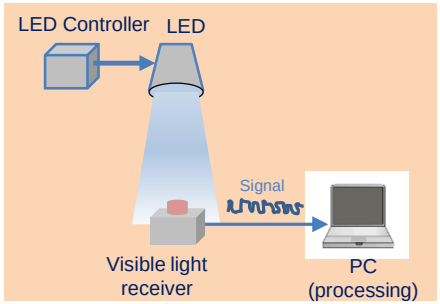
# Smart Lighting for Internet of Things and Smart Homes

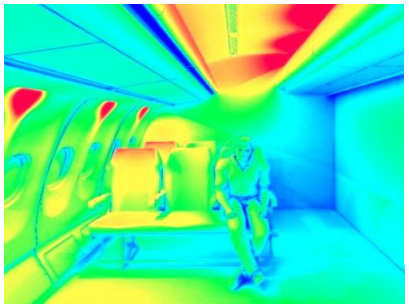
**Background :**



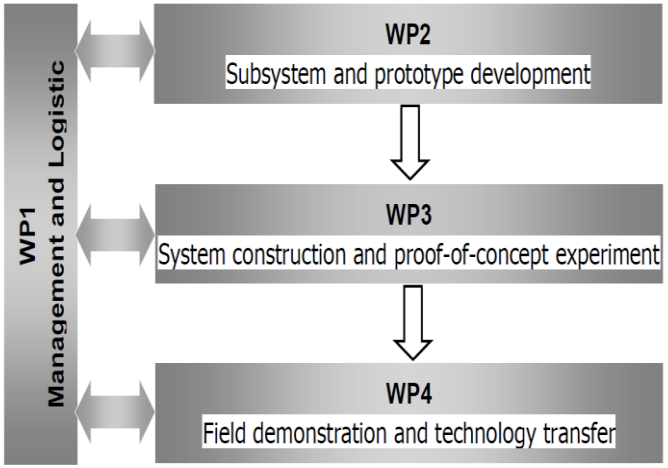

A VLC link


Indoor communications

Inter-vehicle communications



Aircraft cabin communications




**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.
- Measurements of water quality and other liquids.

# Smart Lighting for Internet of Things and Smart Homes

Project Members :

- 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 Duration :

- 3 year (April 2016 - March 2020)

Project Budget:

- 116,000 USD

# 1. Scientific and technological development

- High-speed organic LED and subsystem development for IoT applications
- Camera visible light communication system for smartphones and tablets
- High-speed indoor communication using narrow laser beam and hybrid laser beam /millimeter-wave links
- Indoor localization using visible light communications
- Visible light communication networks: MAC protocol; multiple-user access; secured VLC communications
- Non-invasive optical sensor system development and measurement

## 2. Experiments including field testing

- Experiments of high-spectral efficiency VLC system using organic LEDs
- Experiments of mobile VLC communications for smartphones and tablets
- Experiments of ultrahigh-speed narrow laser beam and hybrid laser beam and millimeter-wave system
- Experiments of indoor localization systems
- Experiments and tests of non-invasive optical sensor

# 3. Budget plan

## 2017

- Budget: 40k USD
- Budget usage: 31,506 USD (PJ meeting: 4,002, 2017 Forum: 1,785, experiment devices: 25,719)

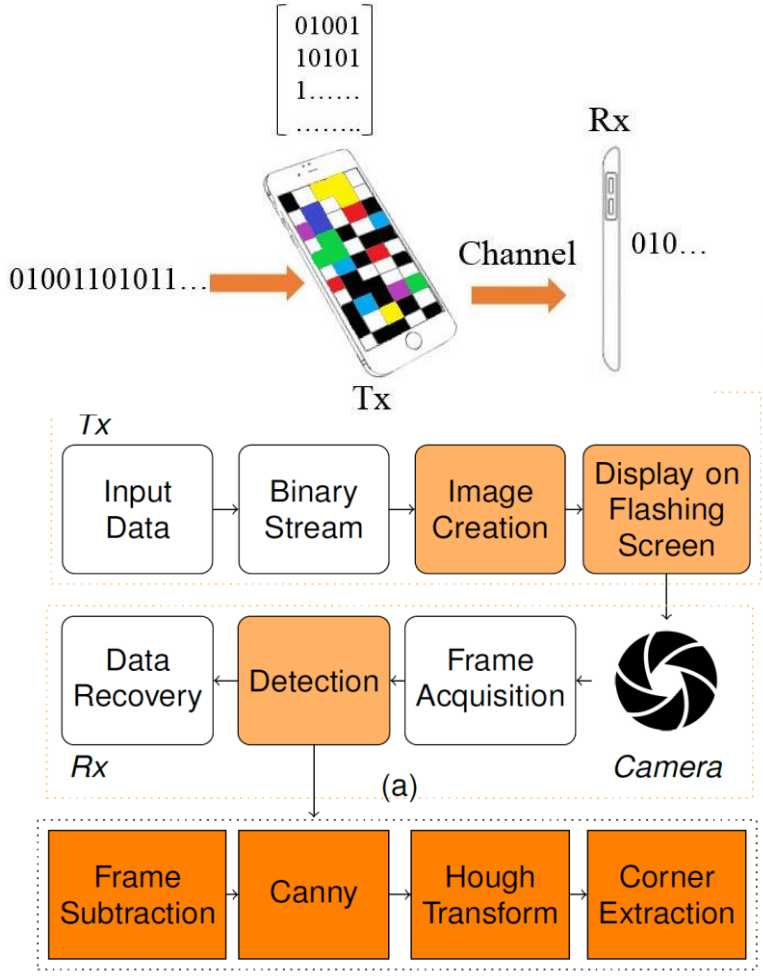
## 2018

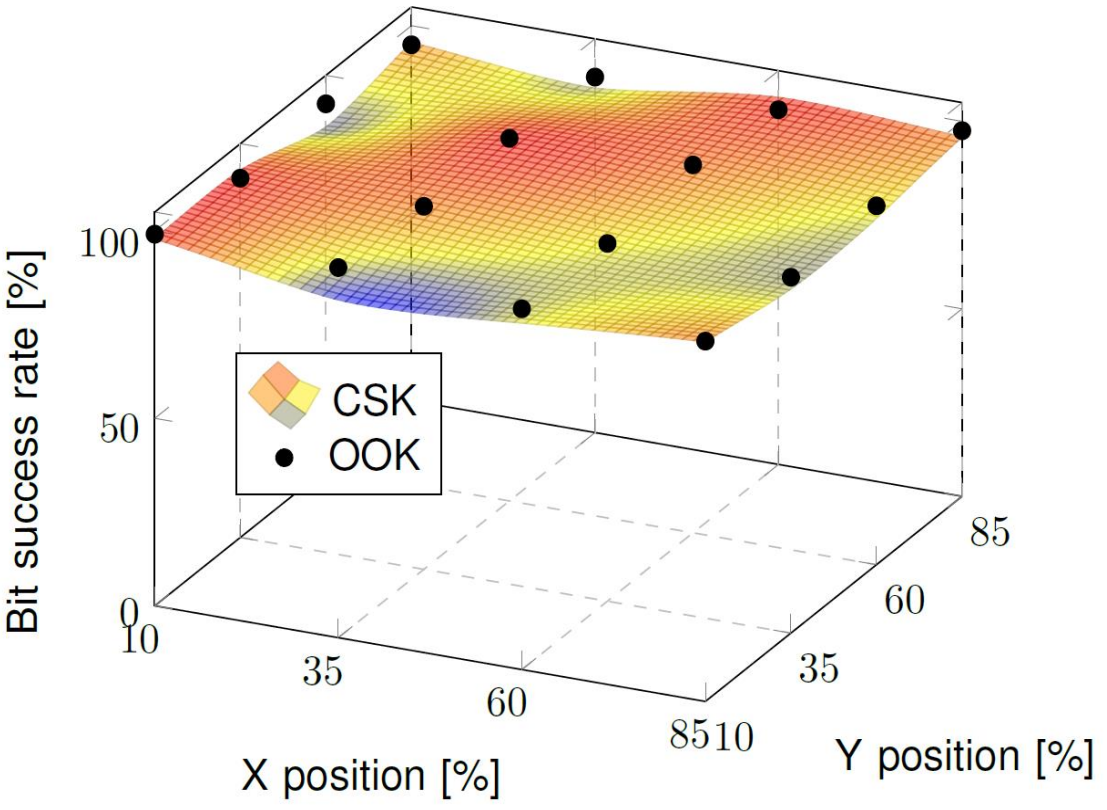
- Budget: 36k USD
- Budget usage: 24,065 USD (PJ meeting: 4729.74, international conference: 12,489; experiment devices: 5139.81; internship: 1470; 2018 Forum: 236.6)

