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

Indoor Self-localization and Wayfinding Services using Visible Light Communication: A model

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ACKNOWLEDGEMENTS

- **FCT /CTS (UIDB/00066/2020)**
- **IPL/IDI&CA/2020/GEO-LOC/SEL**

- **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

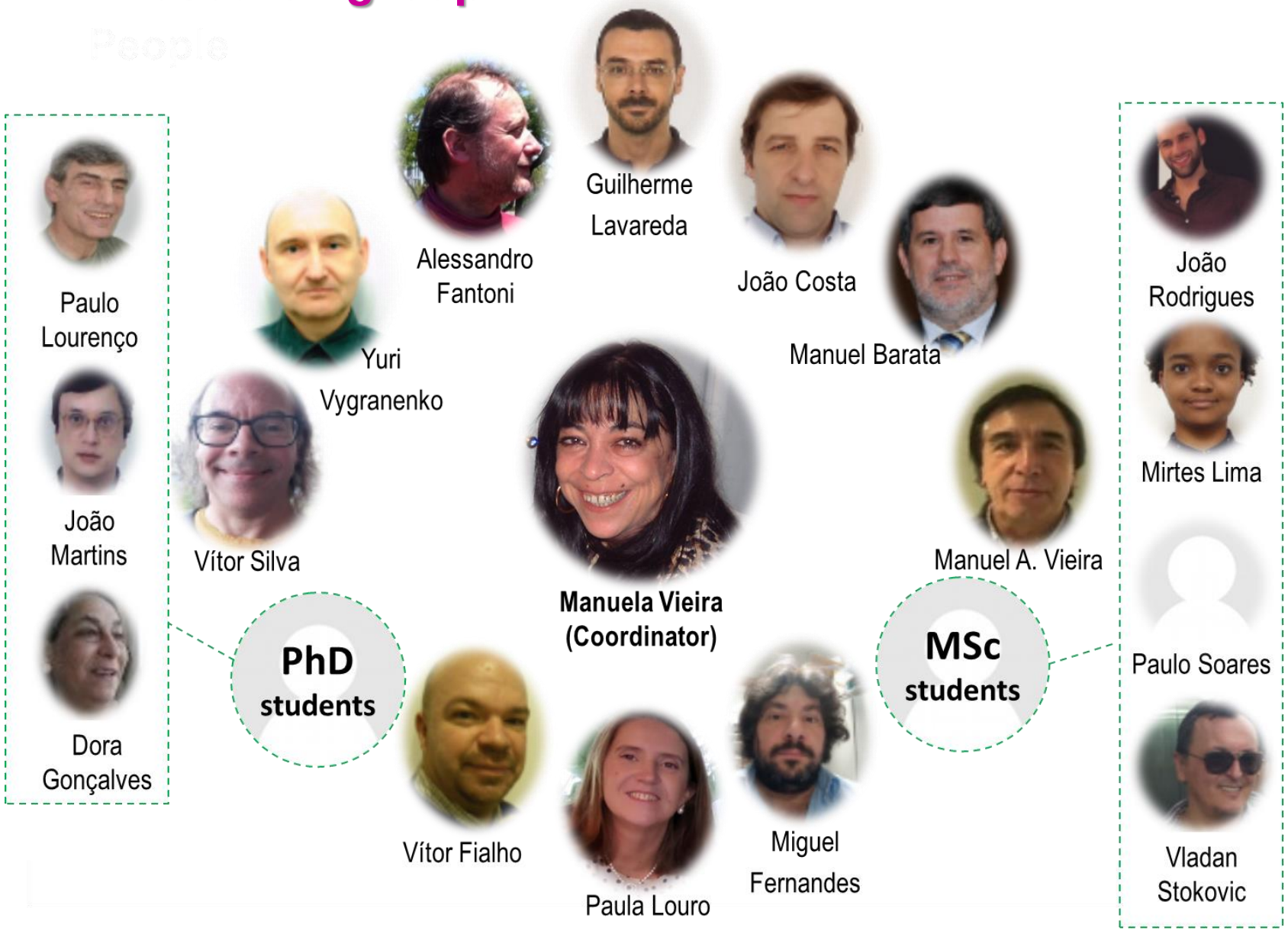
The Centre of Technology and Systems (CTS) aims to develop theoretical and applied research and encourages technology transfer mostly supported by spin offs and deep involvement in international R&D projects. The scientific results are expected to contribute to improve the graduate training in the academia 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.

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



Running projects applications

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

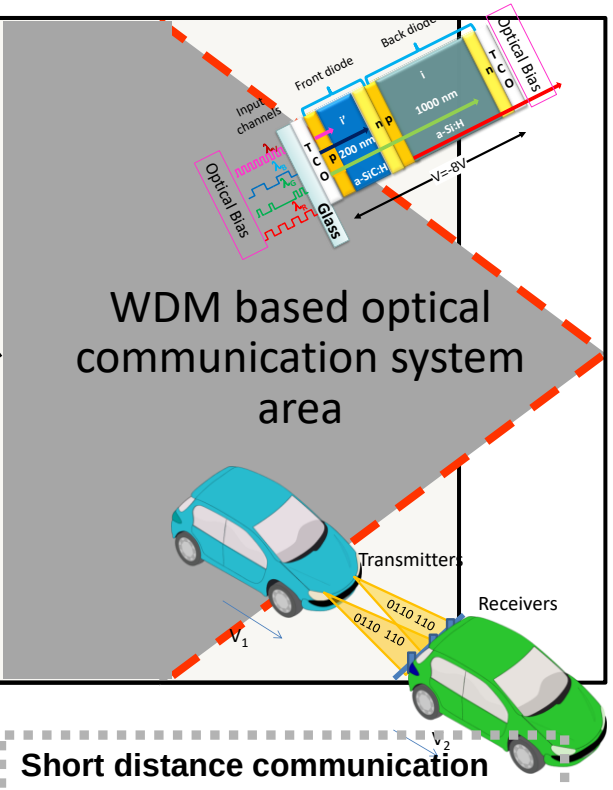
The three priorities of H2020

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

ptical biosensor system

Large area

X-ray flat detector

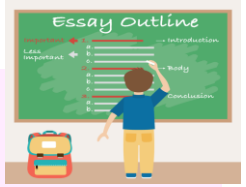


FRET based prototype to detect fluorescence of the excited fluorophores when glucose is present, allowing to monitor its level.

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



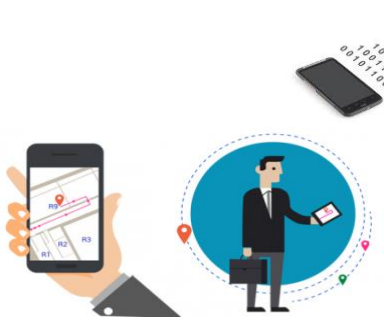
OUTLINE

✓ MOTIVATION

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

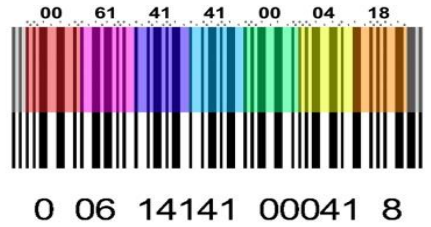
✓ SYSTEM DESIGN

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



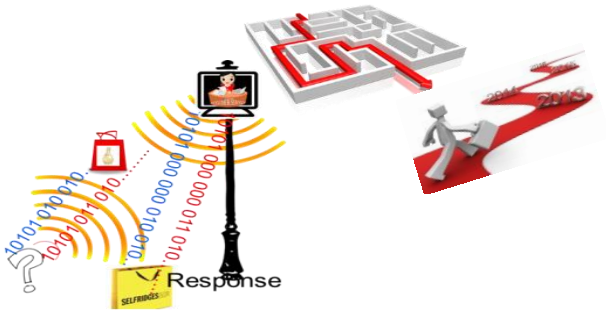
✓ CODING/DECODING TECHNIQUES

- Communication protocol by VLC
- Decoding techniques



✓ ROUTE EVALUATION

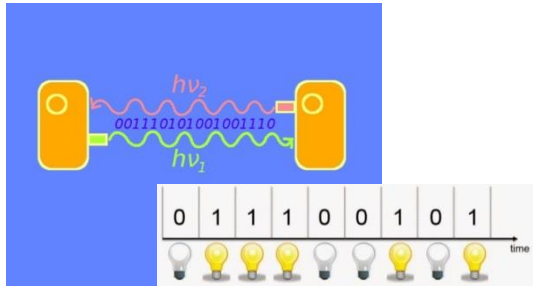
- Fine Grained Localization and travel direction
- Bi-directional Communication and wayfinding services

