融合位置信息的可见光通信技术探研

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Outline

- □ Research background
- □ Visible Light Positioning Using Two luminaires
- □ Location-based Visible light Communication
- □ Summary

Background

Old methods:

Incandescent bulb
- 5% light, 95% heat
- Few thousand hours of life

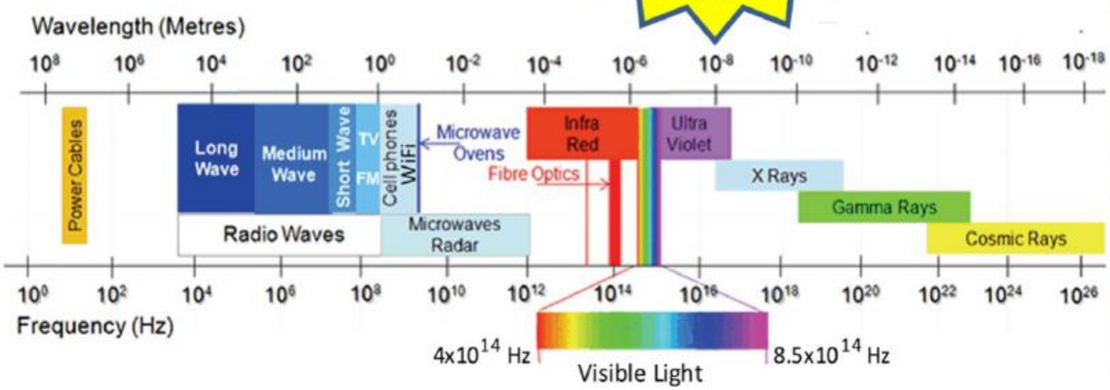
Fluorescent lamp
- 25% light
- Lifetime ~10,000s hours

New method:

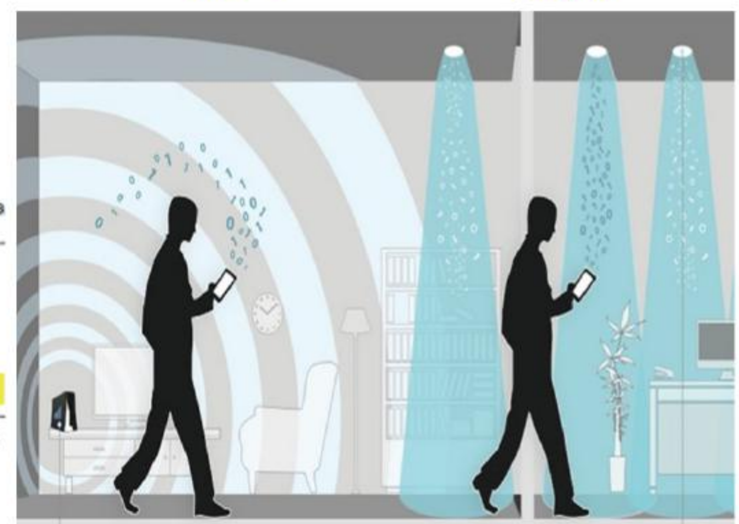
Solid-state light emitting diode (LED)
- Compact and 50% light
- More than 50,000 hours lifespan
- More carbon-friendly
- 75% of all illumination by 2030

Lighting Revolution

Data explosion !!!



WiFi LiFi



Background

中华人民共和国国家互联网信息办公室

Cyberspace Administration of China

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可见光通信技术加持 智慧家庭网络有望更加智慧

2019年07月23日 15:12 来源：科技日报 【打印】【纠错】

新一代信息技术已成为拉动经济增长的新引擎，智慧家庭网

发展高峰论坛上，针对智慧家庭网络的发展，中国工程院院士、国

息技术取得一系列的突破，但遗憾的是，目前我国只有智能的电器

记者了解到，作为新兴产业，智慧家庭网络目前面临使用场景

控、门锁控制等低智慧层面的产品，难以满足消费者高智慧生活的

为此，很多人都看好5G，期望通过加快推进5G商用来解决现实

存在几个突出问题：穿透力差，室内深度覆盖代价高昂；室分网络

邬江兴认为，加速发展可见光通信是有效解决智慧家庭网络建

一技术有着宽带高速、泛在覆盖、绿色节能、精准定位的显著特点

邬江兴介绍，可见光通信是战略新兴产业，可以实现用光上网

年研究，推出的全球首款商品级可见光通信芯片组，扭转了可见光

线光互联技术瓶颈，开创了以虚拟现实为基础功能的智慧家庭新型

第一财经

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天价电费成5G建设“拦路虎”，多省出台政策给运营商减负

第一财经 · 2019-12-23 19:51 听新闻 1879

作者：来莎莎 责编：彭海斌

5G的大宽带、超低延时和海量连接特性将带来无限机遇，但同时，5G基站的功耗也相当之大。

5G基站的大功耗带来了巨额用电成本，这已成为5G运营成本最大负担之一，上千亿的用电成本将蚕食三大电信运营商的所得利润。

数字化室分网络

Green Technology of Indoor VLC

Shopping mall

Convention centre

Stadium

Bank

Meeting room

Home

Hospital

Underground parking

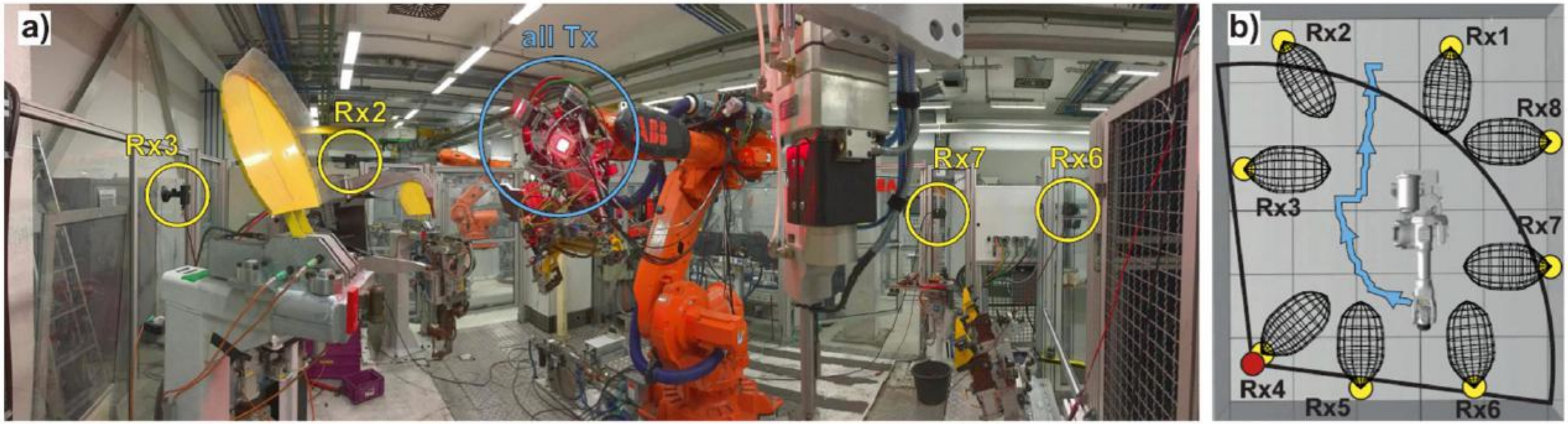
Tunnel

- Unregulated Huge Bandwidth
- Energy-Conservation
- No Health Worry
- Data Secrecy
- Electromagnetic Immunity
- System Integration

Existing LED facilities can provide:

Illumination / Signaling/ Communication / Positioning / Sensing…

VLC Application



P. Wilke Berenguer et al., Optical wireless MIMO experiments in an industrial environment, IEEE Journal on Selected Areas in Communications, 2018.

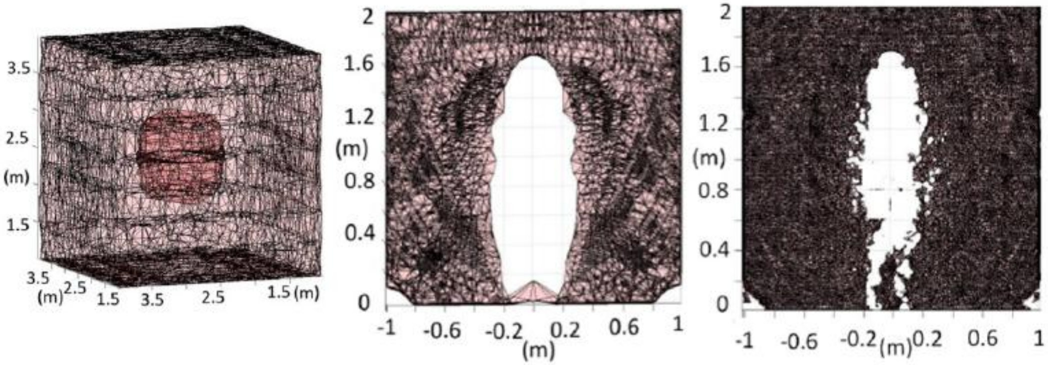
IN A WORLD FIRST, AIR FRANCE TESTS LI-FI TECHNOLOGY DURING A FLIGHT, IN PARTNERSHIP WITH LATÉCOÈRE AND UBISOFT

Published on - October 31st, 2019 — Group

AIRFRANCE

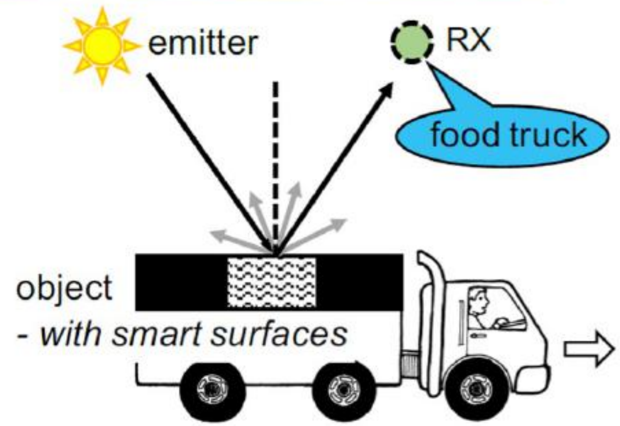
On Wednesday, October 30th, 2019, Air France tested the very first flight equipped with Li-Fi (Light Fidelity) technology, developed by Latécoère on board the commercial flight AF6114 operated by Airbus A321 from Paris-Orly to Toulouse. As part of its commitment to researching new in-flight uses for its customers, Air France welcomed gamers, finalists in the "Air France Trackmania Cup", developed by Ubisoft, who competed in the sky.

VLS Application

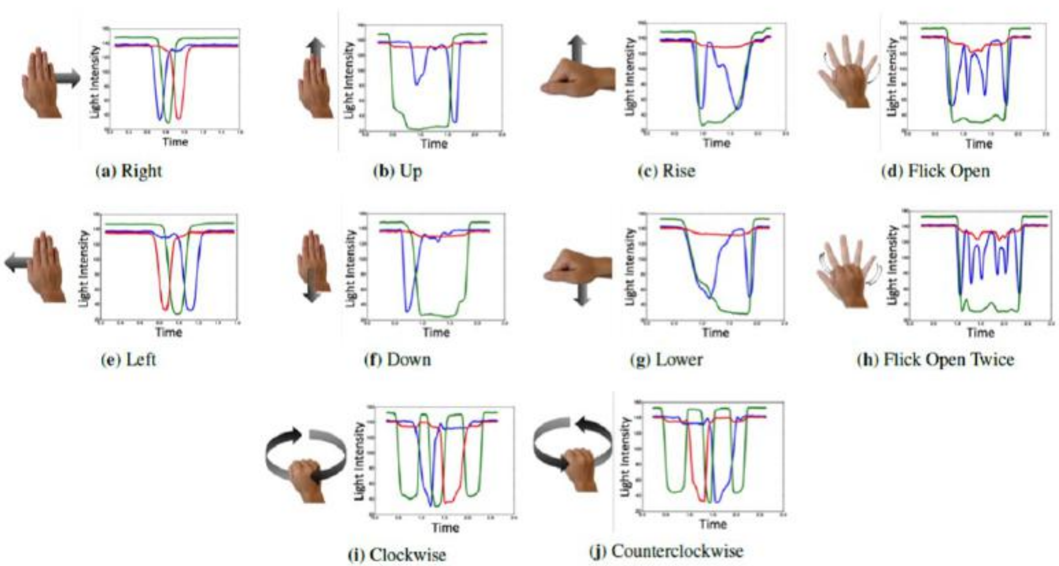


(a) Only LoS rays. (b) LoS and reflected rays.

