Wayfinding Services in Crowded Buildings through Visible Light

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- **Manuela Vieira** was born in Lisbon, Portugal. In 1986, she received the Master of Science in Solid State Physics-Microelectronic and in 1993 the PhD in Semiconductor Materials, both from the New University of Lisbon. She receives the habilitation title in Electronics, in 2003 from New University of Lisbon, Portugal.
- She is a Full Professor, since 2011, in Electronics inside the Department of Electronics Telecommunication and Computers (ISEL-Portugal) and Associated Professor in the New University of Lisbon, School of Sciences and Technology (UNL-FCT, Portugal).
- She is also the Leader of the Research Groups in Applied Research in Microelectronic Optoelectronic and Sensors (GIAMOS / ISEL) and in Microelectronic, Material and Processes (M2P/ CTS-UNINOVA). She has several scientific papers and has participated in many international and national projects, both as a researcher and as a project coordinator. She has 30 years of experience in the field of thin films and devices and on Visible Light Communication.

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, Revista Ibersensors, Physica Status Solidi, Sensors, Journal of Nanoscience Nanotechnology, Journal of Sensors, Journal of Signal and Imaging Systems Engineering (IJSISE), etc.
- Evaluator of proposals submitted to several international funding organizations
- Supervision and co-supervision of Master and PhD students
- Examiner for Master and Doctoral degrees.
- Authored and co-authored over than *400* publications in refereed journals and conferences proceedings. Presented more than 500 communications at conferences and seminars most of which with publication in journals and proceedings. She is an IARIA Fellow since 2018.

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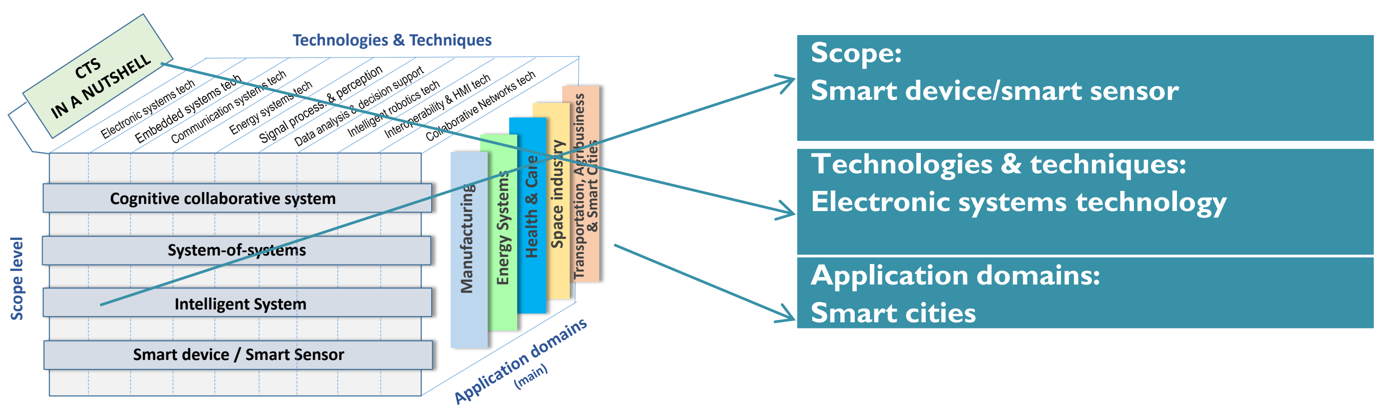
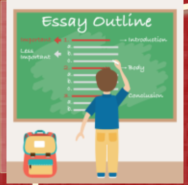




OUTLINE

✓ 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

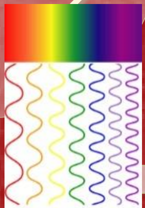
- Communication protocol by VLC
- Decoding techniques

✓ ROUTE EVALUATION

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

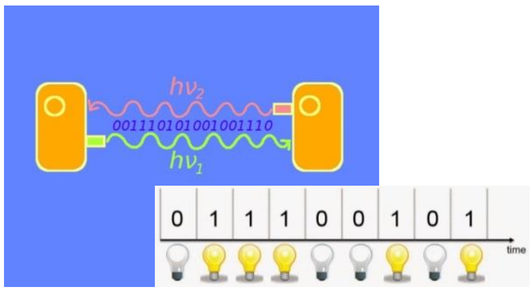
✓ CONCLUSIONS/FUTURE WORK

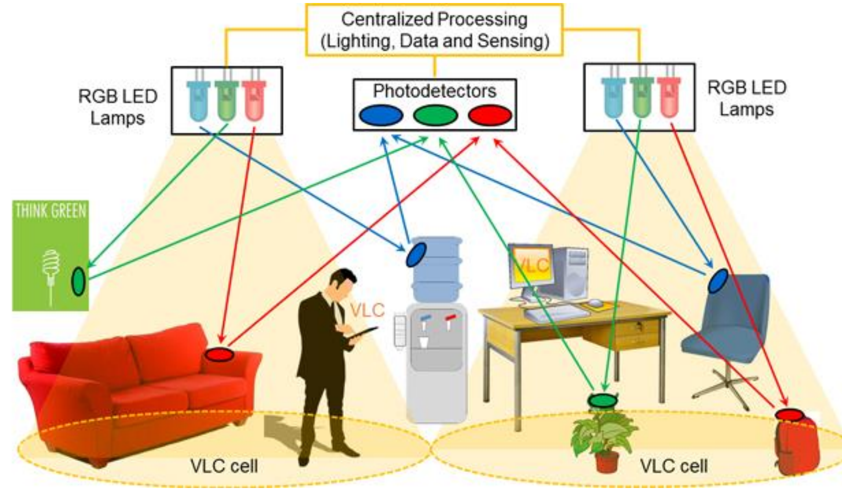
MOTIVATION



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.





- 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.

Wi-Fi will begin to become limited

Wayfinding concepts

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.

