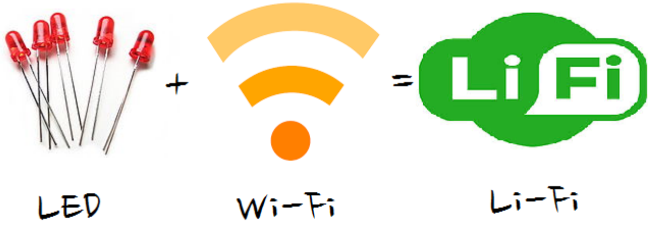




VLC – Visible Light Communication

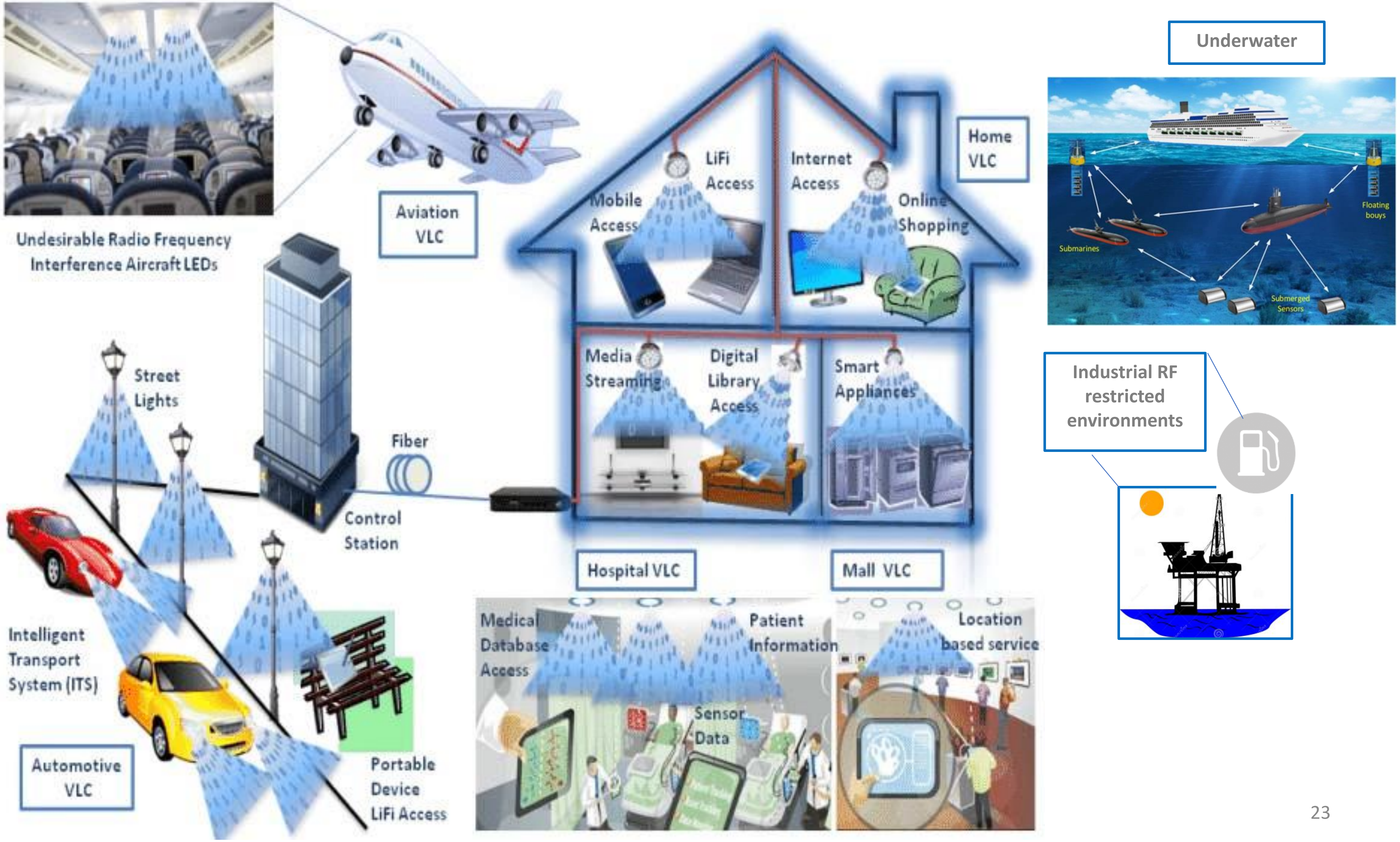






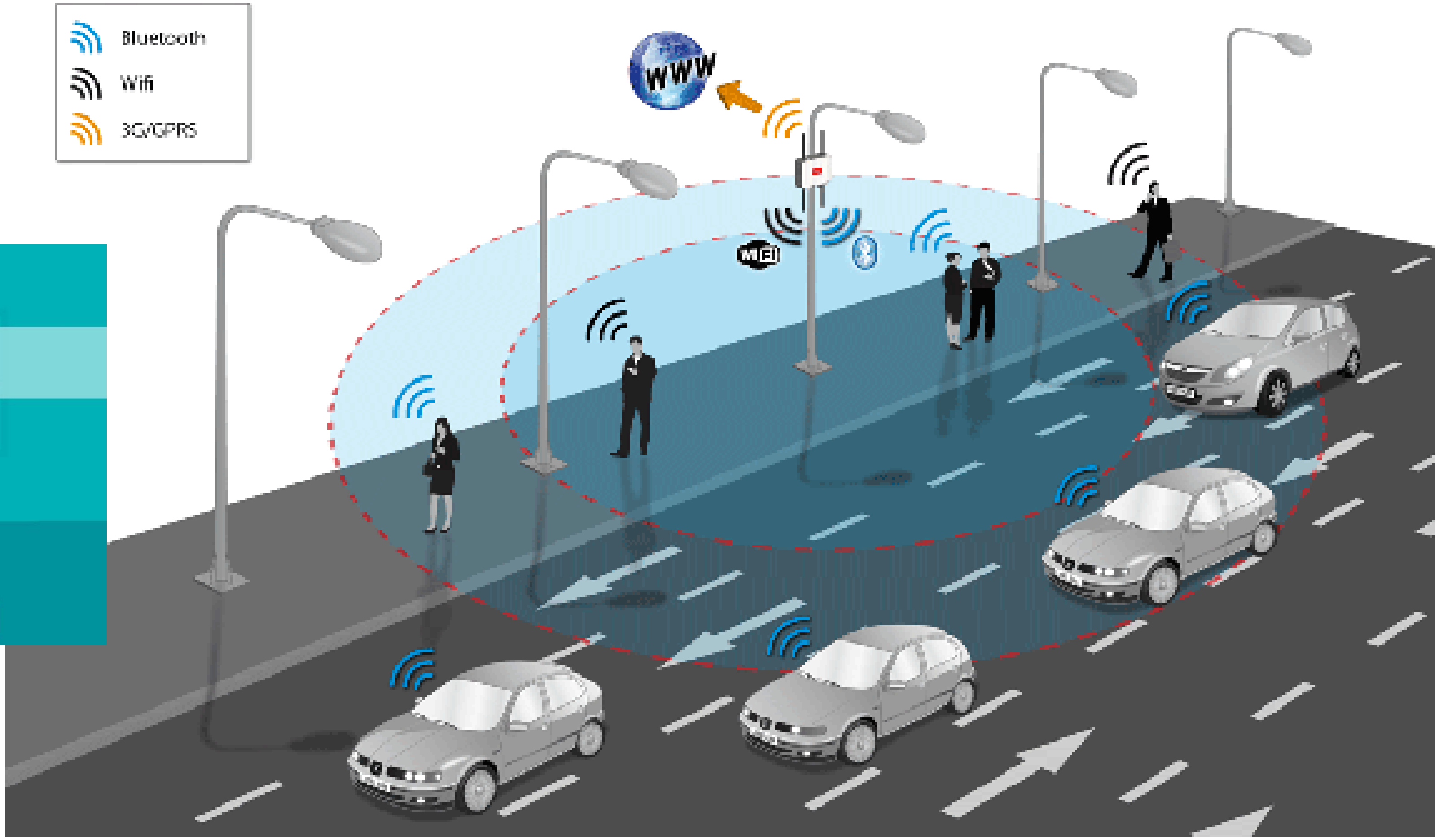
- increased bandwidth
- free and non-regulated spectrum
- line of sight technology (1 – 100 m)
- negligible power
- inexpensive (use of already existing lighting infra-structures)

MAIN APPLICATIONS OF VLC



Wi-Fi vs Li-Fi

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



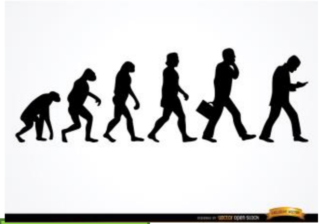
Li-Fi and Wi-Fi are quite similar as both transmit data electromagnetically

VLC: ADVANTAGES/ DISADVANTAGES

- Dual operation: light + comm
- Infrastructure advantage
- Free and non-regulated spectrum
- No **EM** interference
- High spatial confinement (security)
- High energy efficiency (negligible power)
- Harmless to human health

- Line of sight technology (LoS)
- Obstructions
- Atmospheric absorption
- Shadows
- Light dispersion
- Influence of other light sources

- **OWC (FSO/VLC) can be a good alternative or complementary technology to RF wireless solutions**



VLC EVOLUTION

Li-Fi consortium
Fraunhofer IPMS, Germany
IBSENtelecom, Norway
Supreme Architecture, USA

1[st] VLC experiments with LEDs
400 Mbps, Tanaka *et al*

Visible Light Communications Consortium (VLCC)

1ª Li-Fi demo
by Harold Haas

pureLiFi

1[st] OEM company to commercialize Li-Fi

1.6 Gbps 10 Gbps

LED indoor positioning technology, Carrefour, Lille

2000 2003 2007 2009 2011 2013 2015 2017 2020

JEITA
- VLC System (CP-1221)
- Visible Light ID (CP-1222)

IEEE
Task Group 7
IEEE 802.15.7

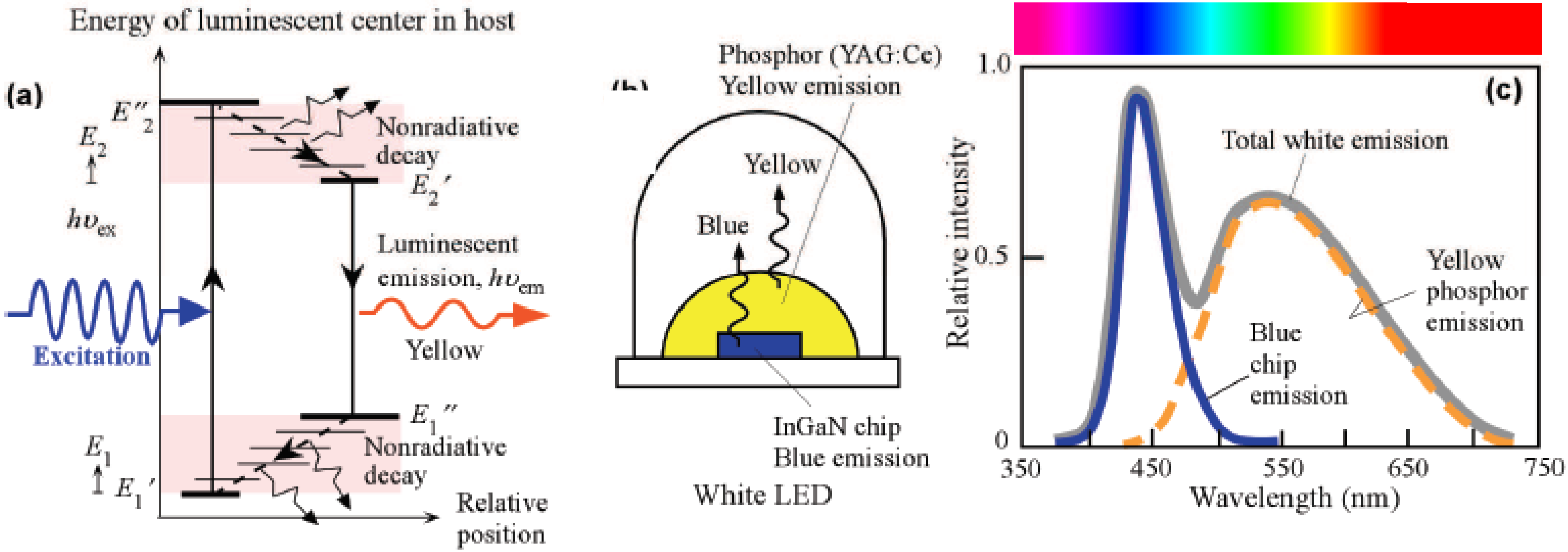
JEITA
Visible Light Beacon System (CP-1223)

IEEE 802.15.7r1
Uni-directional VLC

Cost Action ”European Network on Future Generatiomn Optical Wireless Comm. Tech.”

JEITA - Electronics and Information Technology Industries Association
IEEE - Institute of Electrical and Electronics Engineers

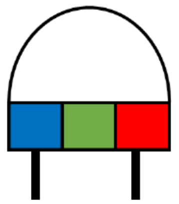
PHOSPHOR WHITE LED



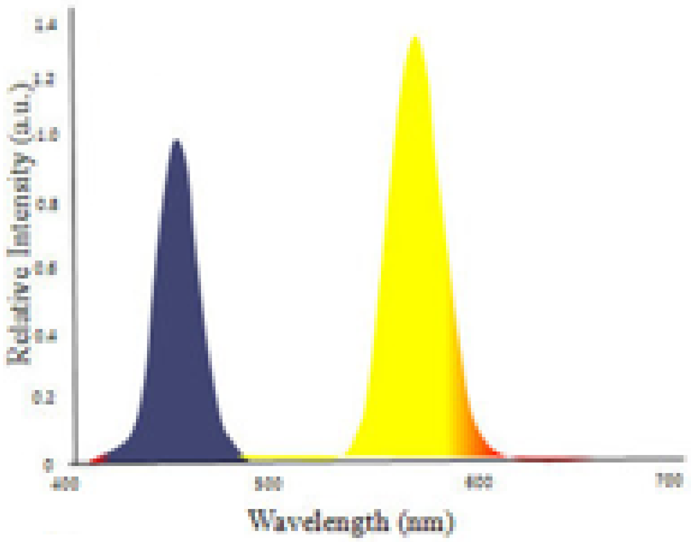
Adapted from Kasap, "Optoelectronics and Photonics, Principles of Operation," 2013

- **Low modulation frequency due to slow response of the phosphor layer**

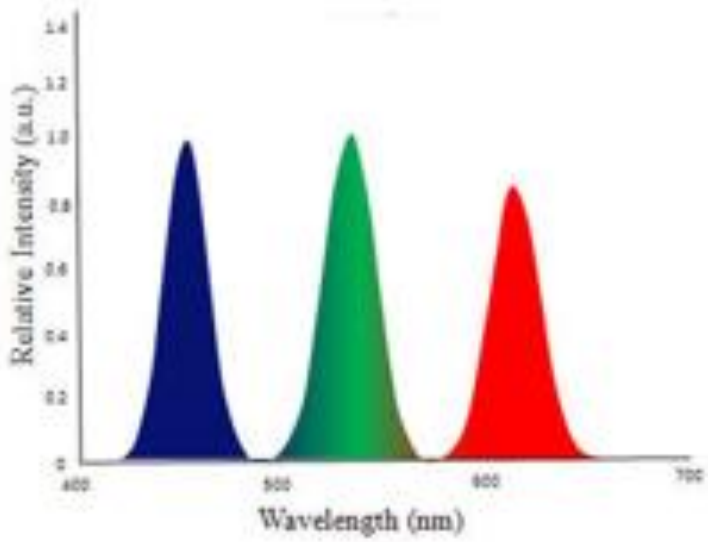
CHROMATIC WHITE LED



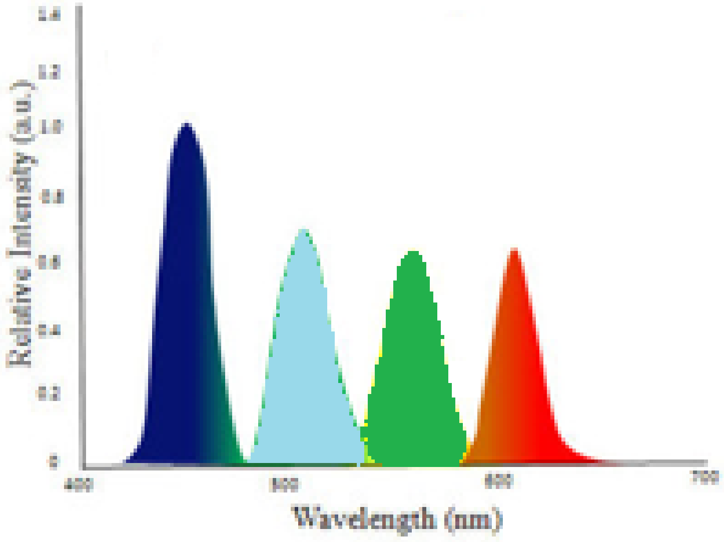
Di-chromatic LEDs
Blue and yellow



Tri-chromatic LEDs
Red, green and blue



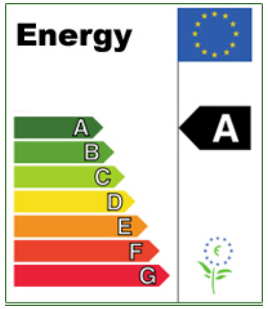
Tetra-chromatic LED
Red, green, cyan and blue



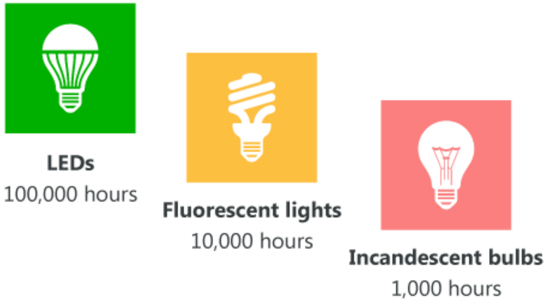
- **Monolithic integration of different direct bandgap semiconductor materials with emission at specific wavelength ranges**

LED LIGHT FOR LIGHTING

EFFICIENCY



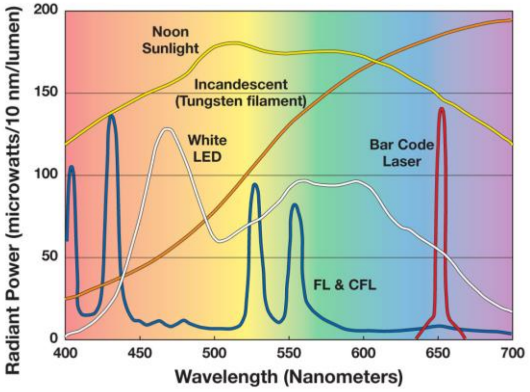
LIFETIME



ROBUSTNESS

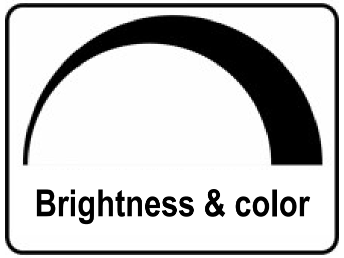
ECO FRIENDLY

COLOR RENDERING



NO WARM-UP

CONTROLLABLE

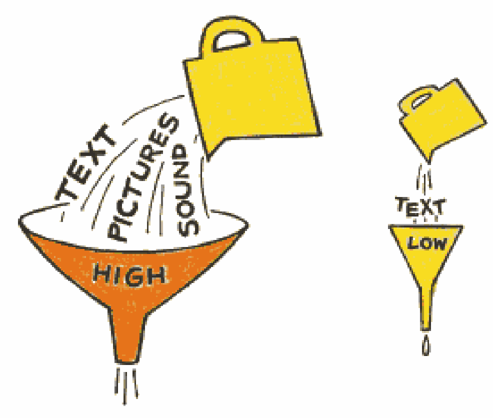


LED LIGHT FOR COMMUNICATION

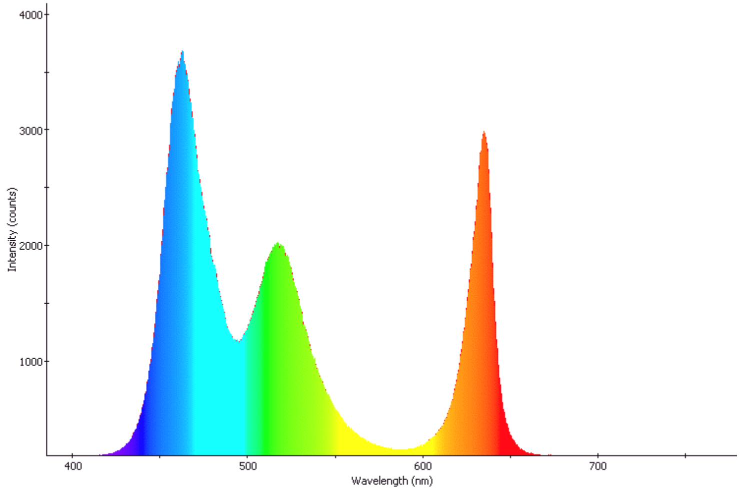
UBIQUITOUS

EASY TO MODULATE

LIMITED BANDWIDTH (few MHz)



MULTIPLEXING POSSIBILITY



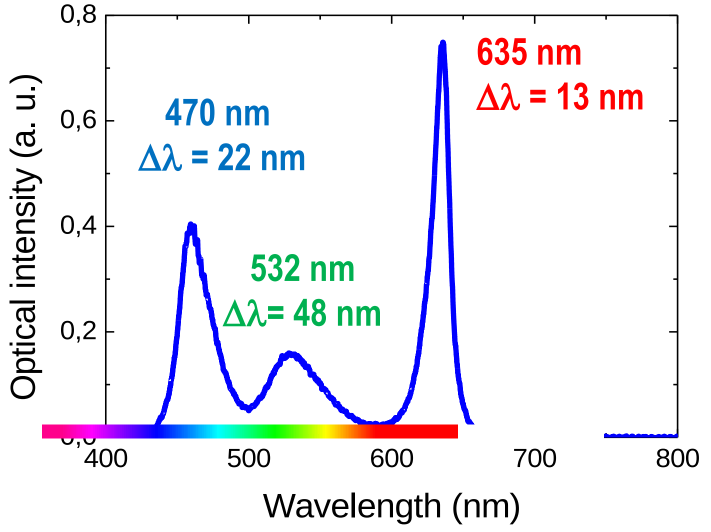
Main challenge:

- LEDs are optical sources not designed for communication!

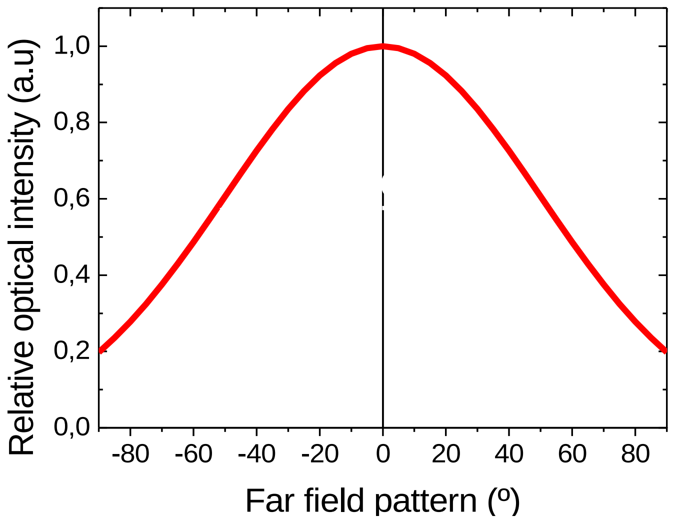
Optical source: RGB white LEDs

RGB WHITE LEDS

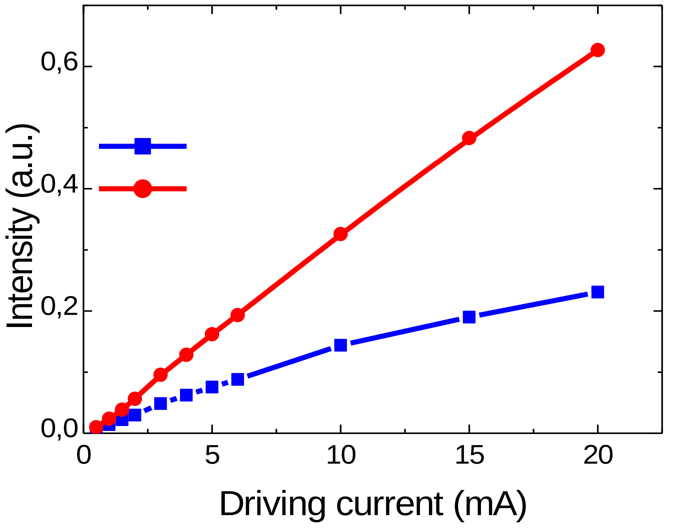
SPECTRAL OUTPUT



FAR FIELD PATTERN



OPTICAL POWER



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

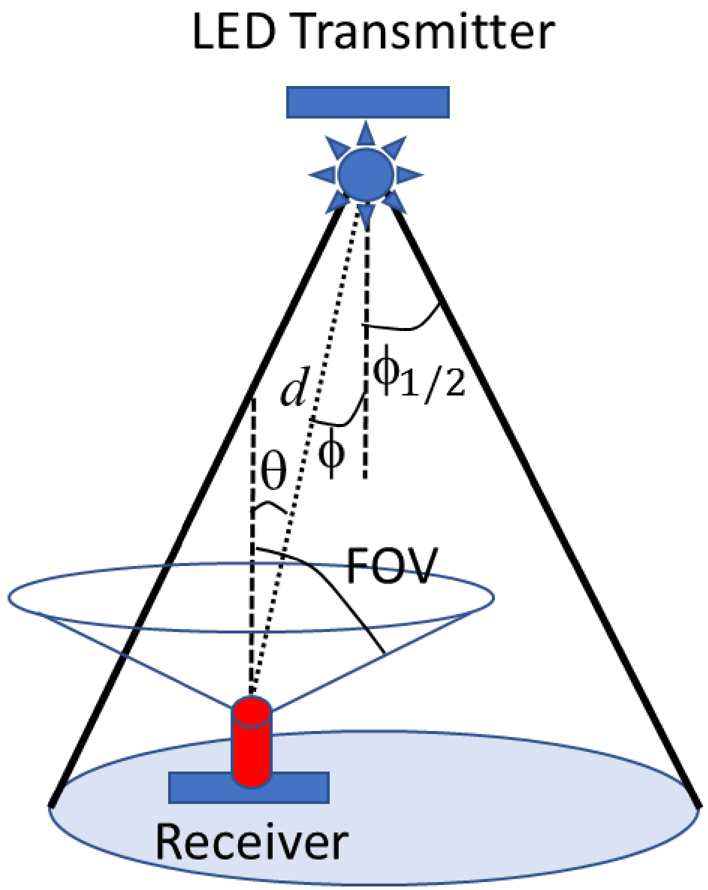
Dominant wavelength	Spectral linewidth	Half view angle	Forward voltage
(nm)	(nm)	(º)	(V)
619-624	24		2
520-540	38	120	3.2
460-480	28		3.2

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 530 nm.
- Wide viewing angle ≅ 60º

VLC LINK MODELS

- LEDs are modeled as **Lambertian sources** where the luminance is distributed uniformly in all directions, whereas the luminous intensity is different in all directions.



$$I(\emptyset) = I_N(\cos\emptyset)^m \qquad m = -\frac{\ln(2)}{\ln\ \cos(\emptyset_{1/2})}$$

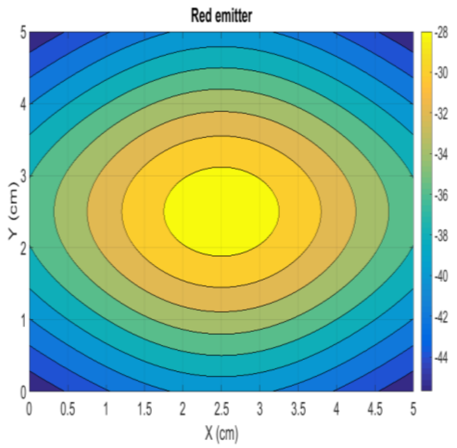
- *m* is the order derived from a Lambertian pattern, I_N is the maximum luminous intensity in the axial direction and , ϕ is the angle of irradiance.

