“Exploration Japon 2024” Program

Optical Wireless Communications Research at LISV
An Overview

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1. UVSQ and Université Paris-Saclay
2. Overview of the LISV
3. Vehicular communication activities
4. Beamsteering activities
5. Other activities (SPAD, FSO…)

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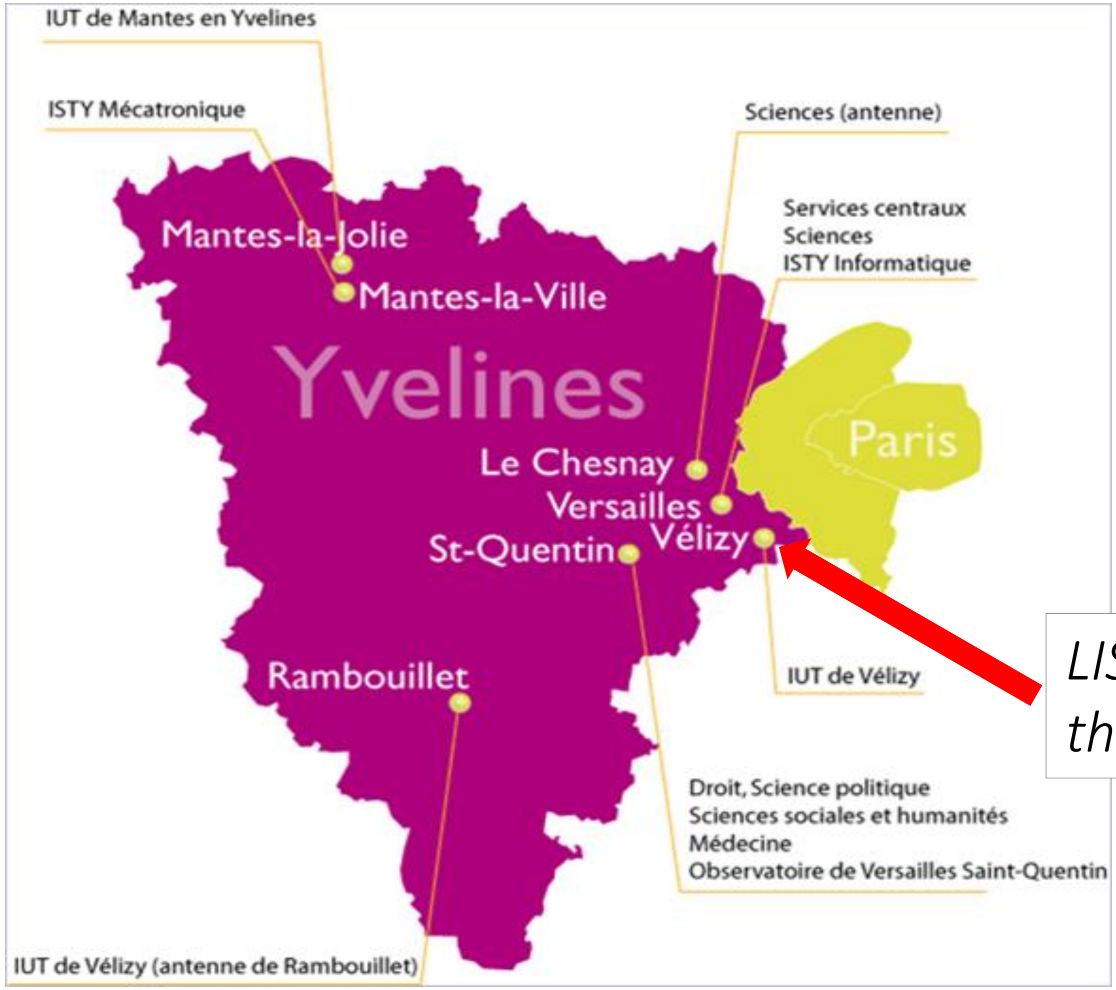
University of Versailles Saint-Quentin (UVSQ): Where Is It?

Near Paris and Versailles Castle

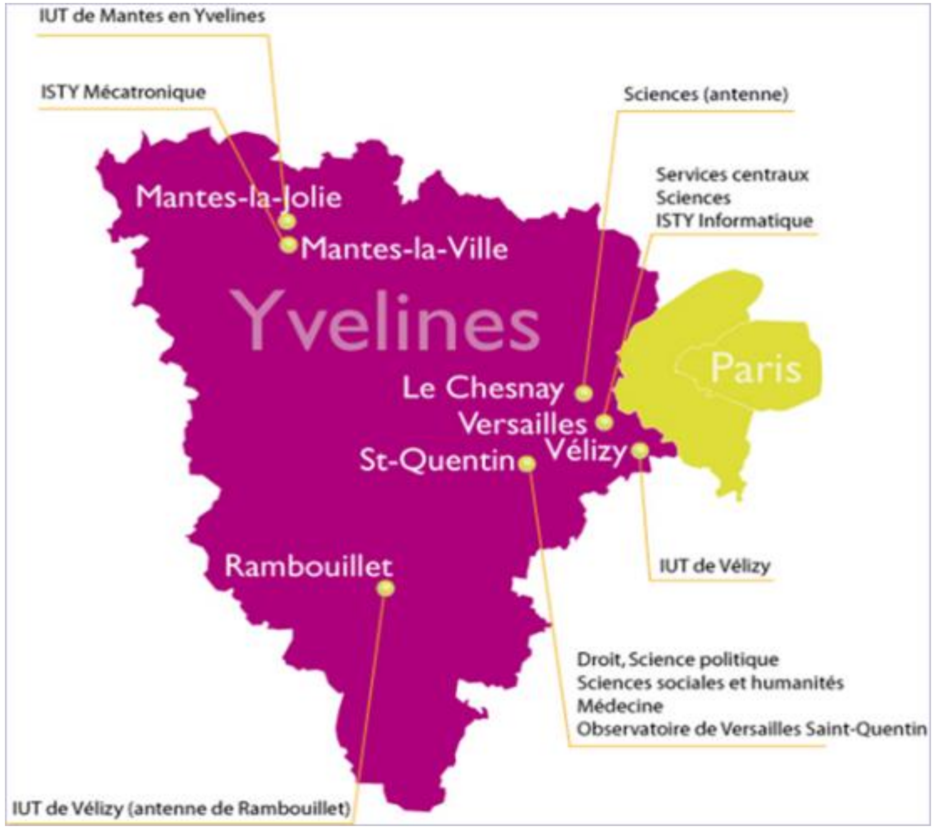
LISV: Laboratory of Engineering Systems



LISV laboratory is on the Vélizy campus

Key Figures of UVSQ

- Around **20,000 students**
- 215 academic programs (including 1**00 Masters programs**)
- 3,750 students enrolled in life-long learning programs
- **2,669 foreign students** from 120 different countries
- **708 PhD students**
- 155 research contracts
- **1,110 faculty members**
- 744 administrative staff
- 310 students enrolled in exchange programs

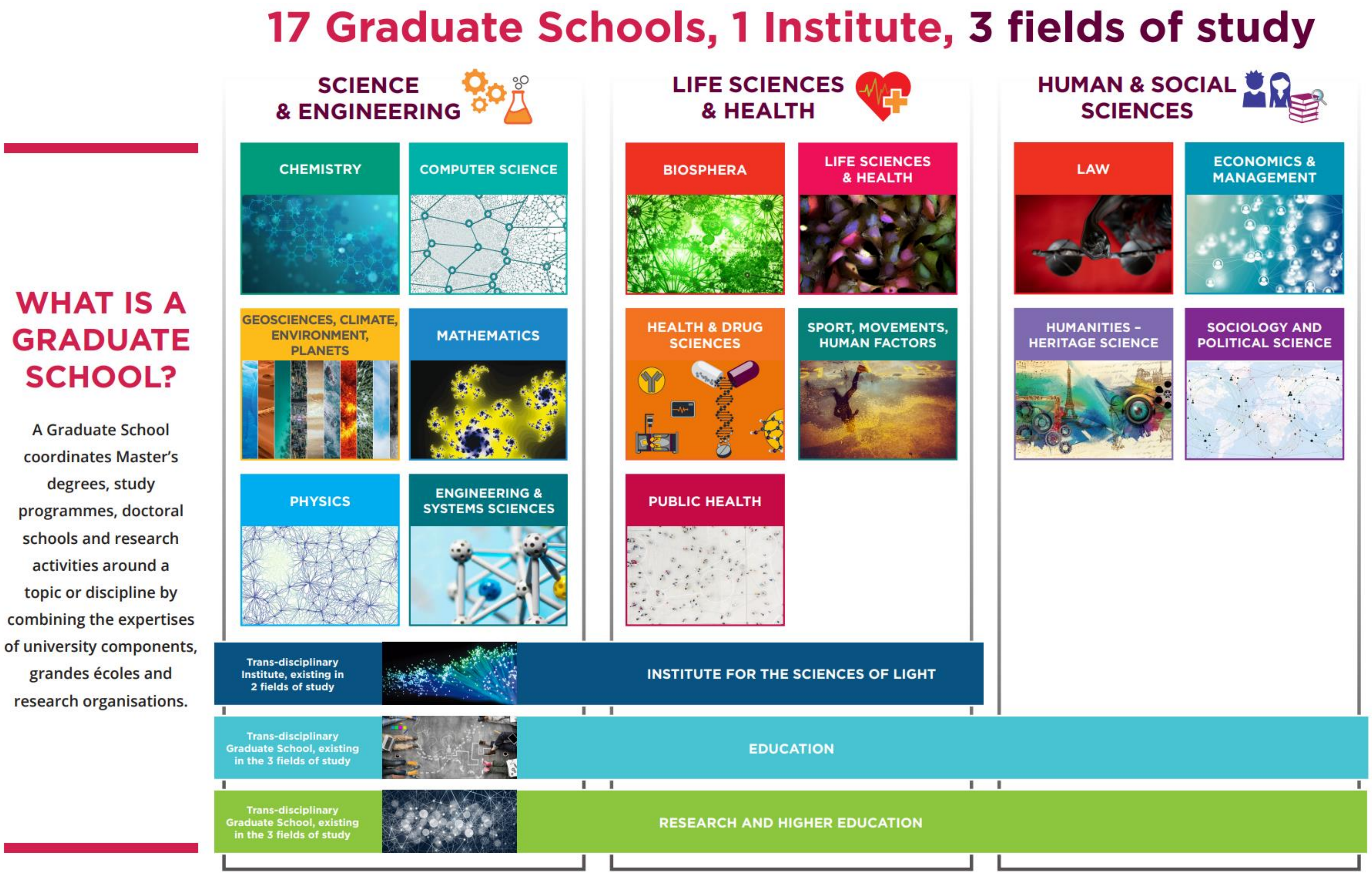


UVSQ Is Now Part of Université Paris-Saclay

A common project to build the university of the 21st century

Around 60,000 students

17 Graduate Schools in Université Paris-Saclay



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History and Structure of the LISV

- The **LISV** exists since 2006:
  - About **30 professors/associate professors** and technical staff,
  - About **40 PhD students** from more than 18 nationalities.
- Building located in Vélizy (mid-distance from Paris and Versailles), around 2700 m^2
- Structured in **three teams**: **ISA**, RI and SyMRIC.
- Two structures are nearly associated with the Lab:
  - **OLEDCOMM**, a startup about LiFi technology
  - **CEREMH**, an association about healthcare and help for disabled persons

