ASEAN IVO 2017 Project Progress Report

Smart Lighting for Internet of Things and Smart Homes

Pham Tien Dat
National Institute of Information and Communication Technology

Outline

1. Project overview
- Motivation
- Targets

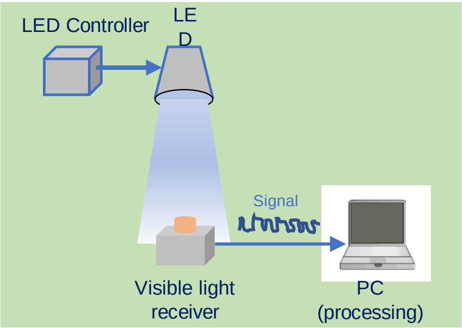
2. Research activities and results
- VLC for indoor communications
- VLC for IoTs and indoor positioning
- VLC for sensing

3. Future Plan

VLC: Visible Light Communications

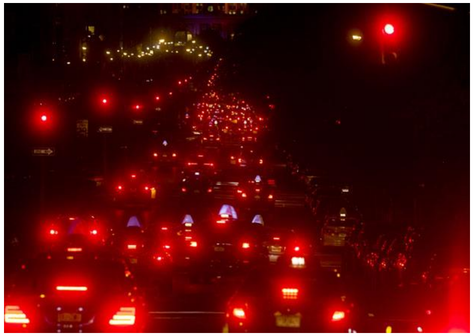
Smart Lighting for Internet of Things and Smart Homes

Concept of a visible light communication link and its possible applications

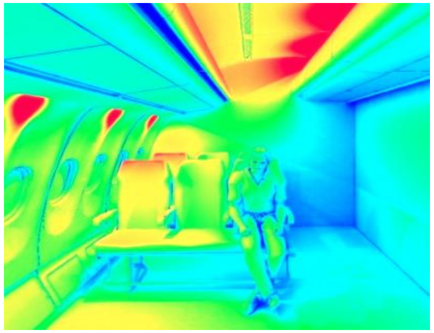


A VLC link

Indoor communications

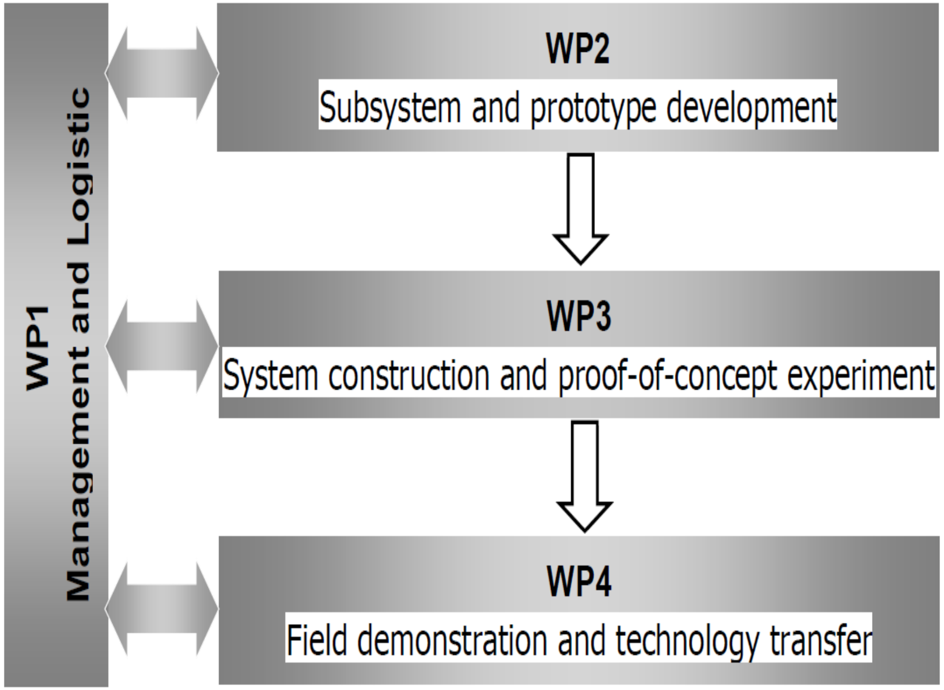


Inter-vehicle communications



Aircraft cabin communications

Project implementation and work packages



- **Project Leader: Pham Tien Dat (NICT, Japan)**
- **Project Members: Pham Quang Thai (HCMUT, Vietnam); Yusuf Nur Wijayanto (LIPI, Indonesia); Dang The Ngoc (PTIT, Vietnam); Jiang Liu (Waseda University, Japan); Purwoko Adhi (LIPI, Indonesia); Naokatsu Yamamoto (NICT, Japan); Mitsuji Matsumoto (Waseda University, Japan) Ukrit Mankong (Chiang Mai University, Thailand), Nguyen Tan Hung (DUT, VN)**

Project targets

- Collaborations between members: joint researches/experiments, researcher exchanges, joint seminars/workshops
- Training young researchers and students
- Sub-system and system prototype development and proof-of-concept experiments
- Field trial test and measurements of water quality
- Contributions to international standardizations

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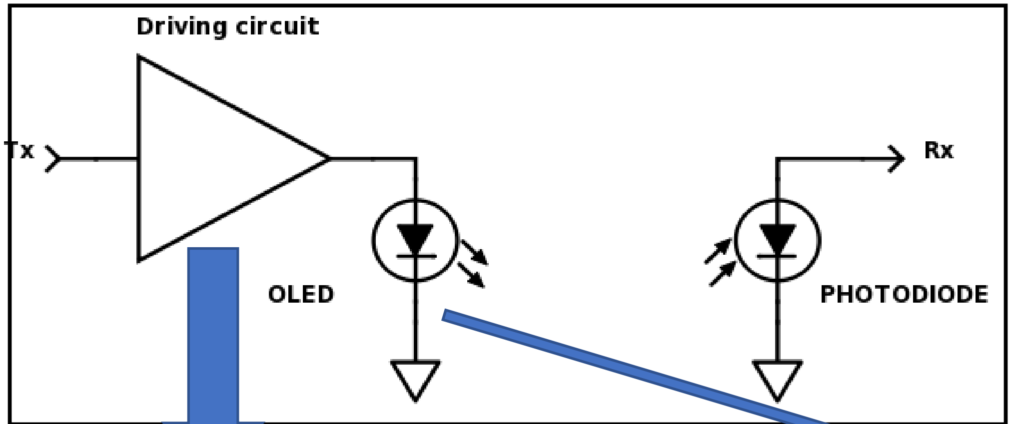
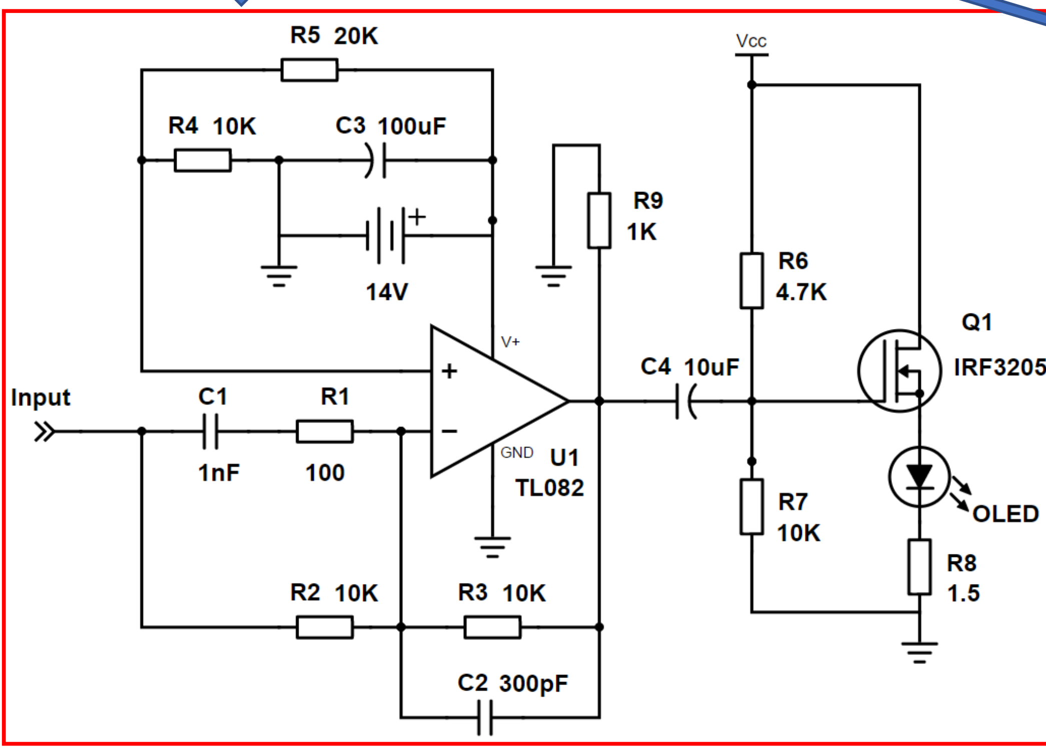
VLC: Visible Light Communications