- For the proposed system, the commercial white LEDs were designed for illumination purposes, exhibiting a wide half intensity angle) of 60º. Thus, the Lambertian order *m* is 1.

- MatLab simulations are used to infer the signal coverage of the LED in the illuminated indoors space

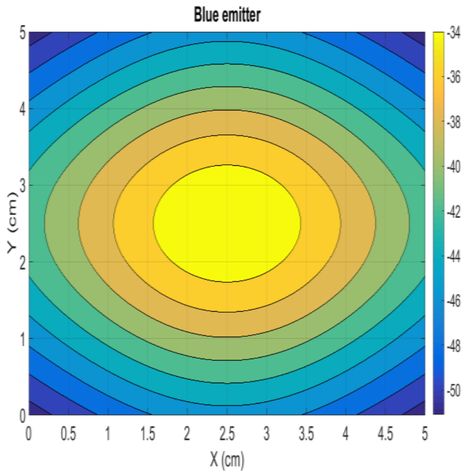
- **The light signal is received by the WDM photodetector that detects the on/off states of the LEDs, generates a binary sequence of the received signals and convert data into the original format.**
- **Line of sight (LoS) connection for both VLC links corresponds to the existence of straight visibility between the transmitter and the receiver.**

CHANNEL GAIN

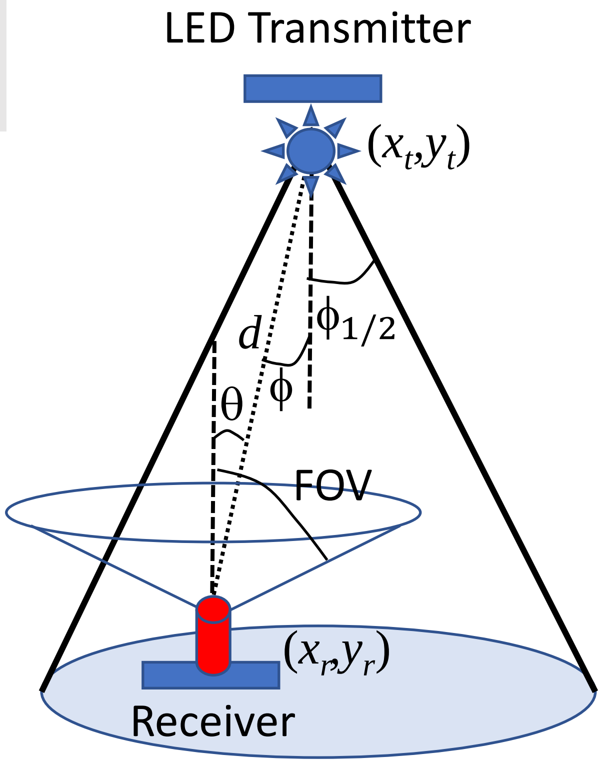


$$P_R = P_T \times G$$

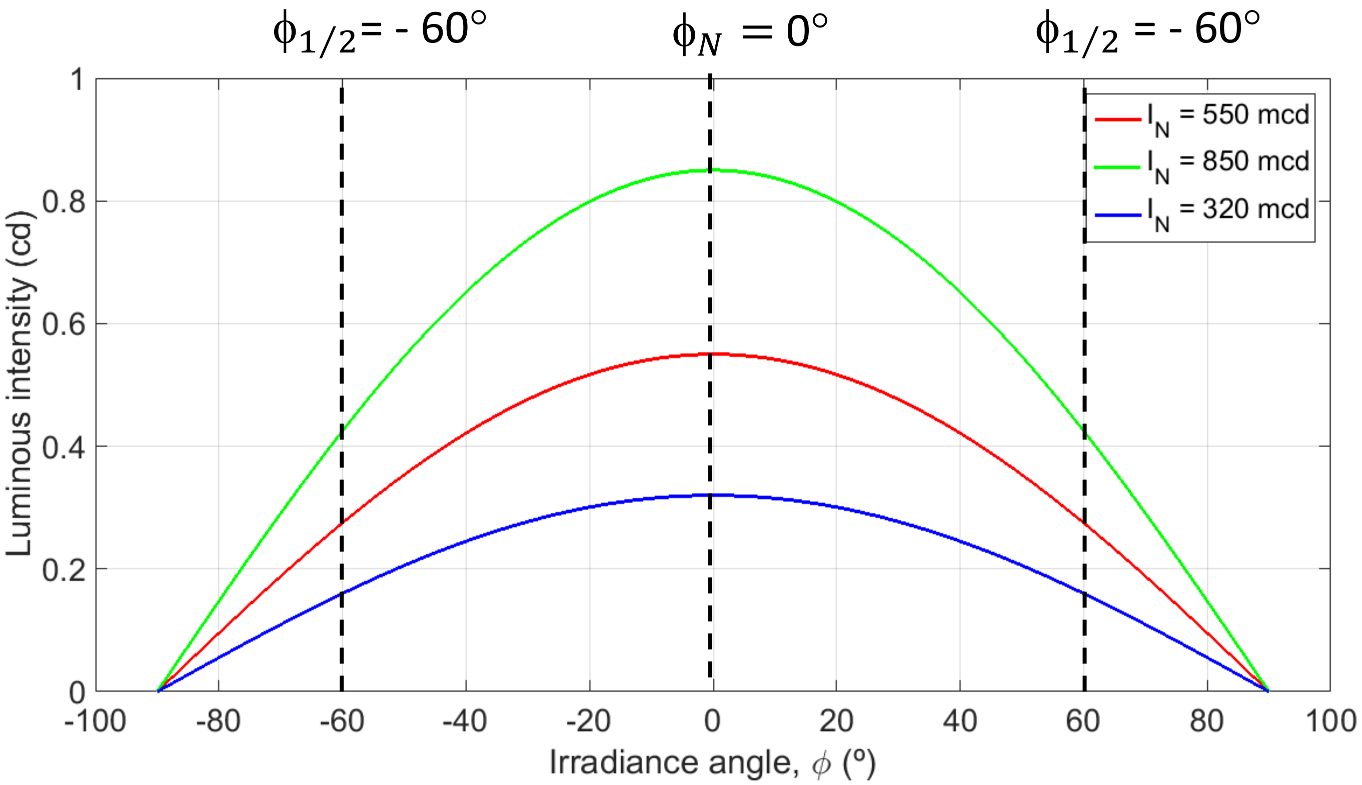
$$G = \frac{(m+1)A}{2\pi D_{t-r}^{2}} I_N \cos^{m}(\phi)\cos(\theta)$$

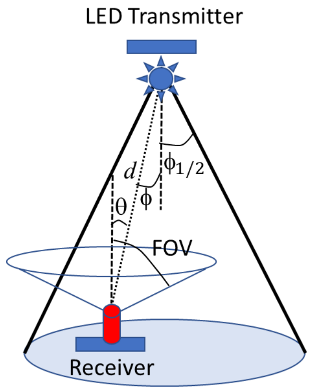


P. Louro, M. Vieira, P. Vieira, J. Rodrigues, M. de Lima, "Geo-localization using indoor visible light communication," Proc. SPIE 11772, Optical Sensors 2021, 117720J (18 April 2021); doi: 10.1117/12.2589477



LAMBERTIAN DISTRIBUTION





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

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

$\phi_{1/2}$= ± 60° → m = 1

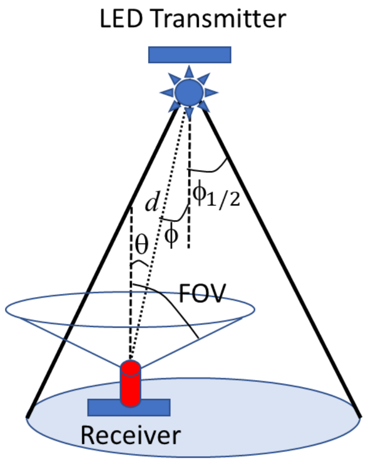
- **The luminous intensity varies with the direction**
- **Exhibits a maximum at the axial direction (0°) and half of the maximum at $\phi_{1/2}$= ± 60°**

LED MODEL

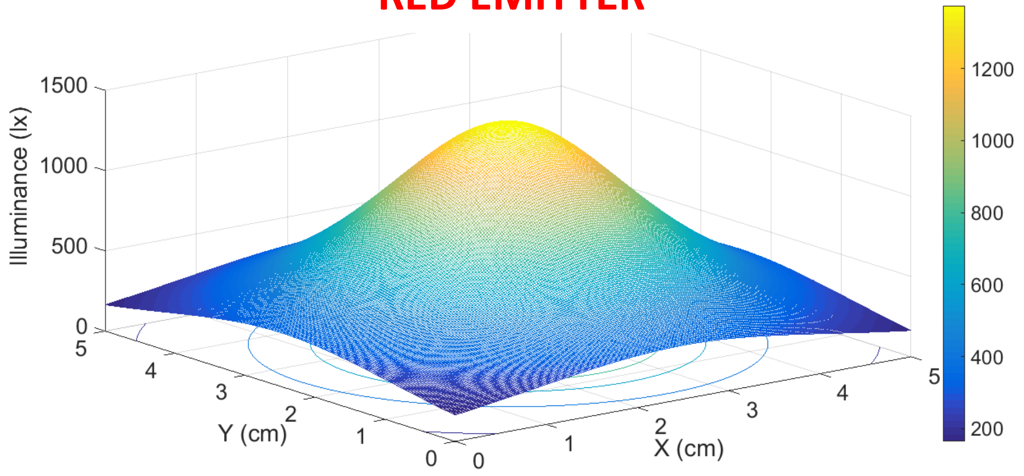
LED ILLUMINANCE

- Simulation at lab prototype scale

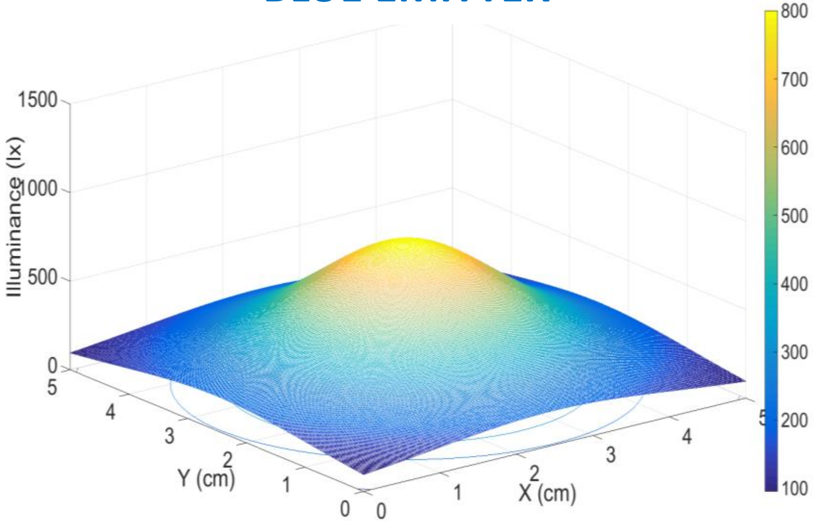
$$E_{hor}(x,y,z) = \frac{I_N\, cos^m(\phi)}{D_{t-r}^2 \cos(\theta)}$$



RED EMITTER



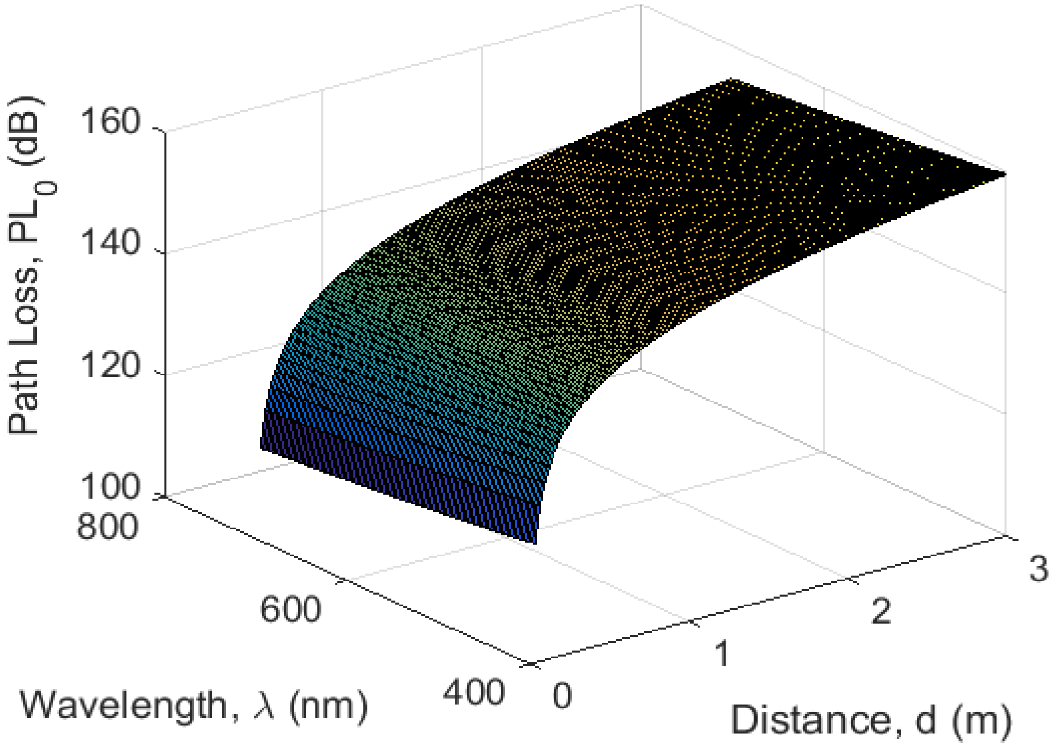
BLUE EMITTER



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

Friis model

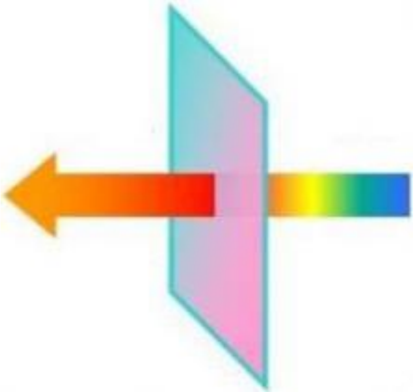
$$PL_0 = 10\log_{10}\left(\frac{4\pi d}{\lambda}\right)^2 = 20\log_{10}4\pi + 20\log_{10}d - 20\log_{10}\lambda$$



- 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).**

CHALLENGES of VLC

- Flickering
- Dimming
- Noise due to ambient light sources
- Receiver saturation
- LoS/Non-LoS
- Downlink/Uplink
- Integration with other communication technologies



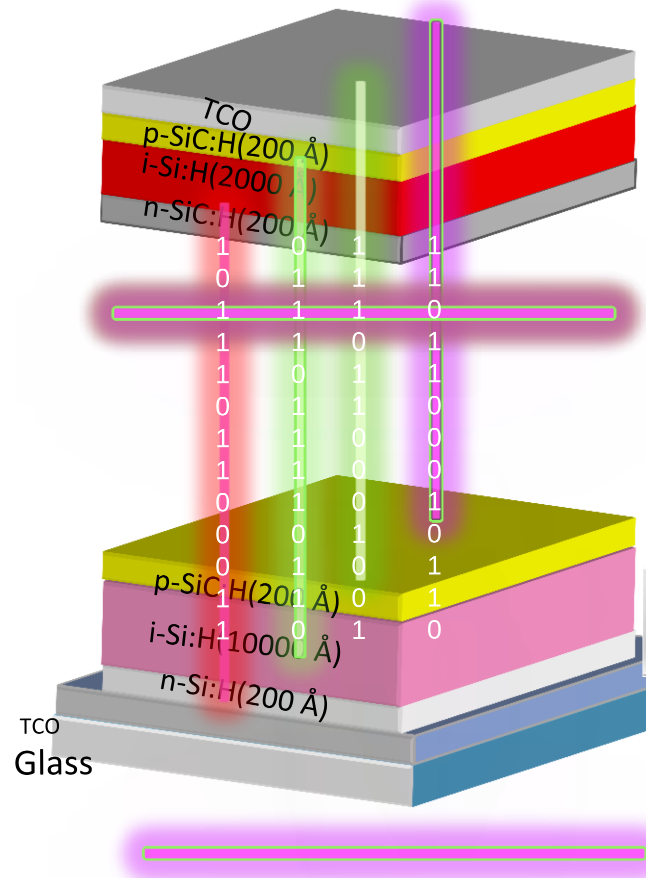
Open research

- Coding/decoding
- White LEDs
- Photodetectors

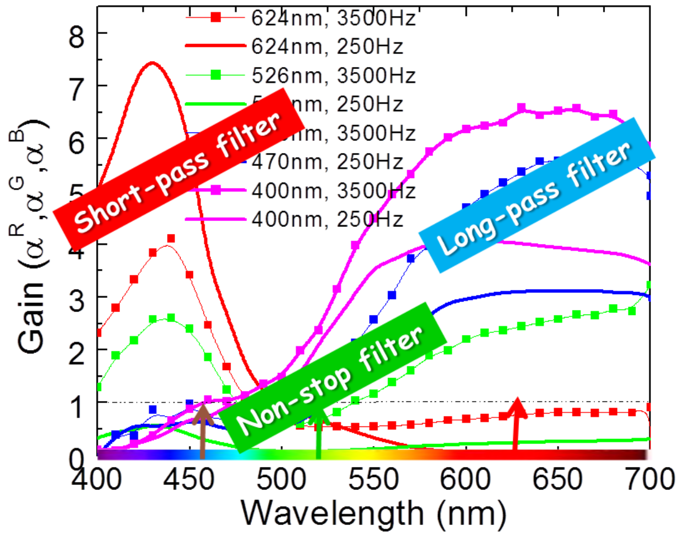
a-Si/SiC Photodiodes

VLC receiver

- **Coder/decoder device I_R/RGBV/UV channels;**



p-i'-n p-i-n

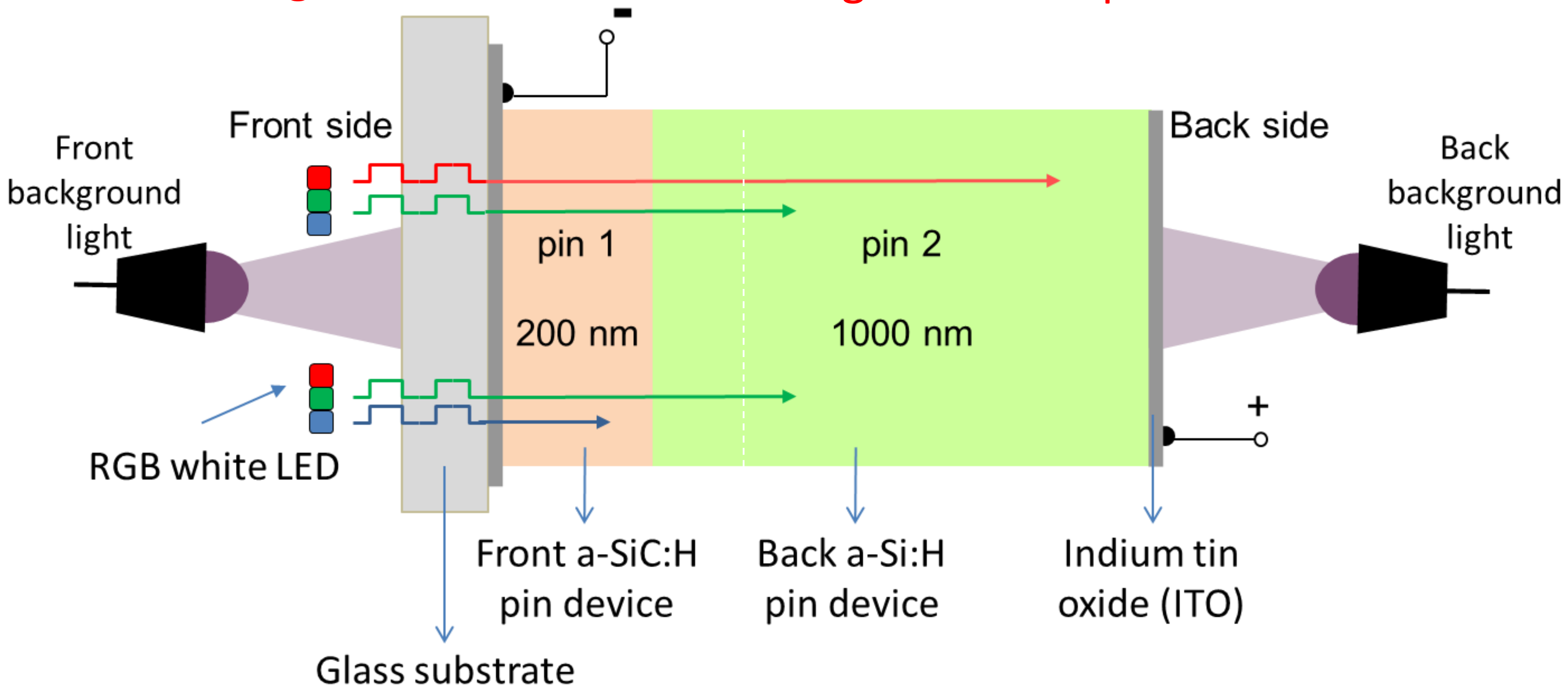


- Light-to-dark sensitivity depends on the *carbon concentration*
- Color recognition depends *on the applied bias*
- Light filtering depends on the *bias wavelength and side*
- WDM device *RGB* channels; *6000*bps

PHOTODETECTOR

- High blue absorption
- High red transmittance

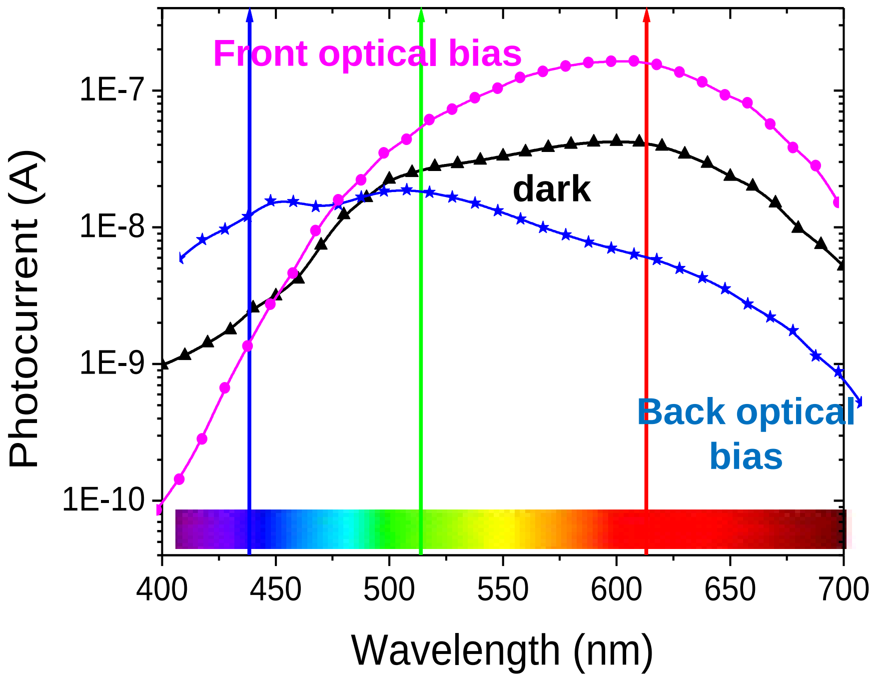
- Full green absorption
- High red absorption



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

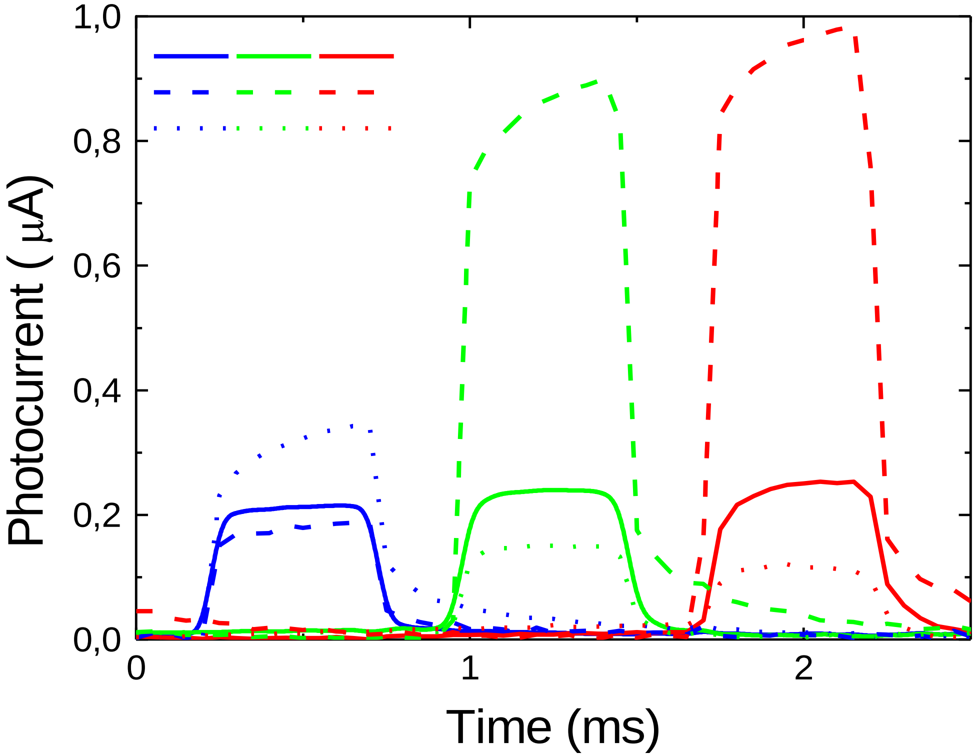
- High sensitivity and linear response
- Signal conditioning techniques (adaptive bandpass filtering and amplification, triggering and demultiplexing) are used.
- Data signal is reconstructed at the data processing unit (digital conversion, decoding and decision).