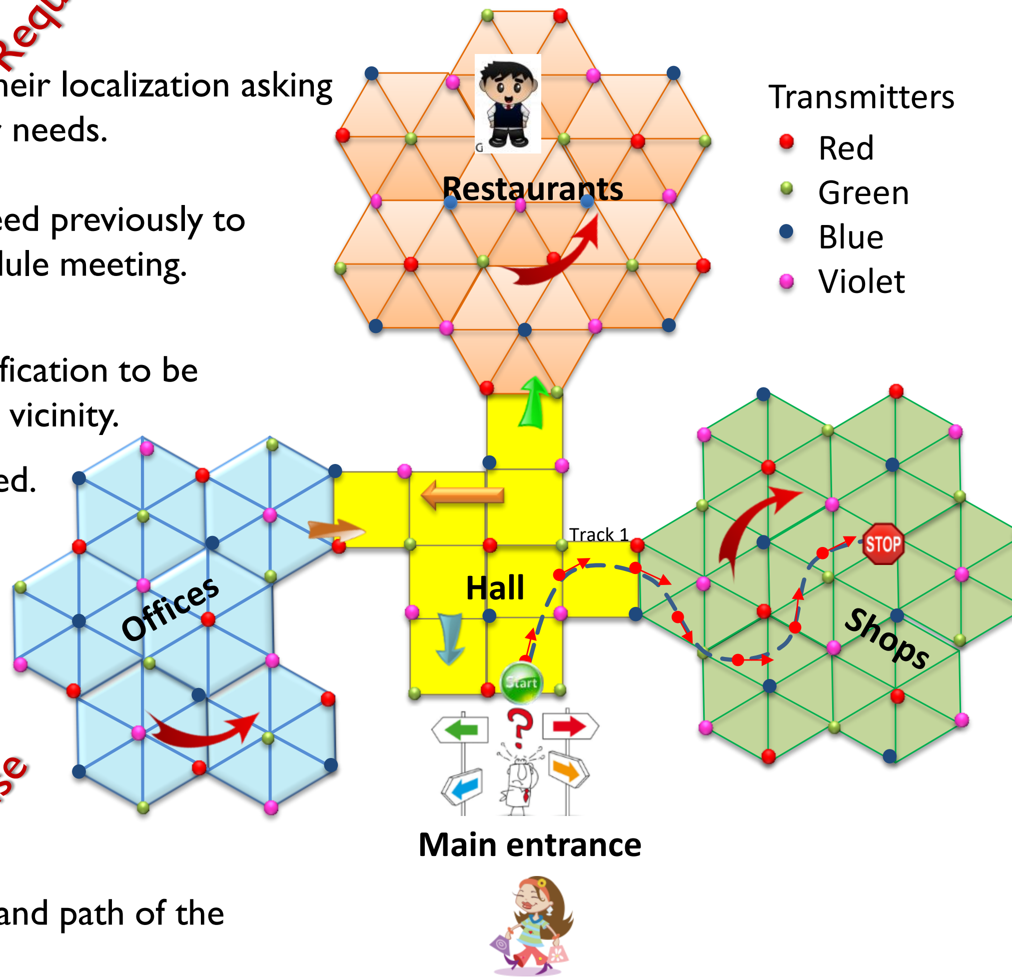
Request

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.



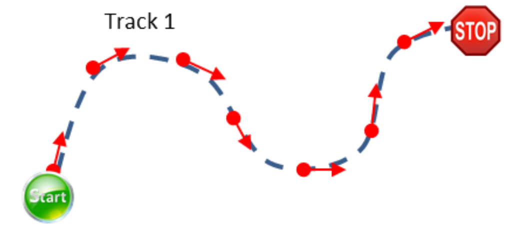
Response

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

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.

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

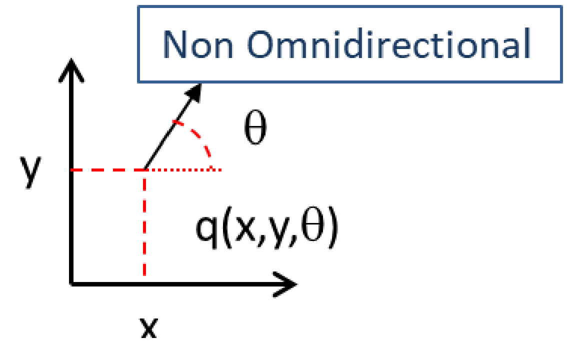


The estimation of both position and orientation are important to path definition.

Pose estimation

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

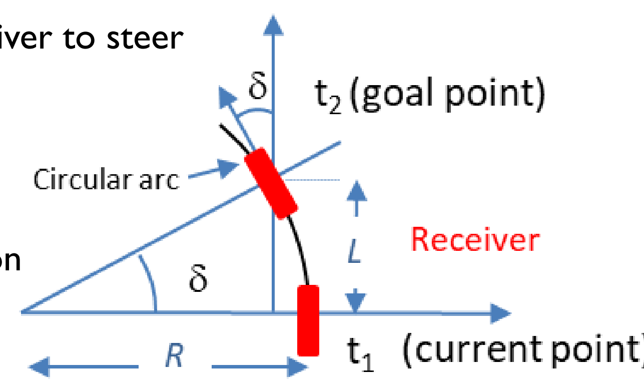
$q(t) = [x(t), y(t), \theta(t)]$



Trajectory: Pursuit approach

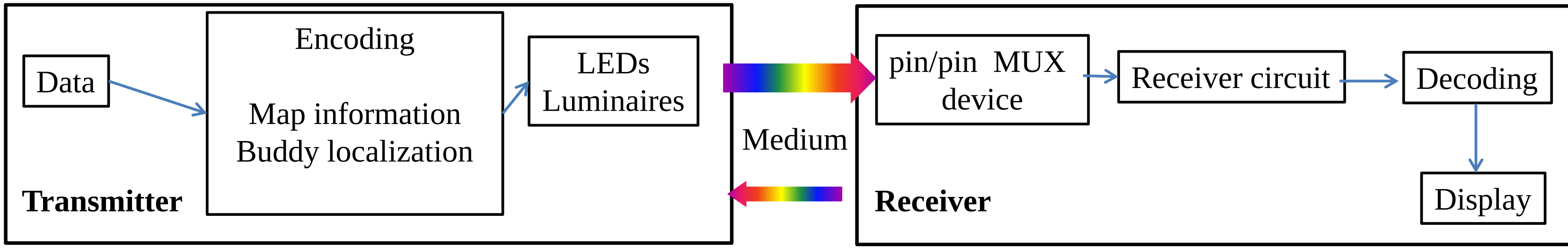
Took into account the curvature required for the mobile receiver to steer from its current position to its intended position.

- 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)

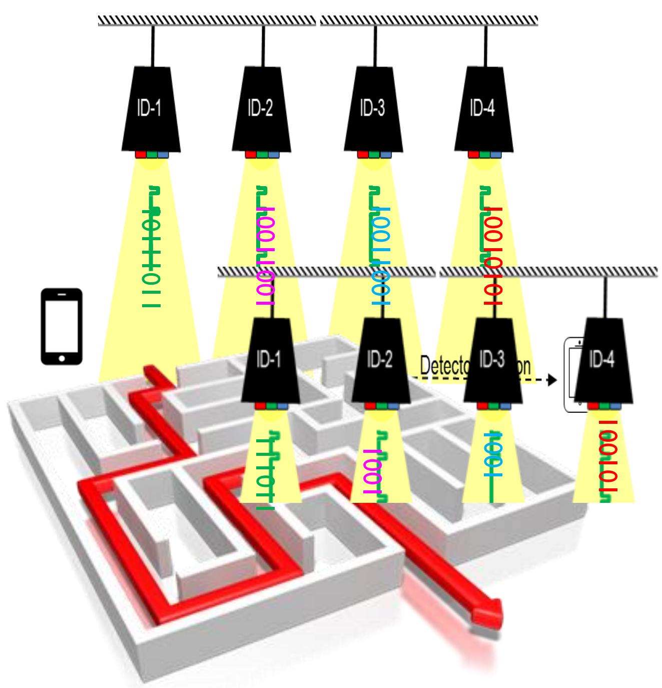
- The system is a self-positioning system in which the measuring unit is mobile.
- This unit receives the signals from several transmitters in known locations, and has the capability to compute its location based on the measured signals.