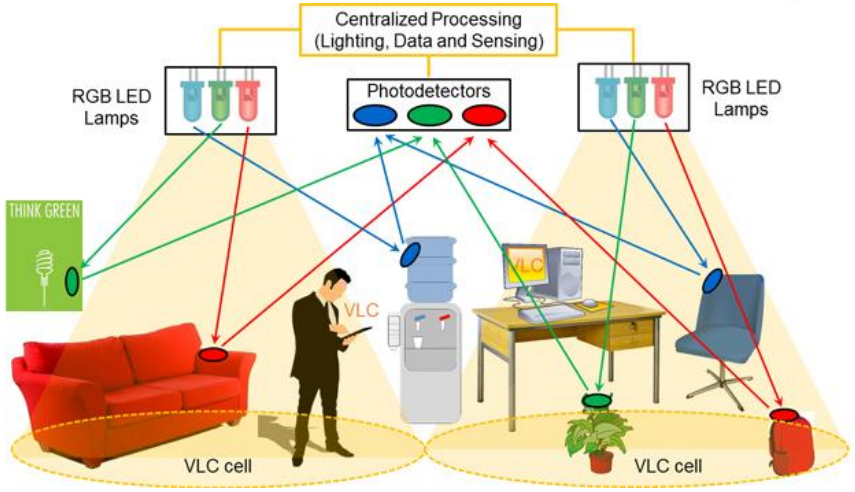


✓ CONCLUSIONS/FUTURE WORK

VLC – Visible Light Communication

Visible light Communication (VLC) is a data transmission technology that can easily be employed in indoor environments since it can use the existing LED lighting infrastructure with simple modifications.





MOTIVATION

- Compared with other sources of illumination these devices can be modulated at high data rates, offering the opportunity for communications as well as illumination from these sources.

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).

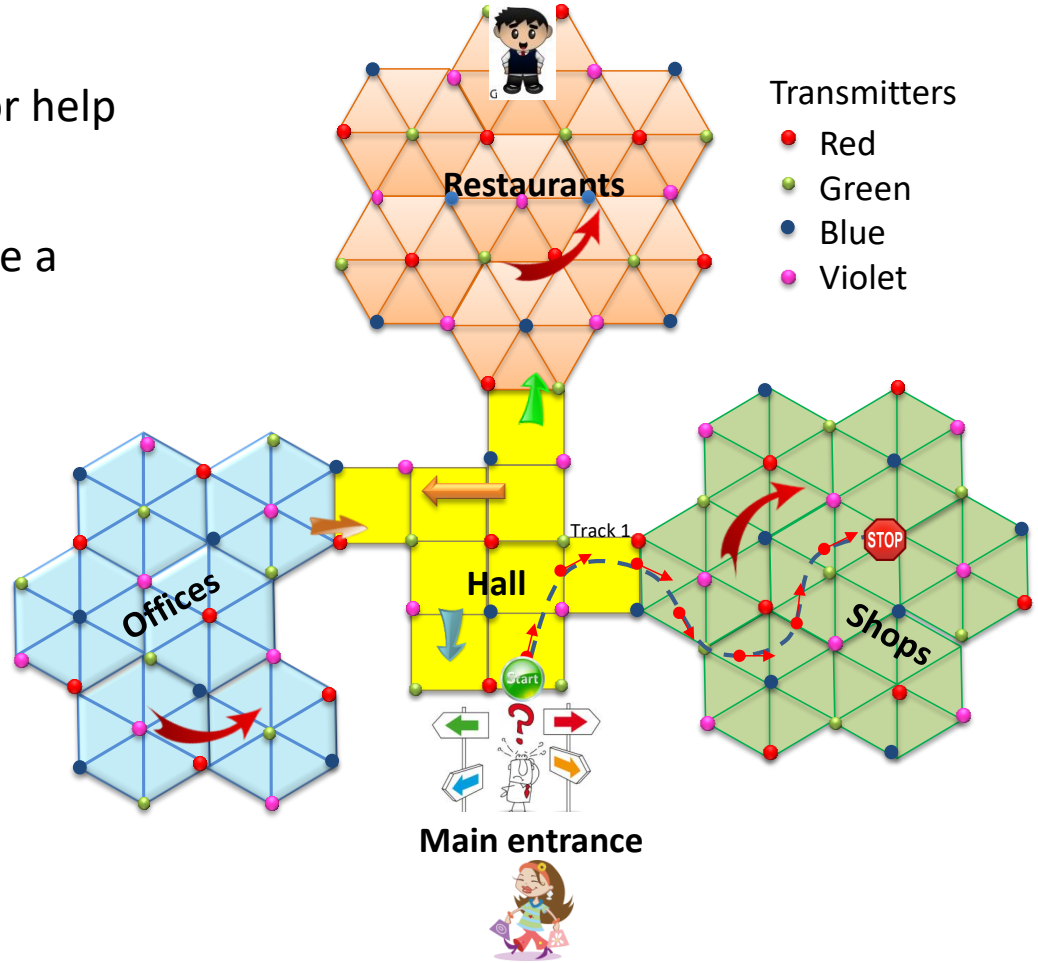
Different users are considered.

- 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.
- 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 both users to determine their proximity.

Request

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

Response

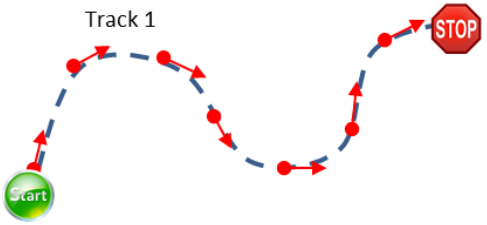


This allows the CM to recalculate, in real time, the best route for the users that request wayfinding services.

Wayfinding services

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.

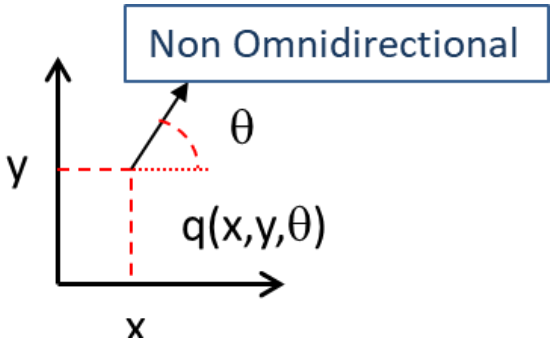


The estimation of both position and orientation are important to path definition.

