Modeling and Analysis of Spatial Inter-Symbol Interference for MIMO Image Sensors Based Visible Light Communication

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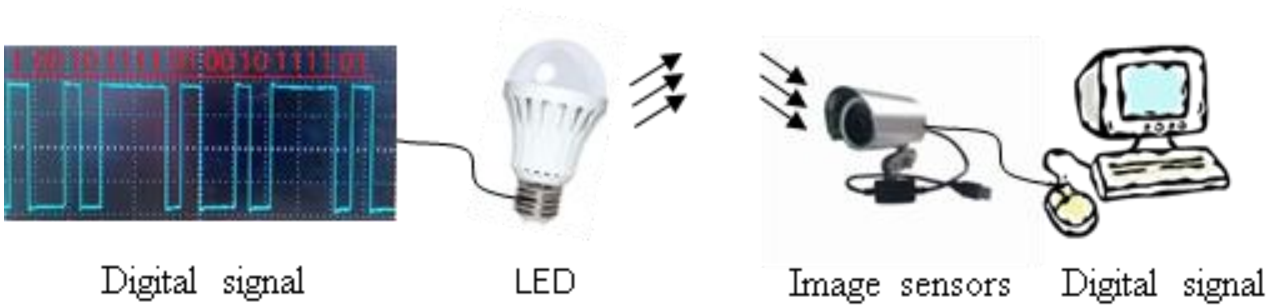
Nanjing, China
27-29 November 2017

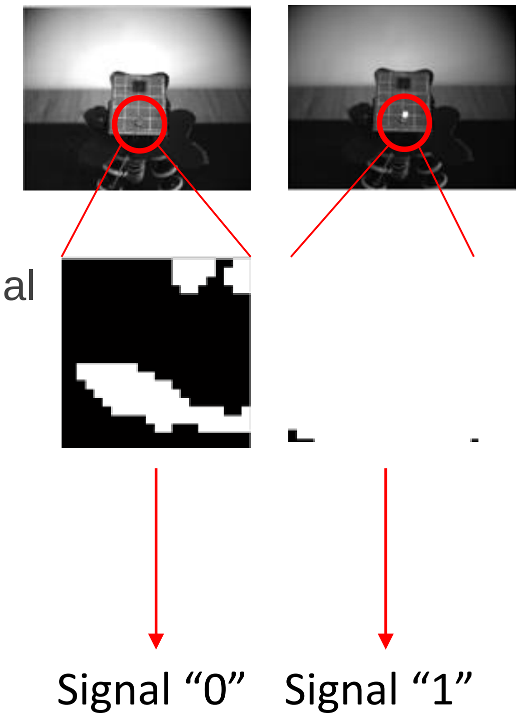
Presentation items

1. What is image sensors based visible light communication technology?
2. Introduction of MIMO IS-VLC technology and its problem.
3. Modeling and analysis of inter-symbol interference.
4. How to improve the system performance?

1.Image sensors based visible light communication (IS-VLC)

- The IS-VLC technology
  - Low speed optical wireless communication (OWC)
  - The transmitter is LED or LED array
  - The receiver is image sensors
  - Image processing algorithms are utilized to extract the LED signal

