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面向6G/IoT的可见光通信定位一体化及光与射频异构融合

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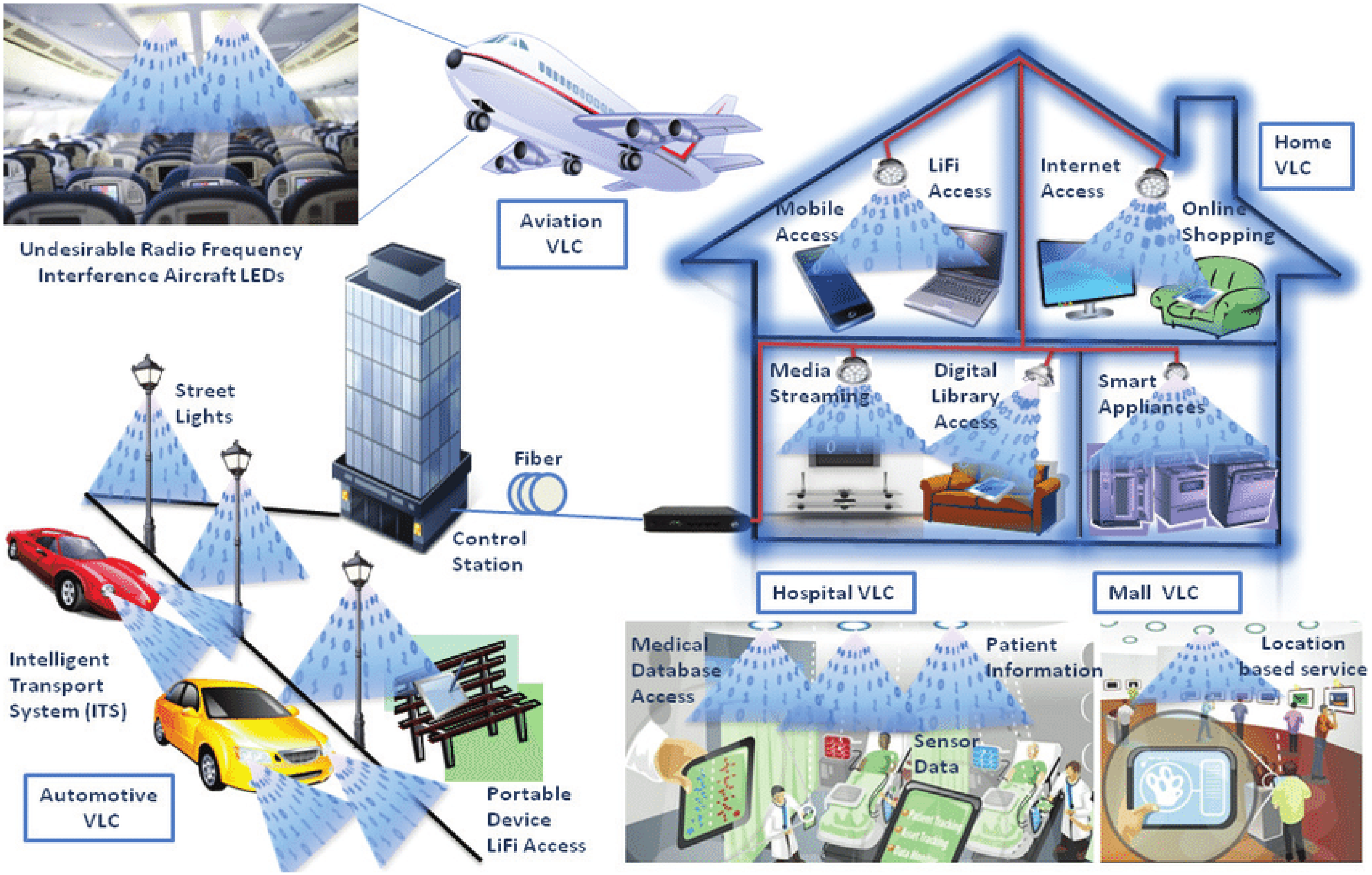
主要报告内容：1. 射频与可见光通信融合，2. 可见光通信与定位融合，3. 机器学习在可见光通信中的应用。

可见光应用场景



1. Peng Deng，Real-Time Software-Defined Adaptive MIMO Visible Light Communications

5G/6G业务需求

满足各色各样的需求

研究难点

- 高速通信
- 高精度定位
- 通信安全
- 无电磁辐射
- 频谱匮乏
- 绿色通信
- . . .

Types of IoT devices	Service characteristics	Applications
Massive IoT	Delay-tolerant and low data rates, but energy-constraint.	Smart city, smart grid, and smart home.
URLLC-IoT	Needs strict low latency, high reliability and stable connectivity, but with low date rates.	Industrial automation, emergency response, and real-time control.
High-accuracy positioning IoT	Requires high-accuracy positioning and real-time tracking services.	Shopping mall localization and robot navigation.
High-speed rate IoT	Needs high data rates, even has latency constraints.	Video surveillance, software downloading, and webpage surfing.
Security IoT	Requires communication security and privacy protection.	Industrial manufacturing and automatic payment.

1. **H.L. Yang**, W. -D. Zhong, C. Chen, and A. Alphones, "Integration of visible light communication and positioning within 5G networks for Internet of Things", ***IEEE Network***, vol. 34, no. 5, pp. 134-140, Sept. 2020.

异构射频与可见光通信

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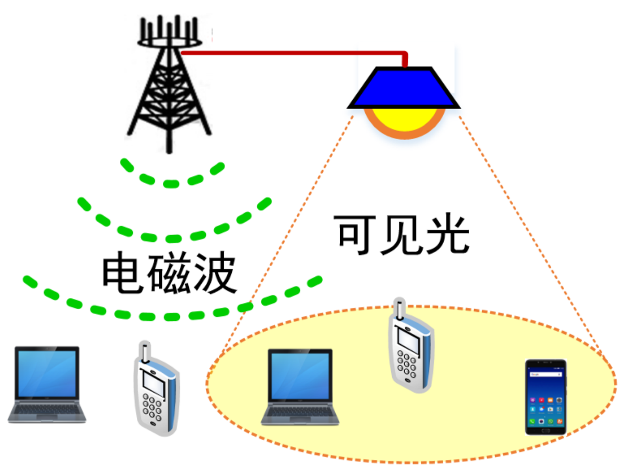
满足各色各样的需求

