

# Underwater Communication Using Visible Light

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# Outline

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

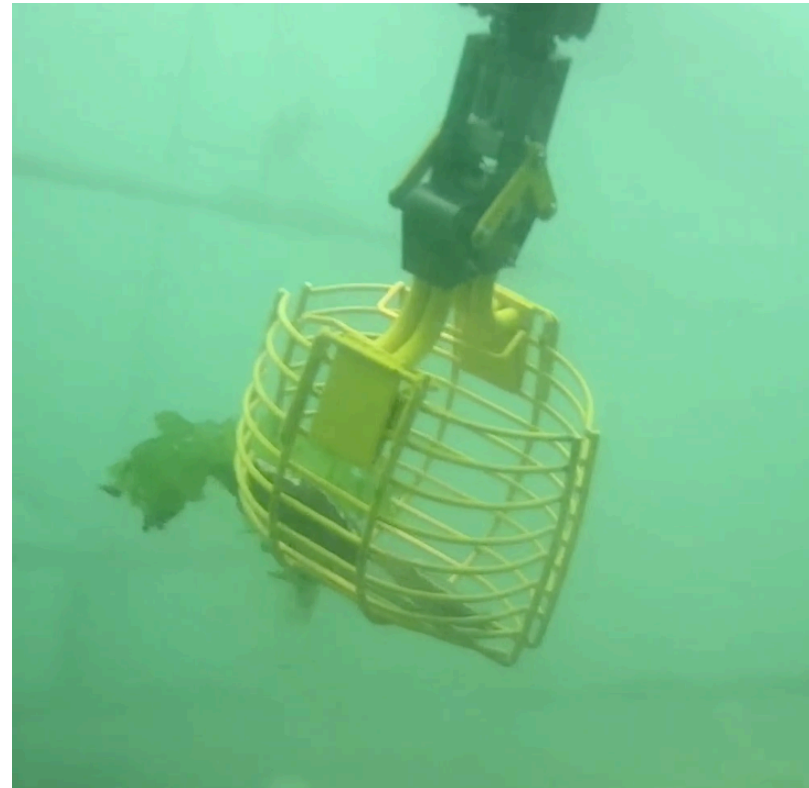
# Problem Formulation

- 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 0.7m)

***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
- Entire prototype costs around 200 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

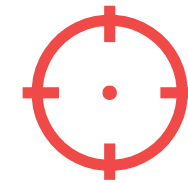
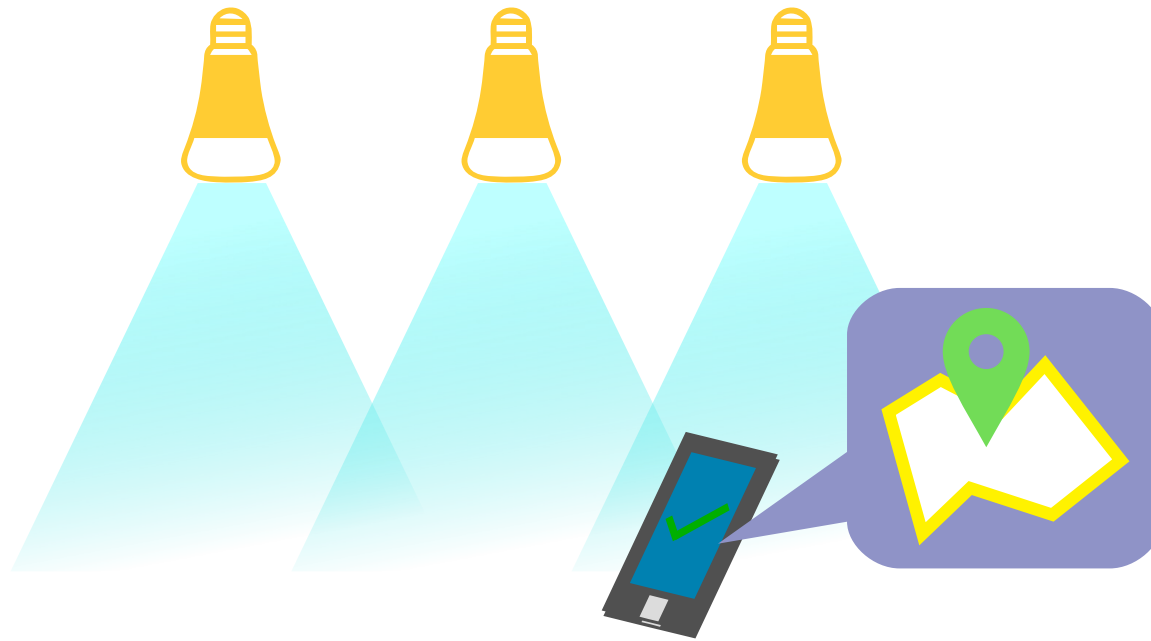
Chi Zhang, Xinyu Zhang