## 2019

- Budget: 40k USD
- Budget usage: 13,394 USD (PJ meeting: 3,773; publication fee: 2,465.51; international conference: 6,976)

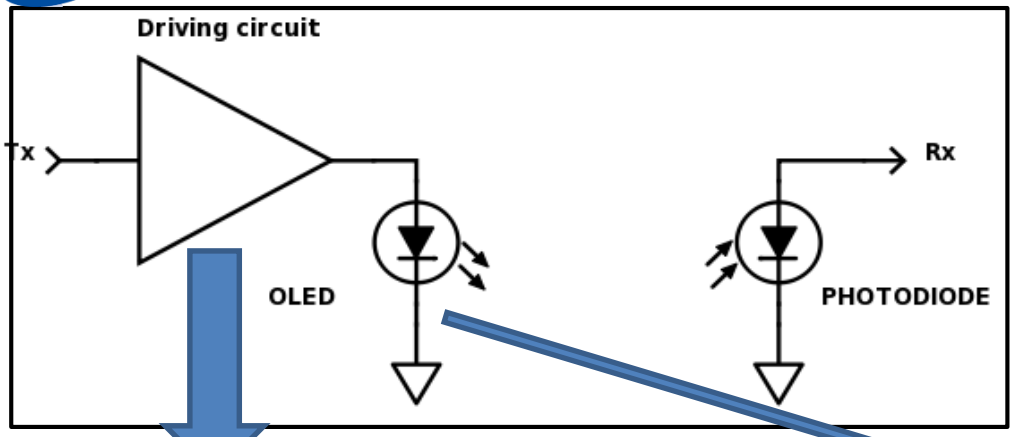
# Project results: terminal to camera VLC system



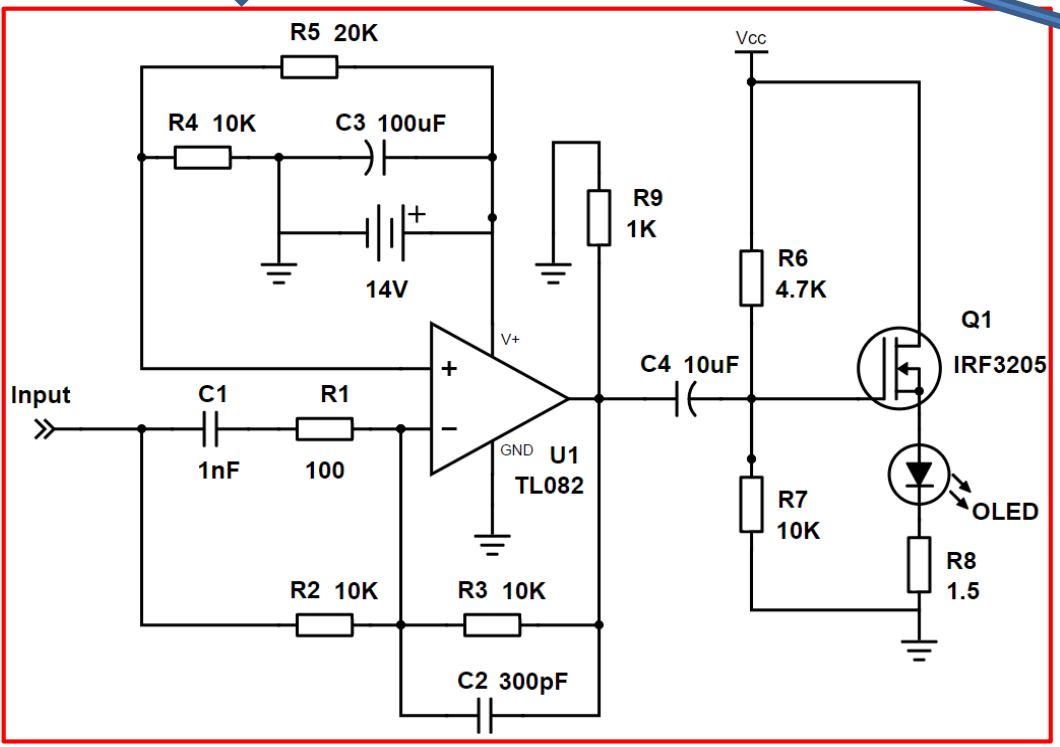

- Design and implementation of a complete screen to camera visible light communication system for mobile smartphones and tablets.
- Channel capacity of more than 2 kb/frame using On-Off Keying and 5.8 kb/frame using Colour-Shift Keying.

# Project results: OLED-based VLC system (1)

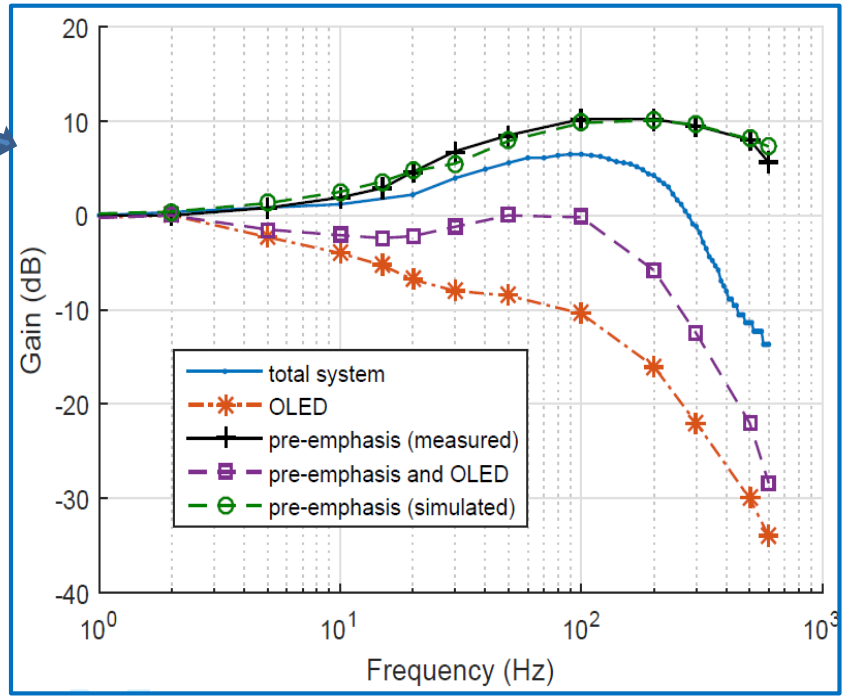



General OELD-based VLC system:

- Very narrow bandwidth
- Low speed data rate

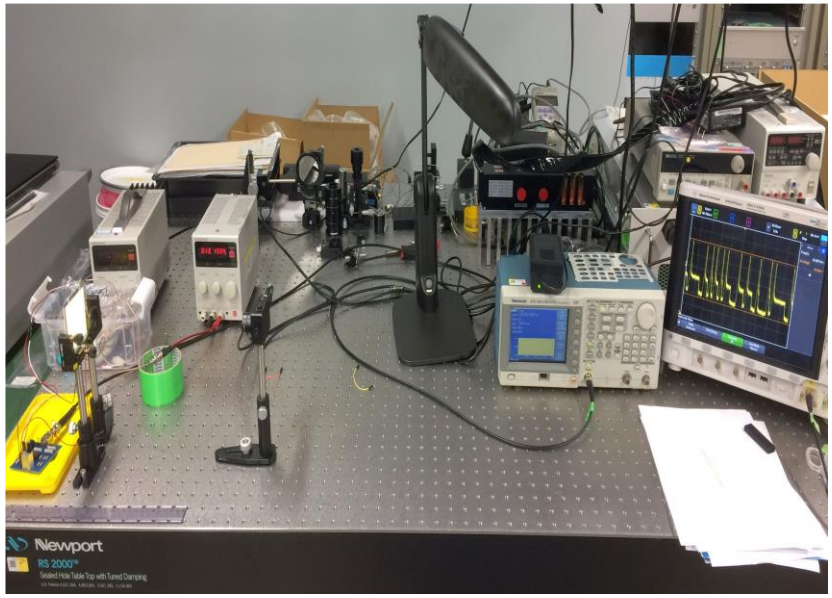



**Developed driving circuit**

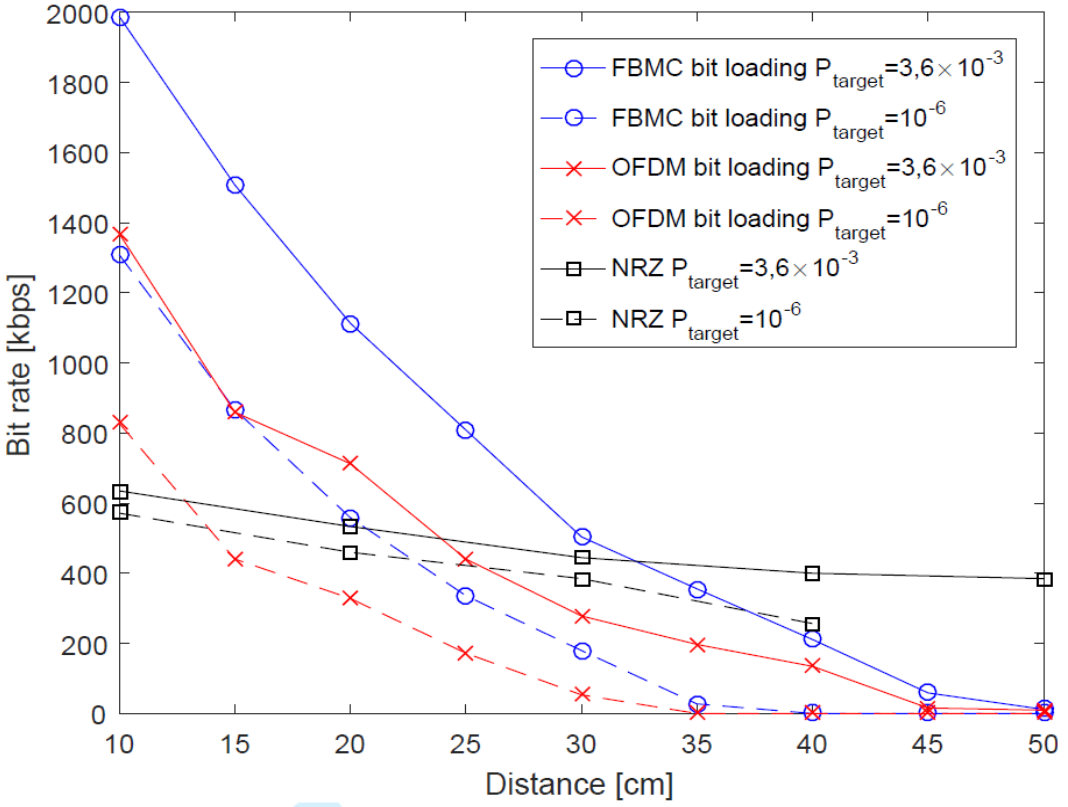



**Increasing the available bandwidth**

# Project results: OLED-based VLC system (2)




**Experimental setup**




**Experimental results**

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

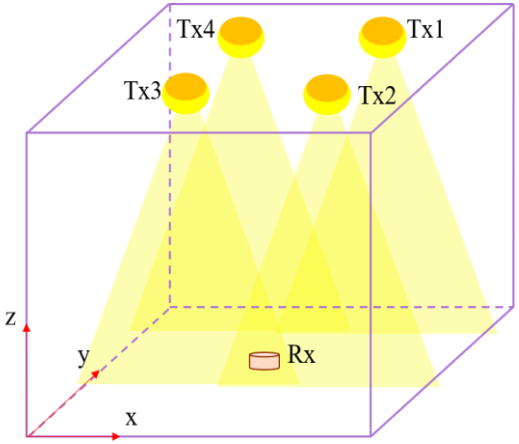
# Project results: indoor localization using VLC (1)

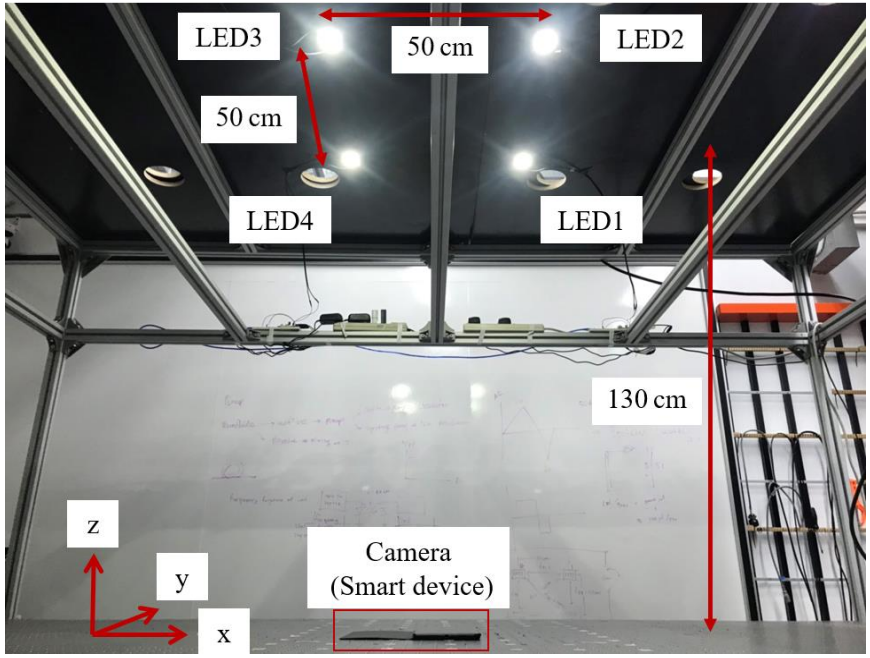
Indoor positioning system using VLC Experiment