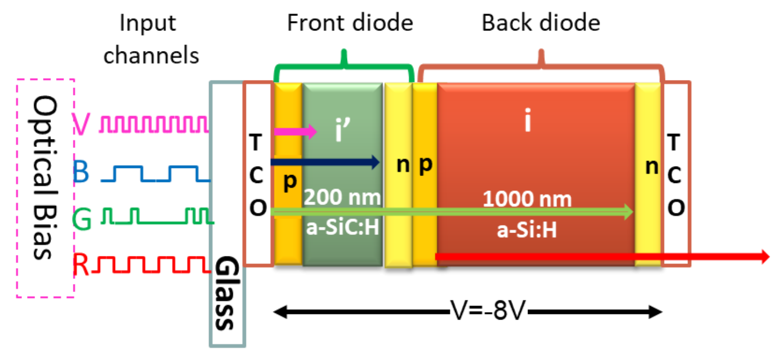


Transmitter

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).

SYSTEM OPERATION

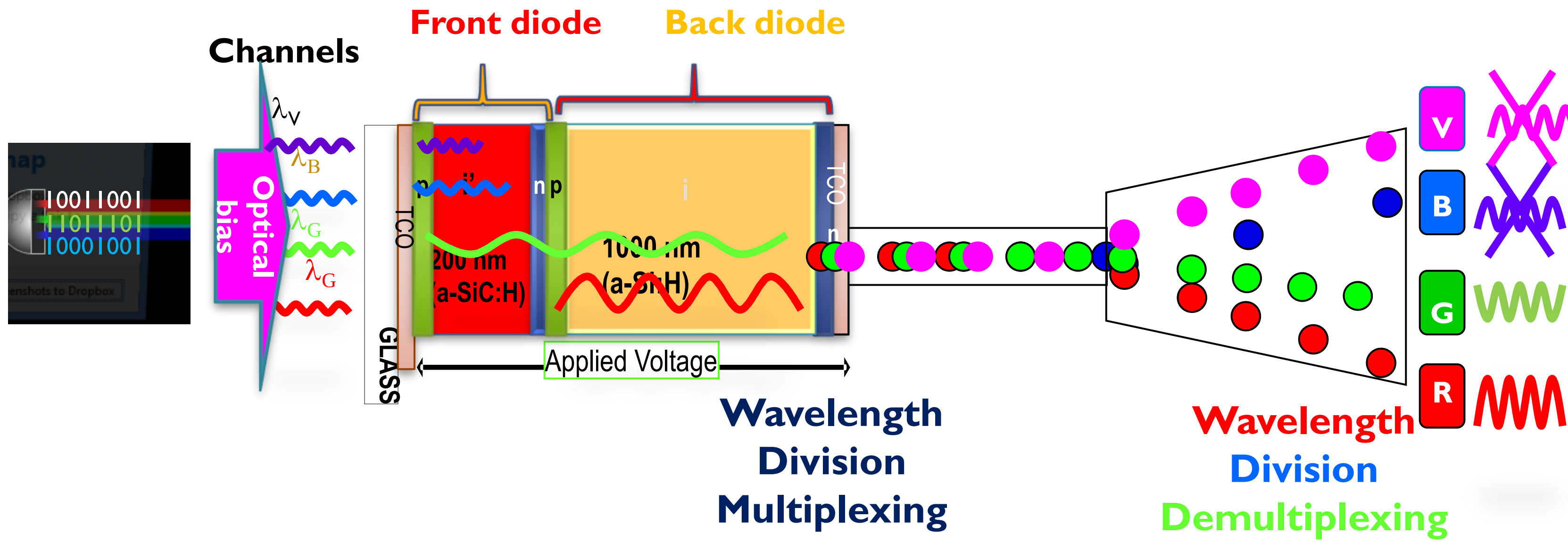
Transmitter / Receiver of VLC

LED

ID data transmit with fast blinking

Coder/decoder device

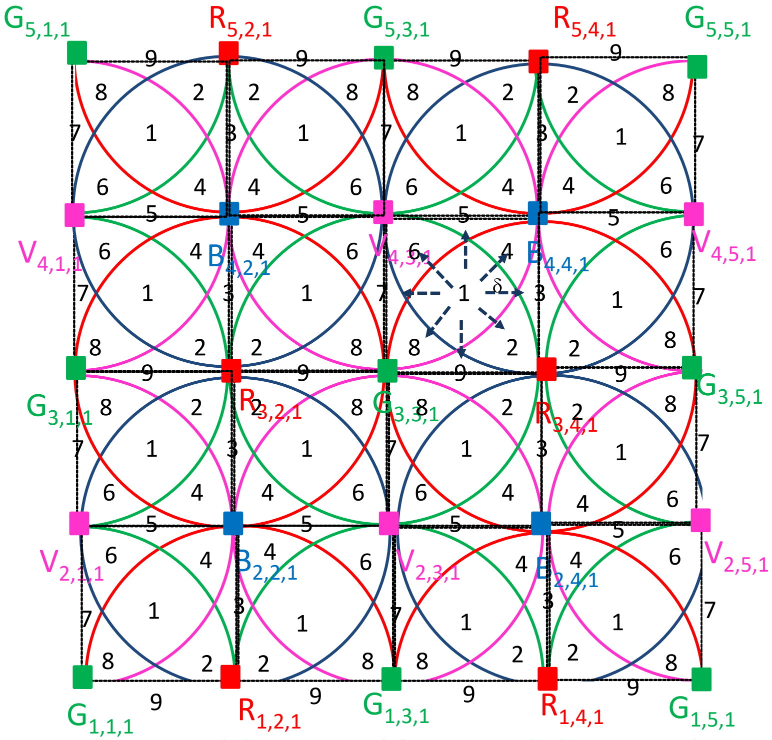
Bit decode



- 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).