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

Pose estimation

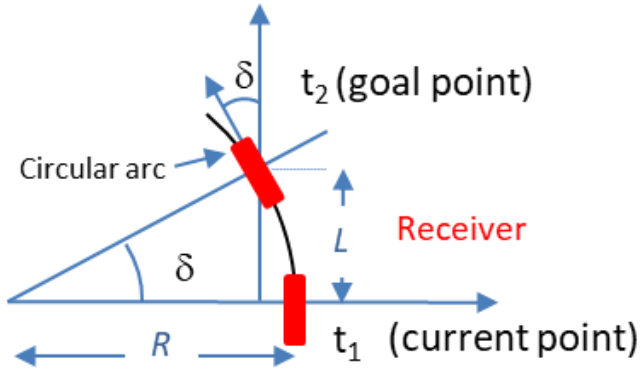
- Position (x,y) and orientation angle θ, with respect to the coordinate axes.
  $q(t) = [x(t), y(t), \theta(t)]$



Trajectory: Pursuit approach

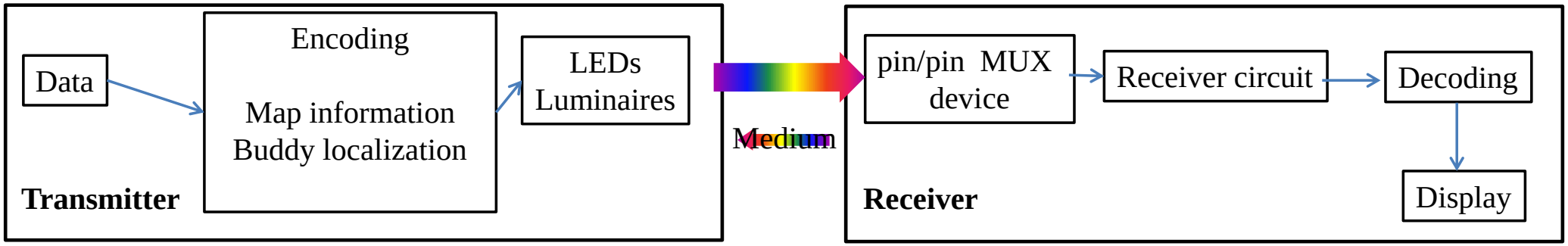
Took into account the curvature required for the mobile receiver to steer from its current position to its intended position.

- 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.

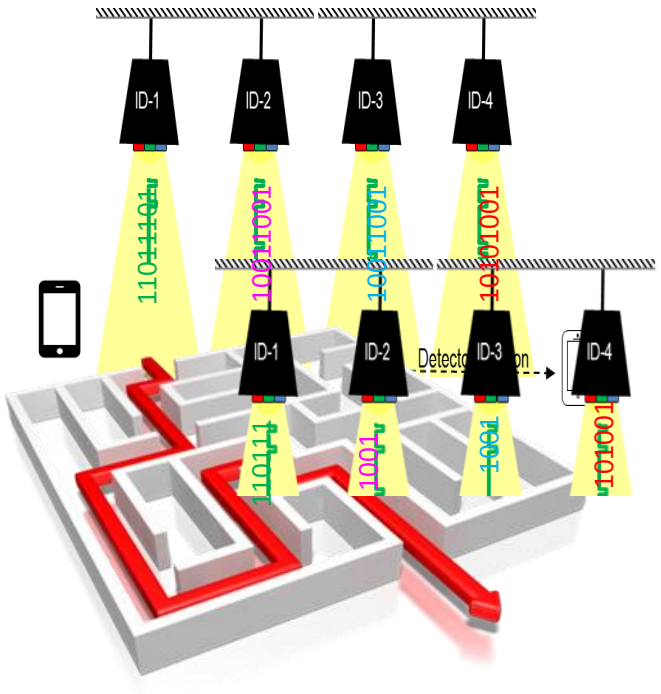


VLC dynamic navigation system (position and route control)

- 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.

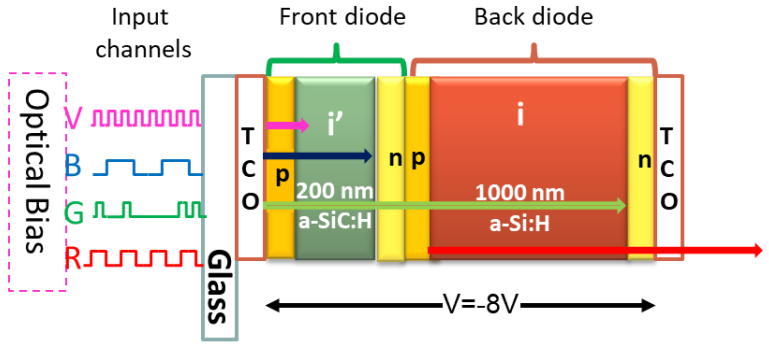


Transmitter



Line of Sight channel

Receiver

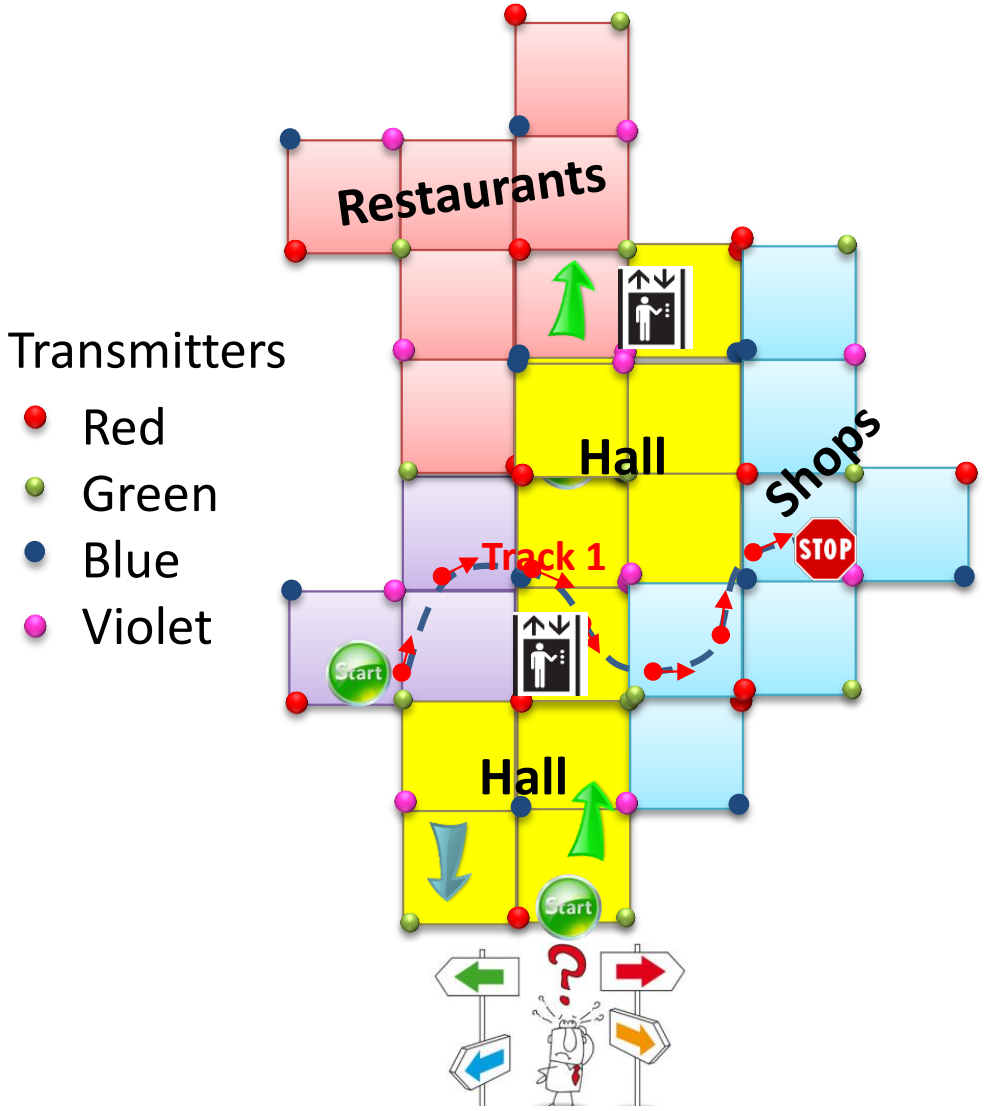


p-i'(a-SiC:H)-n/p-i(a-Si:H)-n heterostructure produced by PECVD.