High-bandwidth-efficiency OLED-based VLC system (1)

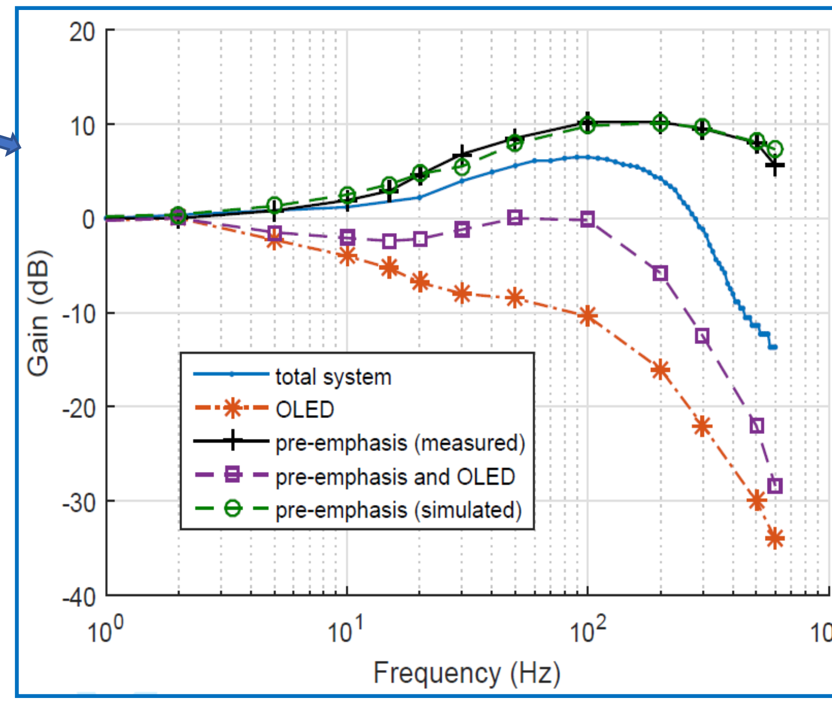


General OELD-based VLC system:

- Very narrow bandwidth
- Low speed data rate



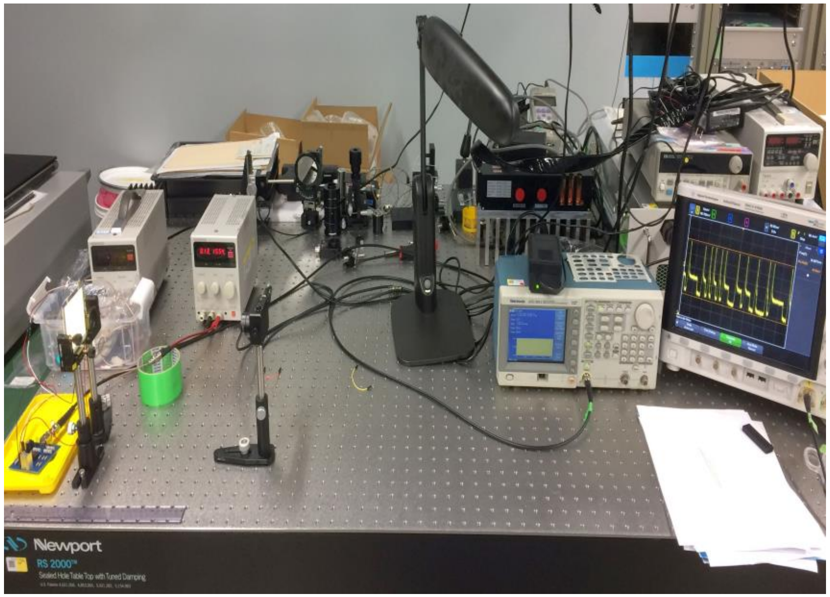
Developed driving circuit



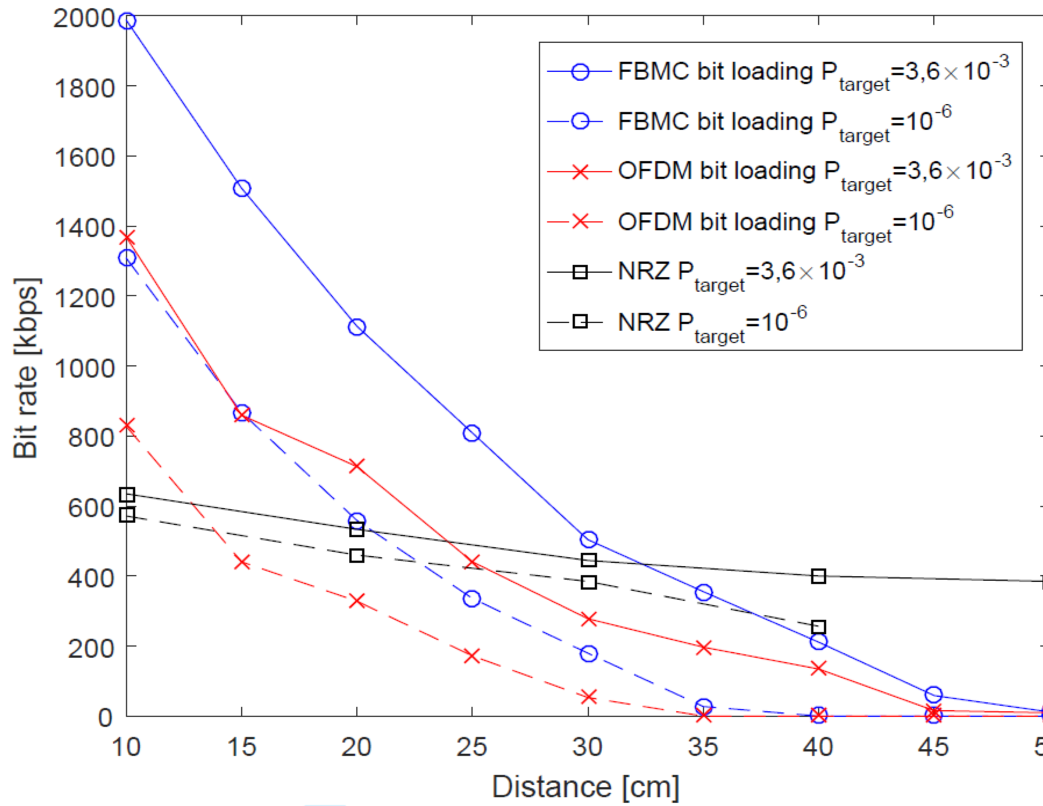
Increasing the available bandwidth

By HCMUT, Vietnam

High-bandwidth-efficiency OLED-based VLC system (2)



Experimental setup (in NICT)