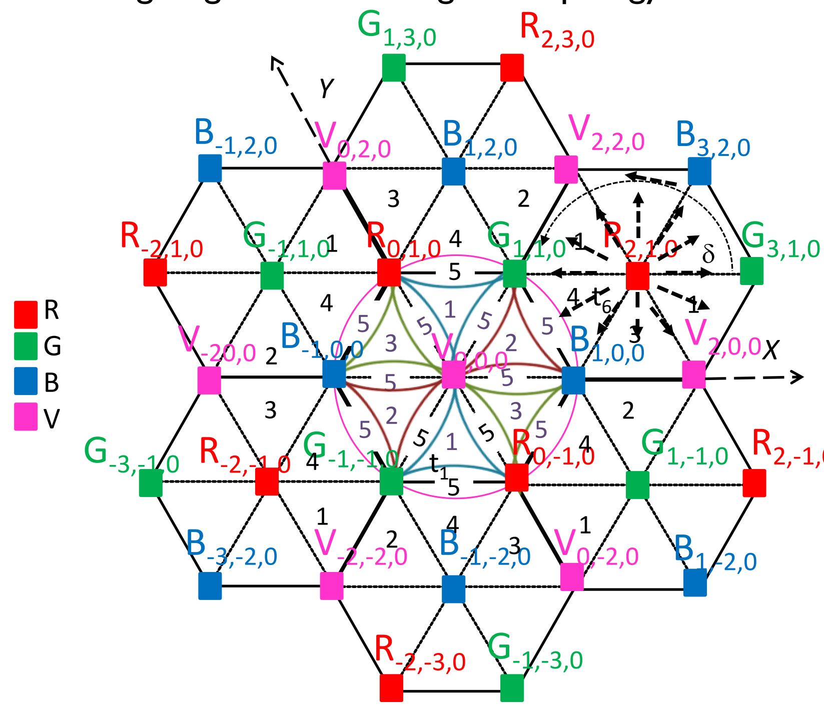
The Emitters for Large Environments



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

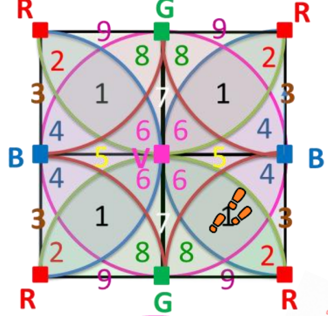
<u>2D model</u>

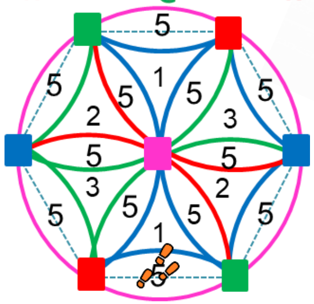
- Each node, $X_{i,j}$, carries its own color, X, (RGBV) as well as its ID position in the network.

<u>3D model</u>

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

Position and route control

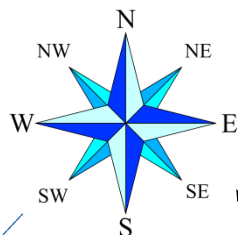


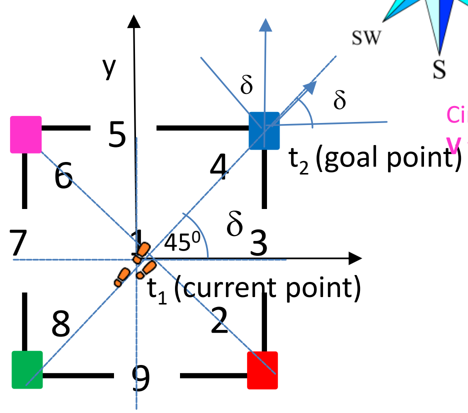


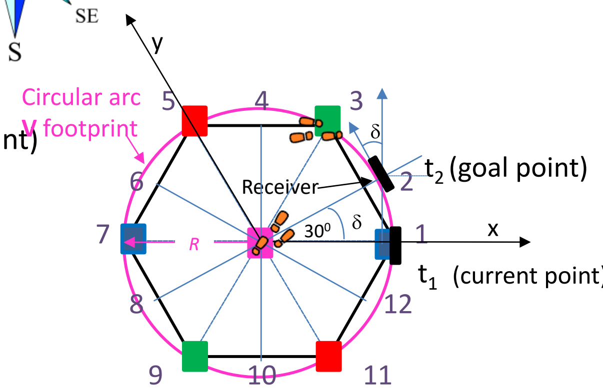
The combined estimation of both position and orientation (pose estimation) are important to path definition.

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	_	_	_	_

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





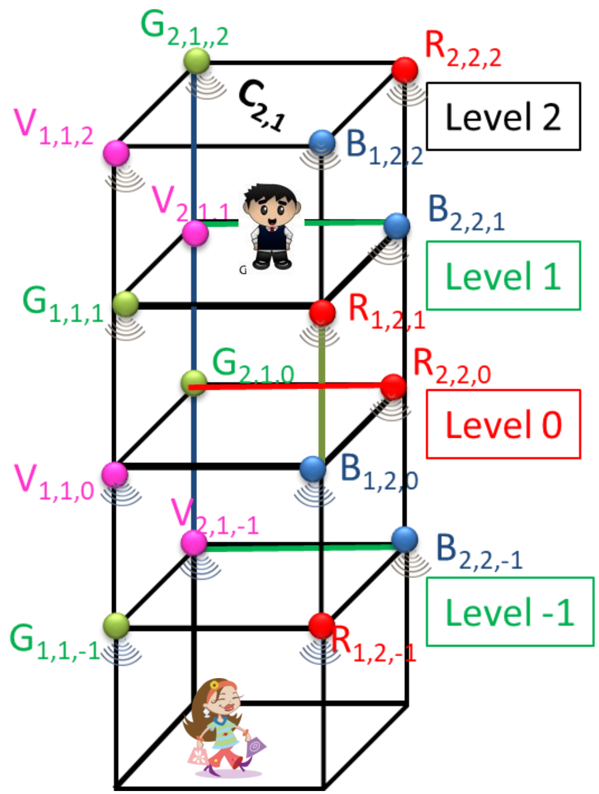


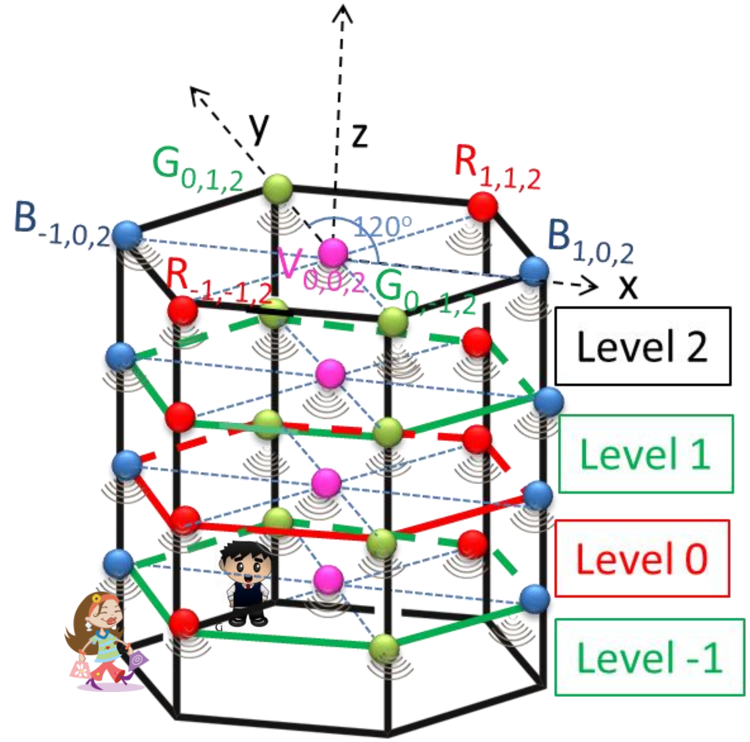
- The steering angle (δ) that guides the user across his path.

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

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.





