

Visible Light Communication: An Introduction

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Outline

- Problem Formulation
- Related Work
- Idea
- Question and Answer

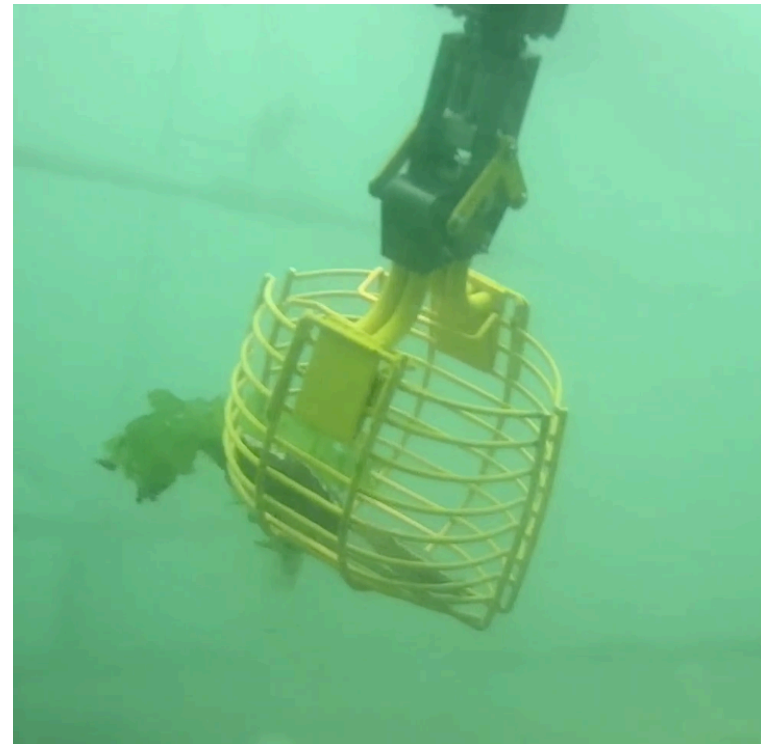
Problem Formulation

- High demand for underwater communication
- Worker: Exchanging work progress



Problem Formulation

- High demand for underwater communication
 - Workers: Exchanging work progress
 - Machine: Knowing location and direction



Problem Formulation

- Gesture, Pipeline
 - Short distance, less information
- Wired Cable
 - Limited by complex underwater geography
- Wi-Fi
 - Extremely strong fading (transmission distance: around 0.7 m)

Where light can reach, it can communicate.

–Visible Light Communication

Visible Light Communication

- Using visible light with the frequency between 400 and 800 THz (780-375 nm)
- Speed: 50 Gbps by the end of 2015
- Range: Up to 2 km (low rate)
- Components: Sensors (photodiodes or cameras) and Light Sources.

Hardware

- Transmitter
 - LED
- Receiver
 - Photodiode: BPW34, PD333, BPV10, etc.
 - Camera: Phone
- OpenVLC: Entire prototype costs around 200-300 yuan (\$30)

A Supplement, Not a Substitute

- Advantages
 - Fast
 - Cheap
- Disadvantages
 - Downwards only
 - Dying in the sun
 - Susceptible to interference

Related Work

- Xinyu Zhang, University of California San Diego.
 - Indoor Localization (Mobicom'17, Mobisys'17, Mobicom'16)
 - Privacy Protection (Mobicom'17)
- Nan Chi, Fudan University.
 - Increasing Speed
- Peking University
 - IoT Application (Mobicom'17)
- National Taiwan University, National Chiao Tung University
 - Localization (Mobisys'17)