Scientific Aims of the LISV

Study, realization and performances evaluation of systems that include opto-mechanical-electronical-instrumentation parts

Modelling

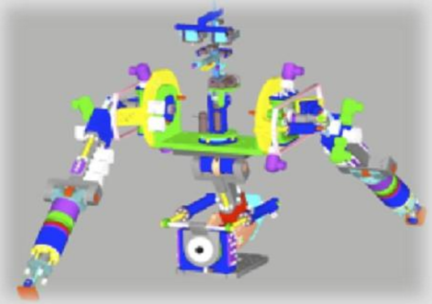
Innovating design

Embedded systems

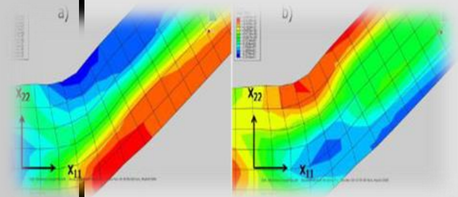
Control and command

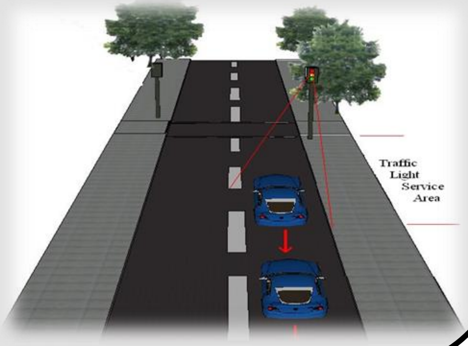
Help and assistance for services

Interactive robotics



Instrumentation and modelling for Systems (ISA)





Sensors

Metrology

Multi-physics models

Instrumentation

Performances evaluation

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Research About Help and Assistance for Disabled Persons

Help for driving

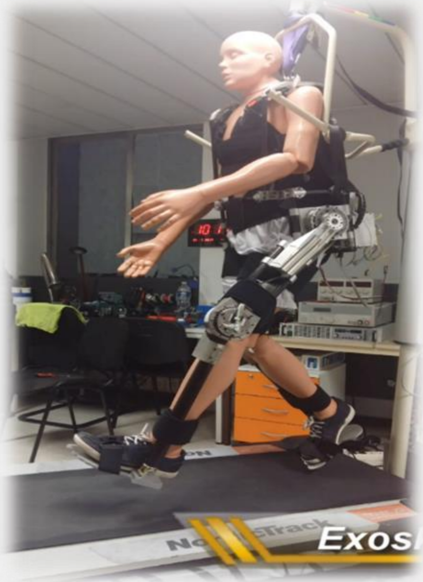
Brain interfaces

Gyrolift
Seagway with
verticalization

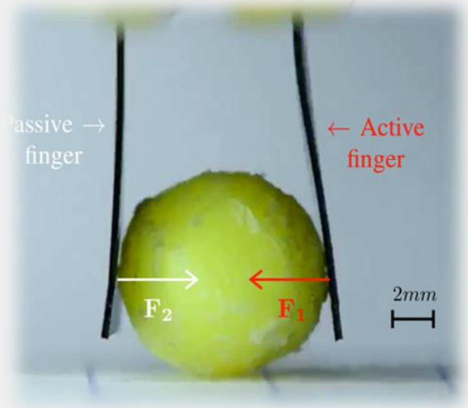
Research About Mechatronic Robotised Systems

Humanoïd control

Drones control



Prosthesis and orthosis



µrobotics

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PhD Students

Thesis (average figures over 5 years period)

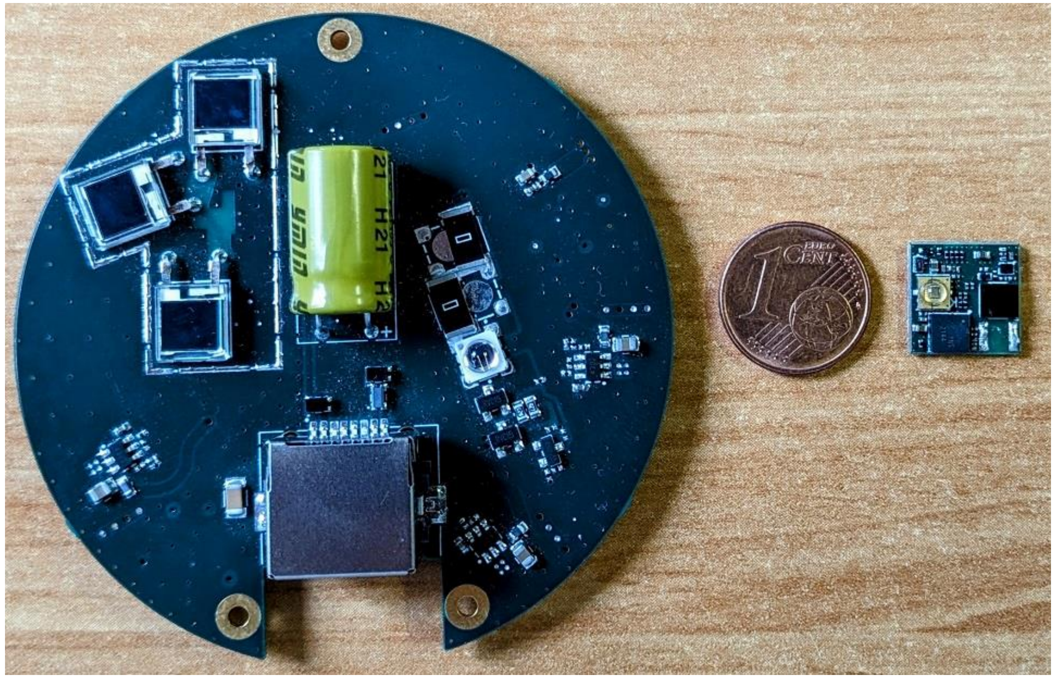
Sources of funding	Number	%
Government	5	7%
Funding with large collaboration with industry	22	30%
CIFRE (direct link with industry)	13	17%
Foreign funding with co-tutelle agreements	25	34%
Others	9	12%
TOTAL	74	100 %

Partnership Between LISV and OLEDCOMM

- About **OLEDCOMM**:
  - **OWC** and **LiFi products design** and **industrialization** company.
  - Created in **2012** by **two Professors of LISV**.
  - Now among the **world leaders** on this market with **pureLiFi** (UK) and **Signify** (NED).
  - Collaboration with **MaxLinear** and **STMicroelectronics** for on-chip embedded system.

- Since 2012, **scientific collaboration agreement** between **LISV/UVSQ** and **OLEDCOMM** for research related to various use cases and markets.

- **Main markets:**
  - **Indoor LiFi** with **high privacy/security/health** requirements (army, education…).
  - **In-satellite cable replacement** (first LiFi-embedded satellite lauched in 2023).
  - High speed and low costs **satellite-to-satellite links**.



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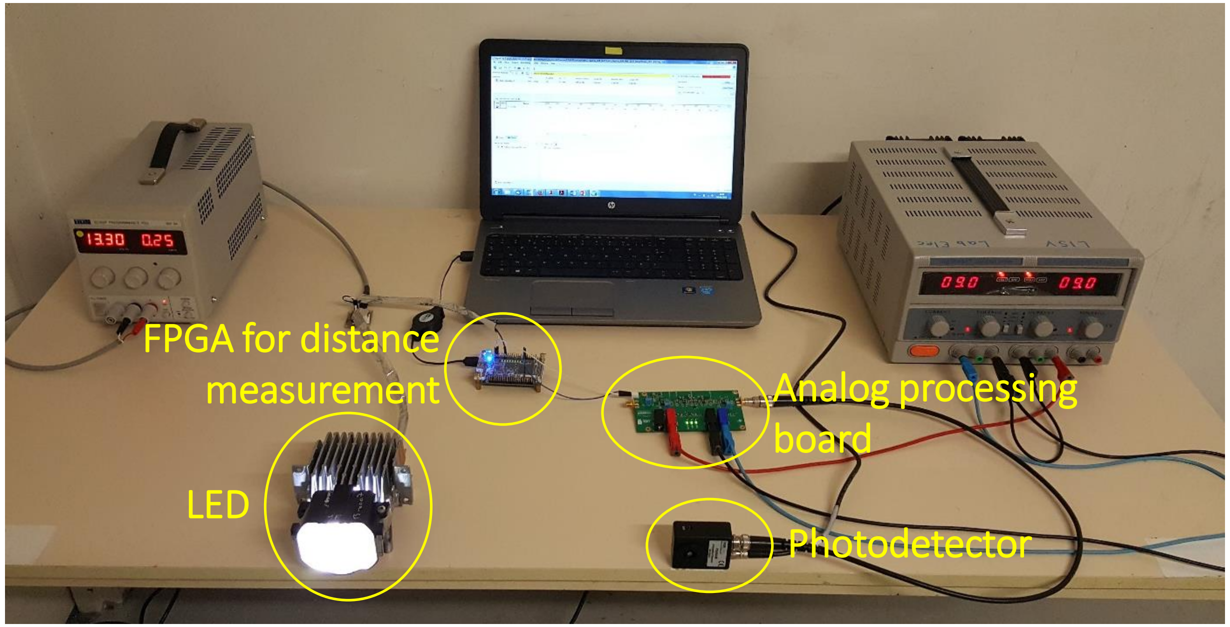
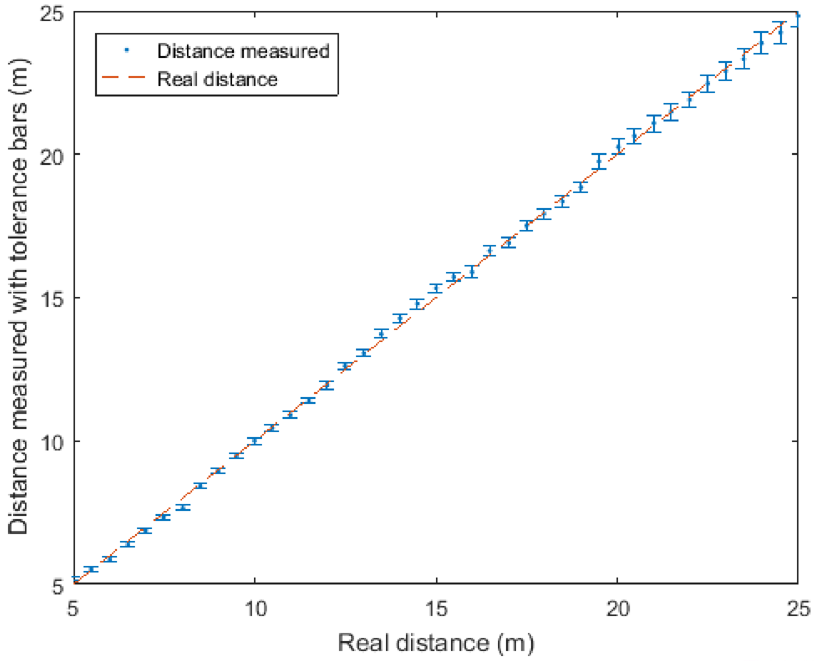
Integrated V2V Sensing and Communication (2014 – 2017)

- **2009–2014**: Work on V2V and I2V/V2I communication started at LISV in 2009 (thesis of A. M Cailean)
  → **Demonstration of 100 m low bit rate** (< 100 kbps) I2V links and 50 m V2V links.
- **2014–2017**: Thesis of B. Béchadergue to study **joint V2V communication and distance measurement** :
  - Simulations validation of the proposed system.
  - **Experimental validation** using COTS car lights: distance measurement from 5 m to 25 m with a **measurement error < 3%.**





B. Béchadergue, "Visible Light Range-Finding and Communication Using the Automotive LED Lighting," *PhD Thesis*, Université Paris-Saclay, 2017.