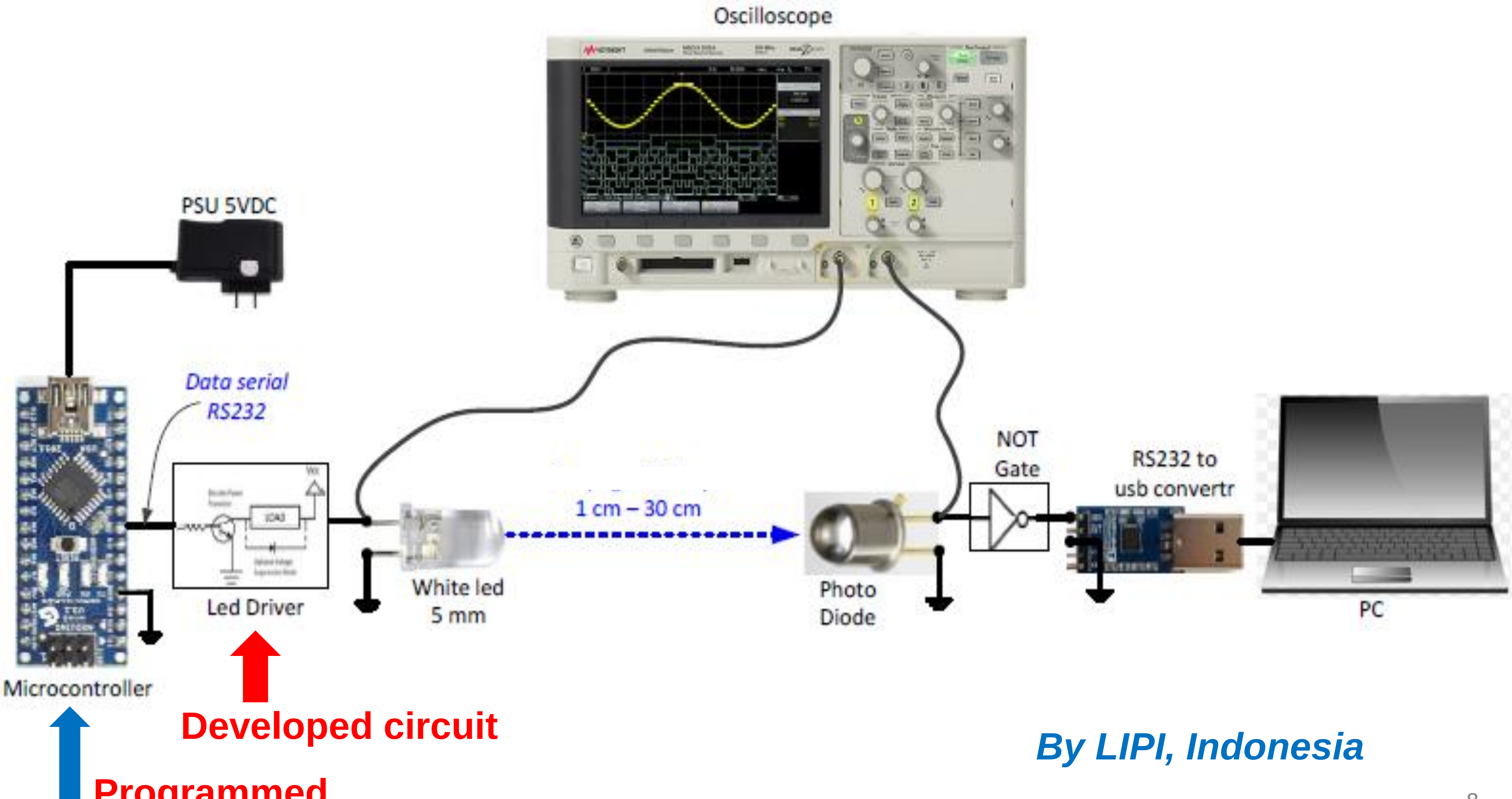
Experimental results

- ❑ **A new combination of active pre-equalizer and Filter Bank Multi-Carrier modulation for VLC system with OLED.**
- ❑ **A bandwidth efficiency of 286 bps/Hz, which was 5 times higher than the state-of-the-art system.**

LED-based VLC system (1)

- Preliminary experiment

Using available and cheap electronic and optical components

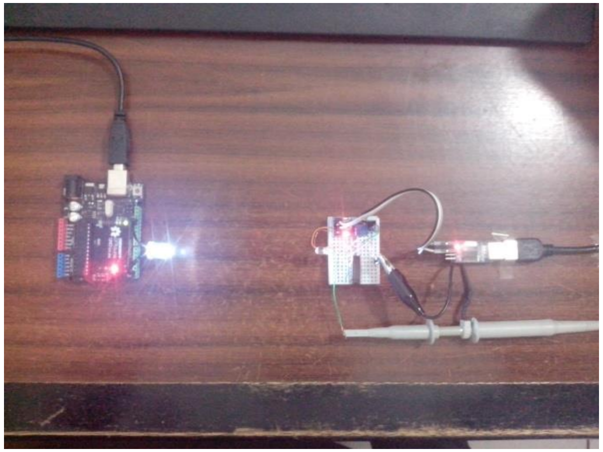


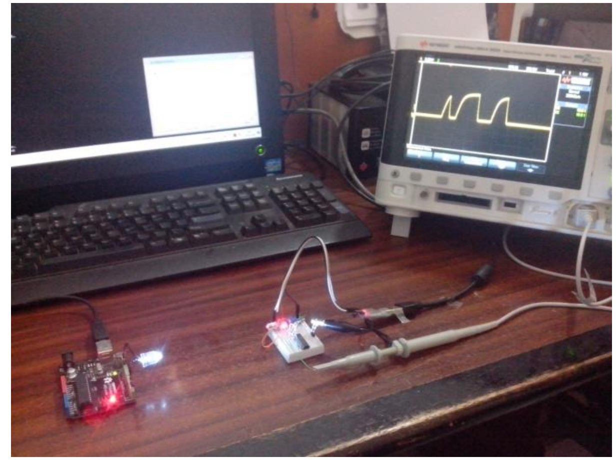
Developed circuit

Programmed

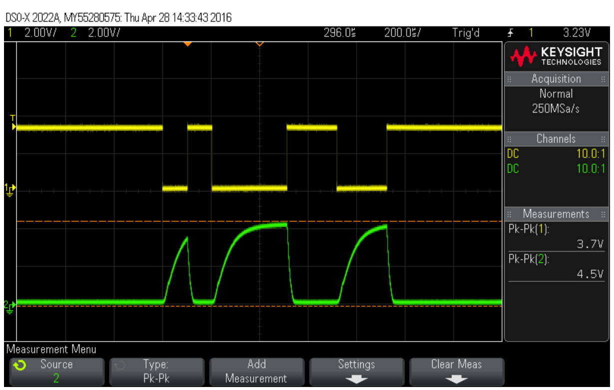
By LIPI, Indonesia

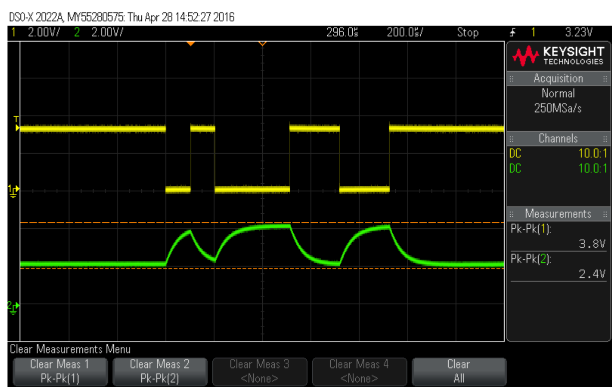
LED-based VLC system (2)

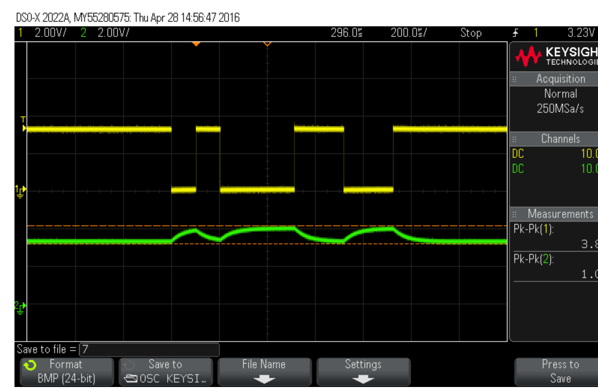




Experimental setup (at LIPI)