E. A. Jarchlo, X. Tang, H. Doroud, V. P. G. Jimenez, B. Lin, P. Casari, Z. Ghassemlooy, Li-Tect: 3-D monitoring and shape detection using visible light sensors, IEEE Sensors Journal, 2018.



Q. Wang and Z. Marco, Passive sensing and communication using visible light: Taxonomy, challenges and opportunities." arXiv preprint arXiv:1704.01331, 2017.



Mahina-Diana Kaholokula, Reusing ambient light to recognize hand gestures, Dartmouth Computer Science Technical Report TR2016-797, 2016.

T. Li, C. An, Z. Tian, et al., Human sensing using visible light communication, Annual International Conference on Mobile Computing and Networking, 2015.

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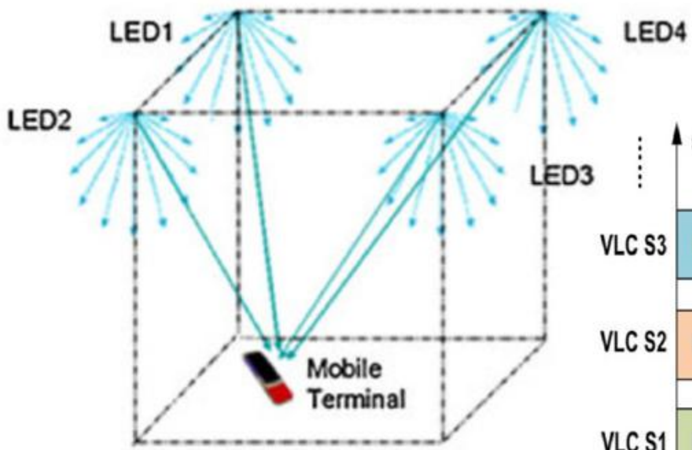
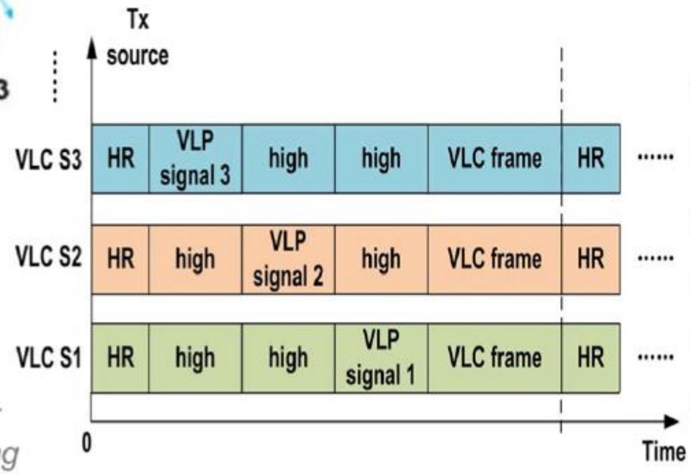
Conventional Trilateration Based VLP

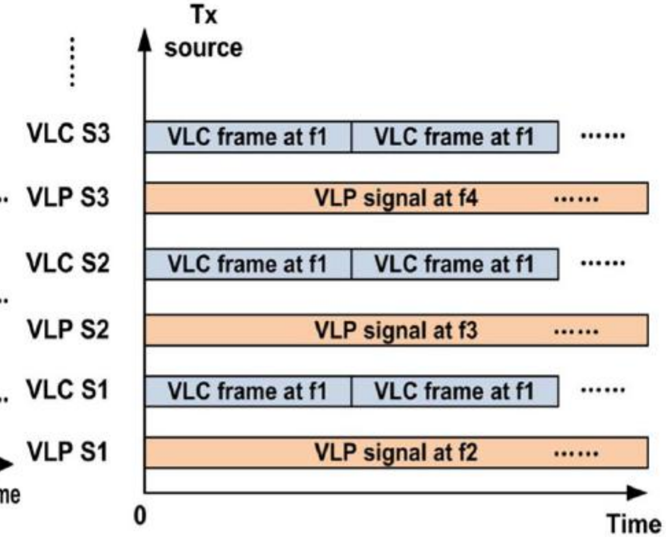


Z. Zhou, M. Kavehrad, P. Deng, Indoor positioning algorithm using light-emitting diode visible light communications. Optical Engineering, 2012.

TDM: time division multiplex



FDM: frequency division multiplex

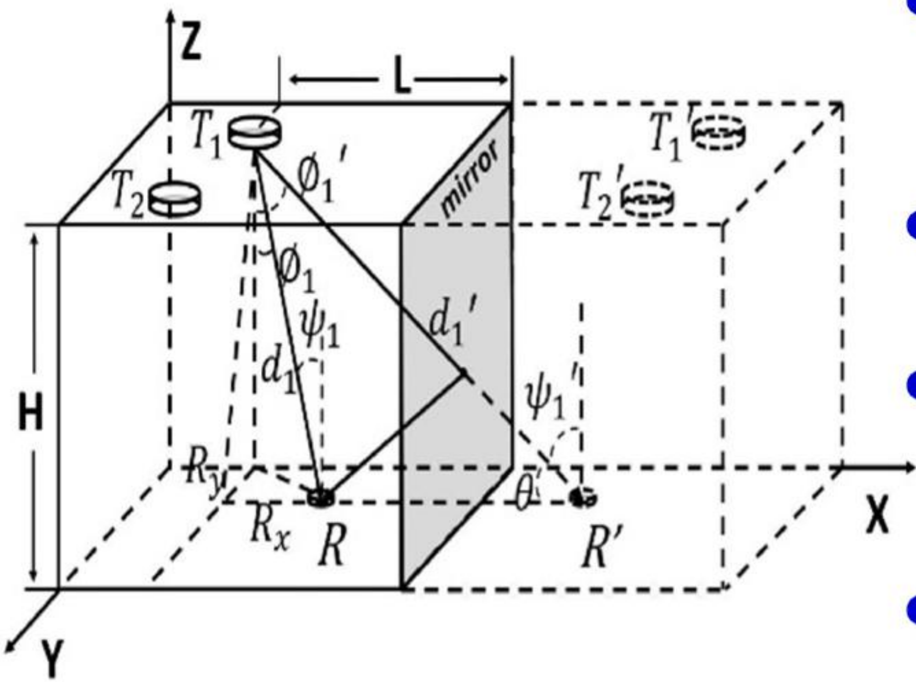


J. Chen and X. You, Visible light positioning and communication cooperative systems, ICOCN, 2017

- Use TDM and FDM protocols to distinguish signals: at least three LEDs
  - For TDM, signals are transmitted at different time slots
  - For FDM, signals are transmitted in different frequency bands
  - Require additional time or frequency resources
  - Cannot be applied in scenarios with limited LED numbers

Proposed CSI-Based VLP Model

CSI: channel state information

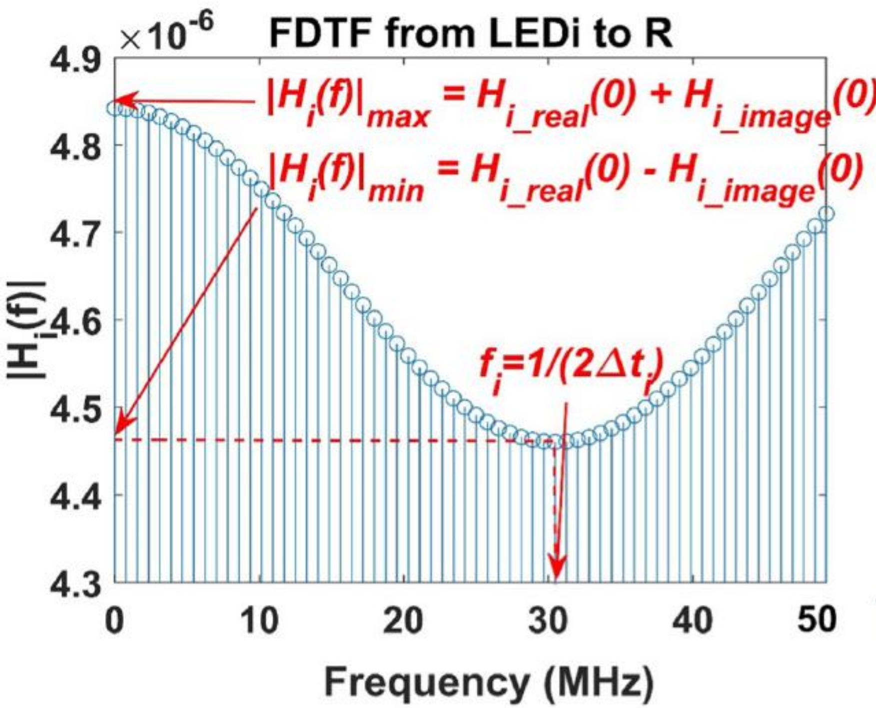


Z. Liu, X. You, J. Chen, C. Yu, Two-LED indoor visible light positioning method based on channel estimation with a mirror, ACP, 2019*

- Due to the reflection of the mirror, two LEDs (T1 and T2) generate two virtual images (T1' and T2')
- T1 and T2 are turned on alternately based on TDM for VLC
- Two mixed signals containing real and virtual signals will arrive at the receiver, respectively
- At receiver end, four transmission distance of real and virtual signals can be obtained from CSI

□ With two LEDs, we can realize positioning, overcoming the limitation of using at least three LEDs for conventional trilateration algorithms

Estimation of Transmission Distance



$$2\pi f \Delta t = k\pi \ (k \text{ is integer})$$

Channel impulse response (CIR):

$$h_i(t) = H_{i\_real}(0)\delta(t) + H_{i\_image}(0)\delta(t - \Delta t_i)$$

Frequency-domain transfer function (FDTF):

$$|H_i(f)| = \left|H_{i\_real}(0) + H_{i\_image}(0)e^{-j2\pi f \Delta t_i}\right|$$

Channel DC gains of real and virtual signals:

$$H_{i\_image}(0) = \frac{|H_i(f)|_{max} - |H_i(f)|_{min}}{2}$$

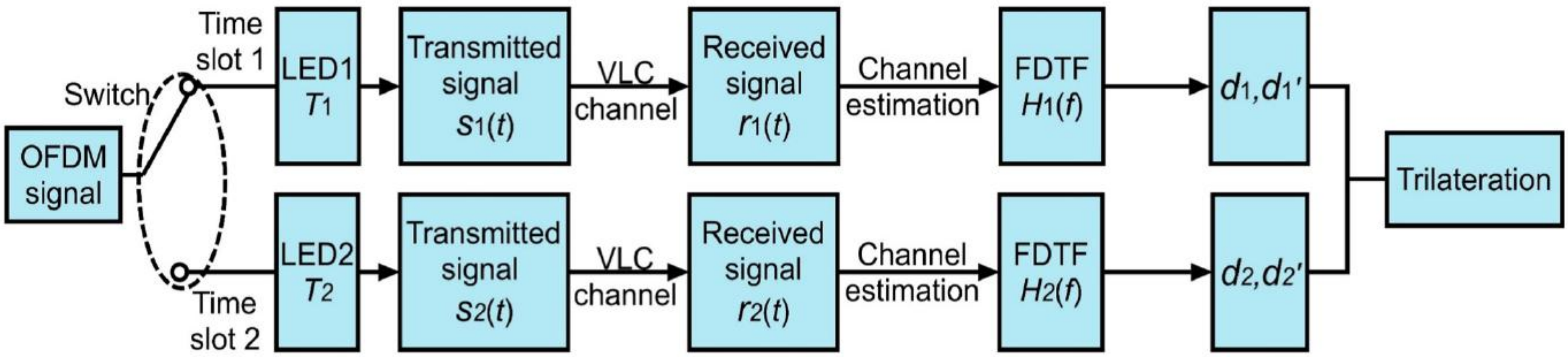
$$H_{i\_real}(0) = \frac{|H_i(f)|_{max} + |H_i(f)|_{min}}{2}$$