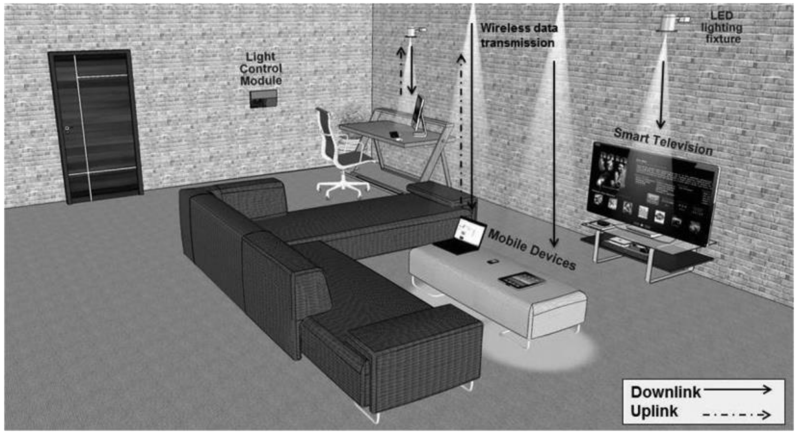


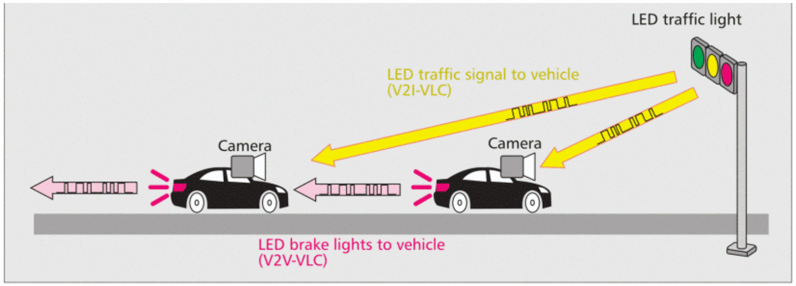


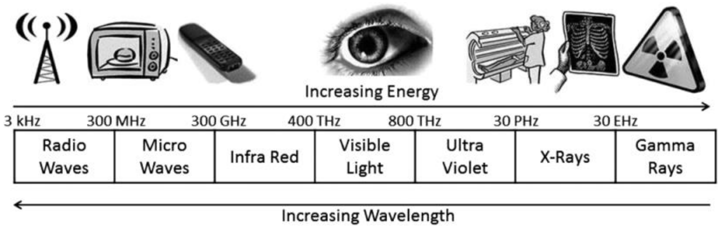
[1] Wu R, Lv L, Liu J, et al. Character-oriented image sensor communication system[M]// Electronics, Communications and Networks IV. 2015.

1.Image sensors based visible light communication (IS-VLC)

- Advantages
  - Saving frequency resource
  - Being harmless to human health
  - Flexible to network (Broadcast)
- Applications of IS-VLC
  - Indoor positioning
  - Intelligent transportation system
  - Machine to machine communication (M2M)
  - Internet of things (IoT)



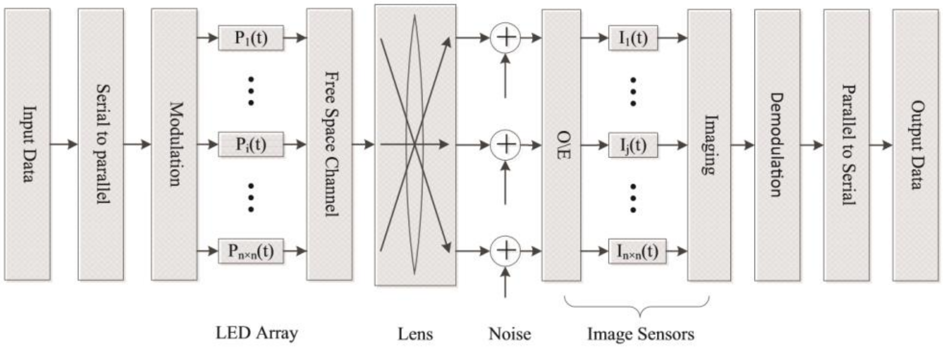


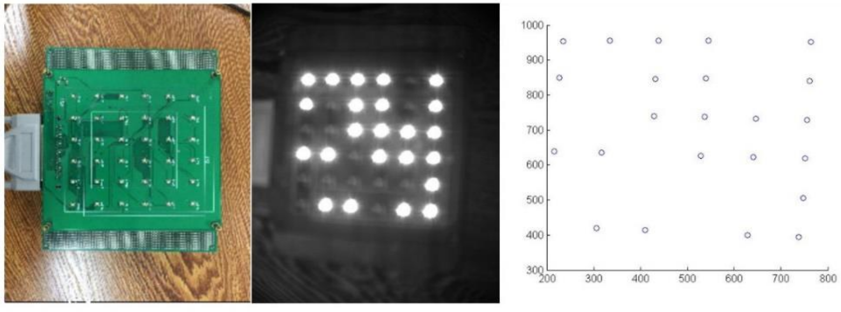


[2] Karunatilaka D, Zafar F, Kalavally V, et al. LED Based Indoor Visible Light Communications: State of the Art[J]. IEEE Communications Surveys & Tutorials, 2015, 17(3):1649-1678.