SPECTRAL RESPONSE



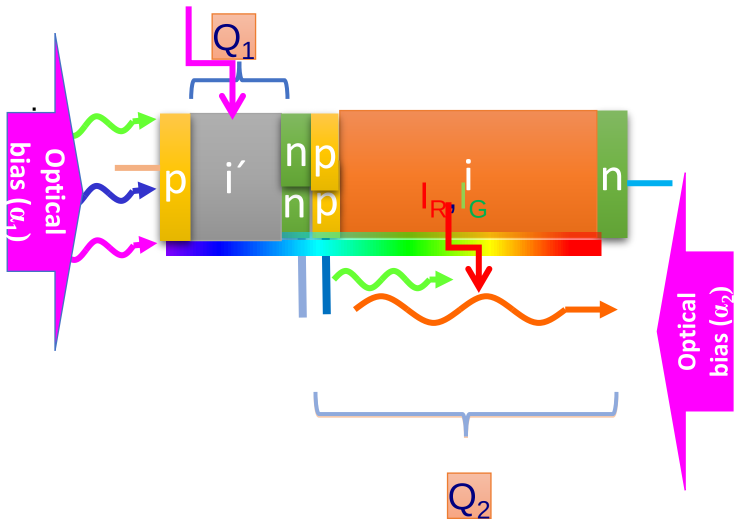
$\alpha_F = 0.8$ $\alpha_F = 3.8$ $\alpha_F = 5$

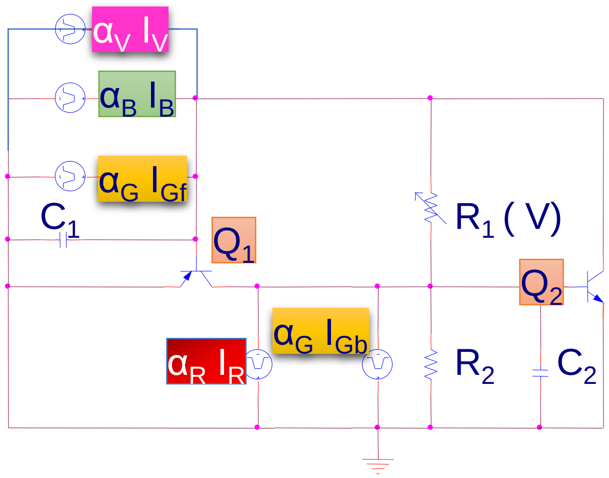
$\alpha_B = 1.6$ $\alpha_B = 0.6$ $\alpha_B = 0.6$



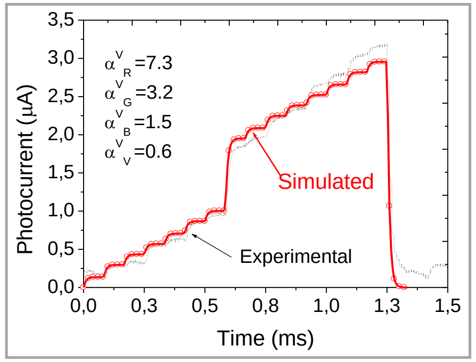
OPTOELECTRONIC MODEL

I_V, I_B, I_G • ***ac* equivalent circuit**





M. A. Vieira, M. Vieira, P. Louro, V. Silva, A. S. Garção, "Light filtering devices using background wavelength processing technique", MRS Proceedings / Volume 1426 / 2012 DOI: http://dx.doi.org/10.1557/opl.2012.1246

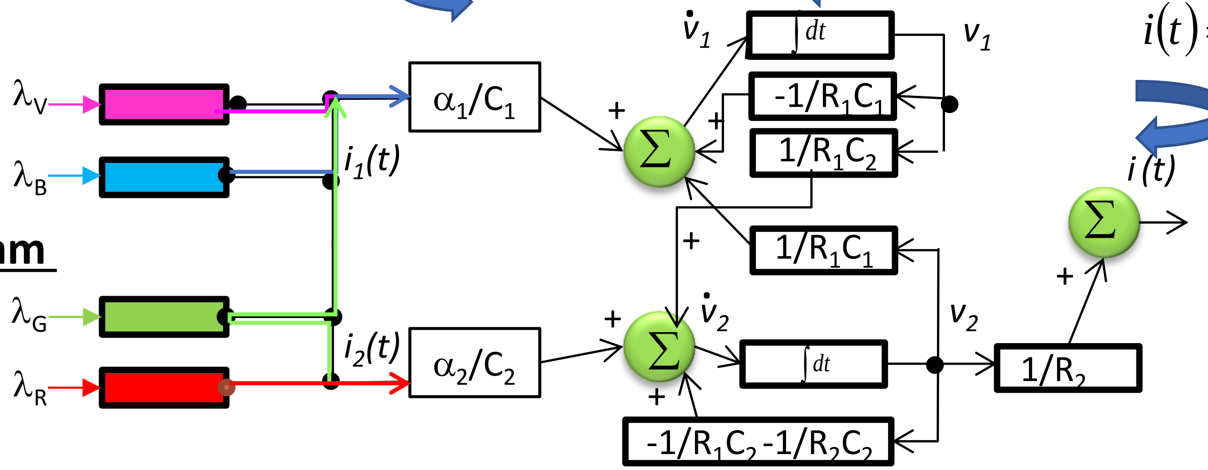


$$\frac{dv_{1,2}}{dt}=\begin{bmatrix}\dfrac{\alpha_1(\alpha_{V,B,G})}{C_1}\\ \dfrac{\alpha_2(\alpha_{R,G})}{C_2}\end{bmatrix} i_{1,2}(t)+\begin{bmatrix}-\dfrac{1}{R_1C_1} & \dfrac{1}{R_1C_1}\\ \dfrac{1}{R_1C_2} & -\dfrac{1}{R_1C_2}-\dfrac{1}{R_2C_2}\end{bmatrix} v_{1,2}(t)$$

- **linearized state equations**

$$i(t)=\begin{bmatrix}0 & \dfrac{1}{R_2}\end{bmatrix} v_{1,2}(t)$$

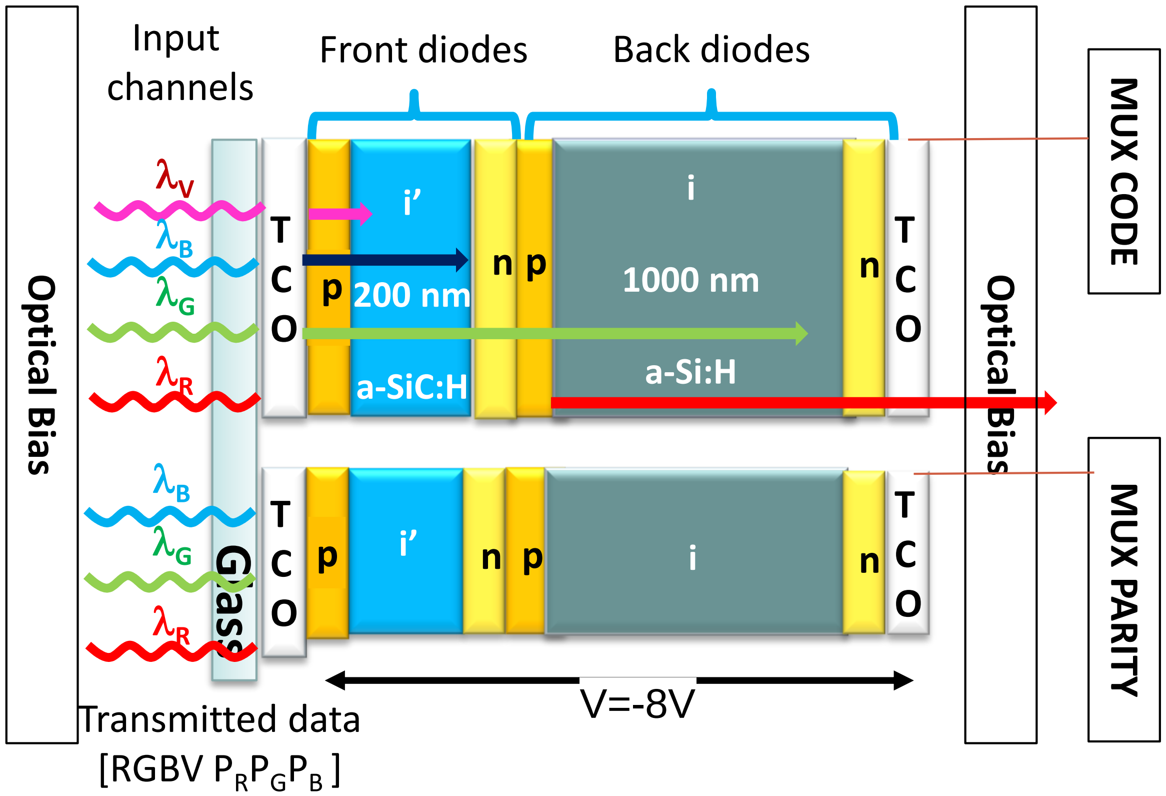
- **the block diagram**



MATLAB as a programming environment and the four order Runge-Kutta method to solve the state equations

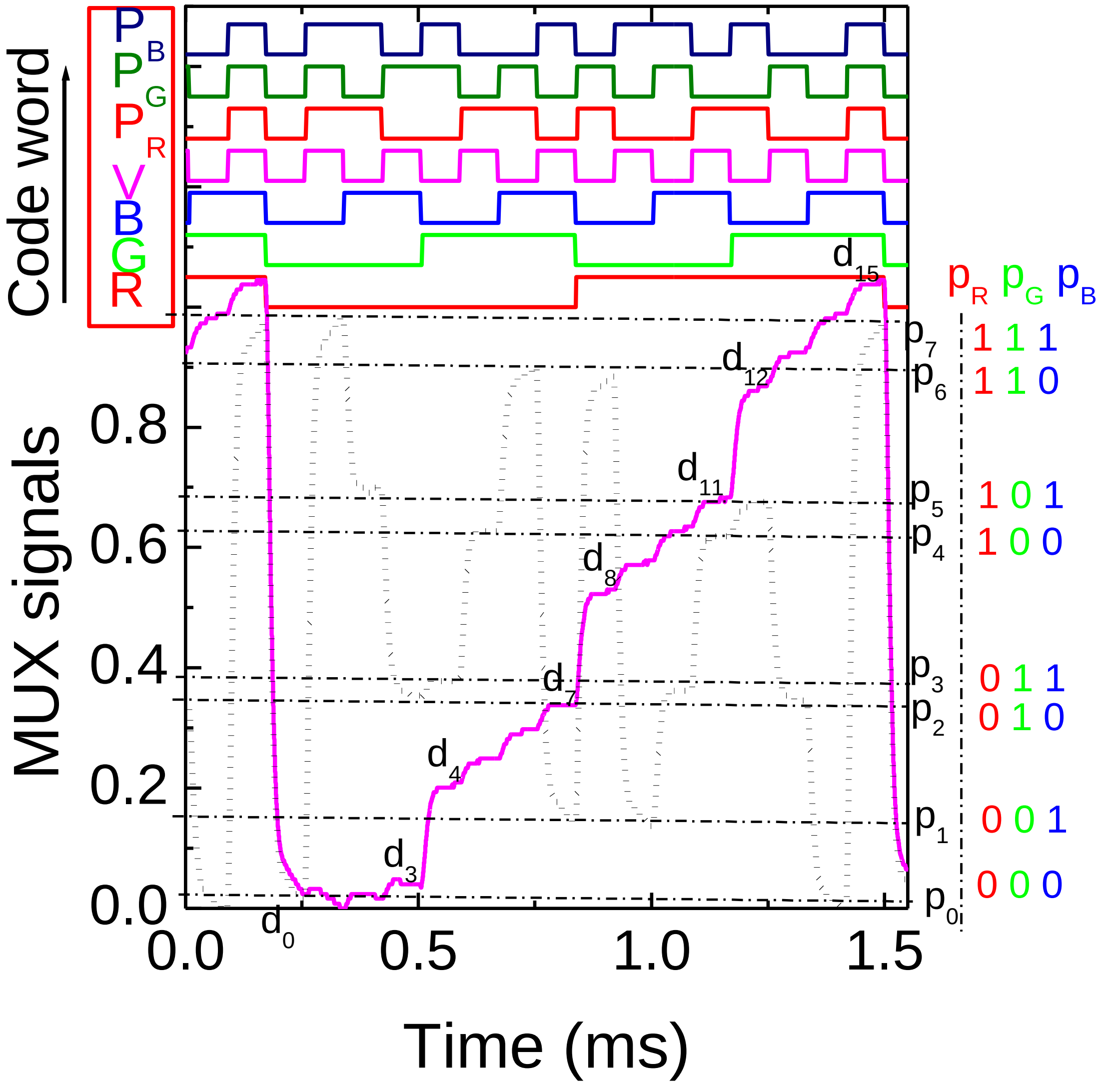
ERROR CONTROL

PARITY CHECK BITS



- The proximity of consecutive levels causes occasional errors in the decoded information that should be corrected.
- For parity check, and in a four or five channel transmission, three or four synchronous channels, red, green, blue and violet were read in simultaneous with the data code.
- As an application, data was sent through one detector while error detection and correction bits were sent through the other.

PARITY CHECK BITS EVALUATION



The parity bits are **SUM** bits of the three-bit additions of **violet** pulsed signal with two additional bits of RGB

Four channels transmission

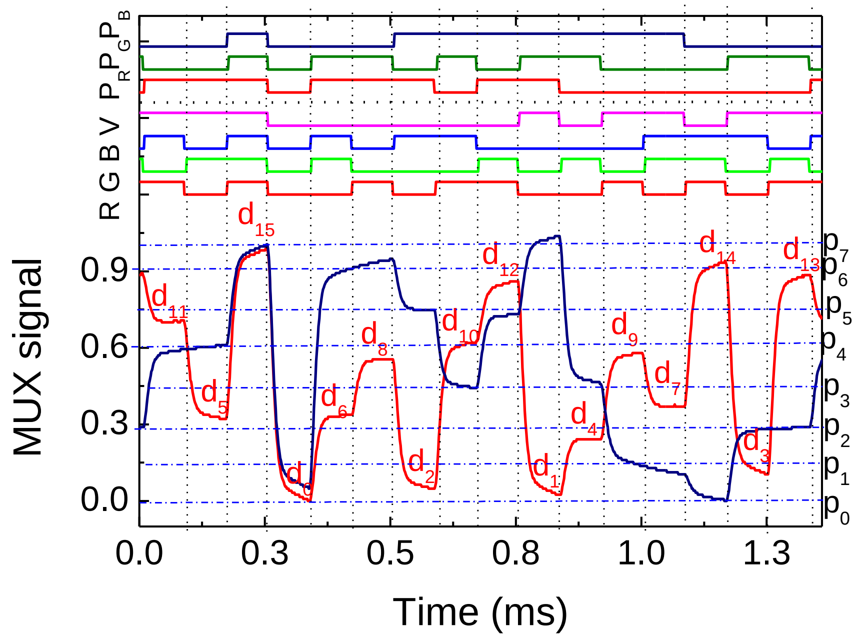
P_R-(VRB) = V + R + B

P_G-(VRG) = V + R + G

P_B-(VGB) = V + G + B

- The parity of the word is checked after reading the word.
- The word is accepted if the parity of the bits read out is correct.
- If the parity of the bits is incorrect, an error is detected and should be corrected.

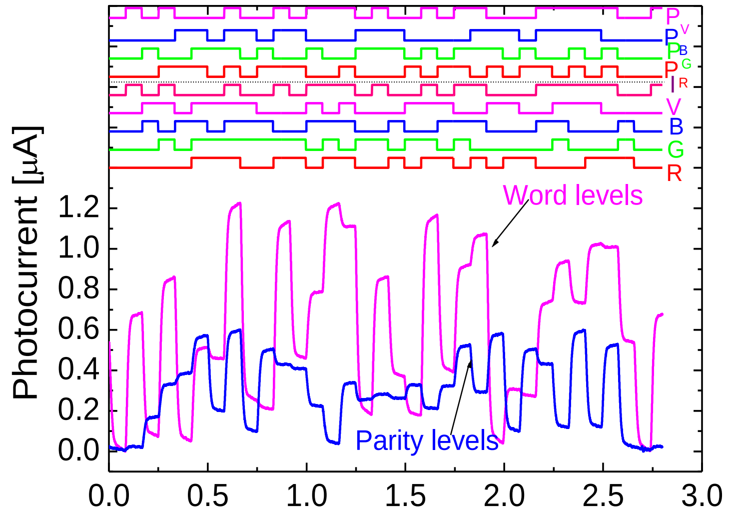
CODE AND PARITY MUX/DEMUX SIGNALS



The decoding algorithm is based on a proximity search after each time slot is translated to a vector in multidimensional space.

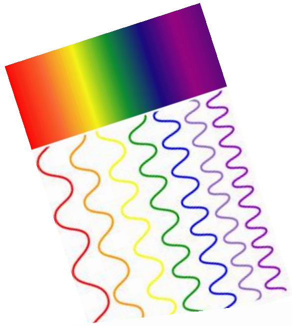
The vector components are determined by I_1 and I_2, where I_1 (d levels) and I_2 (p levels) are the currents measured.

The result is then compared with all vectors obtained from a calibration sequence where to each code level, d(0-31), is assigned the correspondent parity level, p(0-15).

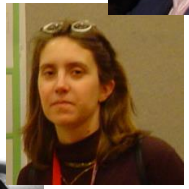


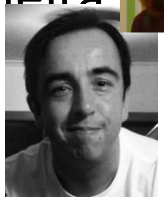
We have tested the algorithm with different random sequences of the channels and we have recovered the original color bits

Cooperative Self-localization and Wayfinding Services Through Visible Light Communication

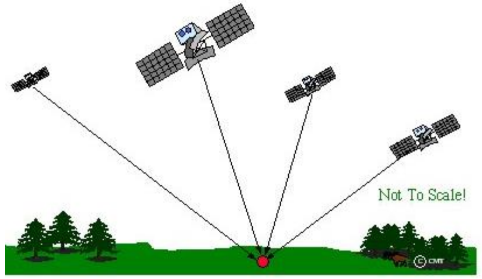


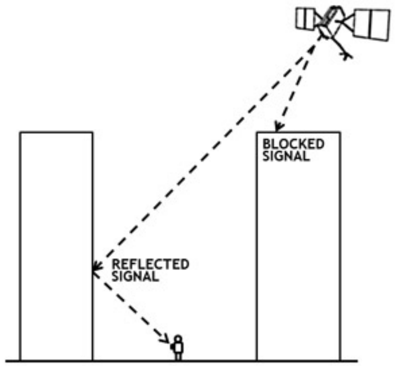
- **Manuela Vieira**
- Manuel A. Vieira
- Paula Louro
- Pedro Vieira

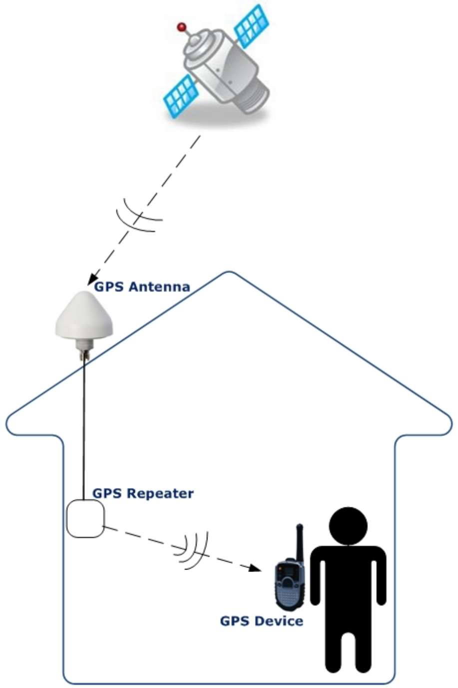




NAVIGATION SYSTEMS







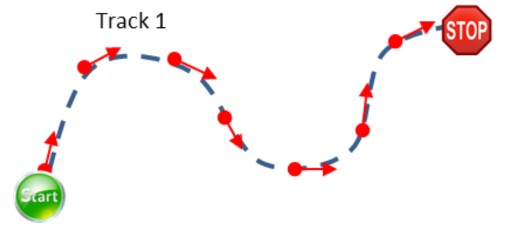
INDOOR POSITIONING SYSTEMS

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)		

WAYFINDING CONCEPTS

Self-localization is a fundamental issue since the person must be able to estimate its position and orientation (pose) within a map of the environment it is navigating.

The estimation of both position and orientation are important to path definition.

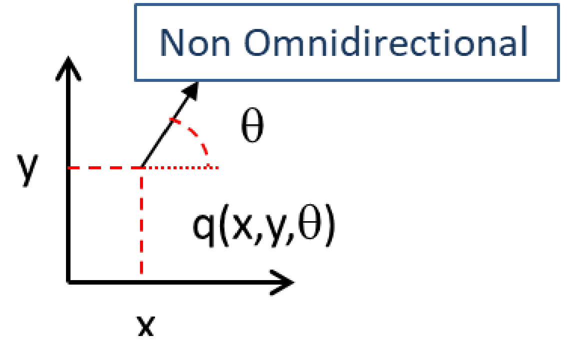


- **A path** is a geometric representation of a plan to move from a start pose to a goal pose

Pose estimation

- Position (x,y) and orientation angle θ, with respect to the coordinate axes.

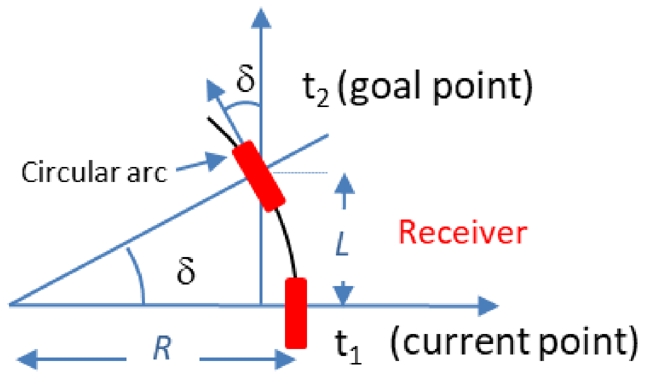
  $q(t) = [x(t), y(t), \theta(t)]$



Trajectory: Pursuit approach

Took into account the curvature required for the mobile receiver to steer from its current position to its intended position.

- Defines an imaginary circle that passes through both positions.
- A control algorithm chooses a steering angle (δ) in relation to this circle
- Iteratively construct the intermediate arcs as it moved obtaining the trajectory to reach its goal position.



WAYFINDING SERVICES

Interaction between planning, control and localization is important.

Where am I? The localization senses the environment and computes the user position,
Where am I going? The planning computes the route to follow from the position,
How do I get there? The control moves the user in order to follow the route.

A destination can be targeted by user request to the Central Manager (CM).