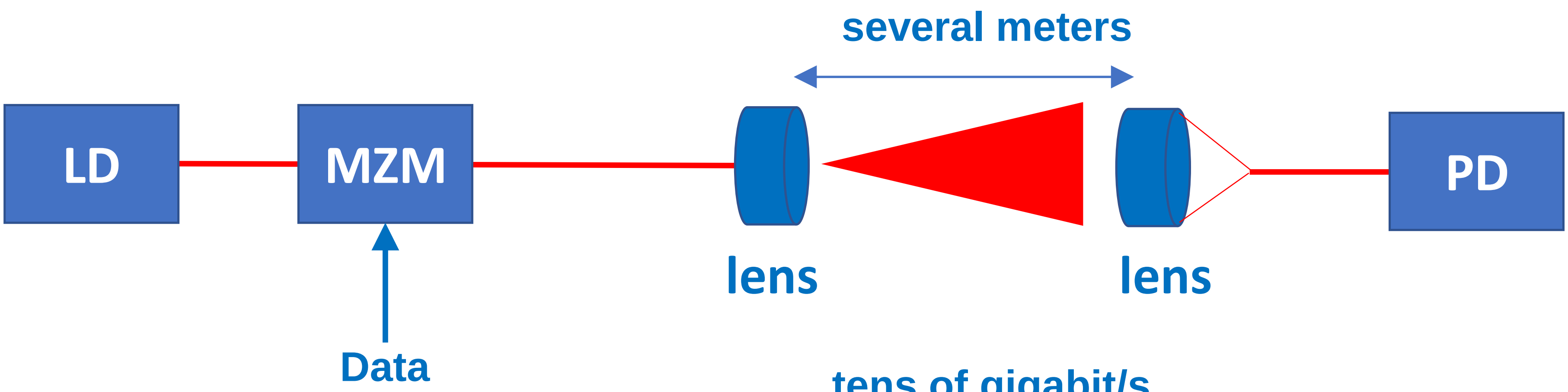




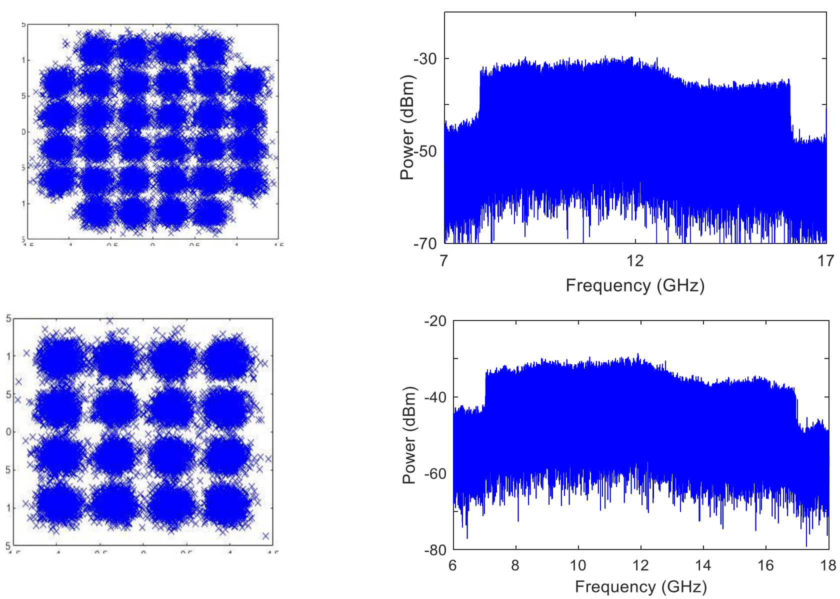


Measured data of transmitting (top) and receiving (below) for 10 mm, 150 mm, and 300 mm.

High-speed communication by lasers



tens of gigabit/s



LD: Laser Diode
MZM: Mach-Zehnder modulator
PD: Photodetector

By NICT

Cross-Layer Analysis for Visible Local Area Network

- Deriving a new cross-layer analysis, which is realized by:
  - From the PHY-layer perspective, the analysis incorporates the effects of VLC channel
  - From the MAC-layer perspective, the analysis takes into account modifications in (i) the backoff algorithm and (ii) the carrier sensing mechanism
- Performance improvement by using of frame retransmissions
- Deriving of various system performance metrics, including delay, reliability and throughput

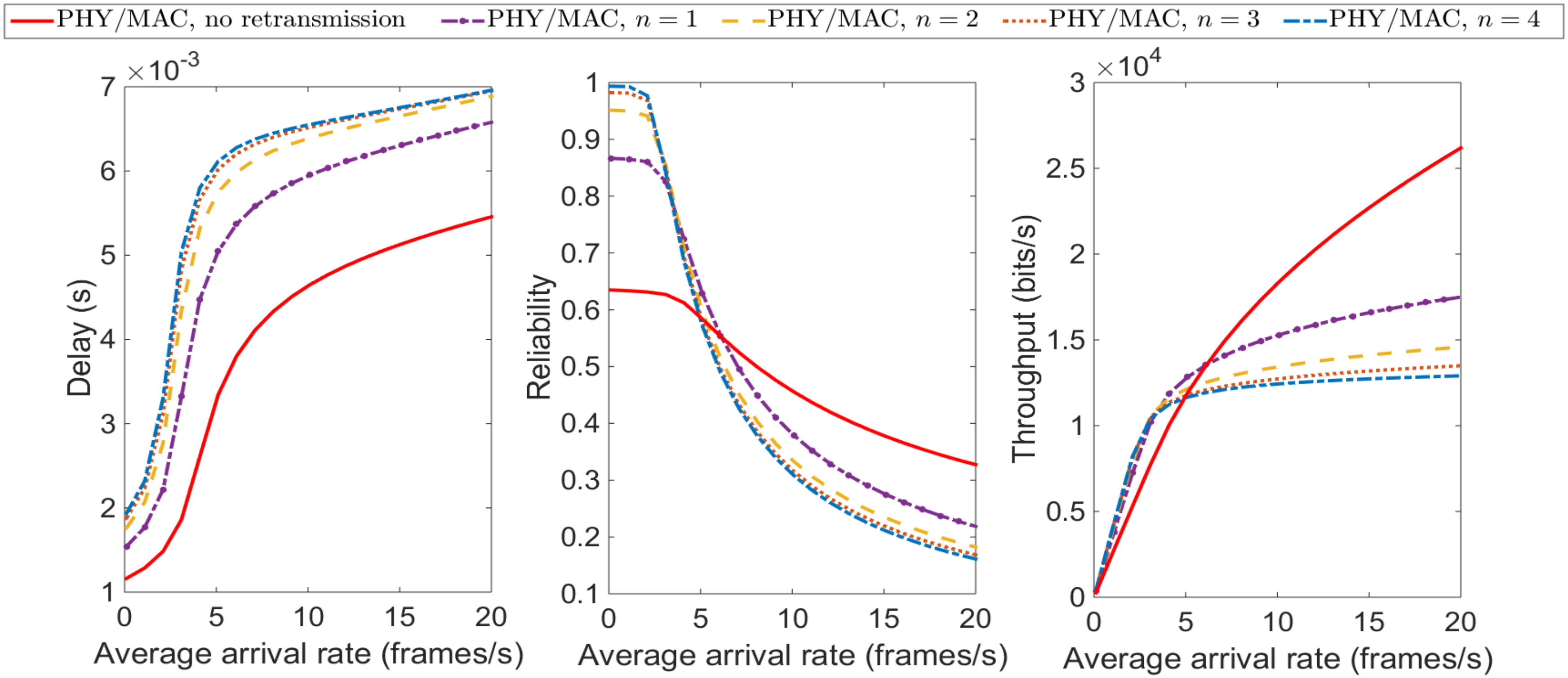
In preparation for journal submission

By PTIT, Vietnam

Cross-Layer Analysis for Visible Local Area Network

Effects of frame retransmissions on MAC performance: *N = 8* users*;*

n: the number of retries; *Q*: mean number of frames; L_p: payload length



In preparation for journal submission

Throughput $\mathscr{T} = \lambda \mathscr{R} L_p,$

Delay $\mathscr{D} = \dfrac{\overline{Q}}{\lambda(1 - P_{full.buff})},$

Reliability $\mathscr{R} = (1 - P_{full.buff})(1 - P_{mac.fail})(1 - P_{trans.error})$

