Localization

Jin Zhang

Department of Computer Science and Engineering

Southern University of Science and Technology

Localization

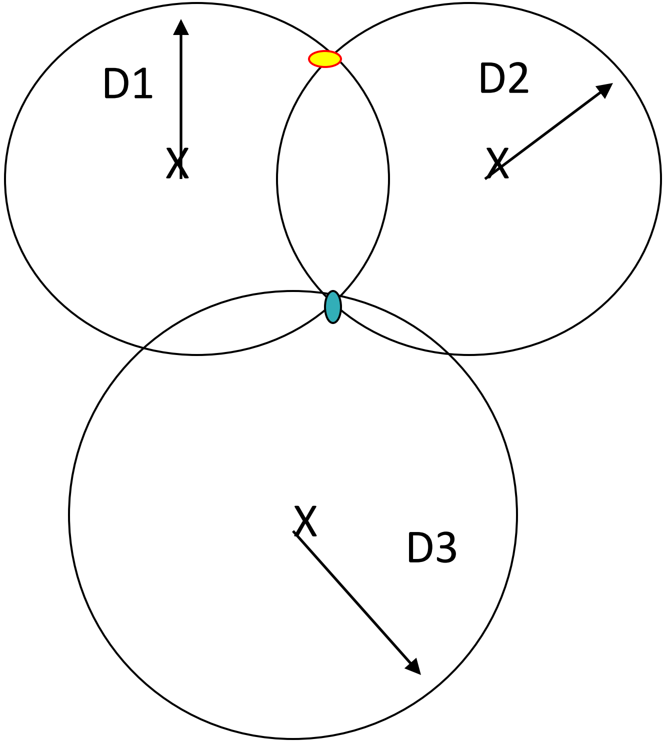
- Well studied topic (3,000+ PhD theses??)
- Application dependent
- Research areas
  - Technology
  - Algorithms and data analysis
  - Visualization
  - Evaluation

Localization Taxonomy

- Range Based
  - Determine distances between nodes (range)
  - Then compute location using geometry
- Range Free
  - No need to determine distances directly, instead use hop count
  - Use average distances between hops
  - Then compute location using geometry

Localization via 3 Distance Measurements

Ideal

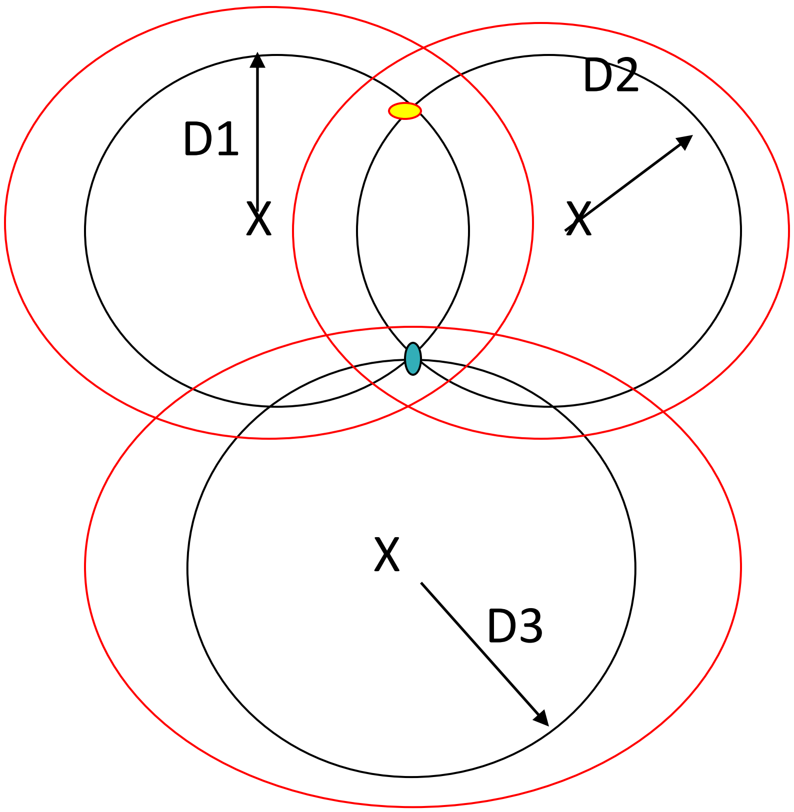


X = anchors or landmarks or beacon

The anchors should be non-collinear

Localization via N Distance Measurements

Realistic

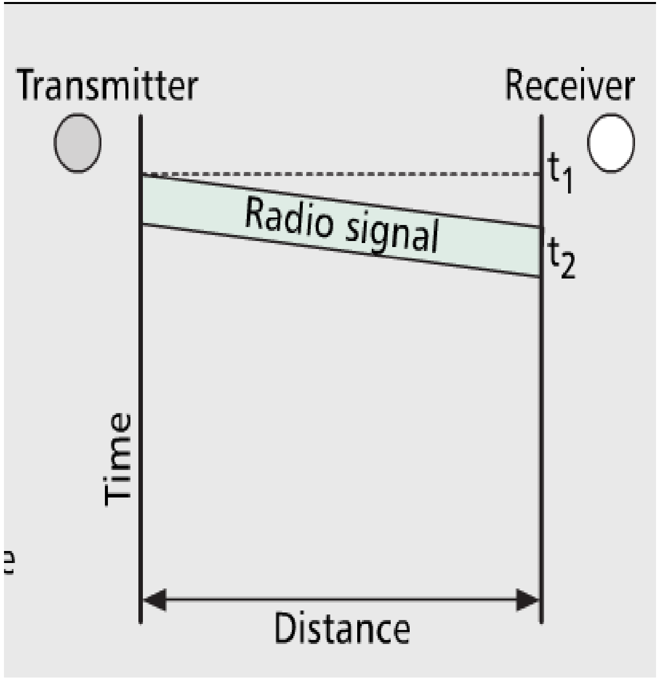


X = anchors or landmarks or beacons

When the distance is not accurate, minimize the mean-square error to calculate the location

Localization Taxonomy

- Range-Based Localization – use absolute point to point distance/angle estimates
  - TOA (Time of Arrival): GPS
  - It's a method that tries to estimate distance between 2 nodes using time based measures
  - Needs synchronization

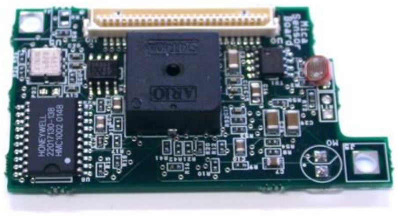


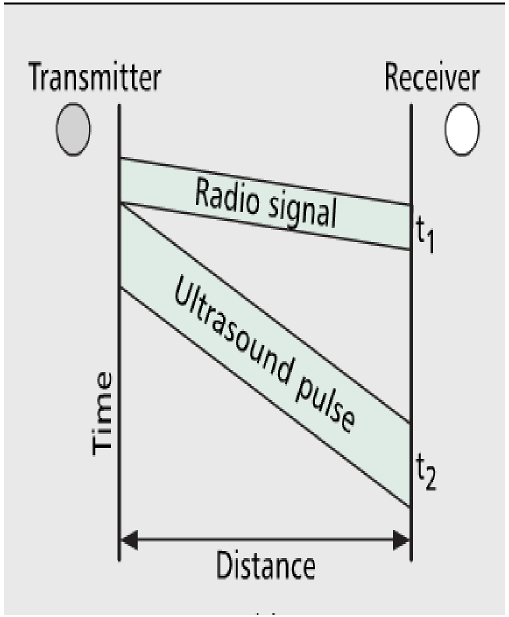
Localization Taxonomy

- <u>Range-Based Localization</u> – use absolute point to point distance/angle estimates
  - TDOA (Time Difference of Arrival):
    - MIT Cricket [1]

X Radio (Speed of light) Y

Sound





[1] Nissanka B. Priyantha, Anit Chakraborty, Hari Balakrishnan, The Cricket Location-Support system, Mobicom 2000.

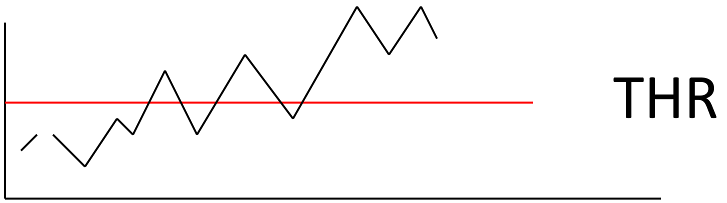
TDOA

- Simultaneously send RF and ultrasound (with limited range) – measure difference in arrival times of signals to compute distance

Speed of sound varies with environment

- Temperature, humidity

– Where is the start of the sound signal, i.e., the signal processing is not precise?



Range-Based (cont.)

- AOA (Angle of Arrival):
  - Aviation System and Rutgers APS
  - direction of signal propagation
  - typically achieved using an array of antennas or microphones
  - angle between signal and some reference is orientation
  - spatial separation of antennas or microphones leads to differences in arrival times, amplitudes, and phases
  - accuracy can be high (within a few degrees)
  - adds significant hardware cost

Range-Based (cont.)

- Signal Strength
  - Microsoft RADAR [1] and UW SpotOn [2]
  - Analyze characteristic properties of the position of a node in comparison with premeasured properties
    - Radio environment has characteristic “fingerprints”
  - Assume signal strength is proportional to distance
    - RSSI (received signal strength indicator)

[1] Paramvir Bahl and Venkata N. Padmanabhan, RADAR: An In-Building RF-based User Location and T racking System, InfoCom 2000.
[2] Jeffrey Hightower, G. Borriello, R. Want, SpotON: An Indoor 3D Location Sensing Technology Base d on RF Signal Strength, Technical Report, 2000.

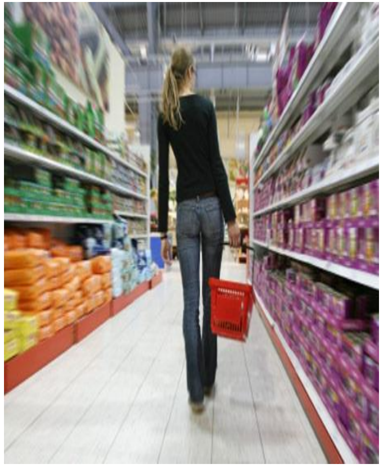
Received Signal Strength Indicator (RSSI)

- Translate signal strength into distance
  - Use model/formula to do the conversion
  - E.g., signal strength drops as inverse square of distance

$$P_{\text{recv}} = c\frac{P_{\text{tx}}}{d^{\alpha}} \Leftrightarrow d = \sqrt[\alpha]{\frac{cP_{\text{tx}}}{P_{\text{recv}}}}$$

- Multi-path fading, background interference, irregular signal propagation render this technique largely unsuitable

Applications of Indoor Localization



Targeted Location Based Advertising

Indoor Navigation (e.g. Airport Terminals)

Real Life Analytics (Gym, Office, etc..)