Transmission distance of real and virtual signals:

$$d_i = \sqrt{\frac{(m+1)A_r cos^m(\phi)T_s(\psi)g(\psi)\cos(\psi)}{2\pi H_{i\_real}(0)}}$$

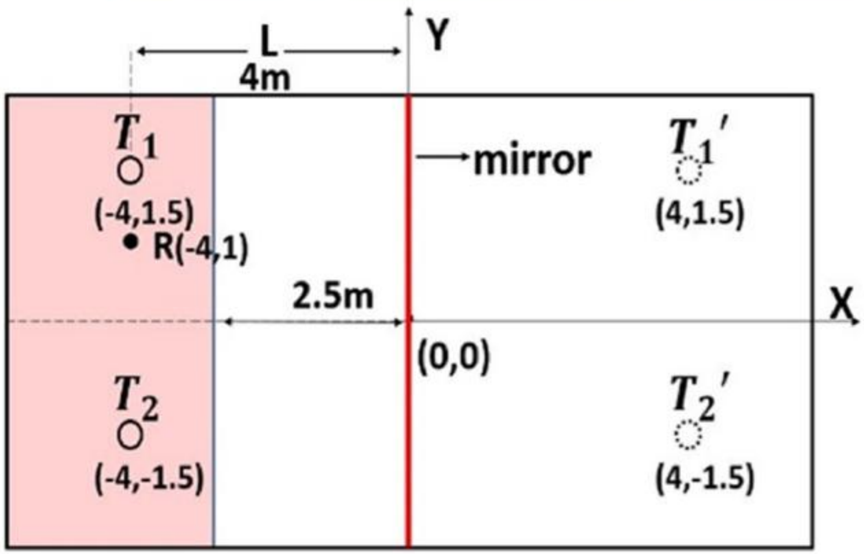
$$d_i' = \sqrt{\frac{(m+1)A_r cos^m(\phi')T_s(\psi')g(\psi')\cos(\psi')}{2\pi H_{i\_image}(0)}}$$

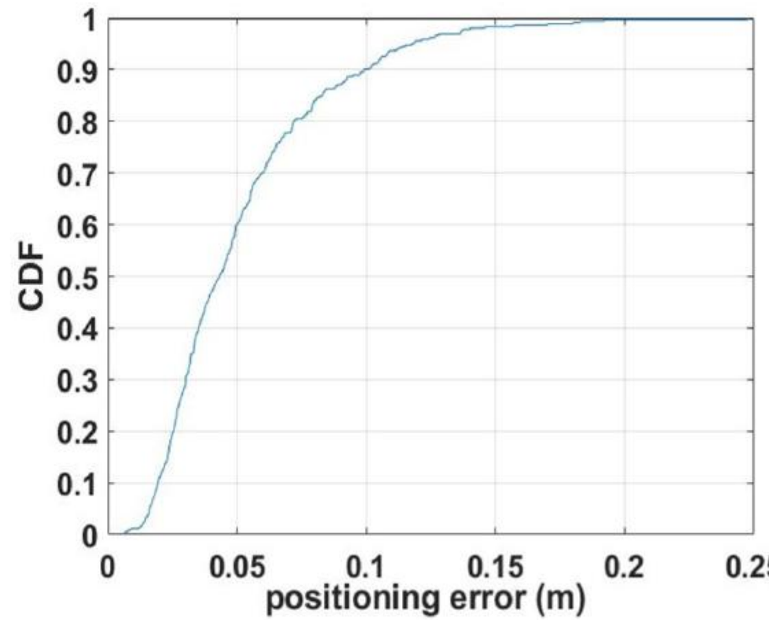
Block Diagram of CSI-Based VLP System

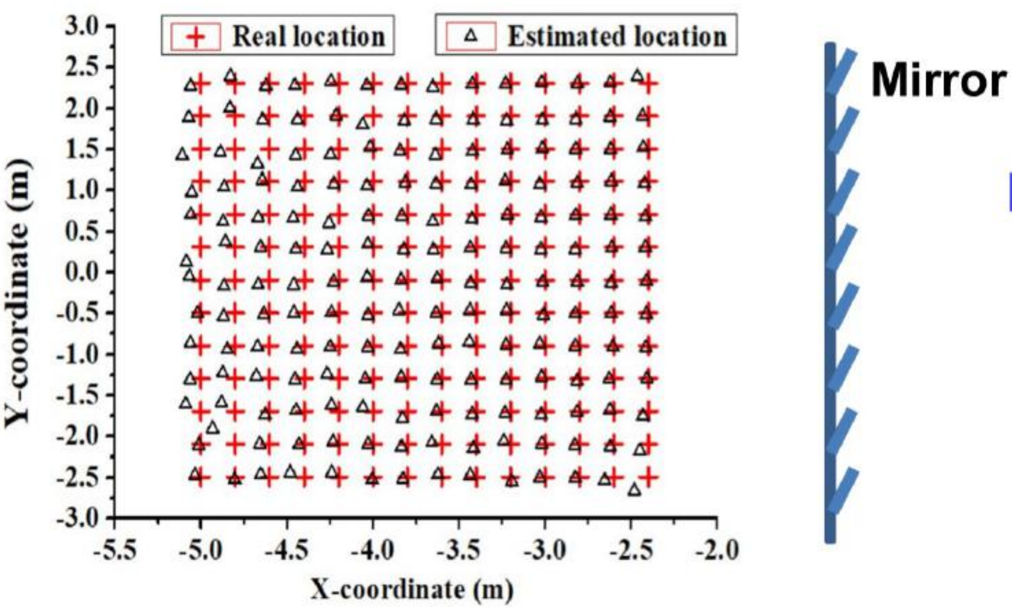


- By estimating the CSI under OFDM transmission, the FDTFs each light path can be calculated
- In each time slot, the transmission distance of real and virtual signals can be obtained, and then be used to realize positioning
- With the proposed CSI-based VLP scheme, we can implement VLP using a VLC system with only two LEDs

Simulation Results

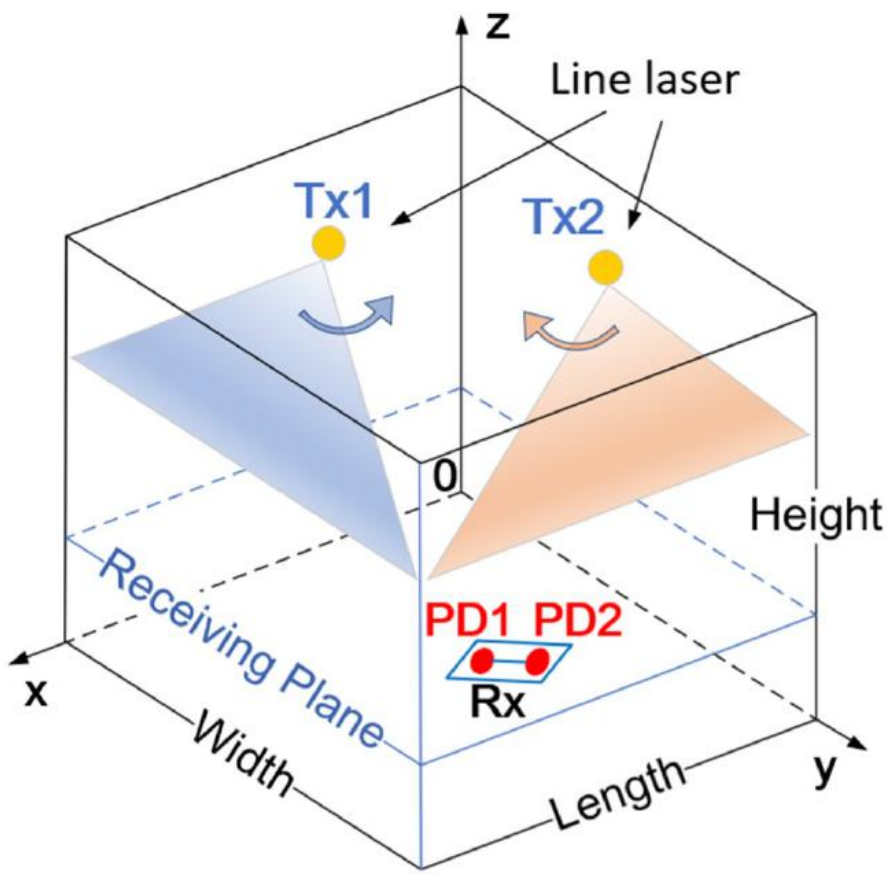






- The cumulative distribution function (CDF) curve shows that about 90% of positioning error is less than 10 cm

Proposed 3D OWP and Orienteering Scheme



X. You, Z. Liu, M. Gao, et al., Indoor three-dimensional optical wireless positioning and orienteering using steerable line Lasers, ACP, 2020

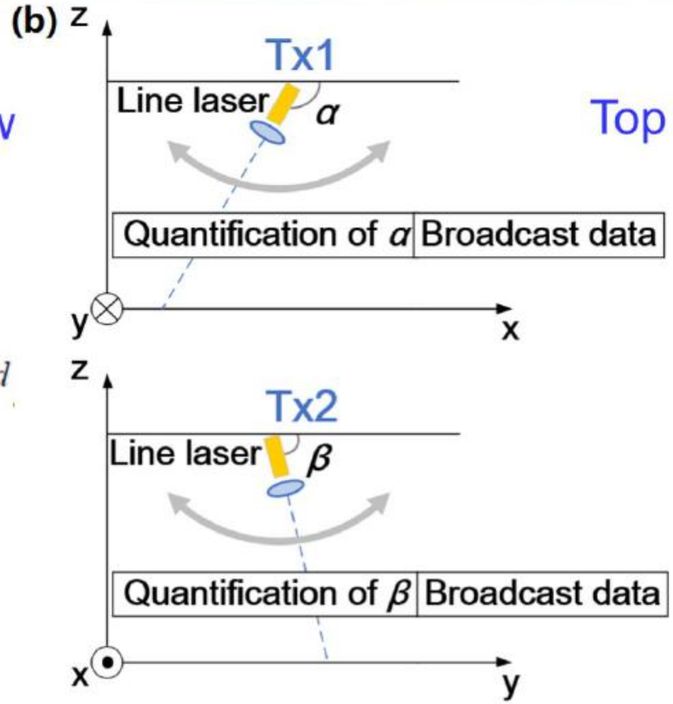
- Two line lasers as transmitters (Tx1 and Tx2) in the ceiling
- Tx1 (x_{t1}, y_{t1}, z_{t1}) is steered along X-axis, and Tx2 (x_{t2}, y_{t2}, z_{t2}) is steered along Y-axis
- A pair of photo-detectors (PD1 and PD2) mounted on the receiver (Rx) terminal in the receiving plane
- PD1 (x_{r1}, y_{r1}, z_{r1}) and PD2 (x_{r2}, y_{r2}, z_{r2}) are facing upwards, and their distance is fixed at l