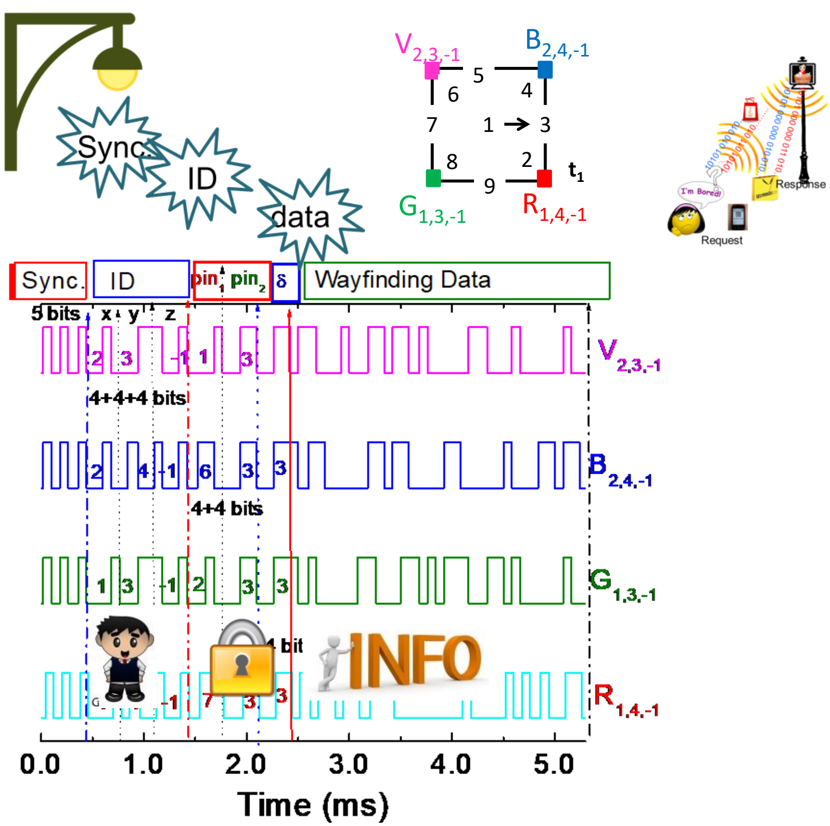
Each unit cell can be referred as $C_{i,j,}$ were *i, j* are the x, y positions in the square unit cell of the top left node or the central node in the hexagonal one.

The indoor route throughout the building is presented to the user by a responding message transmitted by the ceiling luminaires.