Pulsar: Towards Ubiquitous Visible Light Localization

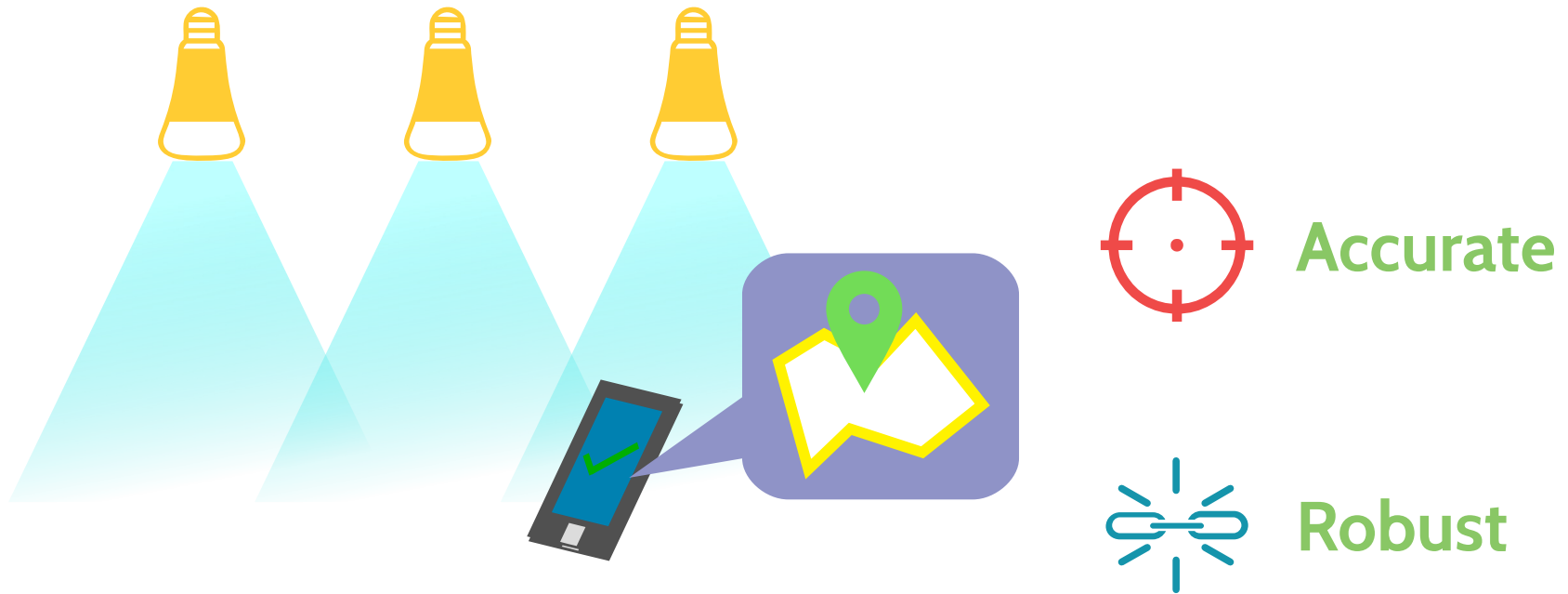
Chi Zhang, Xinyu Zhang

MobiCom'17



UC San Diego

Visible Light Localization



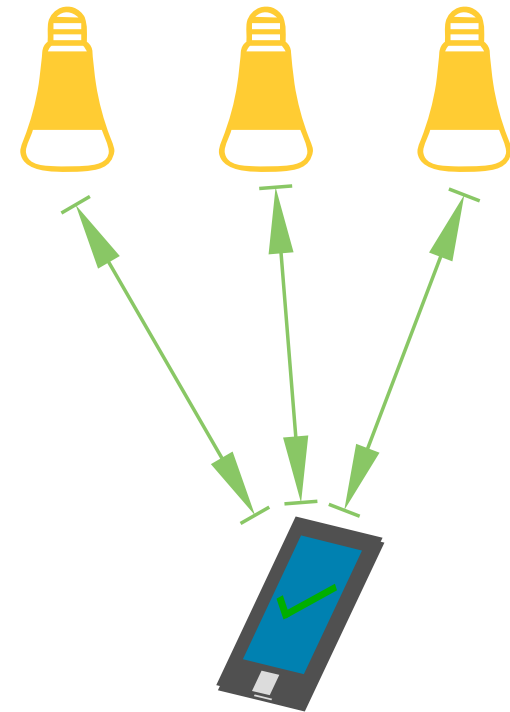
Existing Solutions

✦ **Photodiodes**

📶 **Compact**

⚡ **Low-power**

⚙️ **RSS Propagation Modeling**

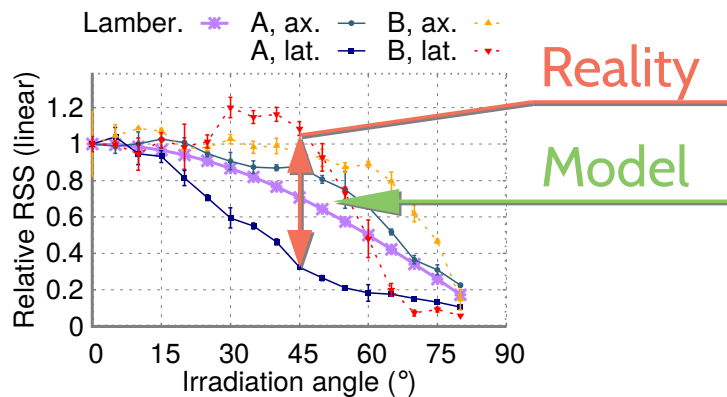


Existing Solutions

✦ Photodiodes

Channel Model is **Unrealistic** for Fixtures