- Develop a technique to estimate 3D position of a smart device camera receiver
- Demonstrate the system in laboratory
- Develop application on smart device

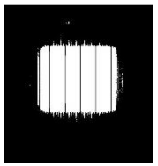
Applications

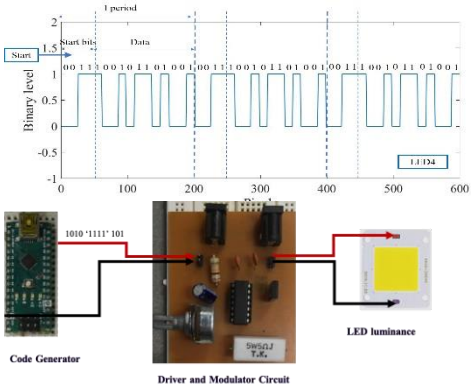
- Indoor positioning system using VLC can be used for indoor navigation and for improve mobile user experience.



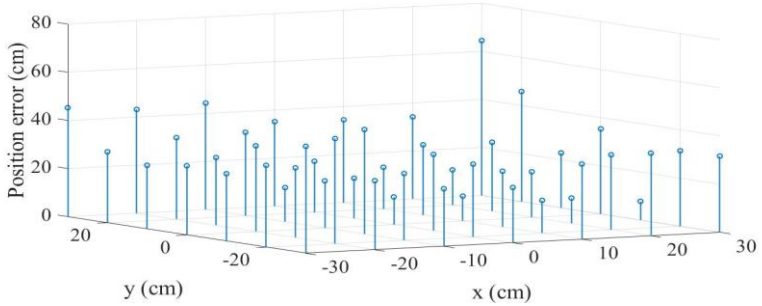



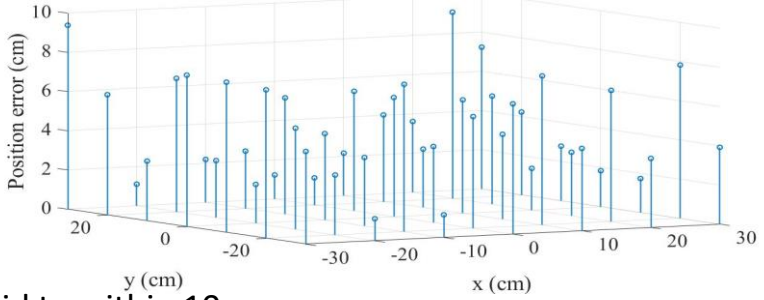
# Project results: indoor localization using VLC (2)



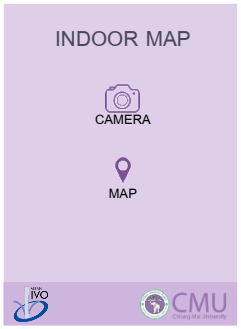


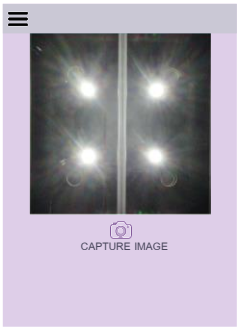

-Develop transmitter circuit for LED ID data modulation
-Use image processing to decode LED ID and distance estimation

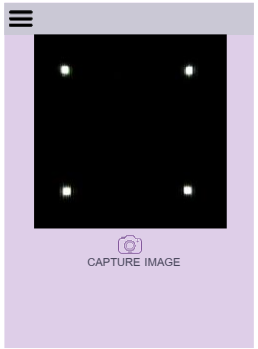



Reduction of Position Error in the test grid to within 10cm

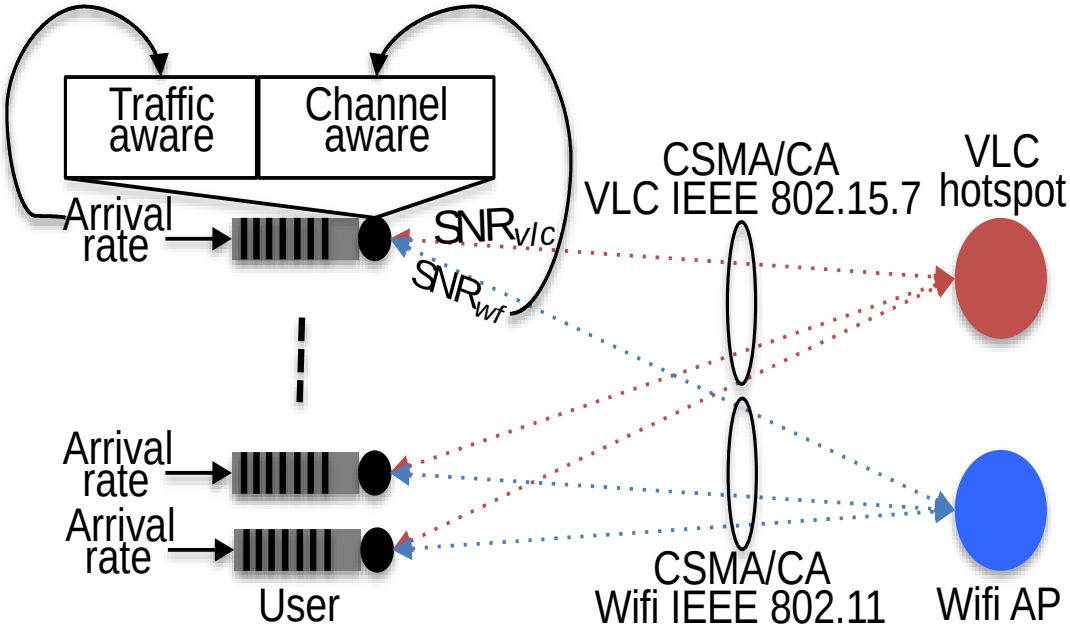



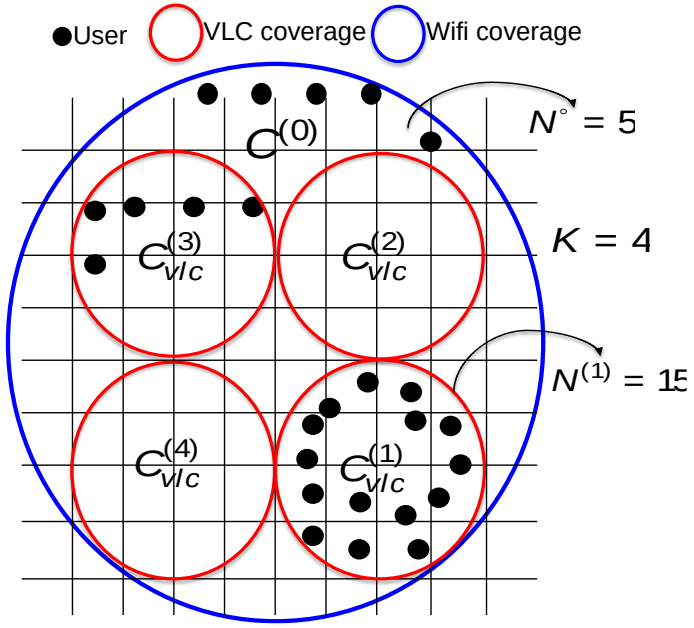




Android application (In Progress)

