Pharos: Enable Physical Analytics through Visible Light based Indoor Localization

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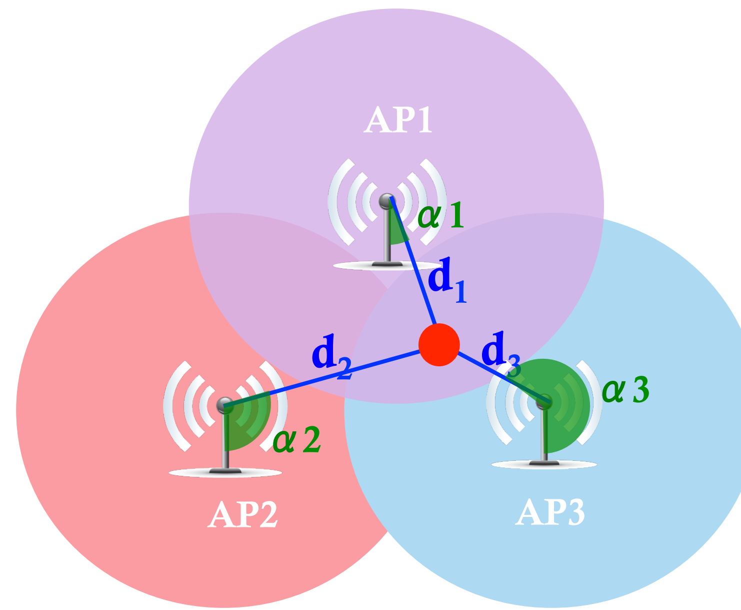
Background

- GPS-like indoor localization is important
- Mainstream localization approach: WiFi-based
- Growing demand for fine-grain indoor localization
  - Indoor navigation: navigate to a physical object
  - Physical analytics: which object customer spend time at

WiFi Localization primer

- Trilateration:
  Calculate position from
  distances to WiFi APs

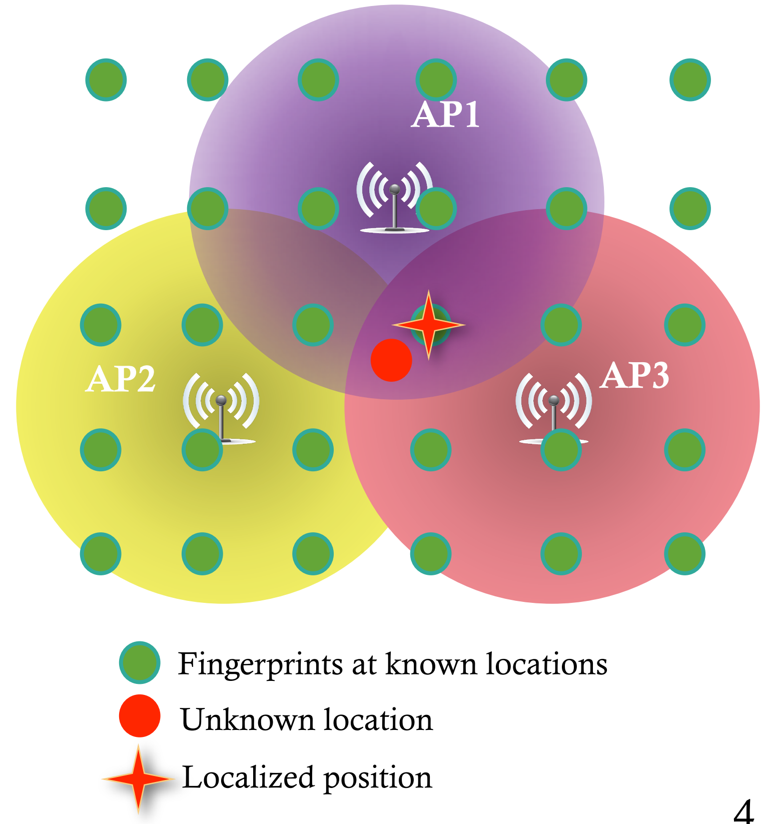
- Angle of Arrival:
  Calculate position from
  angles to WiFi APs



WiFi Localization primer

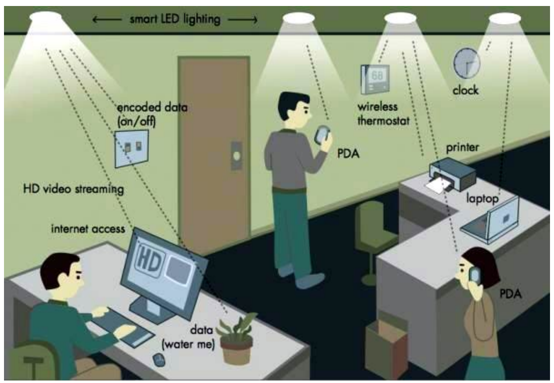
- Fingerprinting:

Calculate position from known positions with similar WiFi signals in a location database

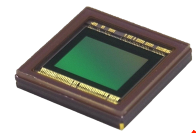


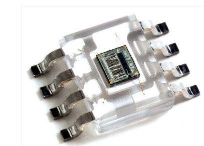
Why Visible Light indoor localization?