Partial Shadowing and Blockage **Breaks** Model



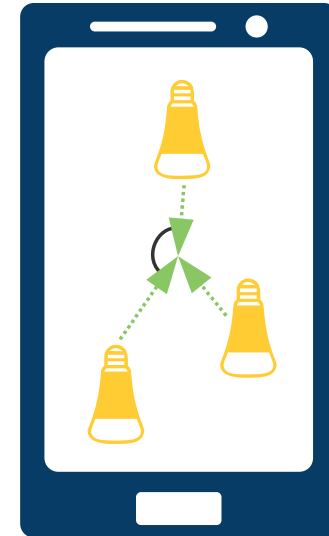
Existing Solutions

📷 Cameras

🎯 **Accurate**

🔗 **Robust**

⚙️ **Triangulation with Photogrammetry**



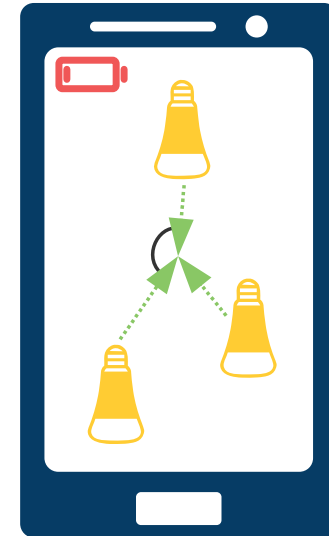
Existing Solutions

📷 Cameras

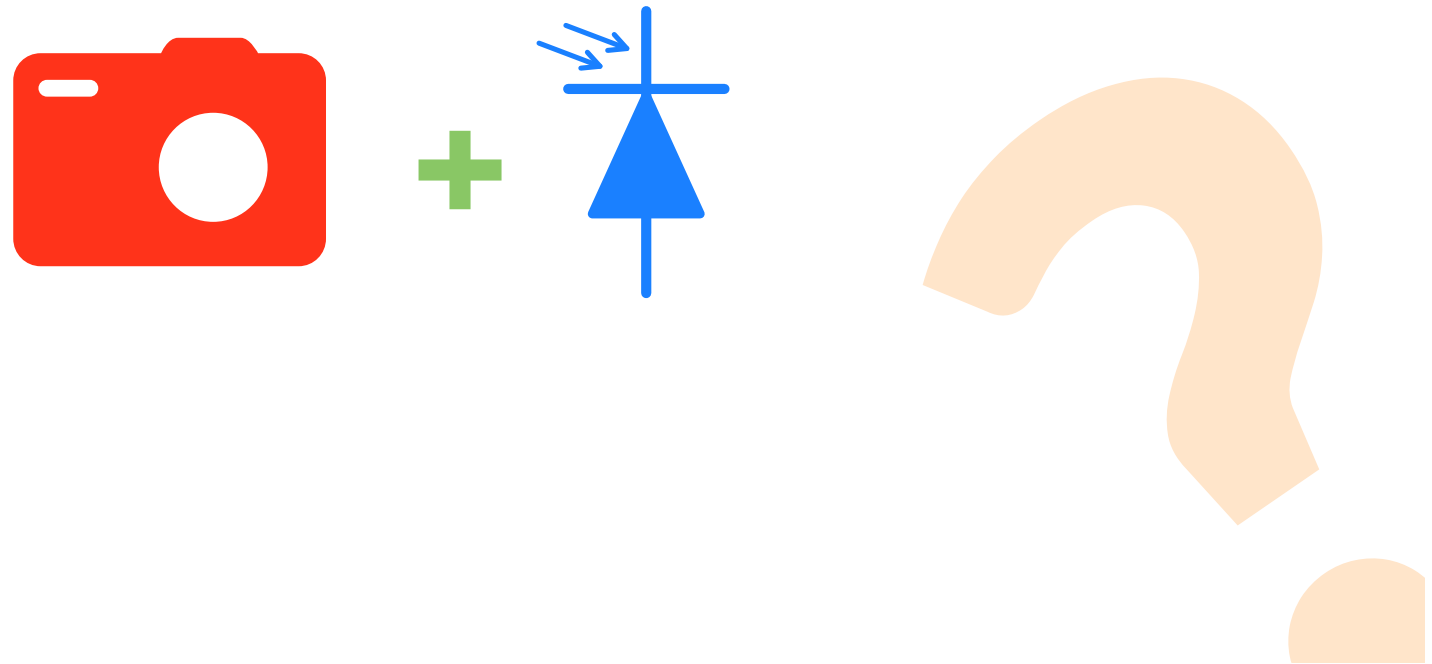
Narrow Field of View

High Energy Consumption

Long Latency



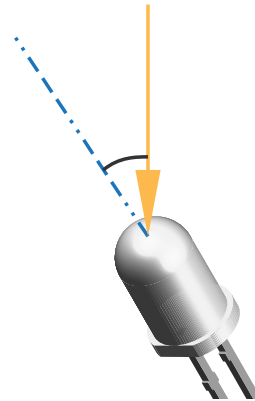
Achieve **Accurate** and **Low-power** Localization