# Project results: VLC network (1)

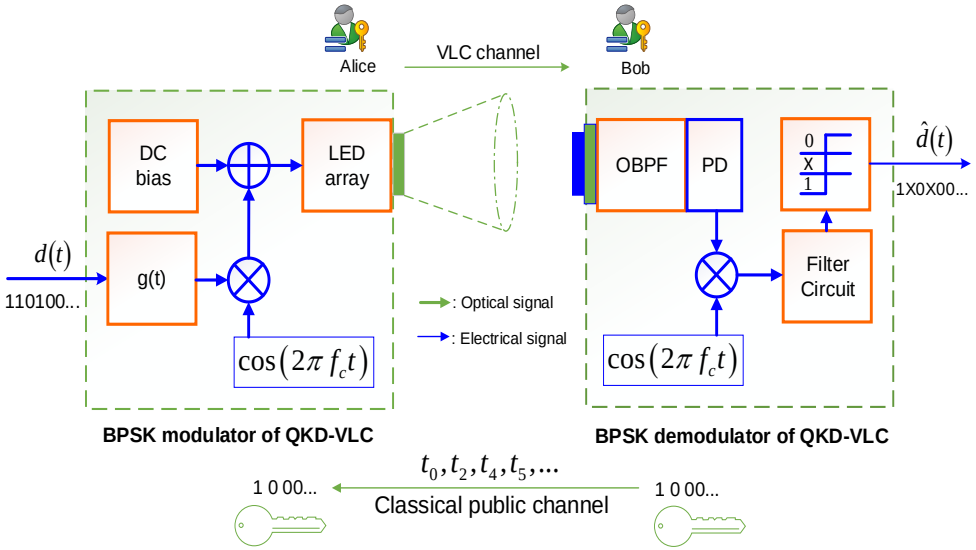
- Proposing a multi-channel medium access control (MAC) protocol for hybrid VLC/Wifi networks
  - The proposed MAC protocol is based on an integration of two standards, IEEE 802.15.7 VLC and IEEE 802.11 Wifi CSMA/CA(s)
  - Newly add on top of current MAC protocols a sub-layer that runs dynamic channel 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



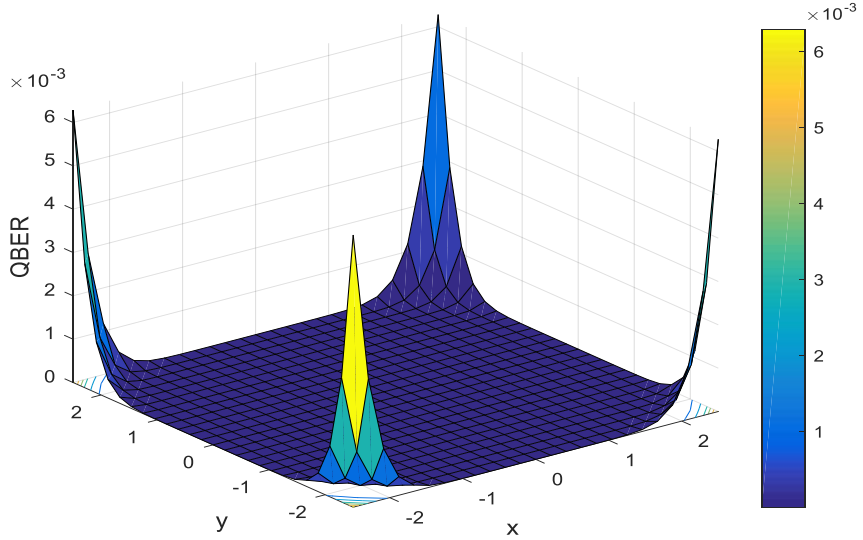



# Project results: VLC network (4)

- Studying an application of quantum key distribution (QKD) for indoor visible light communication (VLC) networks
  - Designing and analyzing the security performance of the QKD protocol based on sub-carrier intensity modulation (SIM) over indoor VLC systems taking into account the effects of VLC channel and other physical layer impairments
  - Deriving the mathematical expressions for quantum bit-error rate (QBER) and secret-key rate. Based on the mathematical expressions, various systems' metrics, including the modulation depth and the dual-threshold scale coefficient, can be determined so as to QBER and secret-key rate meet the design criteria