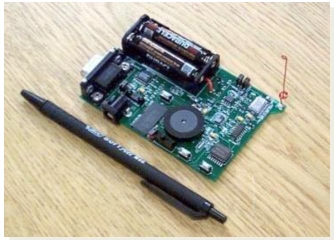
Indoor localization platform providing high accuracy could enable a host of applications

Lots of Technologies!

WiFi Beacons

Ultrasound

Floor pressure



Ad hoc signal strength

Ultrasonic time of flight

Laser range-finding

Stereo camera

Infrared proximity

Array microphone

Physical contact

Agenda

01 Fingerprint-based Solution

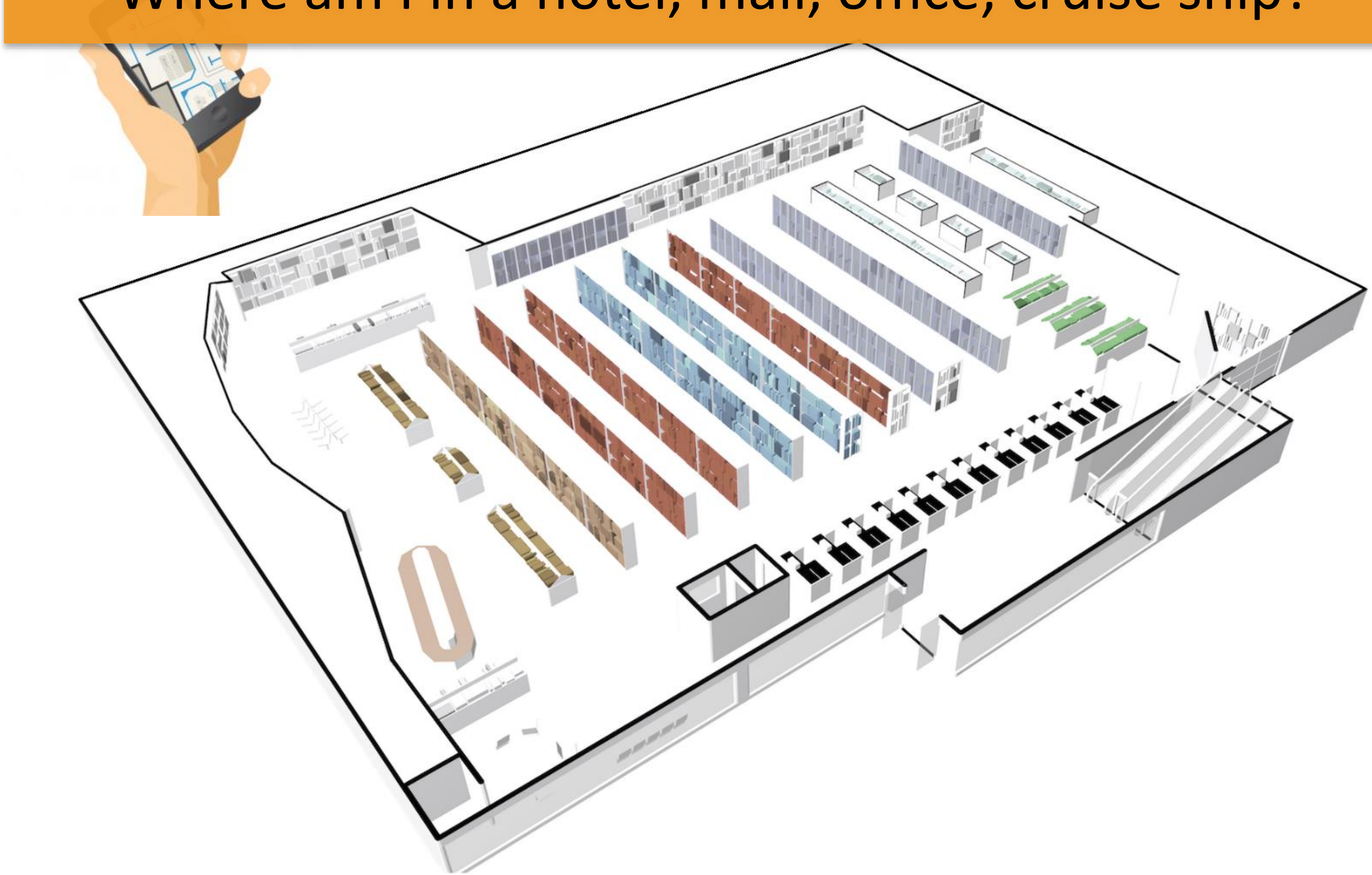
02 VLC-based Solution

03 Multi-Source based Solution

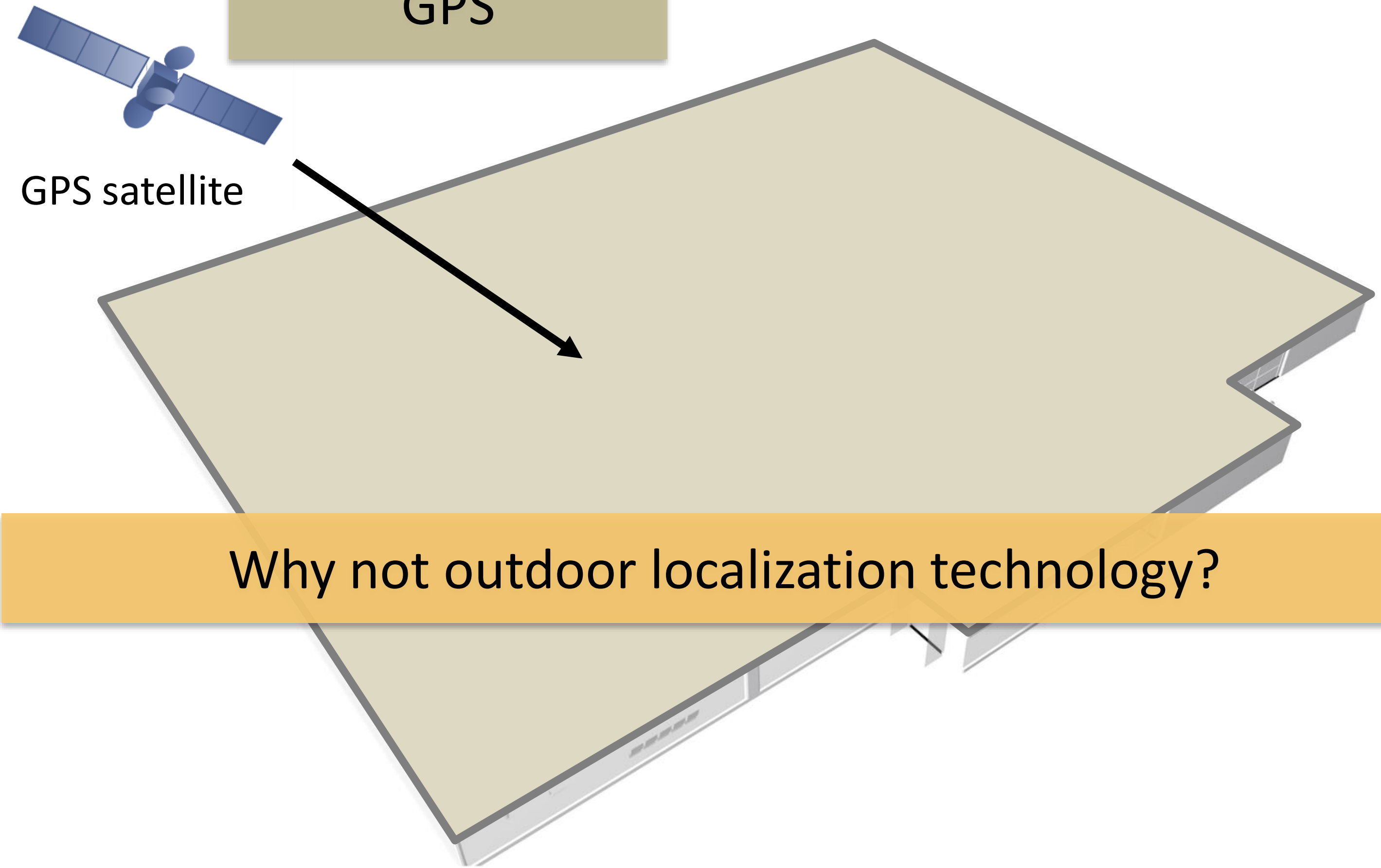
Wireless Technologies for Localization

Name	Effective Range	Pros	Cons
GSM	35km	Long range	Very low accuracy
LTE	30km-100km		
Wi-Fi	50m-100m	Readily available; Medium range	Low accuracy
Ultra Wideband	70m	High accuracy	High cost
Bluetooth	10m	Readily Available; Medium accuracy	Short range
Ultrasound	6-9m	High accuracy	High cost, not scalable
RFID & IR	1m	Moderate to high accuracy	Short range, Line-Of-Sight (LOS)
NFC	<4cm	High accuracy	Very short range

Where am I in a hotel, mall, office, cruise ship?