- Different users are considered.
- When arriving, they notify the CM of their localization asking for help to find the right track for their needs.
- A code identifies each user.
- If a user wishes to find a friend both need previously to combine a common code for the schedule meeting.

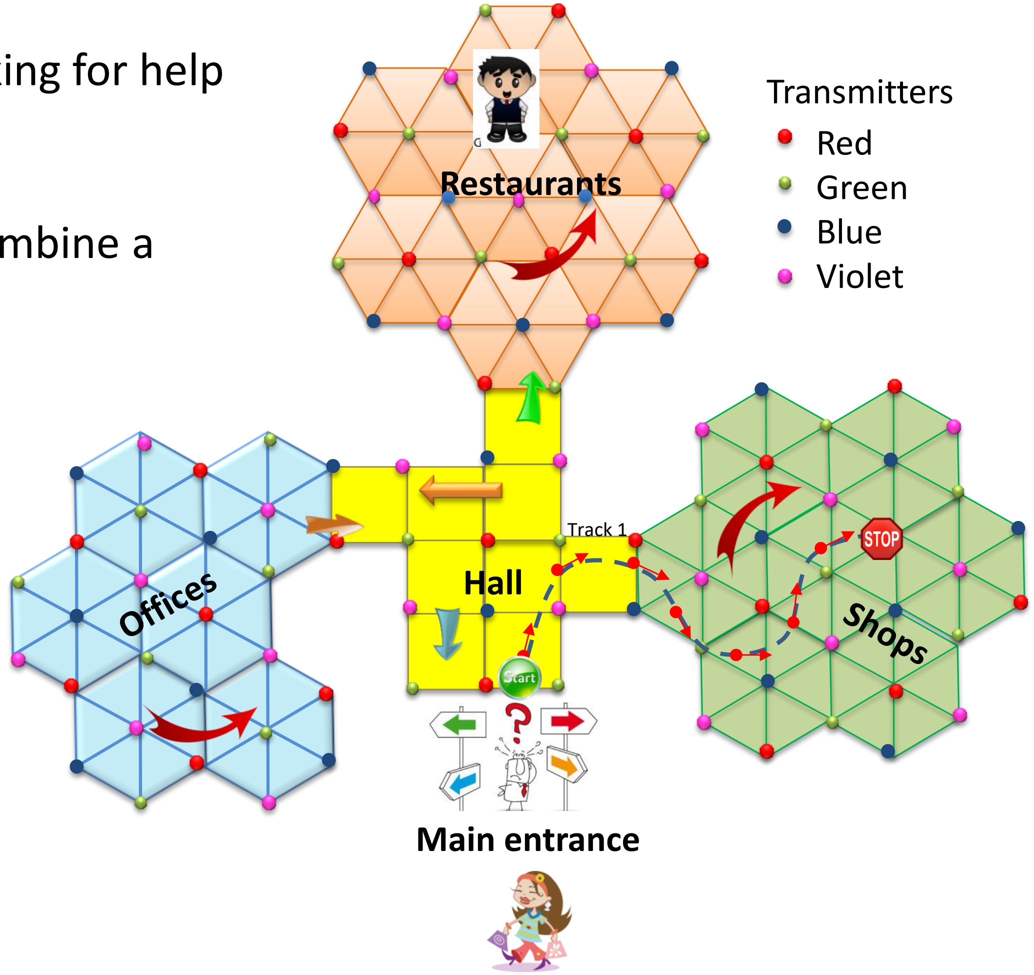
Request

- The first arriving initiates the alert notification to be triggered when the other is in his floor vicinity.

- A buddy list for the meeting is generated.
- The buddy finder service uses the location information from the network's VLC location from both users to determine their proximity.

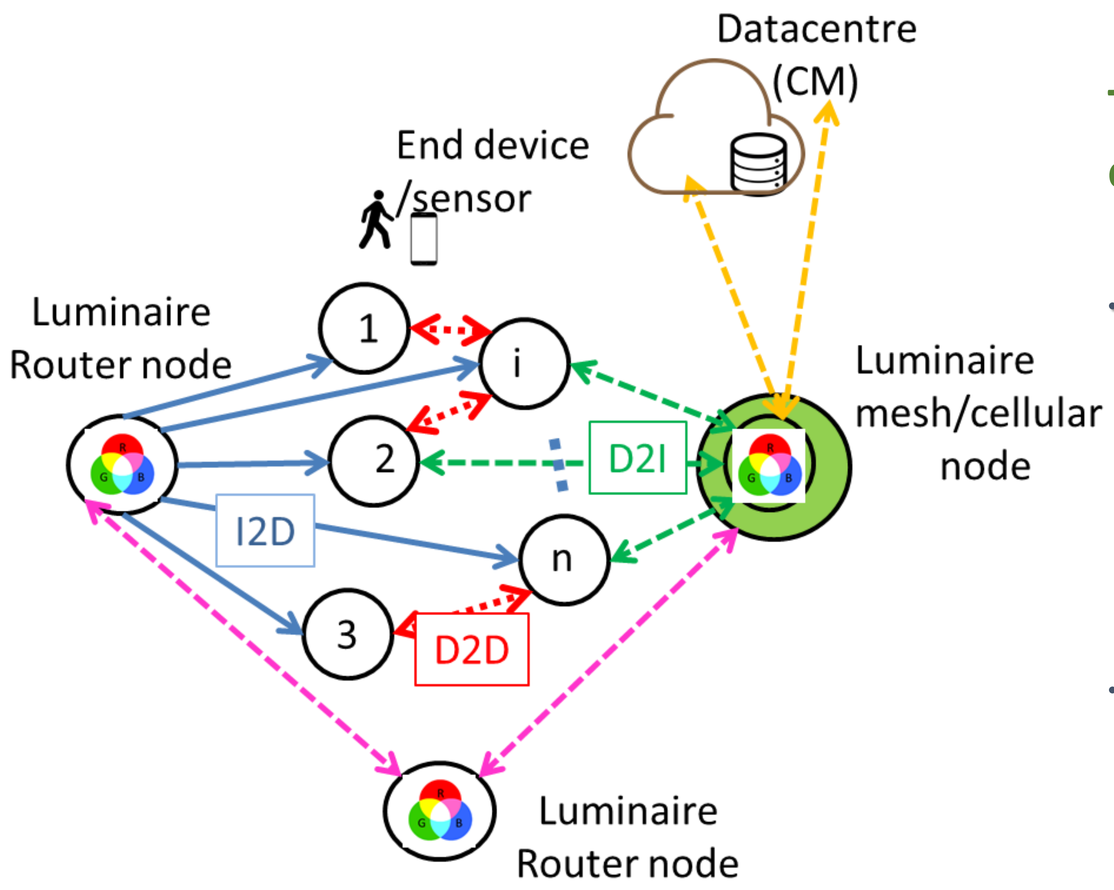
Response

- A response message with the location and path of the meeting point is sent.



MESH CELLULAR HYBRID STRUCTURE

A mesh cellular hybrid structure to create a gateway-less system is proposed.



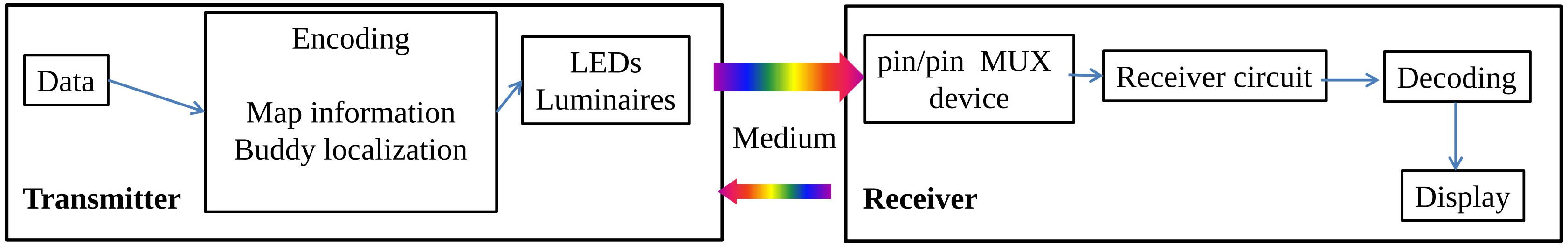
The luminaires are equipped with one of two types of nodes:

- **A “mesh” controller** that connects with other nodes in its vicinity. These controllers can forward messages to other devices (I2D) in the mesh, effectively acting like routers nodes in the network.

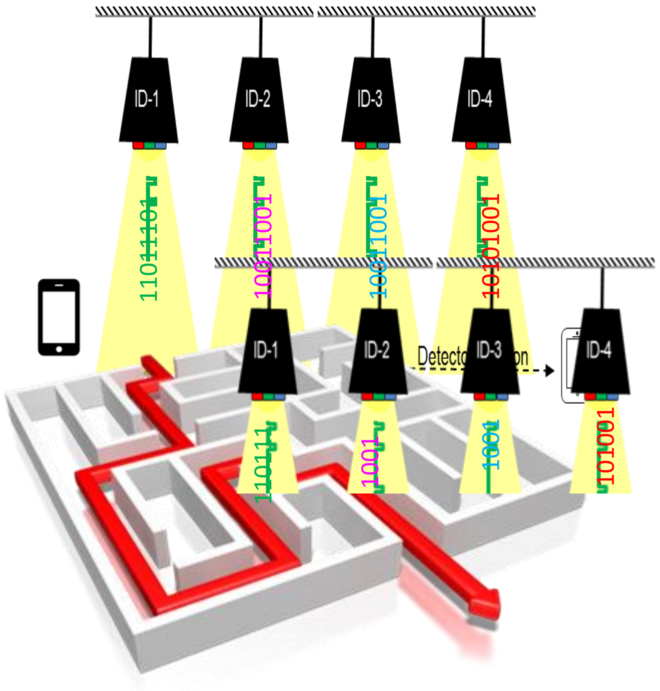
- **A “mesh/cellular” hybrid controller,** that is also equipped with a modem providing IP base connectivity to the central manager services (CM). These nodes act as border-router and can be used for edge computing.

VLC DYNAMIC NAVIGATION SYSTEM (POSITION AND ROUTE CONTROL)

- 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.

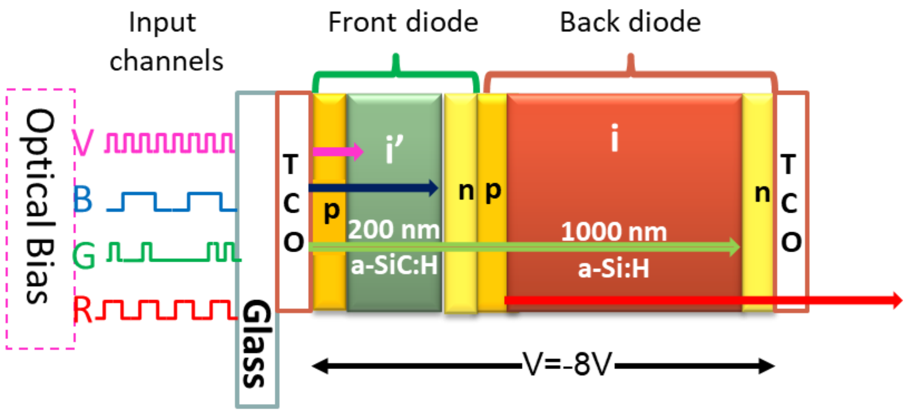


Transmitter



Line of Sight channel

Receiver

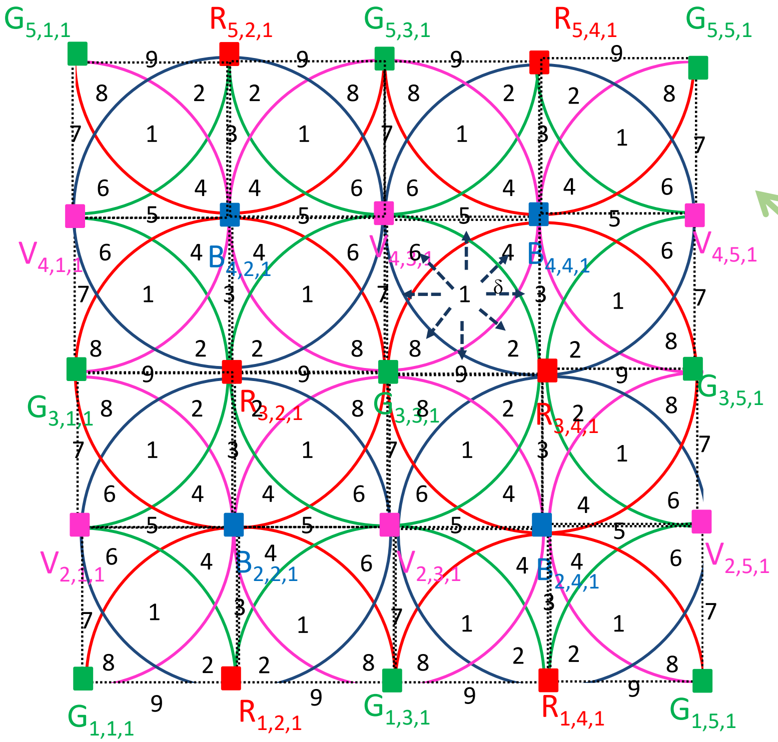


p-i'(a-SiC:H)-n/p-i(a-Si:H)-n heterostructure produced by PECVD.

- High sensitivity and linear response
- Signal conditioning techniques (adaptive bandpass filtering and amplification, triggering and demultiplexing) are used.
- Data signal is reconstructed at the data processing unit (digital conversion, decoding and decision).

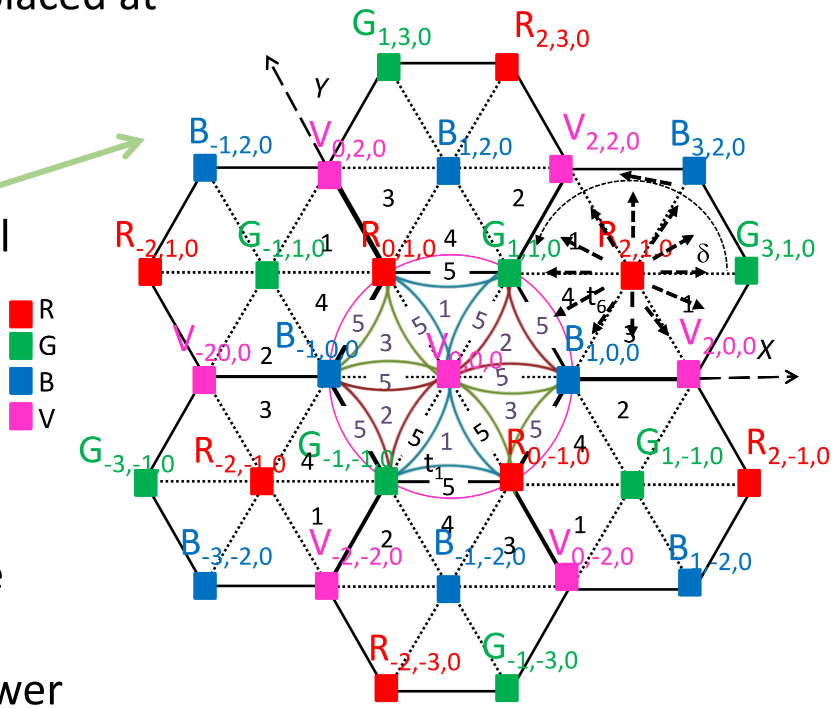
THE EMITTERS FOR LARGE ENVIRONMENTS

Clusters of cell in orthogonal and hexagonal topology



White tetra-chromatic LEDs placed at the corners of a square grid.

Same but in a non-orthogonal system giving rise to a hexagonal topology



- Only one chip, in each node, is modulated, the Red the Green, the Blue or the Violet
- A *dc* driving current for white perception provides high output power

2D model

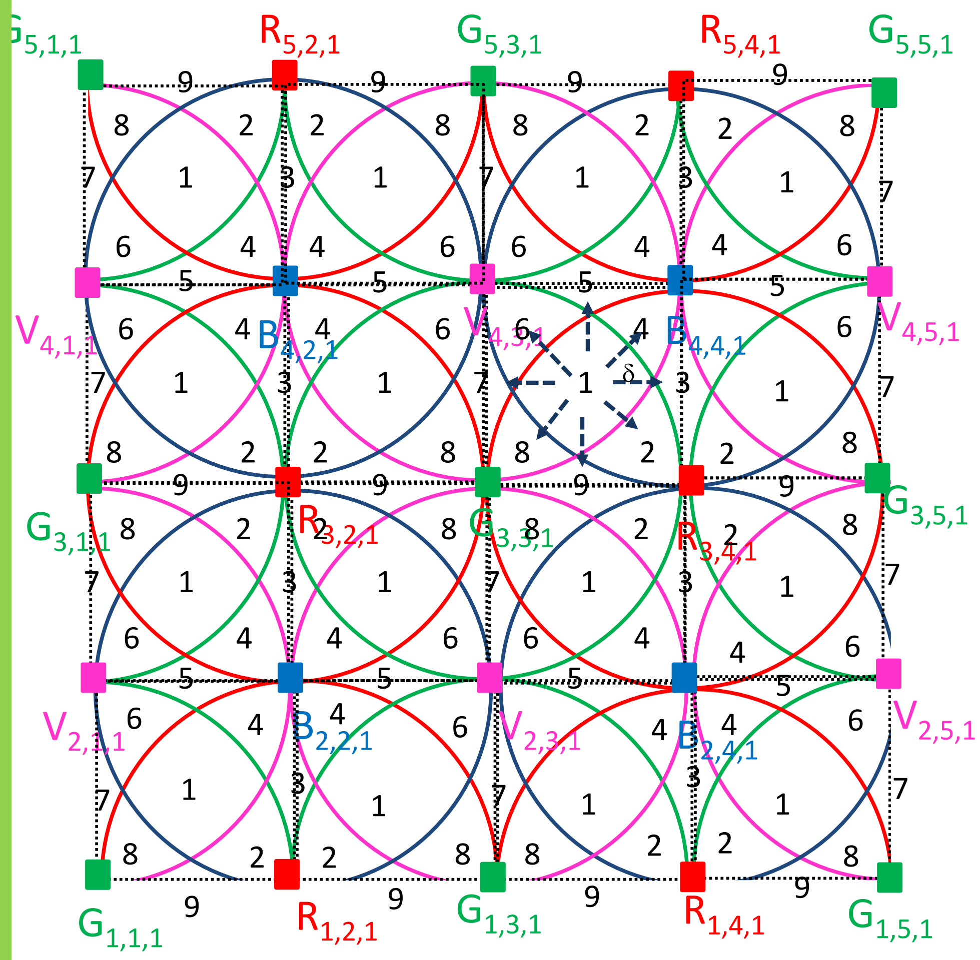
- Each node, $X_{i,j}$, carries its own color, X, (RGBV) as well as its ID position in the network.

3D model

- The user positions is represented as $X_{i,j,k}$ by providing the horizontal positions (x, y) and the correct floor number z.

ILLUSTRATION OF THE OPTICAL SCENARIOS

- Clusters of cells in square topology .



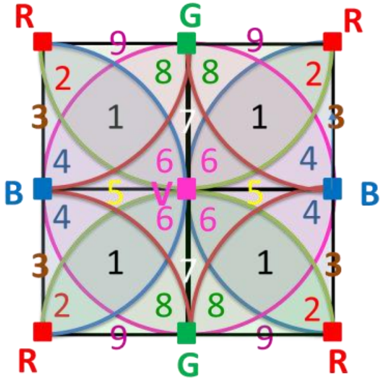
- A square lattice topology was considered. Here, cells have squares shapes to form an orthogonal shaped constellation with the modulated RGBV LEDs at the nodes.
  - For data transmission, commercially available polychromatic white LEDs were used at the nodes of the network.
  - On each node only one chip is modulated for data transmission and carries useful information while the others are only supplied with DC to maintain white color illumination.

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

Steering angle code	1	2	3	4	5	6	7	8	9
Square topology (δ)	-	(SE)º	(E)	(NE)	(N)	(NW)	(W)	(SW)	(S)

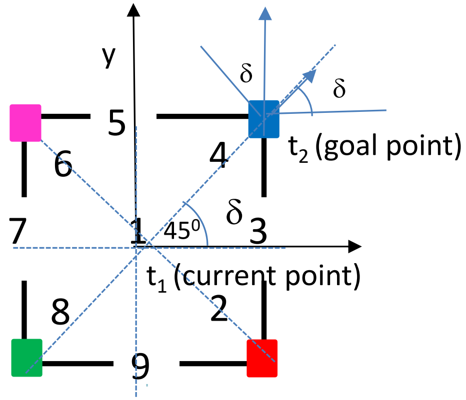
Each luminaire for downlink transmission become a single cell, in which the optical access point (AP) is located in the ceiling and the mobile users are scattered within the overlap discs of each cells underneath (footprints).

POSITION AND ROUTE CONTROL

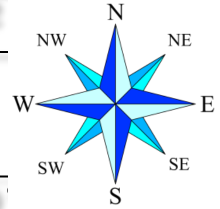


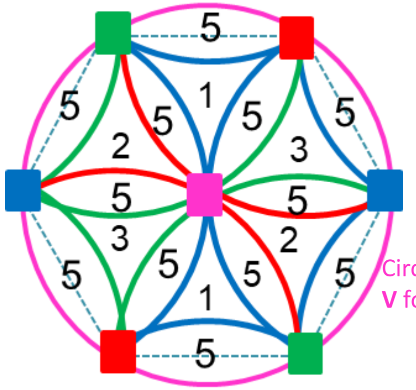
- The combined estimation of both position and orientation (pose estimation) are important to path definition.

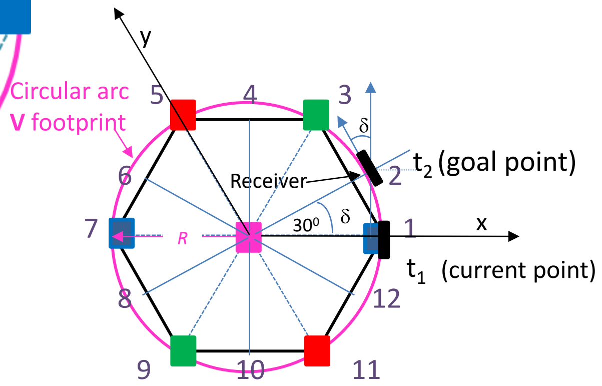
Footprint regions	#1	#2	#3	#4	#5	#6	#7	#8	#9
Square topology	RGBV	RGB	RB	RBV	BV	GBV	GV	RGV	RG
Hexagon topology	RGV	GBV	RBV	RGB	RGBV	_	_	_	_



Steering angle code	1	2	3	4	5	6	7	8	9	10	11	12
Square topology (δ)	-	315 (SE)º	0 º (E)	45 º (NE)	90 º (N)	135 (NW)º	180 º (W)	225 º (SW)	270 º (S)	-	-	-
Hexagon topology (δ)	0 º	30 º	60 º	90 º	120 º	150 º	180 º	210 º	240 º	270 º	300 º	330 º





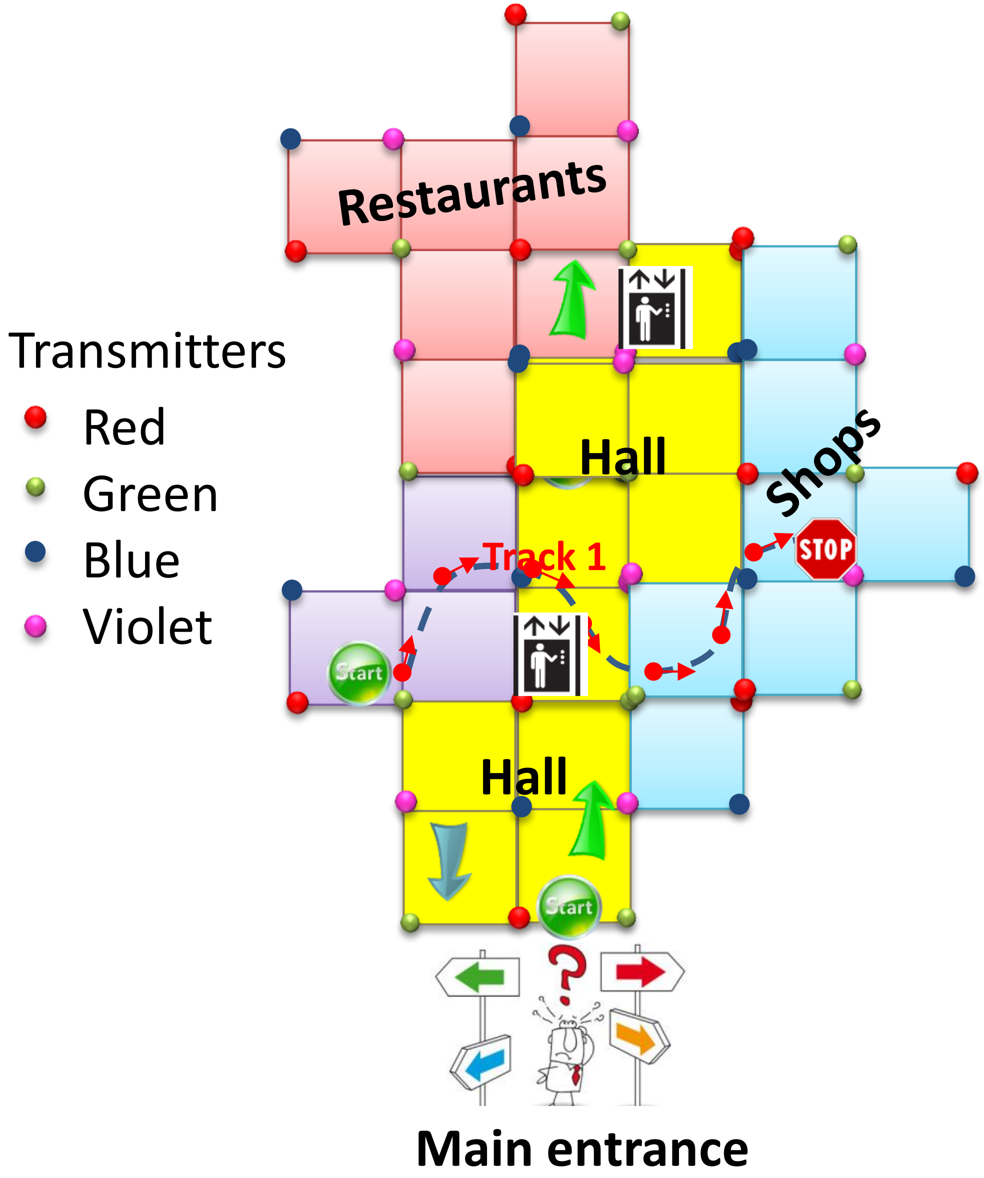


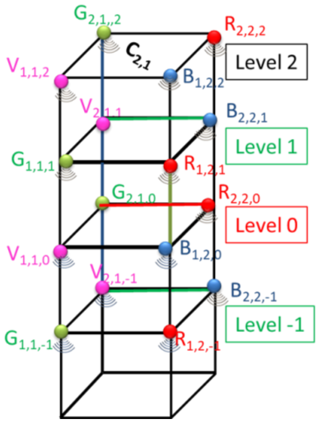
- The device receives multiple signals, finds the centroid of the received coordinates and stores it as the reference point position.