研究难点

高速通信	高精度定位	通信安全	. . .
无电磁辐射	频谱匮乏	绿色通信	

解决方案

异构射频与可见光无线通信网络



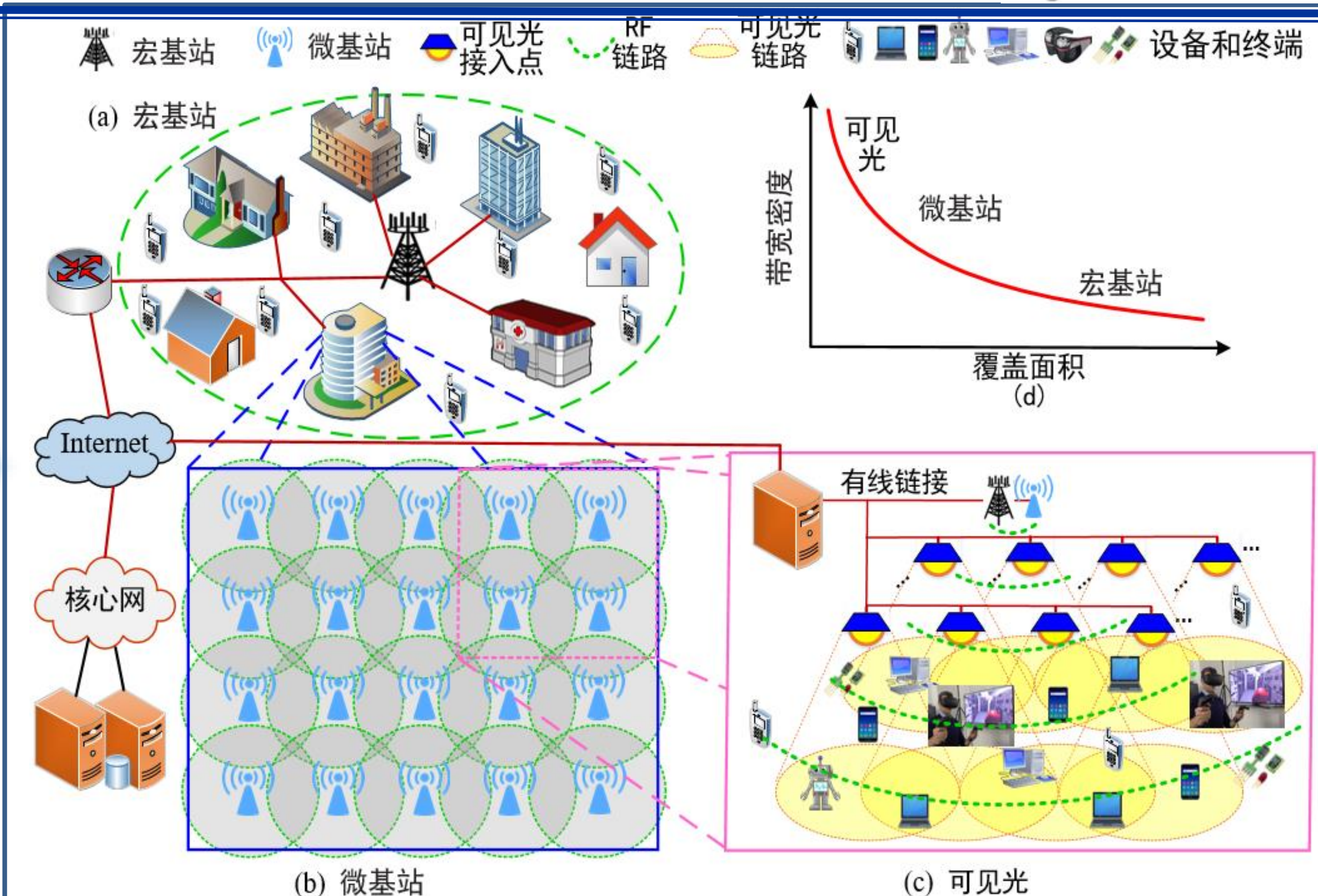
可见光通信		
频谱丰富	不透墙	无电磁波
高速通信	通信安全	室内定位

射频通信		
移动性强	覆盖广	距离远
灵活性强	服务广	. . .

1. **H.L. Yang**, A. Alphones, W. Zhong, C. Chen, and X.Z. Xie., "Learning-based energy-efficient resource management by heterogeneous RF/VLC for ultra-reliable low-latency industrial IoT networks" ***IEEE Transactions on Industrial Informatics***, vol. 16, no. 8, pp. 5565-5576, Aug. 2020.
2. **H.L. Yang**, C. Chen, W.-D. Zhong, and A. Alphones, "Joint precoder and equalizer design for multi-user multi-cell MIMO VLC systems," ***IEEE Transactions on Vehicular Technology***, vol. 67, no. 12, pp. 11354-11364, Dec. 2018.

异构射频与可见光通信

如何与现有5G等网络融合



异构电磁波与可见光融合无线网络

1. **H.L. Yang**, W. -D. Zhong, C. Chen, and A. Alphones, "Integration of visible light communication and positioning within 5G networks for Internet of Things", ***IEEE Network***, vol. 34, no. 5, pp. 134-140, Sept. 2020.

异构射频与可见光通信

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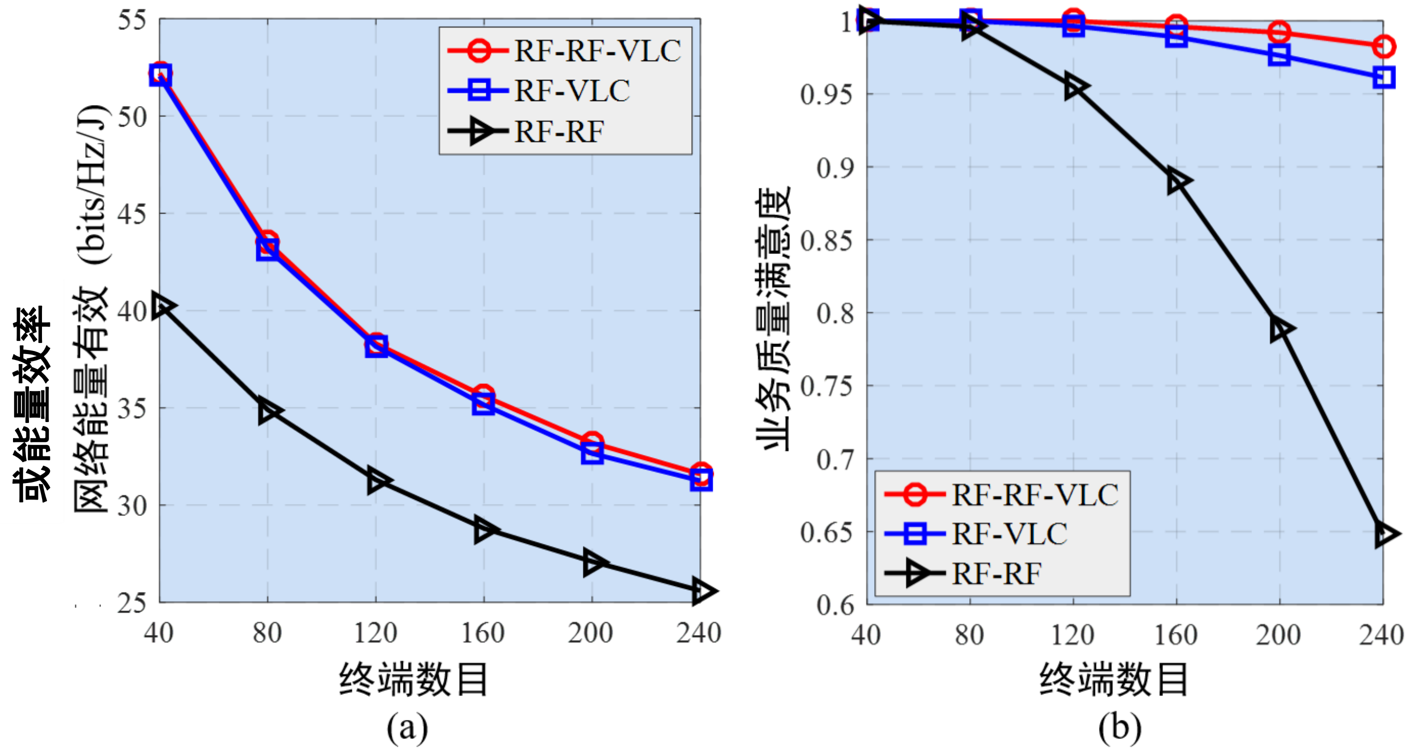
如何与现有5G等网络融合合



部分仿真参数：房间为20m×20m×4.0m，5×5 VLC APs and 2×2 RF APs (Wi-Fi APs)，RF和VLC 接入点的机械消耗功率分别为 6.7 W 和4W。

提出的电磁波与可见光(RF-VLC)异构网络比电磁波(RF-RF)异构网络，在能量有效和业务质量满意度性能上分别提升了25.57% 和 30% 左右。

1. H.L. Yang, W. -D. Zhong, C. Chen, and A. Alphones, "Integration of visible light communication and positioning within 5G networks for Internet of Things", *IEEE Network*, vol. 34, no. 5, pp. 134-140, Sept. 2020.

异构射频与可见光通信

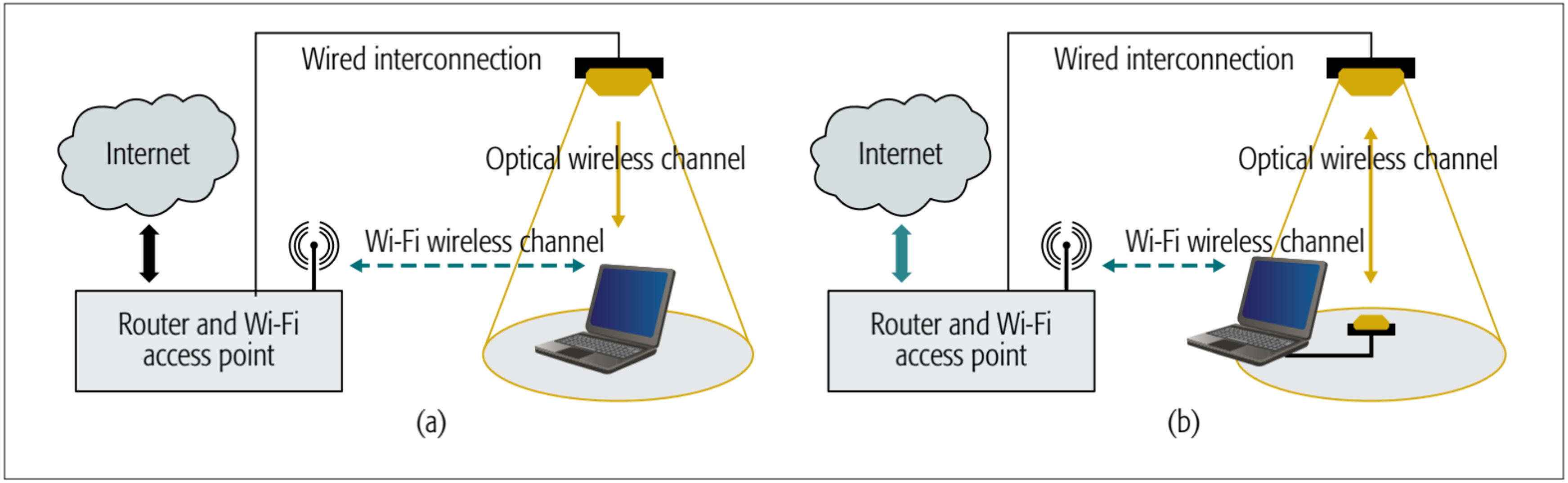


Figure 5. Configurations of the a) hybrid system, and b) the aggregated system.