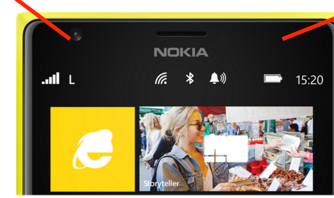
Visible Light Communication



Light/Image Sensor on Cellphone

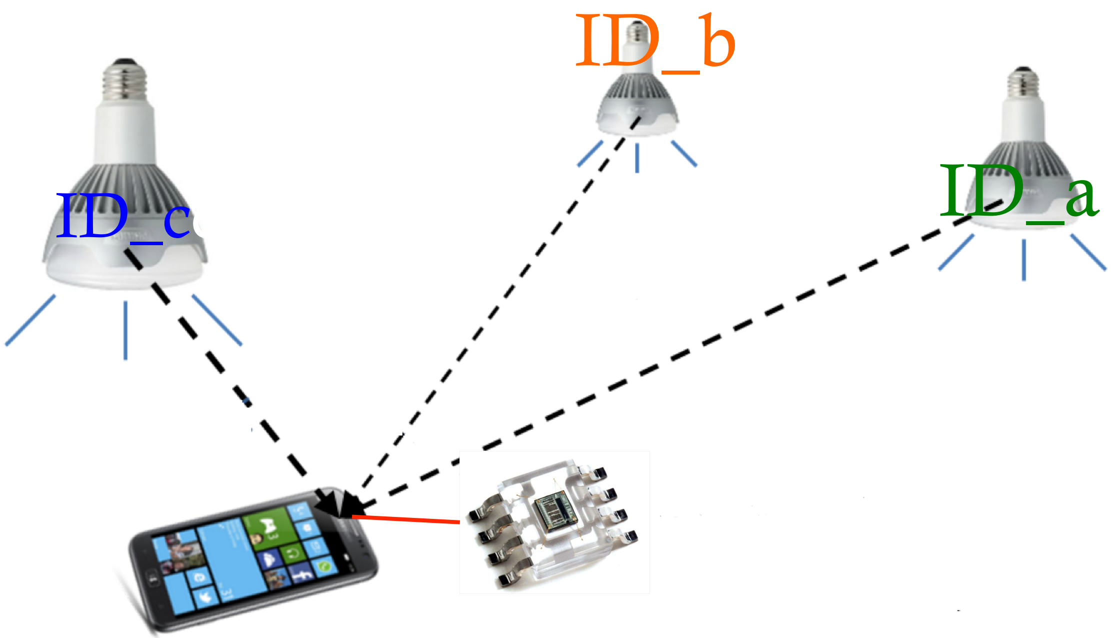






More accurate by leveraging the existing infrastructure!

Basic Concept



Multi-lateration approach

(1) LED lights broadcast IDs and their position information

(2) Cellphone received IDs and estimates signal strength

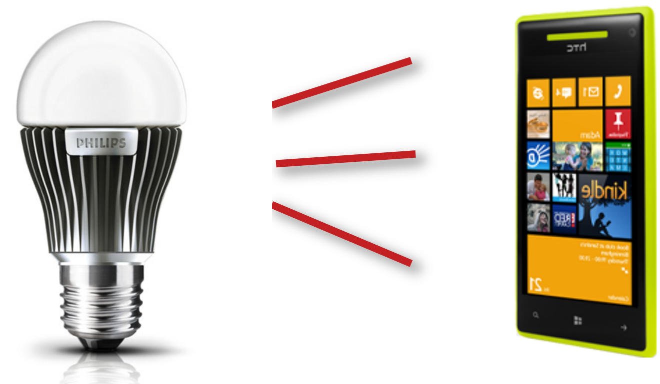
(3) Cellphone calculates distances to LEDs via optical channel model

(4) Cellphone resolves its position via multiple distance estimates

No finger printing –> without pain!