- 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).

Scenario, Architecture and Building model

The scenario simulated is a 3D complex building.

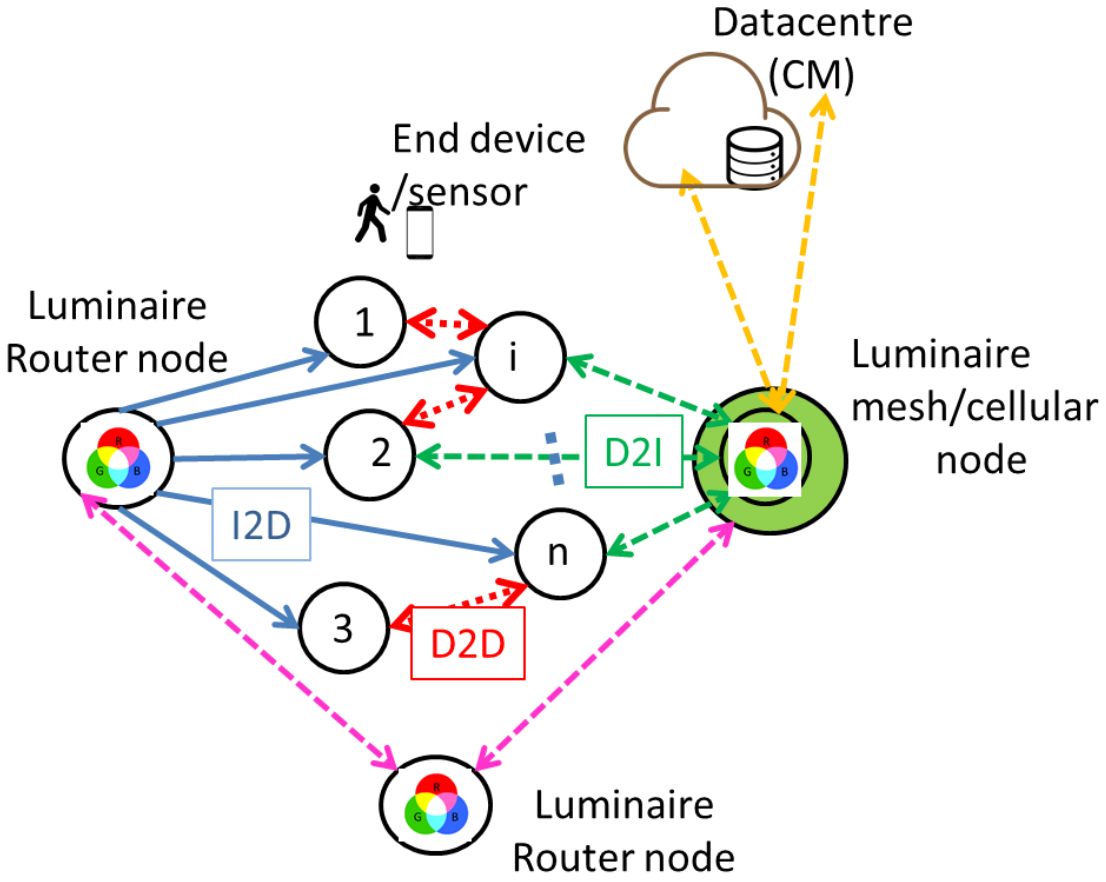


Optical infrastructure and indoor layout.

- 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.

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.

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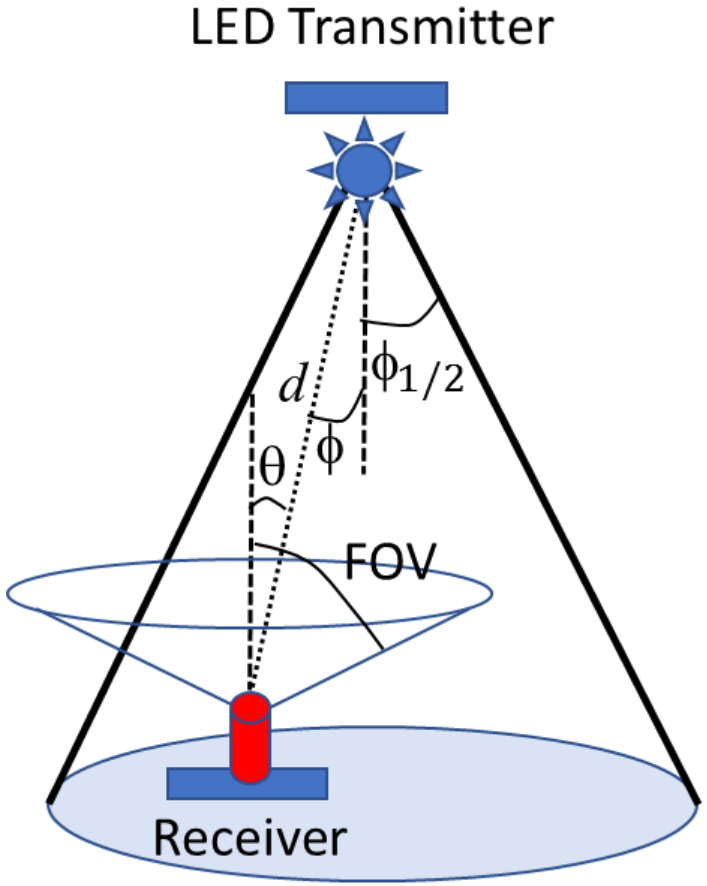
VLC link models

- 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.

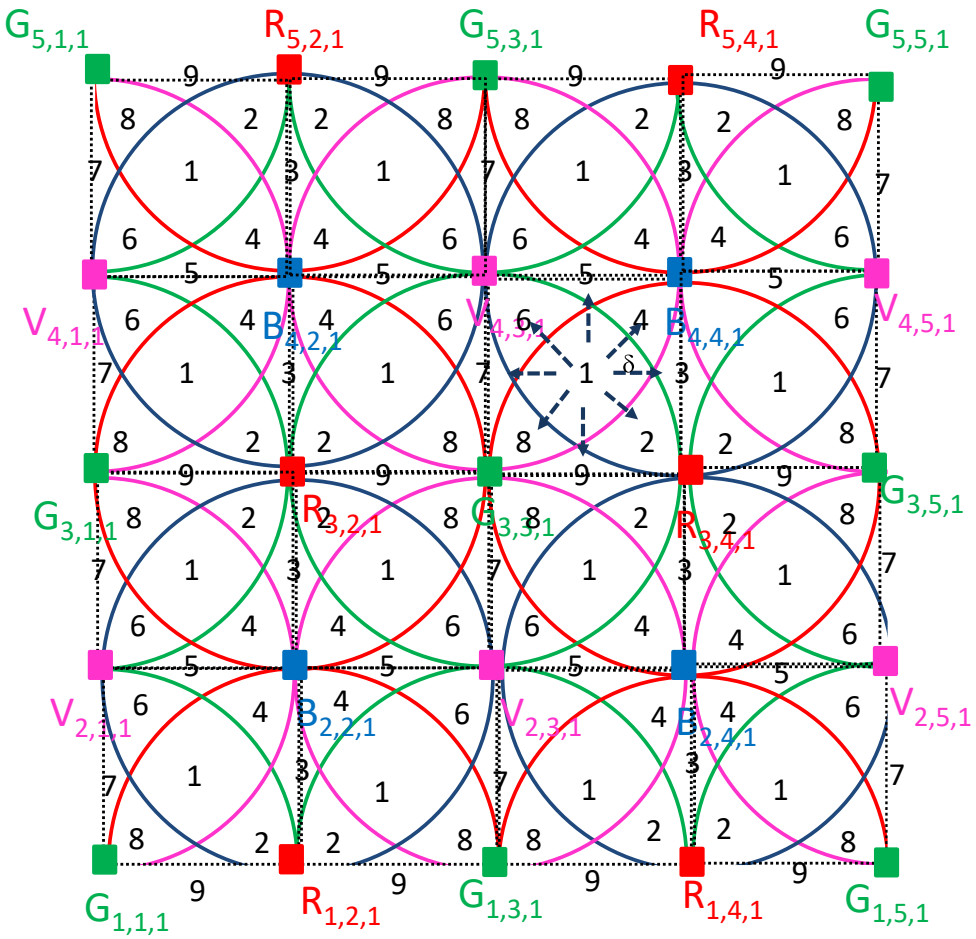
- For the proposed system, the commercial white LEDs were designed for illumination purposes, exhibiting a wide half intensity angle) of 60º. Thus, the Lambertian order *m* is 1.