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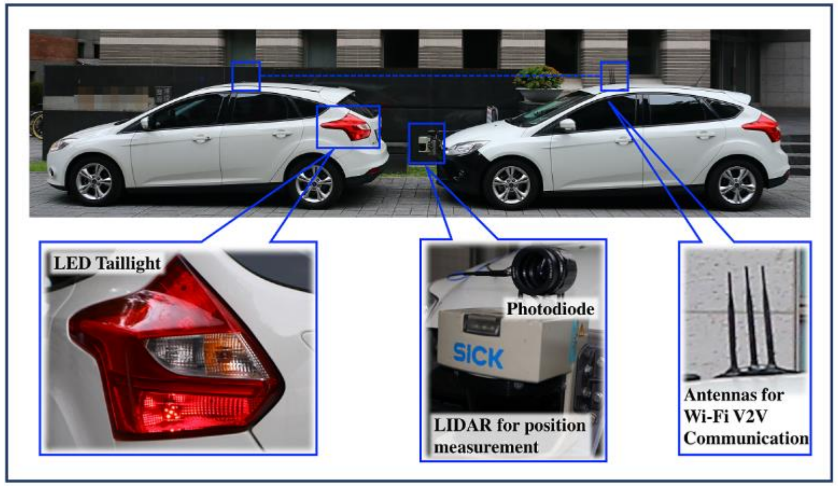
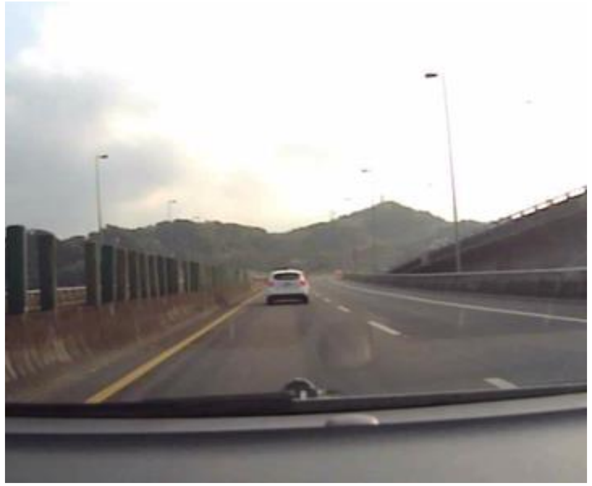
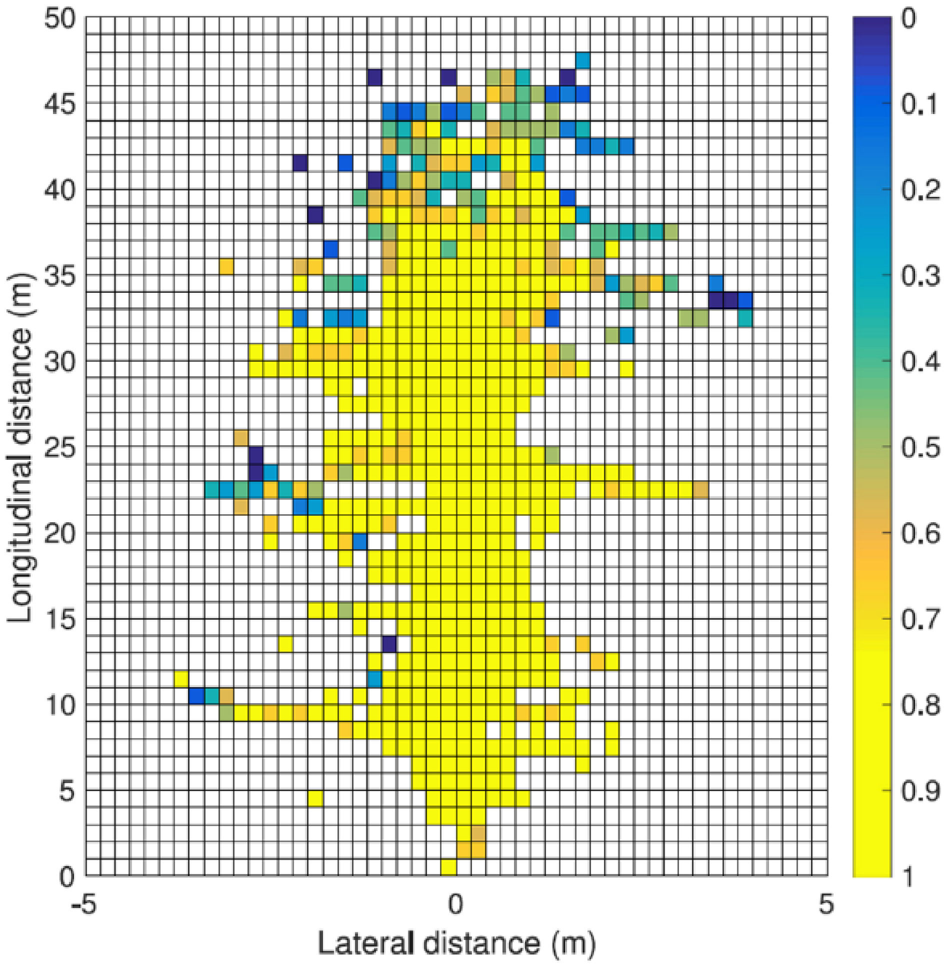
Outdoor V2V Communication Tests (2017)



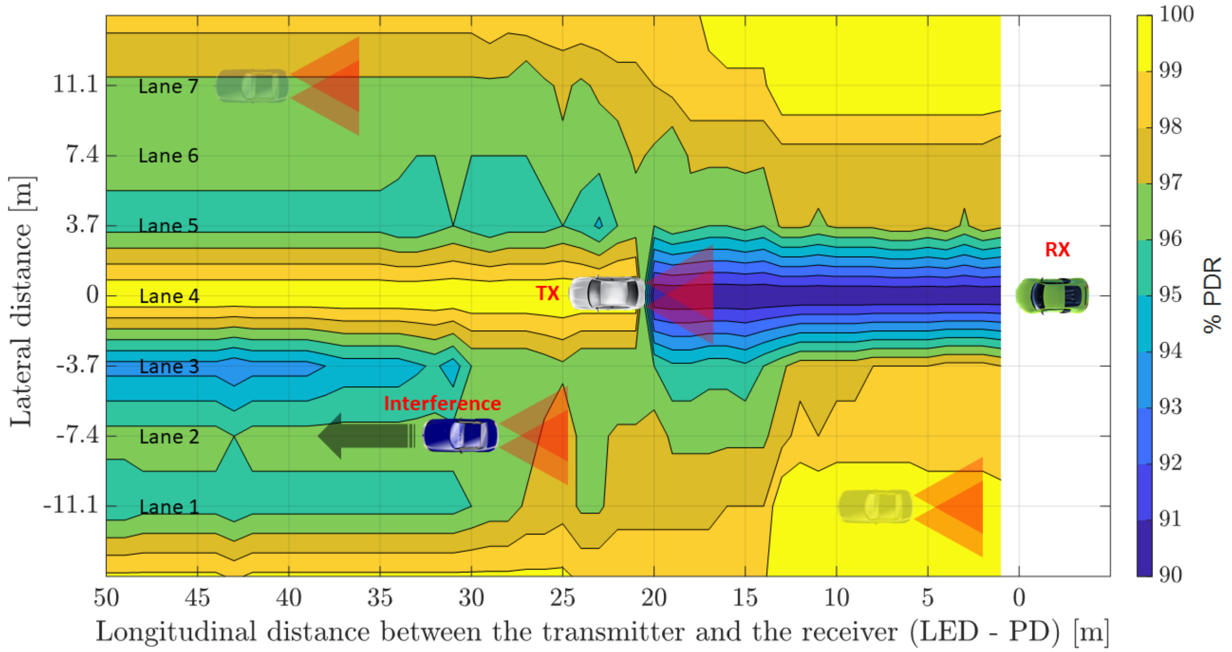


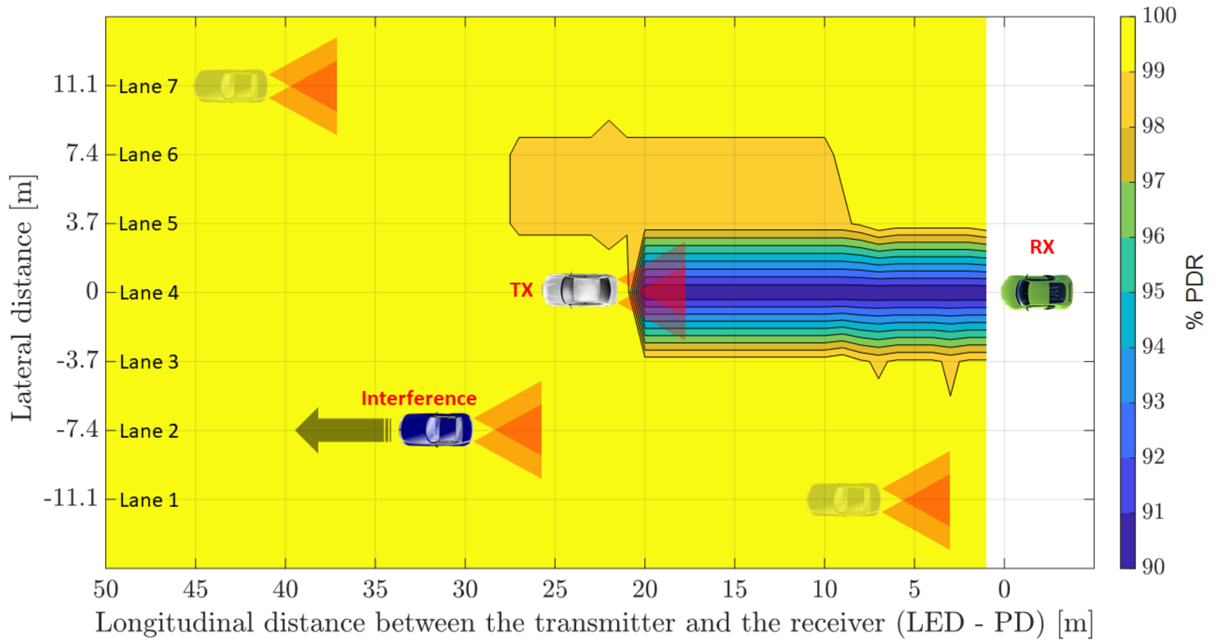


- In **2017**, research visit at **National Taiwan University**, with Hsin-Mu Tsai.
- **V2V** communication **demonstrator** assembled and tested on **open roads**.
- <u>Results</u>: **> 90%** of **packets transmitted without errors** over **30 m at 100 kbps** (35 m à 10 kbps).