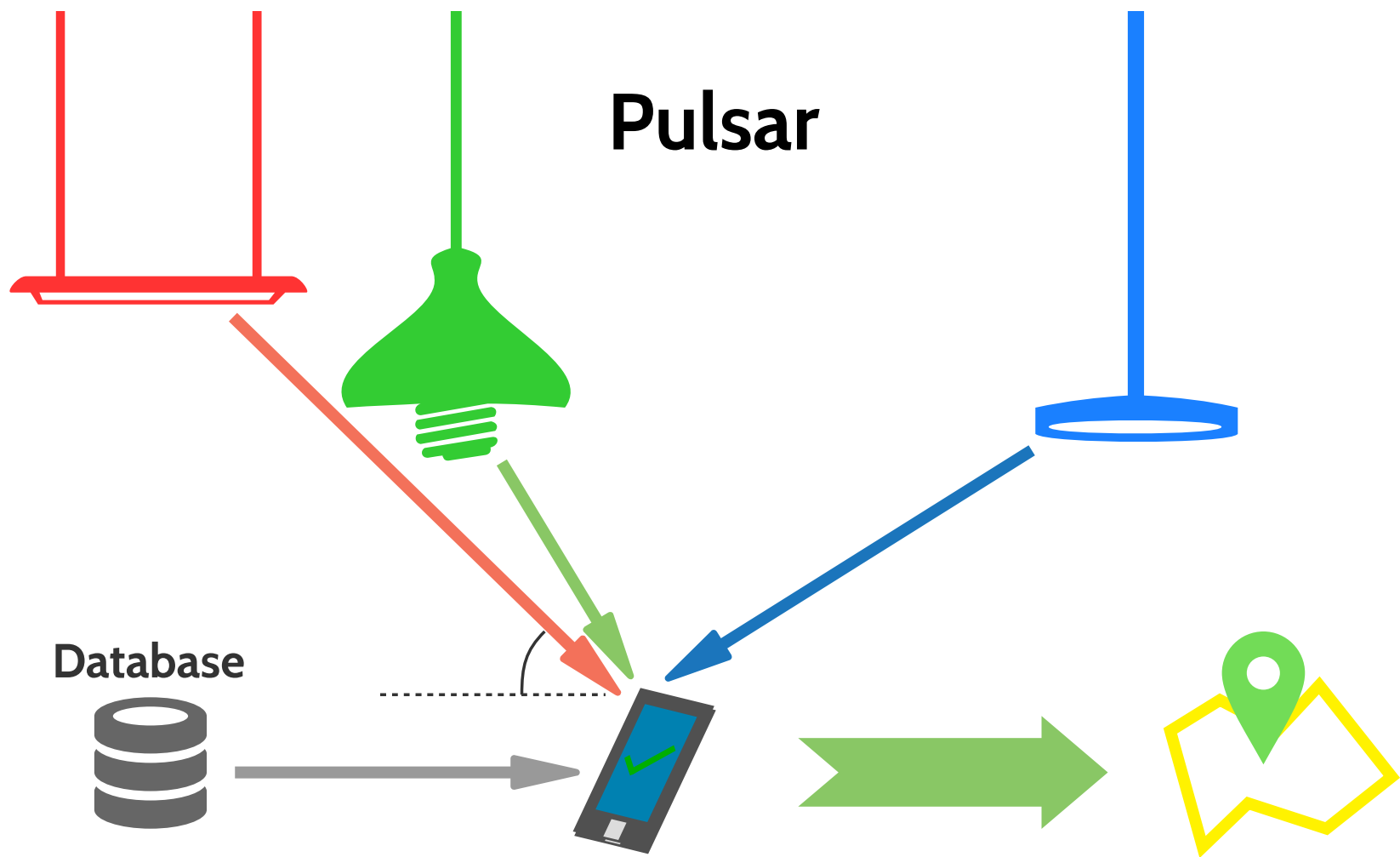


Achieve Accurate and Low-power Localization



Sense **Angle of Arrival** with **Photodiodes**

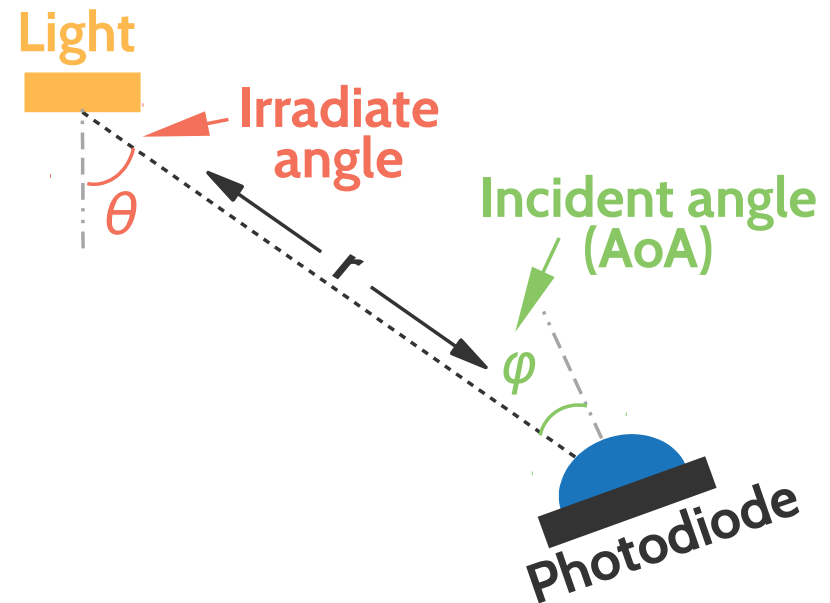




Sensing AoA with Photodiodes

⚙️ Review Channel Model

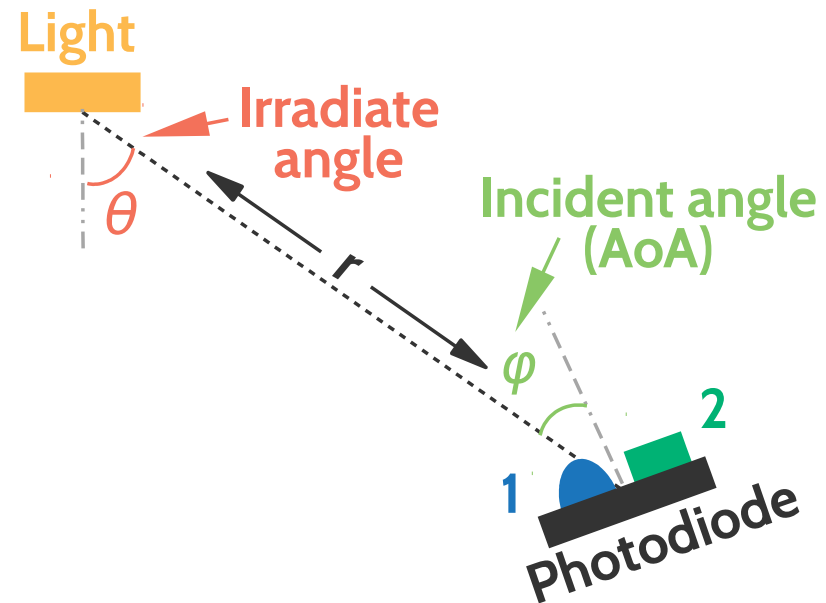
$$\text{RSS} = P_t A_t(\theta) \alpha(r) A_r(\varphi)$$



Sensing AoA with Photodiodes

⚙️ Review Channel Model

$$\text{RSS} = P_t A_t(\theta) \alpha(r) A_r(\varphi)$$
$$\text{RSS}_1 = P_t A_{t1}(\theta_1) \alpha(r_1) A_{r1}(\varphi_1)$$
$$\text{RSS}_2 = P_t A_{t2}(\theta_2) \alpha(r_2) A_{r2}(\varphi_2)$$

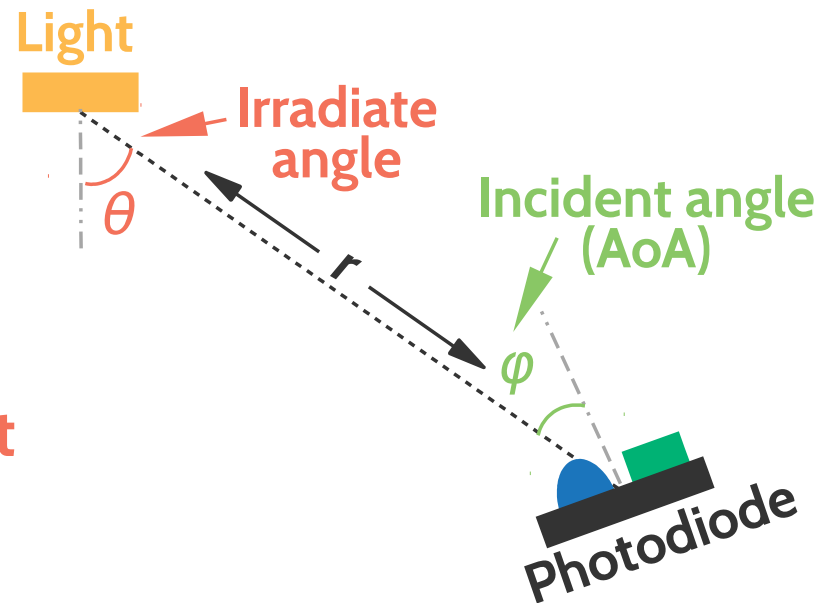


Sensing AoA with Photodiodes

⚙️ Review Channel Model

$$\begin{aligned} \text{RSS}_1 &= P_t A_{t1}(\theta_1) \alpha(r_1) A_{r1}(\varphi_1) \\ \text{RSS}_2 &= P_t A_{t2}(\theta_2) \alpha(r_2) A_{r2}(\varphi_2) \end{aligned}$$