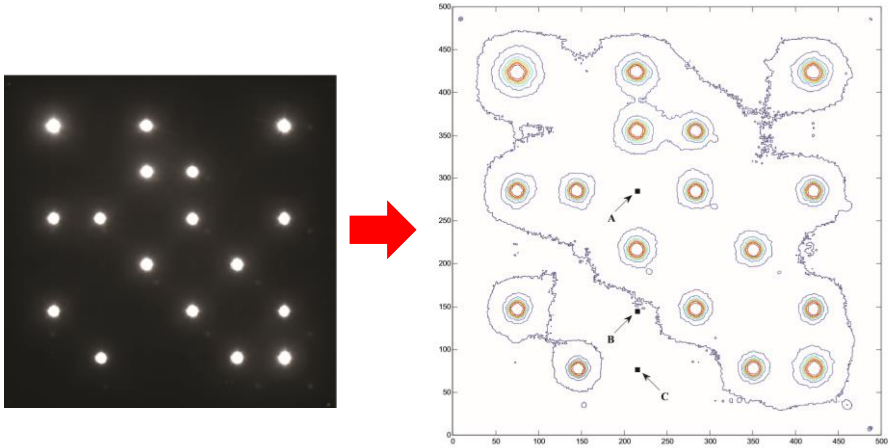
2.MIMO IS-VLC system and Inter-Symbol Interference

- LED array is used as transmitter
- Advantages
  - Improving symbol transmission rate
  - Decreasing bit error rate
  - Using for indoor positioning
- Problems
  - Inter-Symbol Interference





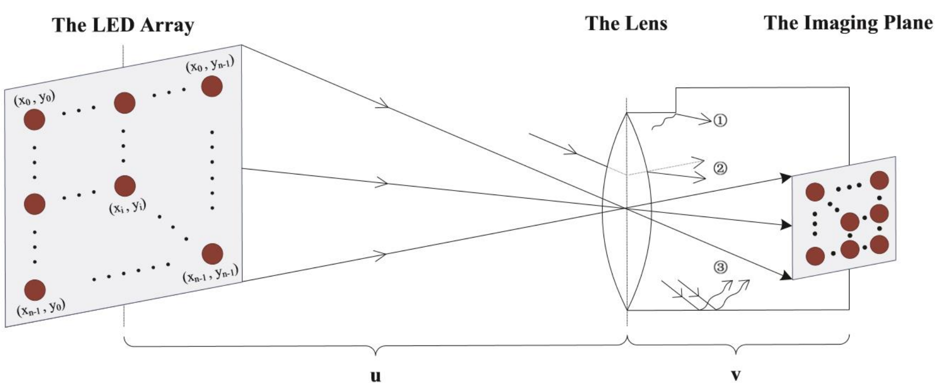
(a) (b) (c)



[3] Leilei Jiang, Rongzhao Wu, et al. Quick Detecting LED Array From the Background for Image Sensor Communication[M]. //IEEE International Conference on Imaging Systems and Techniques, 2015.

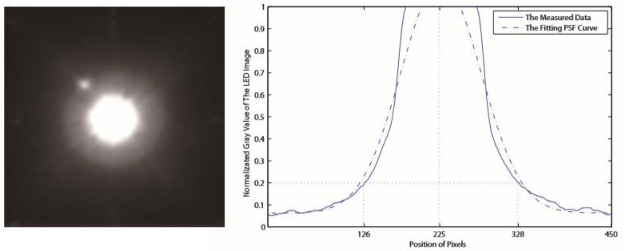
3.Modeling and analysis of IS-VLC channel characteristic

- Produce mechanism
  - The stray light of imaging system
  - Diffraction, refraction and reflection

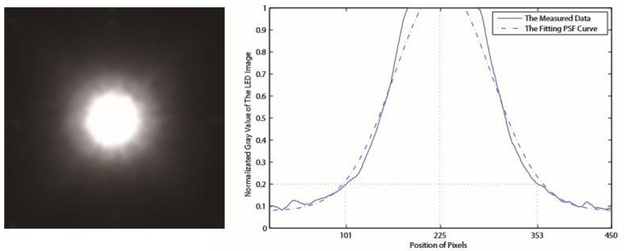


- Distribution model of stray light
  - The point spread function (PSF)

$$s(r_i) = \frac{1}{\sigma\sqrt{2\pi}} exp\left(-\frac{r_i^2}{2\sigma^2}\right)$$