MobiCom'17

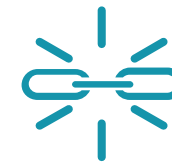


UC San Diego

# Visible Light Localization



Accurate



Robust

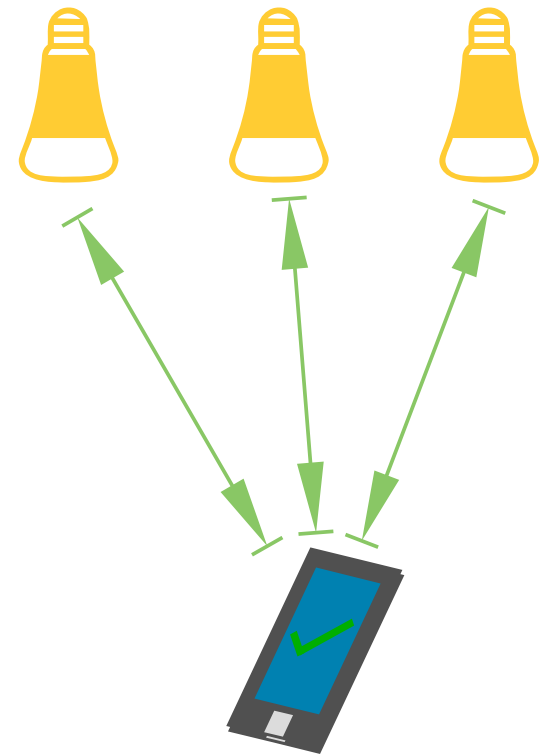
# Existing Solutions

✦ **Photodiodes**

📏 **Compact**

🔋 **Low-power**

⚙️ **RSS Propagation Modeling**

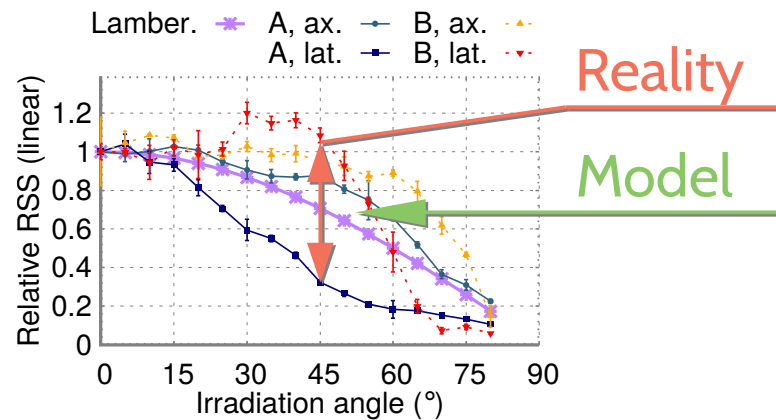


# Existing Solutions

## ✦ Photodiodes

Channel Model is **Unrealistic** for Fixtures

Partial Shadowing and Blockage **Breaks** Model



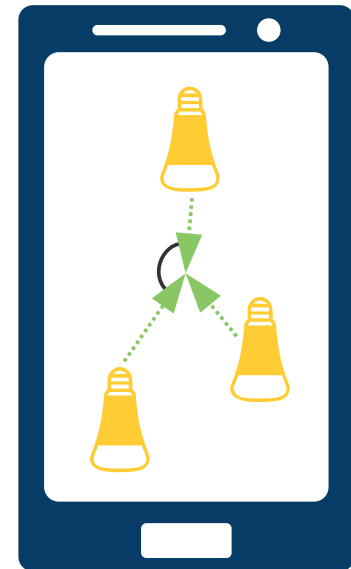
# Existing Solutions

## 📷 Cameras

🎯 **Accurate**

⚡ **Robust**

⚙️ **Triangulation with Photogrammetry**



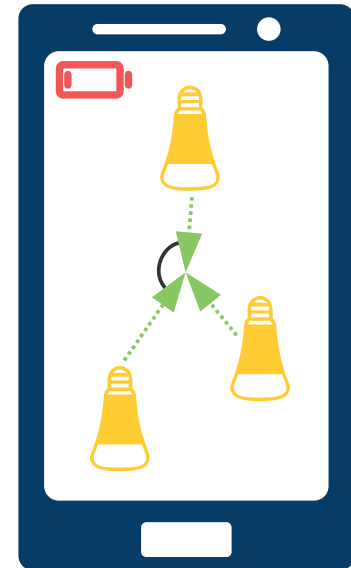
# Existing Solutions

## 📷 Cameras

**Narrow** Field of View

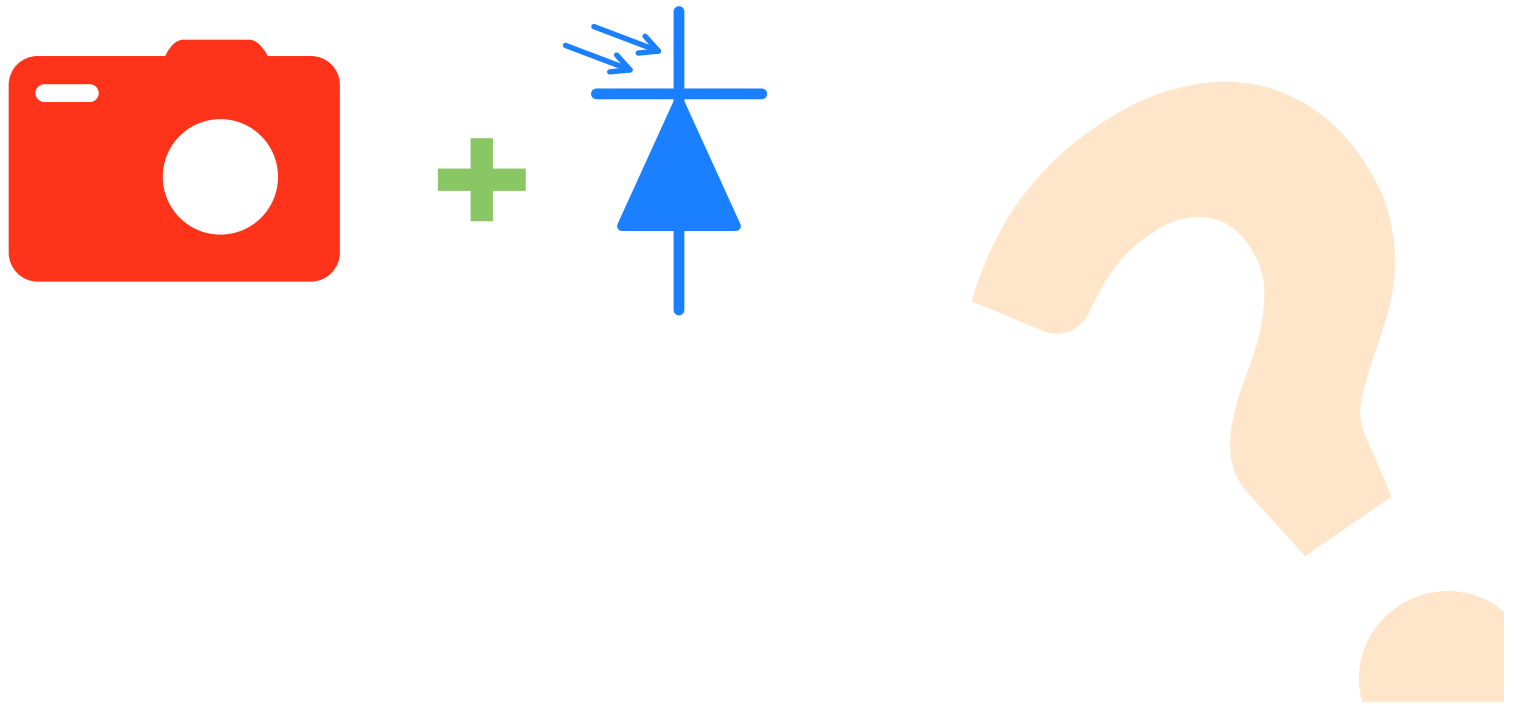
**High** Energy Consumption

**Long** Latency





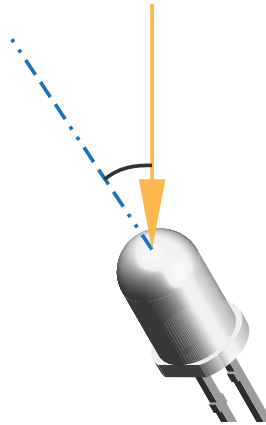
# Achieve **Accurate** and **Low-power** Localization