图（a），Wi-Fi提供下行和上行通信，VLC只提供下行通信

图（b），Wi-Fi提供下行和上行通信，VLC也提供上行和下行通信，电脑或者移动端电池问题？

1. M. Ayyash et al., "Coexistence of WiFi and LiFi toward 5G: concepts, opportunities, and challenges," in IEEE Communications Magazine, vol. 54, no. 2, pp. 64-71, February 2016.

异构射频与可见光通信

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图（a），Wi-Fi不受通信距离影响，而VLC收到通信距离影响大。

图（b），Wi-Fi不受通信遮挡影响，而VLC收到通信遮挡影响大。

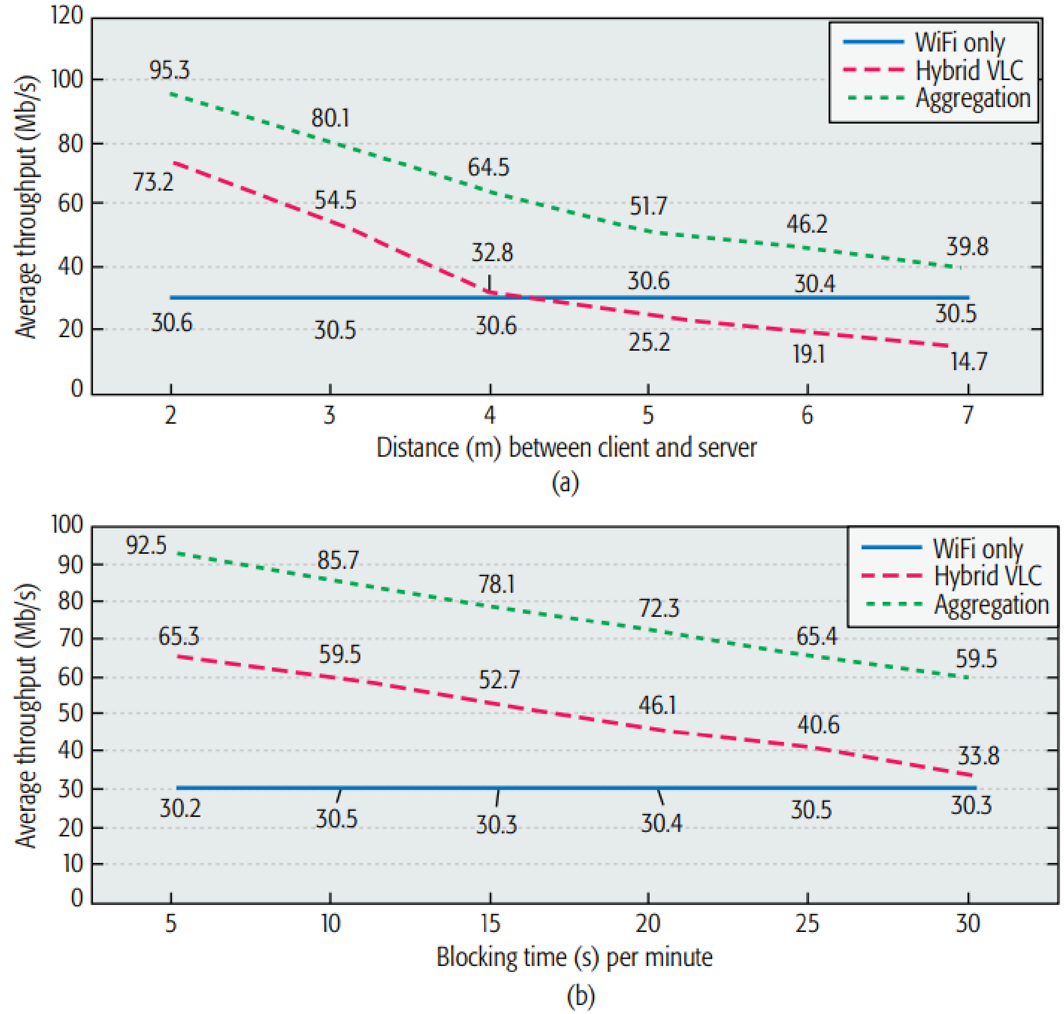
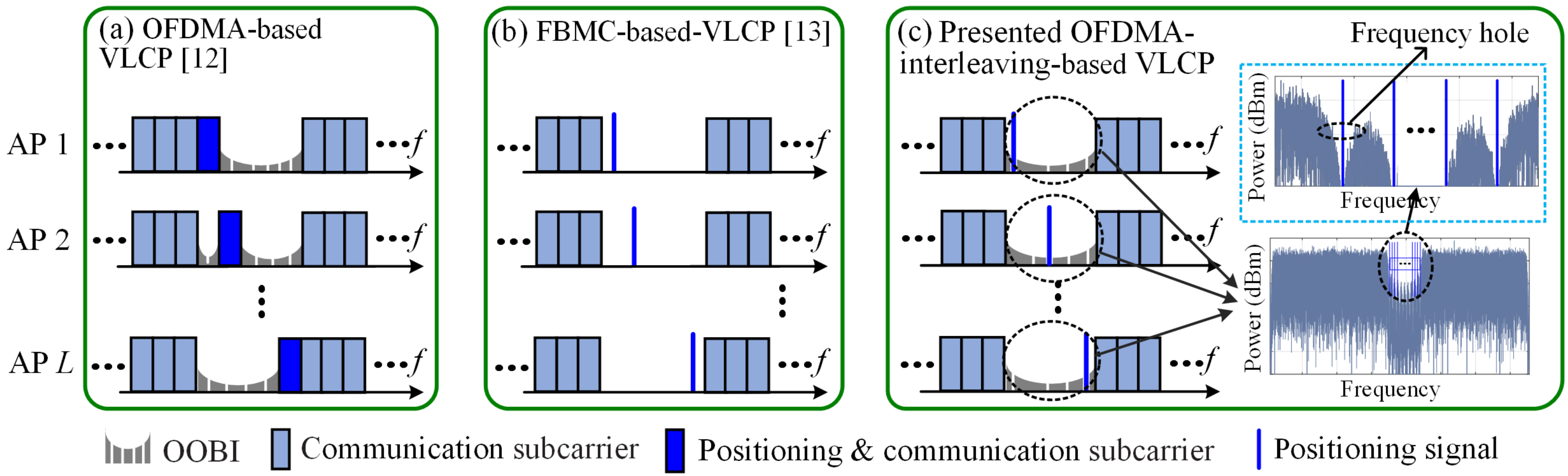


Figure 6. a) throughput vs. distance; b) throughput vs. blockage duration.

1. M. Ayyash et al., "Coexistence of WiFi and LiFi toward 5G: concepts, opportunities, and challenges," in IEEE Communications Magazine, vol. 54, no. 2, pp. 64-71, February 2016.

可见光无线通信与定位



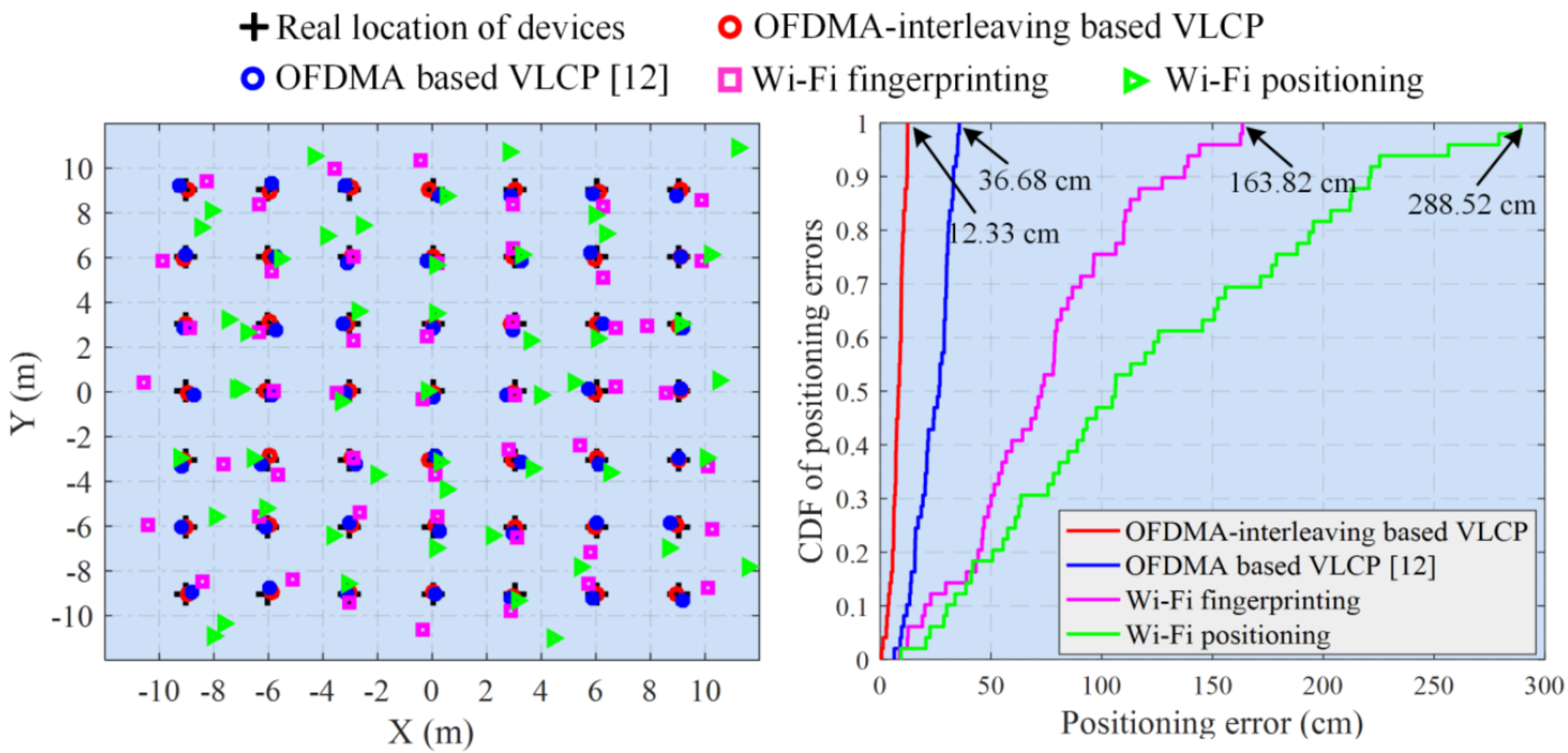
图（a）基于OFDMA的通信与定位模型，把相关子载波的信号强度用来处理定位，同时此信号会收到周围子载波信号的干扰。