- The steering angle (δ) that guides the user across his path.

SCENARIO, ARCHITECTURE AND BUILDING MODEL

The scenario simulated is a 3D complex building.





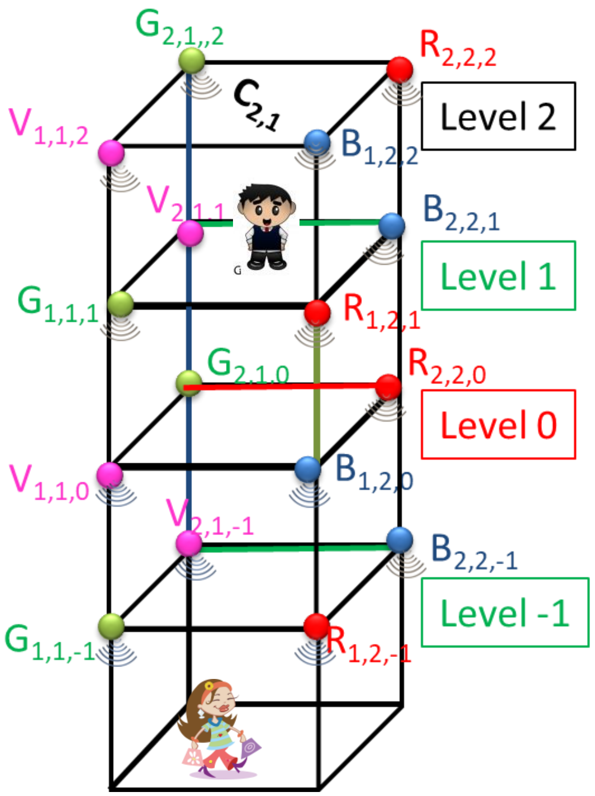
Optical infrastructure and indoor layout.

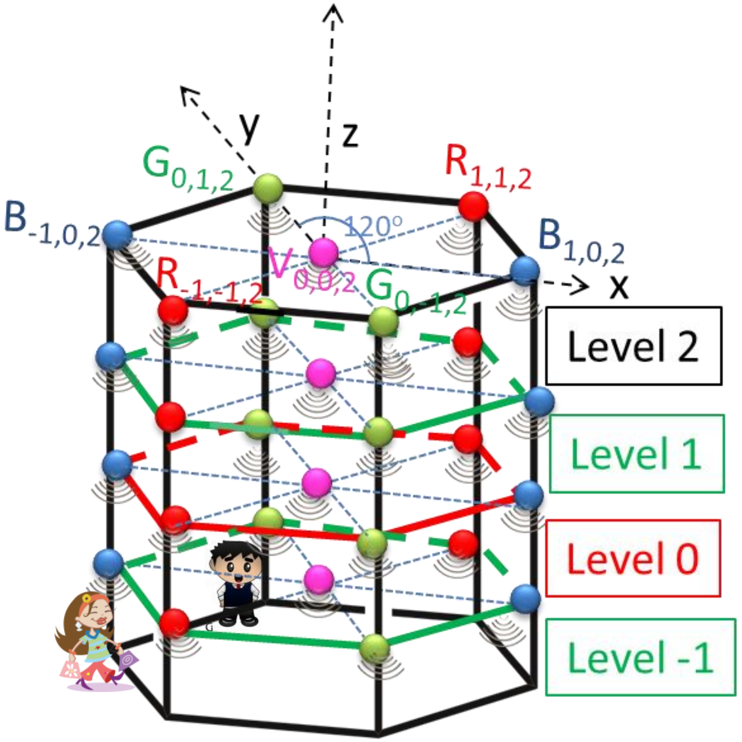
The user navigates from outdoor to indoor.

- It sends a **request** message to find the right track and, in the available time, he adds customized points of interest (wayfinding services).
- The requested information is sent by the emitters at the ceiling to the user receiver.

BUILDING INFRASTRUCTURE (3D MODEL)

The 3D model generation is based on footprints of a multi-level building that are collected from available sources (lights) and are displayed on the user receiver for user orientation.

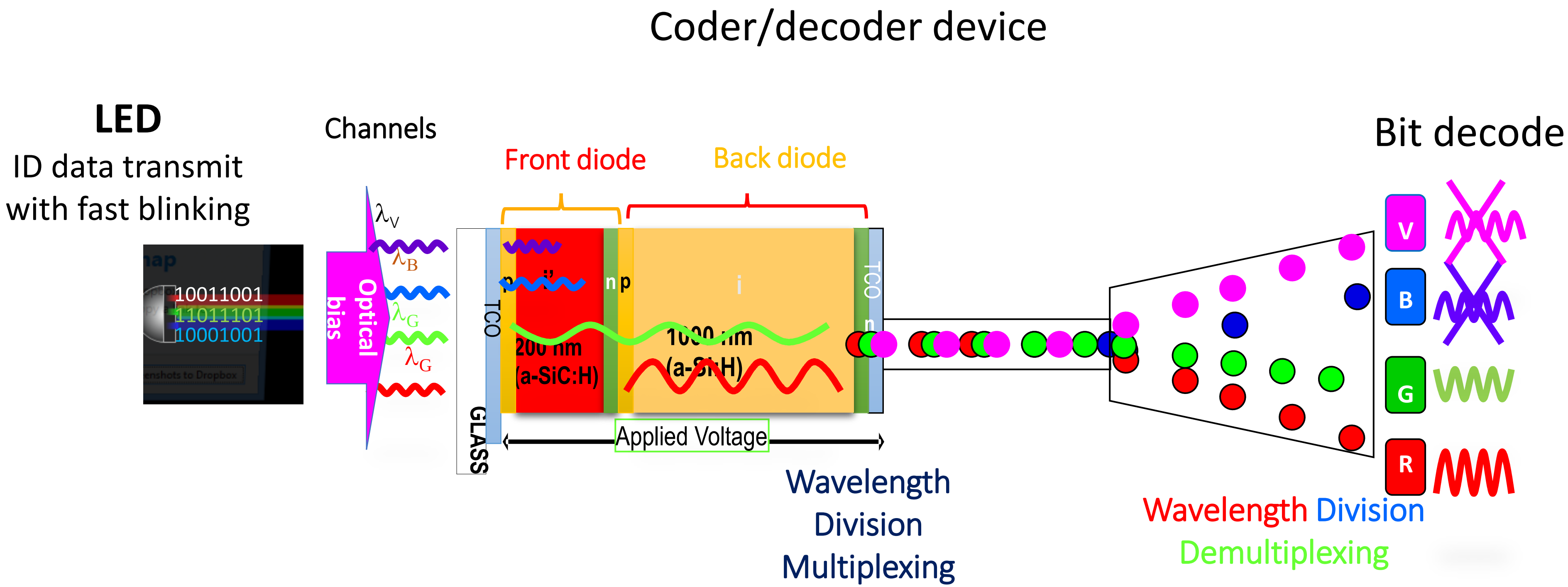




- Each unit cell can be referred as $C_{i,j,}$ were *i, j* are the x, y positions in the square unit cell of the top left node or the central node in the hexagonal one.
- The indoor route throughout the building is presented to the user by a responding message transmitted by the ceiling luminaires.

SYSTEM OPERATION

Transmitter / Receiver of VLC



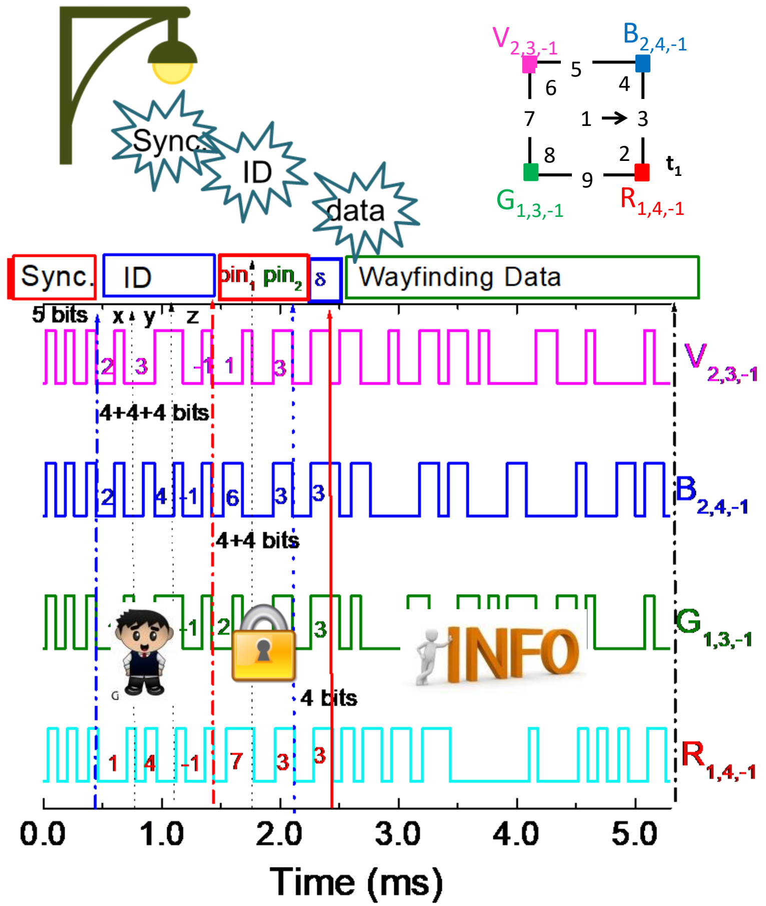
- The device acts not only as a photodetector but also as an active filter under irradiation. As the wavelength increases, the signal strongly increases.

- The generated photocurrent is processed using a transimpedance circuit. With signal conditioning techniques (adaptive bandpass filtering and amplification, triggering and demultiplexing), the signal is reconstructed at the data processing unit (digital conversion, decoding and decision).

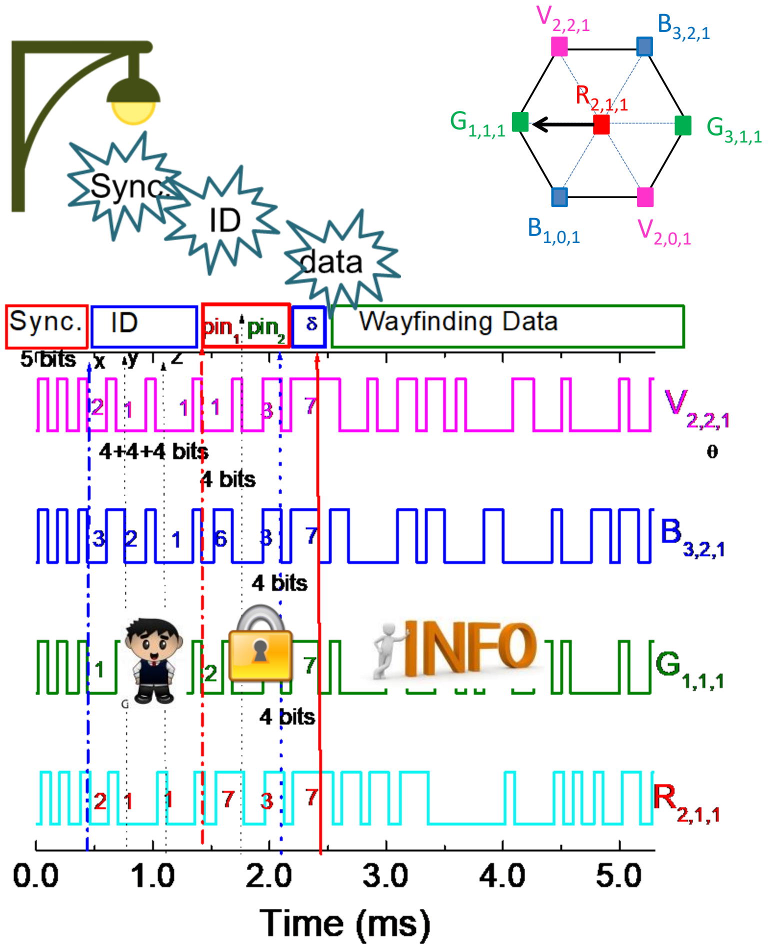
COMMUNICATION PROTOCOL BY VLC

The data are coded using the OOK modulation in a 64-bits word, divided into a header and five blocks.

Transmitted node packet from the unit cell $C_{2,3,-1}$ in the network.
$R_{1,4,-1}$; $G_{1,3,-1}$; $B_{2,4,-1}$ and $V_{2,3-1}$ (#1E)



Transmitted node packet at the unit cell $C_{2,11,1}$.
$R_{2,1,1}$; $G_{1,1,1}$; $B_{3,2,1}$ and $V_{2,2,1}$ (#5W)



- Cell's IDs and passwords are encoded using a 4 bits binary representation for the decimal number.
- User *7261* receives his request message [pose, and wayfinding needs] from the infrastructure.

DECODING ALGORITHM
Calibration

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 supplies an additional tool to enhance the decoding task.

The bit sequence allows all the on/off sixteen possible combinations of the four RGBV input channels (2^4).

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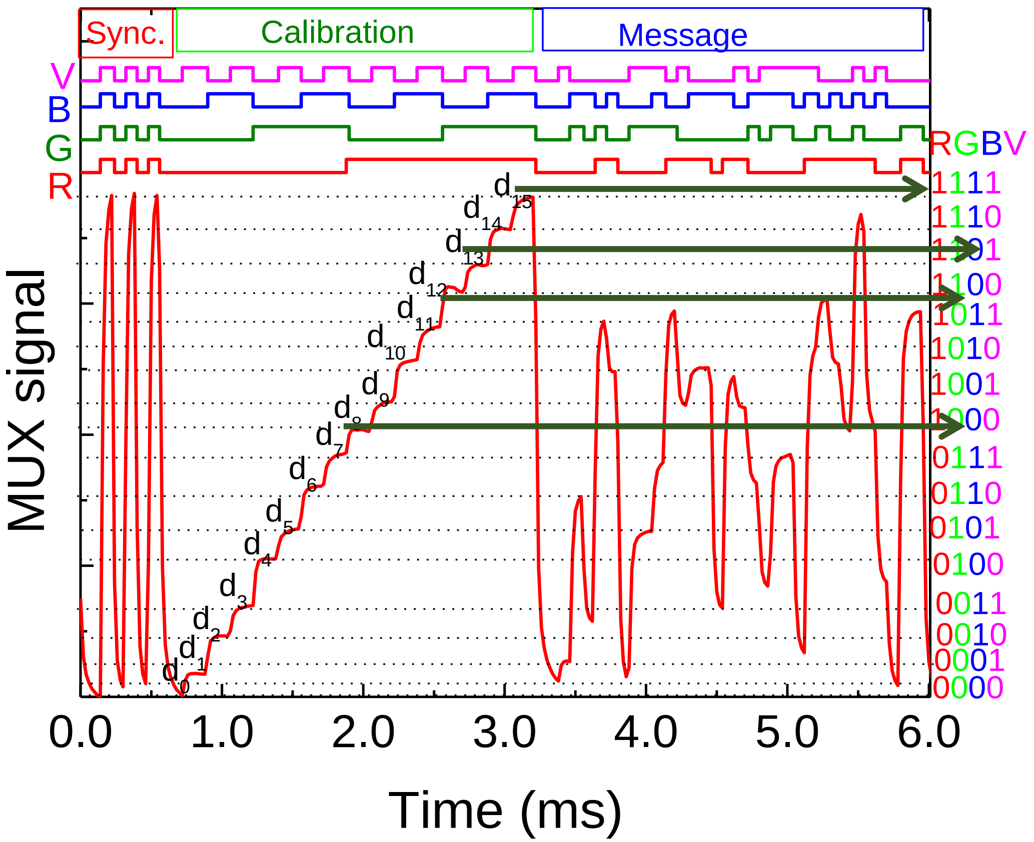
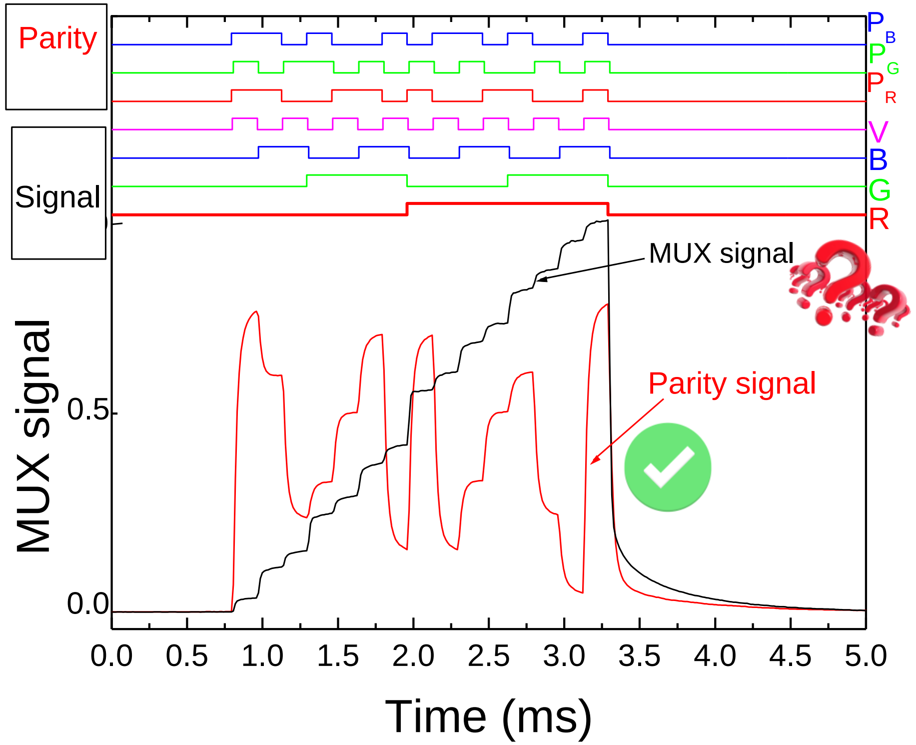
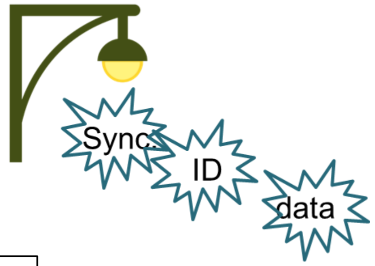


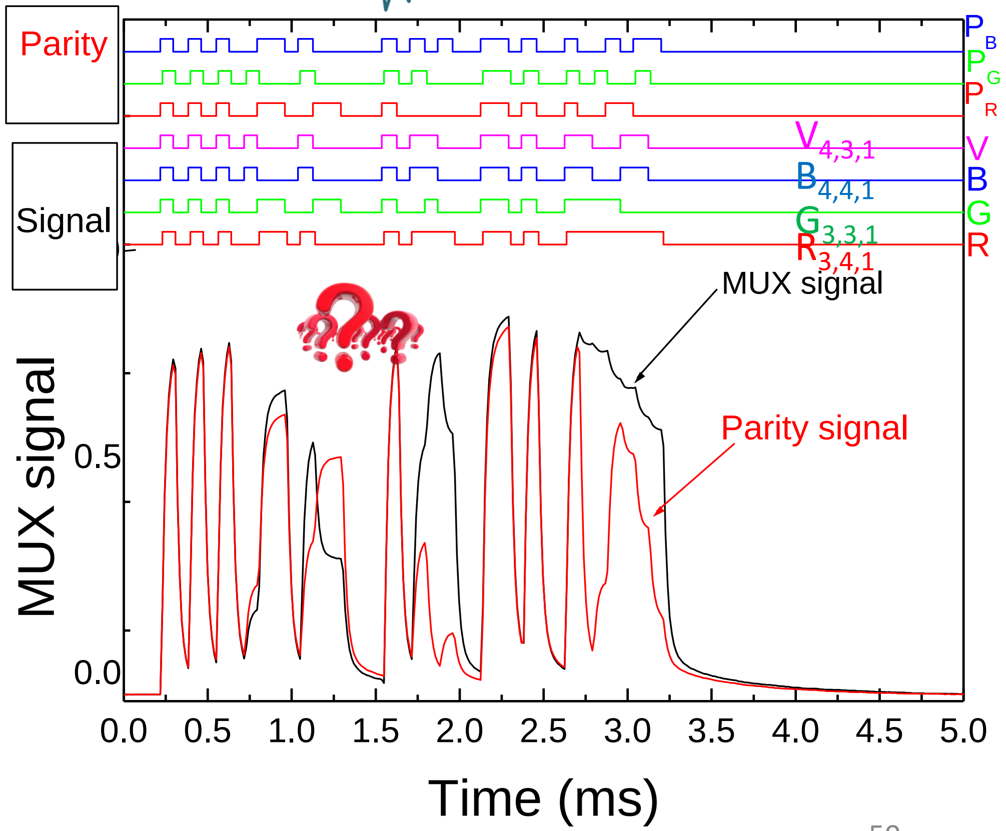
- 2^4 ordered are detected and correspond to all the possible combinations of the *on/off* states.
- By assigning each output level to a 4-digit binary code, [X_R, X_G, X_B, X_V], with X=1 if the channel is *on* and X=0 if it is *off*, the signal can be decoded.
- Comparing the calibrated levels with the different levels in the same frame of time, a simple algorithm is used to perform 1-to-64 demultiplexer function and to decode the multiplex signals.

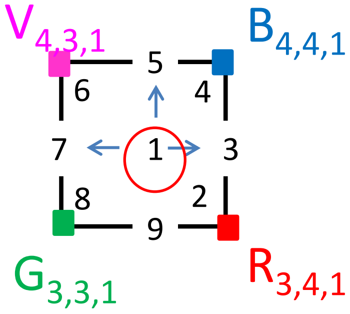
ERROR CONTROL

Calibration



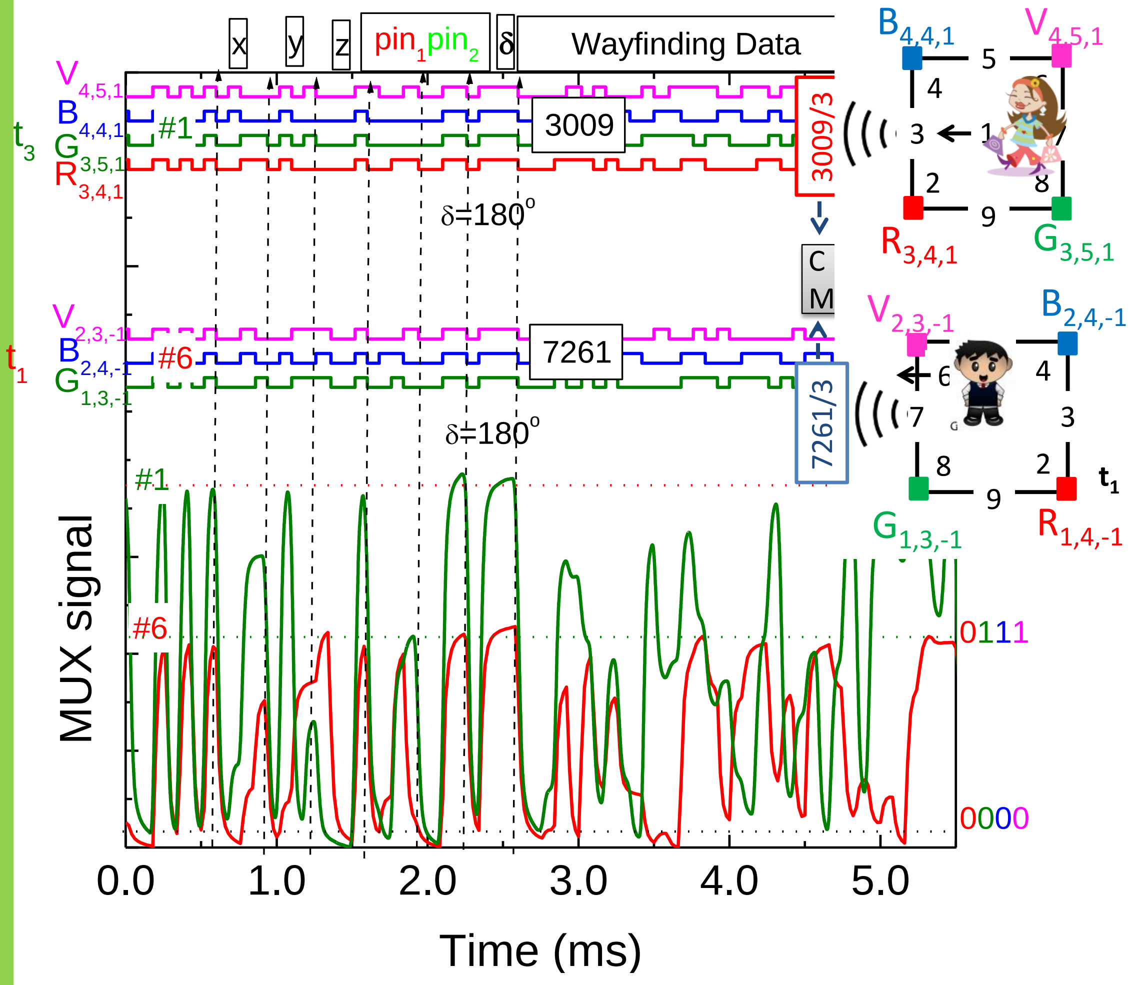






COMMUNICATION PROTOCOL AND DECODING TECHNIQUES

MUX/DEMUX signals from two users, that have request wayfinding services.