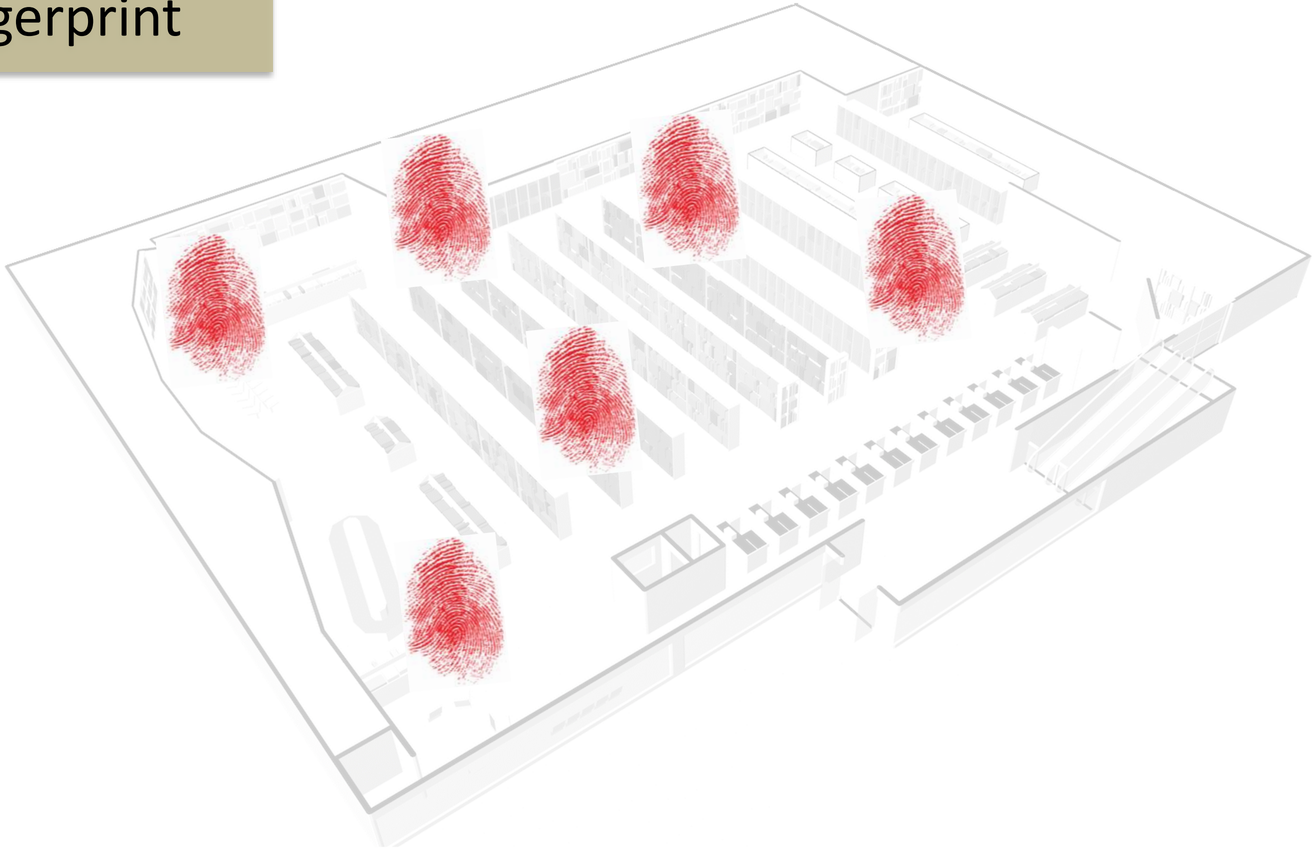


GPS

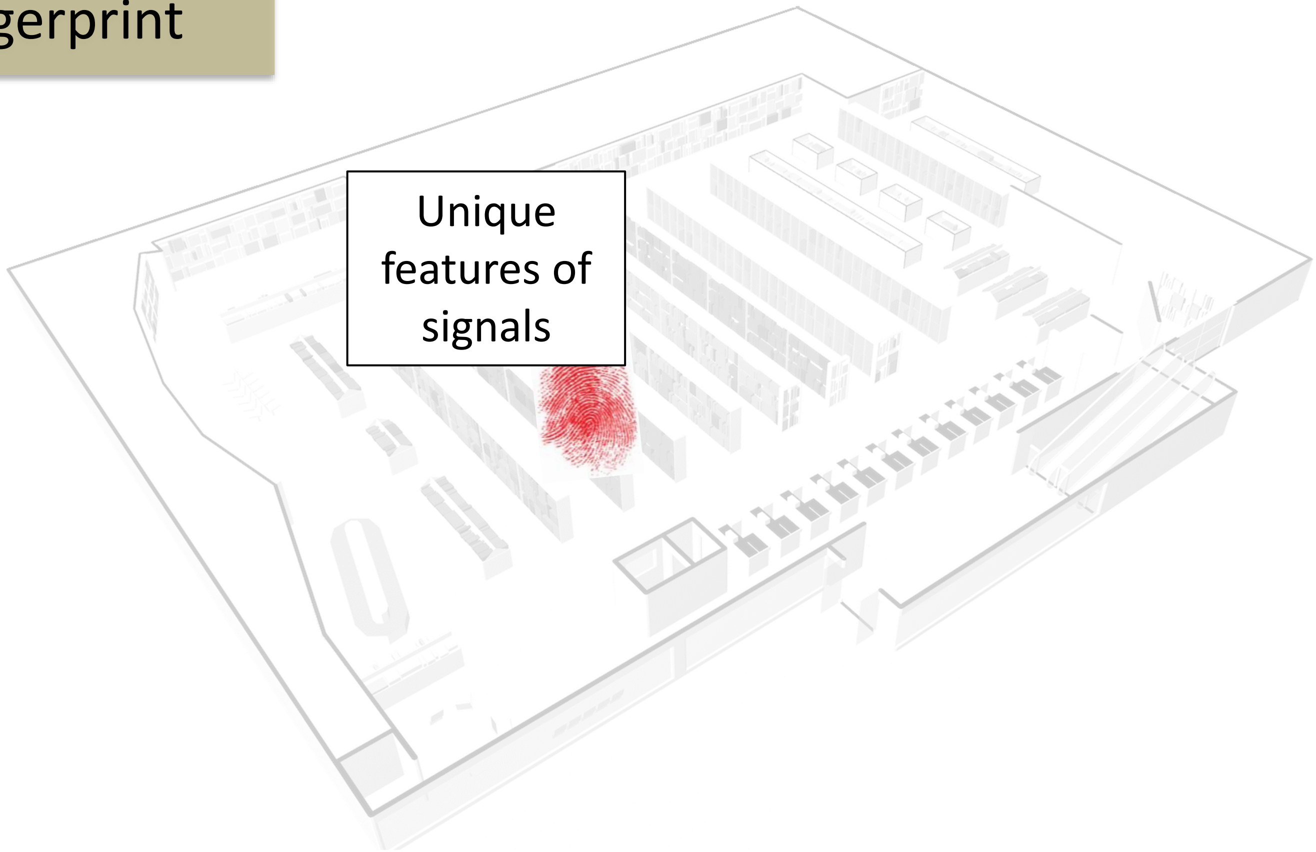


Why not outdoor localization technology?

Fingerprint



Fingerprint



- RF-based Fingerprinting: Radar
- RF and magnetic-based Fingerprinting

Fingerprinting

- Mapping solution
- Address problems with multipath
- Better than modeling complex RF propagation pattern

Fingerprinting

SSID (Name)	BSSID (MAC address)	Signal Strength (RSSI)
linksys	00:0F:66:2A:61:00	18
starbucks	00:0F:C8:00:15:13	15
newark wifi	00:06:25:98:7A:0C	23

Fingerprinting

- Easier than modeling
- Requires a dense site survey
- Usually better for symbolic localization

- Spatial differentiability
- Temporal stability

Received Signal Strength (RSS) Profiling Measurements

- Construct a form of map of the signal strength behavior in the coverage area
- The map is obtained:
  - Offline by a priori measurements
  - Online using sniffing devices deployed at known locations
- They have been mainly used for location estimation in WLANs

Received Signal Strength (RSS) Profiling Measurements

- Different nodes:
  - Anchor nodes
  - Non-anchor nodes
  - A large number of sample points (e.g., sniffing devices)
- At each sample point, a vector of signal strengths is obtained
  - jth entry corresponding to the jth anchor's transmitted signal
- The collection of all these vectors provides a map of the whole region
- The collection constitutes the RSS model
- It is unique with respect to the anchor locations and the environment
- The model is stored in a central location
- A non-anchor node can estimate its location using the RSS measurements from anchors

RADAR: An In-Building RF-Based User Location and Tracking system

Paramvir Bahl and Venkata N. Padmanabhan

- Functional Components
  - Base Stations (Access Points)
  - Mobile Users
- Fundamental Idea in RADAR
  - Signal Strength is a function of the receiver's location
  - Road Maps
- Techniques to build the Road Maps
  - Empirical Method
  - Radio Propagation Model
- Search Techniques
  - Nearest Neighbor in Signal Space (NNSS)
  - NNSS Avg.
  - Viterbi-like Algorithm

Data Collection

- Key Step in the proposed approach
- Records the Radio Signal as a function of the user location
- Off-Line Phase
  - Construct/validate models for signal propagation
- Real-Time Phase (Infer location of user)
- Every packet received by the base station, the WiLIB extracts
  - Signal Strength
  - Noise floor at the transmitter
  - Noise floor at the receiver
  - MAC address of the transmitter

Data Processing

- Traces collected from the off-line phase are unified into a table consisting of tuples of the format

  [x, y, d, ss(i), snr(i)] I € {1,2,3}
- Search Algorithm
  - NNSS
  - NNSS – Avg.
  - Viterbi-like Algorithm
- Layout Information

Algorithm and Experimental Analysis

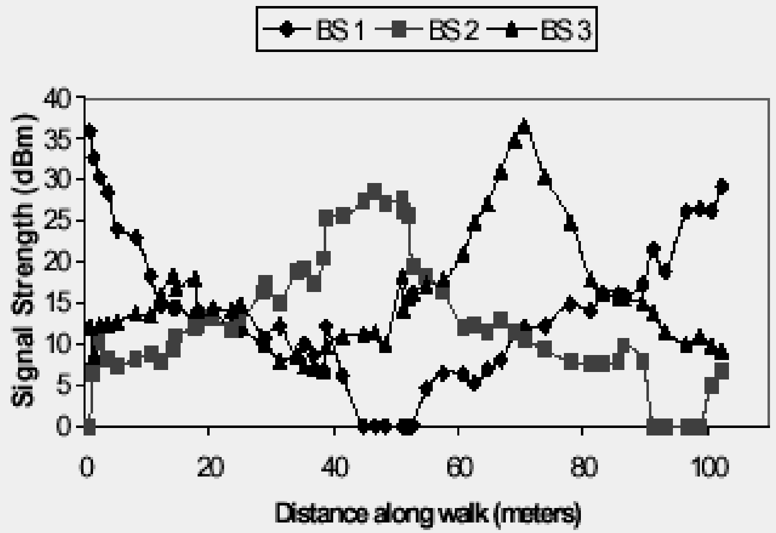


Figure 2 Signal strength recorded at the three base stations as the user walks around the floor.

Empirical Method

- 280 combinations of user location and orientation (70 distinct points, 4 orientations on each point)
- Uses the above empirical data recorded in the off-line phase to construct the search space for the NNSS Algorithm
- Algorithm (Emulates the user location problem)
  - Picks one location and orientation randomly
  - Searches for a corresponding match in the rest of the 69 points and orientations
- Comparison with
  - Strongest Base Station
  - Random Selection

Error Distance Values

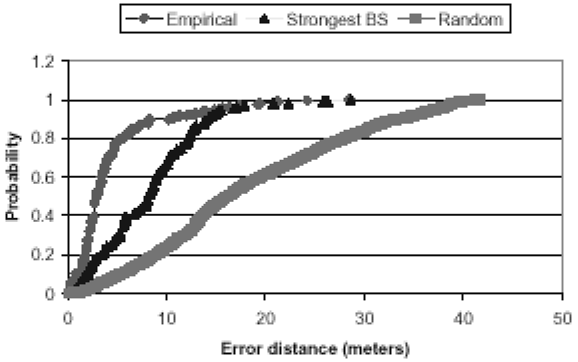


Figure 3 CDF of the error in location estimation.