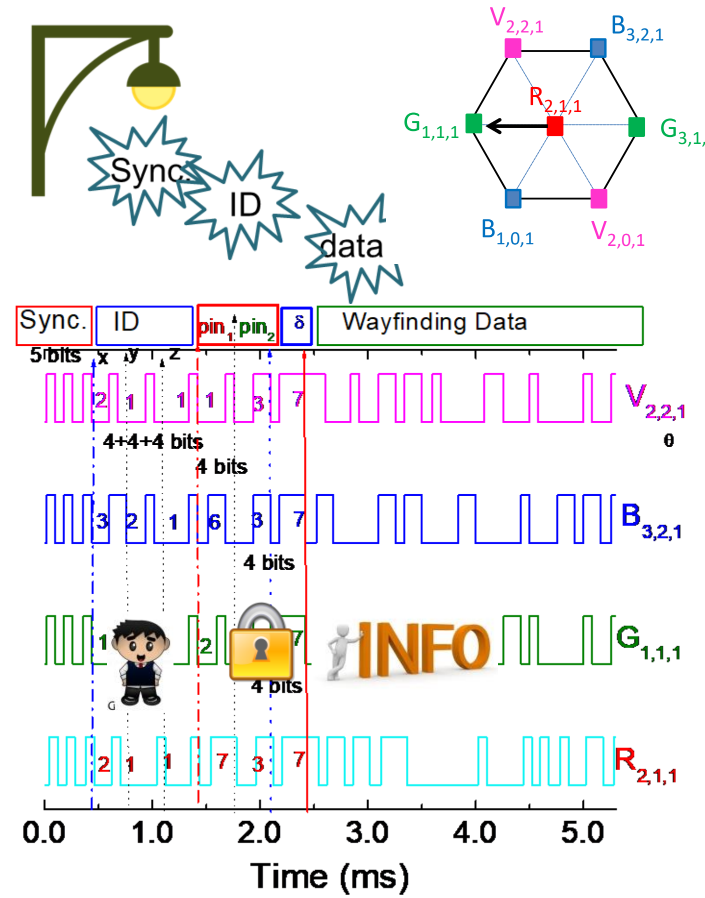
Communication protocol by VLC

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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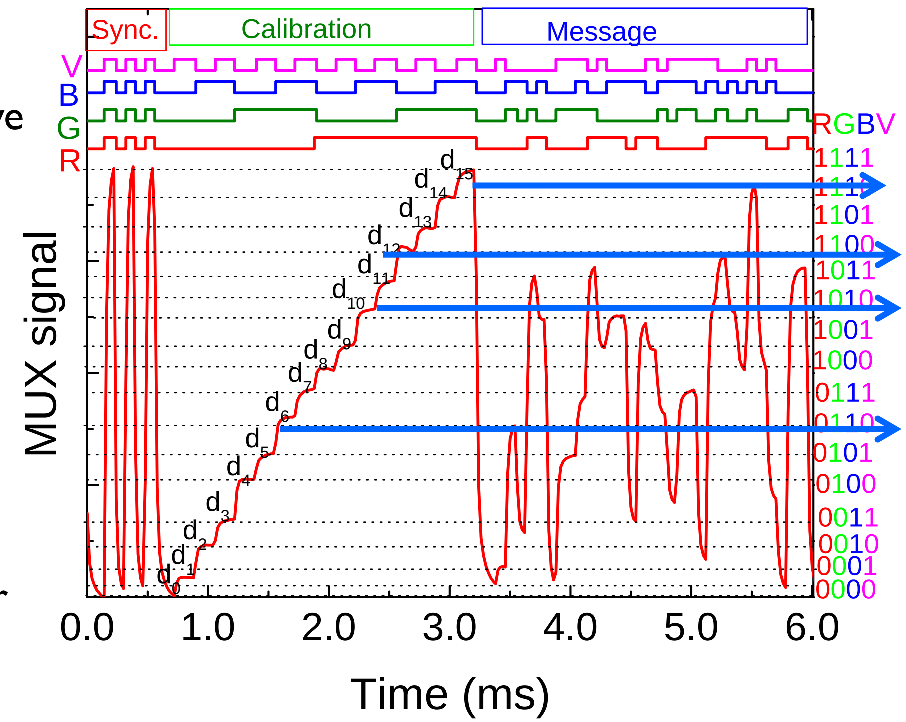
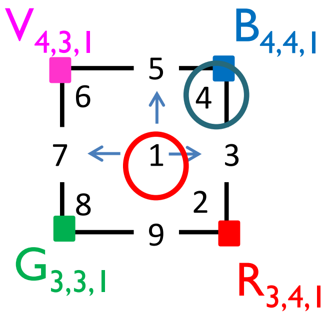
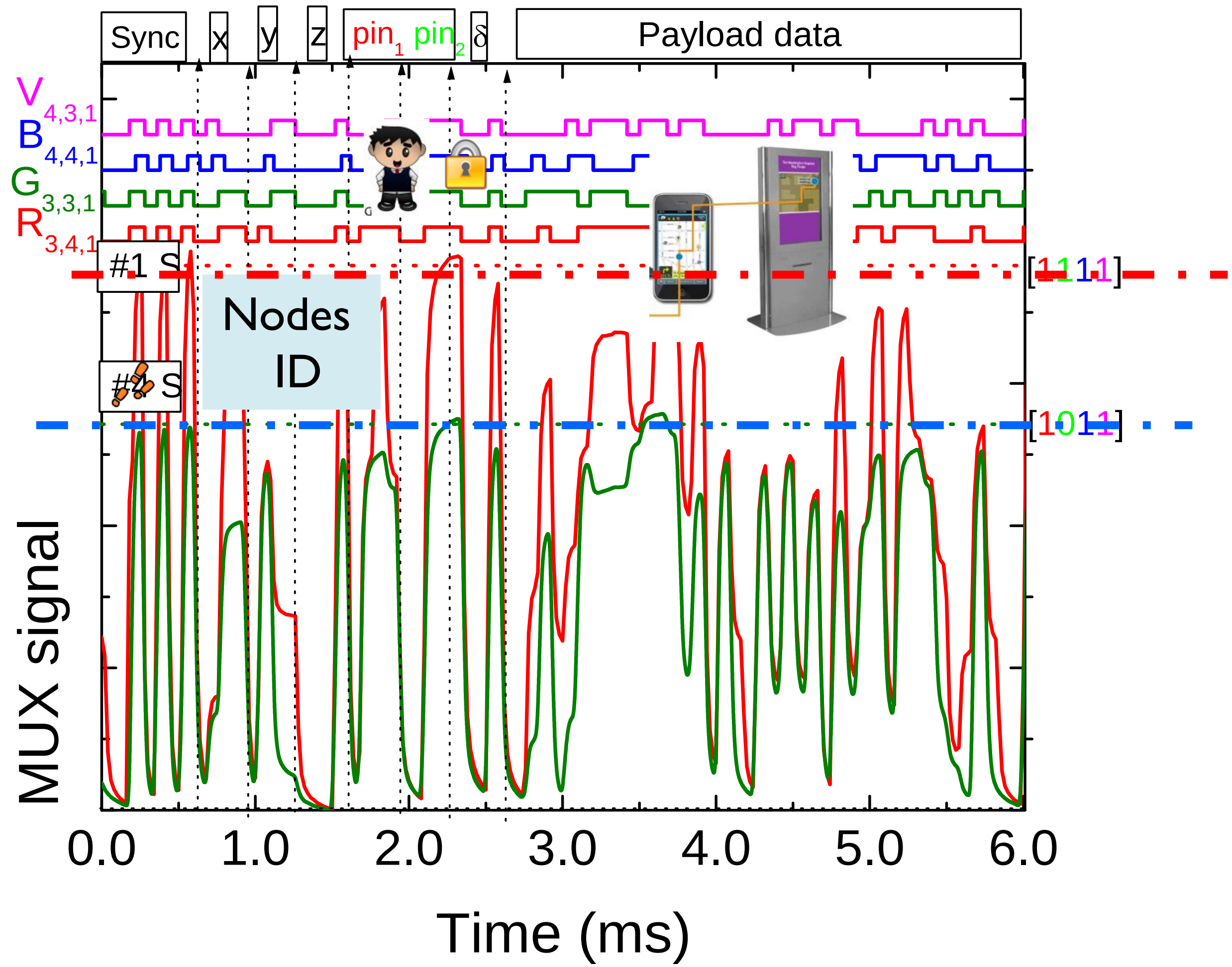


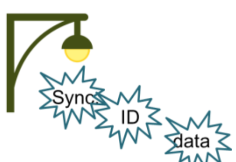
- 2^4 ordered are detected and correspond to all the possible combinations of the *on/off* states.
- By assigning each output level to a 4-digit binary code, [X_R, X_G, X_B, X_V], with X=1 if the channel is *on* and X=0 if it is *off*, the signal can be decoded.
- Comparing the calibrated levels with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

MUX-DEMUX



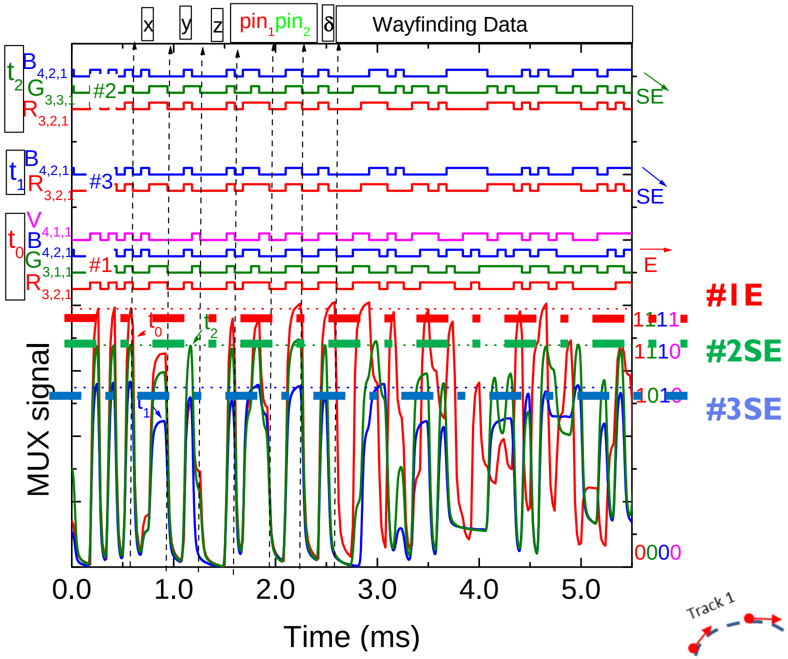
7261/3/S

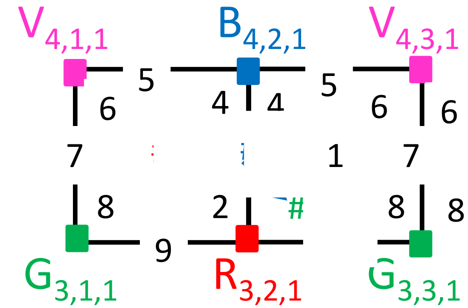




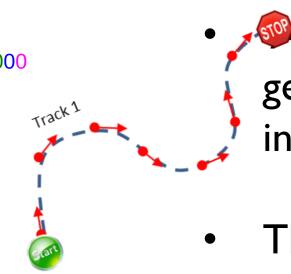
- The footprint position comes directly from the synchronism block, where all the received channels are, simultaneously, *on* or *off*.
- The next block of 12 bits gives de ID of the received nodes.
- The last block is reserved for the transmission of the wayfinding message.