We can not only achieve 3D positioning, but also get terminal orientation

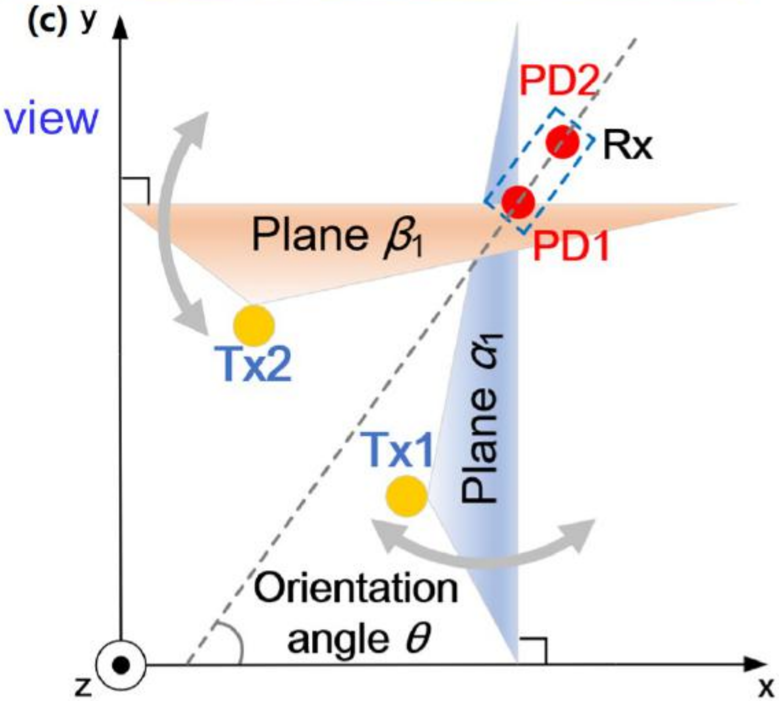
Proposed 3D OWP and Orienteering Scheme

Side view

$180°/2^{N_d}$



Top view



PD1 is within the intersection line of Planes α_1 and β_1 :

$$\left[\hat{x}_{r1}-\left(x_{t1}+z_{t1}\cot\alpha_1\right)\right]/\left(-\cot\alpha_1\right)=\left[\hat{y}_{r1}-\left(y_{t2}+z_{t2}\cot\beta_1\right)\right]/\left(-\cot\beta_1\right)=\hat{z}_{r1}$$

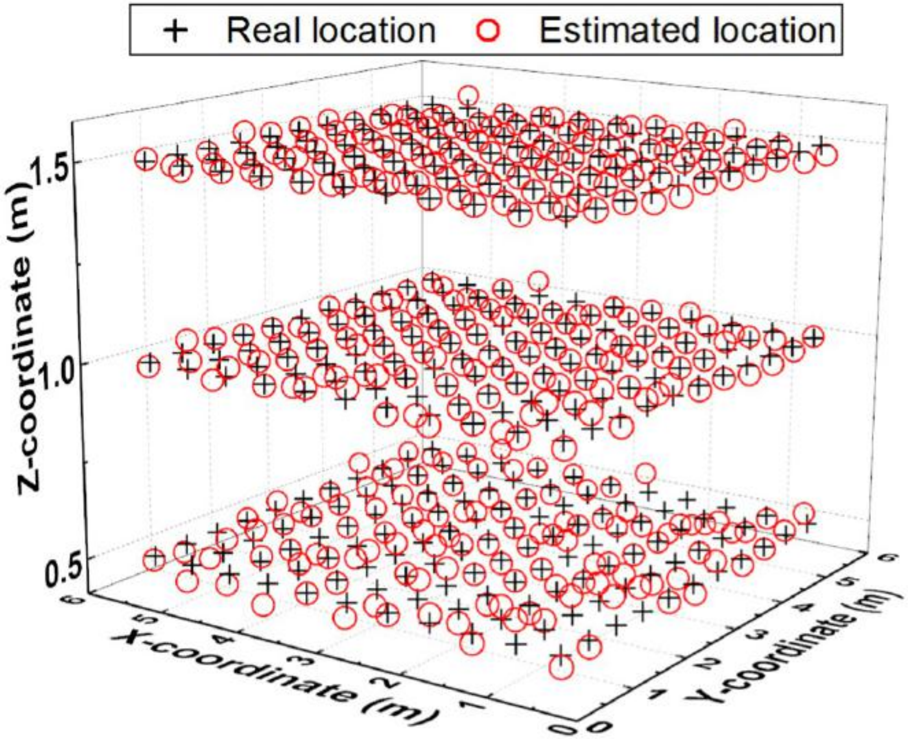
PD2 is within the intersection line of Planes α_2 and β_2 :

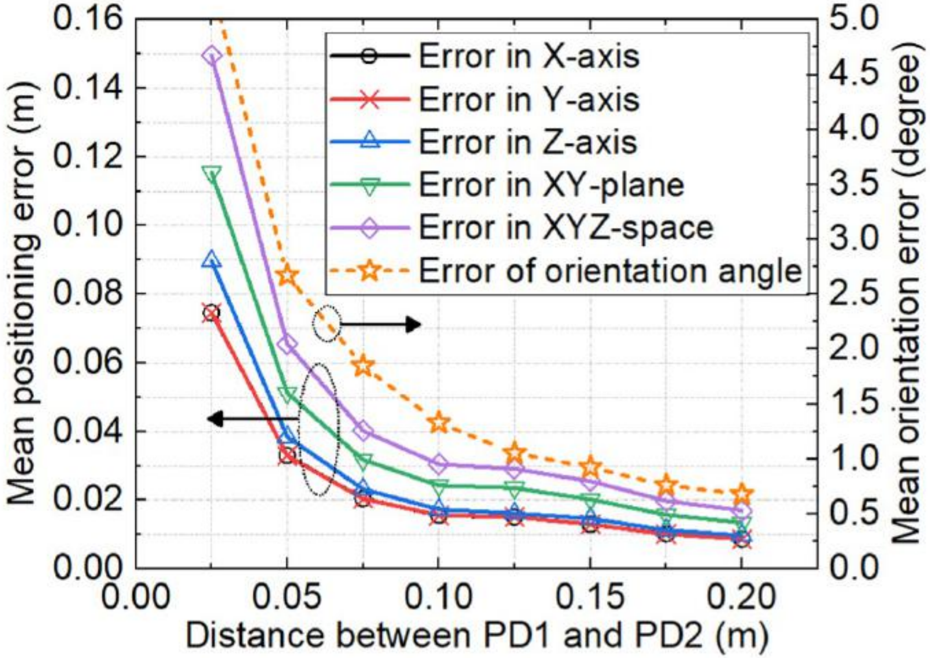
$$\left[\hat{x}_{r2}-\left(x_{t1}+z_{t1}\cot\alpha_2\right)\right]/\left(-\cot\alpha_2\right)=\left[\hat{y}_{r2}-\left(y_{t2}+z_{t2}\cot\beta_2\right)\right]/\left(-\cot\beta_2\right)=\hat{z}_{r2}$$

let $\hat{z}_{r1}=\hat{z}_{r2}=h$

$$\left(\cot\alpha_2-\cot\alpha_1\right)^2\left(h-z_{t1}\right)^2+\left(\cot\beta_2-\cot\beta_1\right)^2\left(h-z_{t2}\right)^2=l^2$$

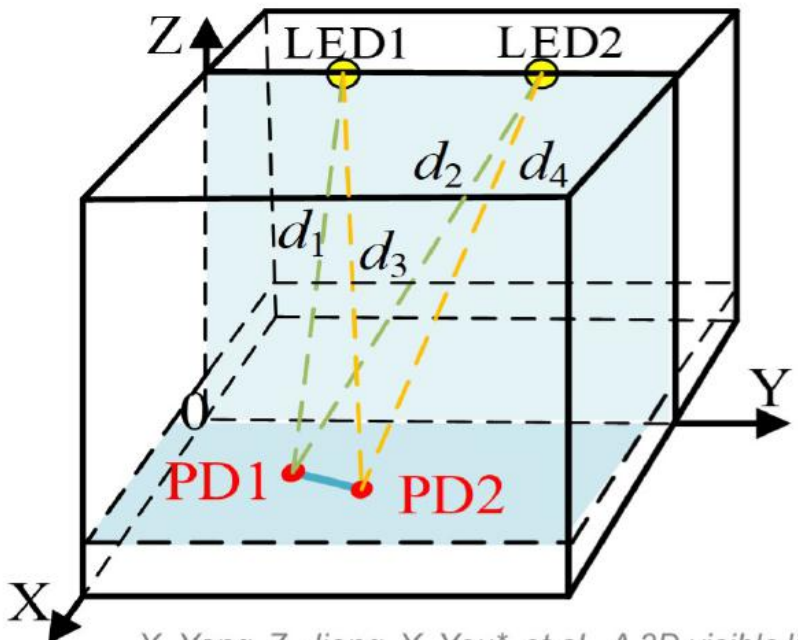
Simulation Results





- A total of around 95% 3D positioning errors are less than 6.01 cm
- When l =2.5 cm and N_d =12, the mean 3D positioning error is 14.94 cm and the mean orientation error is 5.33°

Proposed 3D VLP System



$$
\begin{cases}
{d_1}^2 = (\hat{x}_{r1} - x_{t1})^2 + (\hat{y}_{r1} - y_{t1})^2 + (\hat{z}_{r1} - z_{t1})^2 & (1) \\
{d_2}^2 = (\hat{x}_{r1} - x_{t2})^2 + (\hat{y}_{r1} - y_{t2})^2 + (\hat{z}_{r1} - z_{t2})^2 & (2) \\
{d_3}^2 = (\hat{x}_{r2} - x_{t1})^2 + (\hat{y}_{r2} - y_{t1})^2 + (\hat{z}_{r2} - z_{t1})^2 & (3) \\
{d_4}^2 = (\hat{x}_{r2} - x_{t2})^2 + (\hat{y}_{r2} - y_{t2})^2 + (\hat{z}_{r2} - z_{t2})^2 & (4) \\
l^2 = (\hat{x}_{r2} - \hat{x}_{r1})^2 + (\hat{y}_{r2} - \hat{y}_{r1})^2 + (\hat{z}_{r2} - \hat{z}_{r1})^2 & (5) \\
\hat{z}_{r2} = \hat{z}_{r1} (6)
\end{cases}
$$

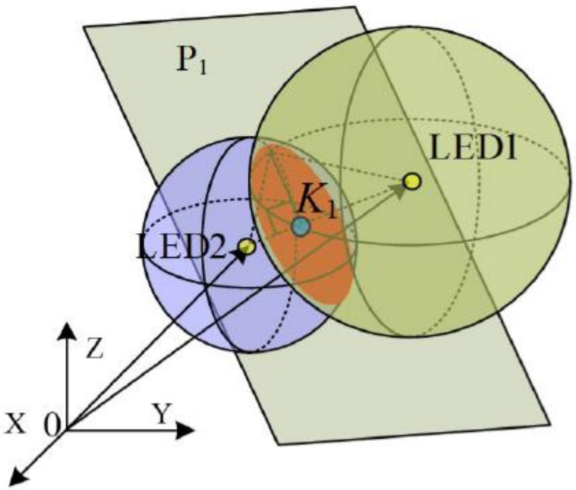
X. Yang, Z. Jiang, X. You, et al., A 3D visible light positioning and orienteering scheme using two LEDs and a pair of photo-detectors, ACP, 2021*

- Two LEDs as transmitters in the ceiling: LED1 (x_{t1}, y_{t1}, z_{t1}) , LED2 (x_{t2}, y_{t2}, z_{t2})
- A receiver contains a pair of PDs: PD1 (x_{r1}, y_{r1}, z_{r1}) , PD2 (x_{r2}, y_{r2}, z_{r2})
- The distance between PD1 and PD2 is fixed at *l*
- PD1 and PD2 are at the same height

We can not only achieve 3D VLP, but also get terminal orientation

Solving Method

Step 1: Subtract between (1) and (2) , (3) and (4)



$$\begin{cases} {d_1}^2 = (\hat{x}_{r1} - x_{t1})^2 + (\hat{y}_{r1} - y_{t1})^2 + (\hat{z}_{r1} - z_{t1})^2 & (1) \\ {d_2}^2 = (\hat{x}_{r1} - x_{t2})^2 + (\hat{y}_{r1} - y_{t2})^2 + (\hat{z}_{r1} - z_{t2})^2 & (2) \\ {d_3}^2 = (\hat{x}_{r2} - x_{t1})^2 + (\hat{y}_{r2} - y_{t1})^2 + (\hat{z}_{r2} - z_{t1})^2 & (3) \\ {d_4}^2 = (\hat{x}_{r2} - x_{t2})^2 + (\hat{y}_{r2} - y_{t2})^2 + (\hat{z}_{r2} - z_{t2})^2 & (4) \end{cases}$$

- Equations 1 to 4 represent spheres
- After equation 1 minus equation 2, we can obtain a plane equation P_1
- PD1 is located on the intersection circle K_1 of plane P_1 and sphere LED1
- The centers and radius of the circles can be obtained:

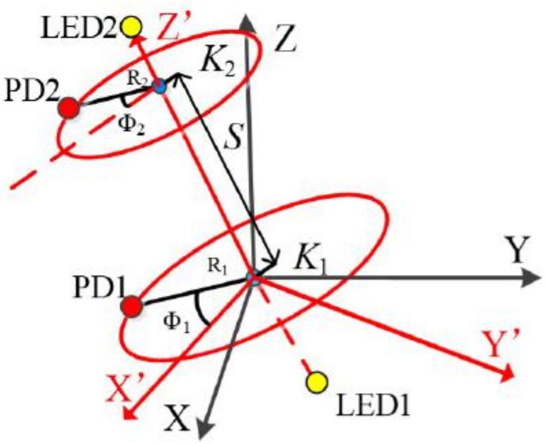
$$K_i(a_i, b_i, c_i) = \left(x_{t1} + (x_{t2} - x_{t1})\frac{w_i}{L}, y_{t1} + (y_{t2} - y_{t1})\frac{w_i}{L}, z_{t1} + (z_{t2} - z_{t1})\frac{w_i}{L}\right) i = 1, 2 \quad (7)$$

$$R_i = \sqrt{{d_1}^2 - {w_i}^2}, \qquad i = 1, 2 \qquad (8)$$

w_i : the distance between LED1 to Plane P_i (i = 1, 2) L : the distance between LED1 and LED2.