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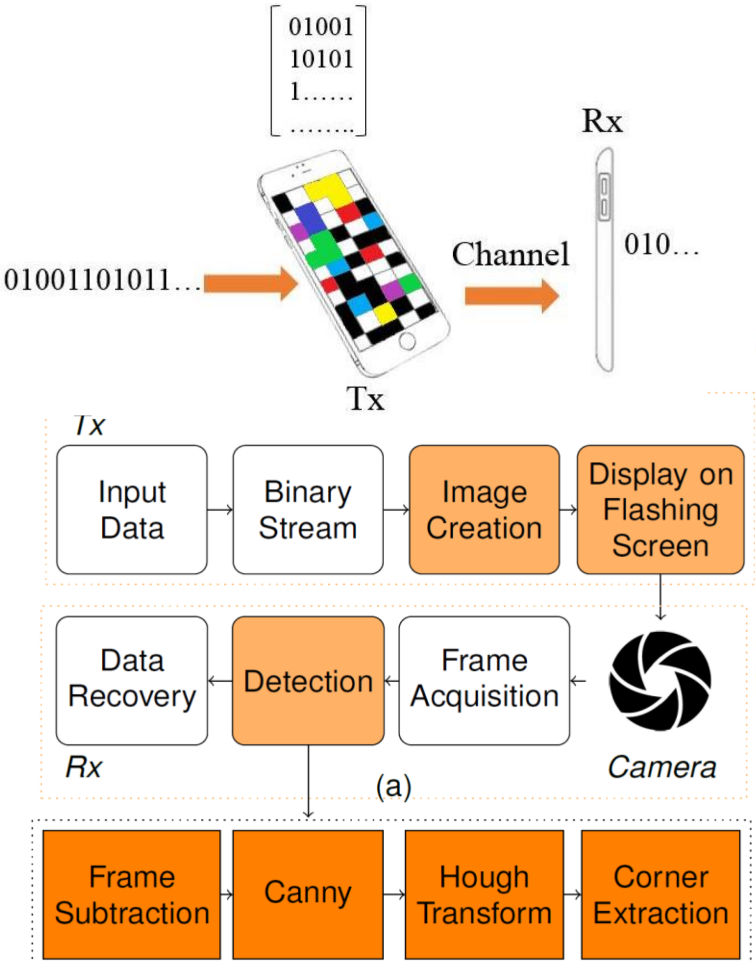
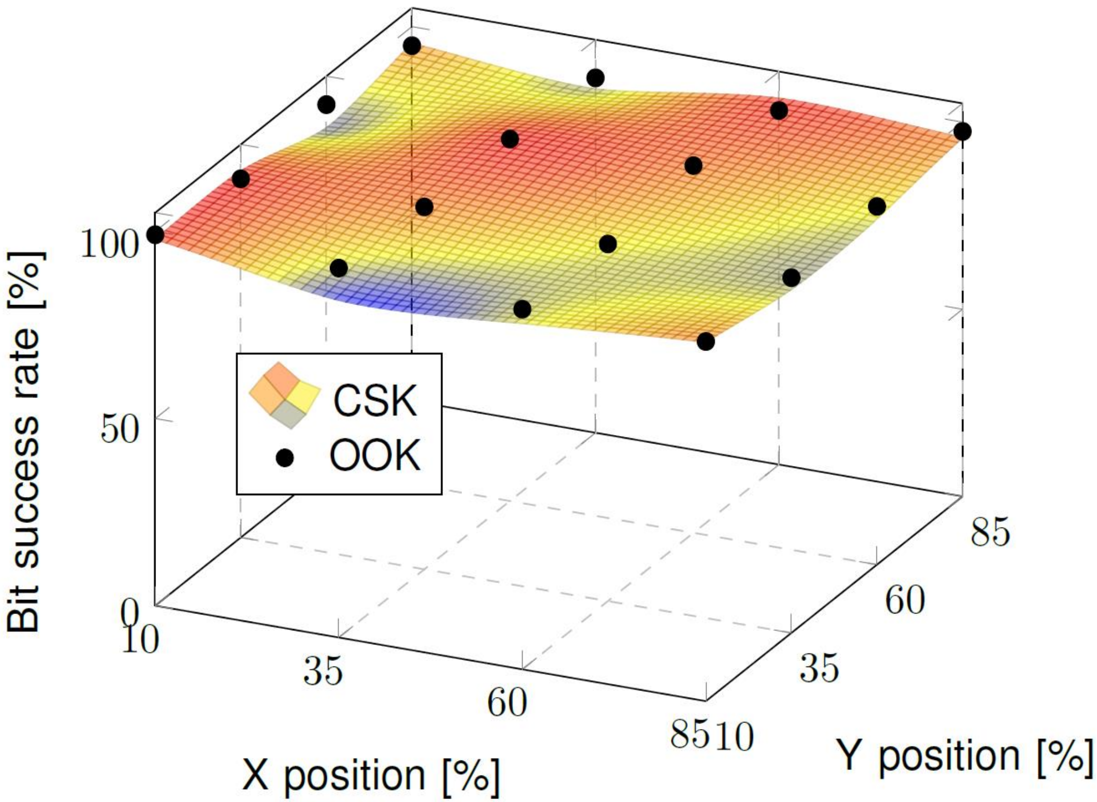
Terminal to Camera Visible Light Communication System





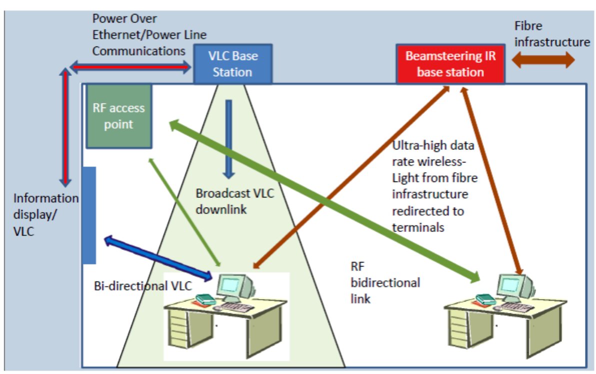
By NICT and collaborators

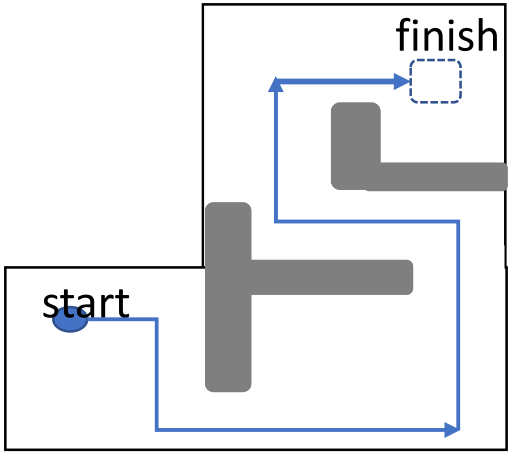
- **Design and implementation of a complete screen to camera visible light communication system, for smartphones and tablets.**
- **Channel capacity of more than 2 kb/frame using On-Off Keying and 5.8 kb/frame using Colour-Shift Keying.**