Method	25th (meter)	50th (meter)	75th (meter)
Empirical	1.92	2.94	4.69
Strongest	4.54 (2.4x)	8.16 (2.8x)	11.5 (2.5x)
Random	10.37 (5.4x)	16.26 (5.5x)	25.63 (5.5x)

Table 1 The 25th, 50th, and 75th percentile values of the error distance. The numbers in parentheses indicate the degradation of the strongest BS and random methods compared to the empirical method.

Empirical Method (Cntd.)

- Multiple Nearest Neighbor
  - Increases the accuracy of the Location Estimation

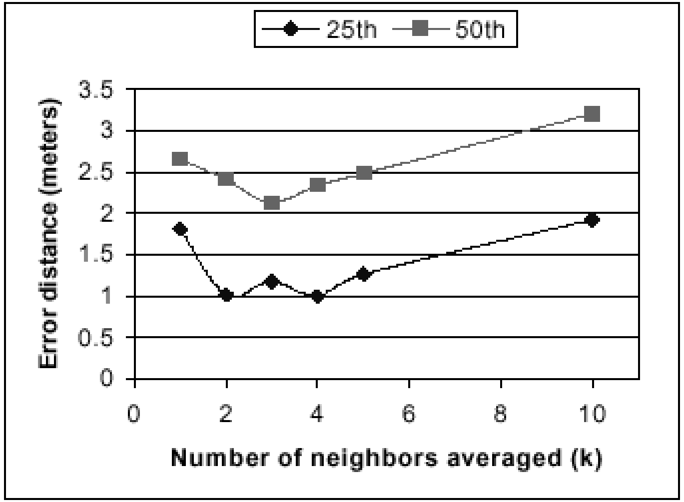


Figure 5 The error distance for the empirical method with averaging on the data set containing the max signal strength measurement for each location.

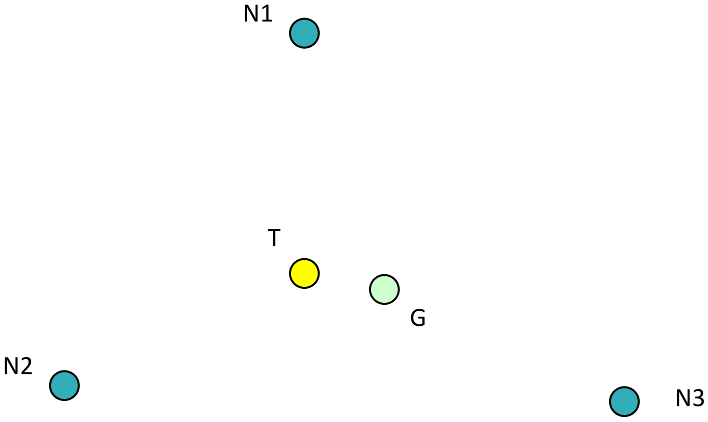


Figure : Multiple Nearest Neighbors
T – True Location
G – Guess
N1,N2,N3 - Neighbors

Empirical Method (Cntd.)

- Impact of Number of Samples
  - Accuracy obtained by all the samples can be obtained if only a few samples are taken

No. Of Real-Time Samples	Error Distance degradation
1	30%
2	11%
3	4%

- Impact of User Orientation
  - Off-line readings for all orientations is not feasible
  - Work around is to calculate the error distance for all combinations

Empirical Method (Cntd.)

- Tracking a Mobile User
  - Analogous to the user location problem
  - New Signal Strength data set
  - Window size of 10 samples
  - 4 Signal Strength Samples every second

- Limitation of Empirical Method
  - To start off with needs an initial signal strength data set
  - Relocation requires re-initialization of the initial data set

Radio Propagation Model

- Introduction
  - Alternative method for extracting signal strength information
  - Based on a mathematical model of indoor signal propagation
- Issues
  - Reflection, scattering and diffraction of radio waves
  - Needs some model to compensate for attenuation due to obstructions
- Models
  - Rayleigh Fading Model : Infeasible
  - Rician Distribution Model : Complex
  - Wall Attenuation Factor

Wall Attenuation Factor

$$P(d)[dBm] = P(d_o)[dBm] - 10n\log\left(\frac{d}{d_o}\right) - \begin{cases} nW * WAF & nW < C \\ C * WAF & nW \geq C \end{cases}$$

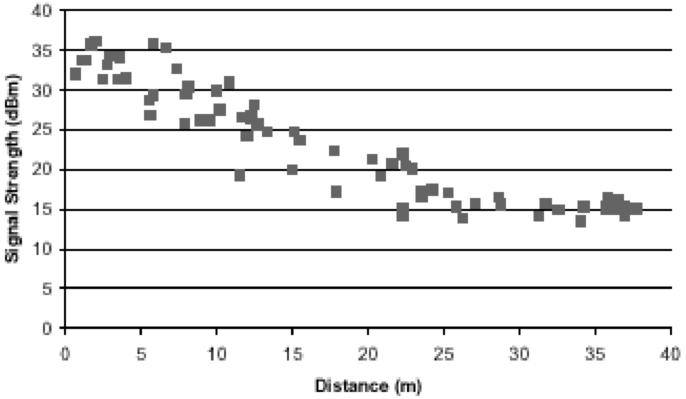


Figure 8 Effect of applying correction for intervening walls between the base station and the mobile user.

Radio Propagation Model (Cntd.)

- Advantages:
  - Cost Effective
  - Easily Relocated

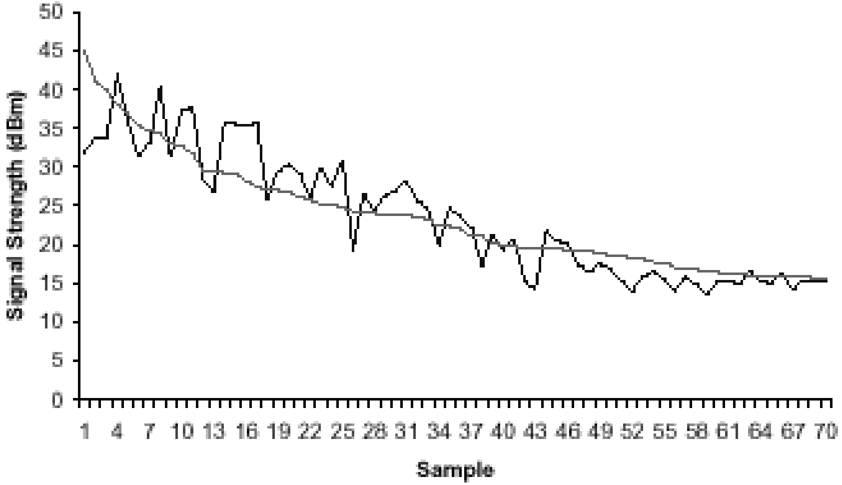


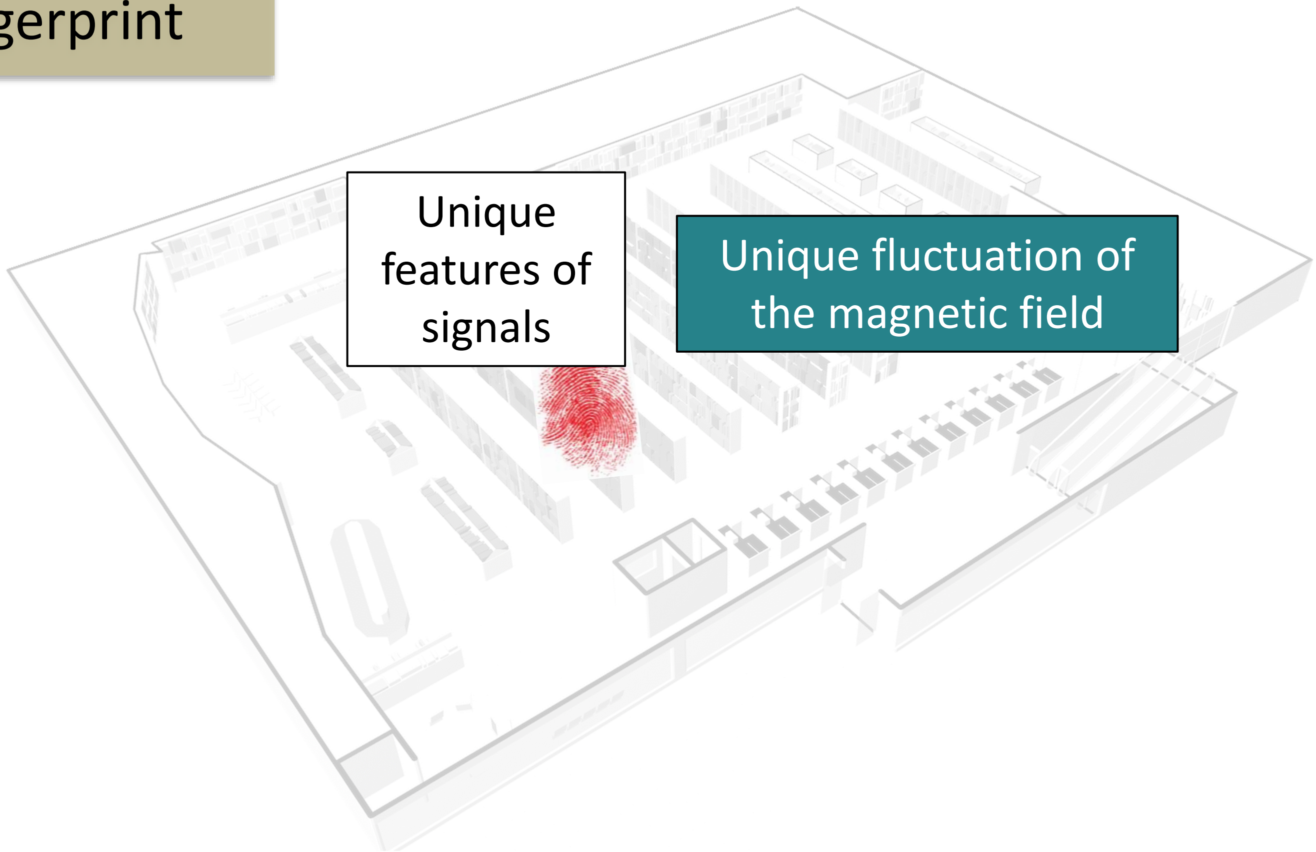
Figure 9 Predicted versus measured signal strength.