- 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.**

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.

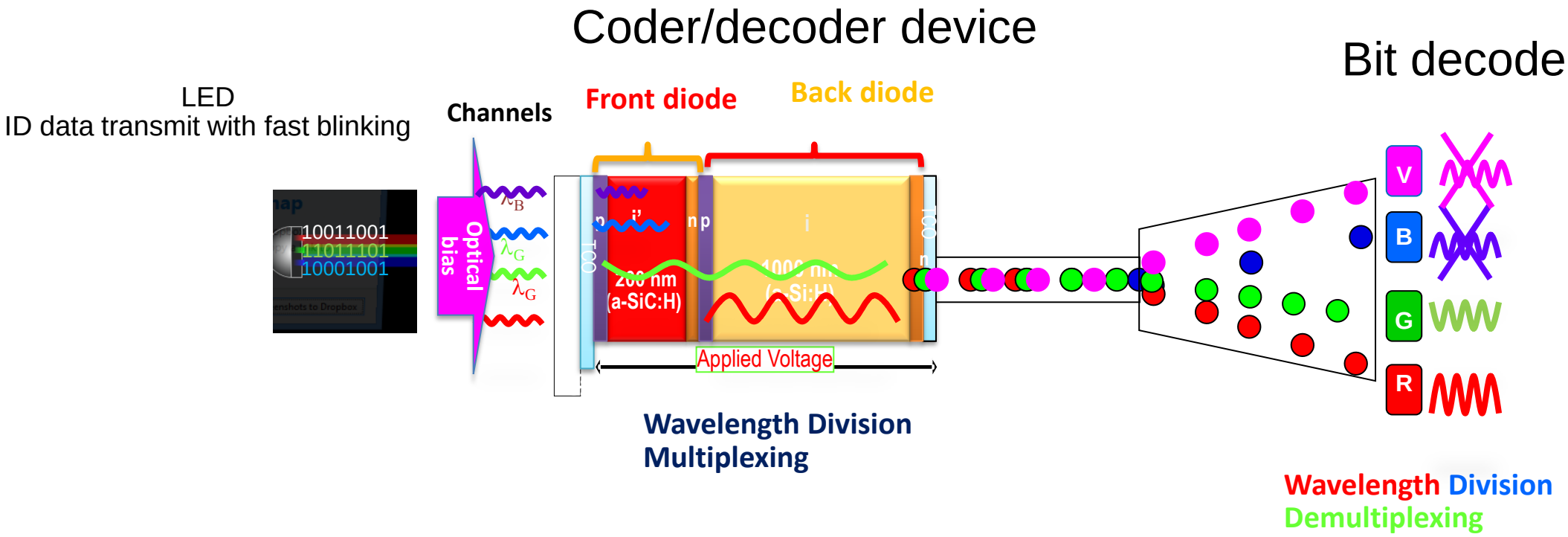
Footprint regions	#1	#2	#3	#4	#5	#6	#7	#8	#9
Square topology	RGBV	RGB	RB	RBV	BV	GBV	GV	RGV	RG

Steering angle code	1	2	3	4	5	6	7	8	9
Square topology (δ)	-	(SE)°	(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).**

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).

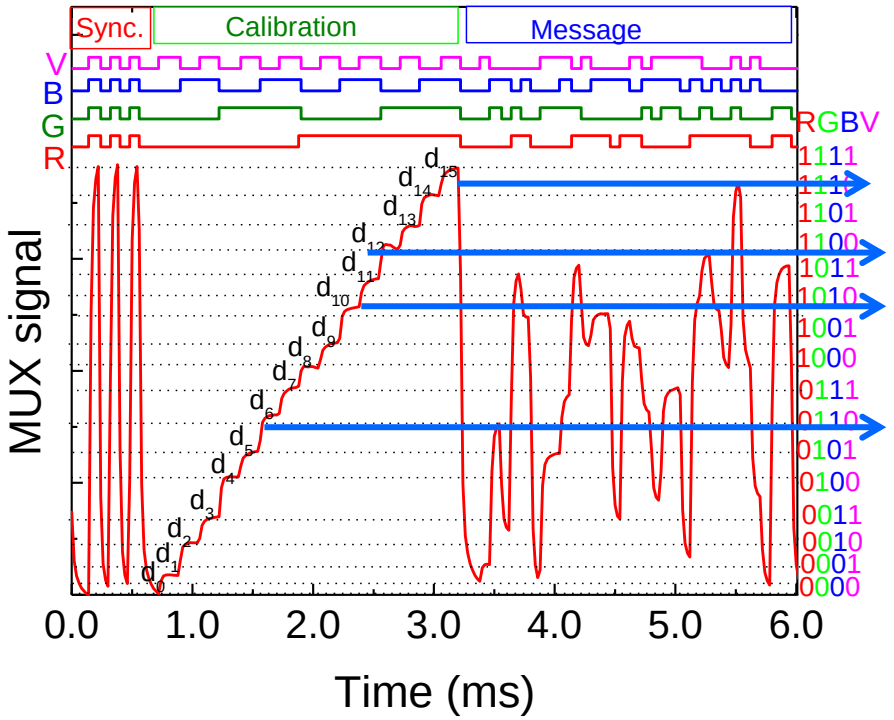
DECODING ALGORITHM

Calibration

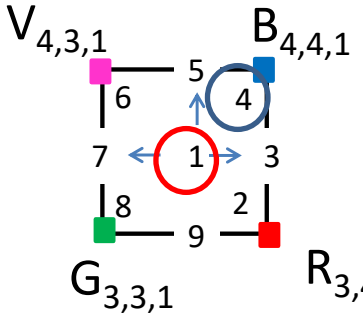
The information about the emitters that are being modulated is crucial to determine the pose of the receiver relative to the lighting/communication infrastructure.

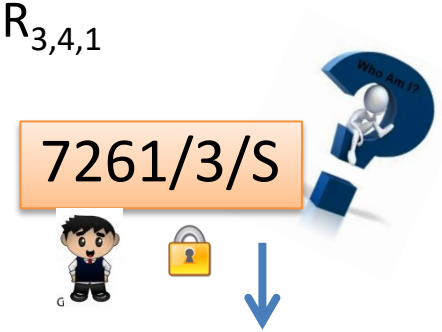
The calibration supplies an additional tool to enhance the decoding task.