图（b）基于FBMC的通信与定位模型，把周围子载波信号的干扰滤去，降低对定位信号的干扰， 但复杂度提升。

图（c）基于OFDMA的通信与定位模型，把定位信号直接插孔到子载波空隙中，收到的干扰信号最小。

[12] B. Lin, X. Tang, Z. Ghassemlooy, C. Lin, and Y. Li, "Experimental Demonstration of an Indoor VLC Positioning System Based on OFDMA," IEEE Photon. J., vol. 9, no. 2, Apr. 2017, pp. 1-9..
[13] H. Yang, C. Chen, W. Zhong, A. Alphones, S. Zhang and P. Du, "Demonstration of a Quasi-Gapless Integrated Visible Light Communication and Positioning System," IEEE Photon. Technol. Lett., vol. 30, no. 23, Dec. 2018, pp. 2001-2004.

可见光无线通信与定位



(a) (b)

总体上，基于可见光定位的方案会比基于Wi-Fi定位的性能要好点。

关于定位精度，OFDMA-interleaving-based VLCP, the OFDMA-based VLCP, Wi-Fi fingerprint and Wi-Fi positioning 的定位精度为7.19 cm, 19.75 cm, 68.76 cm and 113.54 cm,

[12] B. Lin, X. Tang, Z. Ghassemlooy, C. Lin, and Y. Li, "Experimental Demonstration of an Indoor VLC Positioning System Based on OFDMA," IEEE Photon. J., vol. 9, no. 2, Apr. 2017, pp. 1-9..

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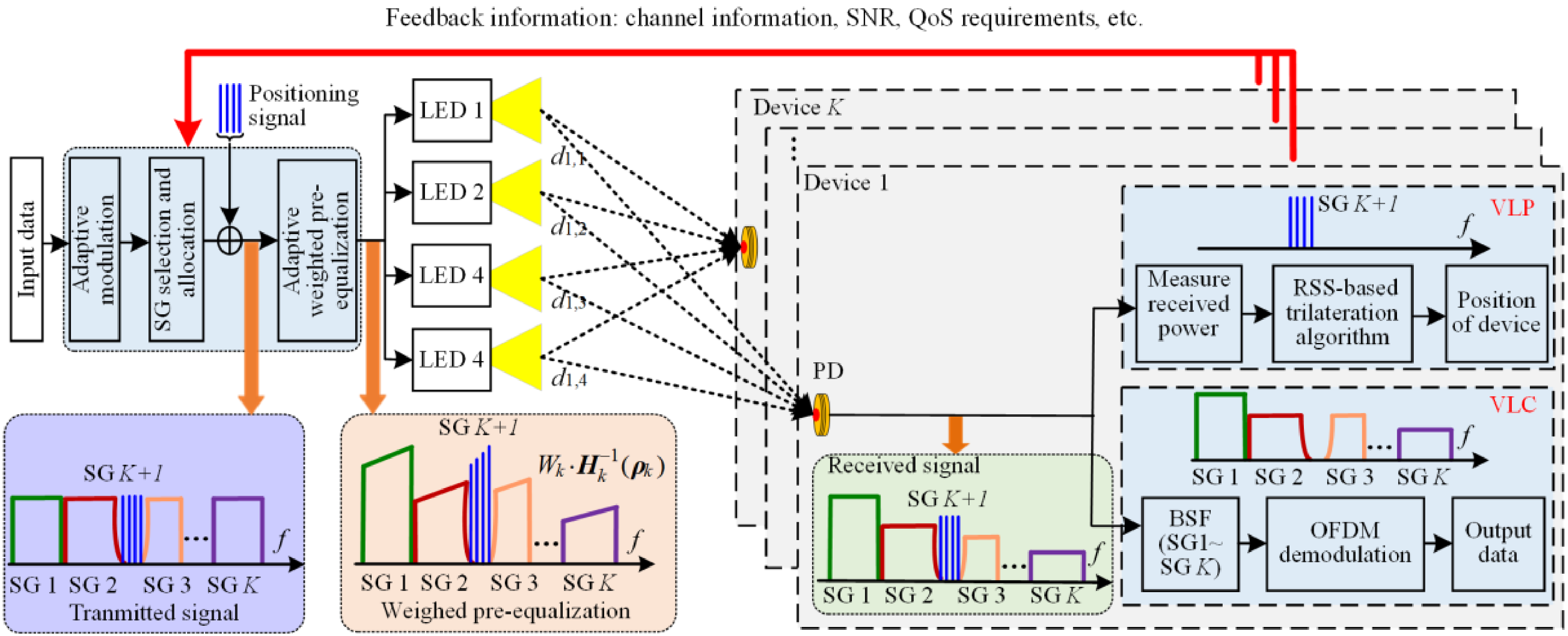
可见光无线通信与定位



1. **H.L. Yang**, A. Alphones, W. Zhong, C. Chen, and X.Z. Xie., "Learning-based energy-efficient resource management by heterogeneous RF/VLC for ultra-reliable low-latency industrial IoT networks" ***IEEE Transactions on Industrial Informatics***, vol. 16, no. 8, pp. 5565-5576, Aug. 2020.
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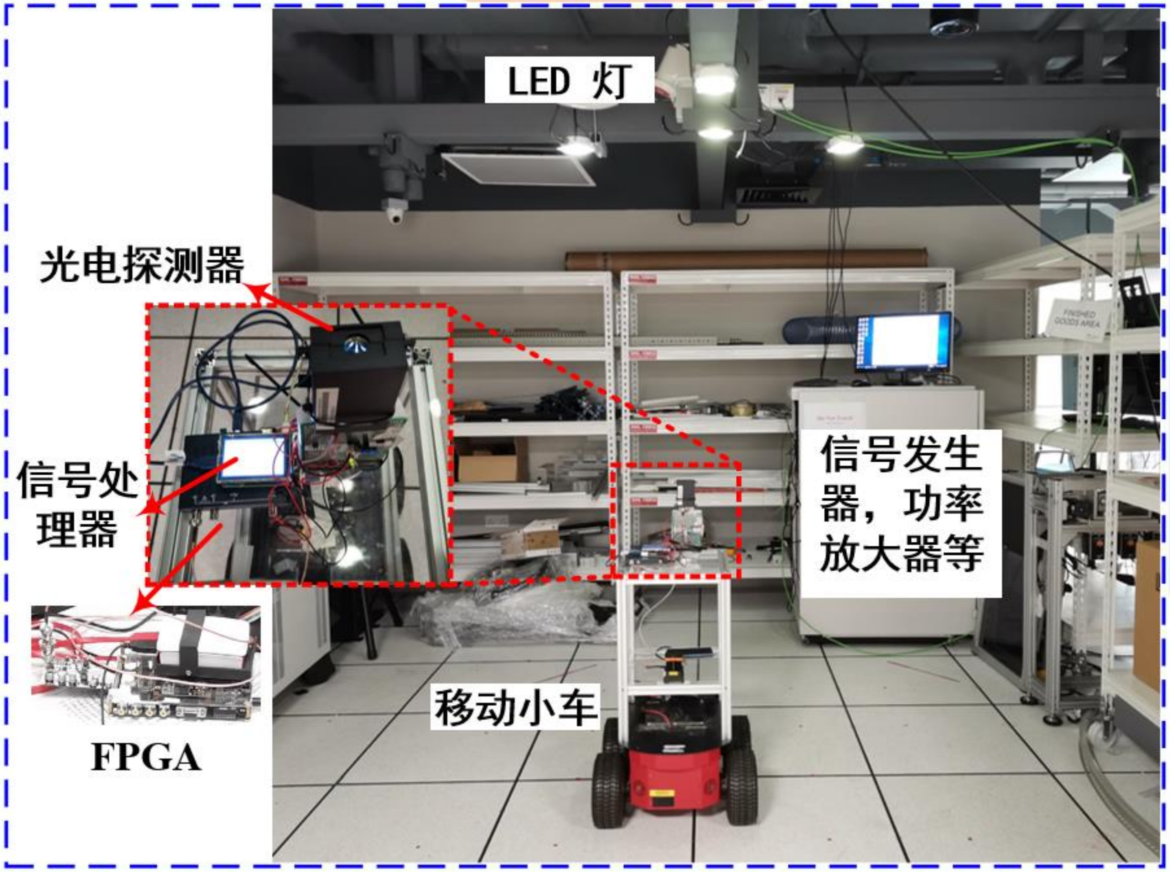
实验演示