Outline

- Model
- Design
- Evaluation
- Summary

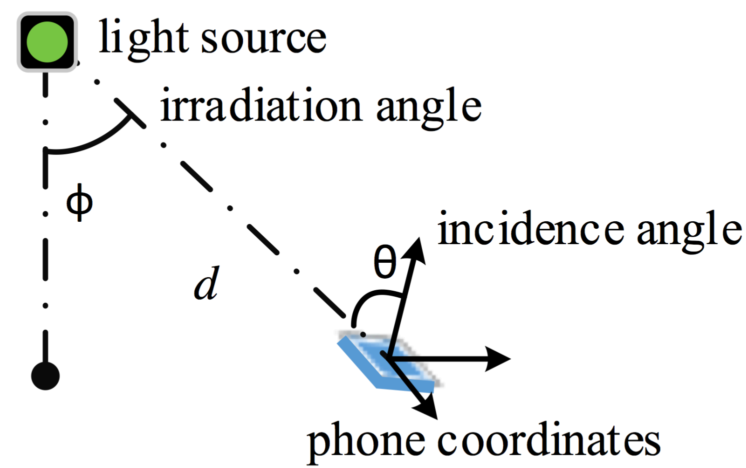


Model: Optical Channel

$$P_r = C \cdot \sin(\alpha\pi) \cdot \frac{\cos\theta \cdot \cos\phi}{d^2}$$

C Normalized Constant

$\sin(\alpha\pi)$ Light luminance



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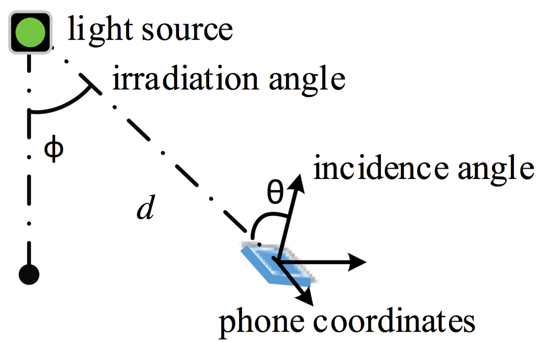
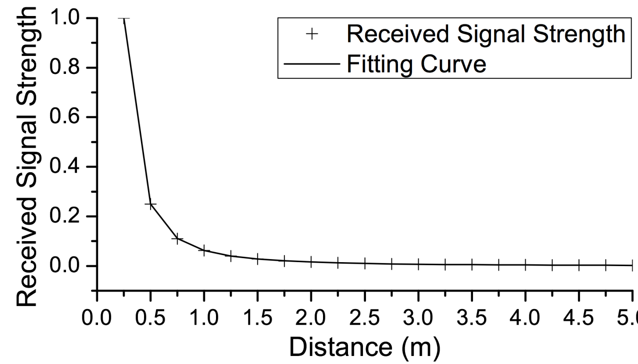
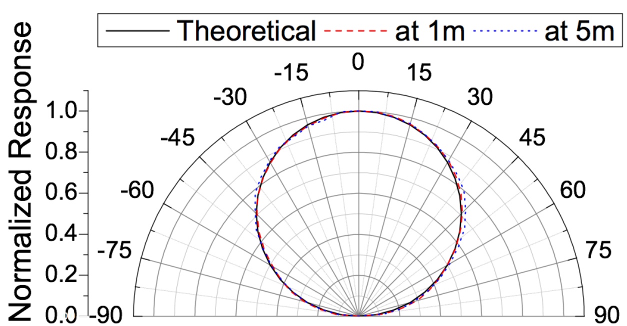
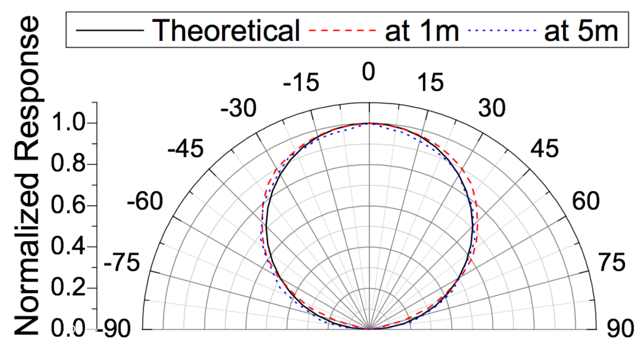