Solving Method

Step 2: Carry out coordinate transformation and inverse transformation



$$\begin{cases} l^2 = (\hat{x}_{r2} - \hat{x}_{r1})^2 + (\hat{y}_{r2} - \hat{y}_{r1})^2 + (\hat{z}_{r2} - \hat{z}_{r1})^2 \quad (5) \\ \hat{z}_{r2} = \hat{z}_{r1} (6) \end{cases}$$

- Transform XYZ-coordinate system into X'Y'Z'-coordinate system
- Transform X'Y'Z'-coordinate system into cylindrical coordinate system

$$\begin{cases} \Phi_1 - \Phi_2 = \pm \arccos M \quad ,(9) \\ \beta(R_2 \sin\Phi_2 - R_1 \sin\Phi_1) = -\gamma S \ , (10) \end{cases} \xrightarrow{\text{calculate}} \text{the value of } \Phi_1、\Phi_2$$

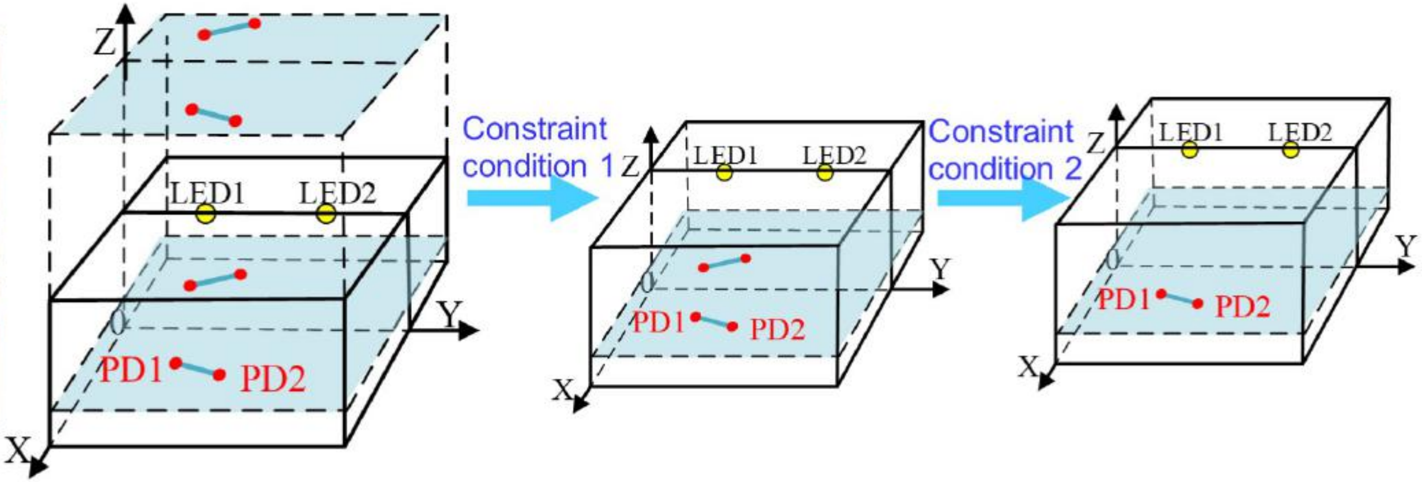
$M = (R_1^2 + R_2^2 + S^2 - l^2)/(2R_1R_2),\ S = \sqrt{a^2 + b^2 + c^2},\ \beta = -\sqrt{(a^2 + b^2)}/S,\ \gamma = c/S,\ a = a_2 - a_1,\ b = b_2 - b_1,\ c = c_2 - c_1$

- Carry out coordinate inverse transformation twice to get the coordinate of PDs

$$(\hat{x}_{r1}, \hat{y}_{r1}, \hat{z}_{r1})' = (e_x, e_y, e_z)(R_1 \cos\Phi_1, R_1 \sin\Phi_1, 0)' + (a_1, b_1, c_1)' \quad ,(11)$$
$$(\hat{x}_{r2}, \hat{y}_{r2}, \hat{z}_{r2})' = (e_x, e_y, e_z)(R_2 \cos\Phi_2, R_2 \sin\Phi_2, S)' + (a_1, b_1, c_1)' \quad .(12)$$

Solving Method

Step 3: Exclude redundant solutions to get the real solution



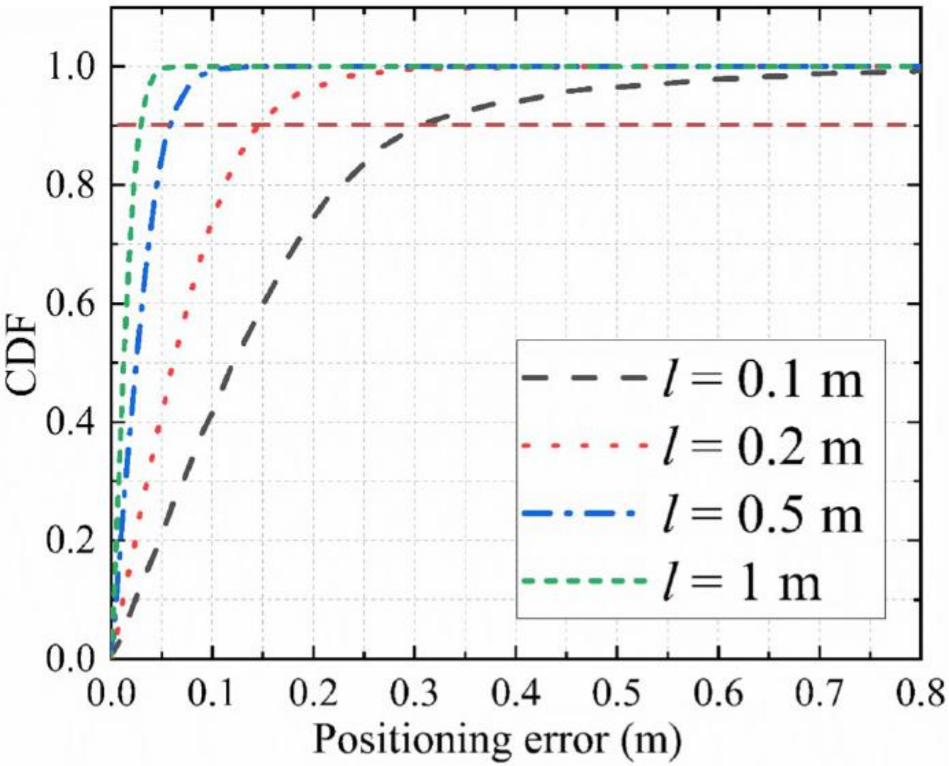
- Constraint condition 1: exclude two solutions above the ceiling
- Constraint condition 2: obtain the real solution on one side of LEDs
- The coordinate of the VLP terminal is estimated as:

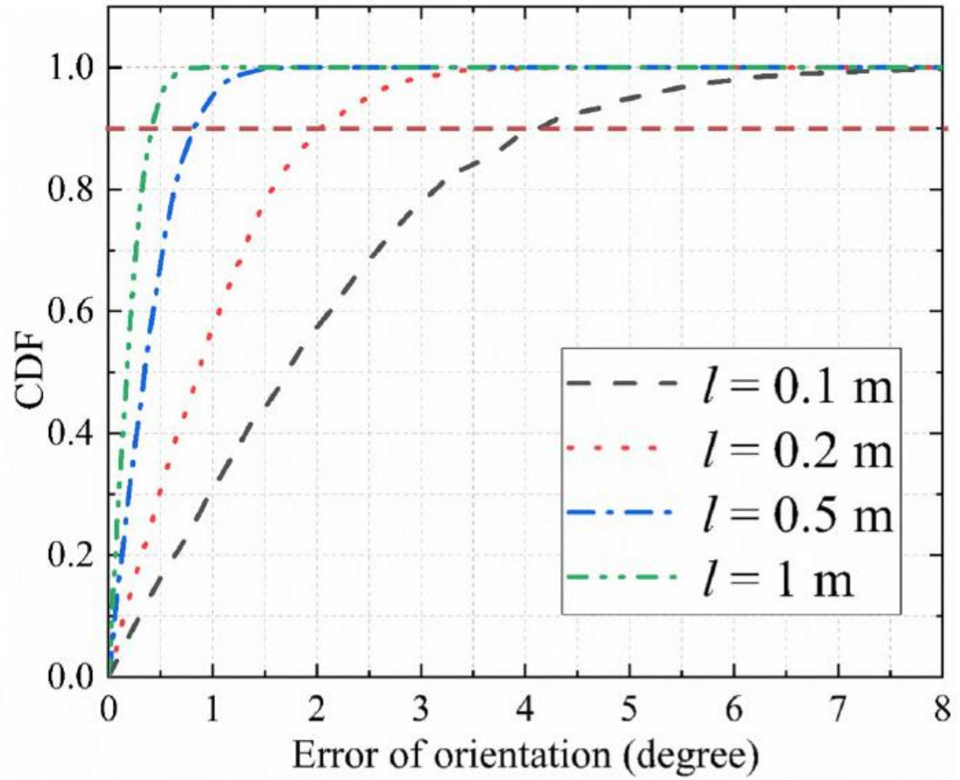
$$[(\hat{x}_{r1}+\hat{x}_{r2})/2, (\hat{y}_{r1}+\hat{y}_{r2})/2, (\hat{z}_{r1}+\hat{z}_{r2})/2]$$

- At the same time, the azimuthal angle of the VLP terminal is estimated as:

$$\hat{\eta} = sign(\hat{y}_{r2}-\hat{y}_{r1}) \arccos\left[(\hat{x}_{r2}-\hat{x}_{r1})/\sqrt{(\hat{x}_{r1}-\hat{x}_{r2})^2+(\hat{y}_{r1}-\hat{y}_{r2})^2}\right]$$

CDFs of Positioning and Orientation Errors





- When l is 0.1 m, 0.2 m, 0.5 m and 1 m, around 90% of 3D positioning errors are less than 30.6 , 14.6 , 5.8 and 3.0 cm, respectively
- When l is 0.1 m, 0.2 m, 0.5 m and 1 m, around 90% of orientation errors are less than 4.1° , 2.0° , 0.8° and 0.4° , respectively

Outline

- ☐ Research background
- ☐ Visible Light Positioning Using Two luminaires
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- ☐ Summary

Location-Based Channel Modelling

channel impulse response:

$$h_{total}(t)=h_{LOS}(t)+h_{NLOS}(t)=\sum_{i=1}^{N_{LED}} w_i\left[H_{i,LOS}(0)\delta\left(t-\tau_{i,LOS}\right)+\int_{\tau_{i,NLOS}=0}^{+\infty} A_{i,NLOS}\left(\tau_{i,NLOS}\right)\delta\left(t-d\tau_{i,NLOS}\right)\right]$$

frequency domain transfer function:

$$H_{total}(f)=\sum_{i=1}^{N_{LED}} w_i\left[H_{i,LOS}(0)\exp\left(-j2\pi f\tau_{i,LOS}\right)+\int_{\tau_{i,NLOS}=0}^{+\infty} A_{i,NLOS}\left(\tau_{i,NLOS}\right)\exp\left(-j2\pi f d\tau_{i,NLOS}\right)\right]$$