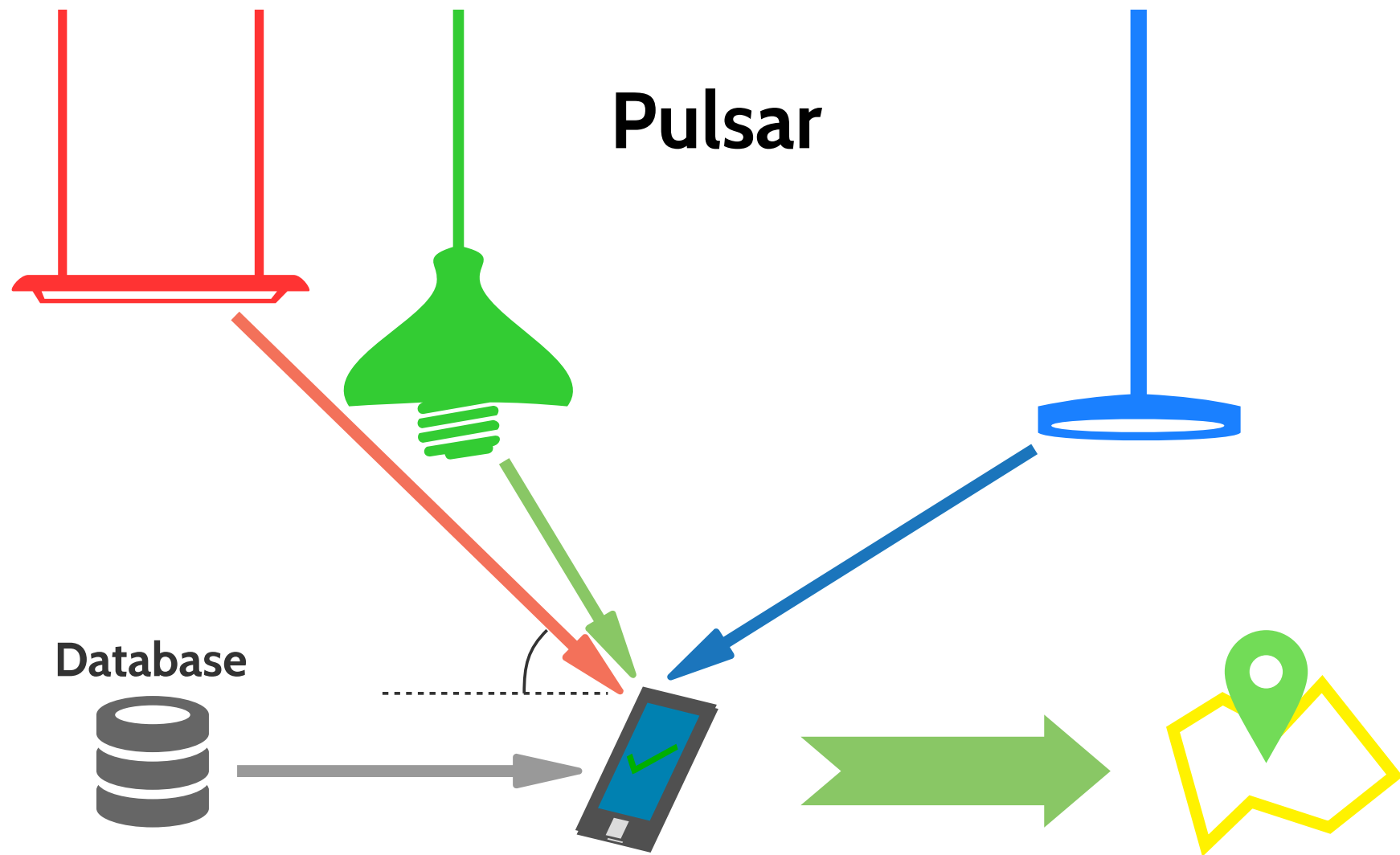


Achieve Accurate and Low-power Localization



**Sense** Angle of Arrival with Photodiodes

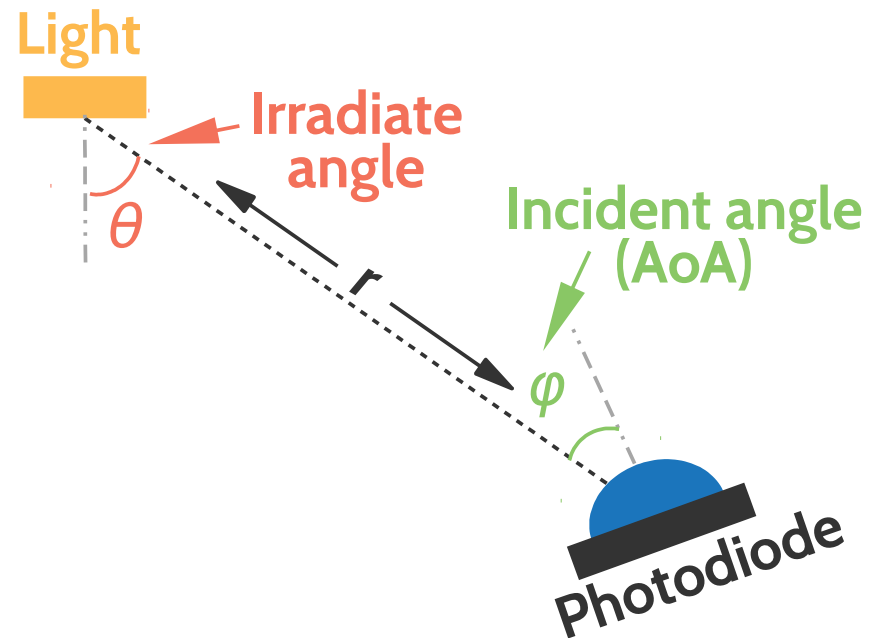




# Sensing AoA with Photodiodes

## ⚙️ Review Channel Model

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



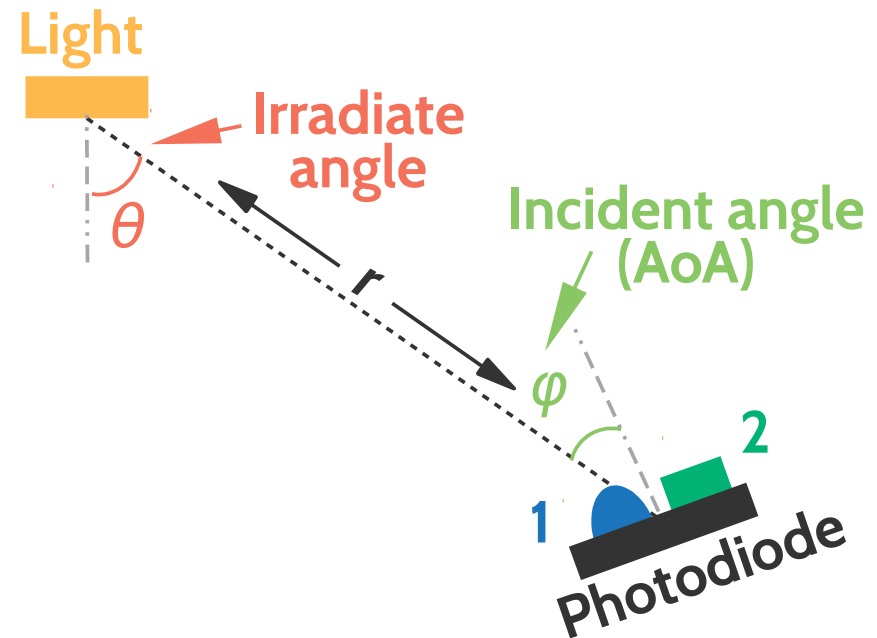
# Sensing AoA with Photodiodes

## ⚙️ Review Channel Model

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