(a) Channel response of θ



(b) Channel response of ϕ

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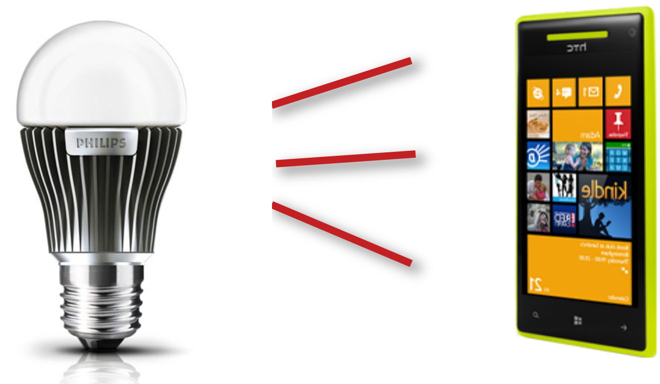
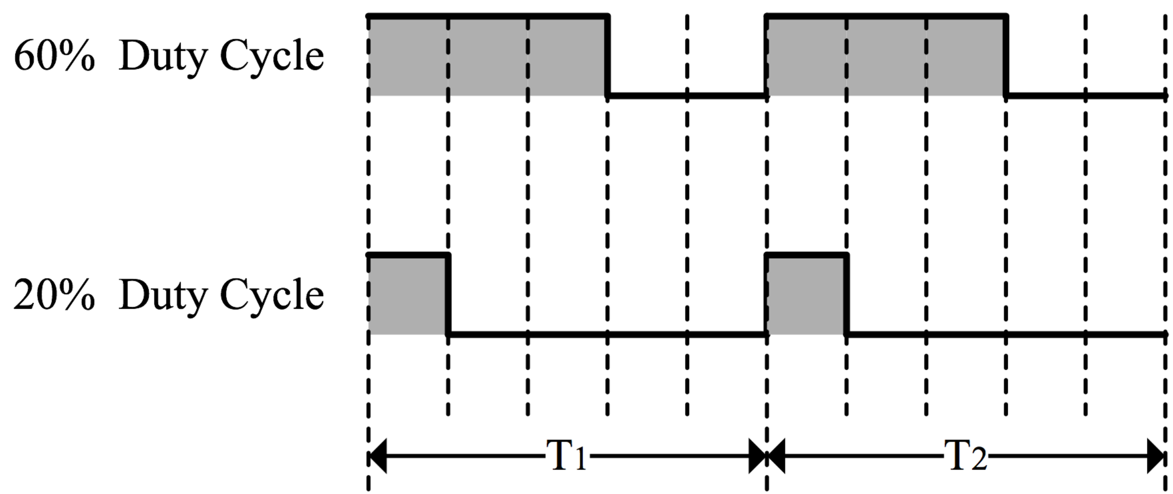


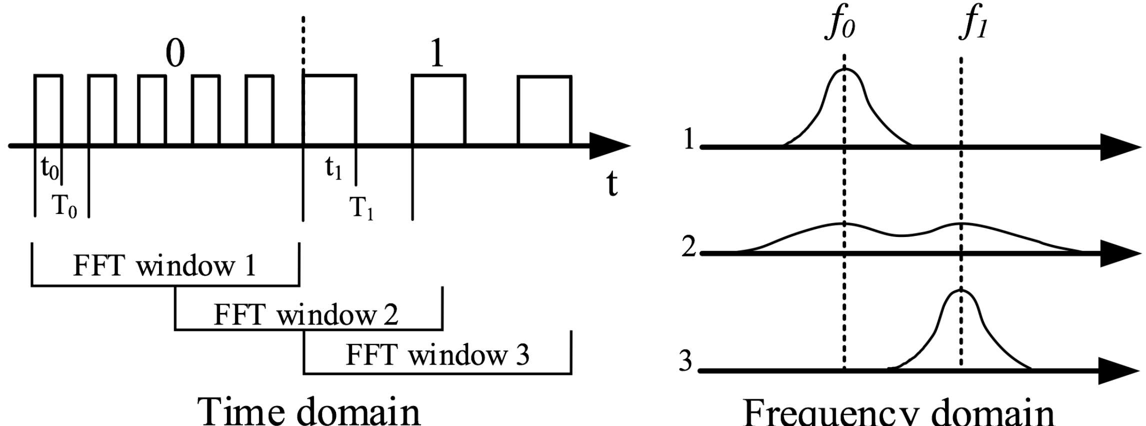
Design: Beaconing Opportunity

- LED lights adjust its luminance by switch on and off very fast.



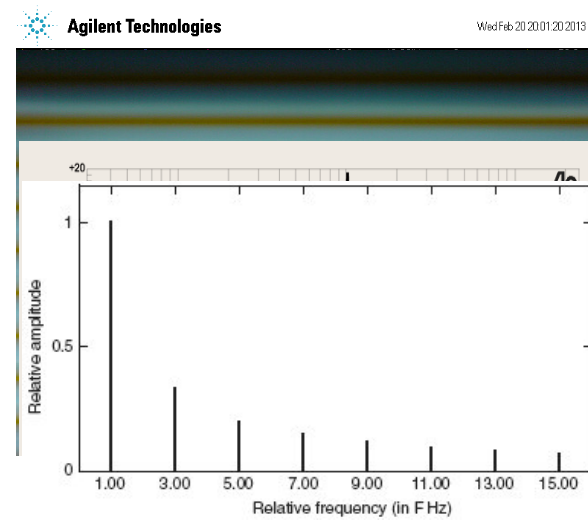
Design: Beaconing with BFSK

- Rationale:
  - Concurrent decoding
  - Avoid flicker



Design: Practical Considerations

- Choosing the right method for communication
  - LED lights support up to 100kHz
  - Must be higher than 200Hz to avoid flicker
  - Stay away from 50/60Hz interference
  - Avoid self-interference by harmonics