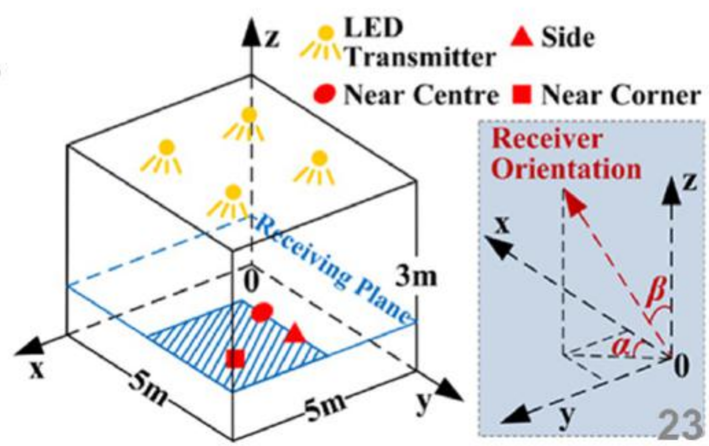
frequency domain transfer function for LOS:

$$\hat{H}_{total}(f)\approx H_{LOS}(f)=\sum_{i=1}^{N_{LED}} w_i H_{i,LOS}(0)\exp\left(-j2\pi f\tau_{i,LOS}\right)$$

$$=\begin{cases}\sum_{i=1}^{N_{LED}}\dfrac{w_i(m+1)a_R\cos^m(\phi_i)T_s(\theta_i)g(\theta_i)\cos(\theta_i)}{2\pi D_i^2}\exp\left(\dfrac{-j2\pi f D_i}{c}\right), 0\le\theta_i\le\psi_c,\\ 0,\theta_i>\psi_c.\end{cases}$$

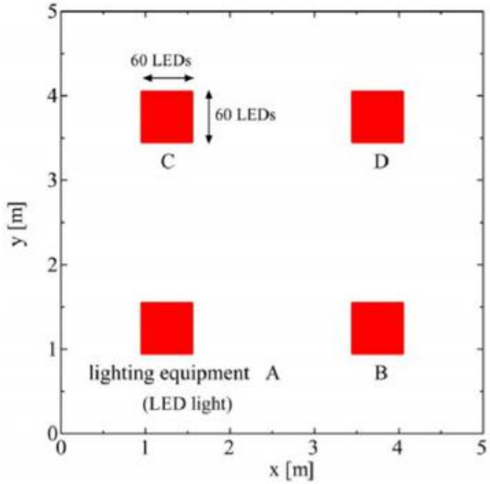
Use coordinates to describe VLC channel:

$$\begin{cases}D_i=\sqrt{(x_{ti}-x_r)^2+(y_{ti}-y_r)^2+(z_{ti}-z_r)^2},\\ \phi_i=\arccos\left(\dfrac{z_{ti}-z_r}{D_i}\right),\\ \theta_i=\arccos\left(\dfrac{(v_{RTi},v_O)}{\|v_{RTi}\|\|v_O\|}\right).\end{cases}$$

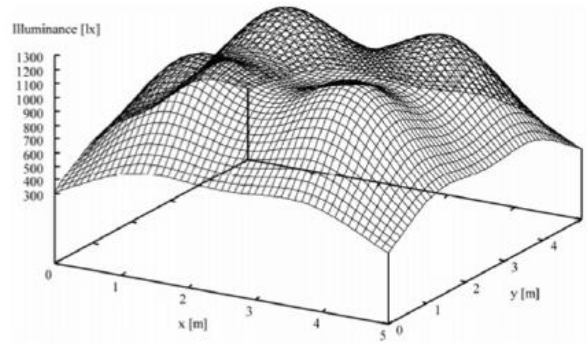


X. You, J. Chen, C. Yu, Performance of location-based equalization for OFDM indoor visible light communications, IEEE Transactions on Cognitive Communications and Networking, 2019.

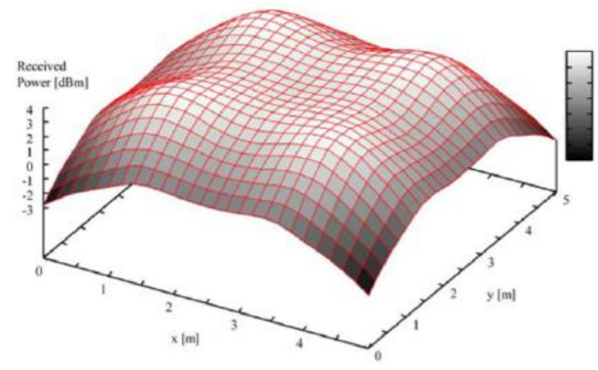
Variable Channel Condition for Mobile VLC



Illuminance:

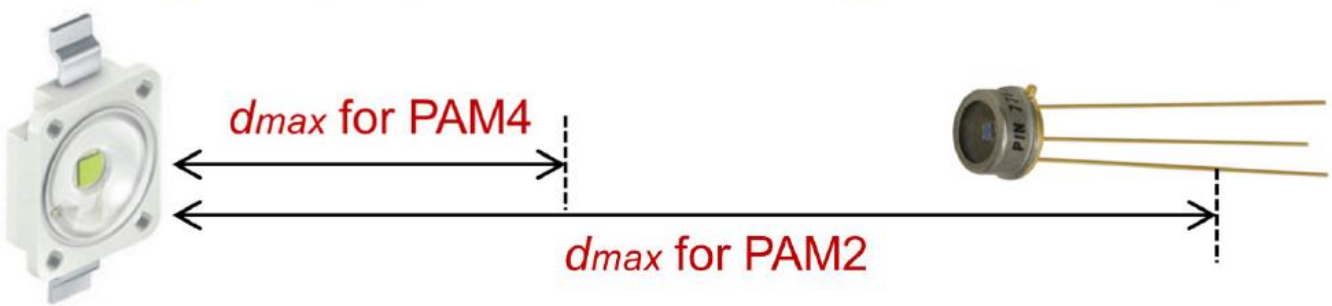


Received Power:

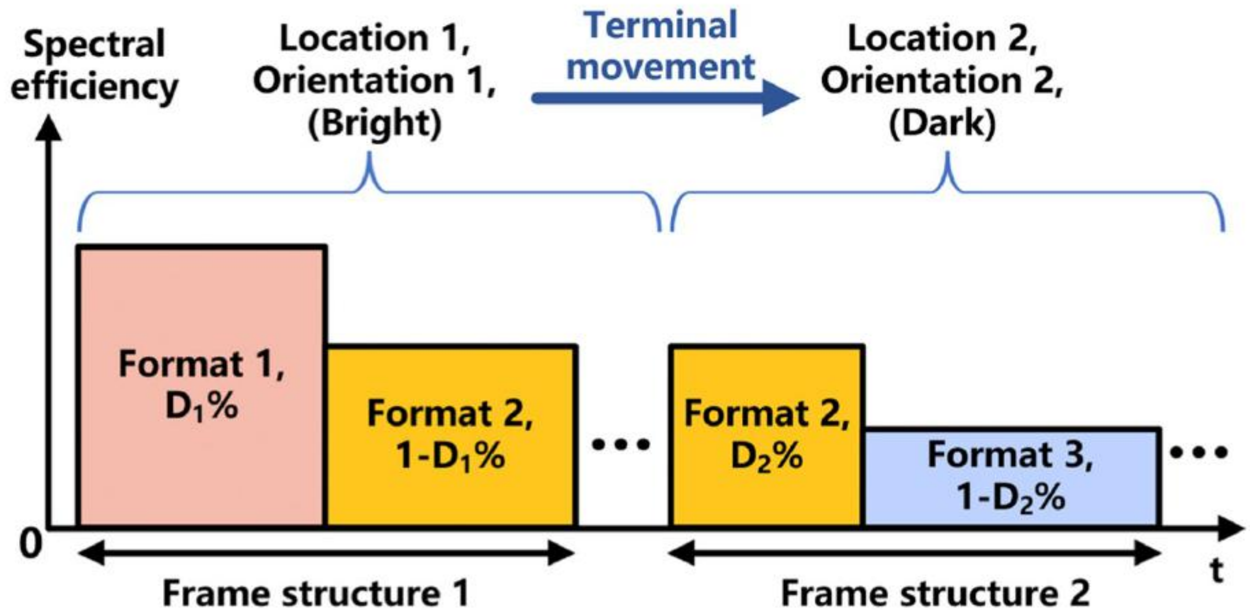


T. Komine et al., IEEE Transactions on Consumer Electronics, 2004

- The layout of LED sources is usually discrete and fixed
- The spatial distribution of light intensity is not uniform
- The user terminal usually moves or changes orientations
- The received power, SNR and channel response will also fluctuate



Proposed Location-Aware TDHM



X. You, Z. Liu, J. Chen, et al., Indoor three-dimensional optical wireless positioning and orienteering using steerable line Lasers, ACP, 2020

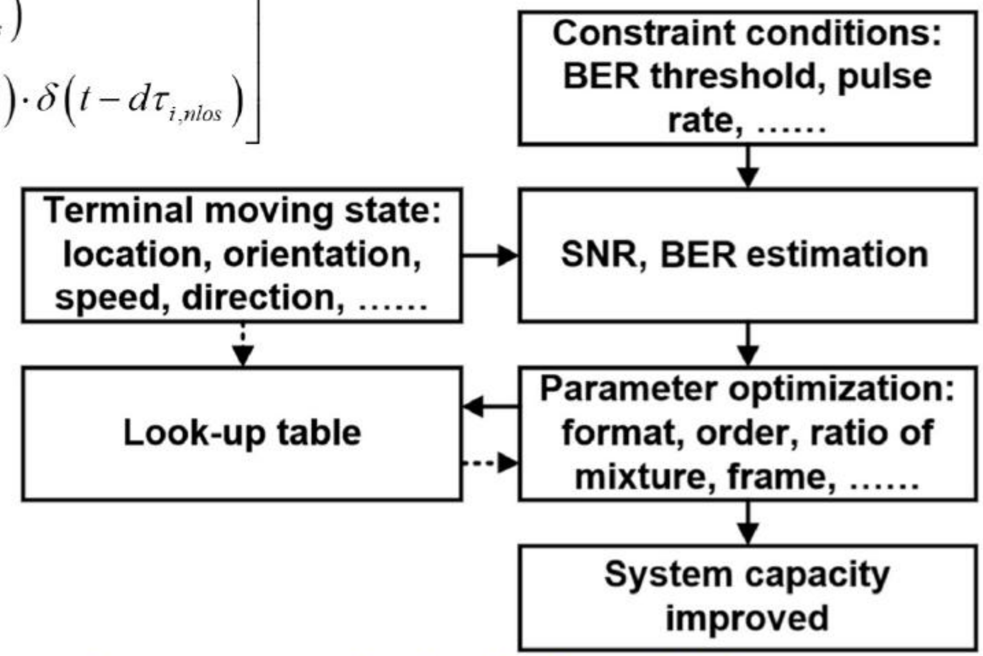
- Through time domain hybrid modulation (TDHM), two different modulation formats are transmitted alternately
- Average SE is adjusted according to the condition of mobile channel
- As long as the average BER in each frame is lower than the FEC threshold required, the system capacity can be improved

Block Diagram

$$h\left(t;\underline{\boldsymbol{T},\boldsymbol{R},\boldsymbol{O}}\right)=\sum_{i=1}^{N_{LED}} w_i \begin{bmatrix} H_{i,los}\left(0;\boldsymbol{T}_i,\boldsymbol{R},\boldsymbol{O}\right)\cdot\delta\left(t-\tau_{i,los}\right) \\ +\int_{\tau_{i,nlos}=0}^{+\infty} A_{i,nlos}\left(\tau_{i,nlos};\boldsymbol{T}_i,\boldsymbol{R},\boldsymbol{O}\right)\cdot\delta\left(t-d\tau_{i,nlos}\right) \end{bmatrix}$$

$$SNR\left(\underline{\boldsymbol{T},\boldsymbol{R},\boldsymbol{O}}\right)=\frac{P_{r,sig}\left(\boldsymbol{T},\boldsymbol{R},\boldsymbol{O}\right)}{P_{r,isi}\left(\boldsymbol{T},\boldsymbol{R},\boldsymbol{O}\right)+N\left(\boldsymbol{T},\boldsymbol{R},\boldsymbol{O}\right)}$$