Conclusion

- RF-based user location and tracking algorithm is based on
  - Empirically measured signal strength model
    - Accurate
  - Radio Propagation Model
    - Easily relocated
- RADAR could locate users with high degree of accuracy
- Median resolution is 2-3 meters, which is fairly good
- Used to build “Location Services”
  - Printing to the nearest printer
  - Navigating through a building

- RF-based Fingerprinting: Radar
- RF and magnetic-based Fingerprinting

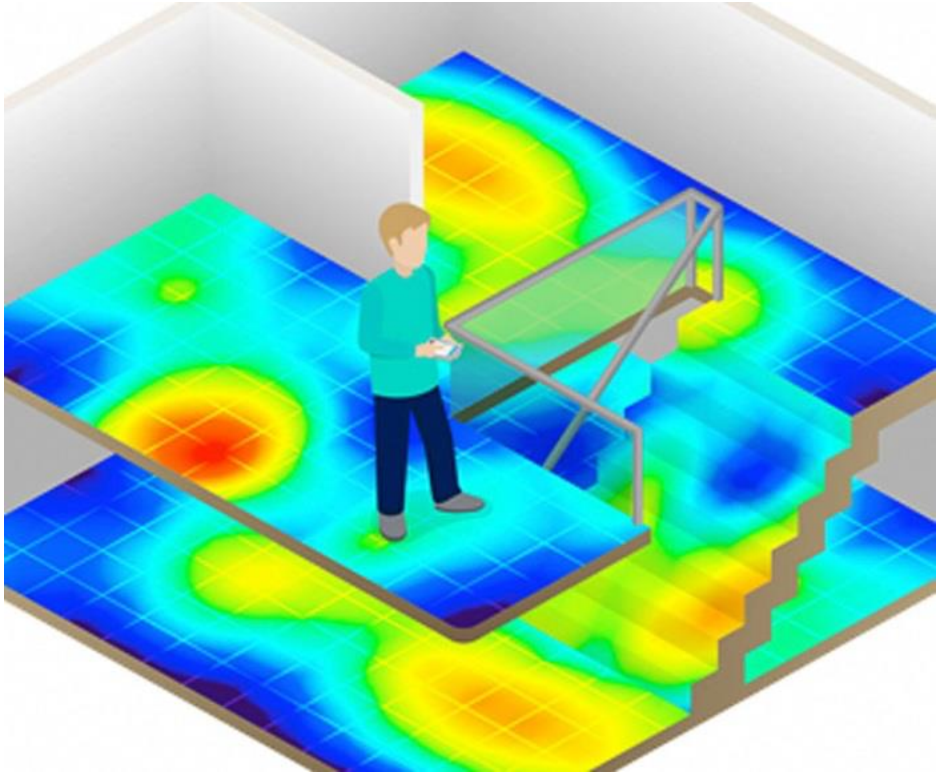
Fingerprint



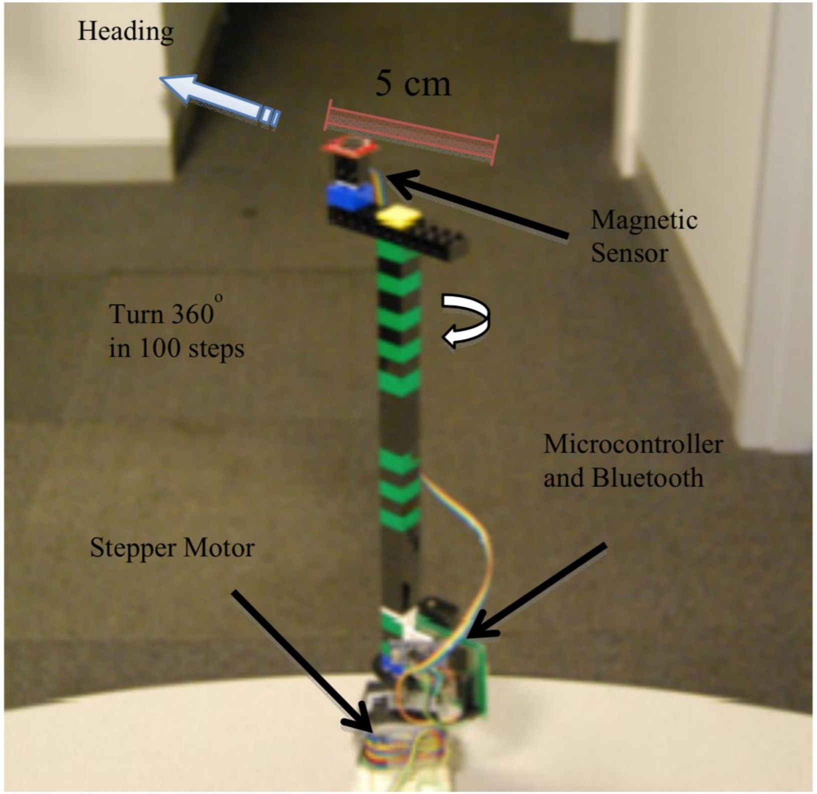
Indoor Location Sensing Using Geo-Magnetism

Jaewoo Chung et al, MIT Media Lab
MobiSys 2011

Indoor Location Sensing Using Geo-Magnetism



Indoor Location Sensing Using Geo-Magnetism



The client device for detecting magnetic signatures

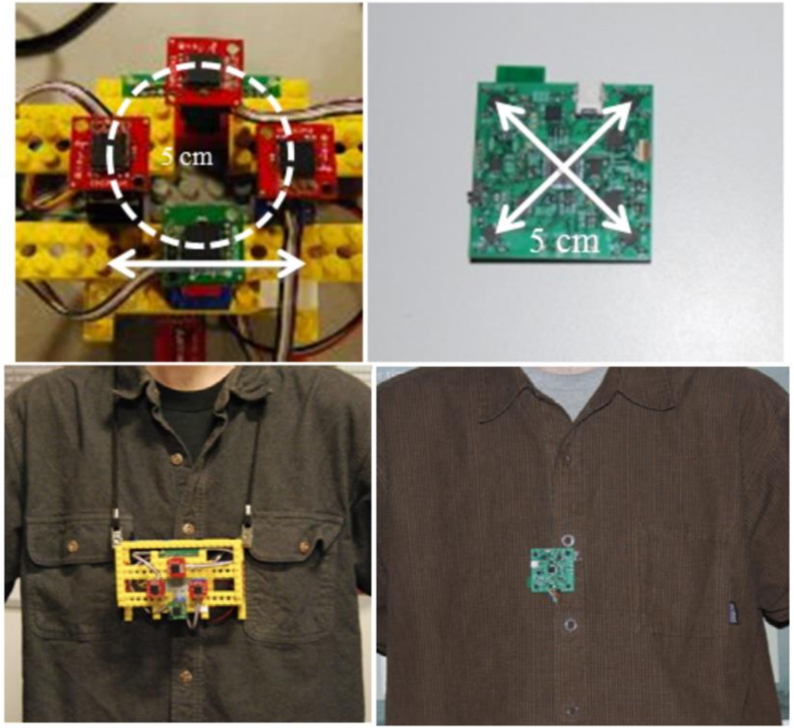
Indoor Location Sensing Using Geo-Magnetism

Database: <mag_x_i, mag_y_i, mag_z_i, Location_i>

Observation: <mag_x, mag_y, mag_z>

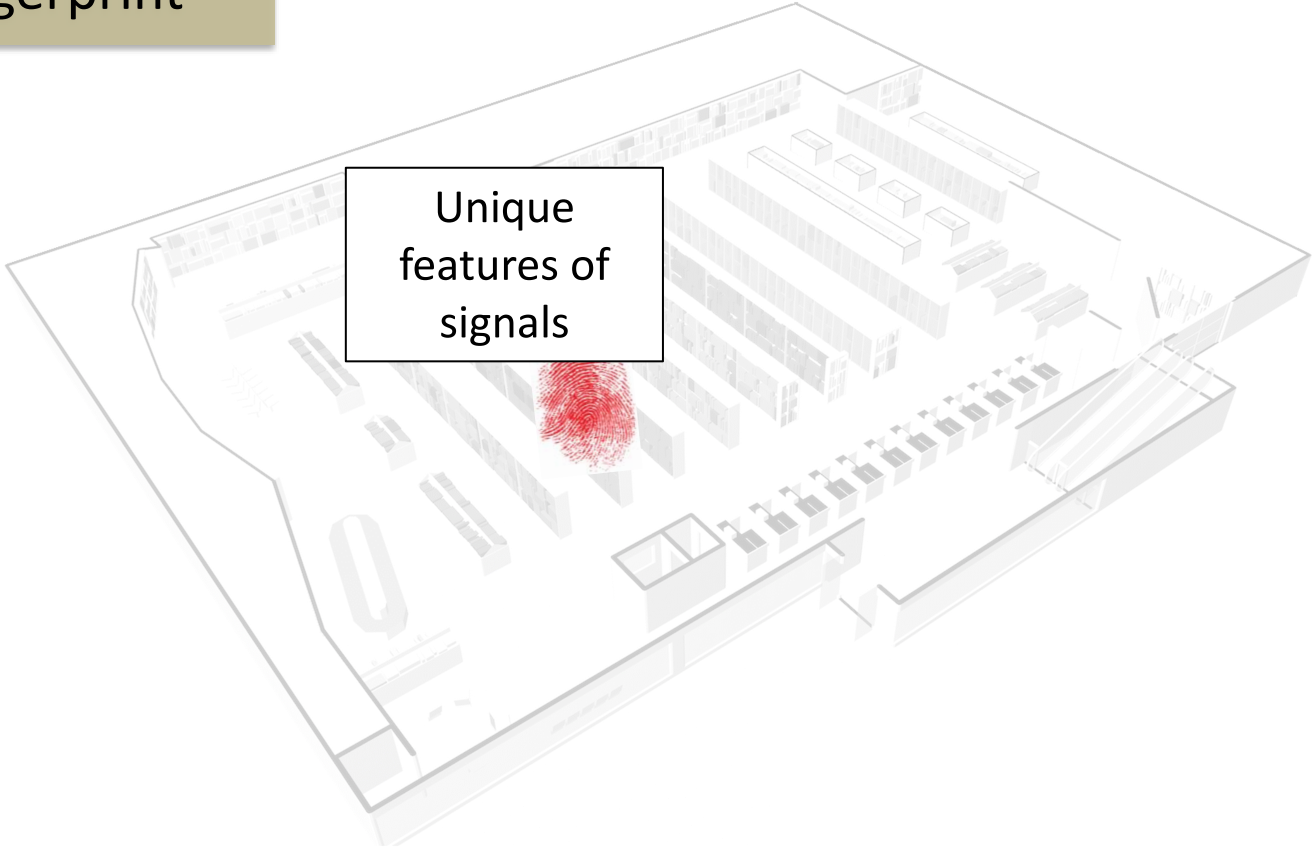
Find the ‘i’ (or a sequence) for which RMS difference between the observation and the stored magnetic value is minimum.