All messages, in a frame, start with the header, Sync.[10101], imposed simultaneously to all emitters.

The next block (ID) gives the geolocation (x,y,z coordinates) of the emitters inside the array ($X_{i,j,k}$). Cell's IDs are encoded using a 4 bits binary representation for the decimal number.

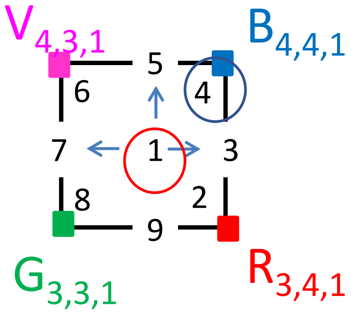
Each user sends to the local controller a "request" with his pose (x,y,z, δ), user code (pin1) and also adds its needs (code meeting and wayfinding data).

When bidirectional communication is required, the user has to register by choosing a user name (pin1) with 4 decimal numbers, each one associated to a colour channel.

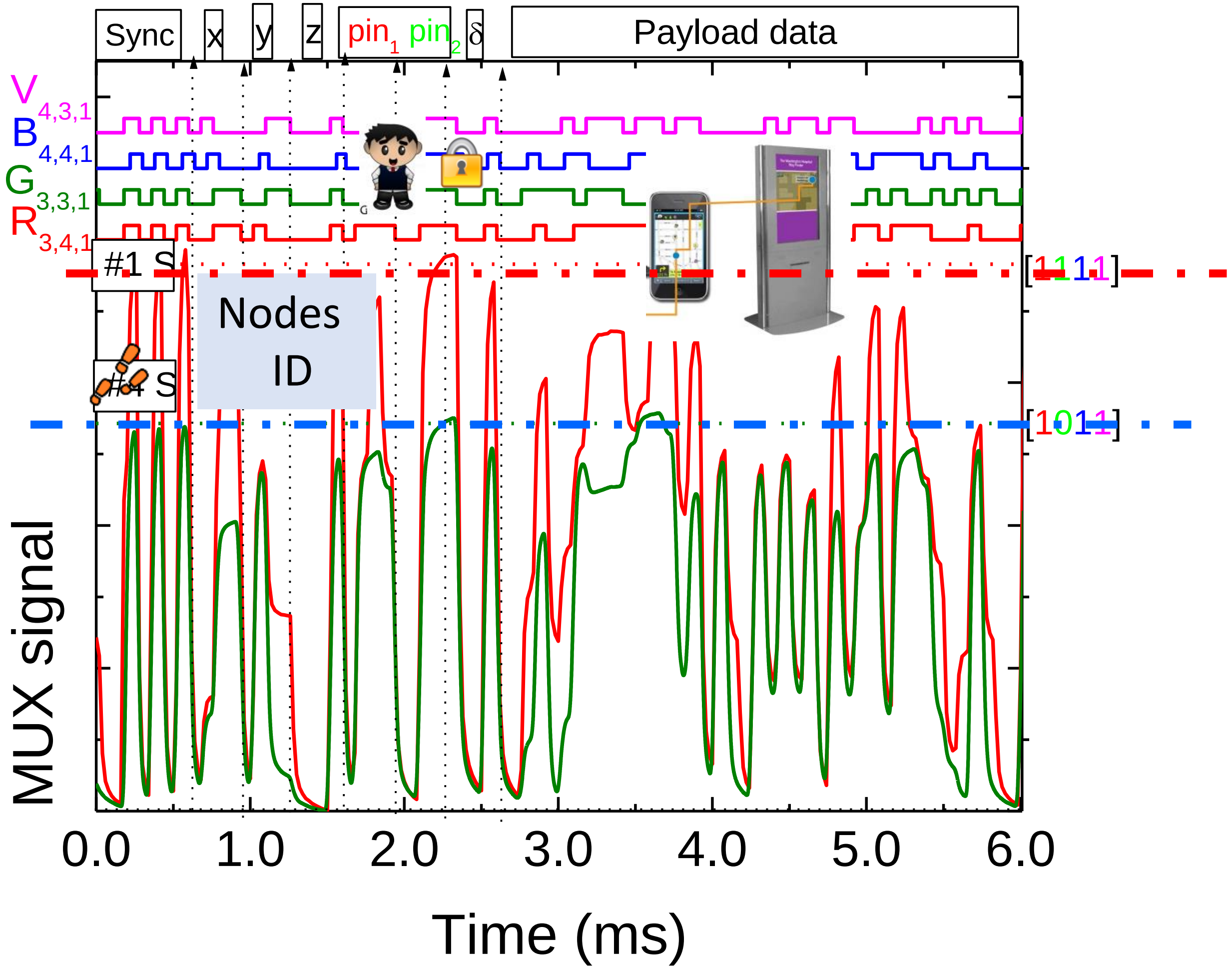
If buddy friend services are required a 4-binary code of the meeting (pin2) has to be inserted.
The coded steering angle (δ) completes the pose in a frame time).

If no wayfinding services are required the last three blocks are set at zero and the user only receives its own location. The last block is used to transmit the wayfinding message. A stop bit is used at the end of each frame.

MUX-DEMUX

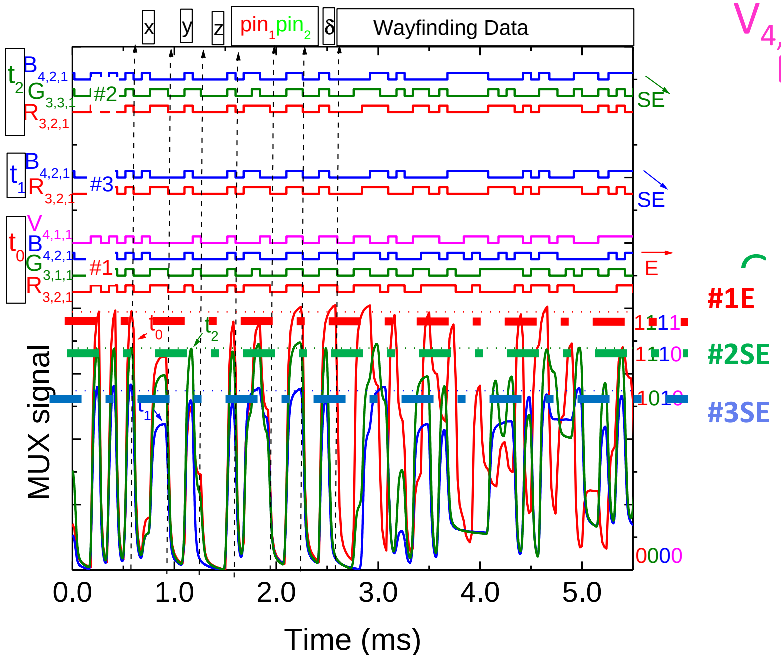


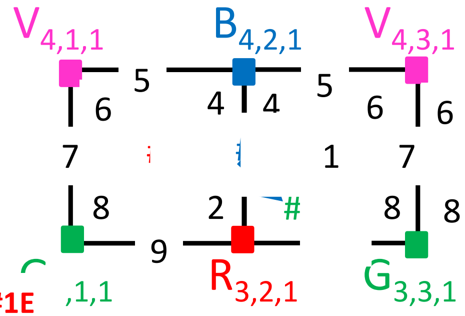
7261/3/S

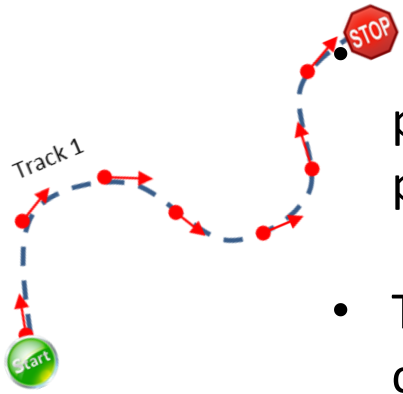


- The footprint position comes directly from the synchronism block, where all the received channels are, simultaneously, *on* or *off*.
- The next block of 12 bits gives de ID of the received nodes.
- The last block is reserved for the transmission of the wayfinding message.

FINE GRAINED LOCALIZATION AND TRAVEL DIRECTION

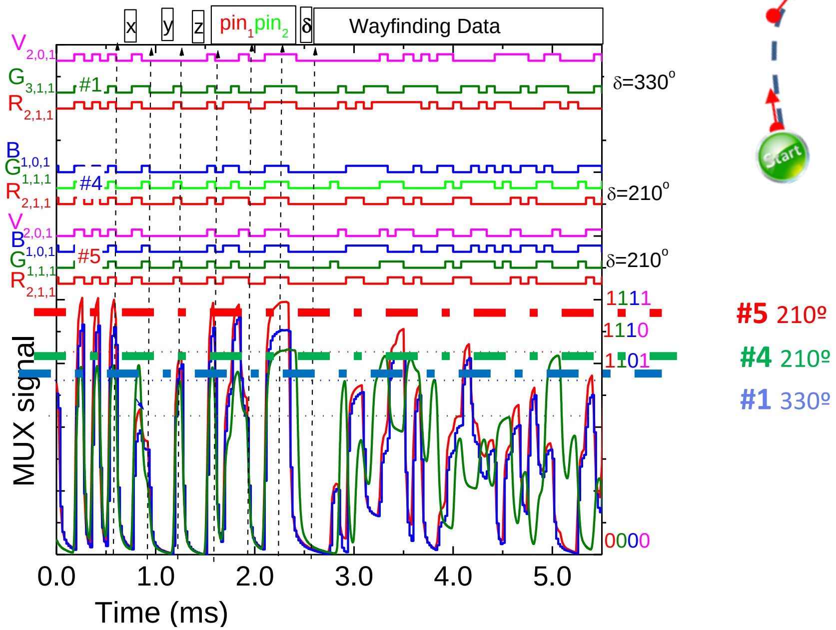


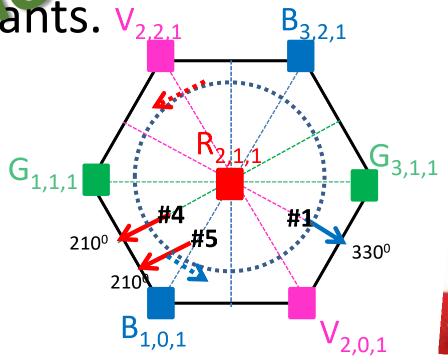




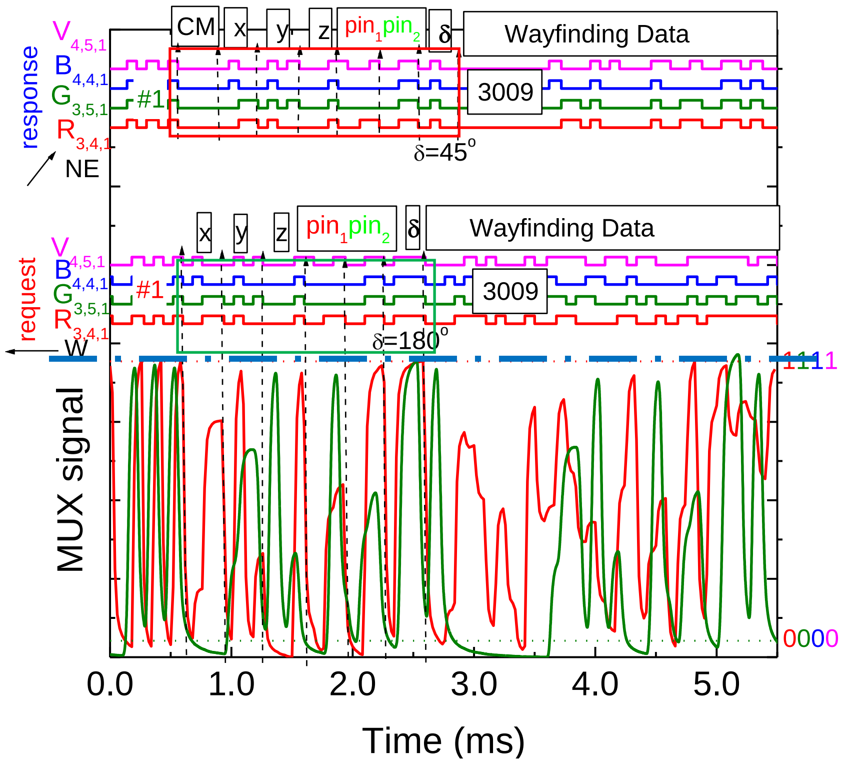
- To compute the point-to-point along a path, we need the data along the path.
- As the receiver moves between generated point regions, the received information pattern changes.
- The transition actions are correlated by calculating the ID position codes in successive instants.

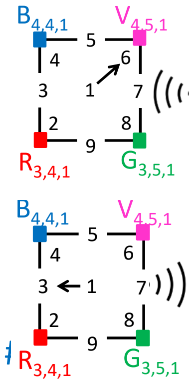
Aided dynamic navigation

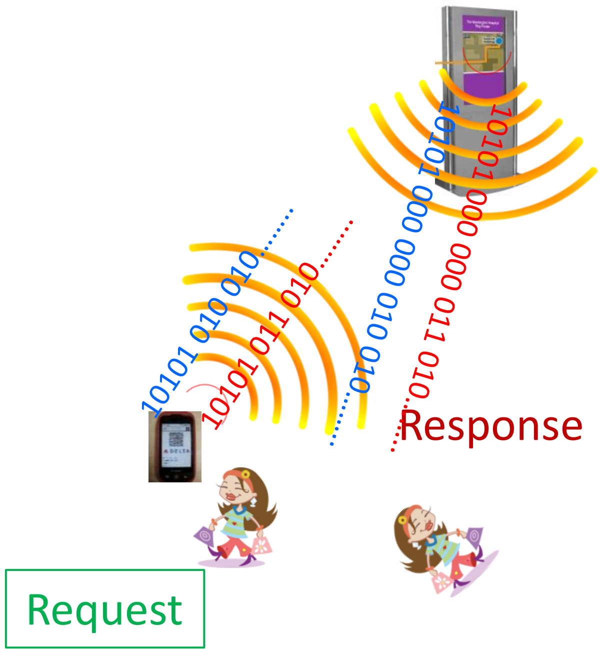




BI-DIRECTIONAL COMMUNICATION

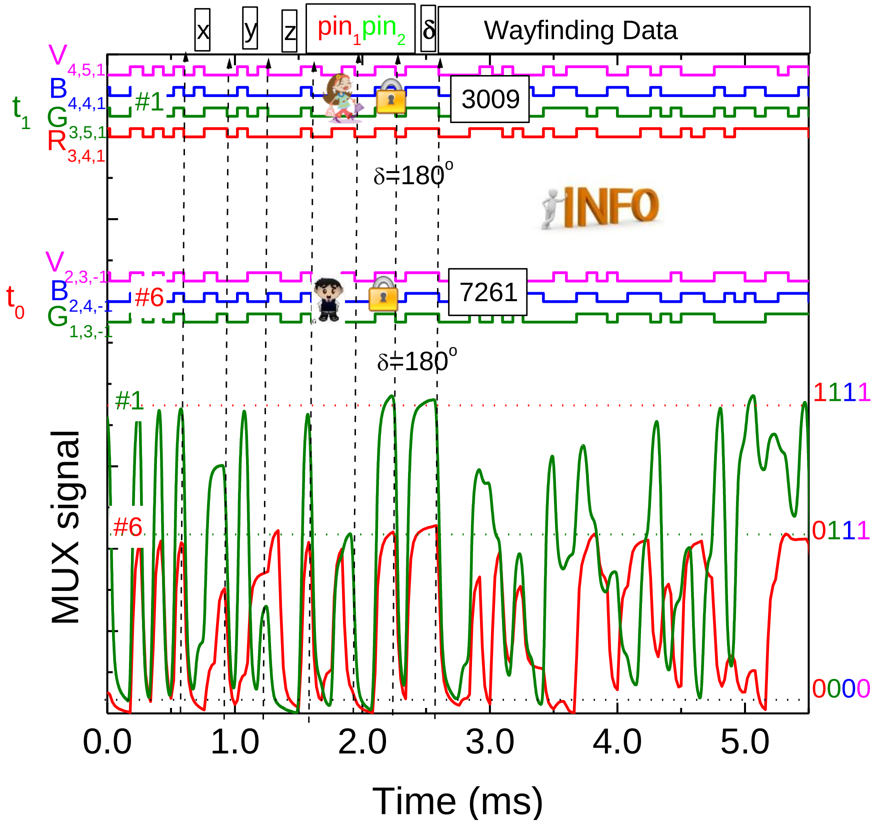


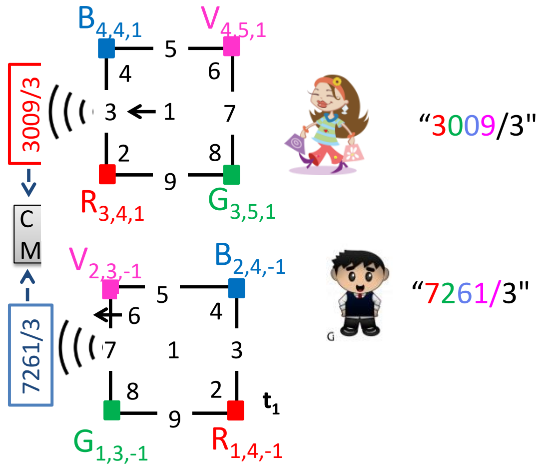




- Bi-directional communication between VLC emitters and receivers at a handheld device can be established through a control manager linked to an indoor billboard.
- Using a white polychromatic LED as transmitter, the receptor sends to the local controller a “request” message with its location (ID) and adds its needs for the available time. For route coordination, the local controller emitter sends the “response” message.
- Each ceiling lamp broadcasts a message with its ID and advertising which is received and processed by the receiver.

WAYFINDING SERVICES





Route Coordination

- User located at $C_{2,3,-1}$, arrived first (t_o), identified himself ("7261") and informed the controller of his intention to find a friend for a previously scheduled meeting ([0011]; 3).

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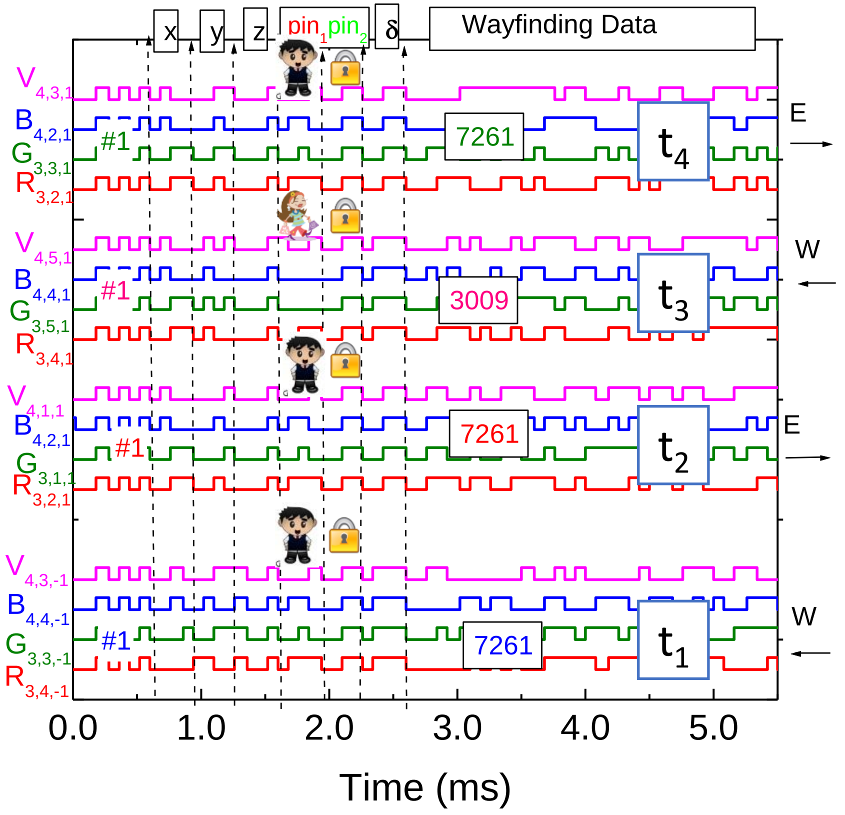
- A buddy list is then generated and will include all the users who have the same meeting code.

.

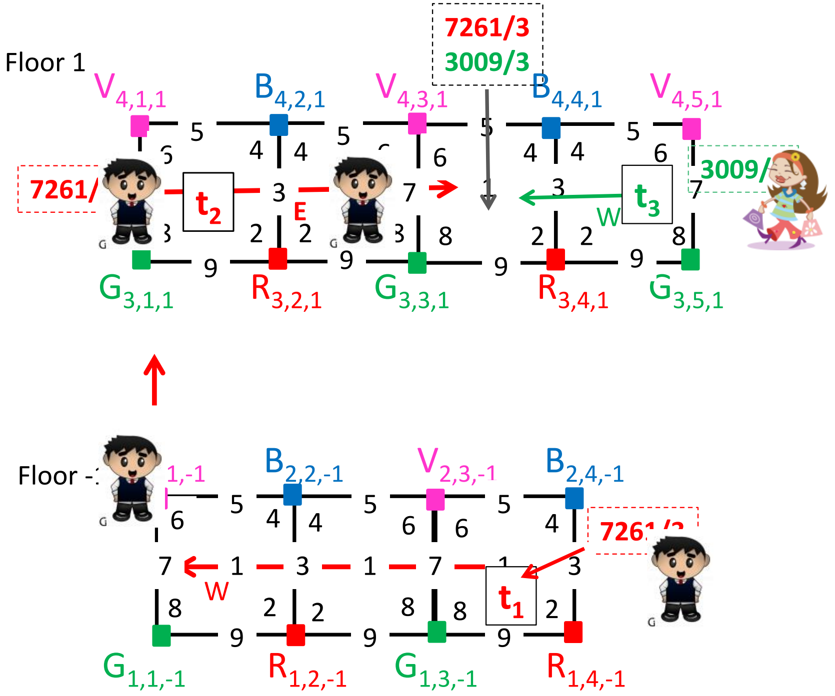
- User "3009" arrives later sends the alert notification ($C_{4,4,1}$; t_3) to be triggered when his friend is in his floor vicinity level 1, identifies himself ("3009") and uses the same code, in the buddy wayfinding services (code 3), to track the best way to his meeting.

Decoded messages from the two users as they travel to the pre-scheduled meeting



- User "7621" starts (t_1) his journey on floor -1, $C_{2,3,-1}$; #1W, goes up to floor 1 in $C_{2,1,-1}$ and at t_2 he arrives at $C_{4,1,1}$ heading for E.

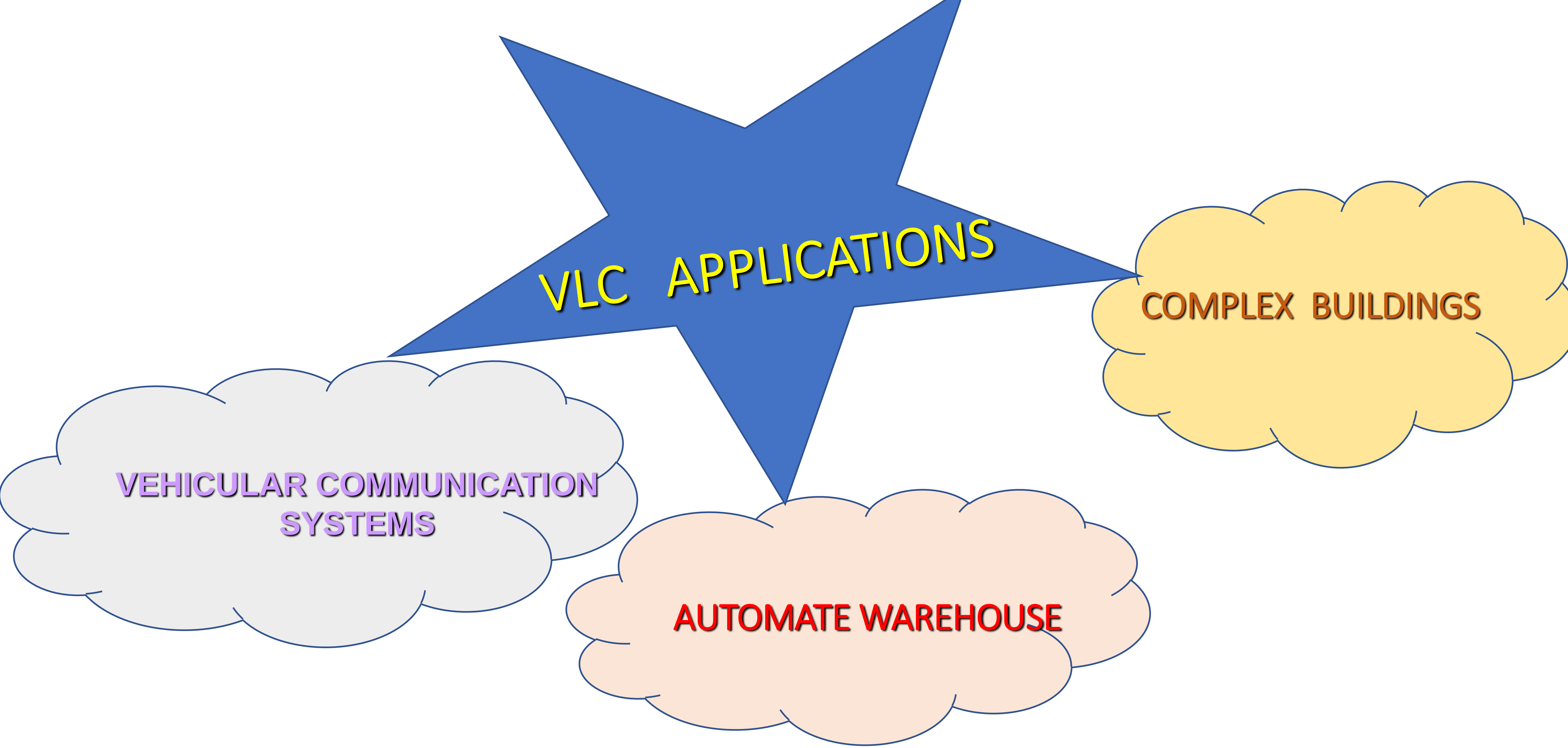
- During his journey, user "3009" from $C_{4,4,1}$ #1 asks the CM (t_3) to forward him to the scheduled meeting and follows course to W. At t_4 both friends join in $C_{4,3,1}$.