研究难点	提供高速无线通信安全与高精度定位

基于可见光通信与定位融合



定位精度约为 7 cm左右

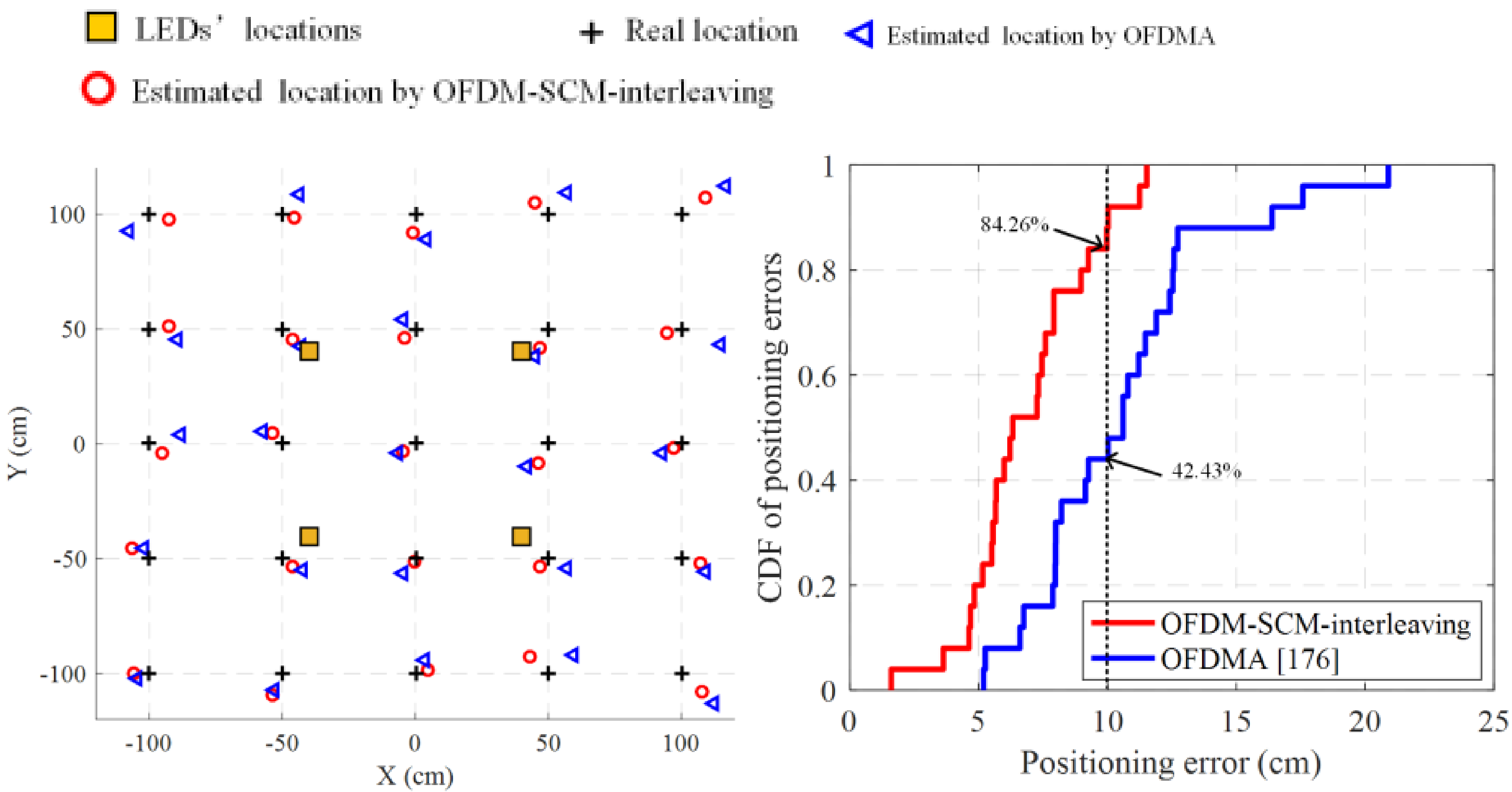
每4 m^2提供 100 Mbits/s速率

1. **H.L. Yang**, W. -D. Zhong, C. Chen, and A. Alphones, "Integration of visible light communication and positioning within 5G networks for Internet of Things", ***IEEE Network***, vol. 34, no. 5, pp. 134-140, Sept. 2020.
2. **H.L. Yang**, W.-D.. Zhong, C. Chen, A. Alphones, P.F. Du, S. Zhang, and X.Z. Xie, "Coordinated resource allocation-based integrated visible light communication and positioning systems for indoor IoT." ***IEEE Transactions on Wireless Communications***, vol. 19, no. 7, pp. 4671-4684, July 2020.

实验演示

1. **H.L. Yang**, W. -D. Zhong, C. Chen, and A. Alphones, "Integration of visible light communication and positioning within 5G networks for Internet of Things", ***IEEE Network***, vol. 34, no. 5, pp. 134-140, Sept. 2020.
2. **H.L. Yang**, W.-D.. Zhong, C. Chen, A. Alphones, P.F. Du, S. Zhang, and X.Z. Xie, "Coordinated resource allocation-based integrated visible light communication and positioning systems for indoor IoT." ***IEEE Transactions on Wireless Communications***, vol. 19, no. 7, pp. 4671-4684, July 2020.

定位实验结果



本人提出的方案与文献[12]提出发方案的定位误差是6.88 cm and 10.56 cm.

[12] B. Lin, X. Tang, Z. Ghassemlooy, C. Lin, and Y. Li, "Experimental Demonstration of an Indoor VLC Positioning System Based on OFDMA," IEEE Photon. J., vol. 9, no. 2, Apr. 2017, pp. 1-9..

通信实验结果

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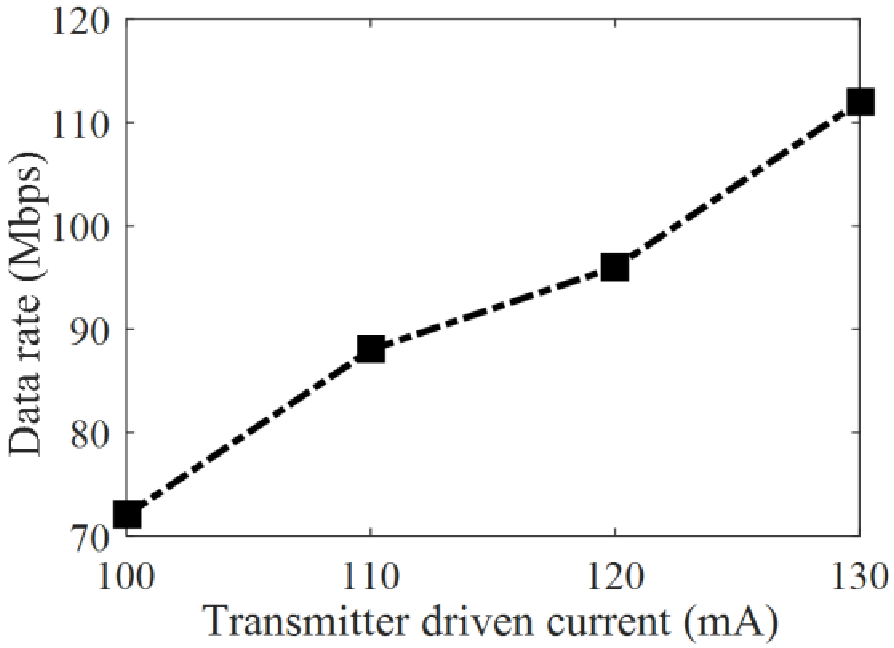
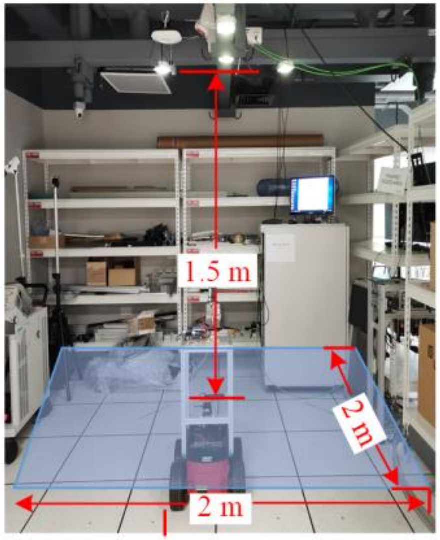