Co-located → Same Different

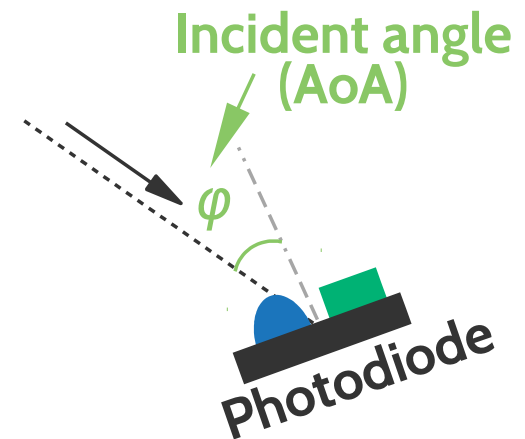


Sensing AoA with Photodiodes

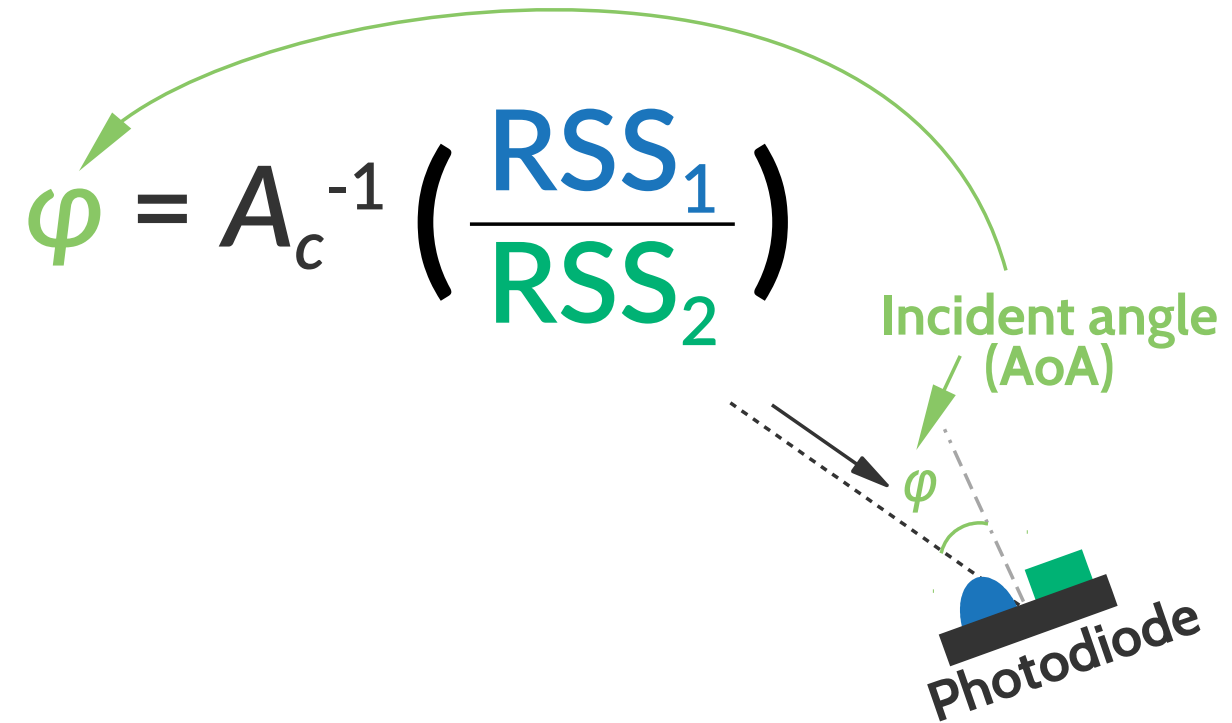
$$\frac{RSS_1}{RSS_2} = \frac{A_{r1}(\varphi_1)}{A_{r2}(\varphi_2)} = A_c(\varphi)$$

Assumptions on light are gone!

Fixed once manufactured



Sensing AoA with Photodiodes



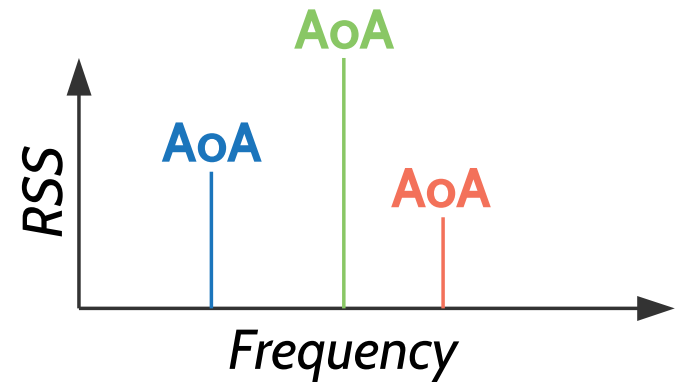
Sensing AoA with Photodiodes

$$\varphi(f) = A_c^{-1} \left[\frac{RSS_1(f)}{RSS_2(f)} \right]$$

RSS at each frequency

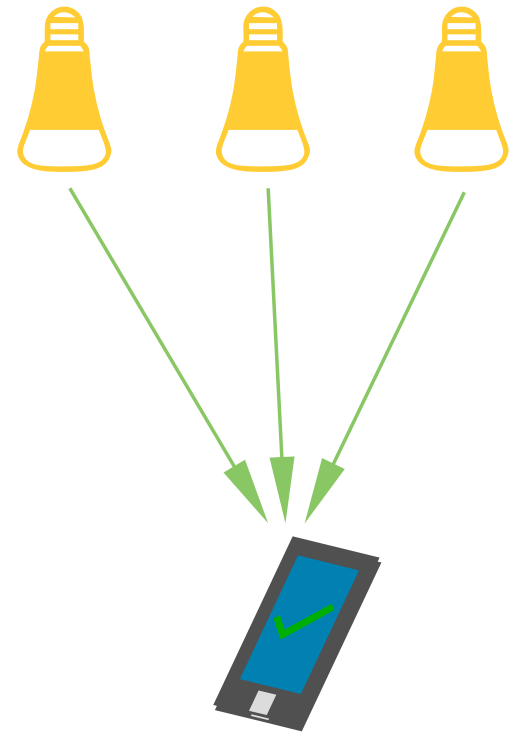


AoA at each frequency



Light Extraction

Triangulation: ≥ 3 lights required

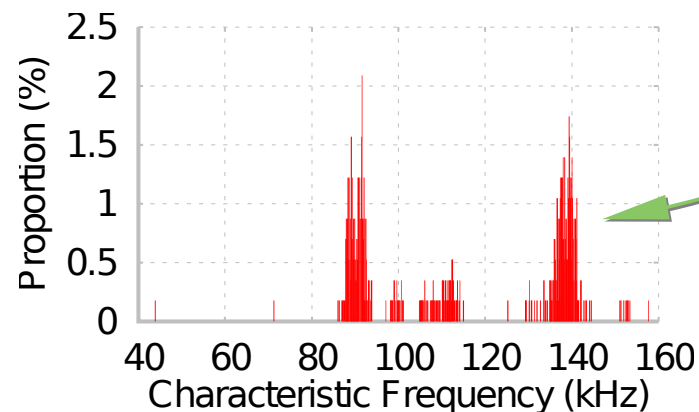


Light Extraction

Triangulation: ≥ 3 lights required

Separate from spectrum:

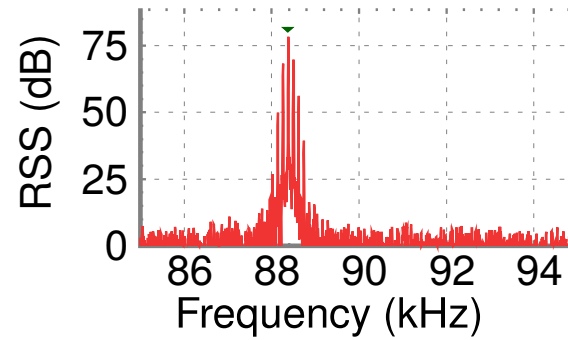
Leverage diversity in **Characteristic Frequency**



(LiTell, MobiCom'16)

Light Extraction

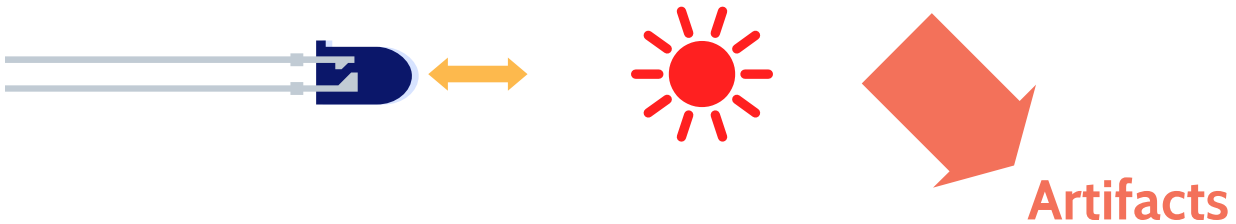
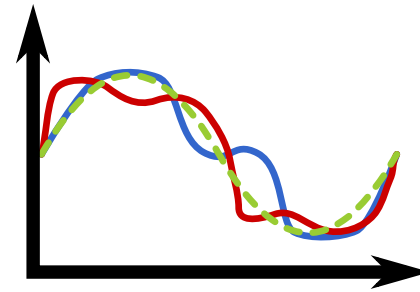
🔍 Spurious peaks!