$$\text{RSS}_1 = P_t A_{t1}(\theta_1) \alpha(r_1) A_{r1}(\varphi_1)$$

$$\text{RSS}_2 = P_t A_{t2}(\theta_2) \alpha(r_2) A_{r2}(\varphi_2)$$

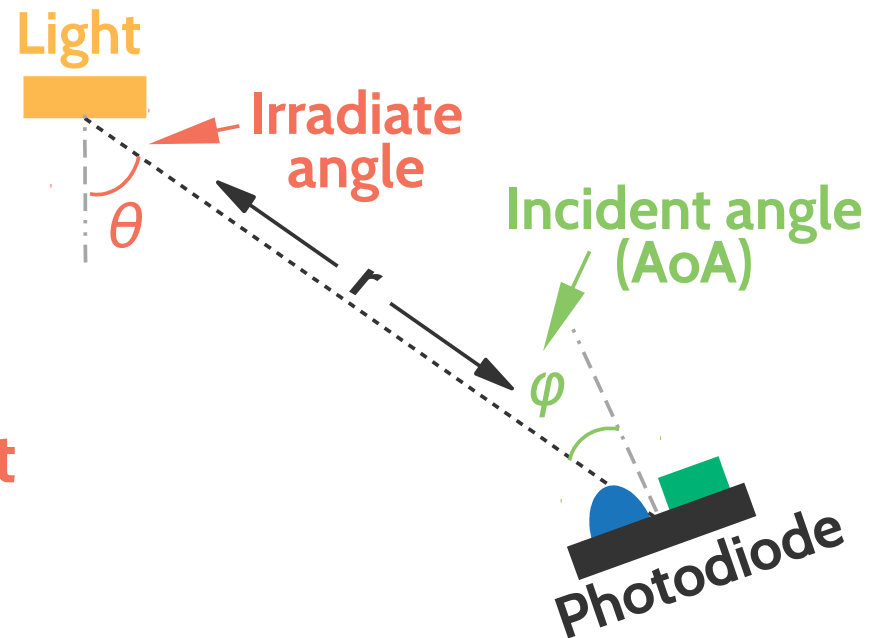


# Sensing AoA with Photodiodes

## ⚙️ 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

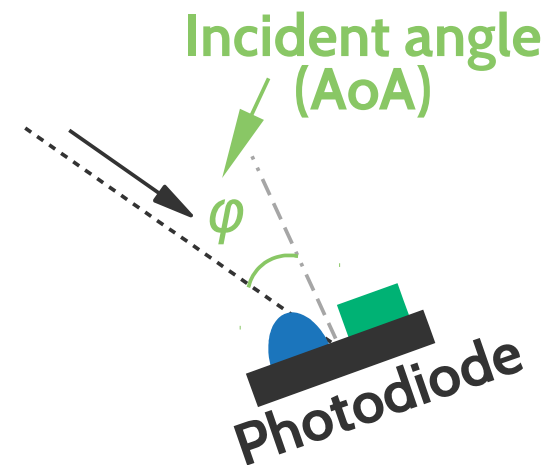


# Sensing AoA with Photodiodes

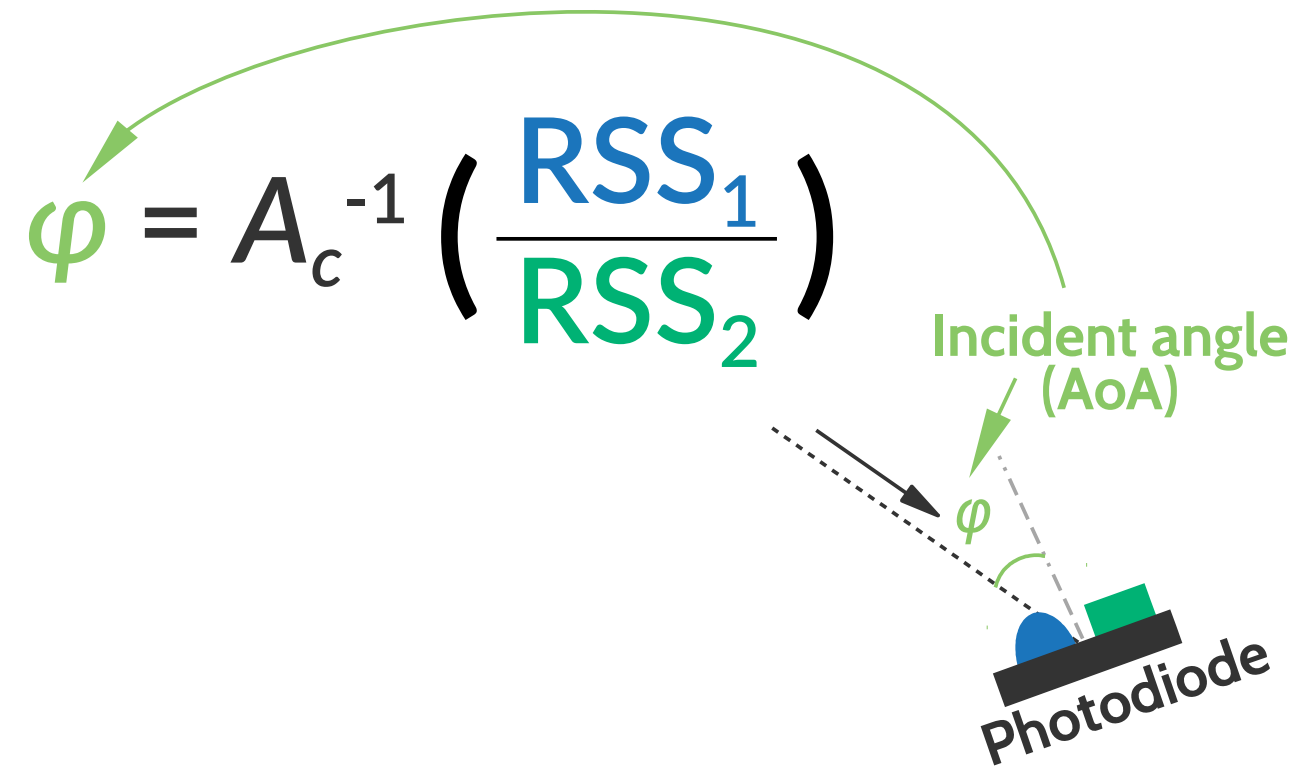
$$\frac{RSS_1}{RSS_2} = \left( \frac{A_{r1}(\varphi_1)}{A_{r2}(\varphi_2)} \right) = A_c(\varphi)$$