(a)



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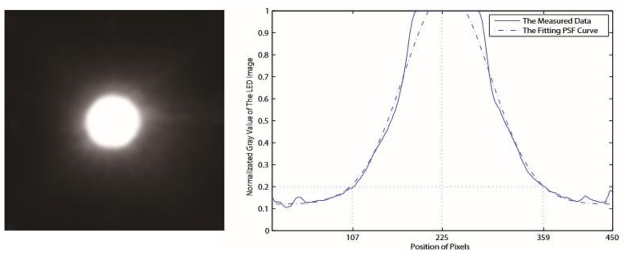


(c)

3.Modeling and analysis of IS-VLC channel characteristic

- Intensity of the stray light
  - To a certain area based on the center coordinate of (x_i,y_i), the stray light intensity is written as

$$S(x_i, y_i) = K + \iint P(x_0, y_0) \cdot s(x - x_i, y - y_i)\, dx\, dy$$

- Channel model of IS-VLC system
  - Assuming the output optical signal of the LED array is $\mathbf{P} = \left(P_1(t), \cdots, P_i(t), \cdots, P_{n\times n}(t)\right)^{\mathrm{T}}$
  - The received current signal of image sensor $\mathbf{I} = \left(i_1(t), \cdots, i_j(t), \cdots, i_{n\times n}(t)\right)^{\mathrm{T}}$ is written as

$$\mathbf{I} = \xi \mathbf{H} \times \mathbf{P} + \mathbf{N}$$

  - Considering the channel as a line of sight (LOS) link, the MIMO channel gain matrix is composed of the link gain $\mathbf{G}$ and the SISI gain $\mathbf{S}$ as well as $\mathbf{H} = \mathbf{G} + \mathbf{S}$.
  - The link gain matrix $\mathbf{G}$ is a diagonal matrix and the SISI gain matrix is a matrix that the diagonal elements is zero.

3.Modeling and analysis of IS-VLC channel characteristic

- Channel model of IS-VLC system
  - The LED light radiation follows the Lambertian model. Thus the diagonal elements of $\mathbf{G}$ is written as

$$g_{ii} = \begin{cases} \frac{A}{u^2} R(\phi) \cdot cos(\psi_i), & 0 \le \psi_i \le \frac{\psi_c}{2} \\ 0, & \psi_i > \frac{\psi_c}{2} \end{cases}$$

  - The off-diagonal elements of $\mathbf{S}$ is written as

$$s_{ij} = \iint P(x_j, y_j) \cdot s({r_{ij}}') \, dx \, dy$$

  - The spacing distance of two adjacent LEDs in the imaging plane is expressed as

$${r_{ij}}' = \frac{f \cdot r_{ij}}{u}$$

  - The received current signal of i^{th} channel is obtained as

$$I_i(t) = \xi t_e \Big\{ g_{ii} \cdot P_i(t) + \sum_{j=1, j \ne i}^{n \times n} s_{ij} \cdot P_j(t) + K \Big\}$$

3.Modeling and analysis of IS-VLC channel characteristic

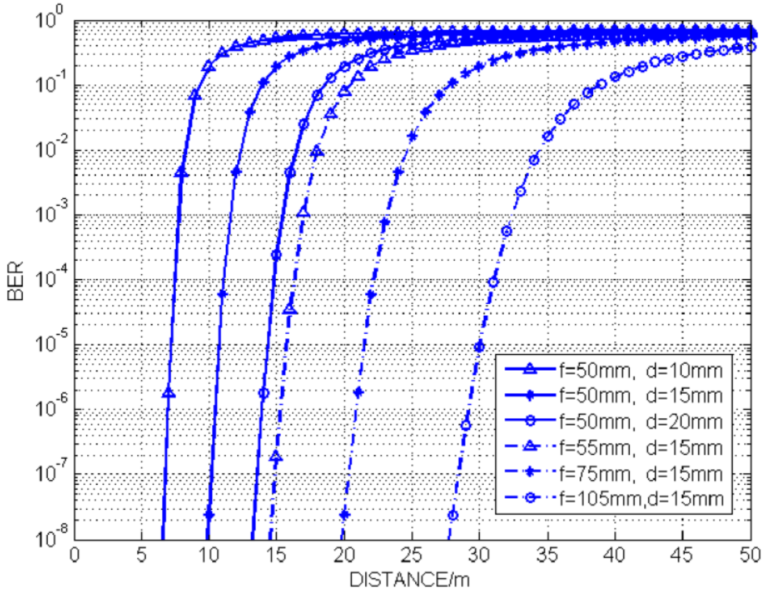
- SNR and BER
  - The received SISI noise of the system is expressed as