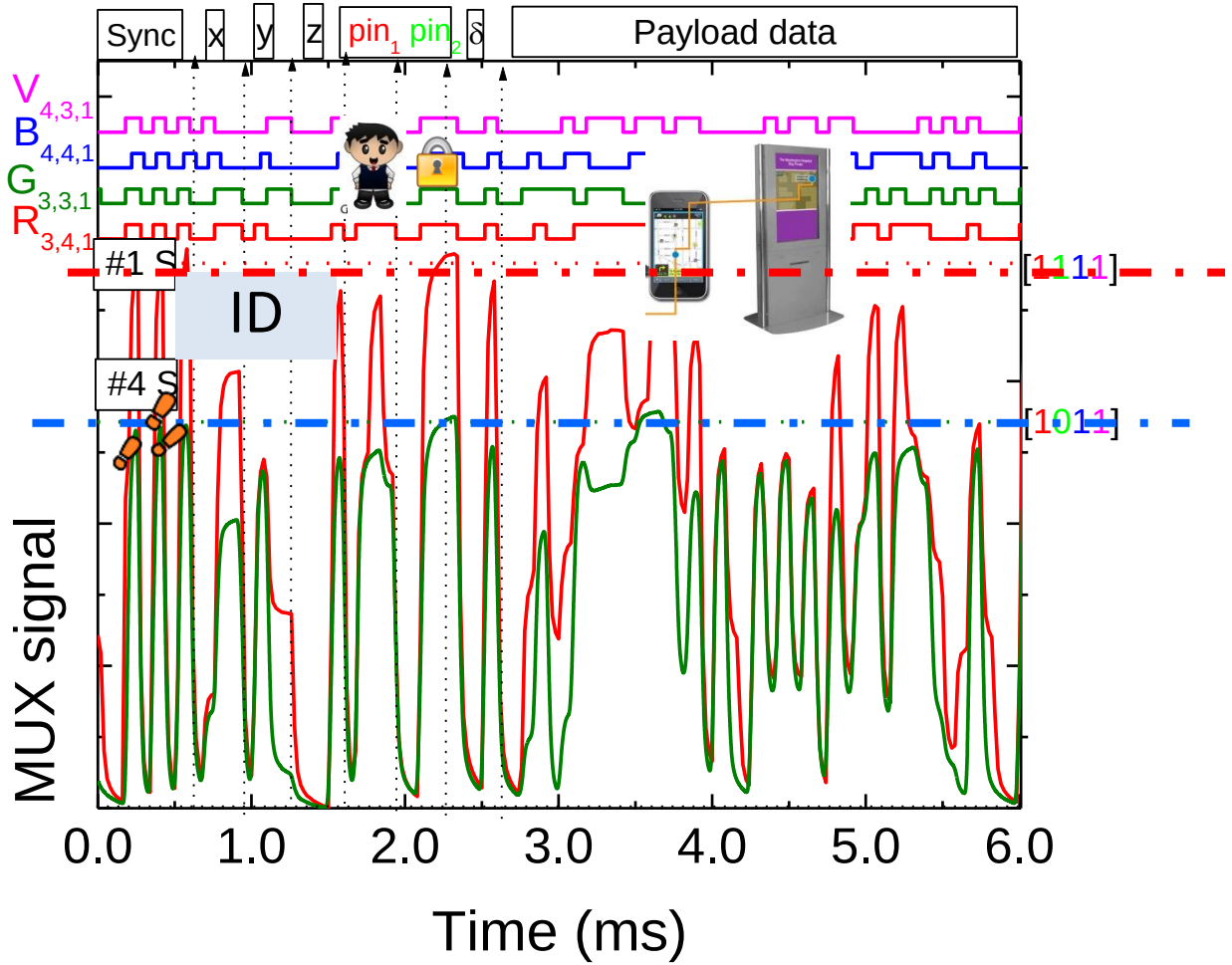
The bit sequence allows all the *on/off* sixteen possible combinations of the four RGBV input channels (2^4).

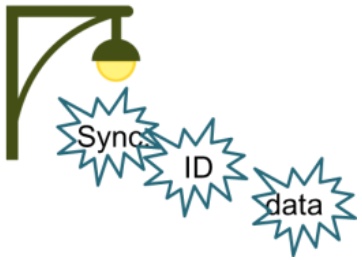


- 2^4 ordered are detected and correspond to all the possible combinations of the *on/off* states.
- By assigning each output level to a 4-digit binary code, [X_R, X_G, X_B, X_V], with X=1 if the channel is *on* and X=0 if it is *off*, the signal can be decoded.
- Comparing the calibrated levels with 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.







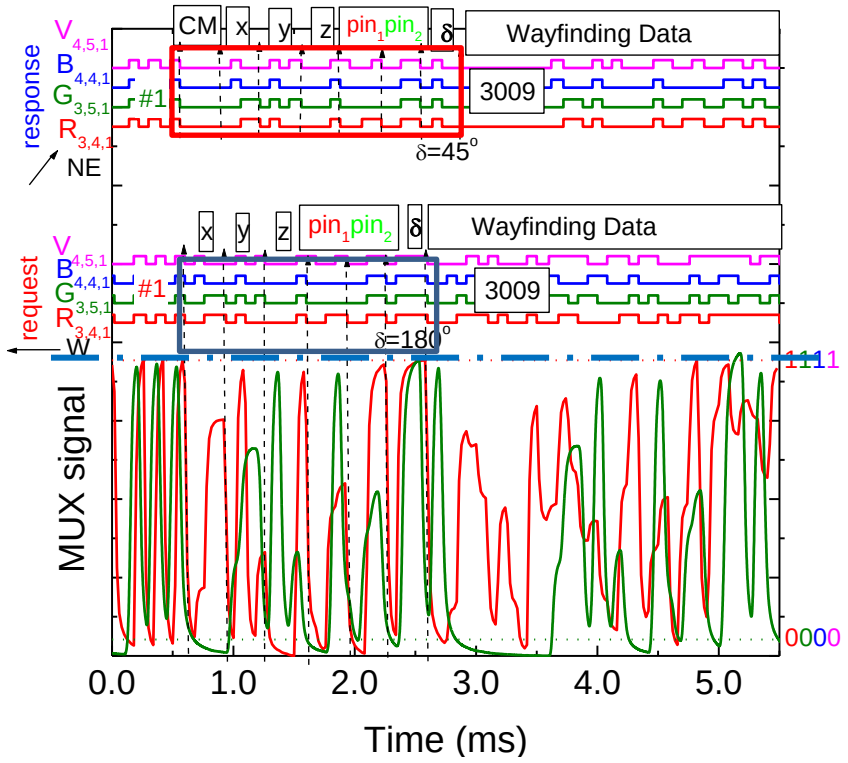


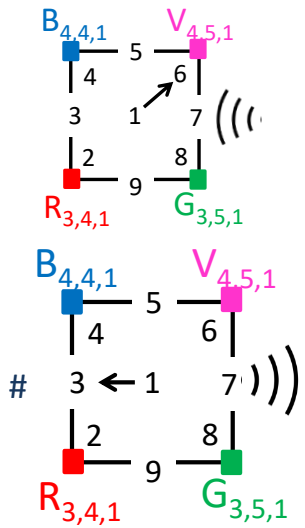
MUX-DEMUX

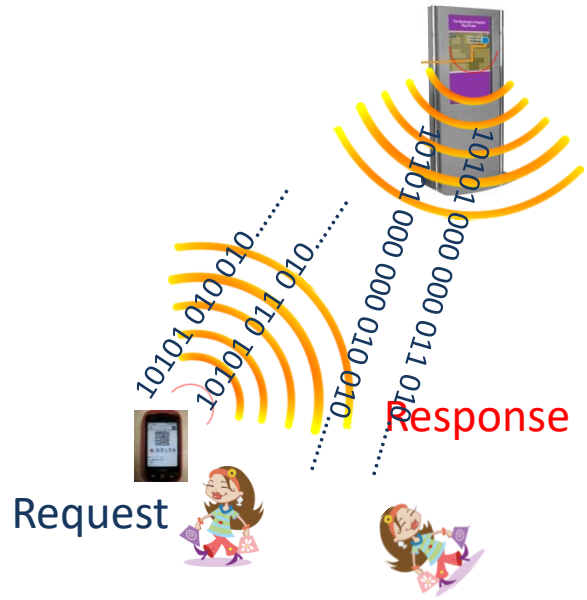
- The footprint position comes directly from the synchronism block, where all the received channels are, simultaneously, *on* or *off*.
- The next block of 12 bits gives de ID of the received nodes.
- The last block is reserved for the transmission of the wayfinding message.