Multiple Access Protocols for V2V Communication (2019-2022)

- **2019–2022**: Thesis of E. Plascencia on **inter-vehicle interferences** in **multi-lanes** scenarios.
- Study of the **performance/complexity tradeoff** of **various CDMA codes** (ROC, PN, OOC, etc.).
- Implementation of an **integrated** and **real time 100 kbps V2V link** and **tests on a circuit**.





L. E. Plascencia Cruz, “Visible light communication control in a platoon vehicle environment”, PhD Thesis, Université Paris-Saclay, 2022.

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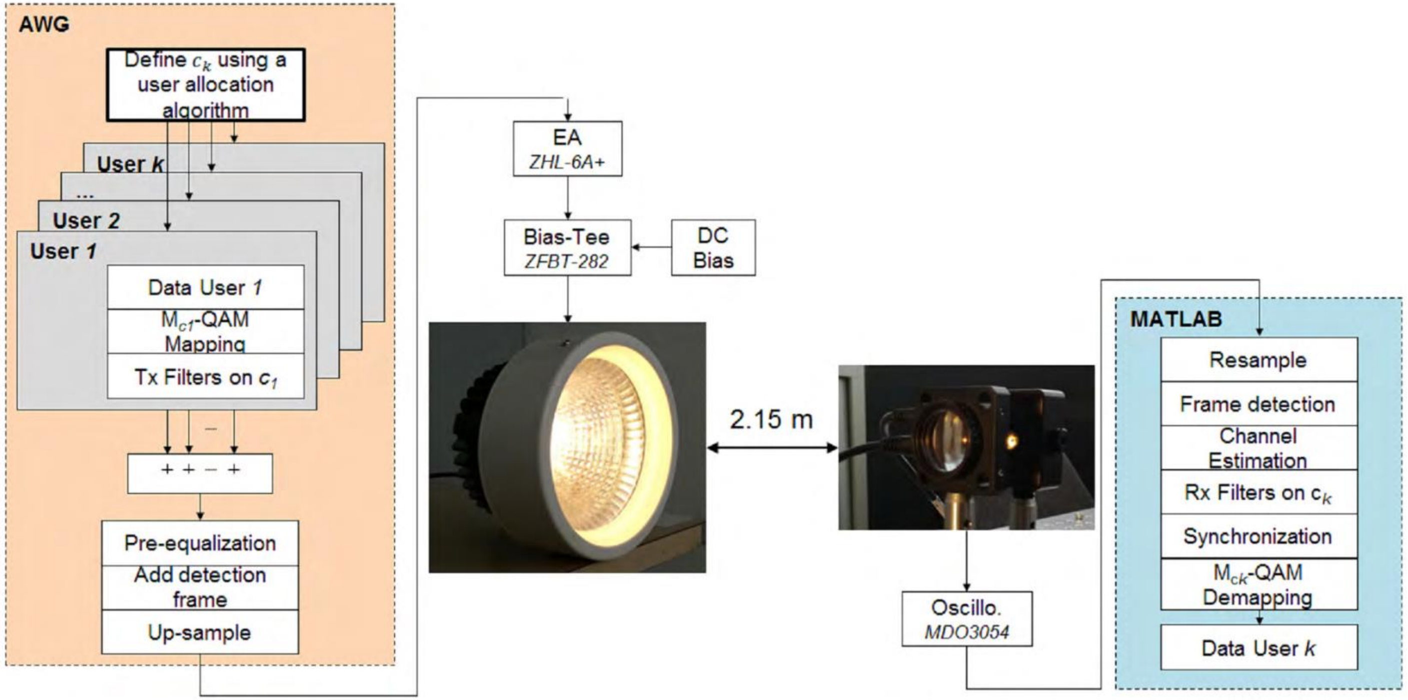
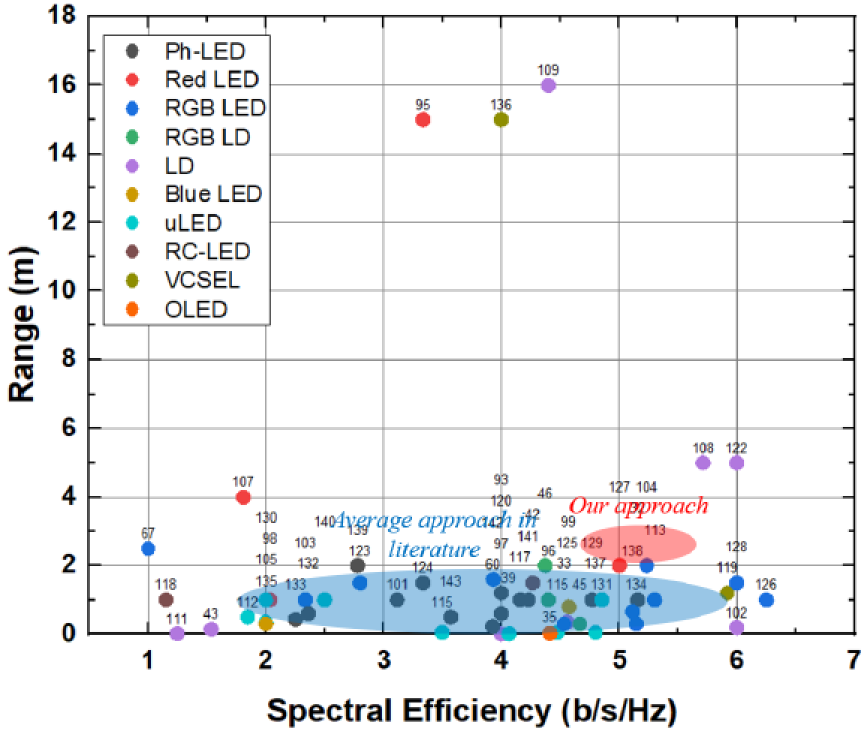
Since 2016, an Interest for Indoor Applications

- **2016–2019**: Thesis of M. Merah to initiate works on indoor applications (e.g. LiFi).
- Experimental work on **modulations** and **multiples access schemes** (m-CAP, OFDMA, NOMA, etc.)
- Demonstration of **300 Mbps capacity cells** shared between up to **20 users** using **commercial white LEDs**.





M. Mohammedi Merah, “Conception and realization of an indoor multi-user Light-Fidelity link”, PhD Thesis, Université Paris-Saclay, 2019.

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Since 2020, a Strong Focus on Beamsteering

- **Motivations for using beamsteering**:
  - In any OWC system, the **larger SNR, the better.**
  - The **main goal** of the OWC receiver is to optimize the SNR, and thus the **received signal power S,** defined as:

$$S = \left[\frac{(m+1)P_t}{2\pi d^2}\cos^m\phi\,\cos\psi\,\gamma A_r g(\psi)\right]^2$$

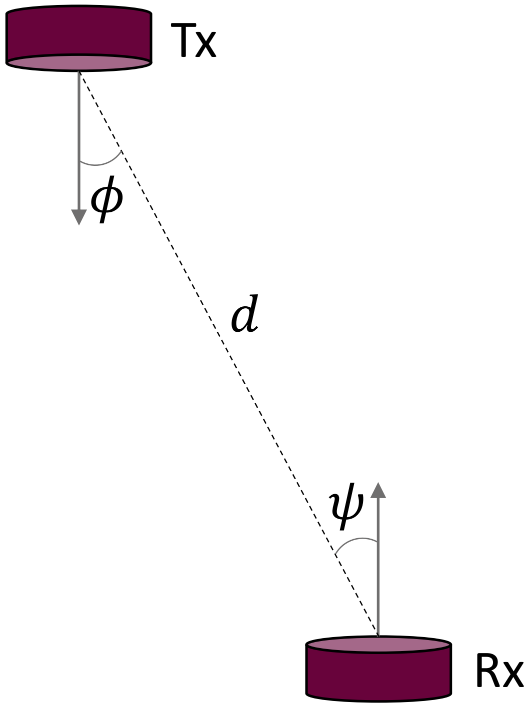
Light source parameters:
- m → directivity

Link geometry:
- ϕ, ψ → Alignment Tx/Rx

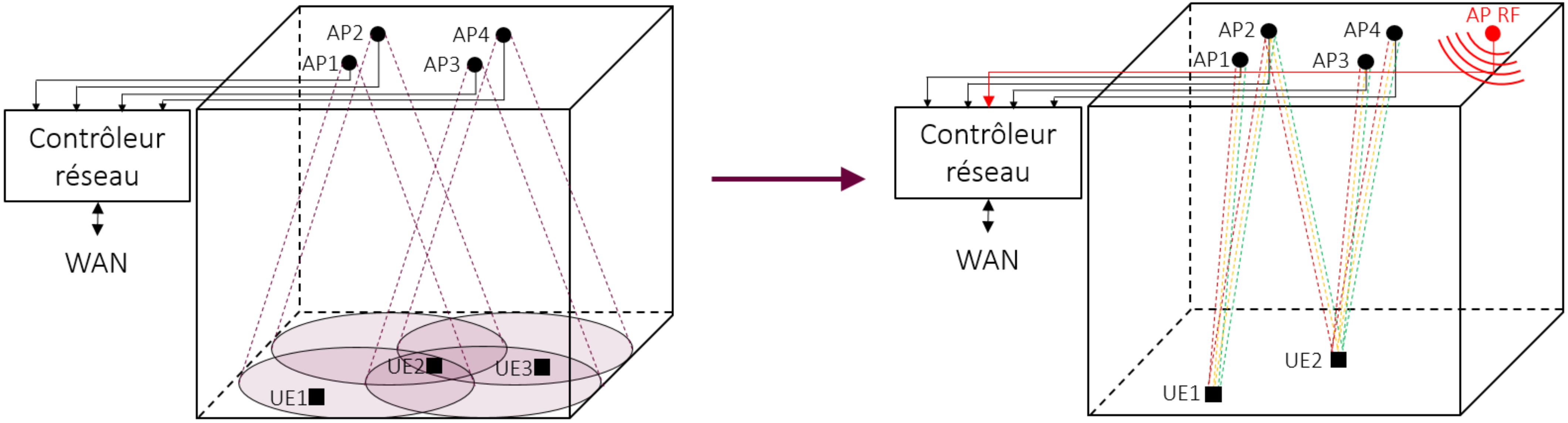
Use *beamsteering*

Receiver parameters:
- γ → *Photosensitivity*
- A_r → *Sensitive area*
- $g(\psi)$ → *Optical gain*