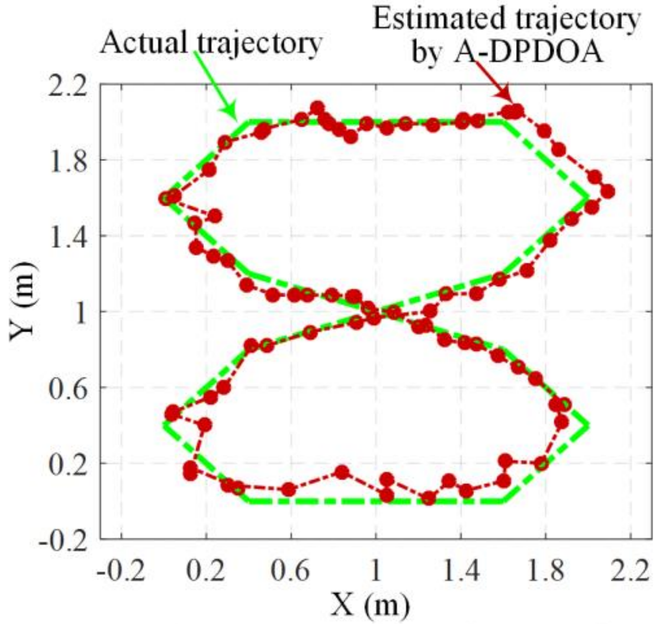
在4平方米区域，可提供约达到110Mbps的速率。

[12] B. Lin, X. Tang, Z. Ghassemlooy, C. Lin, and Y. Li, “Experimental Demonstration of an Indoor VLC Positioning System Based on OFDMA,” IEEE Photon. J., vol. 9, no. 2, Apr. 2017, pp. 1-9..

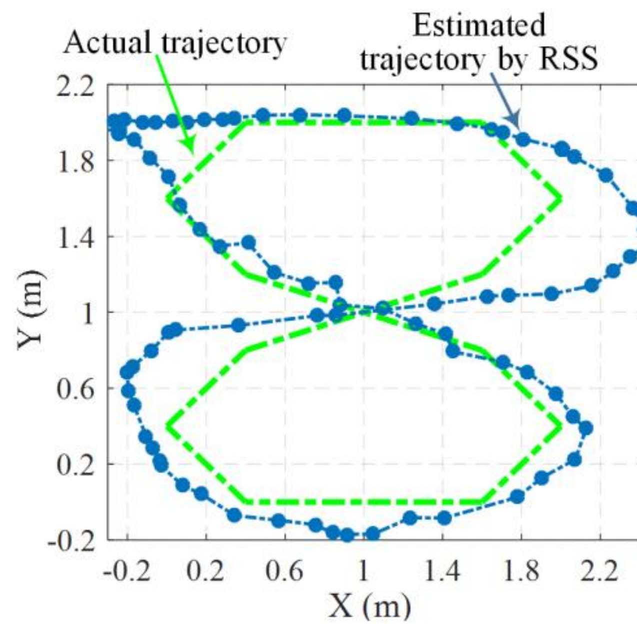
移动跟踪实验结果



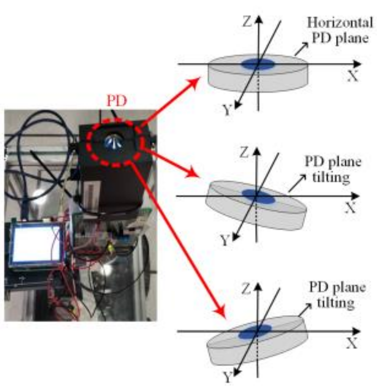
(a) 2D tracking scenario at the vertical height of 1.5 m



(b) Estimated trajectories of A-DPDOA



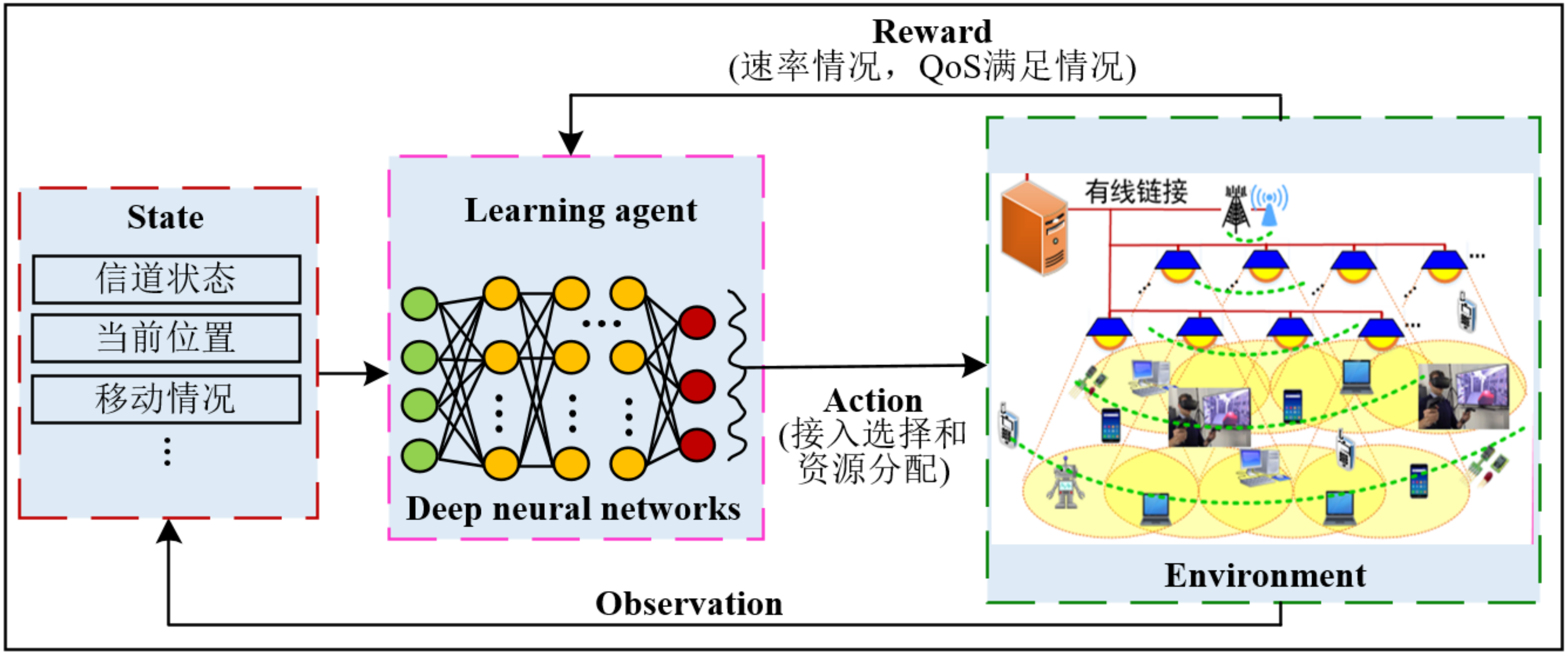
(c) Estimated trajectories of RSS



A-DPDOA和RSS算法，移动物的跟踪精度是 **9.8 cm and 43.5 cm**. 另外，他们的最大跟踪误差是**15.4 cm and 51.0 cm**.

1. **H.L. Yang**, A. Alphones, W. Zhong, C. Chen, and X.Z. Xie., "Learning-based energy-efficient resource management by heterogeneous RF/VLC for ultra-reliable low-latency industrial IoT networks" ***IEEE Transactions on Industrial Informatics***, vol. 16, no. 8, pp. 5565-5576, Aug. 2020.
2. **H.L. Yang**, C. Chen, W.-D. Zhong, and A. Alphones, "Joint precoder and equalizer design for multi-user multi-cell MIMO VLC systems," ***IEEE Transactions on Vehicular Technology***, vol. 67, no. 12, pp. 11354-11364, Dec. 2018.