- Result: Frequency divided multiplexing
- 30 channels from 10kHz to 19kHz
- Frequency hopping to avoid static channel assignment

Design: Calculate

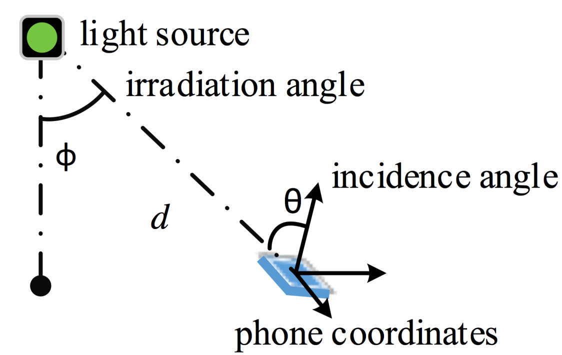
- No explicit solution, using Newton's method to solve it.

$$P_r(i) = C_i \cdot \sin(\alpha_i \pi) \cdot \frac{\cos\theta_i \cdot \cos\phi_i}{d_i^2}$$

$P_r(i)$ Received signal strength from i-th LED

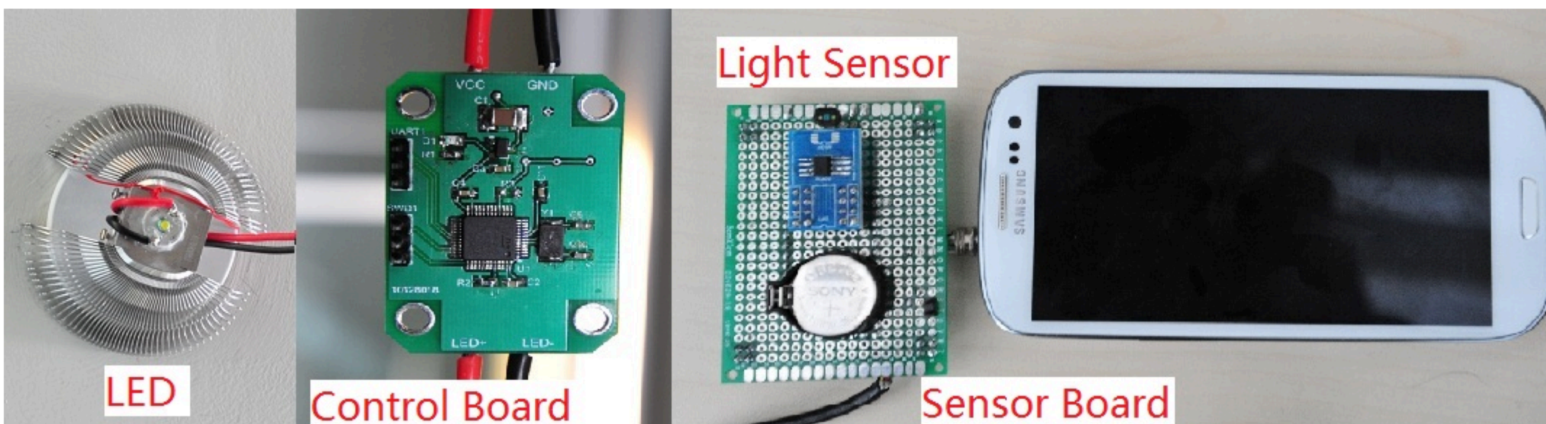
α Duty cycle of the LED

C_i Normalized constant



Design: Hardware

- Hack the dimmer with our control board
- The sample rate of light sensor on cellphone is limited, using external one via audio jack instead.



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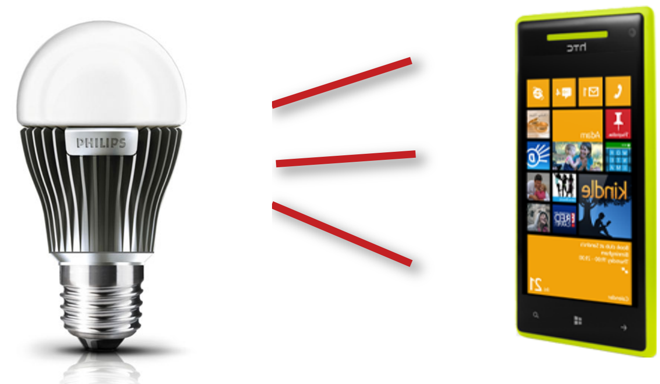
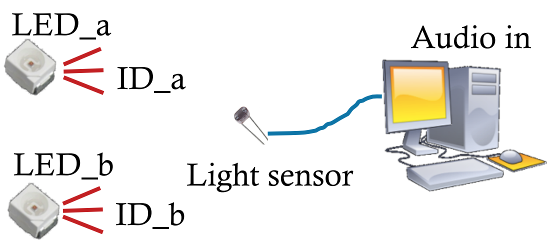