Indoor Location Sensing Using Geo-Magnetism

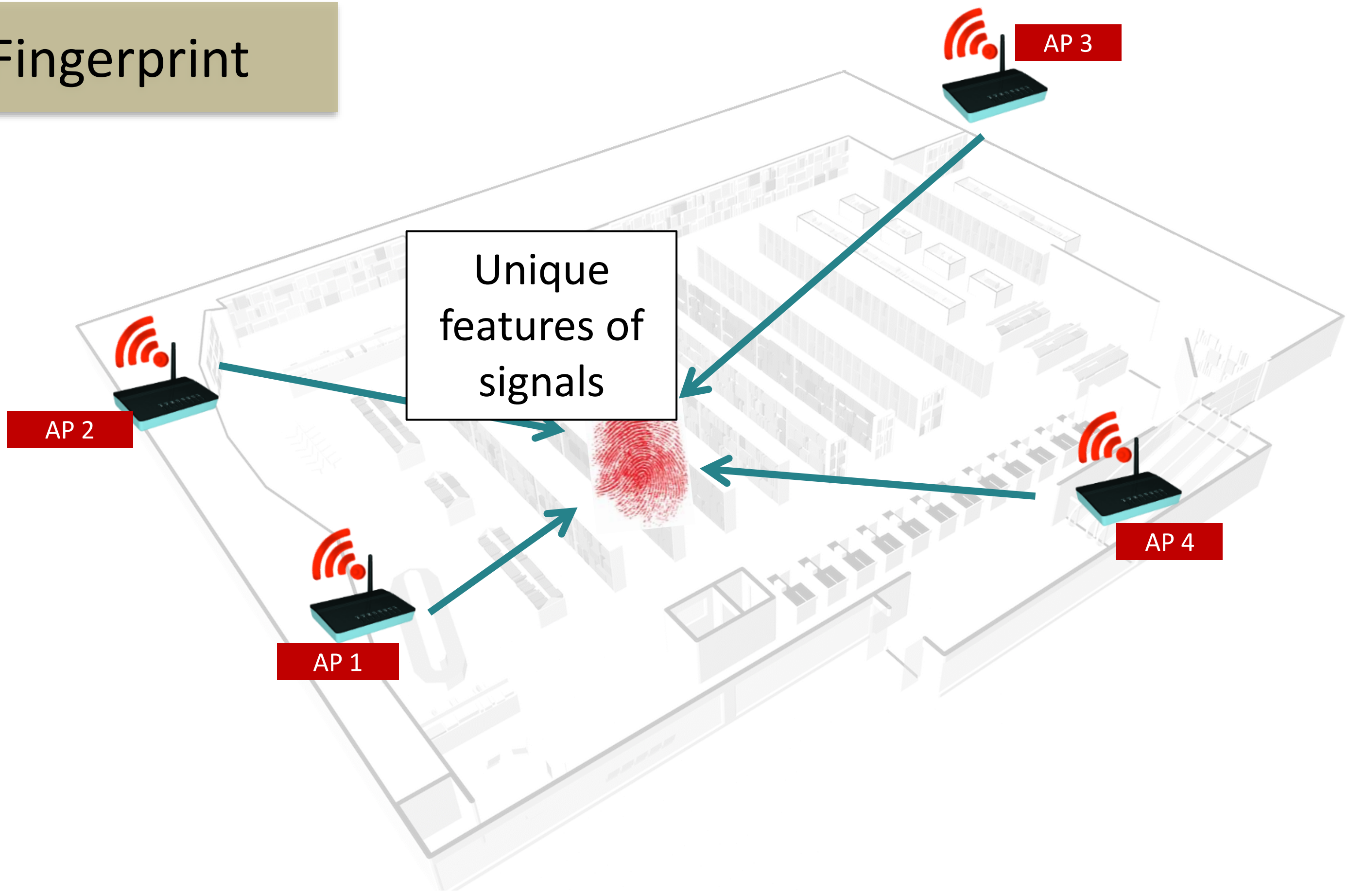


Wearable device for detecting fingerprints

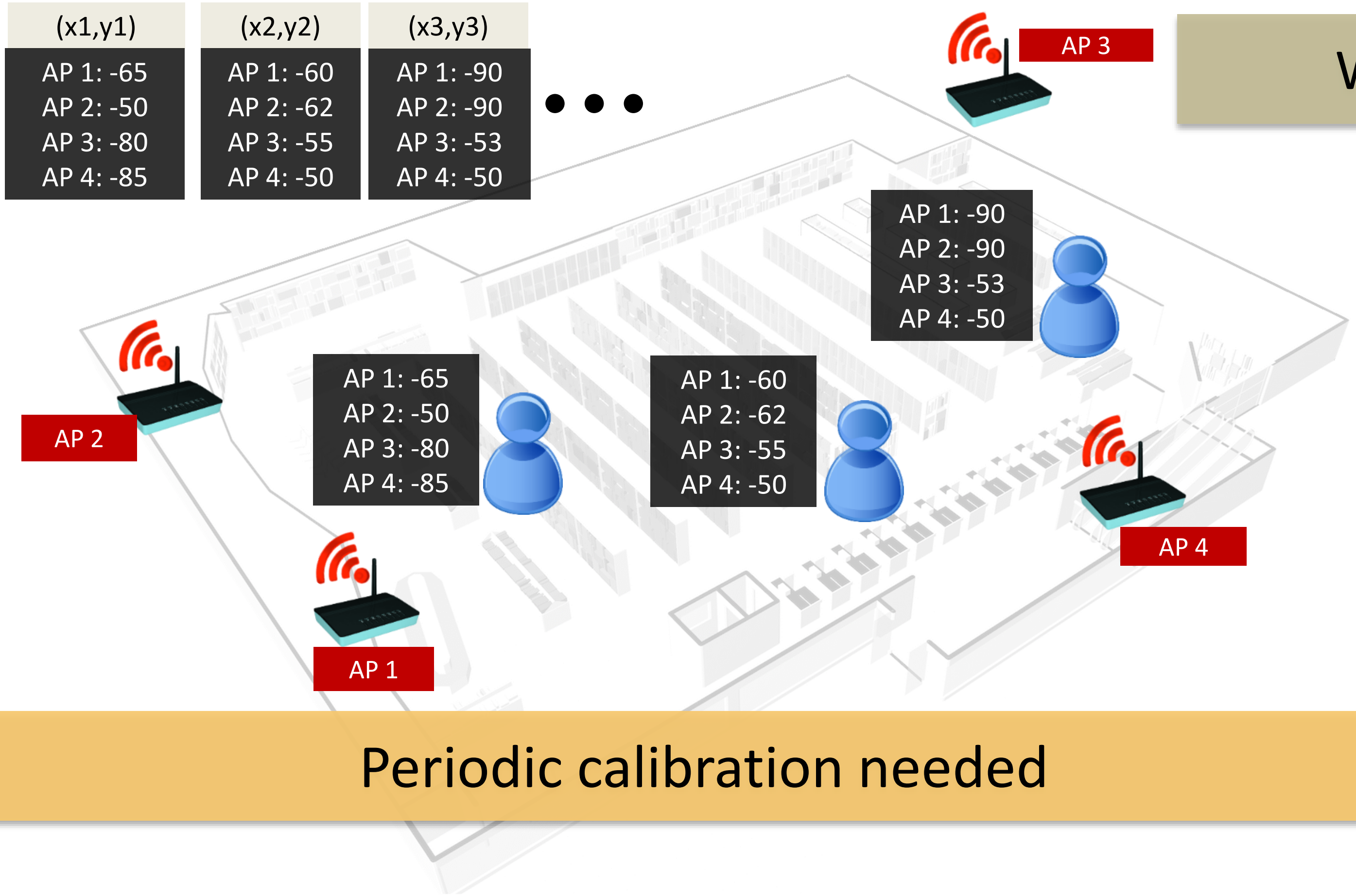
Fingerprint



Fingerprint

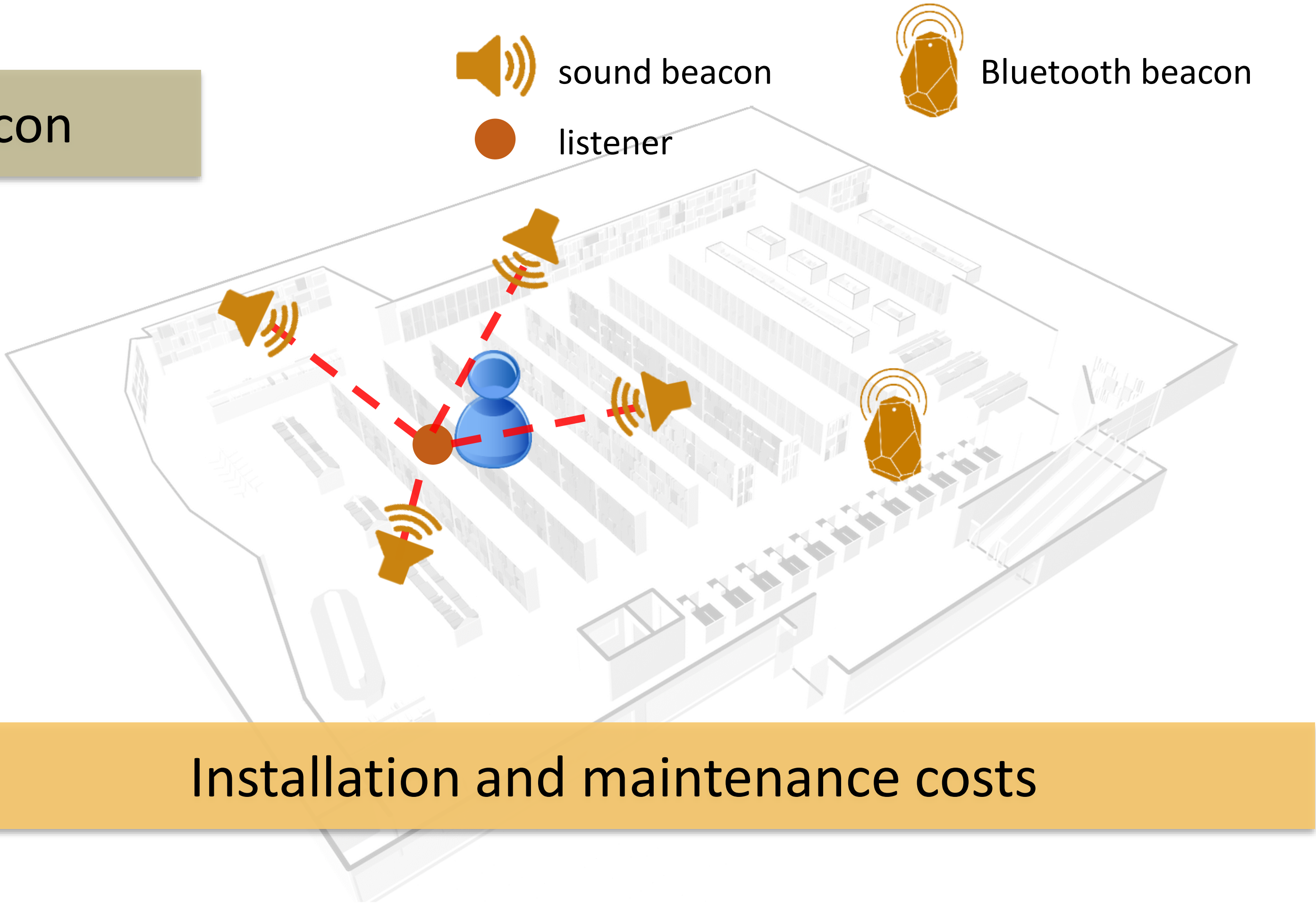


Wi-Fi



Periodic calibration needed

Beacon



Installation and maintenance costs

We do not want to rely on infrastructure

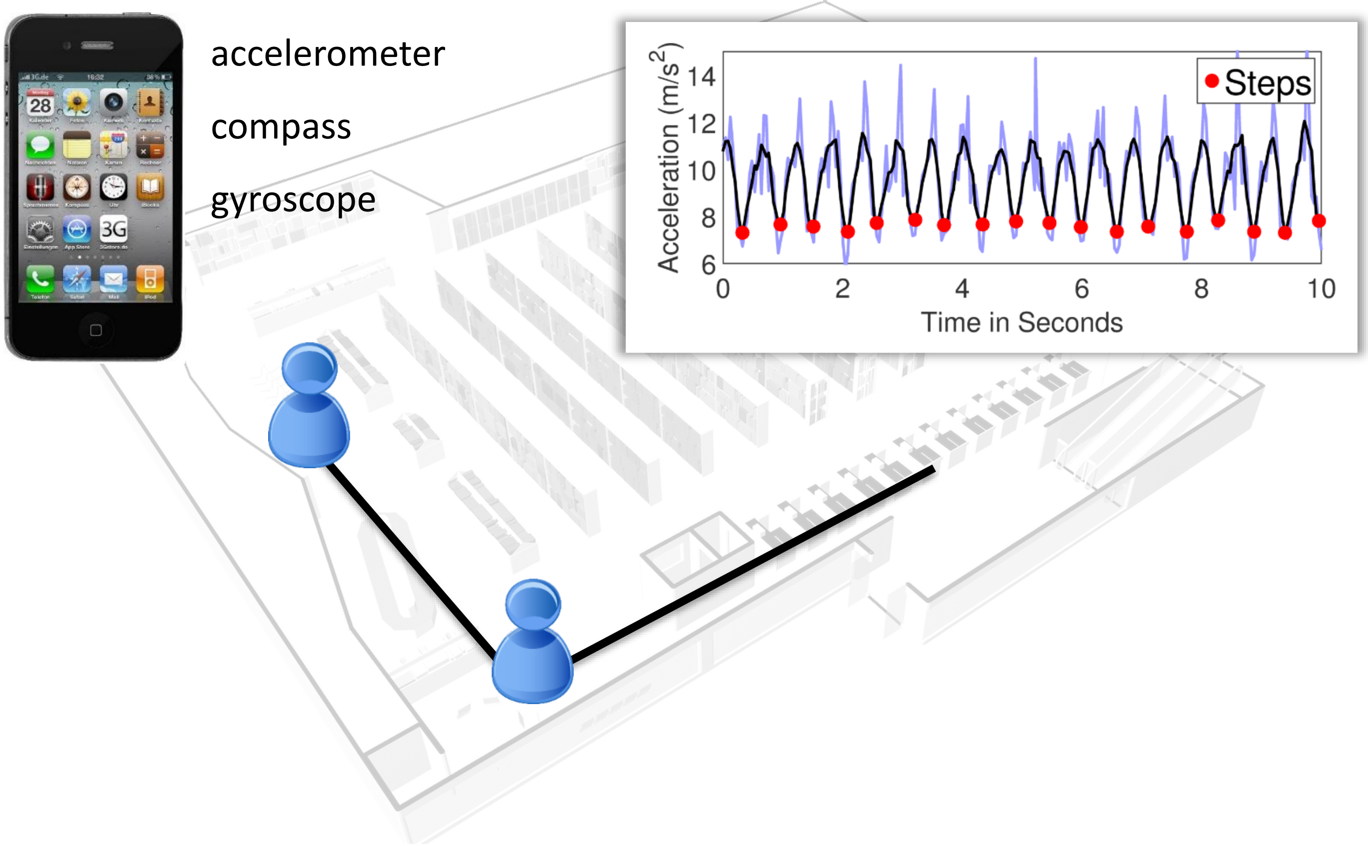
We want a scalable software solution

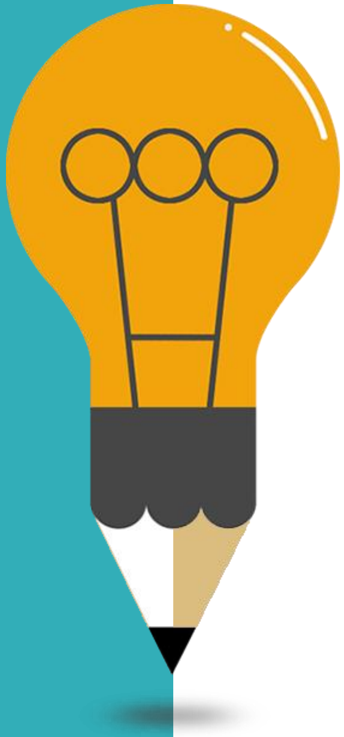
Infrastructure-less Localization

accelerometer

compass

gyroscope





Agenda

01 Wireless-based Solution

02 VLC-based Solution

03 Multi-Source based Solution

Wearables Can Afford: Light-weight Indoor Positioning with Visible Light

Zeyu Wang, Zhice Yang, Jiansong Zhang, Chenyu Huang,Qian Zhang

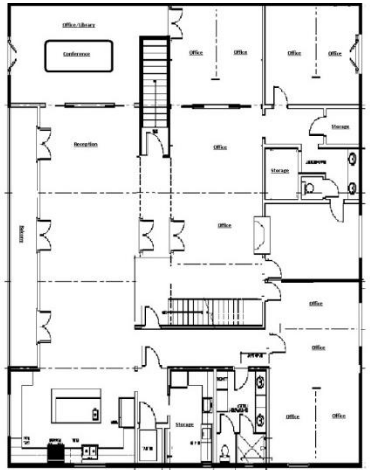
Hong Kong University of Science and Technology

Indoor Localization

- Fingerprinting: Use wireless signal (WiFi, FM, Sound, etc.) to construct the fingerprint map