VLC indoor positioning applications

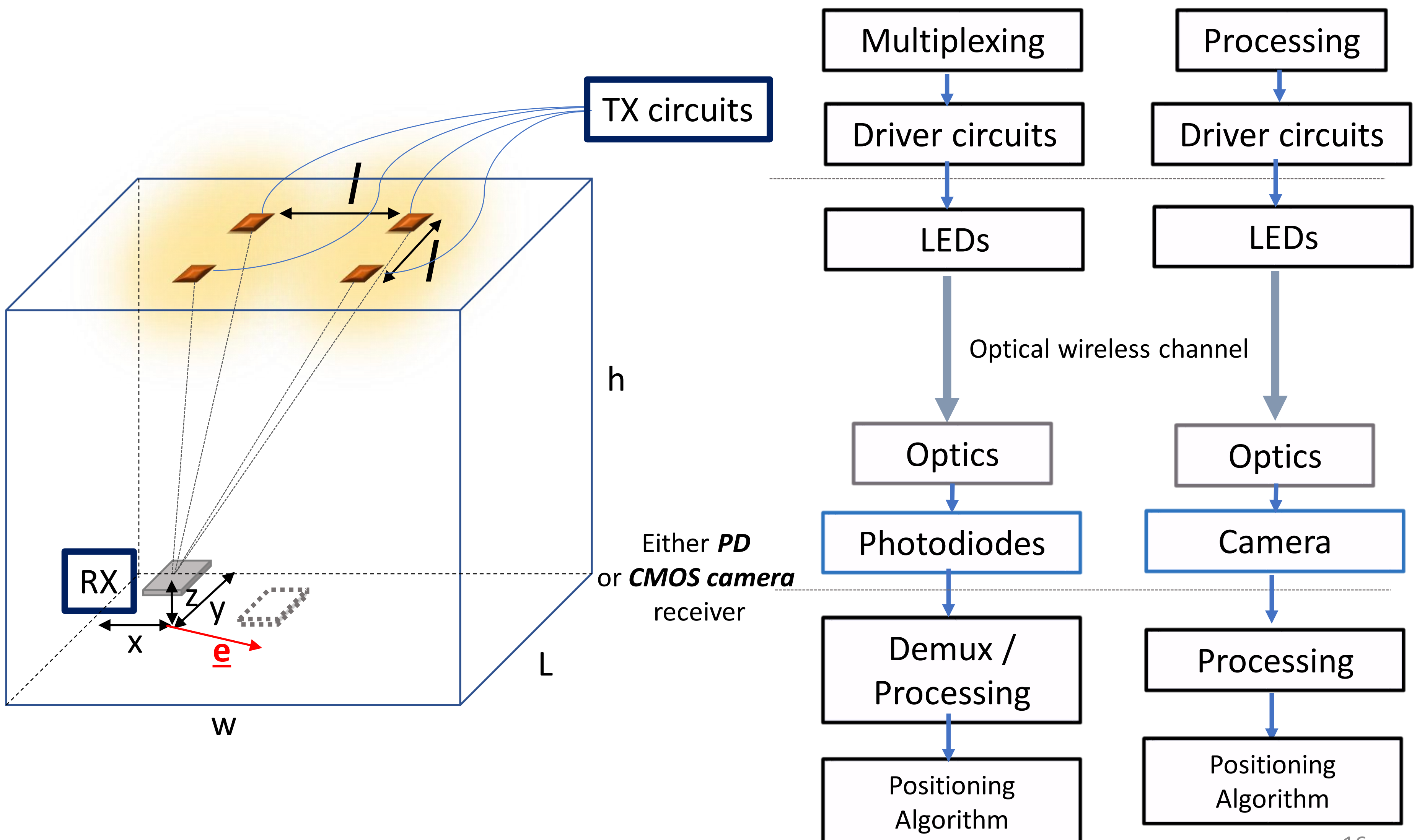
- **Indoor localization**
  - Public venue, e.g. exhibition, museum, supermarkets etc to provide user information
  - enhancing internet experience e.g. to assist OWC beam steering, assist MIMO VLC

- **Accurate indoor positioning for navigation and tracking**
  - Automated navigation: e.g. robots
  - Personal indoor navigation: e.g. transport terminals, shopping malls.

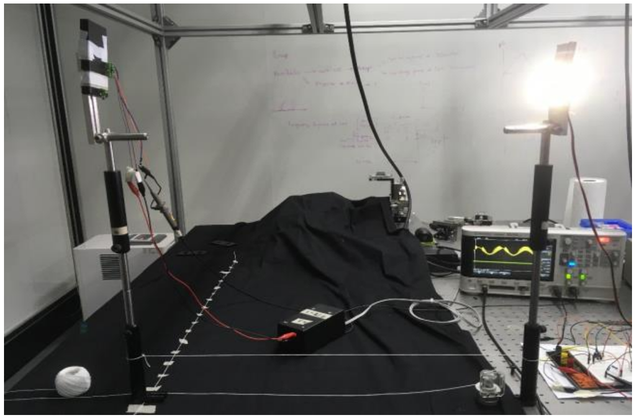


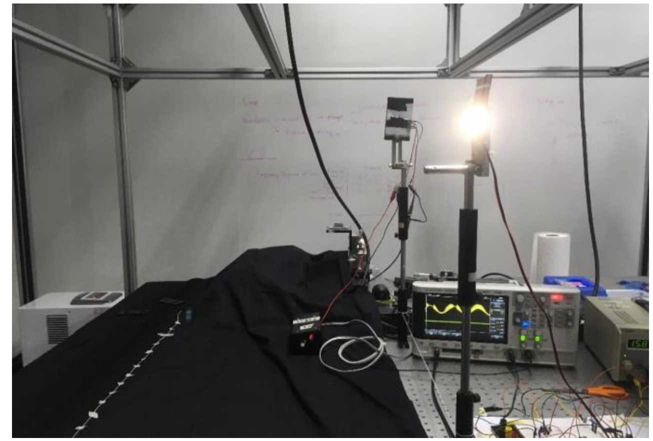


Basic system of indoor positioning

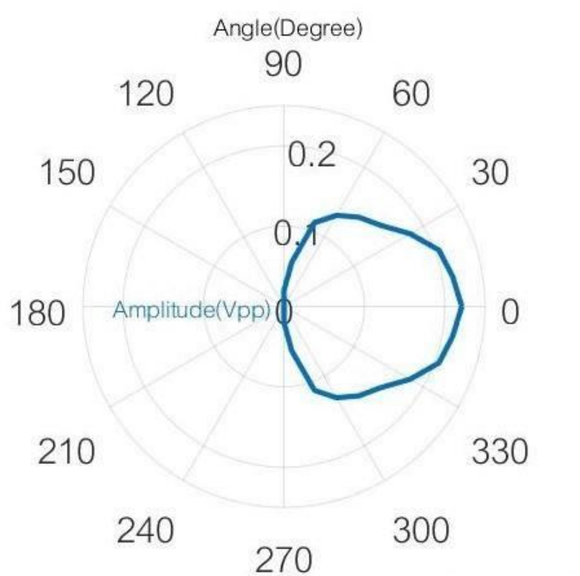


Progress: modelling the received signal strength



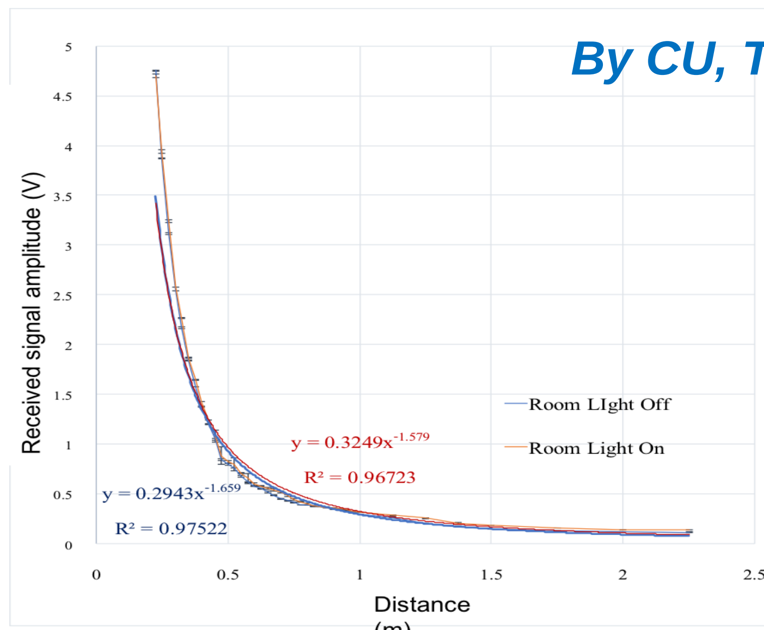


LED beam profile test: Analog sinusoidal modulation, PD receiver



Received signal amplitude vs angle (at 0.50 m)

By CU, Thailand



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- VLC for sensing (water quality measurement)