Use sensitive Rx, e.g. SPAD



Interest of Beamsteering for Indoor Applications



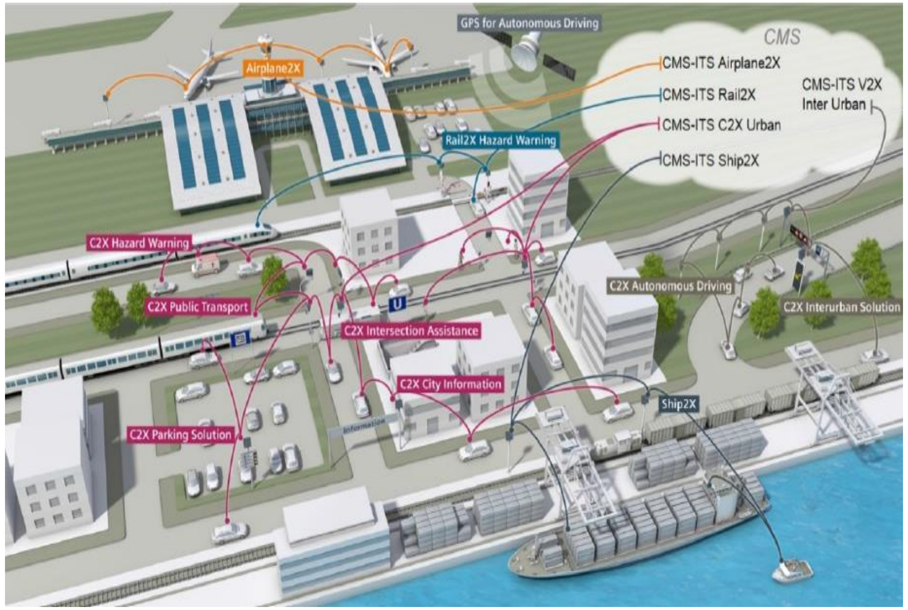
Cell-based architecture:

- Each AP generates a cell
- If UE in the cell, communication possible
- Continuous coverage is ensured by cell overlapping (i.e. interference, handover…)

Proposed cell-free architecture:

- Each AP can target 1+ UEs using *beamsteering*
- Real-time tracking of UEs necessary
- Real-time optical beam orientation necessary
- Focused beam = secured and high SNR link

Interest of Beamsteering for Outdoor Applications



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Strong interest for free-space optics (FSO) applications:

- Acquisition, tracking and pointing (ATP) mechanisms are critical to fight misalignement and maintain high performance.
- Use cases explored:
  - Buiding-to-building communication (Al-Furat Al-Awsat Technical University, Irak)
  - Satellite-to-satellite communications (OLEDCOMM & Thales)

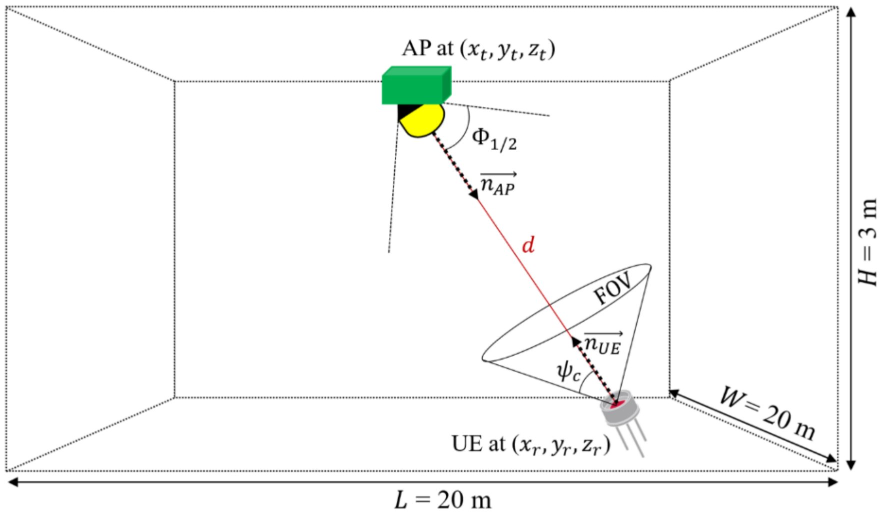
Implement Beamsteering: Open Issues

- **Issue 1**: Is beamsteering really effective to enhance OWC performance?
- **Issue 2**: How to localize the target?
- **Issue 3**: How to ensure actual beam orientation?

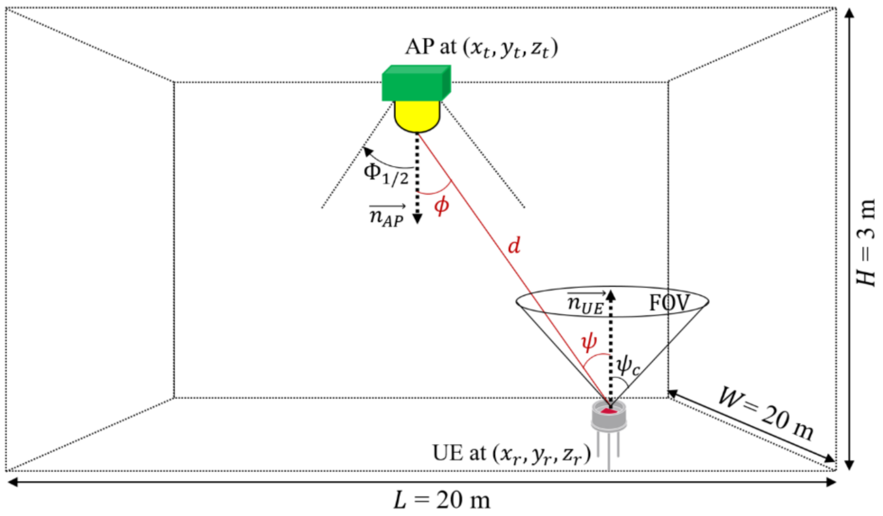
Performance Enhancement With Beamsteering: Approach

- **3 scenarios** studied to determine the OWC system **coverage** (i.e. area where BER < $3,8x10^{-3}$).
  - With ***beamsteeering*** → Tx and Rx perfectly aligned,
  - Without ***beamsteering*** → Tx pointing toward the floor, Rx toward the ceiling,
- **AP = IR-LED source** of **optical power depending** of the source **directivity** (= maximum optical power allowed by photobiological safety standard with this directivity).
- **In beamsteering** configuration, **addition of misalignement** between the AP and UE in a second step.

With *beamsteering*



Without *beamsteering*



H. AL Satai, B. Béchadergue, L. Chassagne and W. M. Ridha Shakir, "Coverage Optimization With Beamsteering-Based Indoor Optical Wireless Communications," *2023 IEEE ICC*, 2023, pp. 1149-1154.

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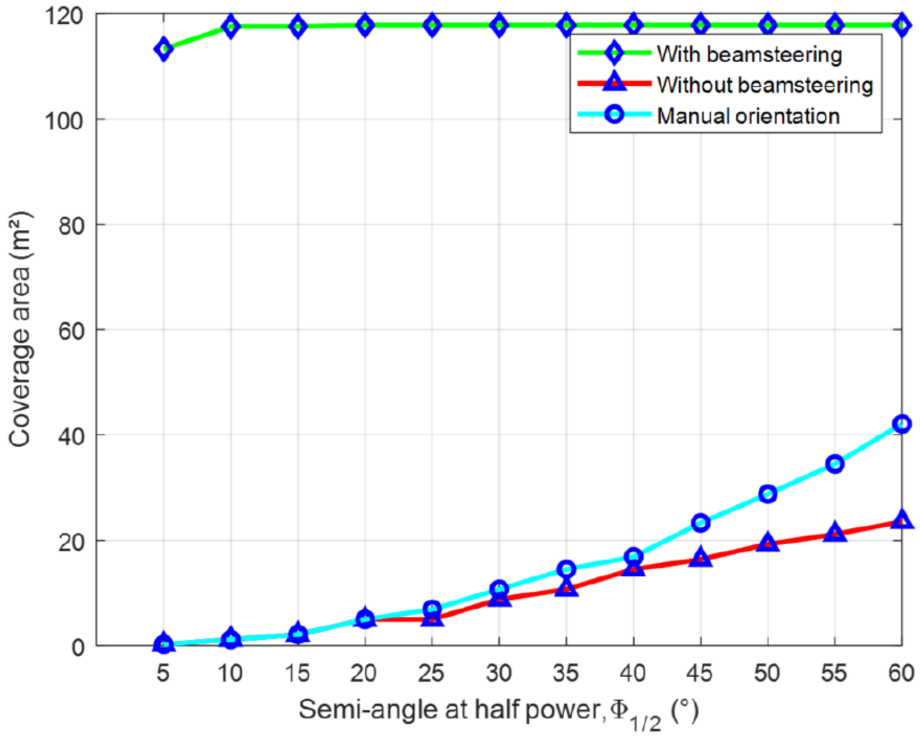
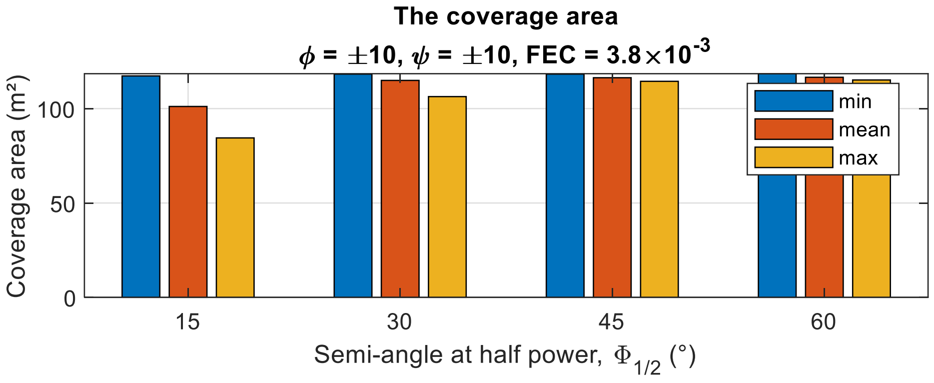
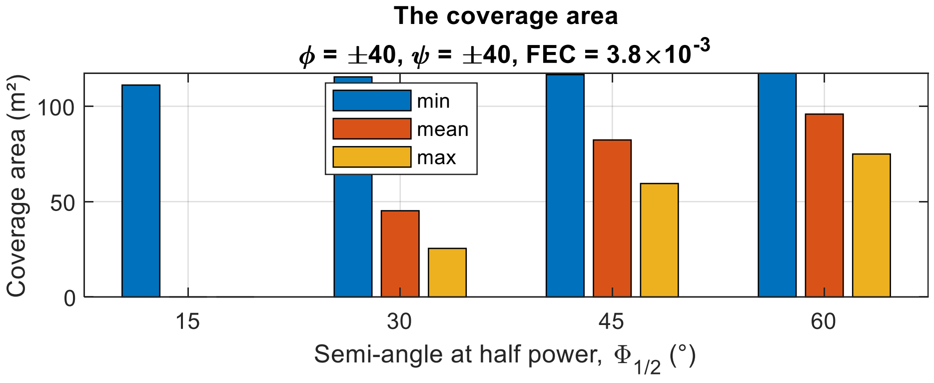
Performance Enhancement With Beamsteering: Results