ID

Bi-directional Communication

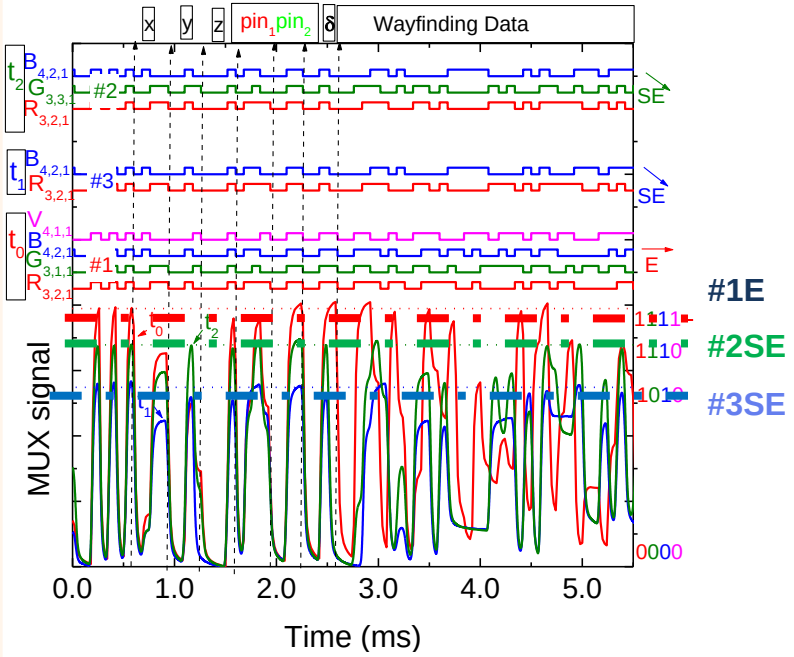


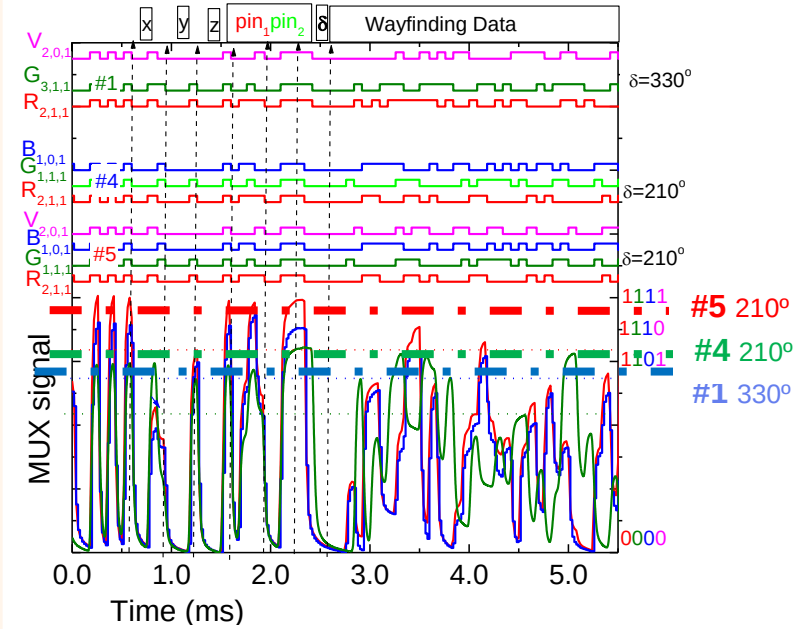


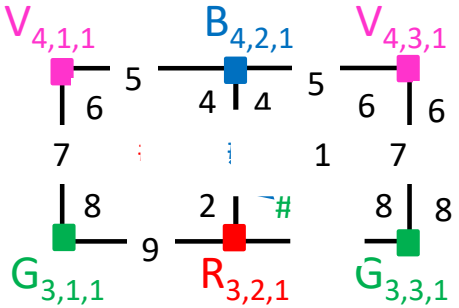


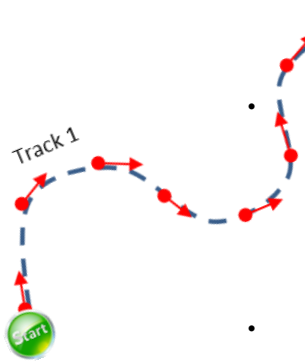
- Bi-directional communication between VLC emitters and receivers at a handheld device can be established through a control manager linked to an indoor billboard.
- Using a white polychromatic LED as transmitter, the receptor sends to the local controller a “request” message with its location (ID) and 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.