Assumptions on light are gone!

Fixed once manufactured



# Sensing AoA with Photodiodes





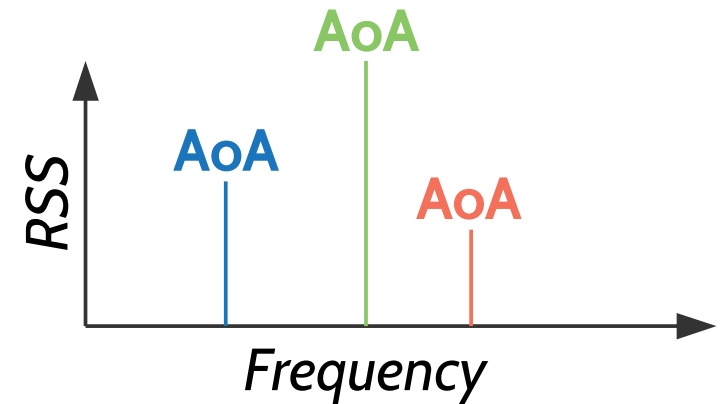
# Sensing AoA with Photodiodes

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

RSS at each frequency

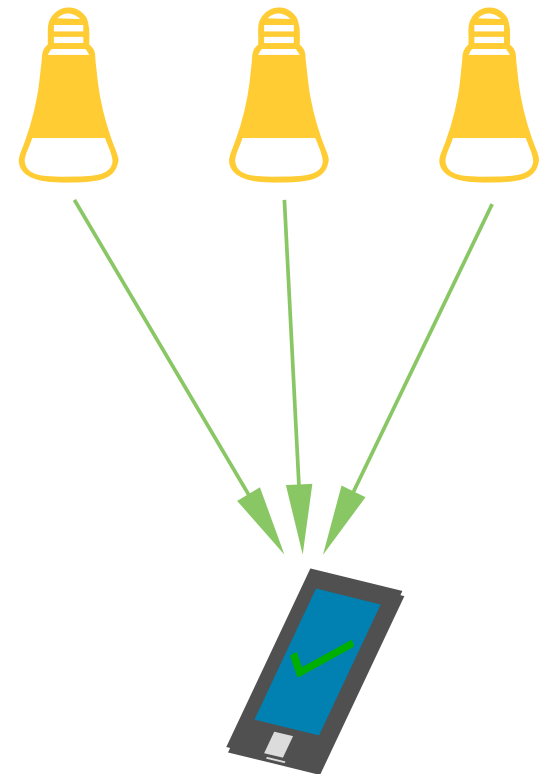


AoA at each frequency



# Light Extraction

Triangulation:  $\geq 3$  lights required

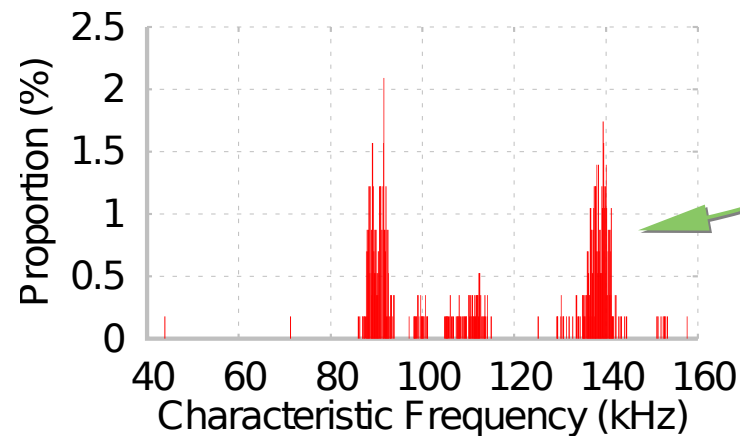


# Light Extraction

Triangulation:  $\geq 3$  lights required

Separate from spectrum:

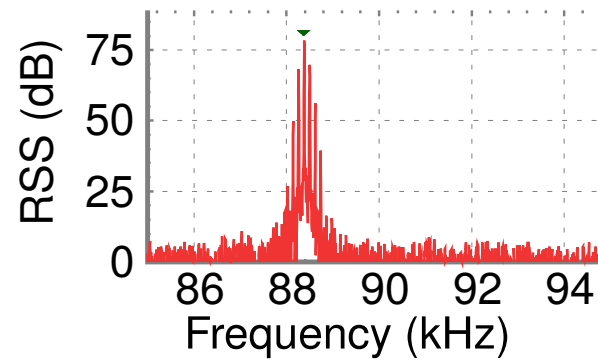
Leverage diversity in **Characteristic Frequency**



(LiTell, MobiCom'16)

# Light Extraction

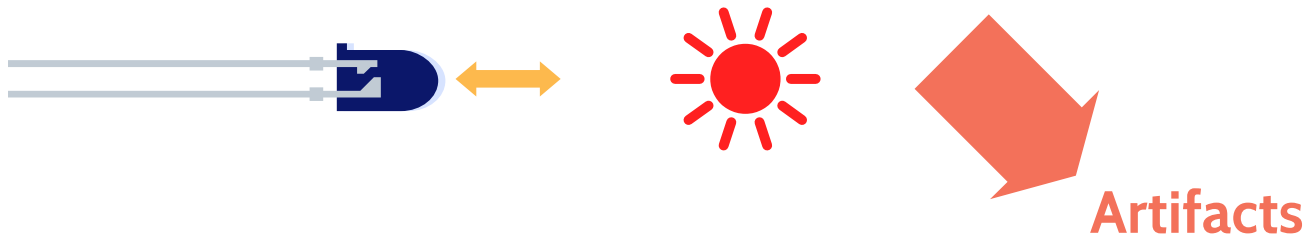
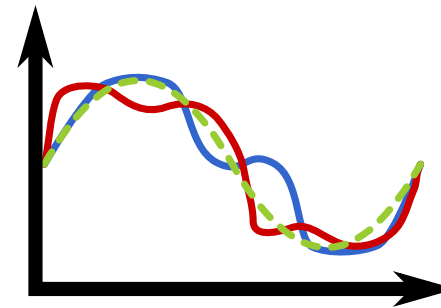
🔍 Spurious peaks!