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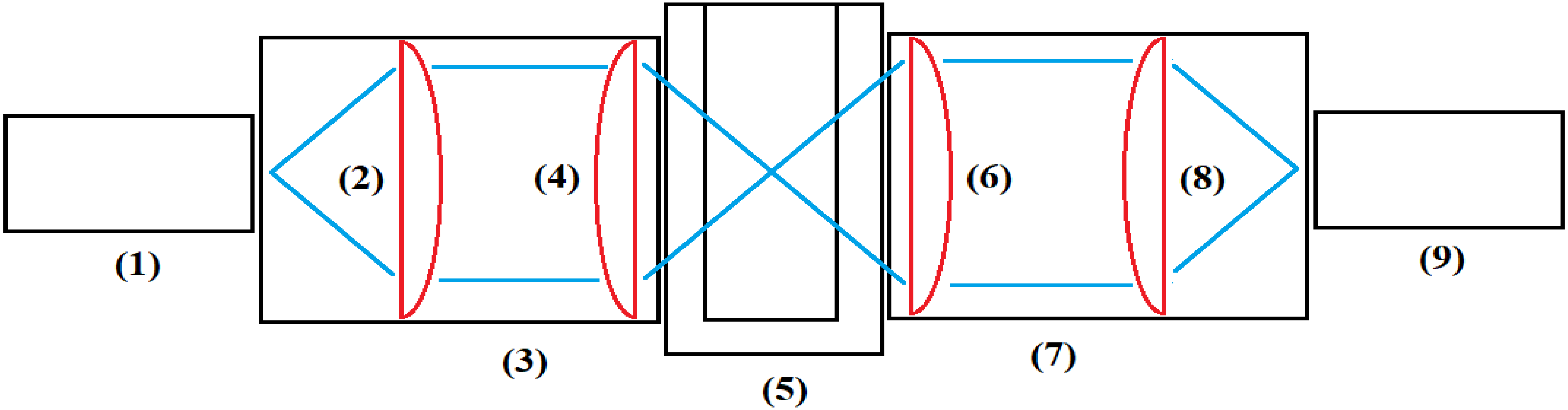
Non-invasive optical sensor system (1)



Block diagram of the water sensor

- the UV source (1) is a Deuterium lamp, provides illumination from 200 nm to 400 nm.
- the UV light is transmitted through free-space along the first lens tube (3)
- inside the lens tube, two plano-convex lenses (2) and (4) are used to focus the light.
- both (2) and (4) have to be quartz lenses to transmit UV wavelength.
- the light beam is then passed through a quartz cuvette (5) holding the sample liquid.
- the second lens tube (7) has two plano-convex lenses (6) and (8) guide the light beam to the spectrometer (9).

❑ Finished prototype design and development

Non-invasive optical sensor system (2)

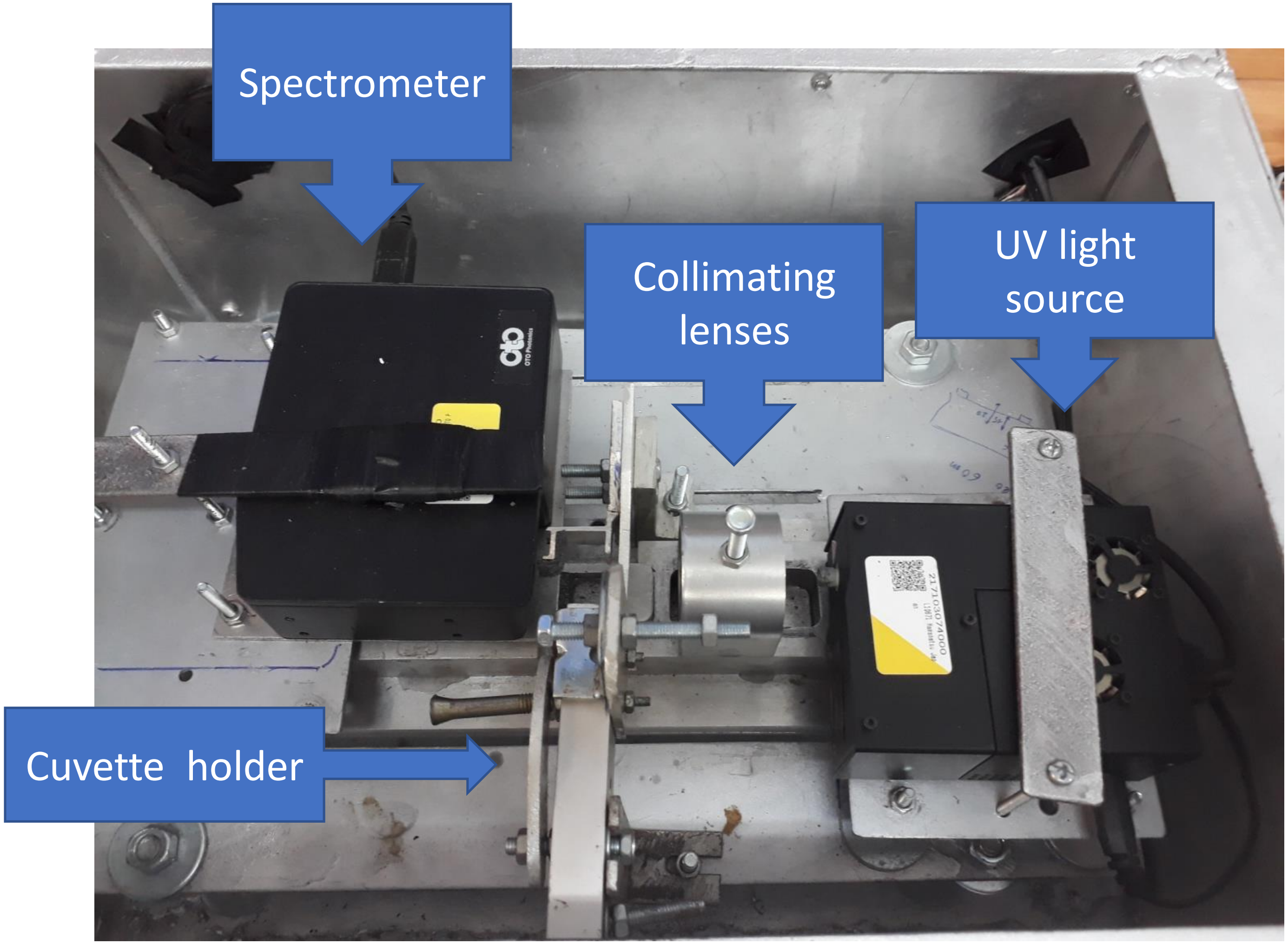
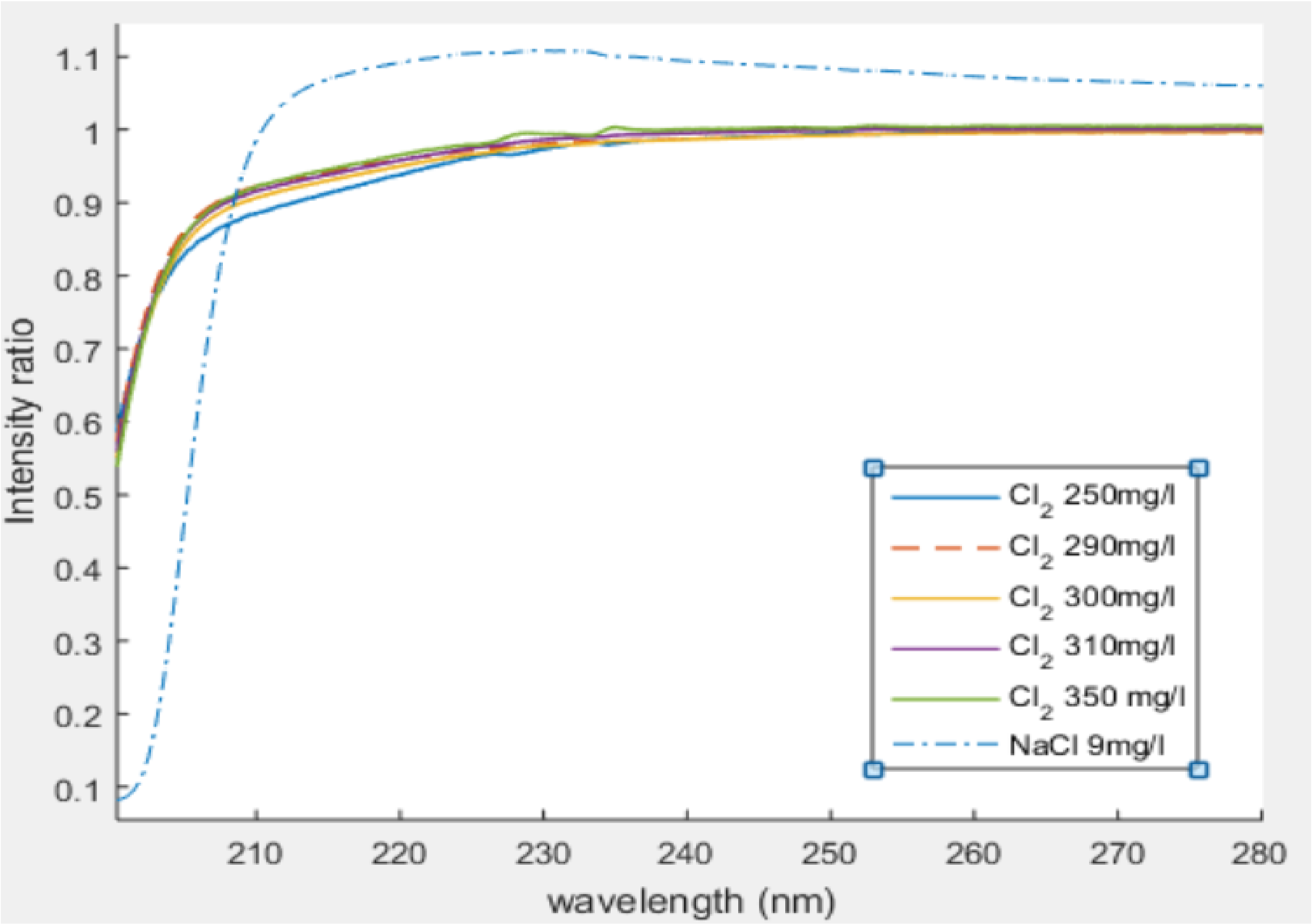