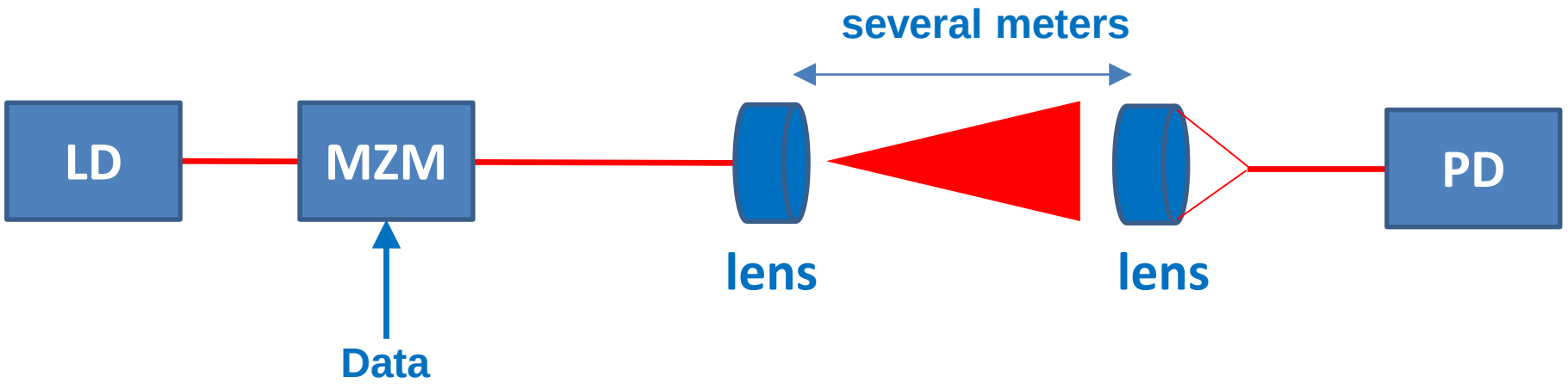


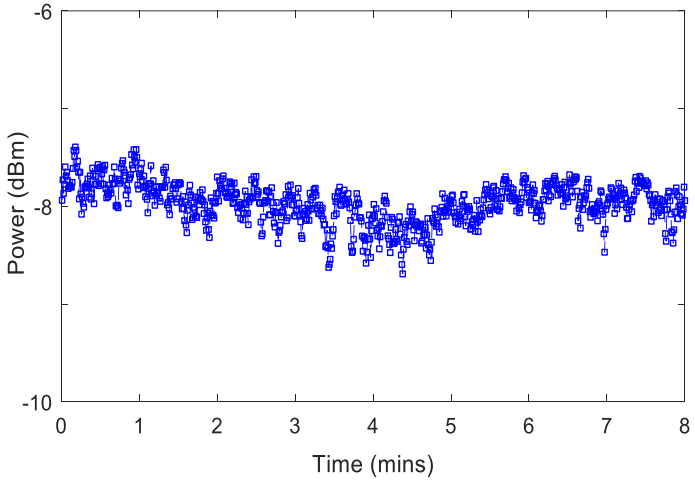

. Block diagram of QKD-VLC system

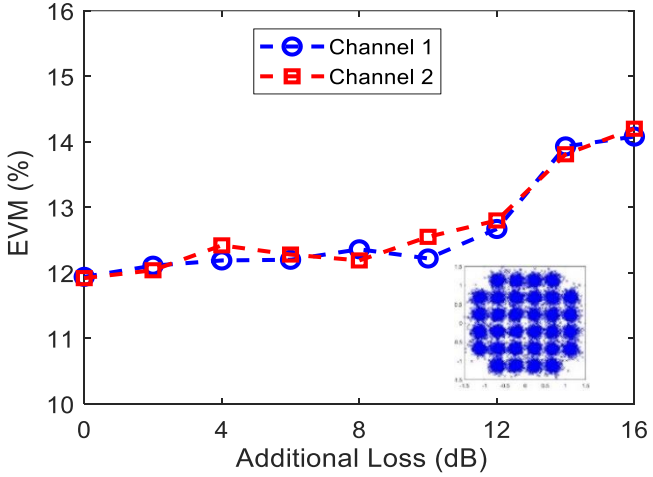


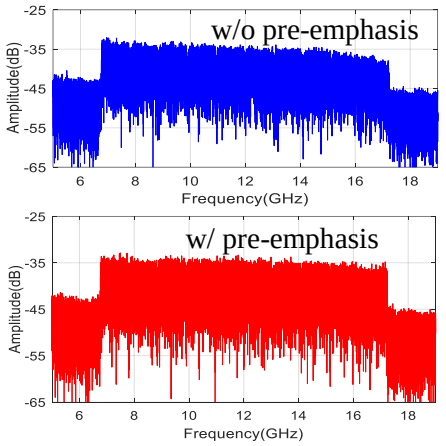

QBER versus different Bob's locations when the dual-threshold scale coefficient $\delta$ = *1.5*, the intensity modulation depth $\rho$ = 0.25 and $P_{LED}$ = -3 dBm

# Project results: ultrahigh-speed indoor



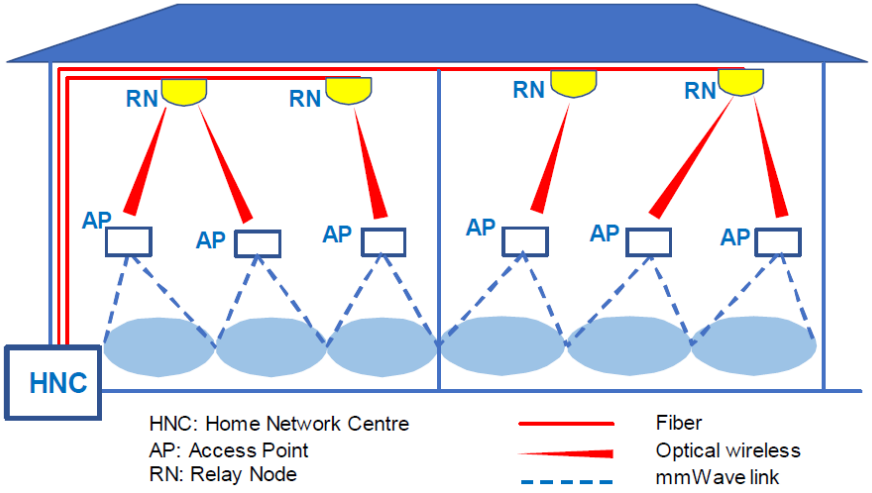

**Performance of 2x50 Gb/s wavelength-division multiplexing OWC system**

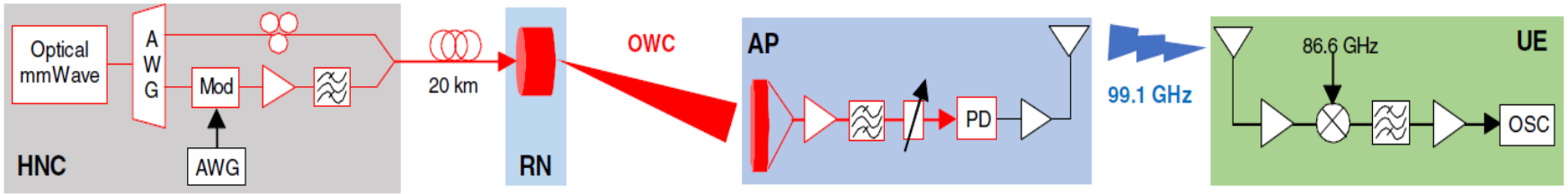
***LD: Laser Diode***
***MZM: Mach-Zehnder modulator***
***PD: Photodetector***

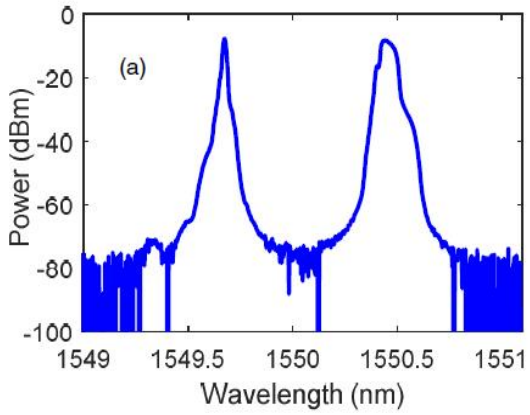
***By NICT, DUT, Waseda***

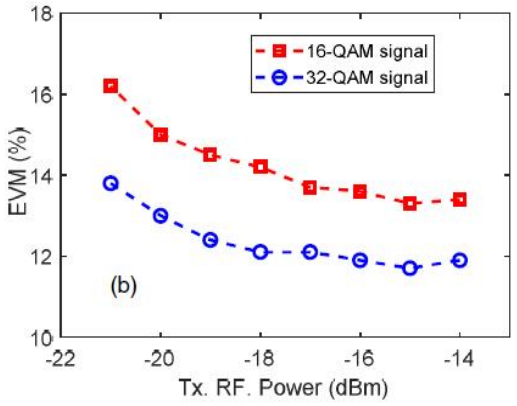
# Project results: hybrid optical wireless/millimetre-wave

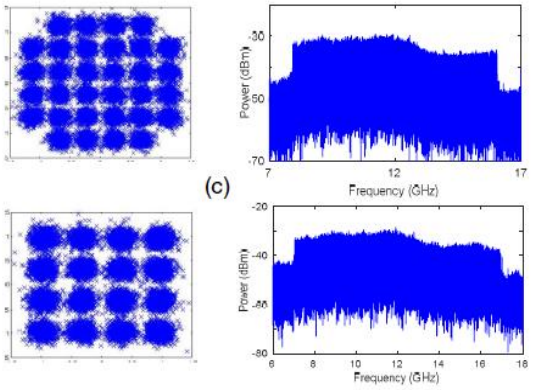
- A dual-hop access network using OWC and mmWave radio links was proposed.
- The radio links work as the access network to users, while the OWC links work as the extension of fiber links.
- The signals with a total capacity of 40 Gb/s were successfully transmitted over the systems.