Light Extraction

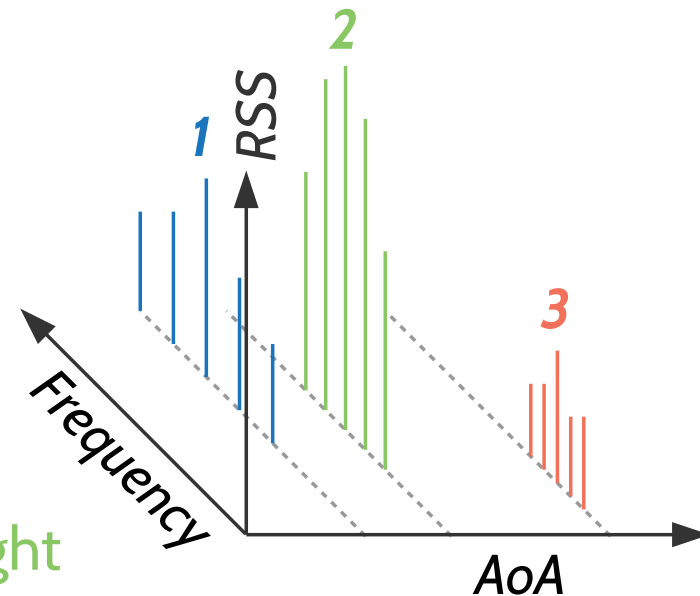
- **Causes:**

- Powerline harmonics
- User motion



Light Extraction

- **Causes:**
 - Powerline harmonics
 - User motion
- **Observe:**
 - AoA unaffected
 - Same AoA = from the Same Light



Separate by AoA Clusters

Light Identification

- **Frequency to ID:**
 - Match individual lights = **poor accuracy**



Light Identification

- Frequency to ID:
 - Match individual lights = poor accuracy
- **Observe:**
 - Correct match likely in ones with lowest freq error
 - Lights in Field-of-View are close to each other

Light Identification

- **Solution:**
 - Identify by whole group of lights
 - Each frequency = 2~3 candidate ID
 - ✓ **Tightly-packed group with low freq error**

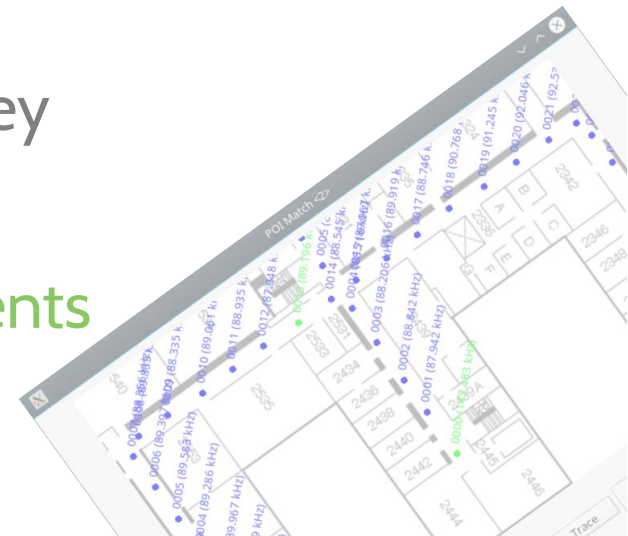
Light Registration

- **Registration is hard work**
 - Even **smart bulbs** do not know their **own locations!**

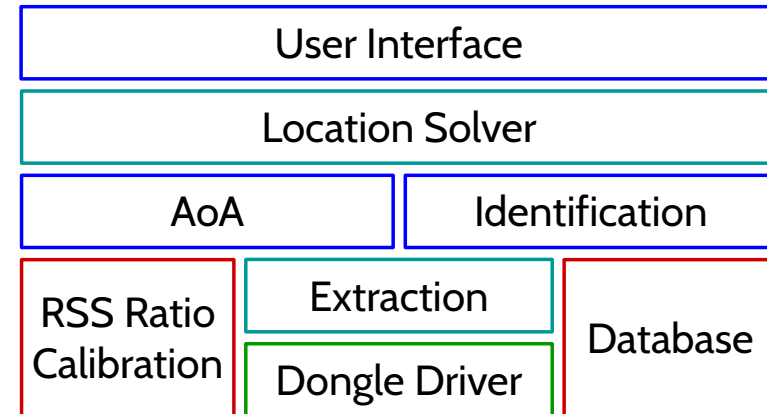
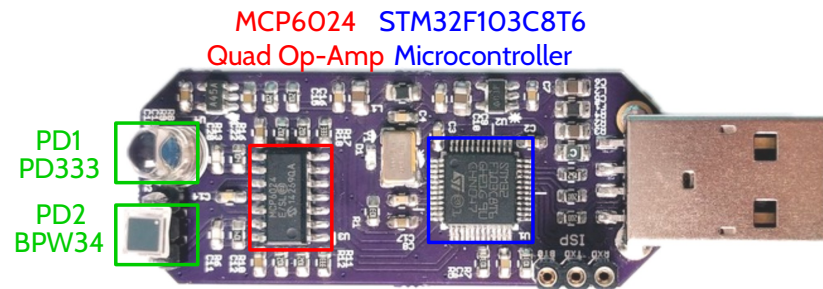