# Light Extraction

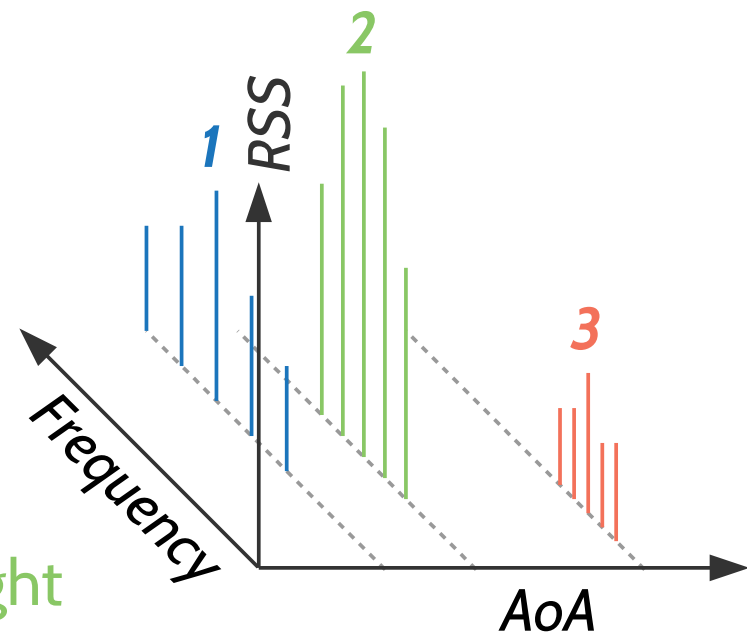
- **Causes:**

- Powerline harmonics
- User motion



# Light Extraction

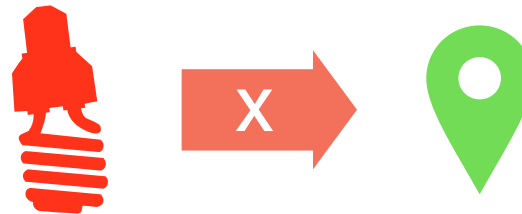
- **Causes:**
  - Powerline harmonics
  - User motion
- **Observe:**
  - AoA unaffected
  - Same AoA = from the Same Light



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**

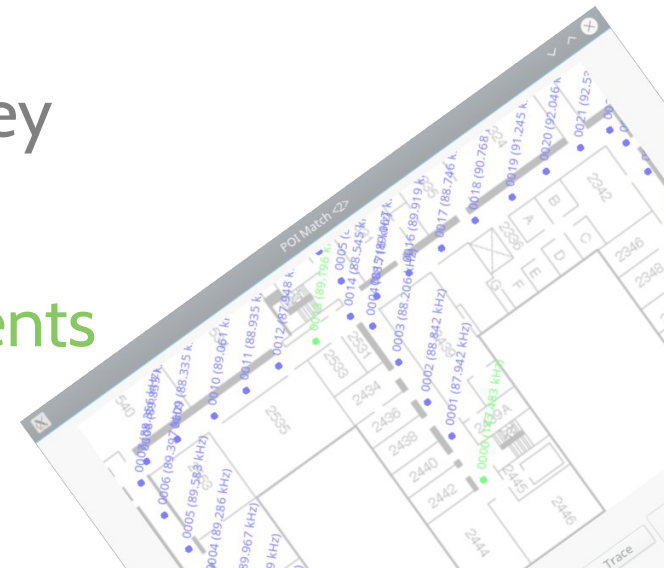
# Light Registration

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

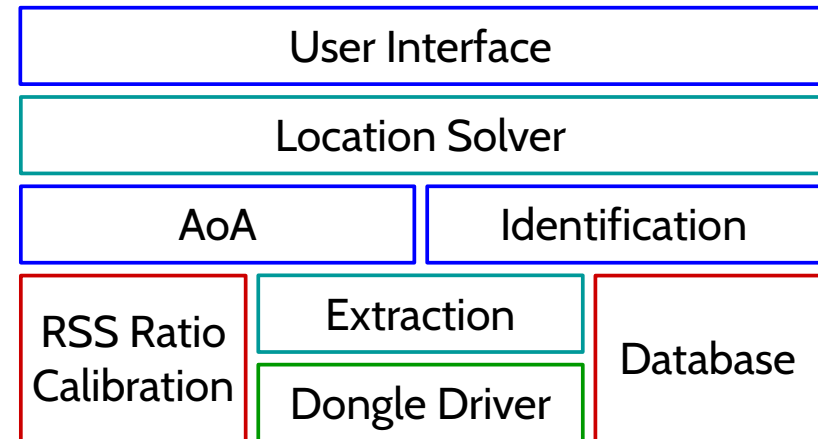
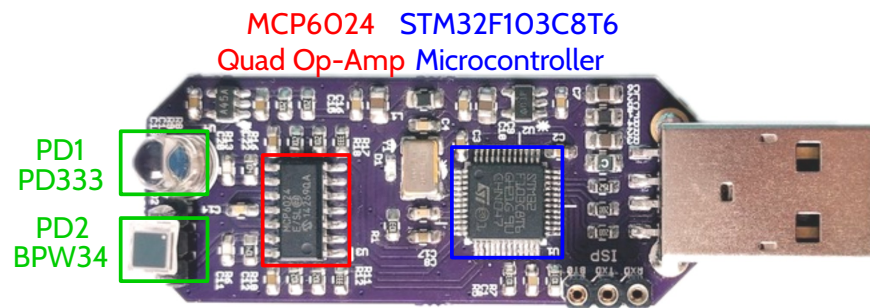