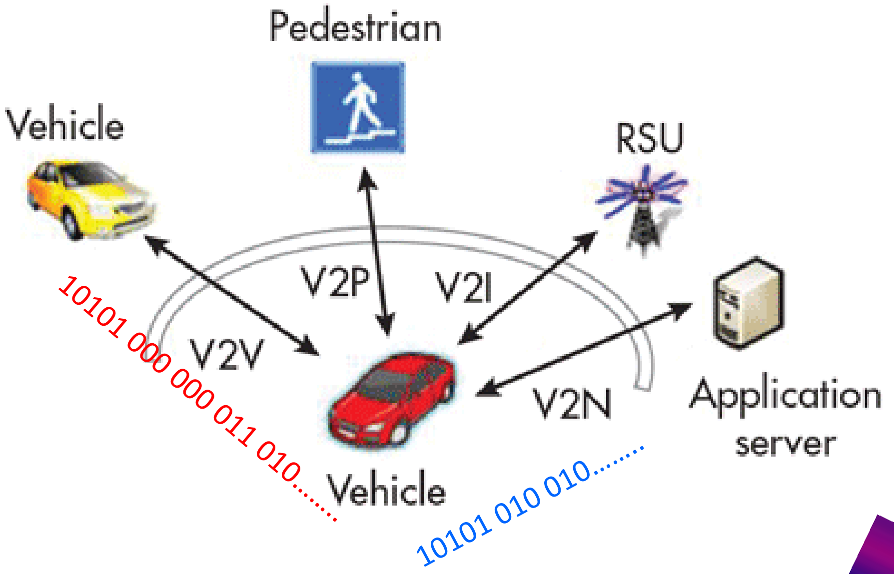


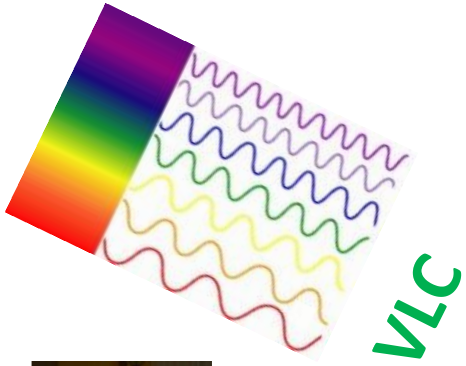
Buddy wayfinding

CONCLUSIONS

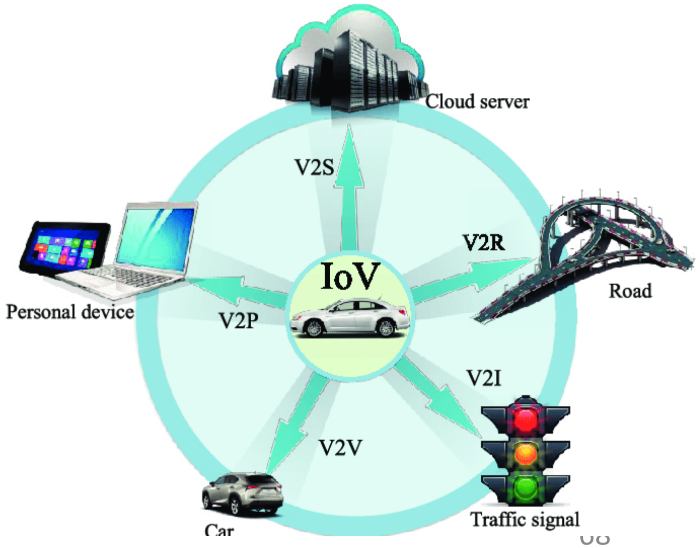
- A dynamic LED-assisted positioning and navigation system was proposed based on ceiling landmark route instructions using VLC.
- Each luminaire for downlink transmission become a single cell in which the optical access point is located. Data is encoded, modulated and converted into light signals. A SiC optical mobile receiver decodes the data and infers path location, timing and user flows.
- Some wayfinding concepts are summarized and a 3D model for the building is established using a match of both hexagonal and orthogonal topologies for the network. A direction strategy was assumed for the route control.
- The communication protocol and decoding techniques were presented. Using the proposed scenario, route control was evaluated and the position, pose, path and trajectory tracking of the mobile users determined. Bi-directional communication between the users and a central manager was analyzed.
- Main results are present showing that the location of a mobile receiver, concomitant with route instructions data is achieved. The dynamic LED-aided VLC navigation system make possible to determine the position and orientation of a mobile target inside the network, to infer the travel direction along the time and to interact with received information..
- Research is still necessary to optimize the coverage; effects as synchronization, shadowing and ambient light could be minimized through MIMO techniques. Also, the design the LED arrangements has to be improved in future to optimize the communication performance while meeting the illumination constraints.


VLC APPLICATIONS
COMPLEX BUILDINGS
VEHICULAR COMMUNICATION SYSTEMS
AUTOMATE WAREHOUSE



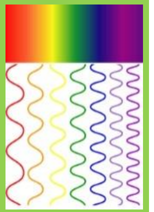


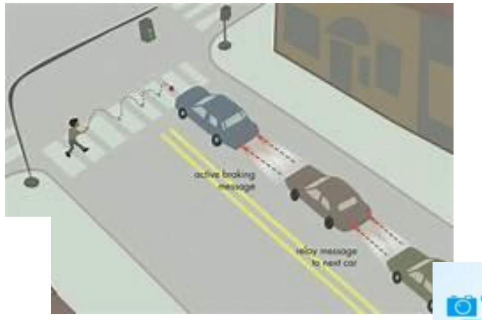
- **Manuela Vieira**
- Manuel A. Vieira
- Paula Louro
- Pedro Vieira

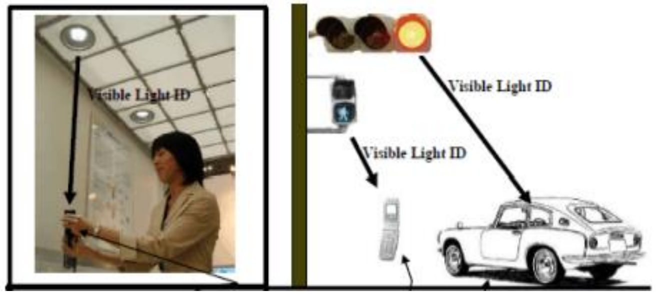


MOTIVATION

VLC – Visible Light Communication

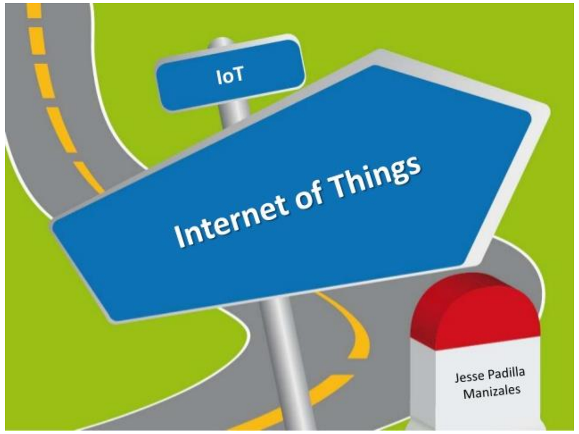






Wi-Fi will begin to become limited

The Internet of Things



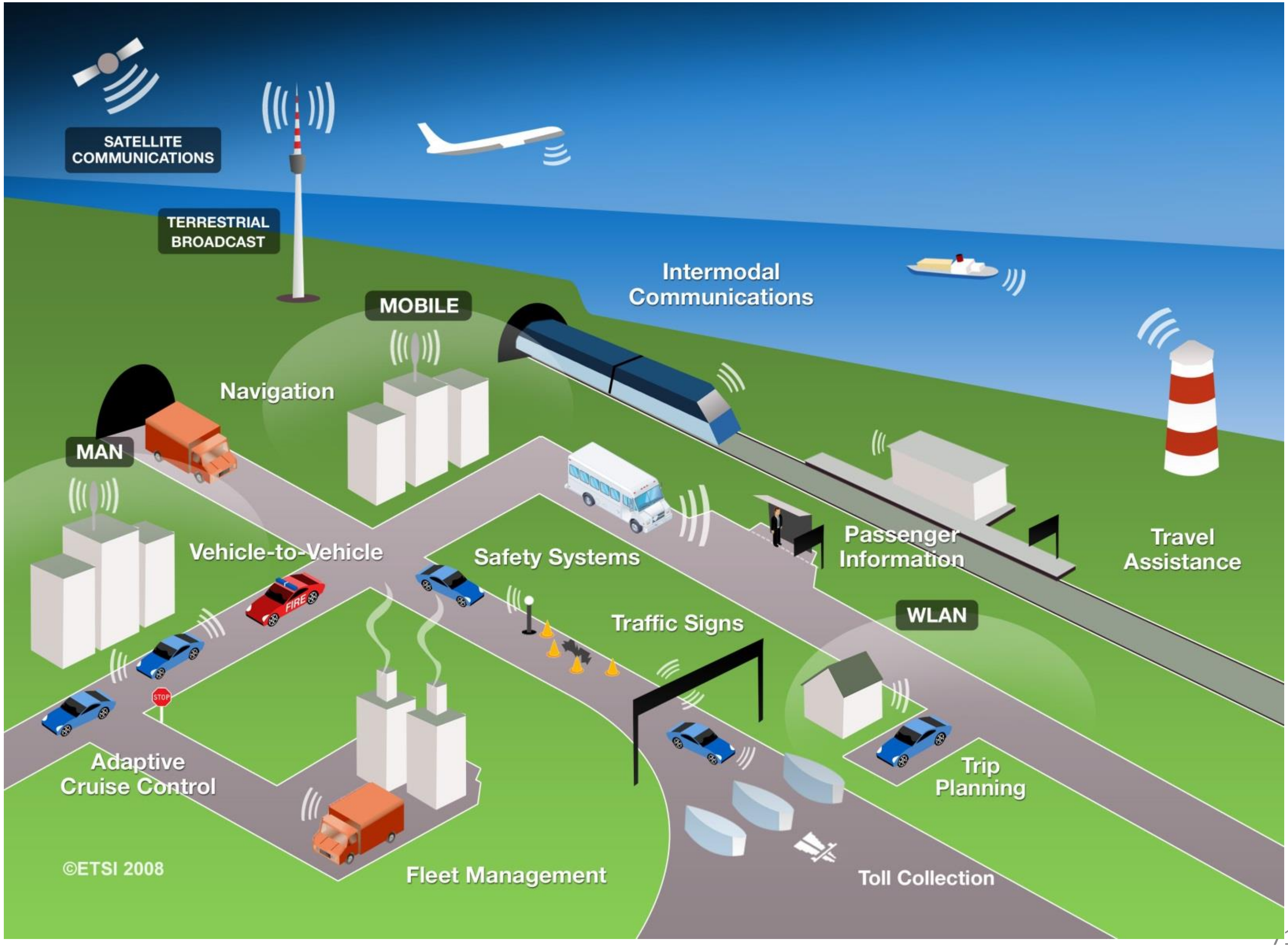
The integration of IoT devices and Li-Fi will provide a wealth of opportunities. For example, shop owners could transmit data to multiple customers' phones quickly, securely and remotely.

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

Speed
Latency
Capacity

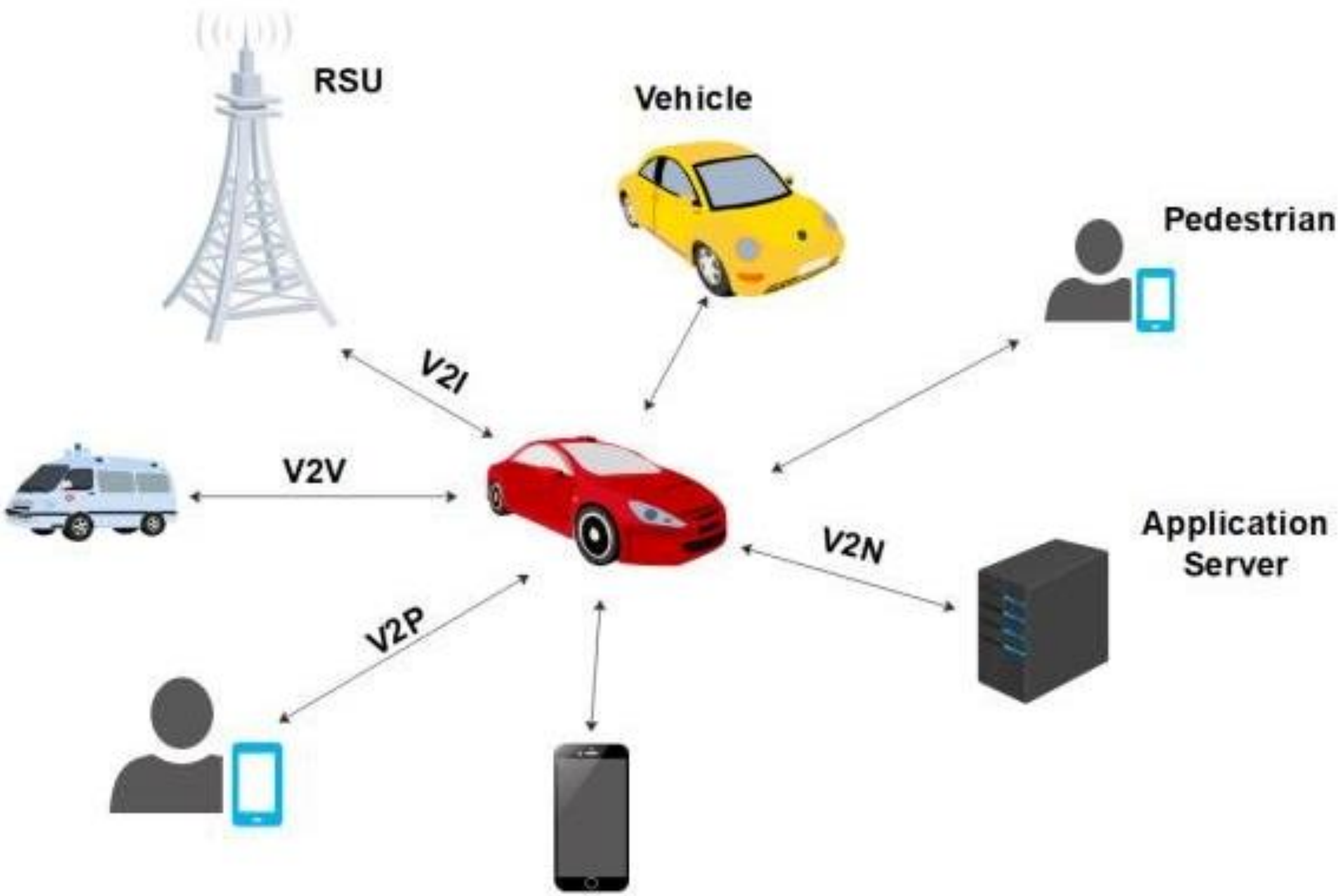
European Commission

Vehicular VLC: Road-to-Vehicle



APPLICATION

VEHICULAR COMMUNICATION SYSTEMS

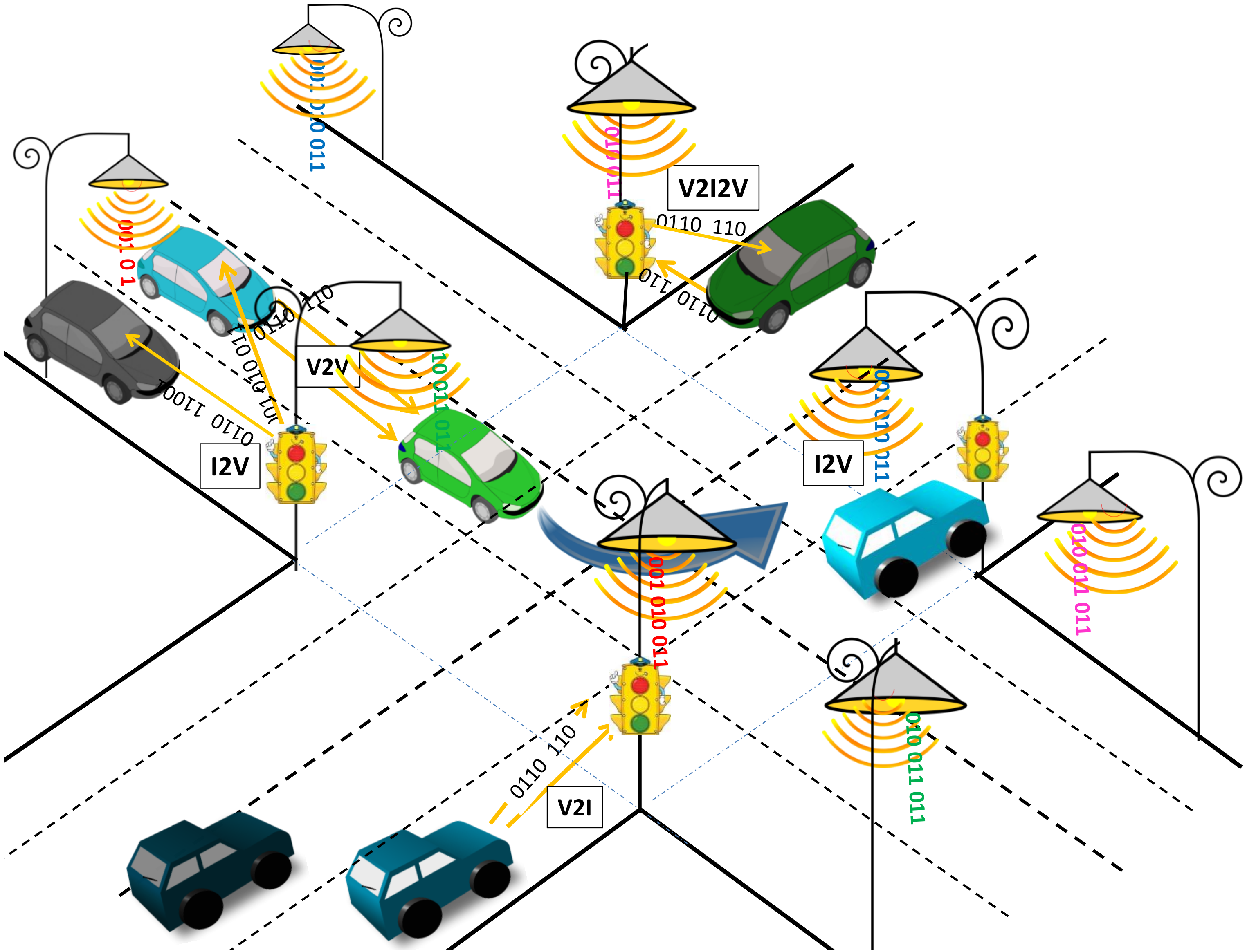


- Vehicular Communication Systems are a type of network in which vehicles and roadside units are the communicating nodes, providing each other with information, such as safety warnings and traffic information.

- Communication between fixed locations and vehicles (Infrastructure-to-Vehicle, **I2V**) between vehicles (Vehicle-to-Vehicle, **V2V**), and between vehicles and fixed locations (Vehicle-to-Infrastructure, **V2I**) is essential to transfer information in real time.

- The I2V applications focus on utilizing the traffic related infrastructure, such as traffic light or streetlight to communicate useful information.

COOPERATIVE SYSTEM ARCHITECTURE

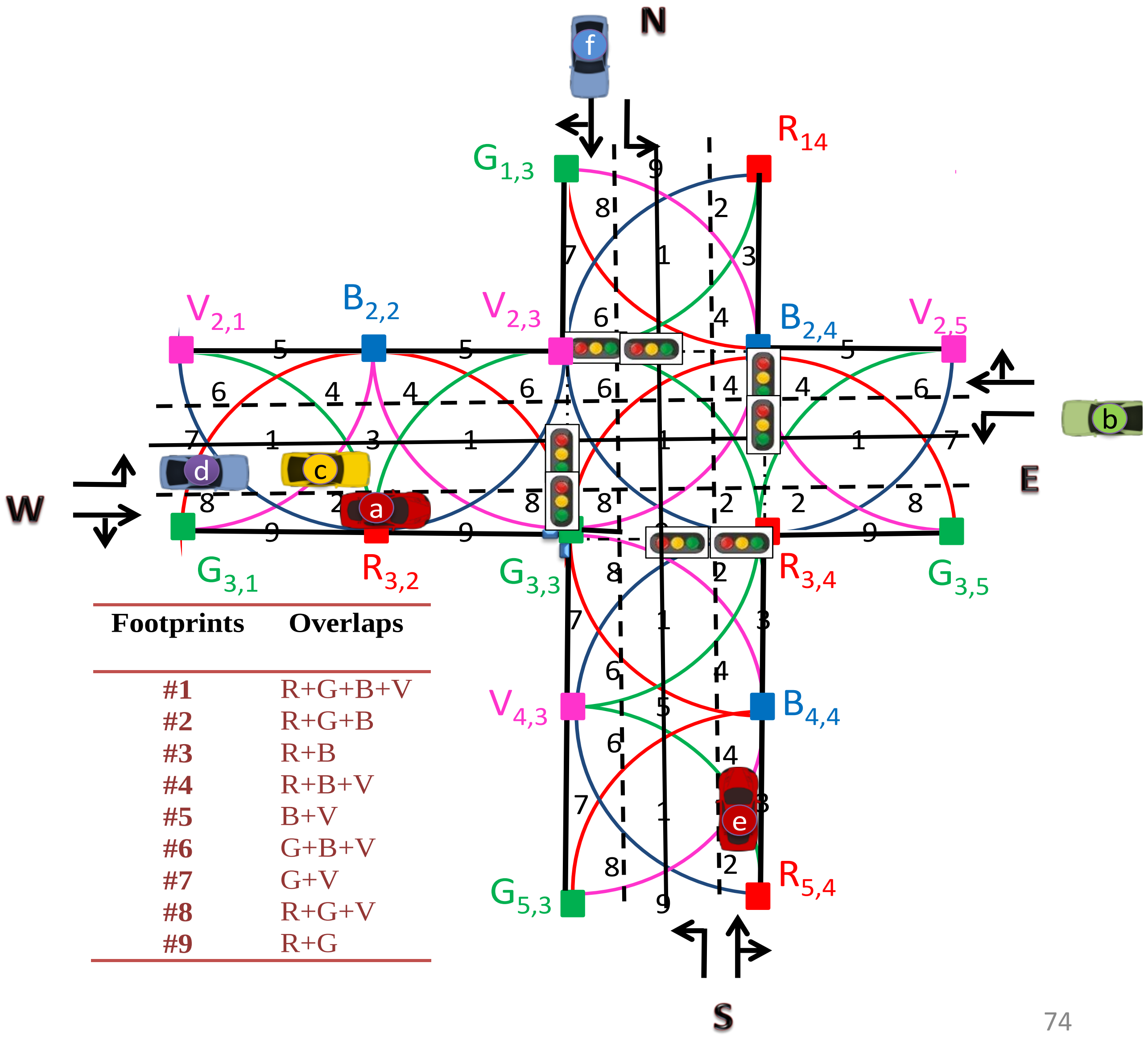


Operational procedure:

- ✓ 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).

SQUARE TOPOLOGY IN A TRAFFIC SCENARIO

- To build the I2V it is proposed a simplified cluster of **unit square** cells in an orthogonal topology that fills all the service area
- Each transmitter, $X_{i,j}$, carries its own color, X, (RGBV) as well as its horizontal and vertical ID position in the surrounding network (*i,j*).