$$I_{SISIN} = \xi t_e \sum_{i=1}^{n\times n} \sum_{\substack{j=1 \\ j\neq i}}^{n\times n} \int_0^{2\pi} d\theta \int_0^{Ra'} \frac{g_{jj}\cdot P_j(t)}{\sigma\sqrt{2\pi}} exp\left(-\frac{{r'_i}^2}{2\sigma^2}\right) dr$$

  - The MIMO-IS-VLC system can be considered as a Unipolar On-Off key modulation system. Thus the BER is expressed as

$$P_e = \frac{1}{2}\left[erfc\left(T - \frac{1}{\sqrt{2}}\right) + erf\left(T - \sqrt{R_{SN}}\right)\right]$$

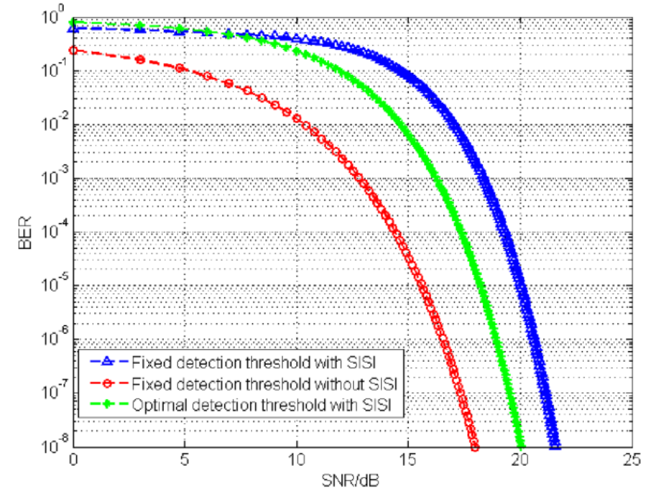
- Simulation results
  - BER performance of different communication distances

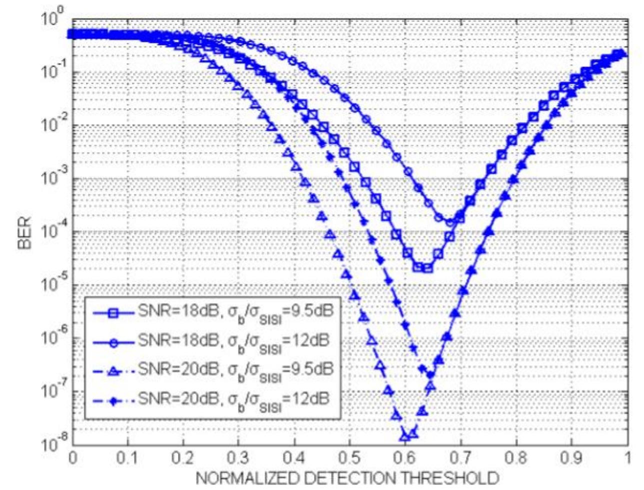


3.Optimal detection threshold

- Definition
  - The optimal detection threshold is defined by finding the extreme value of $\frac{\partial P_e}{\partial T} = 0$.
  - The system stray light produces the SISI noise and the background noise component in the form of additive noise. The additive noise results in the degrade of the system BER performance. Generally, the background noise component can be calculated so that the fixed detection threshold

$$Th = \frac{GP_{LED} + I_{SISI} + \xi K}{2}$$





Thank you for your listening!

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Research Interests: OWC, Lidar
(VLC, FSO, indoor positioning)

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