# Light Registration

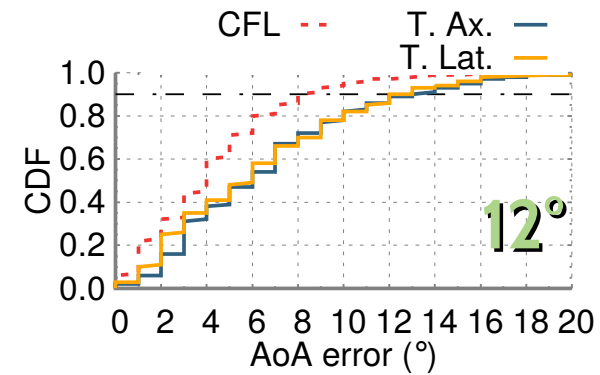
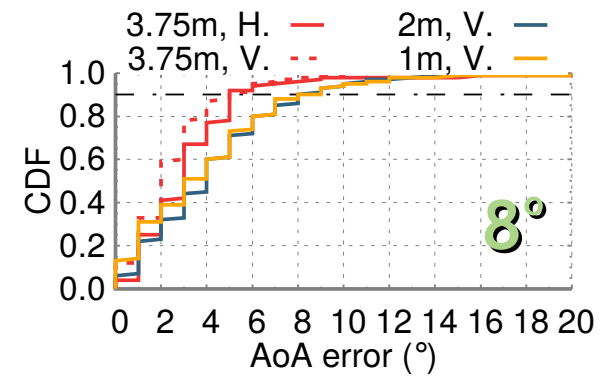
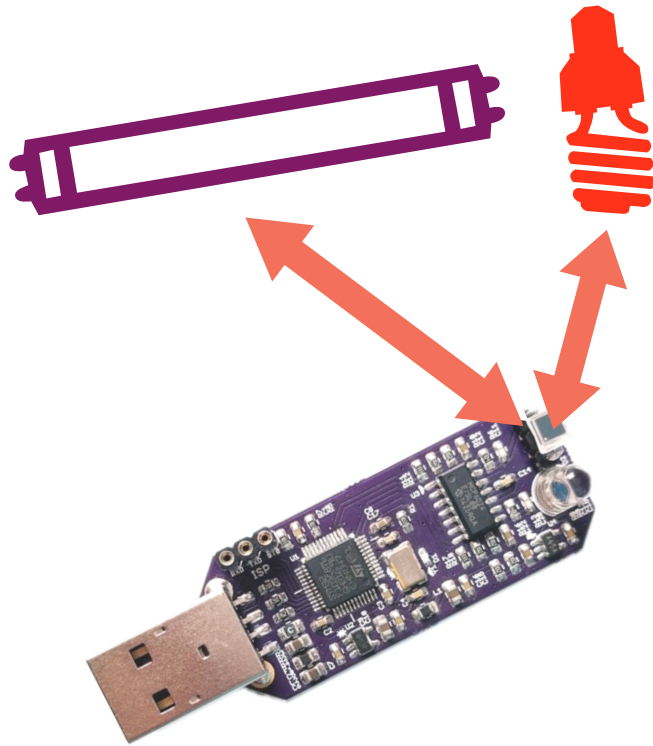
- Registration is hard work
  - Even smart bulb does not know its own location!
- **Motion tracking with Tango**
  - Record relative location during survey
  - Map to absolute location on map
- ✓ Eliminates complicated measurements



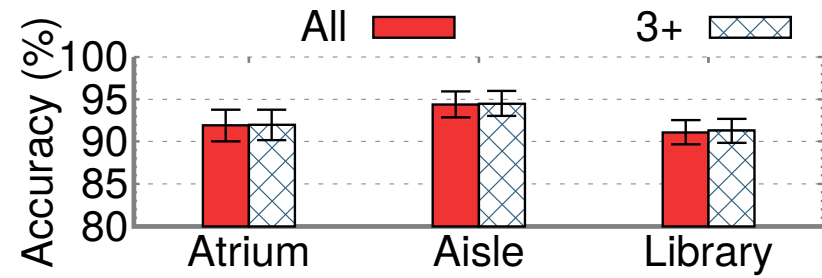
# Implementation



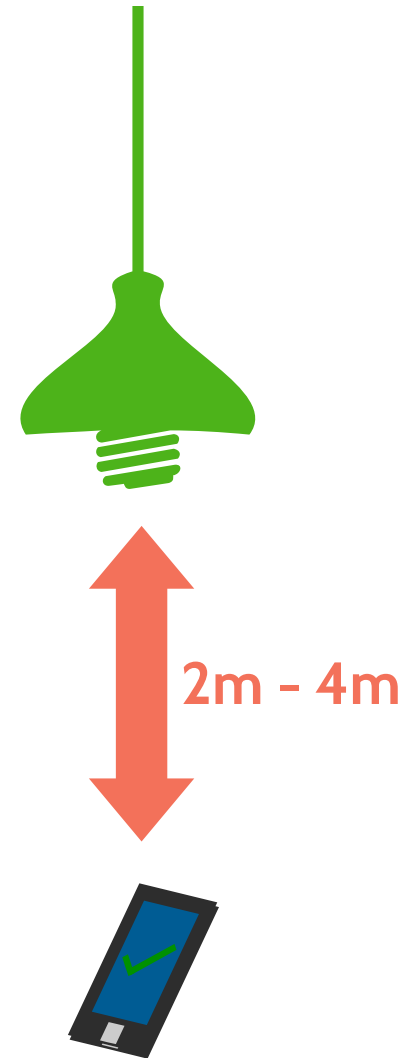
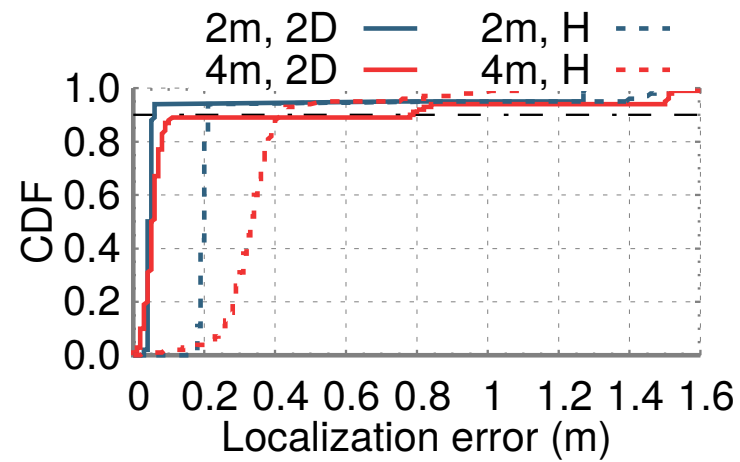
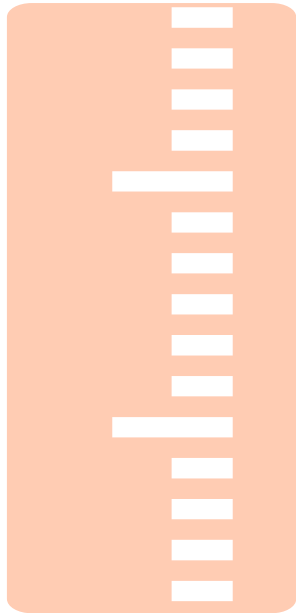
# Accuracy of AoA Sensing