基于强化学习的射频与可见光通信优化



可以借用强化学习算法对射频与可见光通信网络中的资源进行管理，例如AP接入、频谱分配和功率分配。

基于强化学习的射频与可见光通信优化

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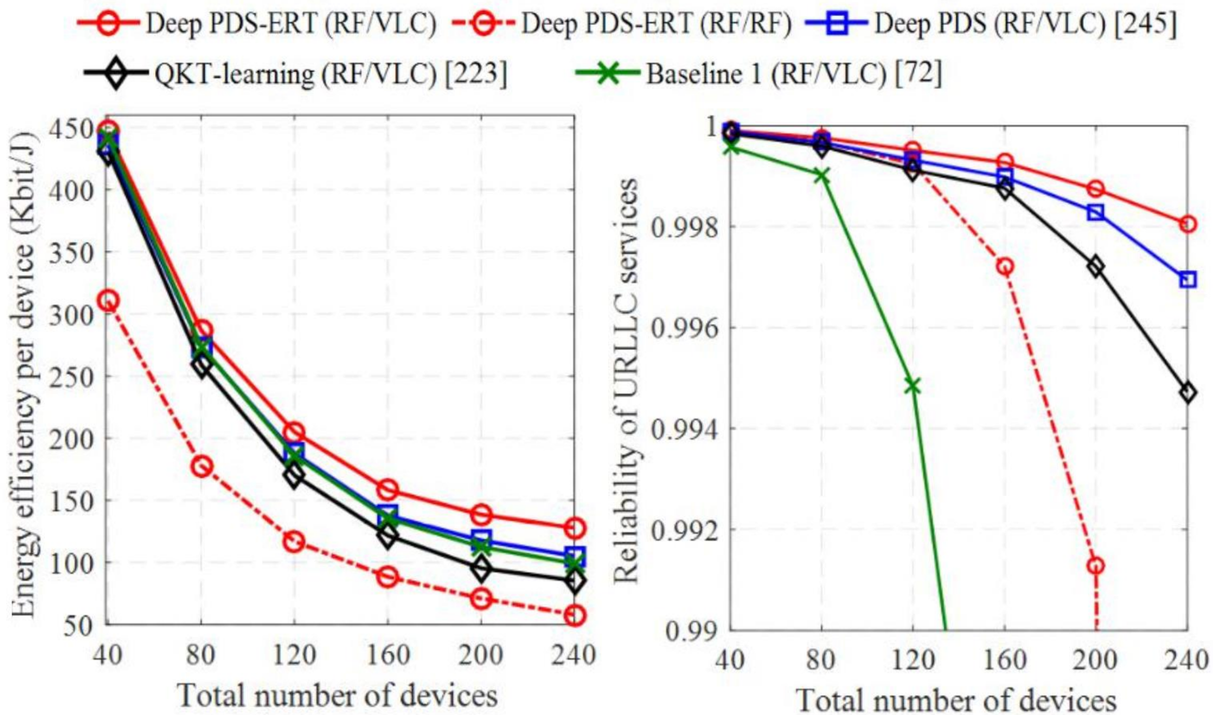
由于网络动态复杂，且业务种类繁多。提出了**改进的深度强化学习**对频谱资源，网络选择和信道接入进行管理。

缺点：环境变化大点，模型立马失效，重新训练



相比于其他算法，深度强化学习可提升网络性能约**20%到40%左右**。

1. **H.L. Yang**, A. Alphones, W. Zhong, C. Chen, and X.Z. Xie., "Learning-based energy-efficient resource management by heterogeneous RF/VLC for ultra-reliable low-latency industrial IoT networks" ***IEEE Transactions on Industrial Informatics***, vol. 16, no. 8, pp. 5565-5576, Aug. 2020.
2. **H.L. Yang**, C. Chen, W.-D. Zhong, and A. Alphones, "Joint precoder and equalizer design for multi-user multi-cell MIMO VLC systems," ***IEEE Transactions on Vehicular Technology***, vol. 67, no. 12, pp. 11354-11364, Dec. 2018.

基于强化学习的通信和定位优化

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在可见光通信与定位融合系统中，如何分配功率资源给通信和定位信号尤为重要。另外又要考虑到用户通信速率和定位精度的需求。

可以借用深度强化学习（演员评论家），actor critic，来训练优化功率与频谱资源。

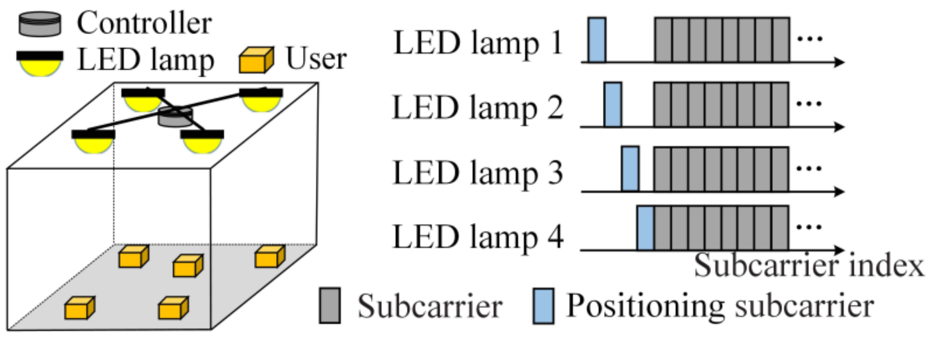
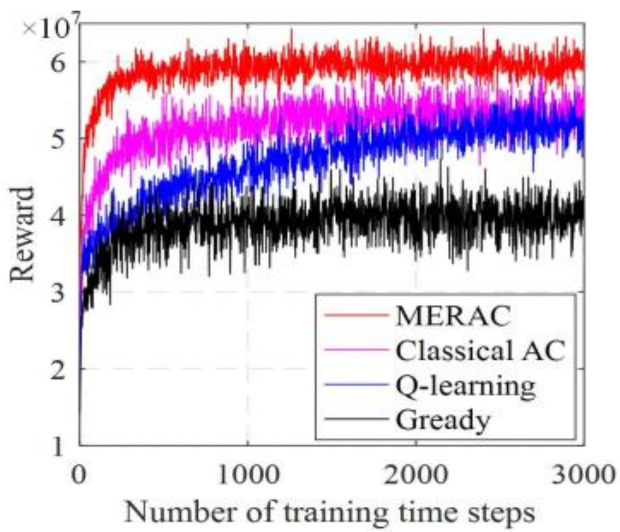


Fig. 1. An indoor multi-user integrated VLCP system.



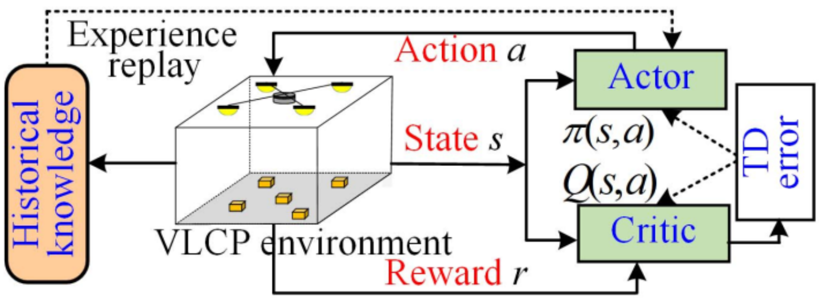


Fig. 2. MERAC learning framework for integrated VLCP systems.

Helin Yang, Pengfei Du, Wen-De. Zhong, Chen Chen, Arokiaswami Alphones, and Sheng Zhang, “Reinforcement learning based intelligent resource allocation for integrated VLCP systems,” ***IEEE Wireless Communication Letters***, vol. 8, no. 4, pp. 1204-1207, Aug. 2019.

基于深度学习的室内定位

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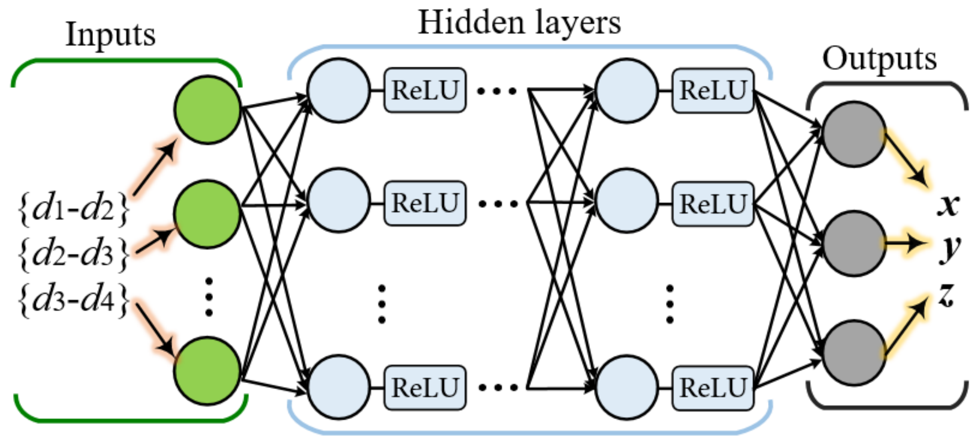
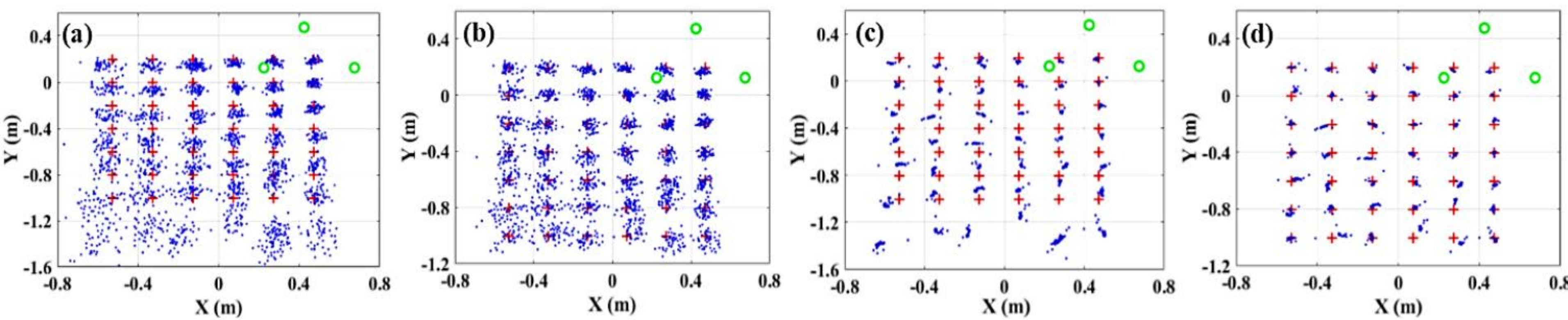
基于深度学习（NN）的定位，通过测量好的距离差（d_{i+1}-d_i）输入深度学校输入层，移动端坐标为输出层。