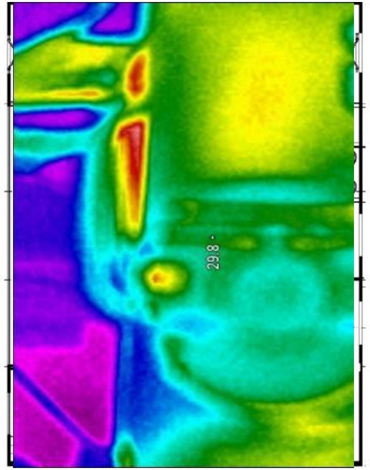
Indoor Localization

- Fingerprinting: Use wireless signal (WiFi, FM, Sound, etc.) to construct the fingerprint map



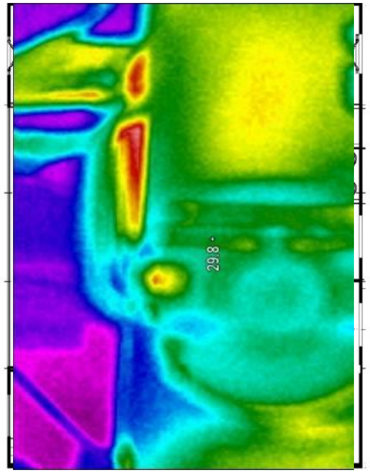
Indoor Localization

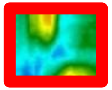
- Fingerprinting: Use wireless signal (WiFi, FM, Sound, etc.) to construct the fingerprint map



Indoor Localization

- Fingerprinting: Use wireless signal (WiFi, FM, Sound, etc.) to construct the fingerprint map



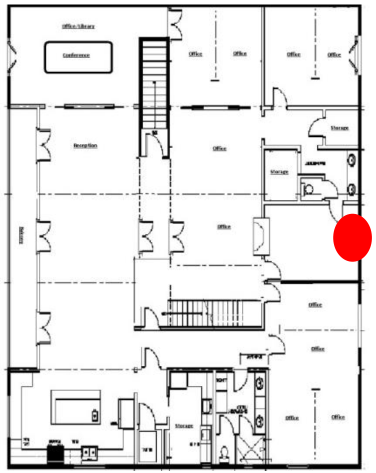


Indoor Localization

- Fingerprinting: Use wireless signal (WiFi, FM, Sound, etc.) to construct the fingerprint map
- Dead reckoning: Use inertial sensors to calculate moving path

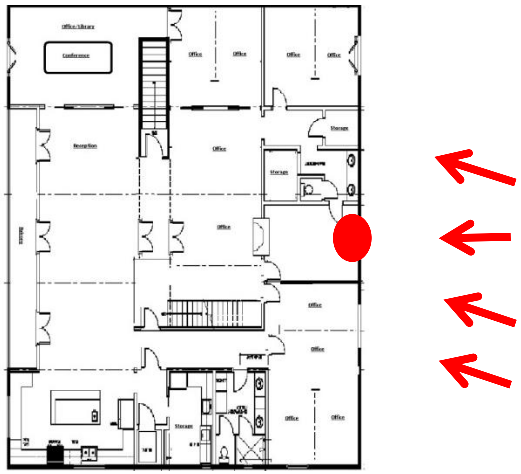
Indoor Localization

- Fingerprinting: Use wireless signal (WiFi, FM, Sound, etc.) to construct the fingerprint map
- Dead reckoning: Use inertial sensors to calculate moving path