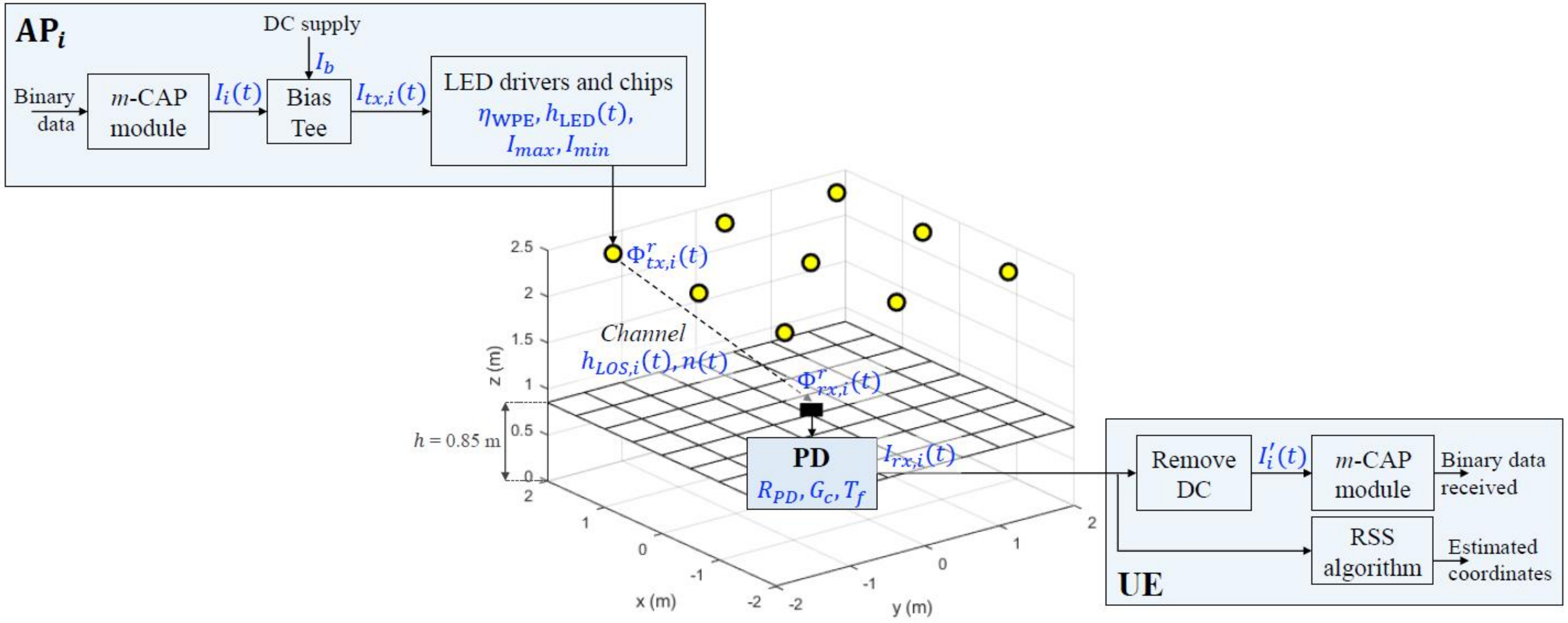


- Conclusions:
  - Whathever the directivity, **beamsteering** enables a **large increase in the communication coverage**.
  - But, **the more directive the source**, **the more sensitive** the link **to misalignement**.

How to Localize the Target? Integrated Sensing and Communication

- **Objectives:** Model, build and evaluate a system for **joint** :
  - **Lighting** (except if IR source),
  - **Communication** (VLC),
  - **Positioning** (VLP).

- **Methodology:** We considered:
  - The use of **m-CAP** modulation and **RSS** positioning technique,
  - First through **simulations** and then **experimentally**.



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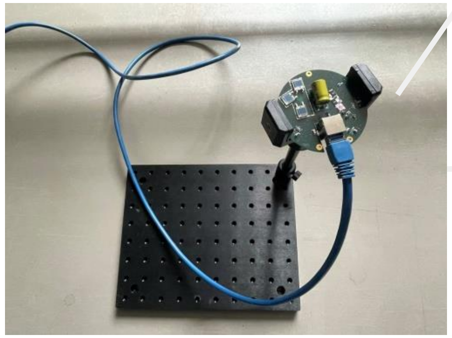
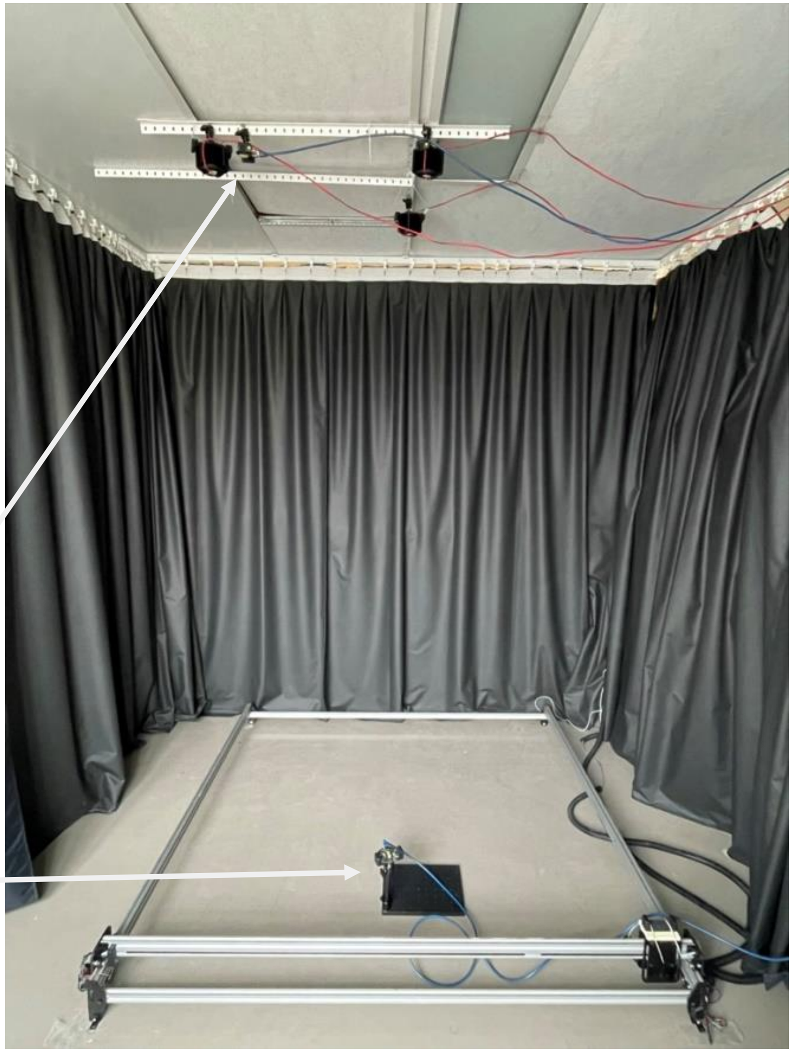
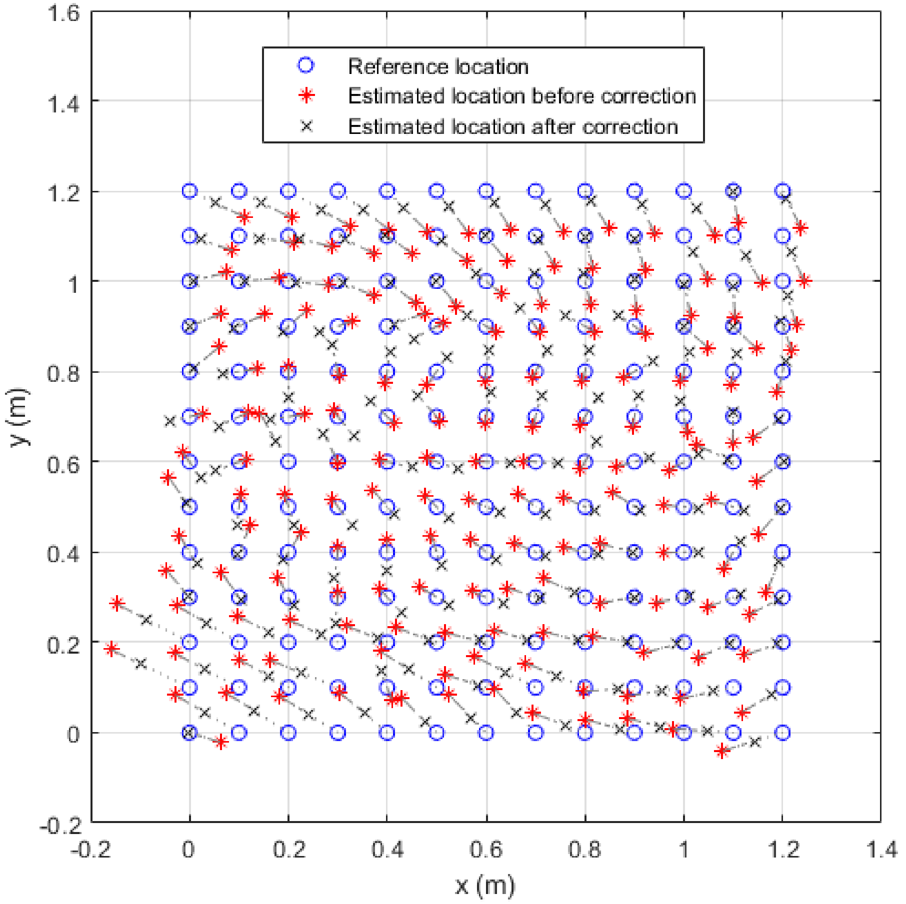
Positioning Performance (Experimental Results)

- **Experimental** testbed developed.
- **90% of the positioning error < 5.9 cm**
- **Communication performance**: BER < 3.8x10^{-3} over the whole 1.2 x 1.2 m zone.