Light Registration

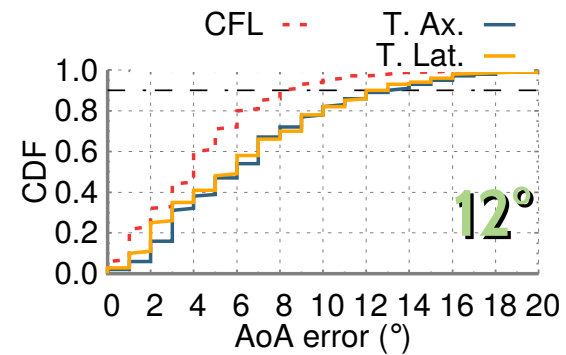
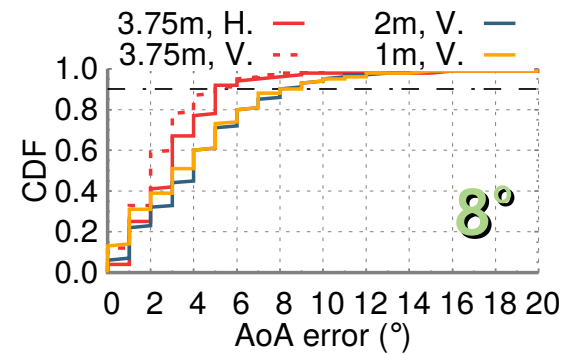
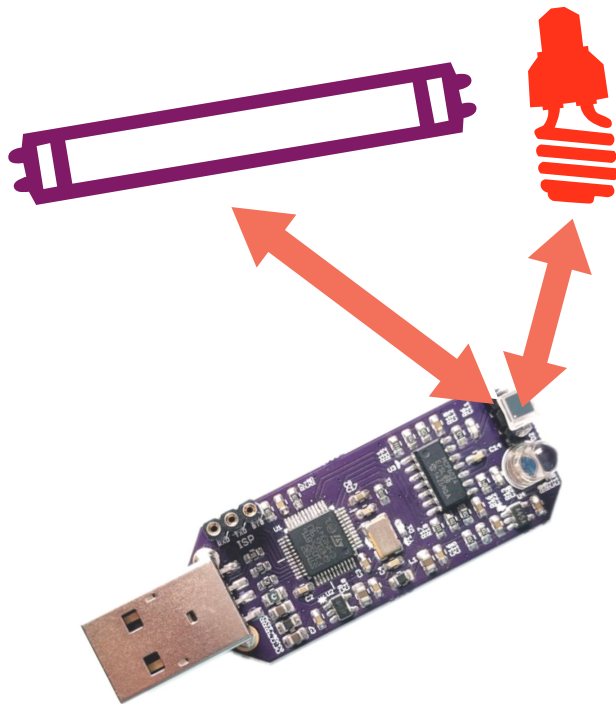
- Registration is hard work
 - Even smart bulb does not know its own location!
- **Motion tracking with Tango**
 - Record relative location during survey
 - Map to absolute location on map
- ✓ Eliminates complicated measurements



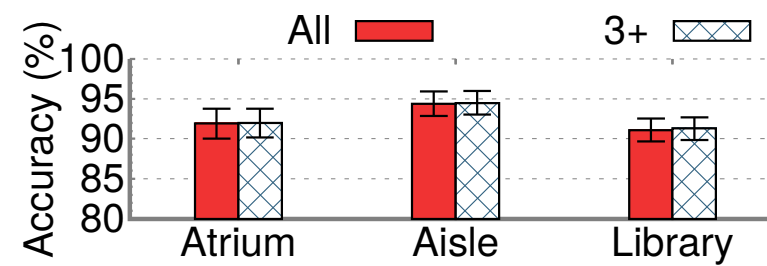
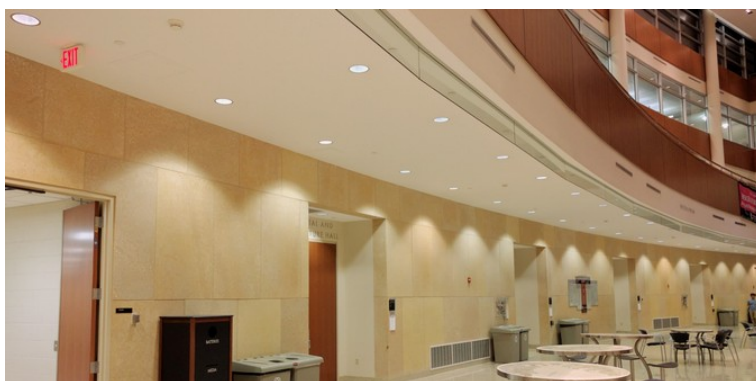
Implementation

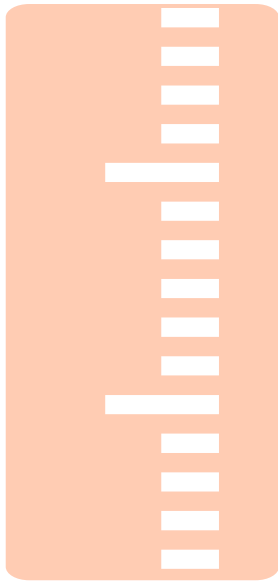


Accuracy of AoA Sensing

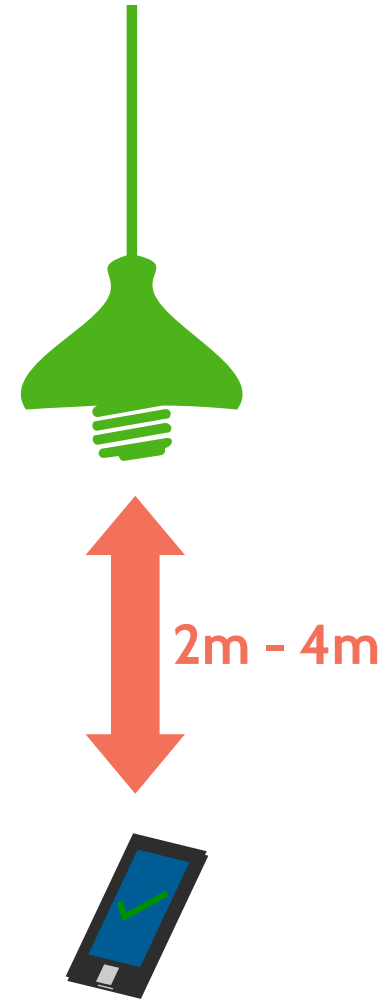
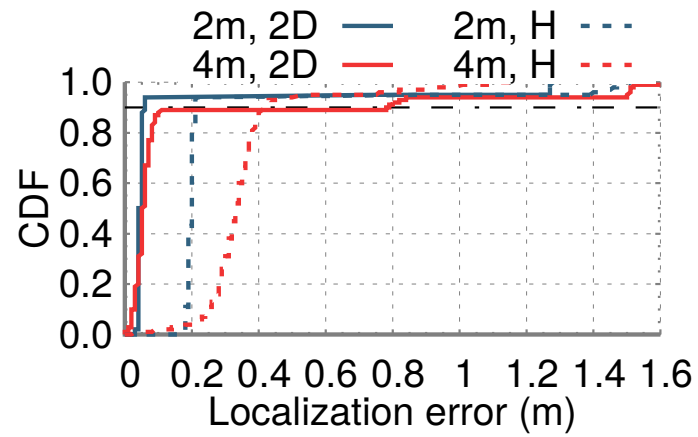