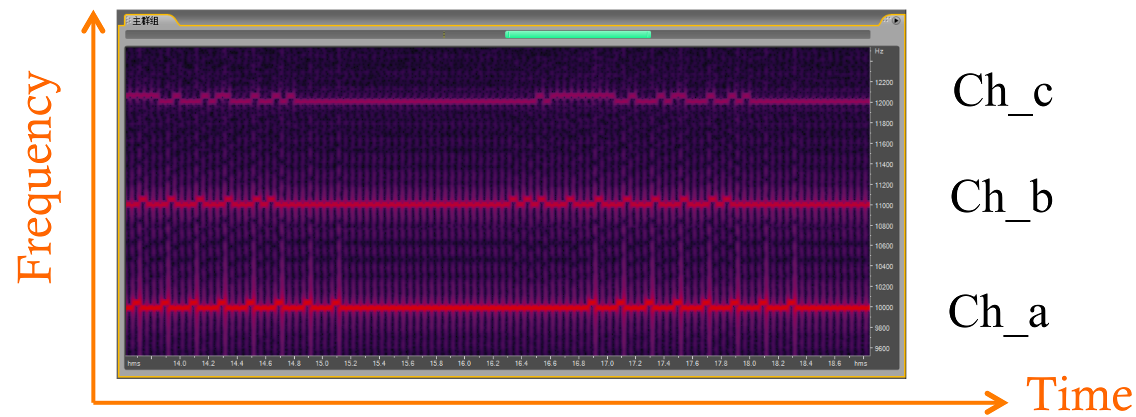
Evaluation: Modulation

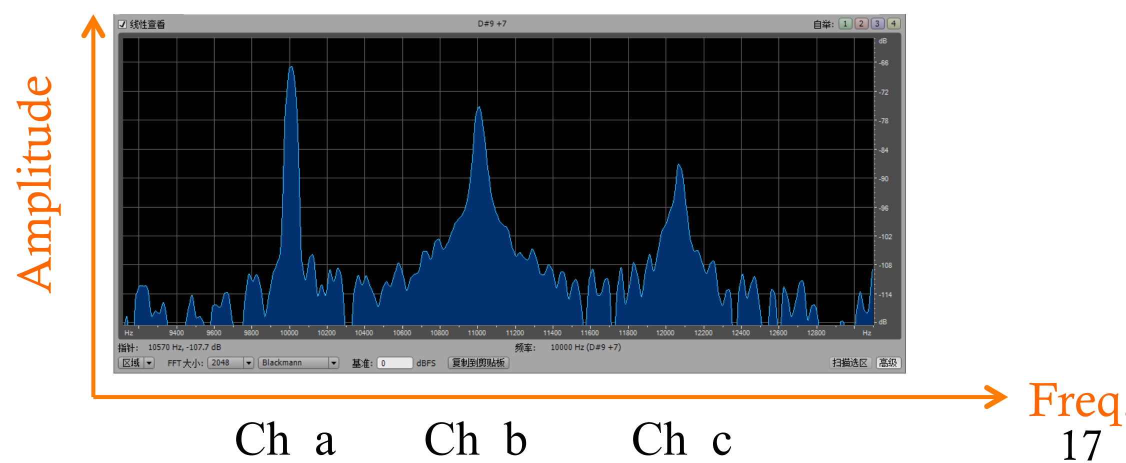


ID_a: 0x0F0F0F0A…
ID_b: 0x0F0FAF1F…

Ch_a: 10 KHz
Ch_b: 11 KHz
Ch_c: 12 KHz

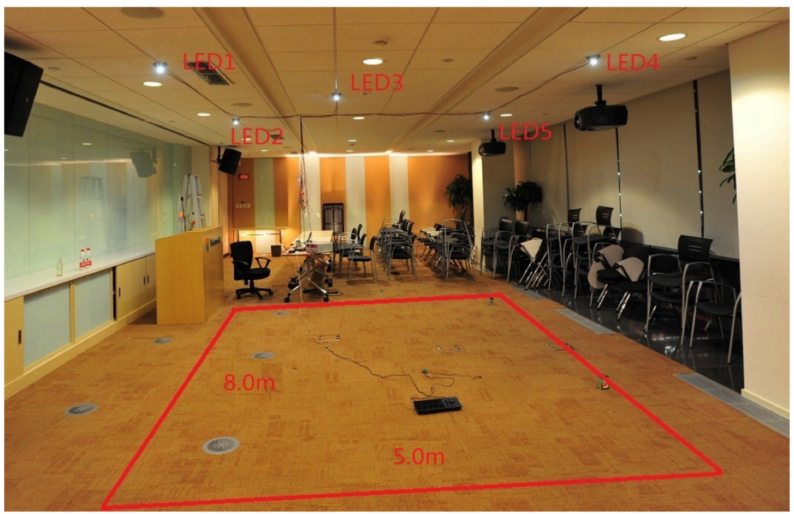
Data rate: 32 bit/s
Sampling freq: 44.1 KHz