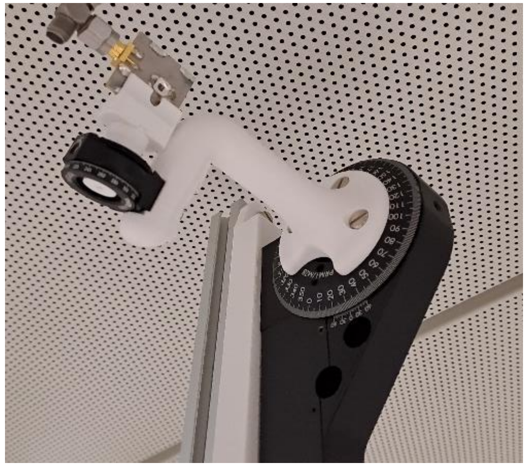


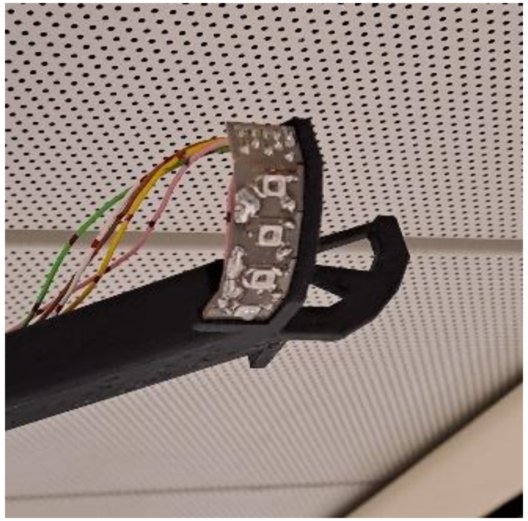




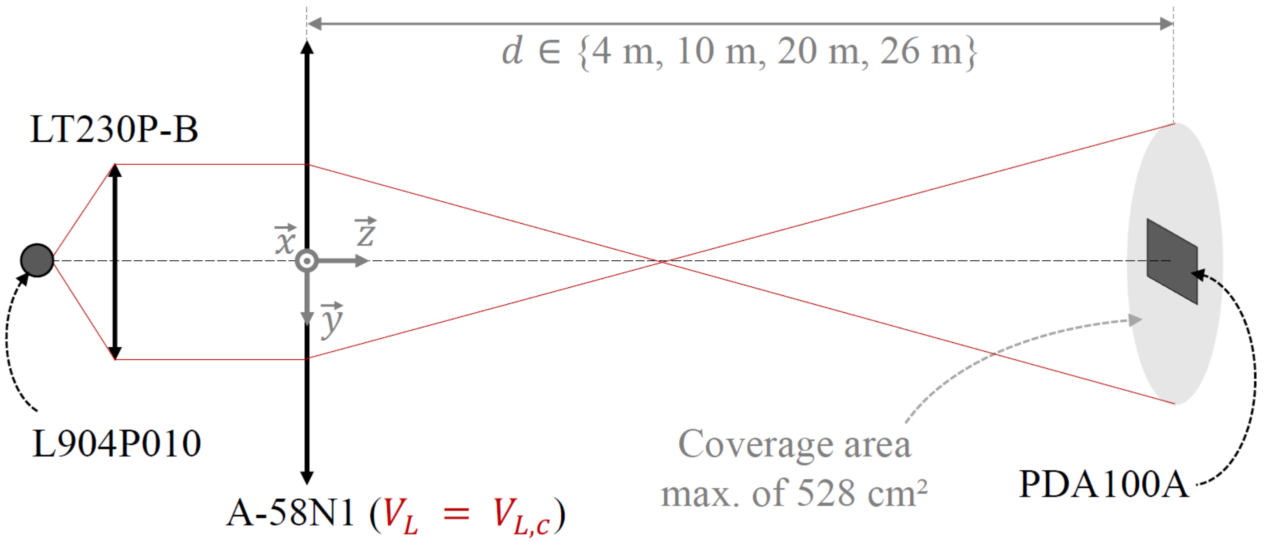
How to Actually Steer the Optical Beam?

Technique	Operates by varying the…	…mainly with…
Motorized gimbal	Orientation of the source/receiver	All types of sources and receivers.
Array of optical sources	Active optical source	Arrays of VCSEL/LED
Mobile mirrors (e.g. MEMS)	Mirrors position	Laser source or LED (of low divergence)
Delay lines with silicon photonics	Time/phase delays between copies of the same signal	Laser source
Lens with variable focal length	The focal length of a lens	Laser source or LED (of low divergence)
…	…	…
Reconfigurable intelligent surfaces (RIS)	**Multiple working principles**	**Various types of sources and receivers.**



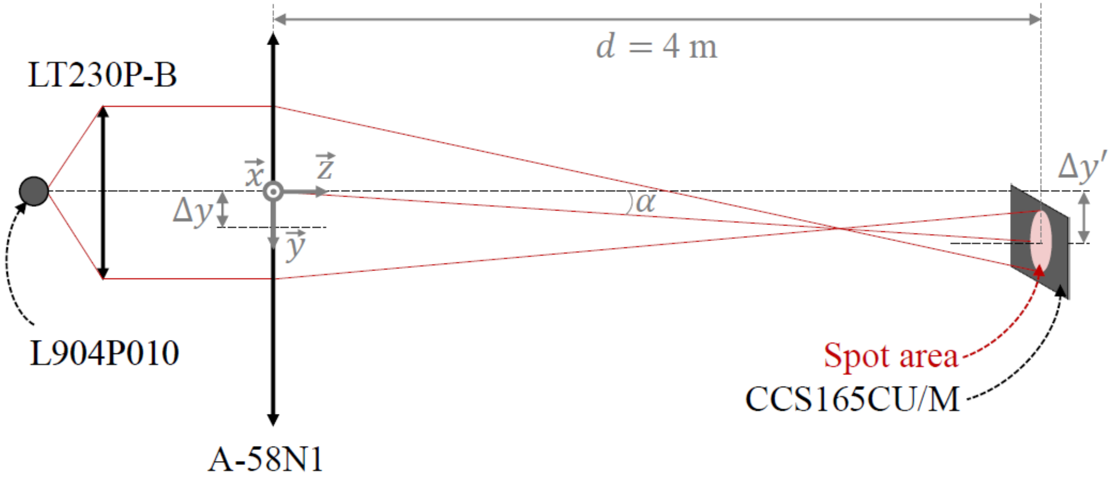


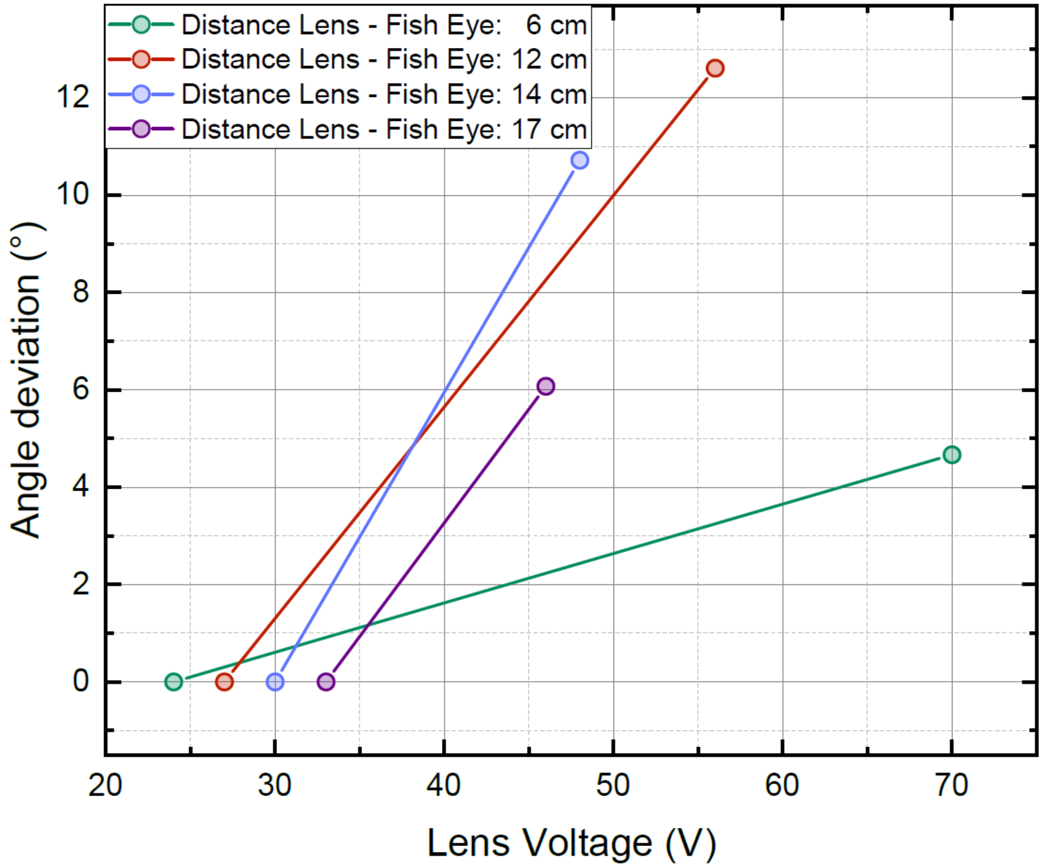
Liquid Lenses for Cells of Variable Size



- By varying the liquid lens **drive voltage**, the **focal distance changes.**
  ⇒ **So are** the **beam spot size** and therefore the **coverage area** at a given distance.
- Cells of areas ranging from **6 mm² to 528 cm²** over distances **from 4 à 26 m** demonstrated.
- Great interest for **tracking before beamsteering** and to fight **misalignement**.

Liquid Lenses for Beamsteering

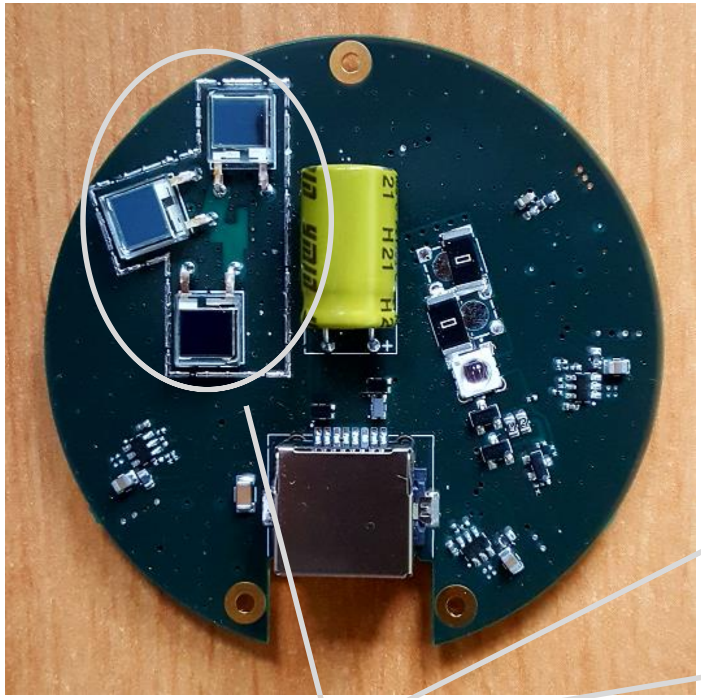




- If the liquid lens **is shifted** from the **source optical axis** ⇒ **Beam deflection** is possible **by varying the lens voltage**.
- **Deflection angle** up to **13° demontrated**.
- Angles **> 70° possible** with more complex setup (multiple lenses for abberation correction etc.).