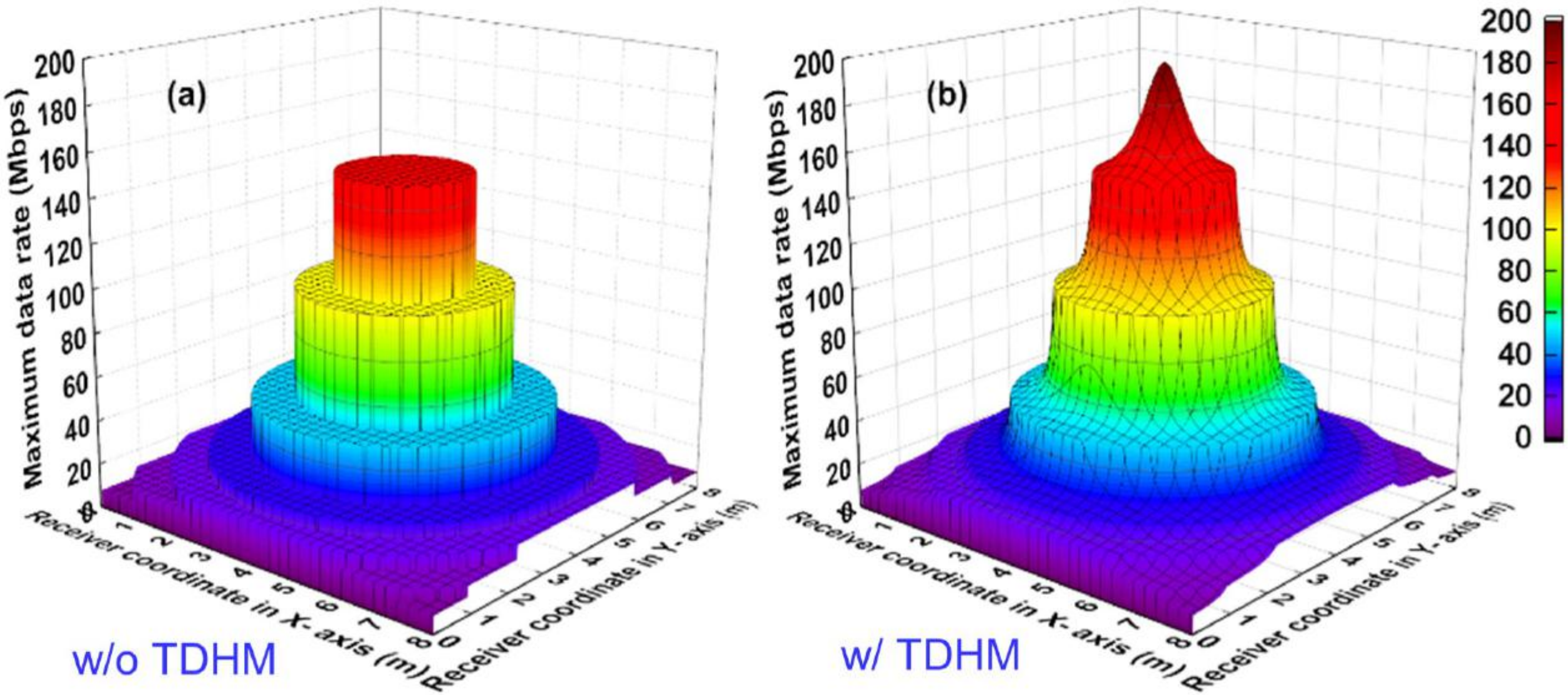
$$BER_{TDHM}\left(\underline{\boldsymbol{T},\boldsymbol{R},\boldsymbol{O}}\right)\le BER_T$$



- VLC channel mainly depends on the geometrical relationship between transmitters and a receiver
- The mobile channel impulse response is based on terminal moving state:
  - Transmitters' coordinates ($\boldsymbol{T}_i$: (x_{ti}, y_{ti}, z_{ti}))
  - Receiver coordinates ($\boldsymbol{R}$: (x_r, y_r, z_r))
  - Receiver orientation like azimuthal/polar angles ($\boldsymbol{O}$: (α, β))

Comparison of Capacity within Receiving Plane

R_s = 50 MHz



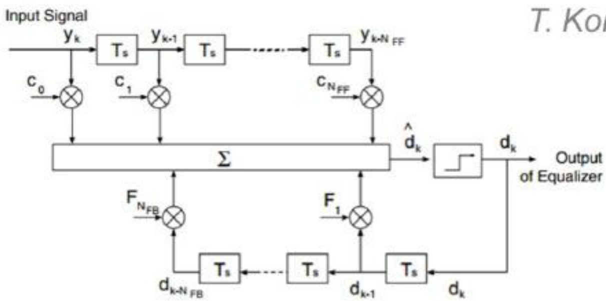
- ◻ At (4, 4, 0.85), the maximum data rate can increase from 150 Mbps (only PAM8) to 197 Mbps (hybrid PAM8+PAM16)

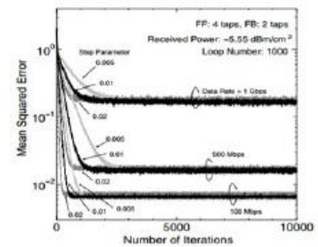
Conventional Schemes against Multi-path

- Inherent multiple transmitters and indoor reflections → ISI

T. Komine, et al., 2009

Adaptive equalization in SC:

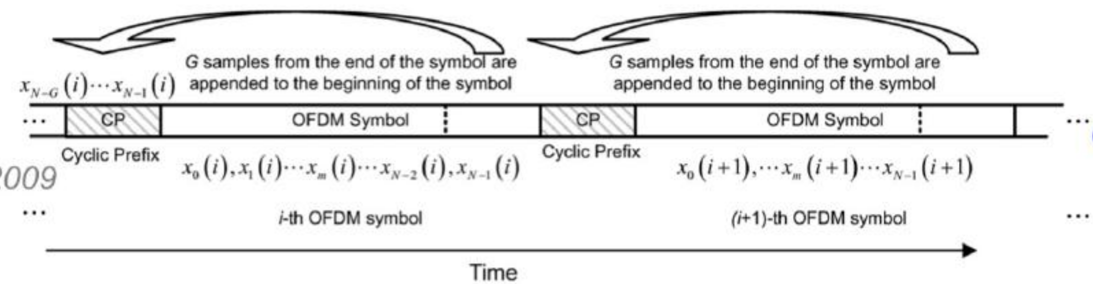




- Need TS
- Long convergence time

OFDM:

J. Armstrong, 2009

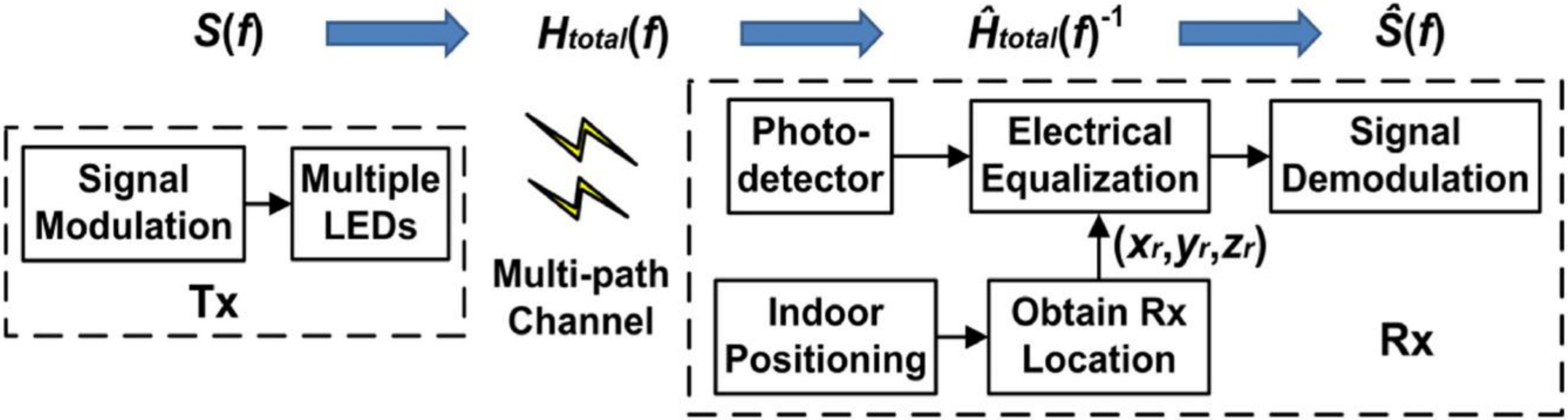


- Need TS or pilot

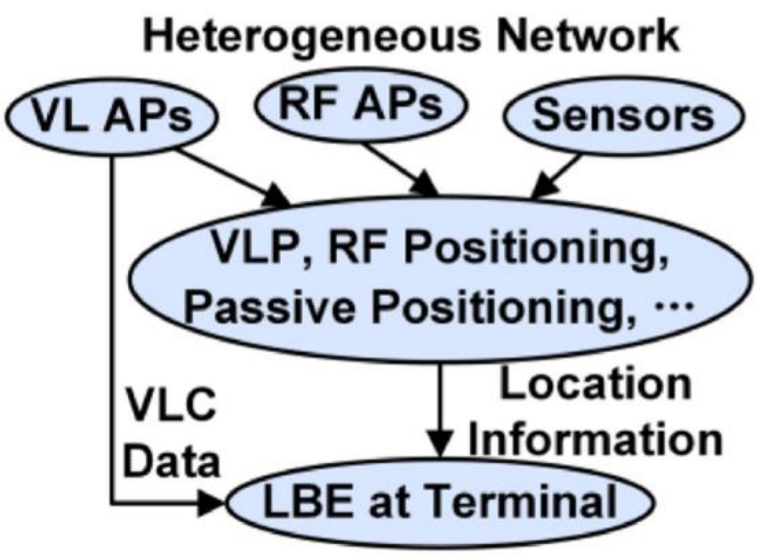
IPS	Characteristics
GPS	Inapplicable in indoor environments
RF-ID, Cellular, WLAN, ……	Widely adopted but limited: low accuracy, electromagnetic interference, low security
Visible light positioning (VLP)	A hot area: high accuracy, energy efficiency, low cost, and simple implementation