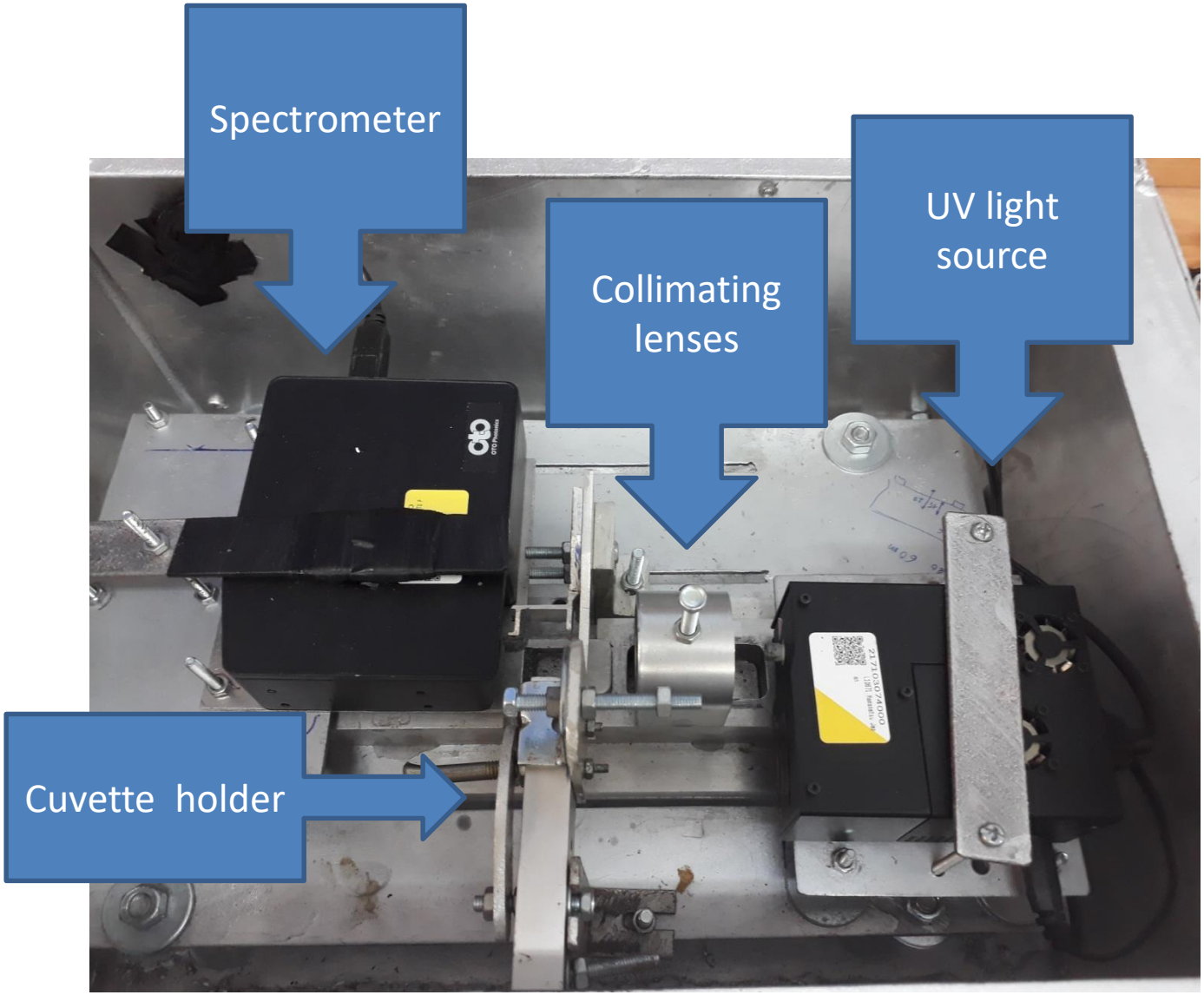



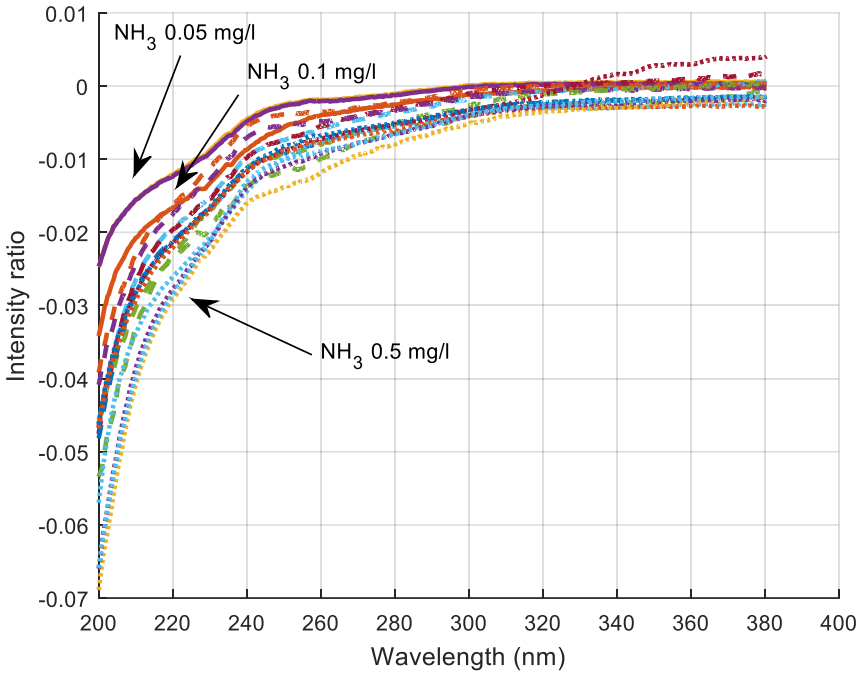
# Project results: Non-invasive optical sensor (1)