Fine Grained Localization and travel direction







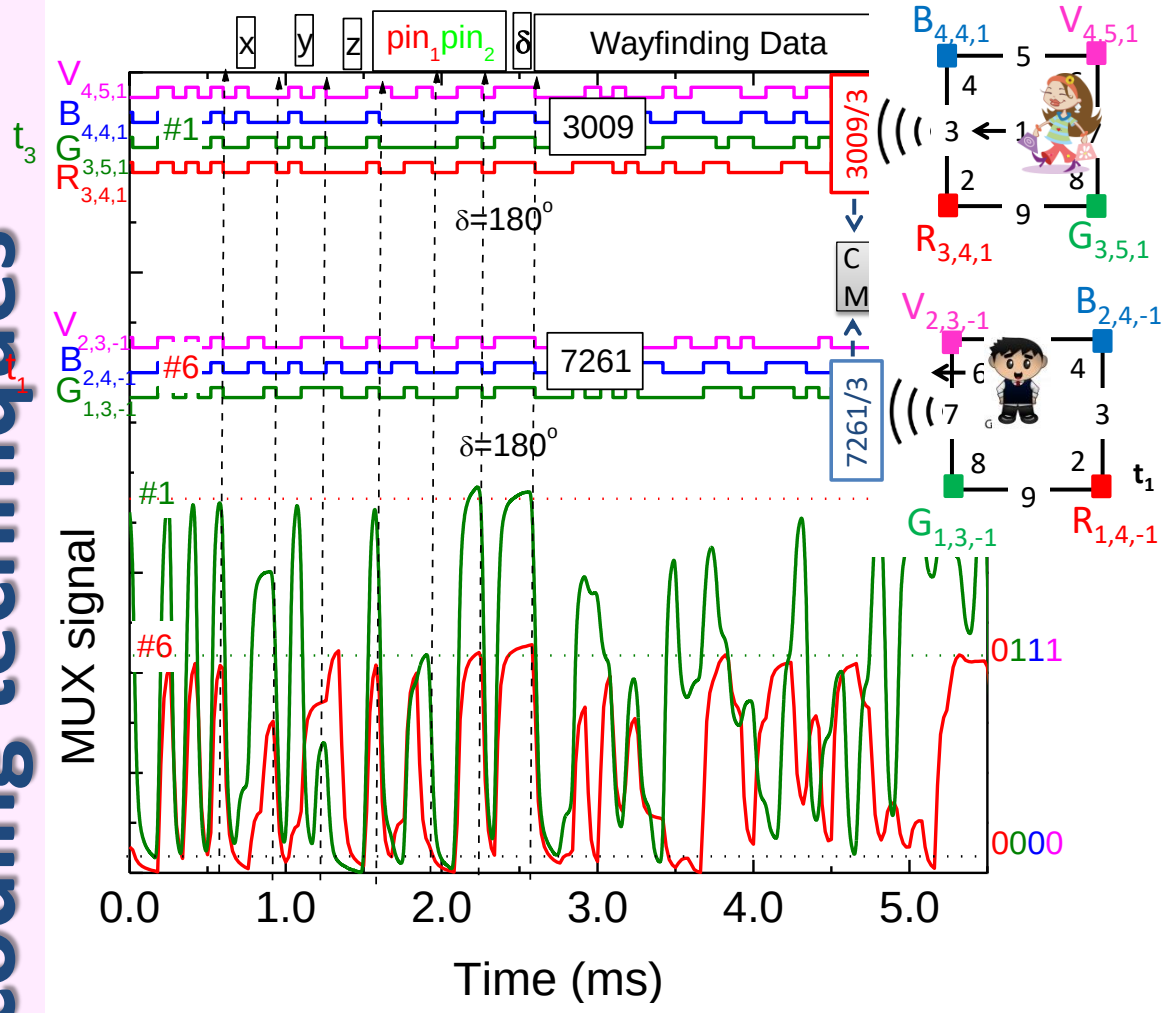


- To compute the point-to-point along a path, we need the data along the path.
- As the receiver moves between generated point regions, the received information pattern changes.
- The transition actions are correlated by calculating the ID position codes in successive instants.

Aided dynamic navigation

Communication protocol and decoding techniques

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



The data was coded using an On-Off keying (OOK) modulation in a 64-bits word.

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).

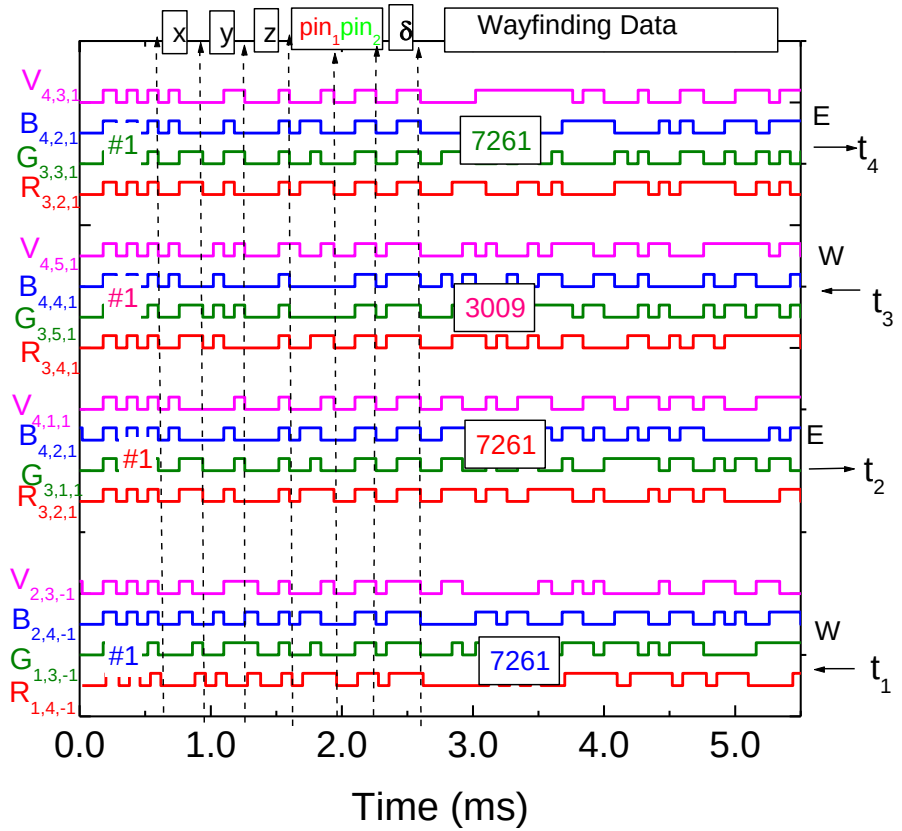
When bidirectional communication is required, the user has to register by choosing a user name (pin1) with 4 decimal numbers, each one associated to a colour channel.

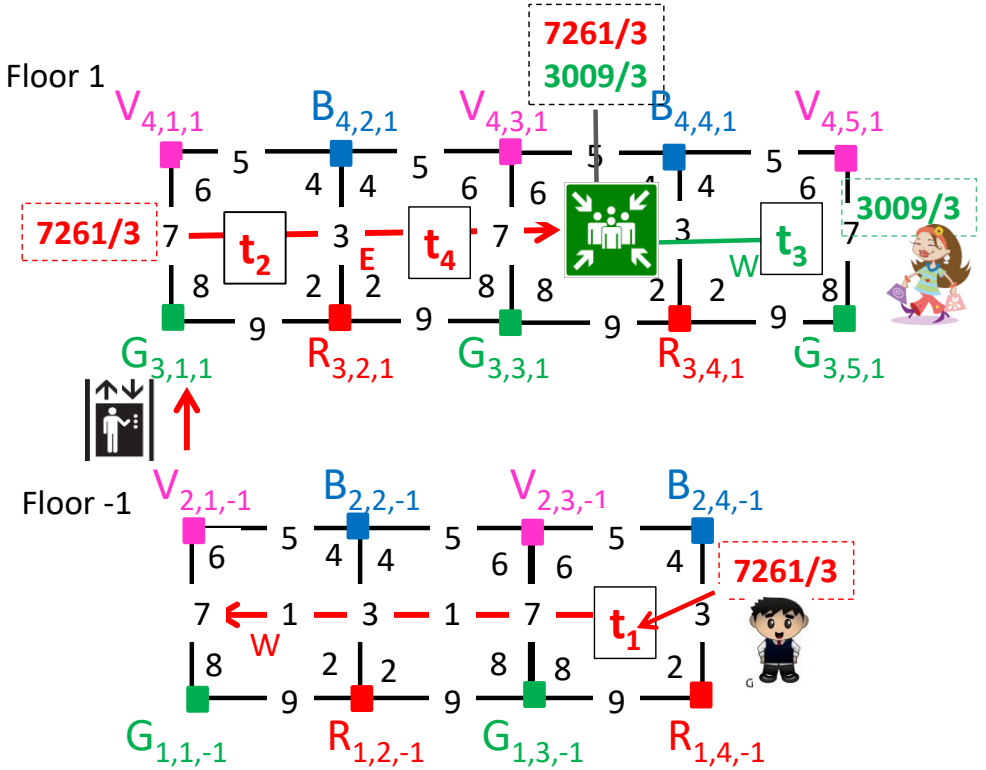
If buddy friend services are required a 4-binary code of the meeting (pin2) has to be inserted.
The coded steering angle (δ) completes the pose in a frame time).

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.

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

Wayfinding Services





- Data shows that 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 $C_{4,3,1}$.
- The existence of congested zones can be locally detected by the "mesh / cellular" hybrid controller), which is also equipped with a modem providing IP base connectivity to the central manager. The hybrid controller integrates the number of requests and individual poses, qi (t), received during the same time interval. Once the individual poses are known, the relative poses, q_{ij} (t) are calculated. An alert notifies the user of the best route.

Conclusions

- A VLC multi-person cooperative localization dynamic LED-assisted positioning and navigation system was proposed based on ceiling landmark route instructions using VLC.
- A 3D building model for large indoor environments was presented, and a VLC scenario in a multilevel building was established.
- The communication protocol was presented. Bi-directional communication between the infrastructure and the mobile receiver was analyzed.
- Global results show that the location of a mobile receiver, concomitant with data transmission is achieved. The dynamic LED-aided VLC navigation system enables to determine the position of a mobile target inside the network, to infer the travel direction along the time and to interact with received information.
- The VLC system, when applied to large building, can help to find the shortest path to a place, guiding the users on a direct, shortest path to their destinations.

THANK YOU
FOR YOUR ATTENTION