Photo of the sensor prototype

Non-invasive optical sensor system (4)

- Preliminary measurement



Project activities

- First project meeting: Ho Chi Minh city, Vietnam, December 2017
- Second Project meeting: Danang University of Science and Technology, Vietnam: May 2018
- International workshop: ISCE 2017, HCM city, Vietnam, December 2017.
- Special Session at PIERS 2018, Toyama, Japan, August 2018.
- Research exchanges: Dr. Pham Quang Thai (to NICT, 2017), Mr. Nguyen Quoc Hieu (to NICT, 2018).

Project publications

1. M. Matsumoto, *Overview of Optical Wireless Communications*, ISCE, 2017.

2. D. T. Ngoc, *Hybrid VLC/WiFi Networks: CSMA/CA-based MAC Protocol Design and Performance Analysis*, ISCE, 2017.

3. Y. N. Wijayanto, *Short-Range Visible Light Communication with Low-Cost Optoelectronic Devices for Smart Homes*, ISCE 2017.

4. P. Q. Thai, *Pre-Emphasis Circuit for OLED VLC Systems*, ISCE 2017.

5. M. Matsumoto, *Trend of High-speed Optical Wireless System*, PIERS 2018

6. D. T. Ngoc, *Relay-assisted VLC Networks Using Code Division Multiple Access and Analog Network Coding*, PIERS 2018

7. P. Q. Thai, *Filter Bank Multi-carrier and Non Orthogonal Multiple Access in MIMO OLED VLC System*, PIERS 2018

8. Mankong, *Comparison of Indoor Positioning System Techniques Using Visible Light Communication*, PIERS 2018.

9. N. T. Hung, N. V. Tho, N. Q. Hieu, T. C. Dung, and P. T. Dat, *Chaos-secured Software-defined Visible Light Communications*, PIERS 2018.

10. Y. N. Wijayanto, E. J. Pristianto, D. Mahmudin, P. T. Dat, and P. Adhi, *Short Range Visible Light Communication for Data Transfer Using Simple Optoelectronic Circuits*, PIERS 2018.

11. N. T. Hung, P. Q. Thai, P. T. Dat, *Smart lighting for internet of things and smart homes*, IEEE ICCE 2018.

12. P. Q. Thai, F. Rottenberg, P. T. Dat, S. Shigeru, *Increase Data Rate of OLED VLC System Using Pre-Emphasis Circuit and FBMC Modulation*, Imaging and Applied Optics 2018

Future plans

- Prototype development and proof-of-concept demonstrations for indoor communications and positioning
- Field trial measurements of water quality: Tra Vinh province, Vietnam
- Contributions to international standardization: IEEE 802.11bb on visible light wireless local access networks

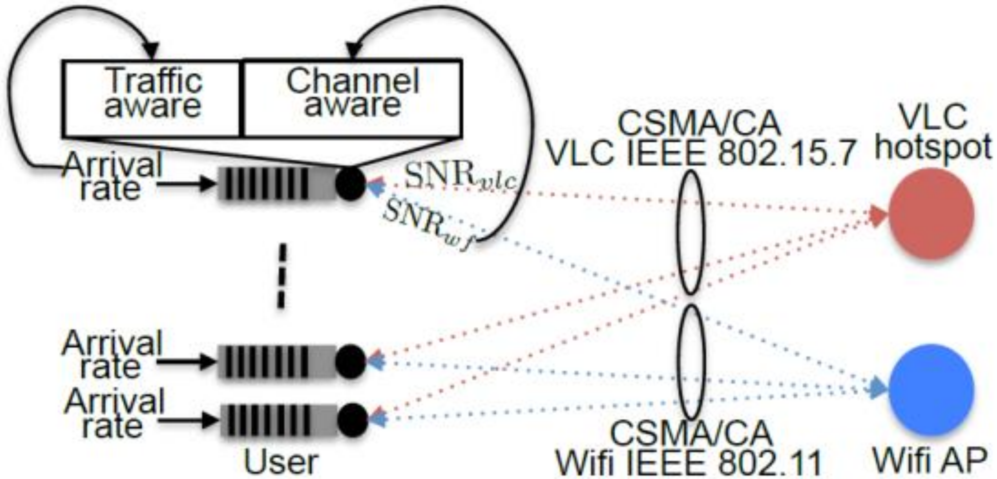
Thank you very much!

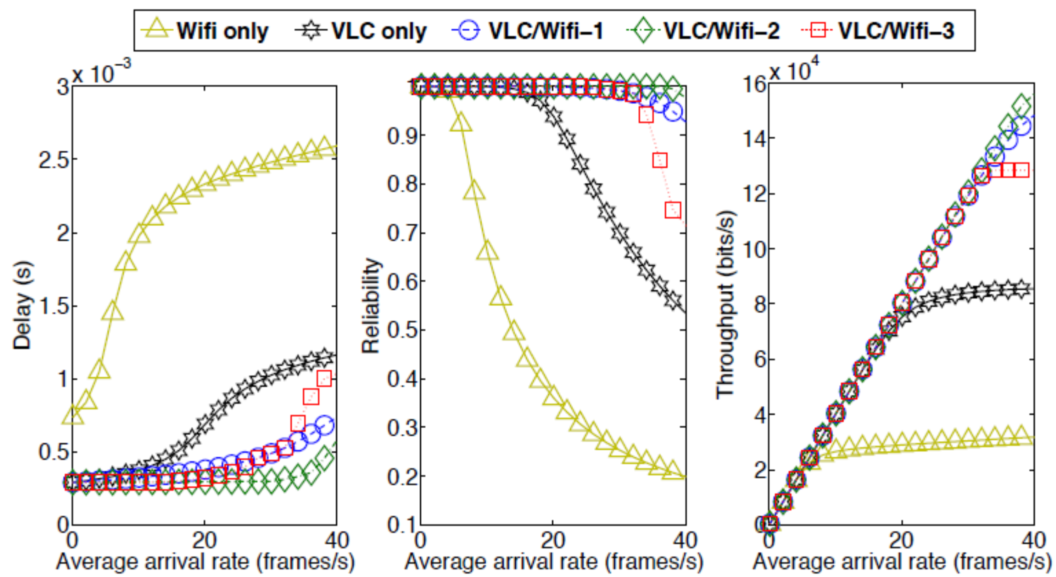
ptdat@nict.go.jp

Hybrid VLC/Wi-Fi Networks

CSMA/CA-based MAC protocol design and performance analysis

- Propose a multi-channel medium access control (MAC) protocol for hybrid VLC/Wi-Fi networks.
- Add on top of current MAC protocols a sub-layer that runs dynamic channel selection by taking intelligent control decisions, regarding channel aware and traffic aware.
- System performance metrics are analytically studied based on a combination of queuing and Markov chain theories.





Non-invasive optical sensor system (3)

- Preliminary measurement