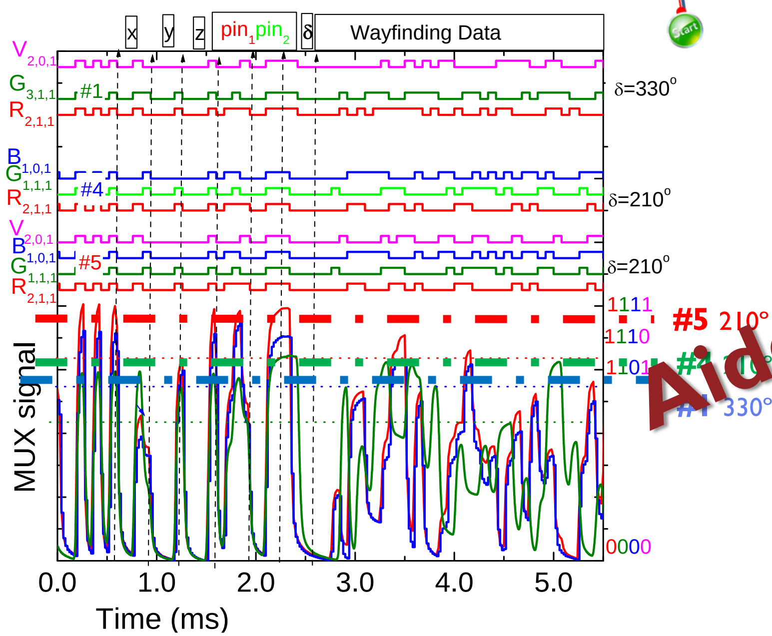
Fine Grained Localization and travel direction



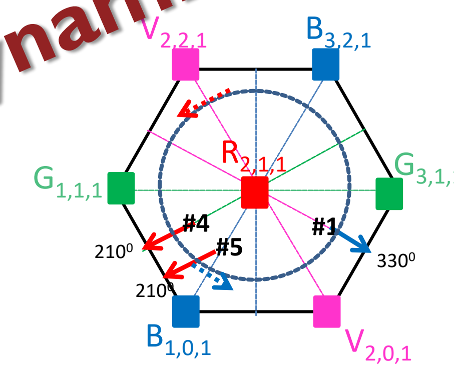


- To compute the point-to-point along a path, we need the data along the path.
- As the receiver moves between generated point regions, the received information pattern changes.
- The transition actions are correlated by calculating the ID position codes in successive instants.