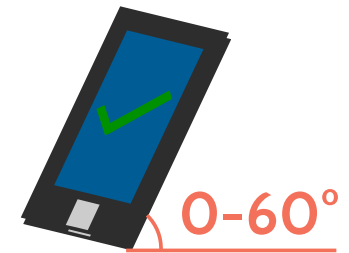
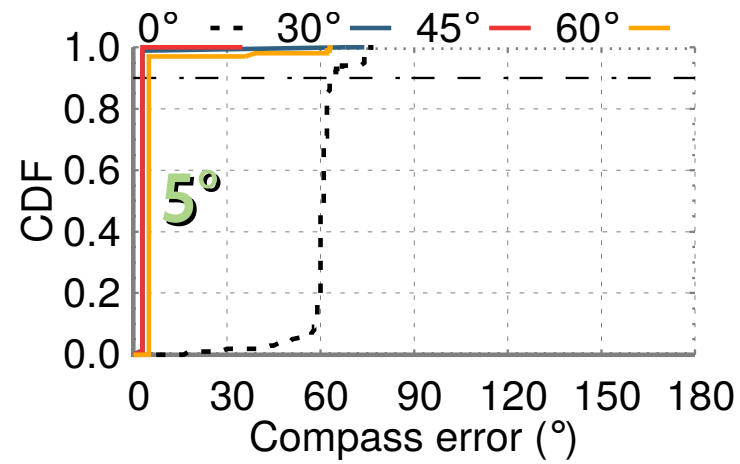
# Identification



# Localization

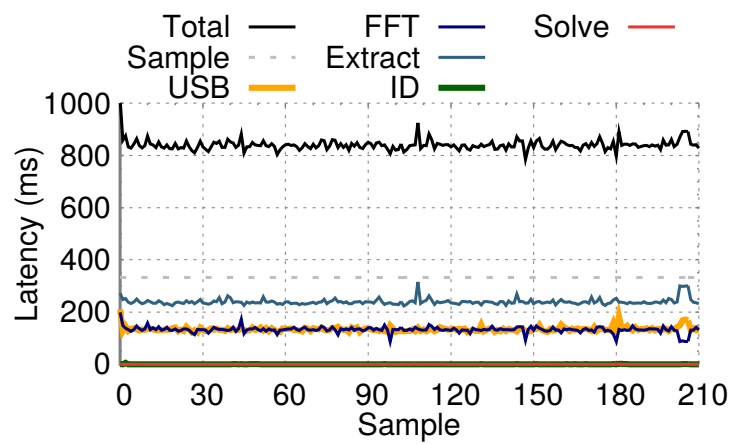


# Orientation

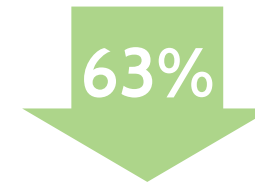
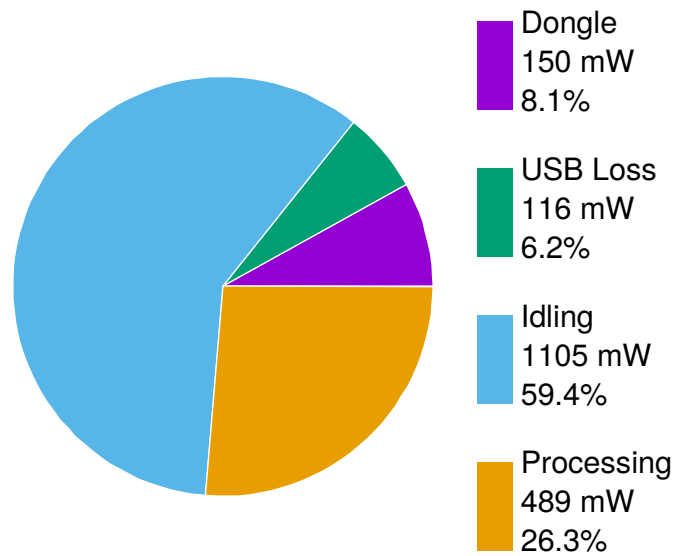




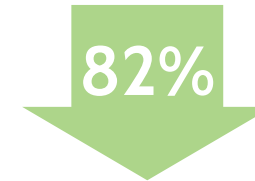
# Latency



# Energy



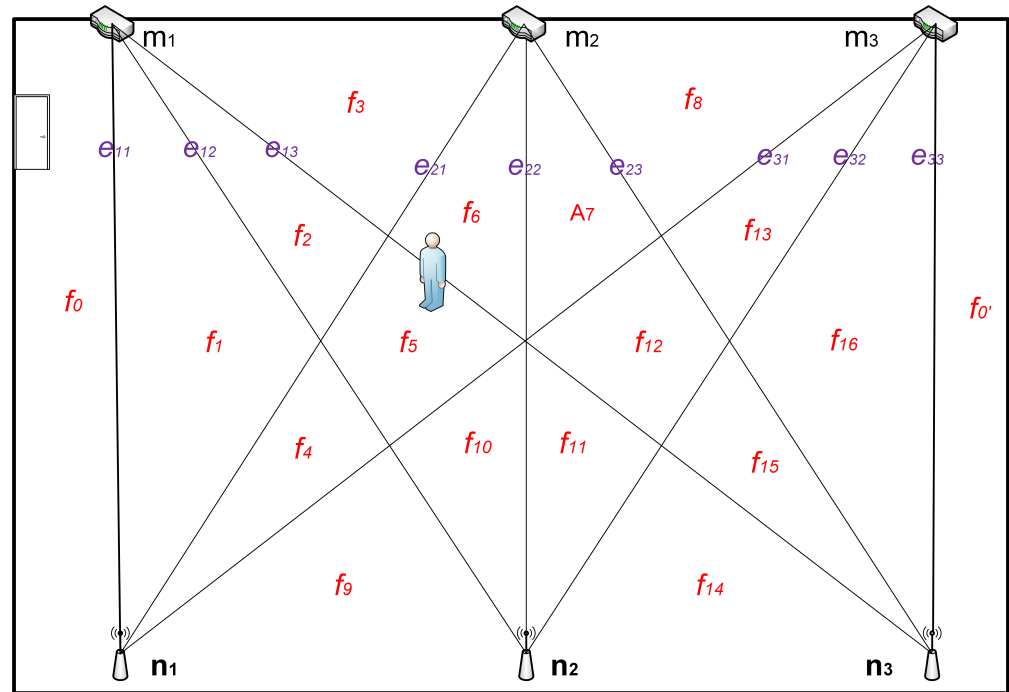
Power



Energy per  
Location

# Idea

- 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/>