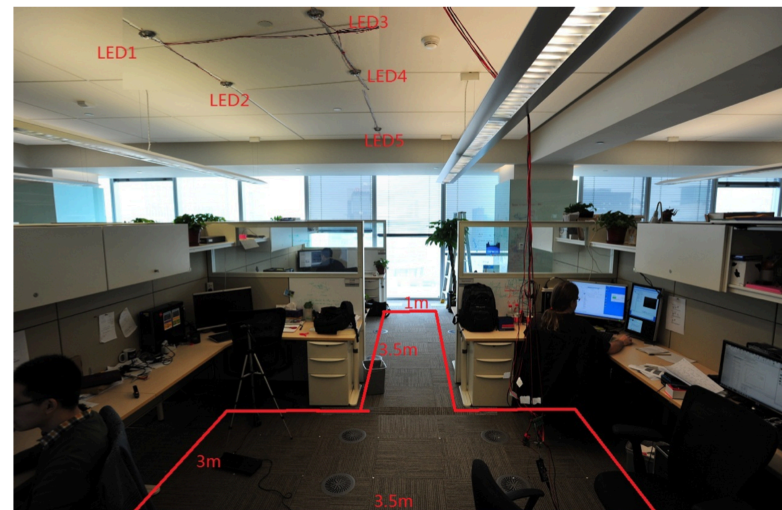


Evaluation: Localization

- Localization scenario:

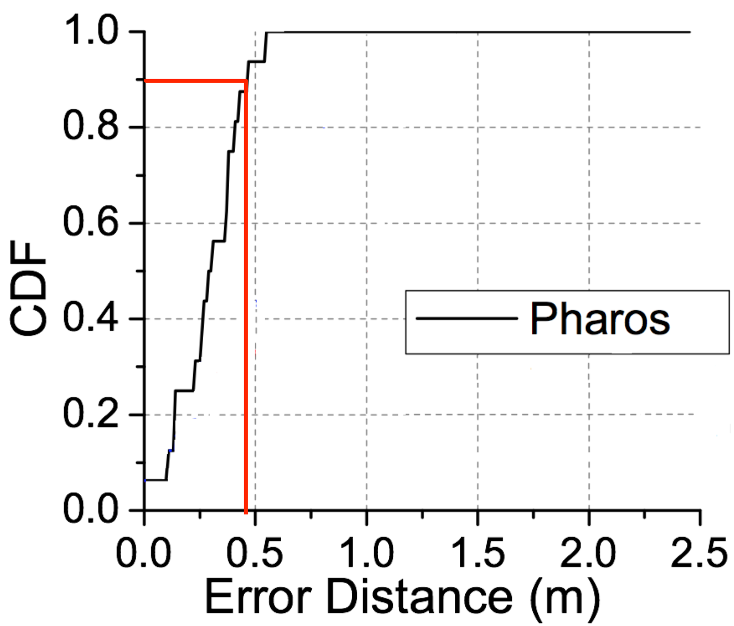


(a) Conference Room

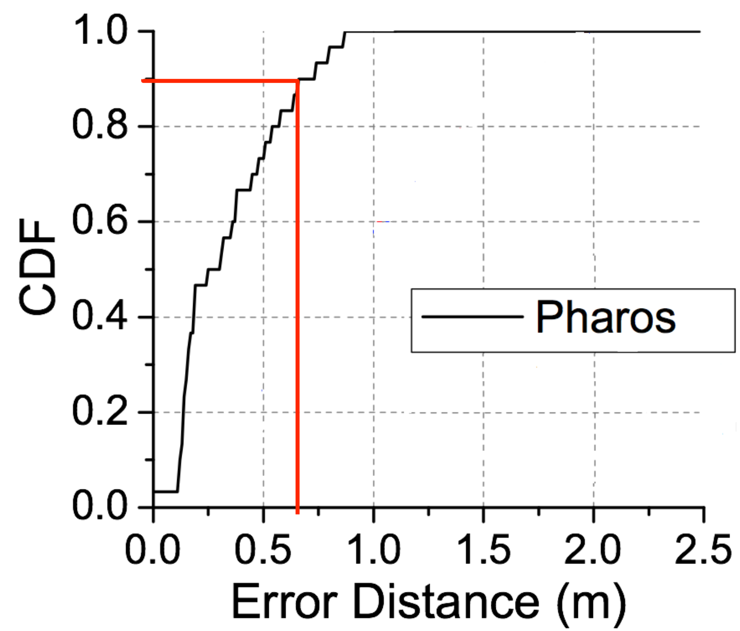


(b) Cubicle Area

Evaluation: Experimental Results



(a) Conference Room



(b) Cubicle Area

Evaluation: Accuracy Comparison

Maximum error at 90 percentile of different methods:

Name	EZ MobiCom'10	Radar INFOCOM'00	Horus MobiSys'05	PinPoint NSDI'13	ArrayTrack NSDI'13	Pharos This paper
Accuracy	2~7m	3~5m	~1m	2~3m	~0.9m	0.4~0.7m
Method	Model	Fingerprint	Fingerprint	Angle	Angle	Model
Database	Yes	Yes	Yes	No	No	No
Overhead	Minimum	Wardriving	Wardriving	Dense AP	16 Antennas	LED Light

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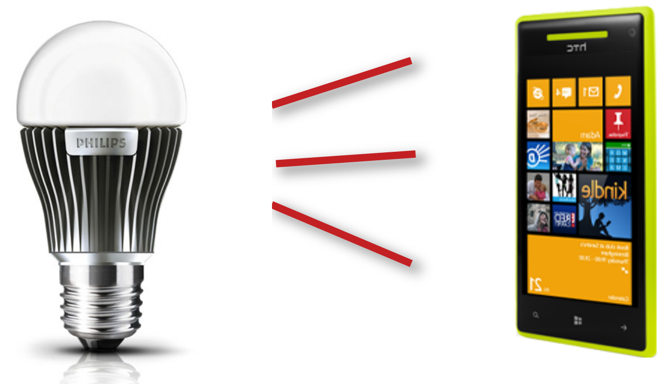
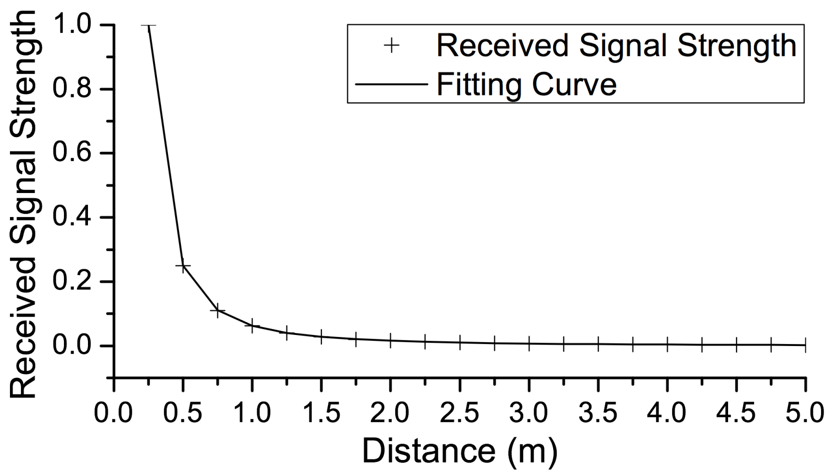


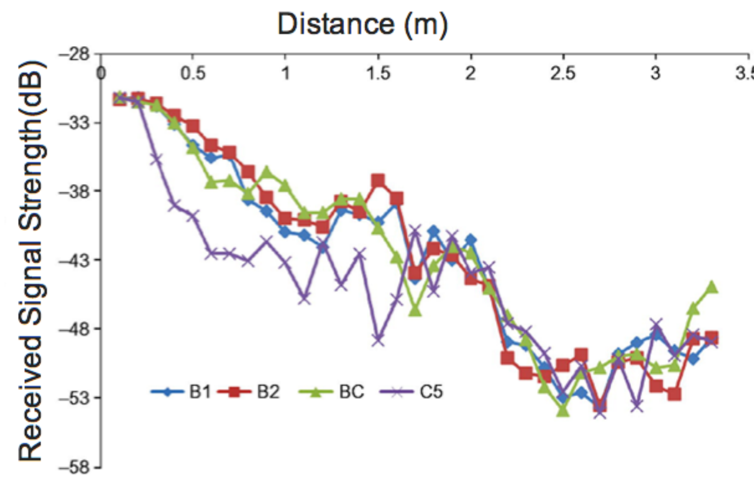
Summary

- Visible light offers opportunities to perform fine-grained localization
  - Dense deployment
  - Stable signals

Thank you!

Optical Channel vs Radio Channel





- Stable, no fluctuation.
- Unstable, Rayleigh fading.

Additional questions

- You said light channel is stable, but just like radio, light is actually bounced back and forth in indoor environment. Why it does not affect the model?

- Why you design your own LED lights, instead of buying commercial ones?