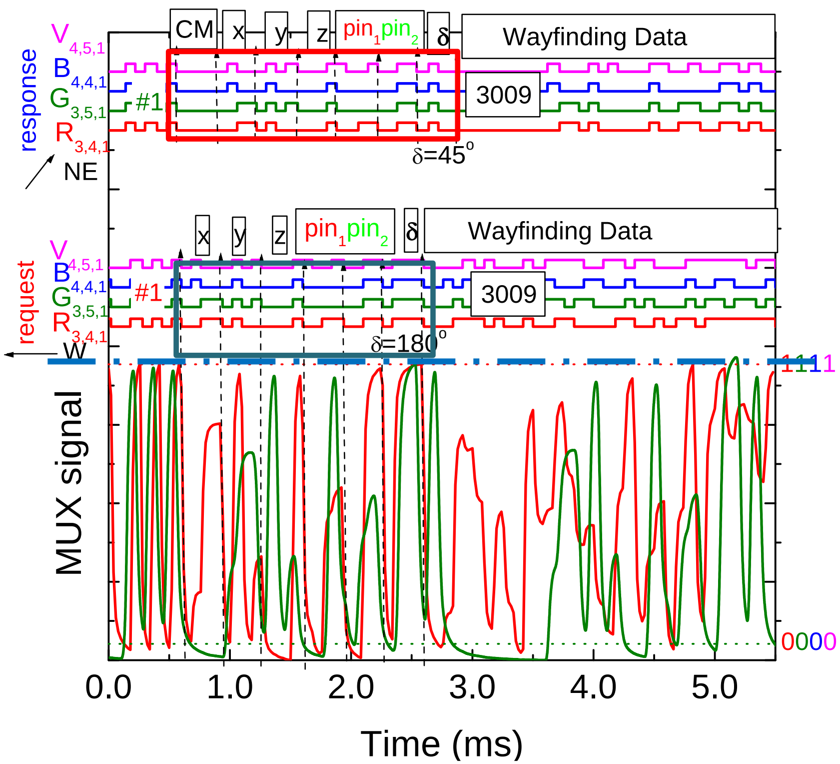


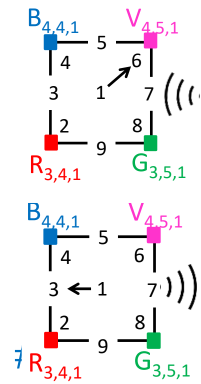


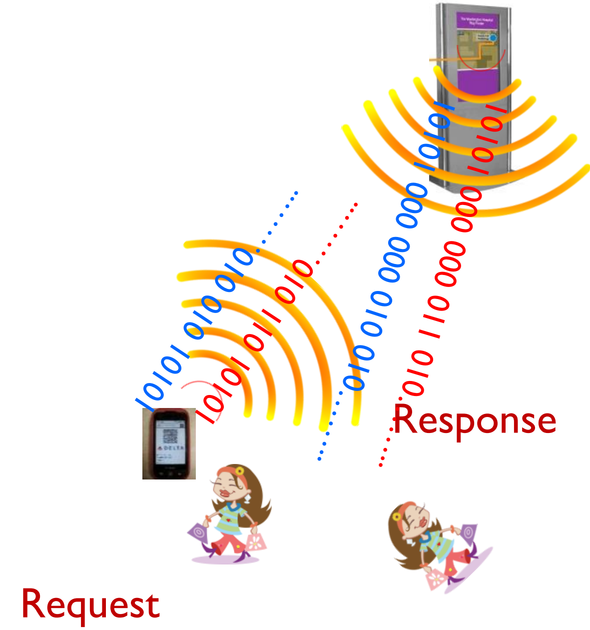
Aided dynamic navigation



Bi-directional Communication

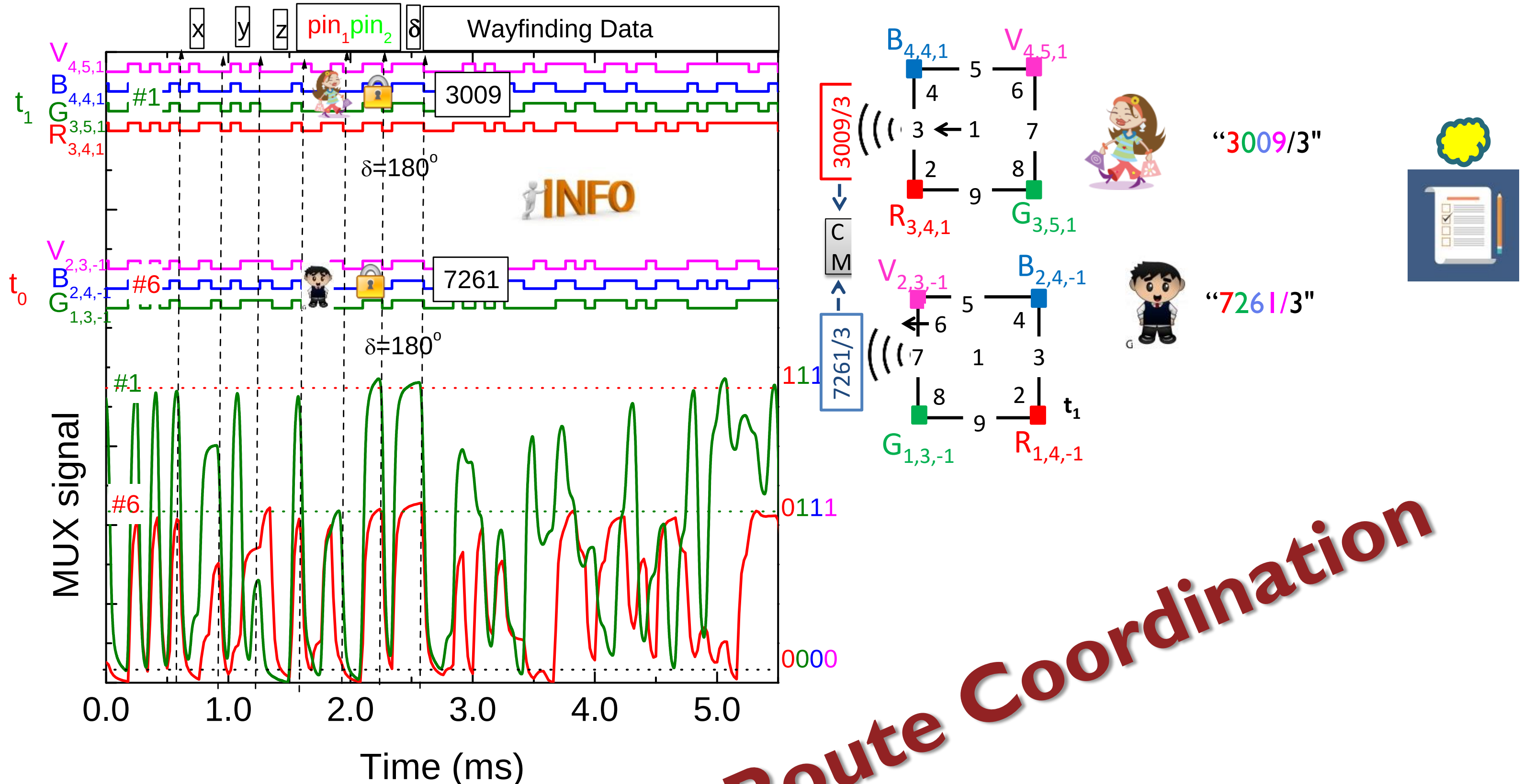






- Bi-directional communication between VLC emitters and receivers at a handheld device can be established through a control manager linked to an indoor billboard.
- Using a white polychromatic LED as transmitter, the receptor sends to the local controller a "request" message with its location (ID) and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

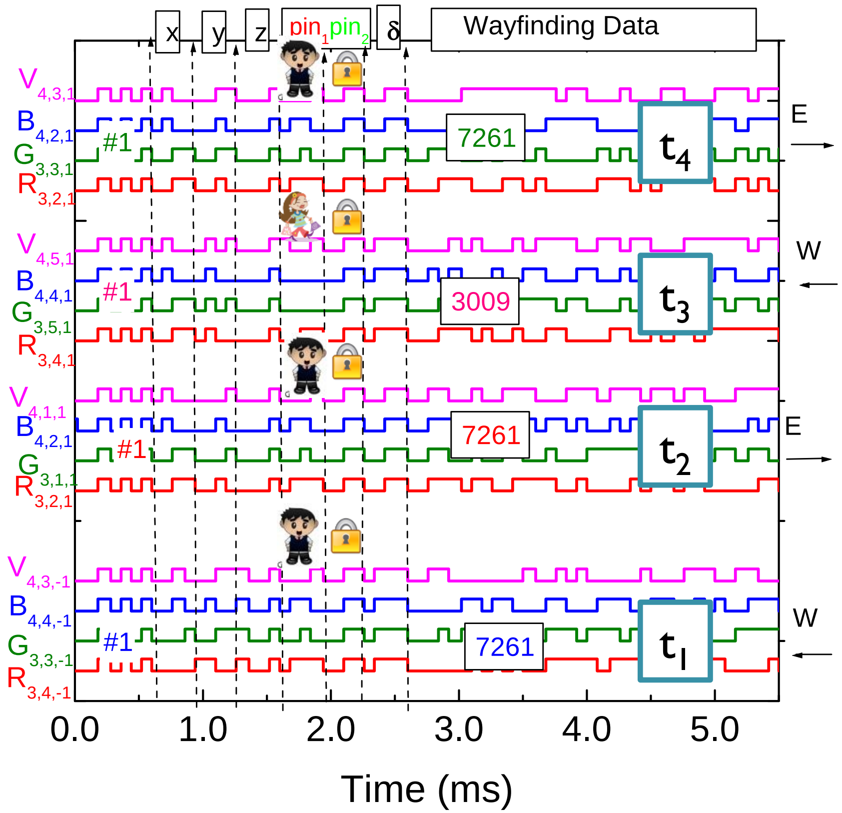
- User located at $C_{2,3,-1}$, arrived first (t_o), identified himself ("7261") and informed the controller of his intention to find a friend for a previously scheduled meeting ([0011]; 3).

- 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.

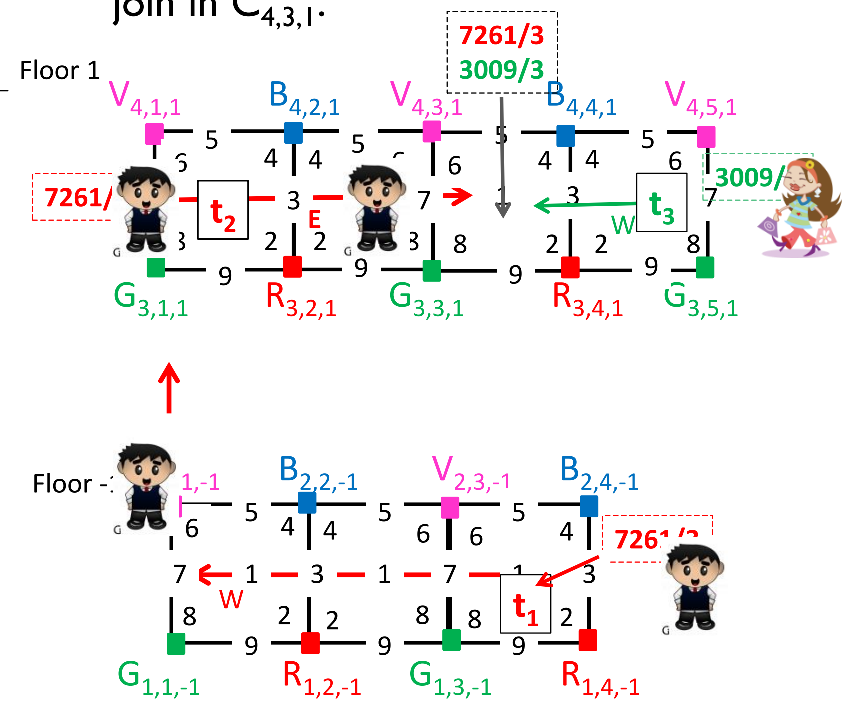
WAYFINDING SERVICES

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

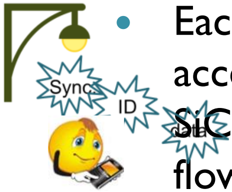


Buddy wayfinding

- 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 $C_{4,3,1}$.



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.