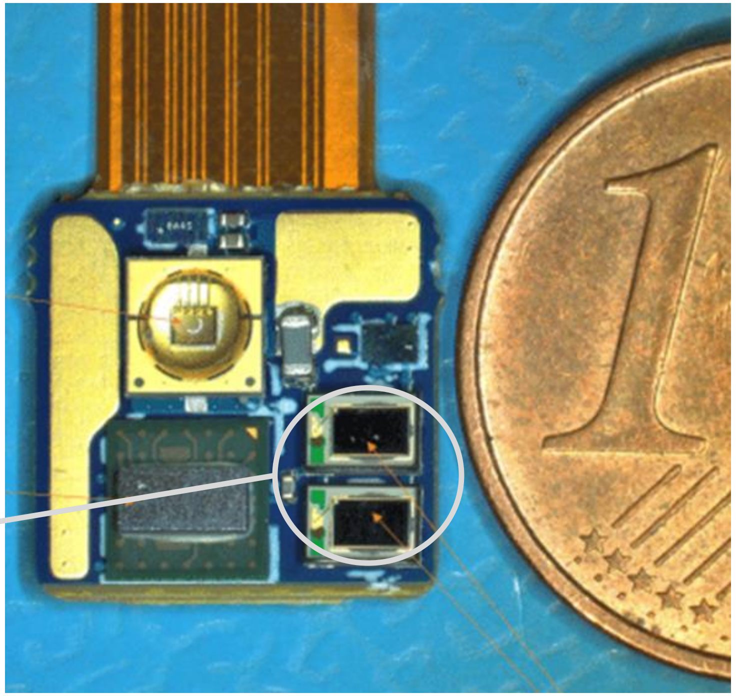
The Sensitivity/Size Tradeoff

Access point by Oledcomm



User equipment by pureLiFi

ASIC optical antenna by Oledcomm



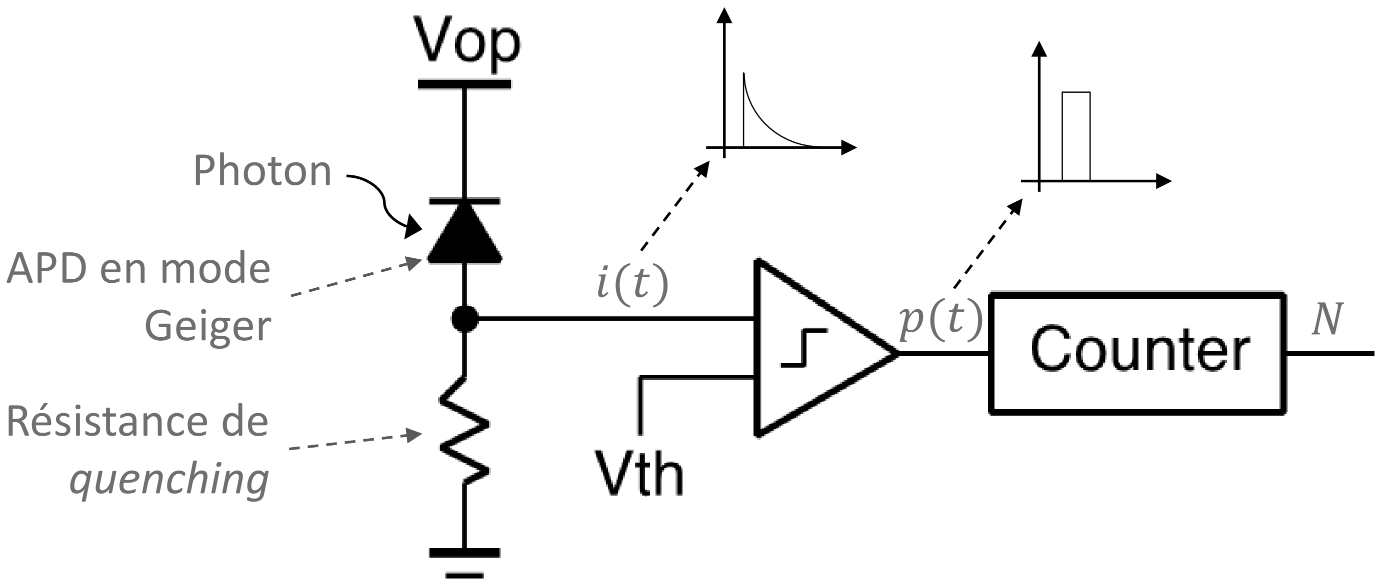
Several photodides (PD) are commonly used to increase the collected optical power…

→ … but current **off-the-shelf receivers** too **bulky** for mass market applications

→ Which solution to this issue? **Single-photon avalanche diodes (SPADs)**

Working Principles of a SPAD

- A SPAD transforms a **detected photon** into a **current pulse**.
- The **number of pulses** over a duration T_s is **proportional** to the received **photon flux**.
- Problem : **After a photon detection**, the **SPAD cannot detect** another photon over a certain **dead time**.



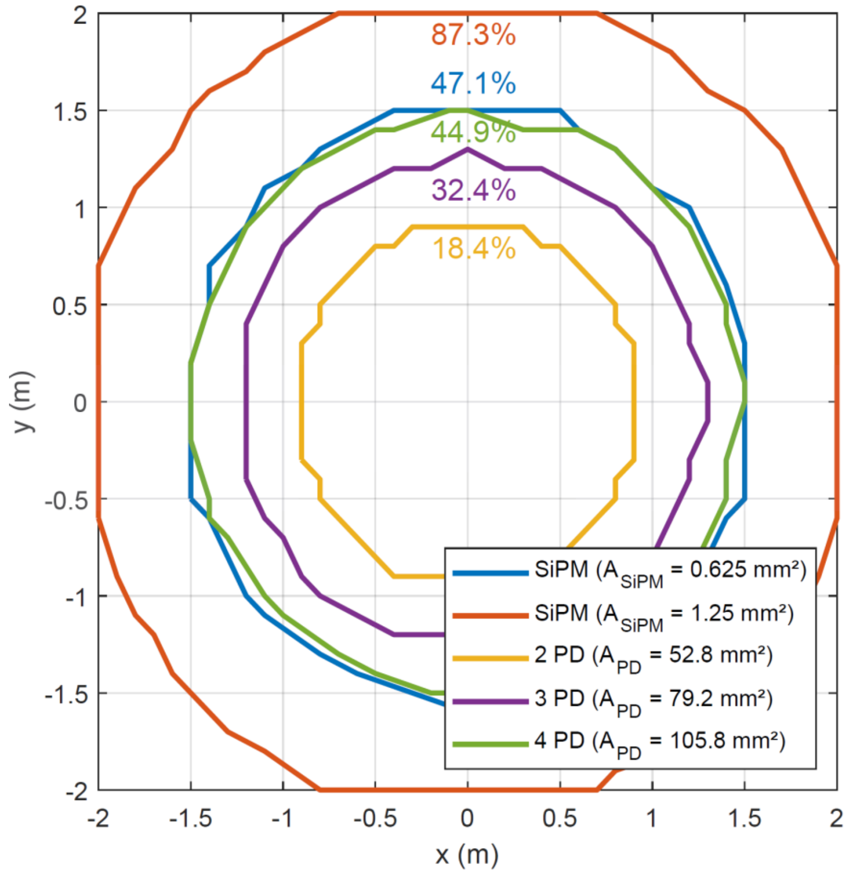
- Solution : Use instead a SPAD array, or silicon photomultiplier (**SiPM**) $\Longrightarrow$ Increase the probability of having **at least one active SPAD** at a given time instant.
- In practice, SiPM = 10000+ SPAD, spread over < 1 mm^2 $\Longrightarrow$ **very small and sensitive sensor!**

OWC Performance Optimization: SPAD *vs* PD

Question: Does a SiPM enable to enhance the OWC communication performance?

- <u>Principle</u> : Simulations, in similar conditions, of the **communication coverage** (i.e. zone where BER $< 3.8 \times 10^{-3}$) with state-of-the-art **SiPM** and **PDs**.
- <u>Results (in a 4x4 m room)</u>:
  - **0%** of the room covered **with a single PD** of 26.4 mm^2.
  - **Similar coverage** (~50%) with a **0.625 mm^2 SiPM** and a **105.8 mm^2 PD** de surface **105.8 mm^2** (i.e. 66 time larfer!).
  - Room **entirely covered** with a SiPM **smaller than 1.5 mm^2**.

Conclusion: SiPMs ensure a **significant increase** in **coverage area** with a **very small footprint.**



Top view of the coverage areas ensured by various kinds of SiPMs and arrays of PDs.

B. Béchadergue, T. Cazimajou, F. Mandorlo, and F. Calmon, "Indoor Optical Wireless Communication Coverage Optimisation Using a SiPM Photoreceiver," *2023 IEEE WCNC*, 2023, pp. 1-6.

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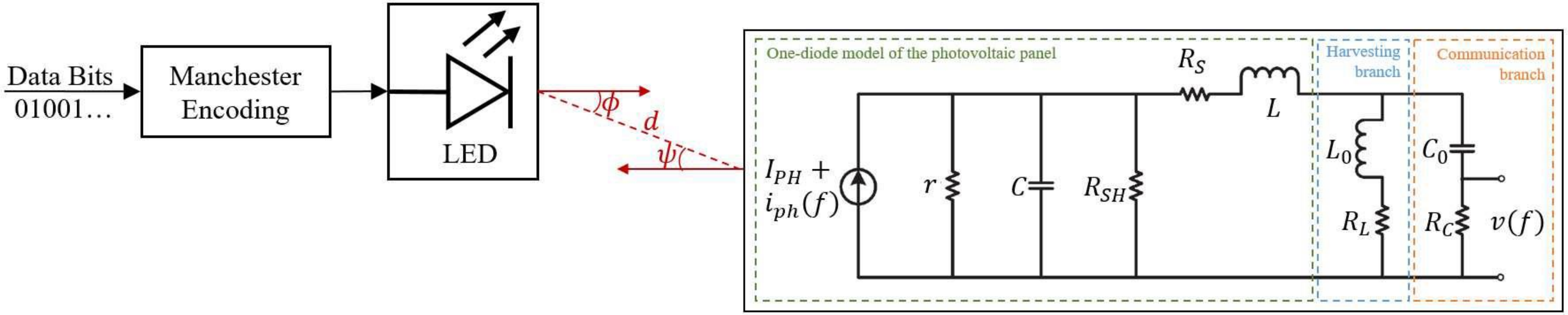
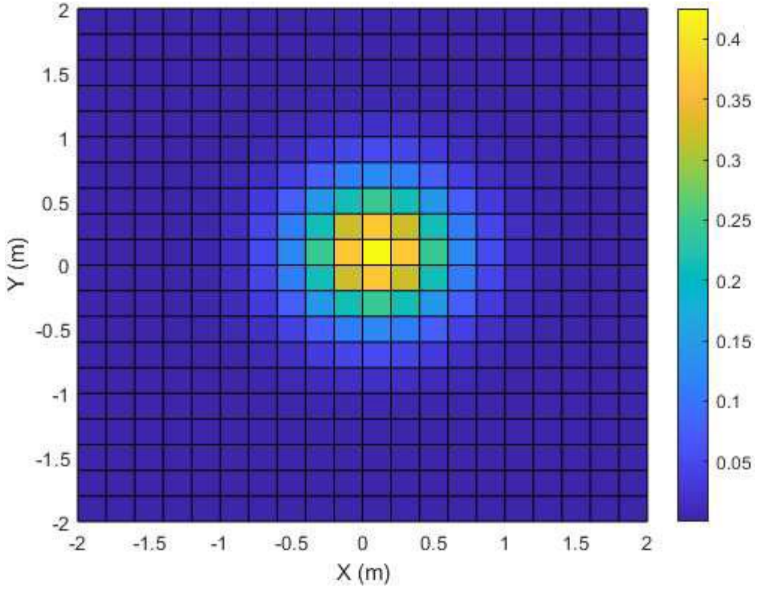
Energy Harvesting With Photovoltaic Modules



- **Question**: Is beamsteering interesting to enhance energy harvesting performance despite its own power cost?
- **Ongoing work**: Implementation of a simple simulation platform to estimate the energy harvested and BER of an OWC system with PV module as receiver and with(out) beamsteering.
- First results obtained without beamsteering. More results to come next.



O. Cissoko, B. Béchadergue, and I. Tavakkolnia, "Performance of a Photovoltaic Module for Energy Harvesting and Optical Wireless Communications," *2023 JWOC*, 2023, pp. 1-2.

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Thanks For Your Attention

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