Identification

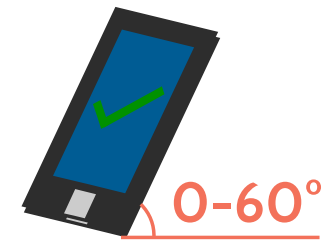
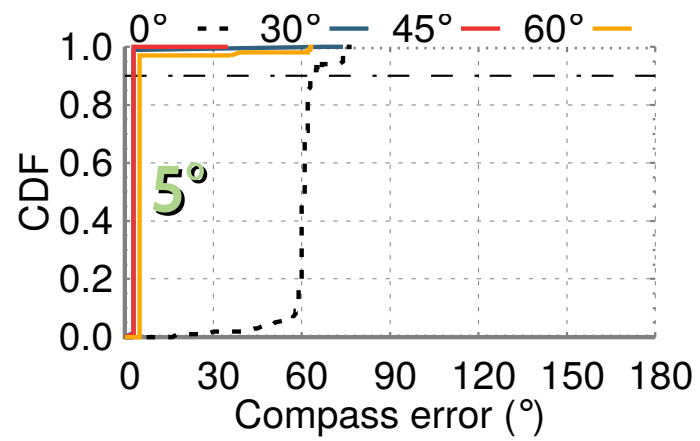




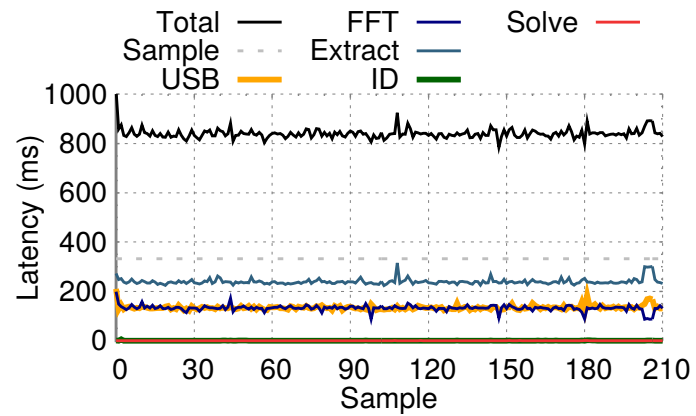
Localization



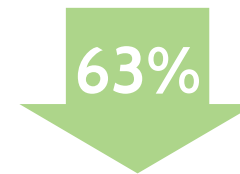
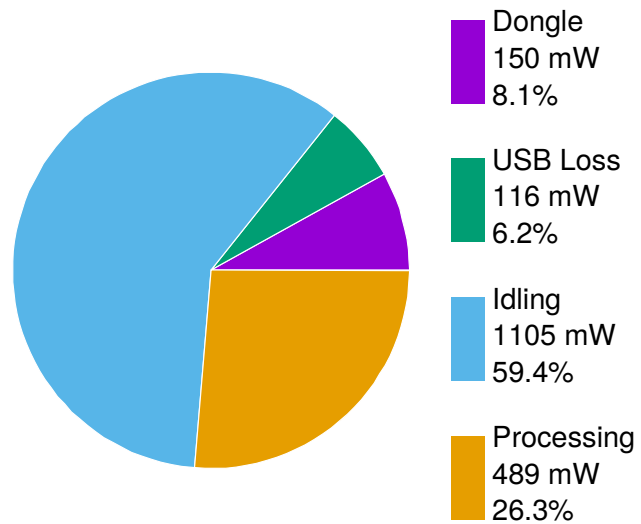
Orientation



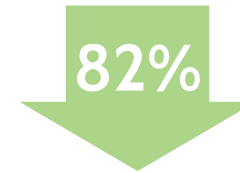
Latency



Energy



Power



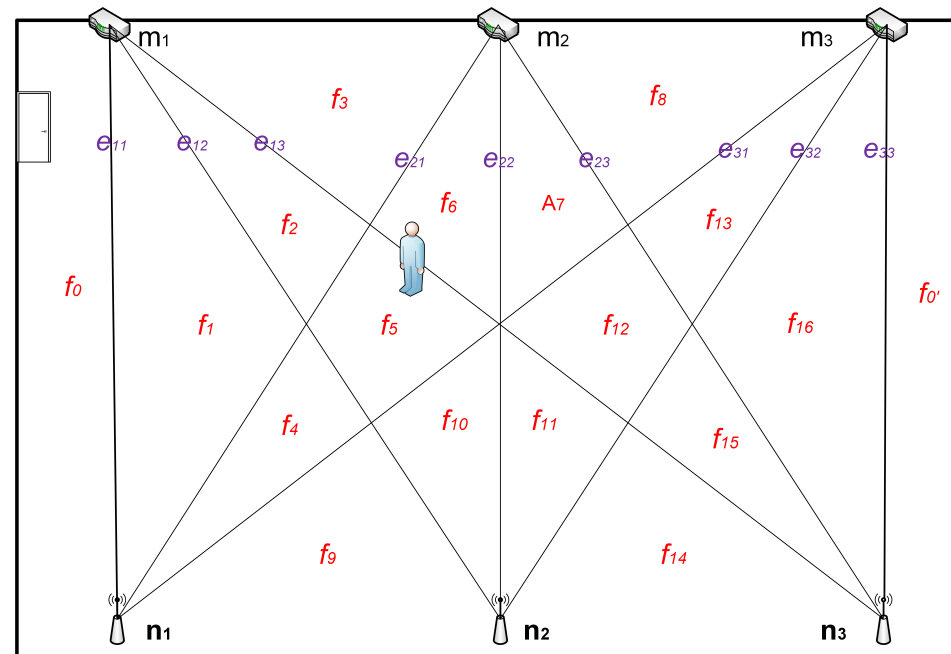
Energy per
Location

Idea

- **Localization**
- **Human activities detection**
- **Coexistence and switching problems**

Idea

- Feature of Line of Sight (LoS)
- Tracking \rightarrow Coarse-grained Localization \rightarrow Fine-grained Localization
- Simple, Fast and Energy Efficient



Question and Answer

- For this slides, please scan the QR code and visit my blog.
- For paper and slides mentioned in my talk, please visit the homepage of the author.
 - Zhang C, Zhang X. Pulsar: Towards Ubiquitous Visible Light Localization[C]//Proceedings of the 23rd Annual International Conference on Mobile Computing and Networking. ACM, 2017: 208-221.
- <http://dword1511.info/me/>