It is easy for a mobile VLC Rx terminal to obtain its indoor location

Proposed Location-based Equalization (LBE) Concept

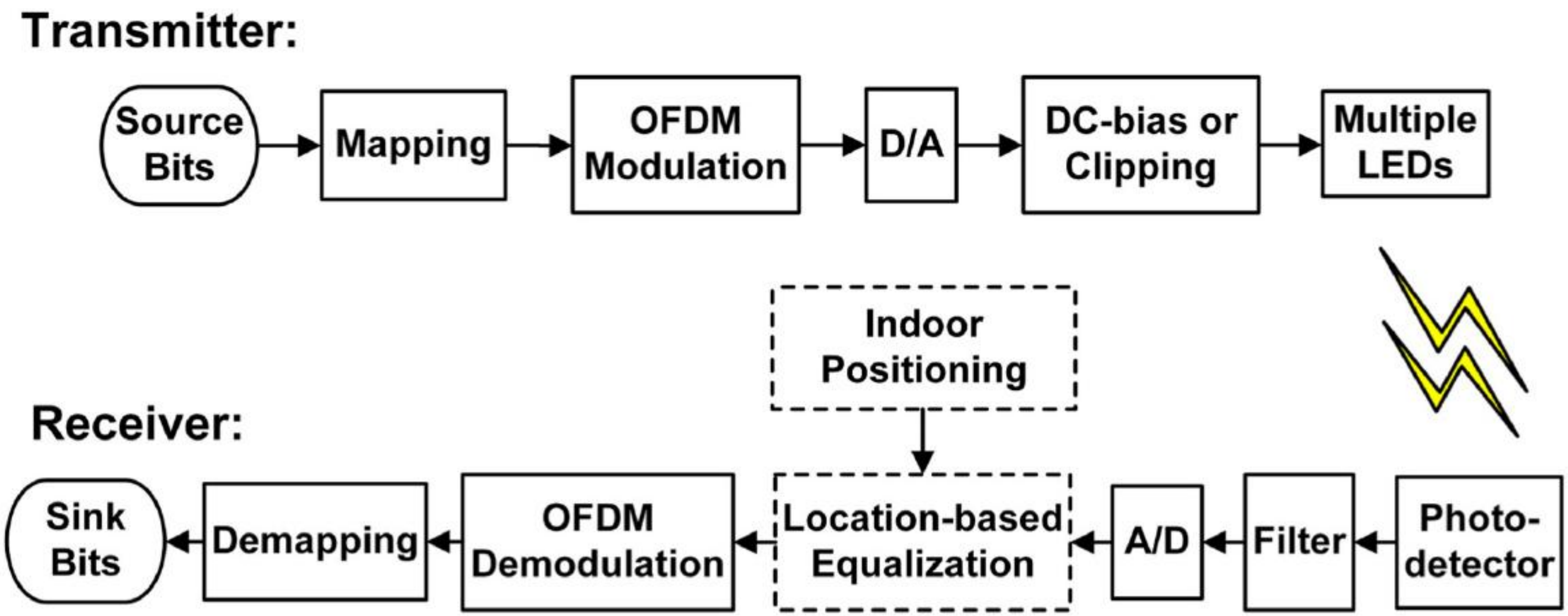


X. You, J. Chen, C. Yu, Performance of location-based equalization for OFDM indoor visible light communications, IEEE Transactions on Cognitive Communications and Networking, 2019



- □ VLC become a location-based value-added service

LBE for OFDM



Implementation schemes of LBE:

1. Based on the line-of-sight (LOS) CIR: $$H_{ZF1}(f) = 1/H_{LOS}(f)$$

2. Based on the distance: $$H_{ZF2}(f) = 1/H_D(f) = 1\Big/\left[\sum_{i=1}^{N_{LED}} \frac{1}{D_i^2} \exp\left(\frac{-j2\pi f D_i}{c}\right)\right]$$

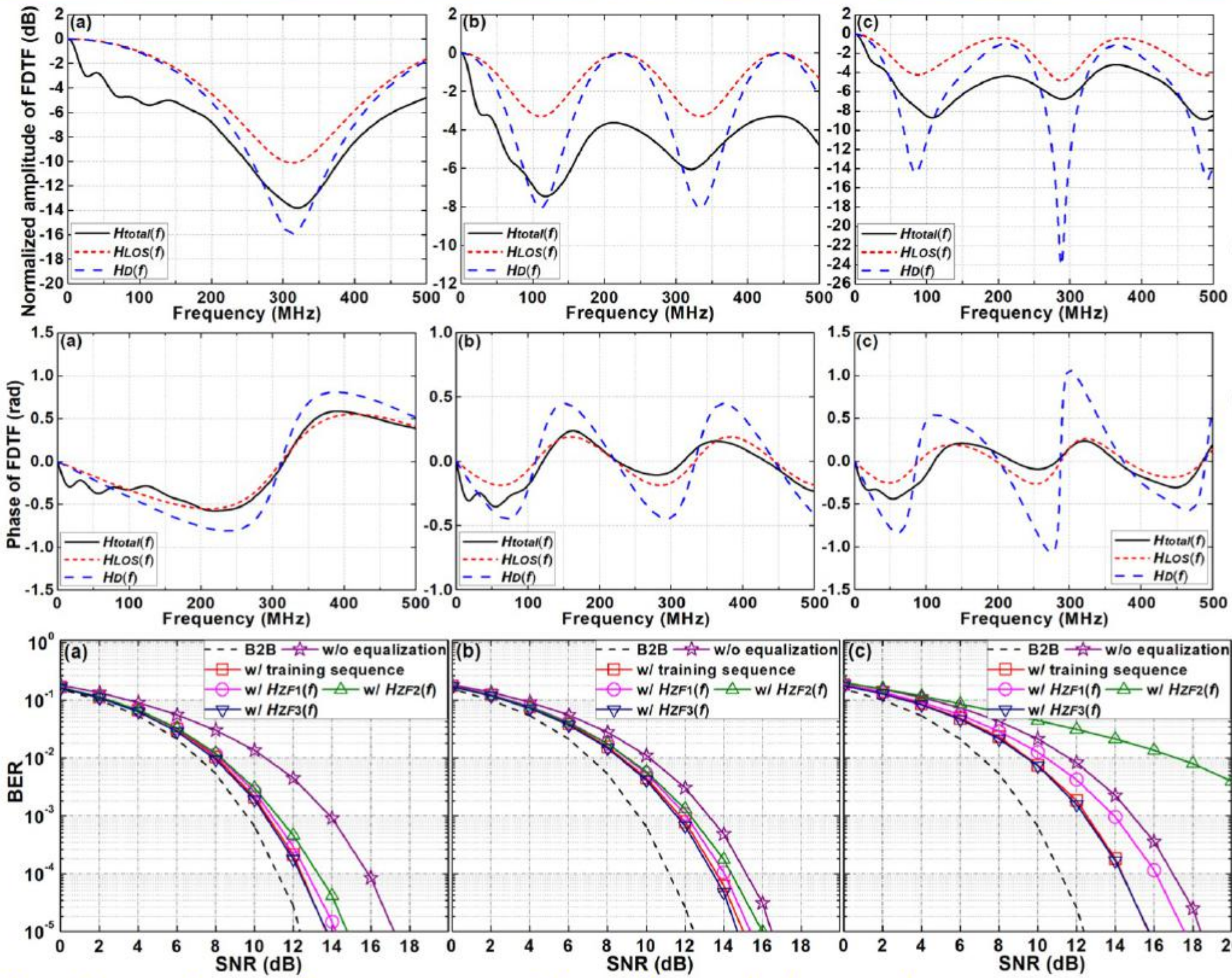
3. Based on look-up table (LOS+non-LOS): $$H_{ZF3}(f) \approx 1/H_{total}(f)$$

FDTF & BER Improvement

FDTF Amplitude:

FDTF Phase:

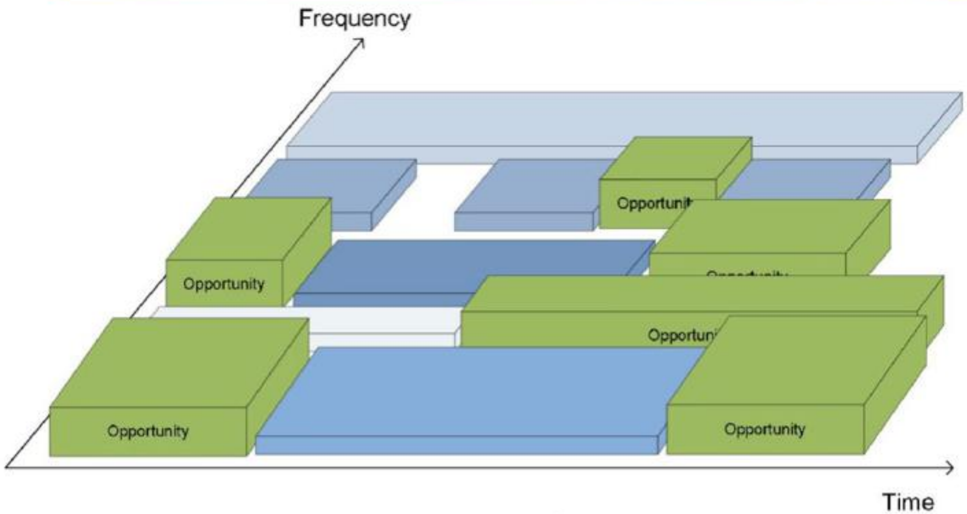
BER comparison:



Rx is located at (a) near centre; (b) side; (c) near corner

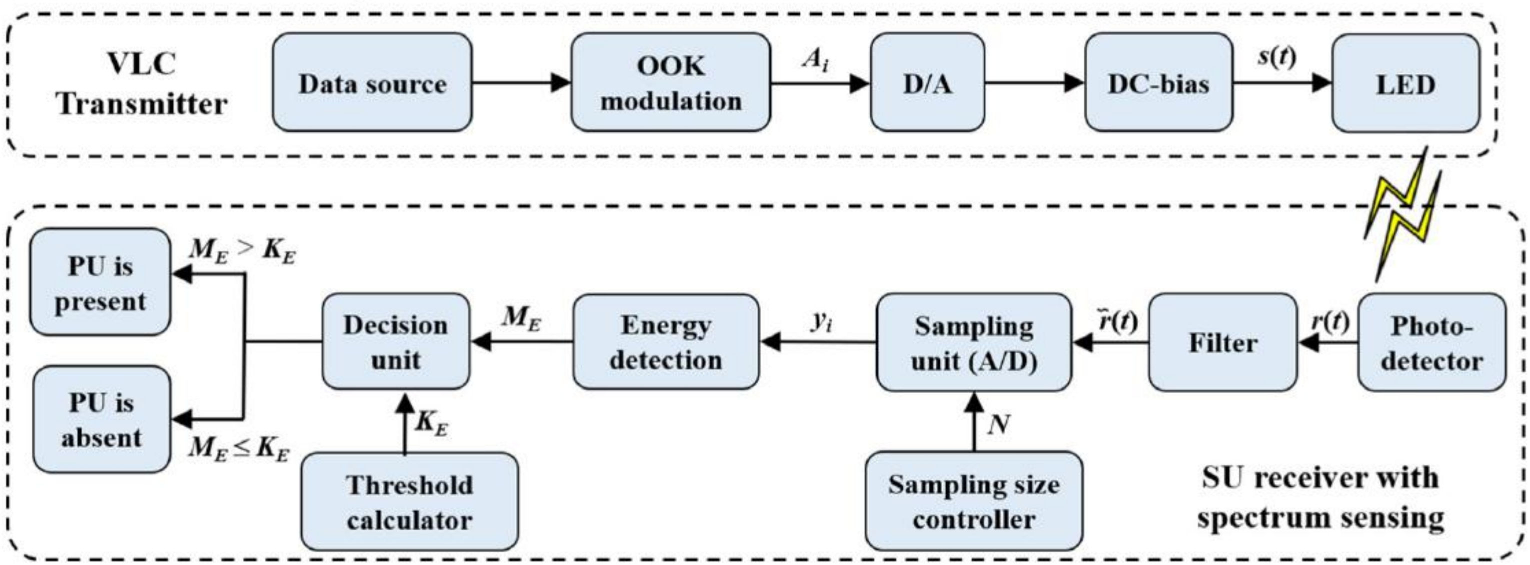
- Location-based equalizer can match with real channel
- Adopting LBE can achieve BER improvement effectively

Spectrum Sensing for Cognitive VLC



- PU: primary user
- SU: secondary user

T. Yucek and H. Arslan, A survey of spectrum sensing algorithms for cognitive radio applications, IEEE Communications Surveys & Tutorials, 2009



Z. Jiang, X. You, C. Xiong, G. Shen, and B. Mukherjee, Collaborative spectrum sensing for cognitive visible light communications, Optics Express, 2021*

Proposed Location-Aware Spectrum Sensing

Please see the paper to be published, thanks!

Z. Jiang, X. You, G. Shen, and B. Mukherjee, Location-aware spectrum sensing for cognitive visible light communications over multipath channels, submitted, 2021*

Summary

- 3D VLP and orienteering
- VLC can assist VLP
- VLP can assist VLC
- Coexisting VLC and VLP
- Coexisting RF and VLC
- How will location information play an important role in VLC?
- What’s more …..

Some Issues

- White light illumination
- LEDs with ideal Lambertian radiation pattern
- Data source
- Turn off the lights / uplink
- Mobility
- killer application and potential users
- What’s more …..

Thank you for your attention !