主要是克服LED灯材料不均匀产生的定位漂移的问题。



基于深度学习的定位，通过测量好的距离差（d_{i+1}-d_i）输入深度学习的输入层，移动端的坐标作为输出层。卡尔曼滤波（KF）可以提高定位精度。

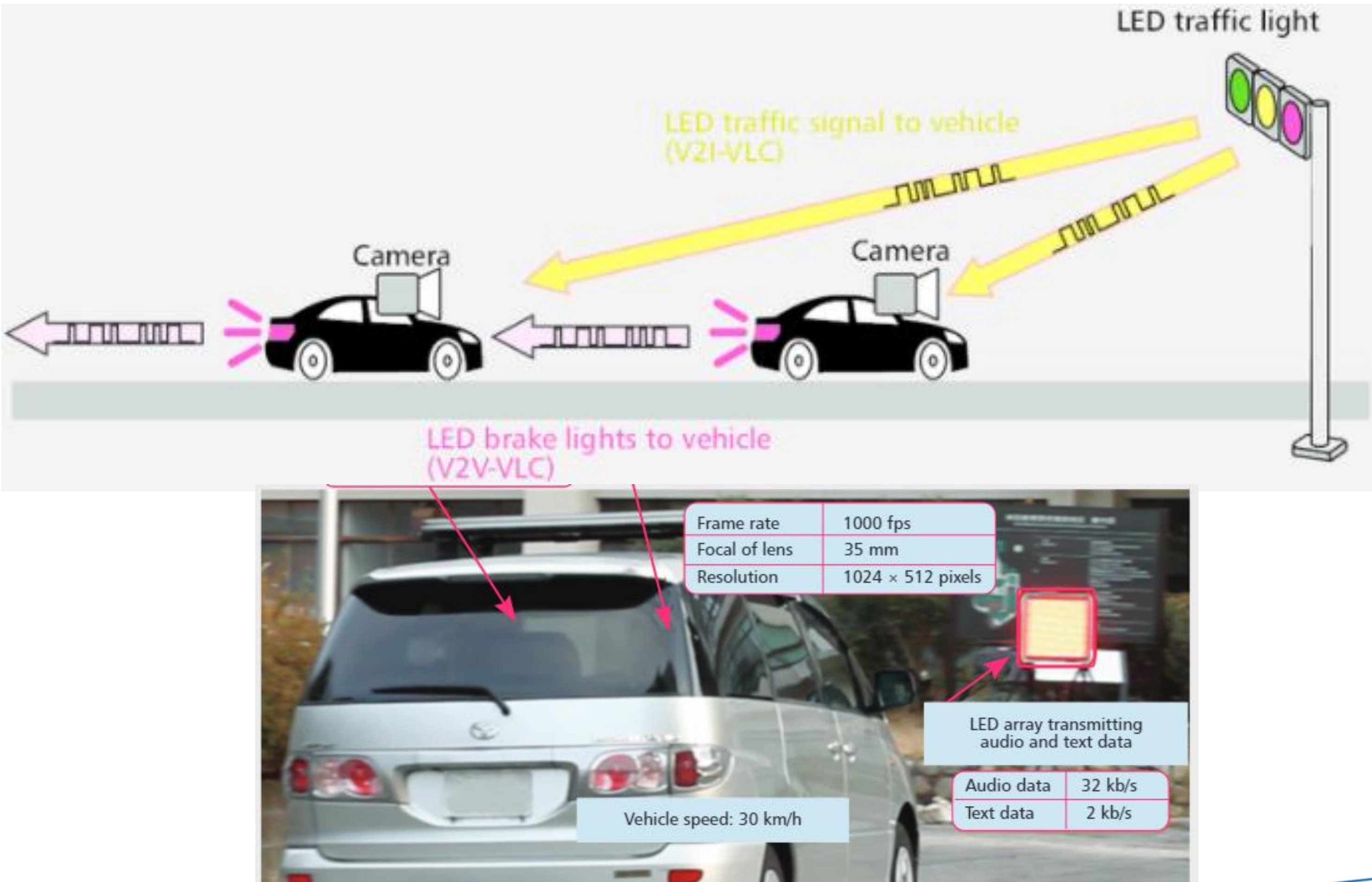


图（a）定位未用NN和KF， 图（b）只用NN定位，图（c）只用KF定位，图（d）用NN和KF定位.

1. S. Zhang, W.-D. Zhong, P. Du, and C. Chen, “Experimental demonstration of indoor sub-decimeter accuracy VLP system using differential PDOA,” ***IEEE Photonics Technology Letters***, vol. 30, no. 19, pp. 1703-1706, 2018.

可见光通信与定位发展趋势

1. 基于可见光的车载通信。基于发光二极管的可见光通信技术由于其具有安全、无电磁干扰与无需频谱申请的特点被视作车联网中一种行之有效的通信方式。



T. Yamazato et al., "Image-sensor-based visible light communication for automotive applications," in IEEE Communications Magazine, vol. 52, no. 7, pp. 88-97, July 2014

可见光通信与定位发展趋势

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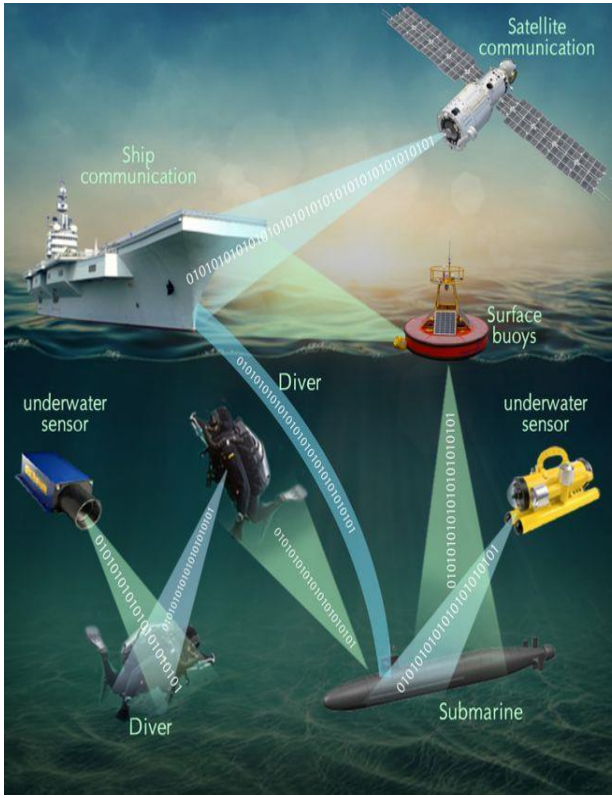
2.基于可见光的水下光通信。利用可见光在水下进行高速无线通信的装置。使用在水中衰减率较低的通用蓝色LED,在水下实现了最大50Mbit/秒的通信速度。

UWC 技术	优点	局限性
声波	• 使用最广泛的UWC技术 • 通信距离长达20公里	• 数据传输速率低（kbps级别） • 严重的通信延时 • 收发器的体积大、成本高、耗能大 • 对海洋生物有害
射频(RF)	• 跨越空气/水边界的相对平滑过渡 • 更耐水湍流和浊度 • 宽松的指向要求 • 近距离的中等数据传输速率（高达100 Mbps）	• 通信距离短 • 收发器的体积大、成本高、耗能大
光波	• 超高数据传输速率（高达Gbps） • 无传输延迟 • 收发器的低成本、体积小	• 不能轻易跨越水/空气边界 • 水下吸收和散射严重 • 通信距离中等（几十米）



https://blog.csdn.net/polyhedronx/article/details/82729766

可见光通信与定位发展趋势

3. 基于可见光的室内通信与定位。在工业中，例如工厂中，可以利用可见光通信和定位为机器人提供通信与导航。同时通信安全性高。

在AR/VR环境中，可以利用可见光通信和定位为AR/VR头盔提供通信与定位。同时提供高速通信。

https://zhuanlan.zhihu.com/p/335674444

结尾

谢谢！

请专家提问与讨论