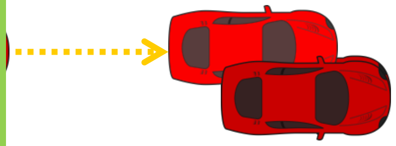
Footprints	Overlaps
#1	R+G+B+V
#2	R+G+B
#3	R+B
#4	R+B+V
#5	B+V
#6	G+B+V
#7	G+V
#8	R+G+V
#9	R+G

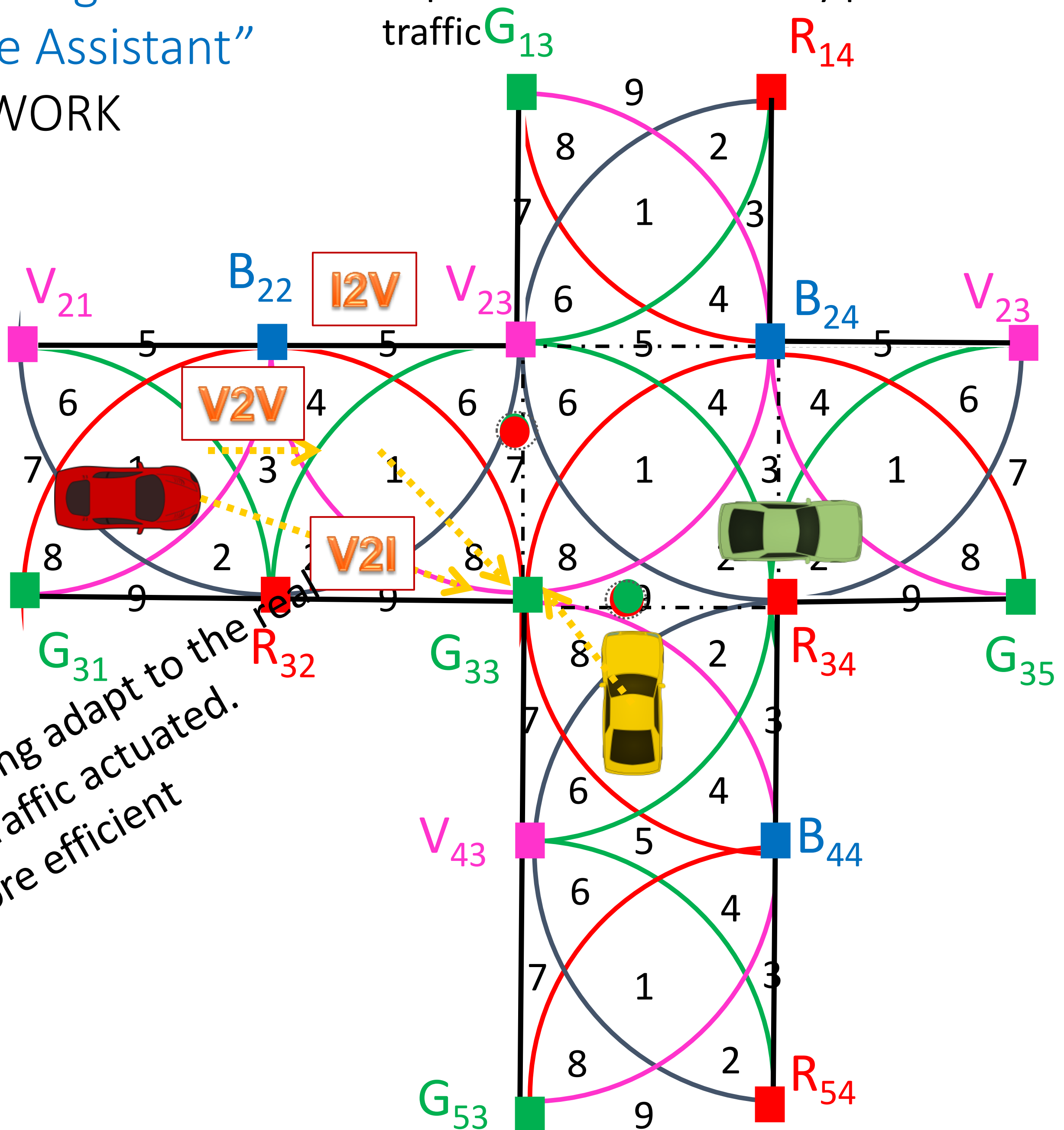
Manuel A. Vieira, Manuela Vieira, Paula Louro, Pedro Vieira, "Cooperative vehicular communication systems based on visible light communication," Opt. Eng. **57**(7), 076101 (2018), doi: 10.1117/1.OE.57.7.076101

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

WAYFINDING SERVICES

Interaction between planning, control and localization is important.

Where am I? The localization senses the environment and computes the user position,
Where am I going? The planning computes the route to follow from the position,
How do I get there? The control moves the user in order to follow the route.

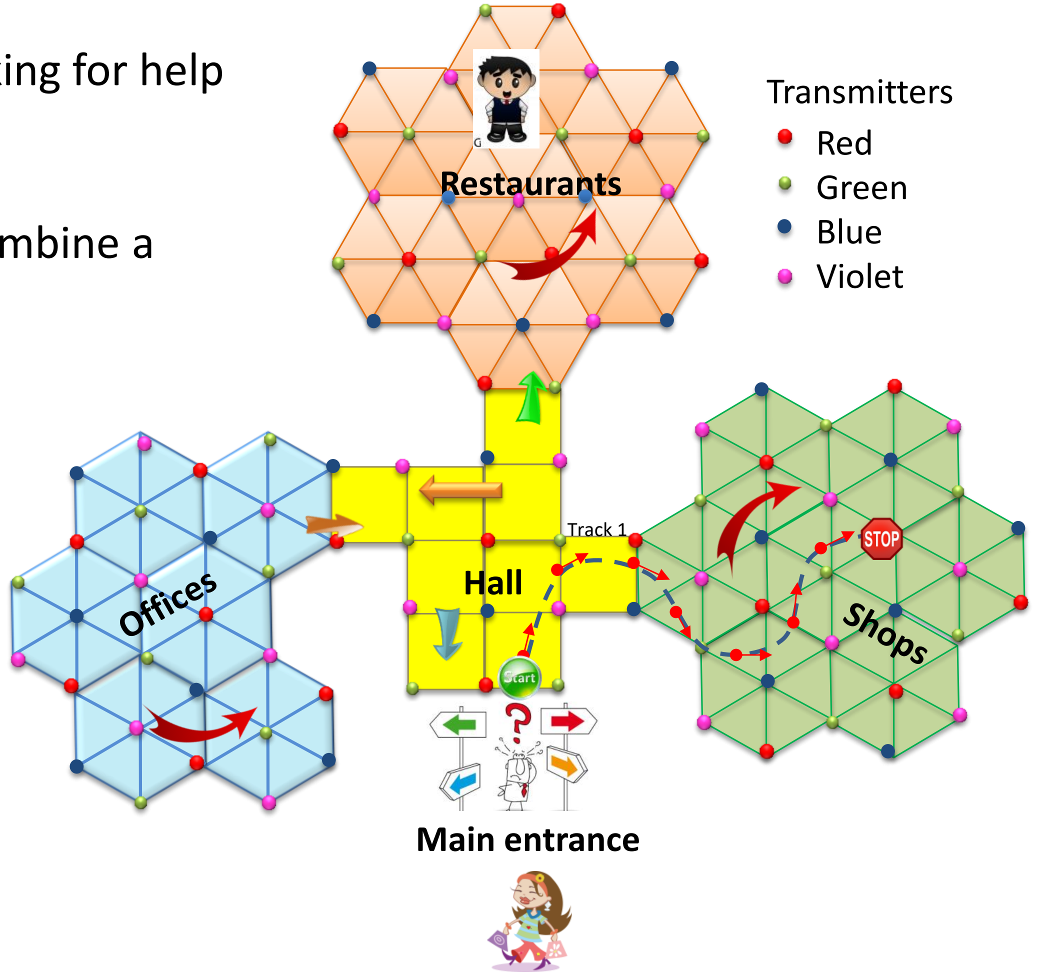
A destination can be targeted by user request to the Central Manager (CM).

Request

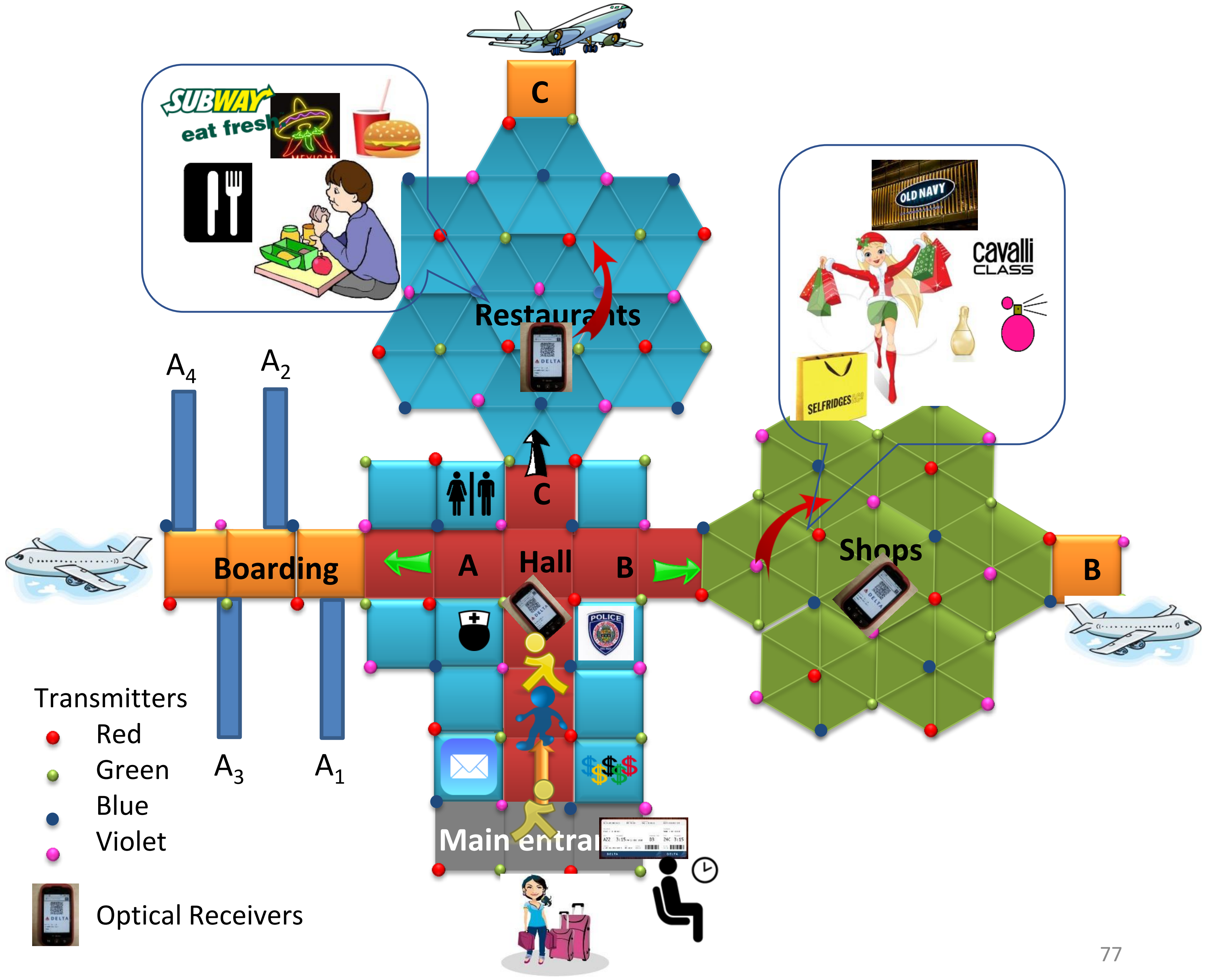
- Different users are considered.
- When arriving, they notify the CM of their localization asking for help to find the right track for their needs.
- A code identifies each user.
- If a user wishes to find a friend both need previously to combine a common code for the schedule meeting.
- The first arriving initiates the alert notification to be triggered when the other is in his floor vicinity.
- A buddy list for the meeting is generated.
- The buddy finder service uses the location information from the network's VLC location from both users to determine their proximity.

Response

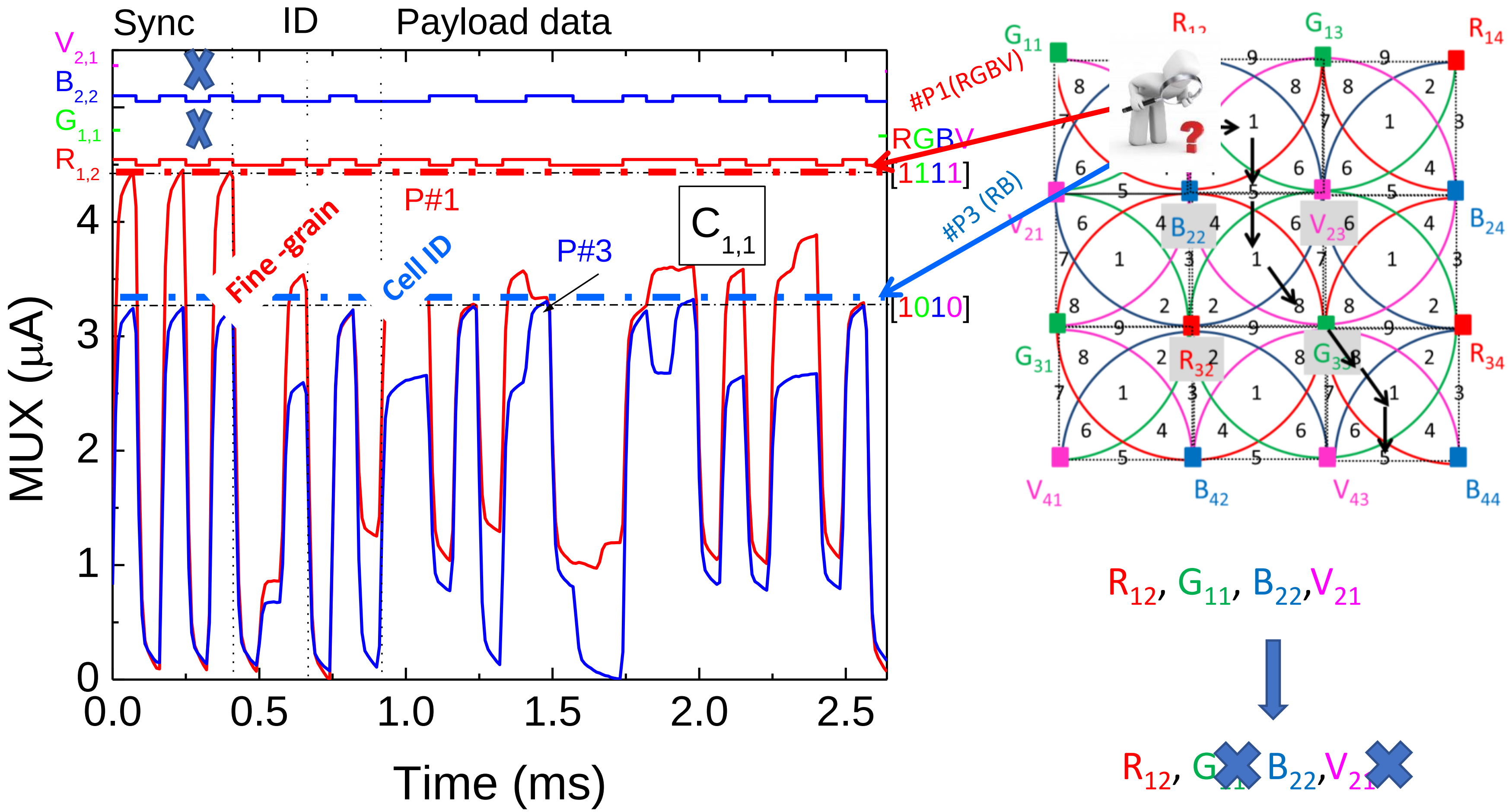
- A response message with the location and path of the meeting point is sent.



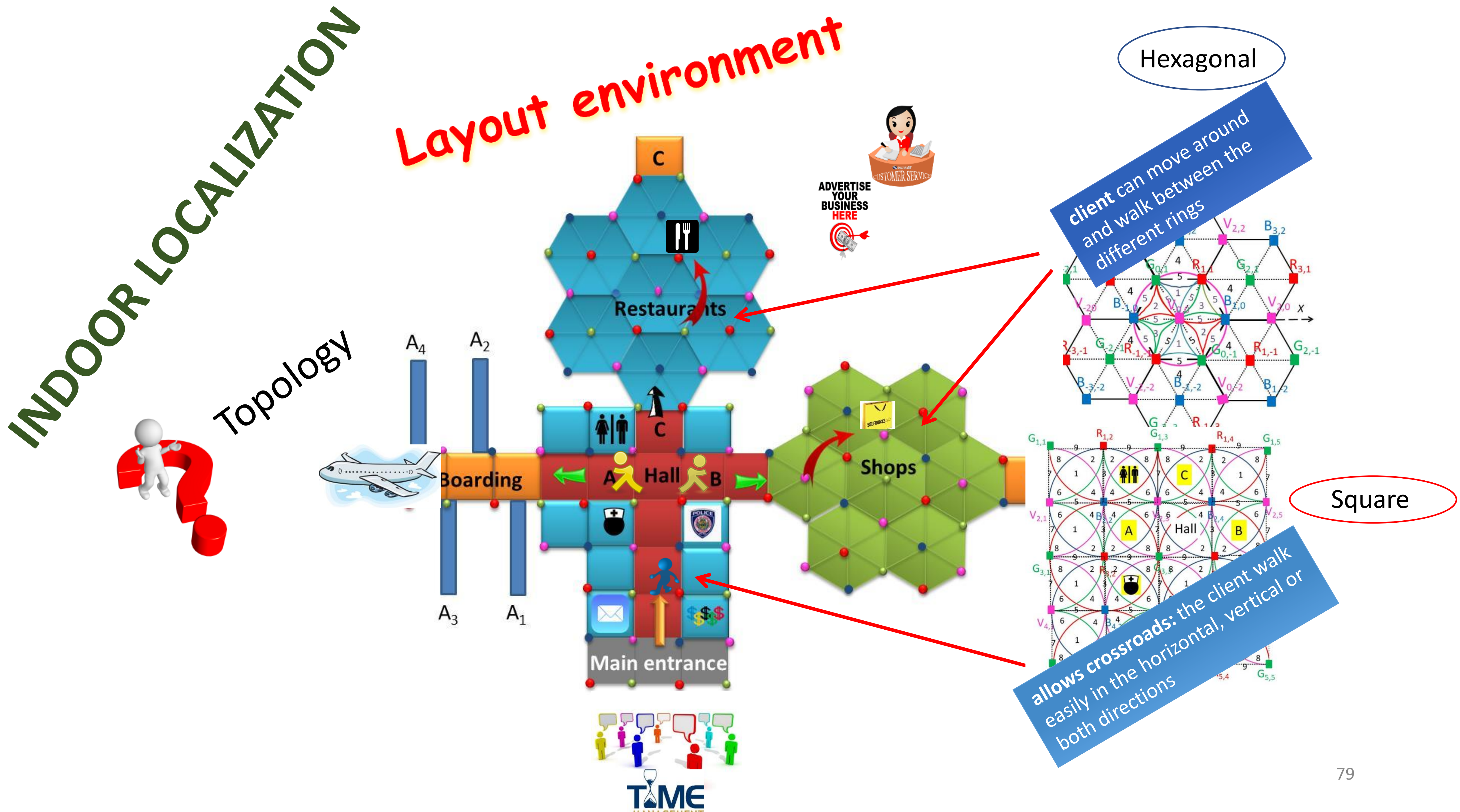
VLC SCENARIO



CELLULAR VLC SYSTEM EVALUATION



- The device position (**ID**) is given by the highest detected level*:* the level where all the *n* (n=1, 2, 3, 4) channels are simultaneously on.

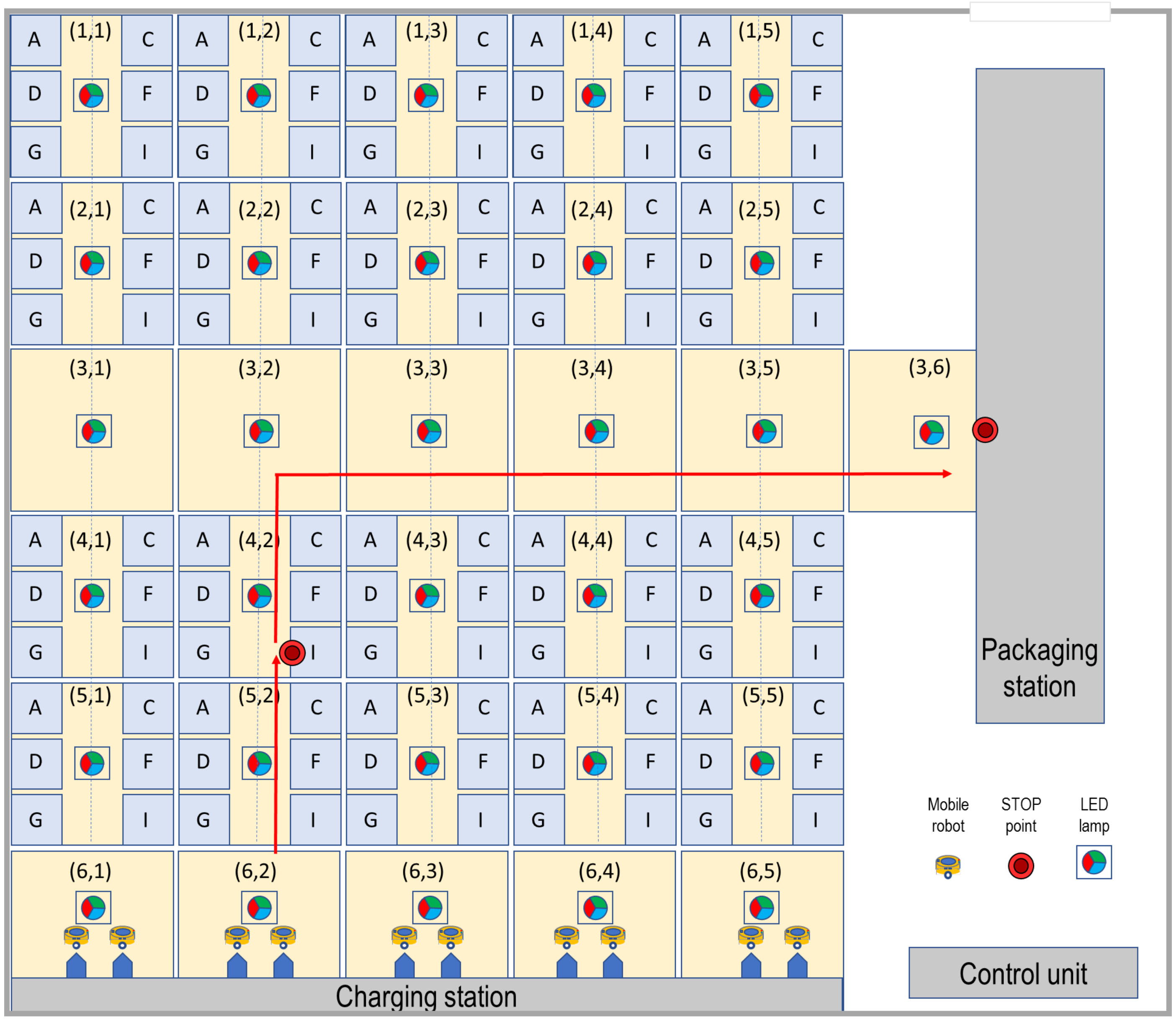


INDOOR LOCALIZATION
Layout environment
Topology
Hexagonal
client can move around and walk between the different rings
Square
allows crossroads: the client walk easily in the horizontal, vertical or both directions
Restaurants
Shops
Boarding
Hall
A
B
C
Main entrance
A_4
A_2
A_3
A_1
ADVERTISE YOUR BUSINESS HERE
CUSTOMER SERVICE
TIME

AUTOMATED WAREHOUSE

- 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

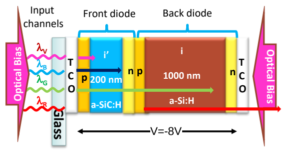
AUTONOMOUS GUIDED VEHICLE



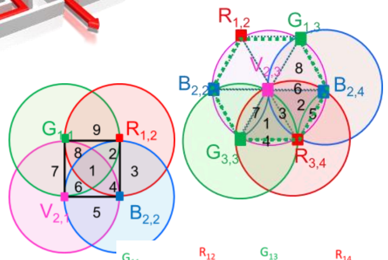
- Warehouse with 5 corridors with racks on both left and right sides.
- The indoor space is lightened using LED lamps that establish the navigation cell in a squared geometry.
- In this example there are 30 LED lamps - 30 navigation cells,
- Numbering of the cells - matrix

CONCLUSIONS

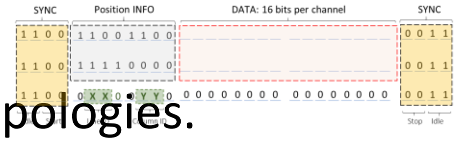
- Tunable sensitivity of a-SiC:H/a-Si:H in the visible range.



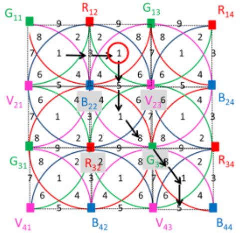
- VLC system for: data transmission and **indoor positioning**



- On-Off Keying, different cellular topologies, multiple wavelengths, several coding schemes

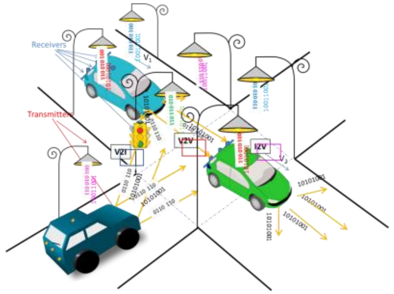


- Fine-grained indoor localization in all proposed topologies.



- A 2D localization design, demonstrated by a prototype implementation was developed.

- VLC system for: **vehicle communication** (V2V, I2V, V2I). Determination of the driving distance and position of a mobile target.



- Further efforts should be made towards the investigation and the development of a system compatible with **MIMO** applications.

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Acknowledgements

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