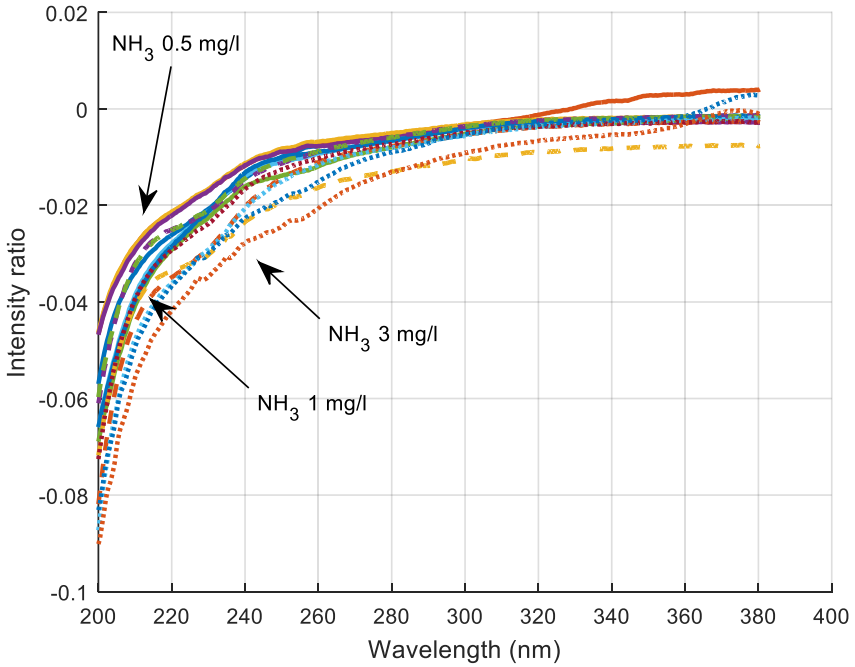
## Sensor prototype



# Project results: Non-invasive optical sensor (2)

## Measurement examples:




Absorption characteristics of $NH_3$ from 0.05 mg/l to 3 mg/l

# Scientific Contribution: International Conferences

| No: | Paper title: | Author names | Affiliation | Conference name: | The date of the conference | The venue of the conference |
|---|---|---|---|---|---|---|
| 1 | OLED-based visible light communication system using Universal Filtered Multicarrier | P. Q. Thai, P. T. Dat, N. T. Hung | HCMUT, DUT, NICT | IEEE ATC 2020 | Oct. 8-10, 2020 | Vietnam |
| 2 | Hybrid FSO/mmwave system for high-speed and reliable mobile fronthaul | Pham T. Dat, Nguyen T. Hung, M. Matsumoto et al., | NICT, DUT, Waseda Uni. | ECOC 2019 | 2019 | Dublin, Ireland |
| 3 | Filter Bank Multi-carrier and Non-Orthogonal Multiple Access in MIMO OLED VLC System | Pham Quang Thai | HCMUT | Progress in Electromagnetics Research Symposium (PIERS) | 2018 | Toyama – Japan |
| 4 | Brix percentage estimation using artificial intelligence approaches | Pham Quang Thai, Pham Tien Dat | HCMUT, NICT | ICPS 2019 | 2019 | Chiang Mai, Thailand |
| 5 | Counterfeit bottled water detection using absorption spectroscopy and convolutional neural networks | Pham Quang Thai, Pham Tien Dat, | HCMUT, NICT | MORSE 2019 | 2019 | Bali, Indonesia |
| 6 | Comparison of modulation methods for visible light communication system using organic LED | Nghi Vinh Khanh, Pham Quang Thai, Vu Dinh Thanh | HCMUT | ICSPCS 2019 | 2019 | Gold Coast, Australia |
| 7 | Increase Data Rate of OLED VLC System Using Pre-Emphasis Circuit and FBMC Modulation | Pham Quang Thai; Francois Rottenberg; Dat Pham; Shimamoto Shigeru | HCMUT, NICT | OSA Imaging and Applied Optics Congress | 2018 | Orlando, FL - United States |

# Scientific Contribution: International Conferences

| No: | Paper title: | Author names | Affiliation | Conference name: | Date of the conference | The venue of the conference |
|---|---|---|---|---|---|---|
| 8 | Hybrid VLC/WIFI Networks: CSMA/CA-based MAC Protocol Design and Performance Analysis | Vuong V. Mai, Ngoc T. Dang, Truong C. Thang, and Anh T. Pham | PTIT | The 2017 International Symposium on Electrical and Electronics Engineering | Nov. 2017 | Ho Chi Minh City, Vietnam |
| 9 | Relay-Assisted VLC Networks using Code Division Multiple Access and Analog Network Coding | Ngoc T. Dang | PTIT | 2018 Progress In Electromagnetic Research Symposium | August 2018 | Toyama, Japan |
| 10 | Quantum Key Distribution Solution over Indoor Visible Light Communication Networks | Ngoc T. Dang, Minh B. Vua, Thu A. Pham, Hien T.T. Pham, Vuong Mai | PTIT | The 4th International Conference on Photonics Solutions | Nov. 2019 | Chiang Mai, Thailand |
| 11 | Overview of Optical Wireless Communications | Mitsuji Matsumoto | Waseda Uni. | The 2017 International Symposium on Electrical and Electronics Engineering | Nov. 2019 | Ho Chi Minh City, Vietnam |
| 12 | Short-Range Visible Light Communication with Low-Cost Devices for Smart Homes | Yusuf Nur Wijayanto | LIPI | The 2017 International Symposium on Electrical and Electronics Engineering | Nov. 2019 | Ho Chi Minh City, Vietnam |
| 13 | Pre-Emphasis Circuit for OLED VLC Systems | Pham Quang Thai | HCMUT | The 2017 International Symposium on Electrical and Electronics Engineering | Nov. 2019 | Ho Chi Minh City, Vietnam |

# Scientific Contribution: International Conferences

| No: | Paper title: | Author names | Affiliation | Conference name: | The date of the conference | The venue of the conference |
|---|---|---|---|---|---|---|
| 14 | Trend of high-speed optical wireless system | Mitsuji Matsumoto | Waseda Uni. | PIERS 2018 | 2018 | Toyama – Japan |
| 15 | Short Range Visible Light Communication for Data Transfer Using Simple Optoelectronic Circuits | Yusuf Nur Wijayanto, Pham T. Dat et al., | LIPI, NICT | PIERS 2018 | 2018 | Toyama – Japan |
| 16 | Chaos-secured Software-defined Visible Light Communications | Nguyen T. Hung, Pham T. Dat et al., | DUT, NICT | PIERS 2018 | 2018 | Toyama – Japan |
| 17 | Comparison of Indoor Positioning System Techniques Using Visible Light Communication | Ukrit Mankong Sangdaun Potha Pornthep Srisang | CMU | PIERS 2018 | 2018 | Toyama – Japan |
| 18 | Three-Dimensional VLC Indoor Positioning System Using Smart Device Camera Receiver with Image Processing Technique | P.Rattakorna, U.Mankong, S. Pothab | CMU | ICPS 2019 | 2019 | Chiang Mai, Thailand |
| 19 | Smart lighting for internet of things and smart homes | Nguyen T. Hung, Pham Q. Thai, P. T. Dat, | DUT, HCMUT, NICT | ICCE 2018 | 2018 | Hue, Vietnam |

# Scientific Contribution: Published Journal Papers

| No: | Paper title: | Author names | Affiliation | Journal name: | The publisher of the Journal | The volume number and Pages |
|---|---|---|---|---|---|---|
| 1 | Dynamic Physical-Layer Secured Link in a Mobile MIMO VLC System | O. Younus, H. Minh, P. T. Dat, N. Yamamoto, A. T. Pham, and Z. Ghassemlooy | NICT and collaborators | IEEE Photonics Journal | IEEE | Vol. 12, No. 3, pp. 7902814, 2020. |
| 2 | A PHY/MAC Cross-Layer Analysis for IEEE 802.15.7 Uplink Visible Local Area Network | Ngoc T. Dang and Vuong V. Mai | PTIT | IEEE Photonics Journal | IEEE | Vol. 11, No. 3, pp. 7903517, 2019. |
| 3 | Analog Network Coding-aided Multiuser Visible Light Communication Networks Using Optical CDMA | Hien T. T. Pham and Ngoc T. Dang | PTIT | OSA Continuum | OSA | Vol. 2, No. 9, pp. 2569-2580, Sept. 2019 |

# Societal Impact

- Development of energy- and cost-efficient techniques for internet of things, communications, and sensing systems using visible light communication technologies.
- Initiation and enhancement of research collaborations between ASEAN counties and NICT on promising technologies for practical applications.
- Active contribution to international academics (international conferences, journals, organizing international workshops/special sessions at international conferences)
- Receiving a best paper award at the IEEE ATC 2020.
- Potential technology transfer for practical applications (field water measurement using developed non-invasive optical sensor).

# Conclusion and Future prospects

- The main targets of the project were successfully attained.
- Several light-based communication and sensing technologies have been developed and demonstrated.
- The achieved results were published at international conferences and journals, including IEEE journal papers.
- Received a best paper award at the international conference.
- Future work: Contributions to international standardizations: IEEE 802.11bb on visible light wireless local access networks and ASTAP.
- Continue the research collaborations between the members on the LiFi and high-speed optical wireless communications.