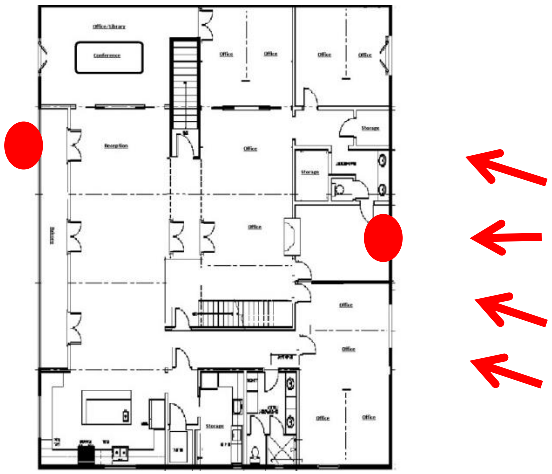
Indoor Localization

- Fingerprinting: Use wireless signal (WiFi, FM, Sound, etc.) to construct the fingerprint map
- Dead reckoning: Use inertial sensors to calculate moving path



Indoor Localization

- Fingerprinting: Use wireless signal (WiFi, FM, Sound, etc.) to construct the fingerprint map
- Dead reckoning: Use inertial sensors to calculate moving path



Indoor Localization

- Fingerprinting: Use wireless signal (WiFi, FM, Sound, etc.) to construct the fingerprint map
- Dead reckoning: Use inertial sensors to calculate moving path

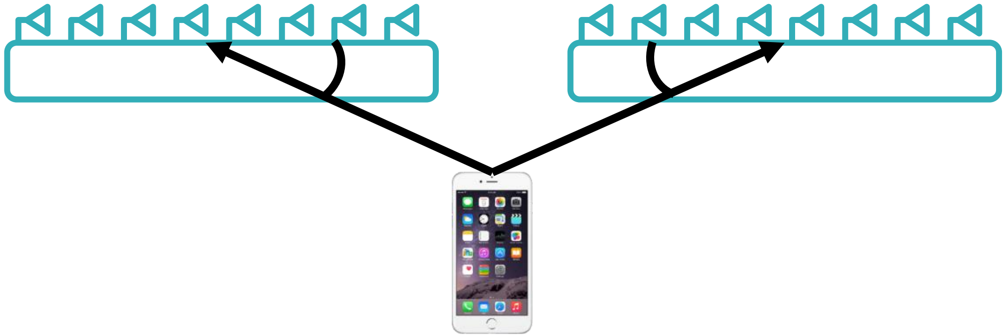
Accuracy is not enough
(~several meters)

Indoor Localization

- Fingerprinting: Use wireless signal (WiFi, FM, Sound, etc.) to construct the fingerprint map
- Dead reckoning: Use inertial sensors to calculate moving path
- Dedicated localization infrastructure

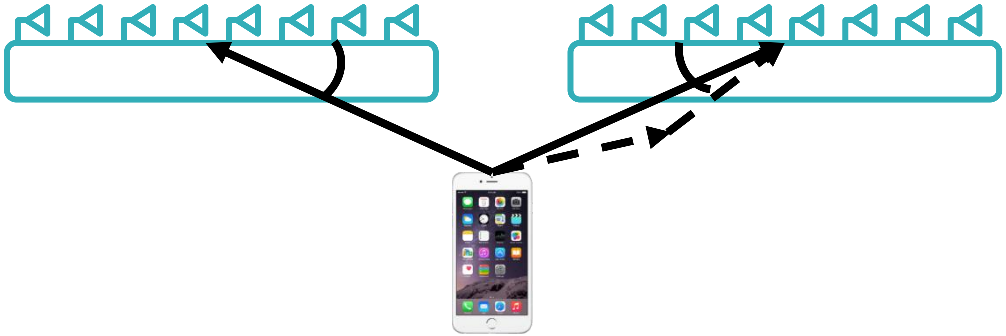
Indoor Localization

- Fingerprinting: Use wireless signal (WiFi, FM, Sound, etc.) to construct the fingerprint map
- Dead reckoning: Use inertial sensors to calculate moving path
- Dedicated localization infrastructure



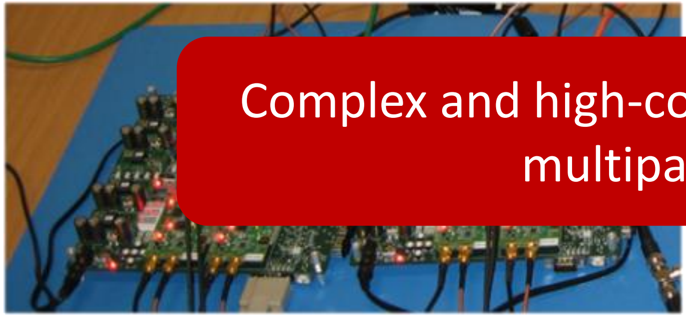
Indoor Localization

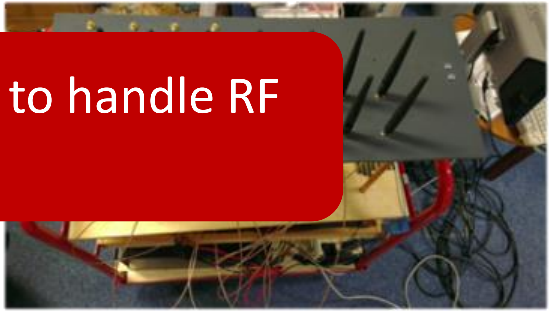
- Fingerprinting: Use wireless signal (WiFi, FM, Sound, etc.) to construct the fingerprint map
- Dead reckoning: Use inertial sensors to calculate moving path
- Dedicated localization infrastructure



Indoor Localization

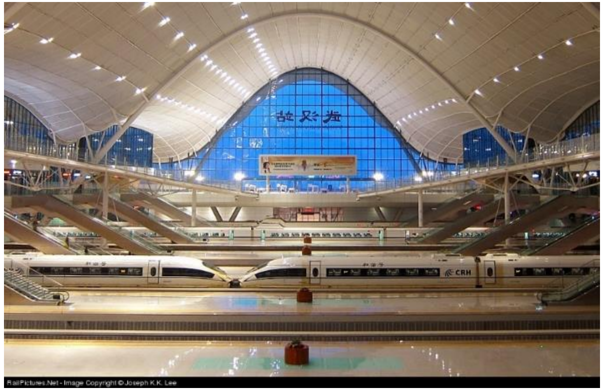
- Fingerprinting: Use wireless signal (WiFi, FM, Sound, etc.) to construct the fingerprint map
- Dead reckoning: Use inertial sensors to calculate moving path
- Dedicated localization infrastructure

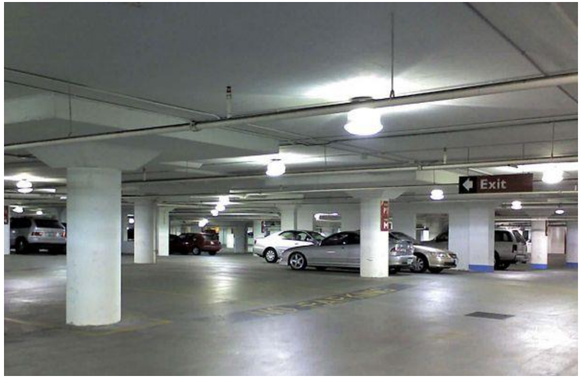




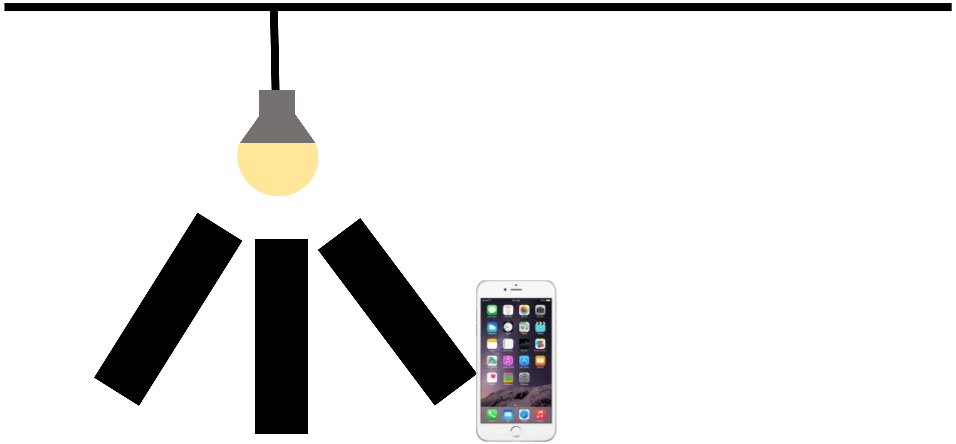
Complex and high-cost to handle RF multipath

Visible Light Positioning

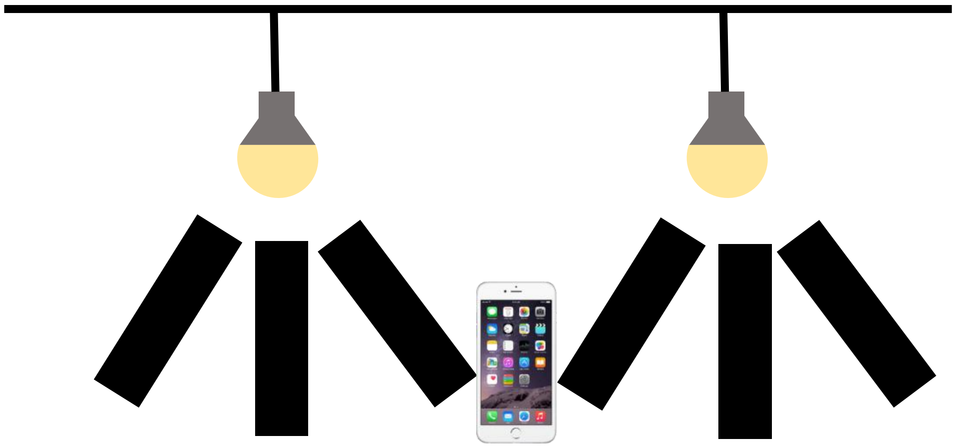




Visible Light Positioning



Visible Light Positioning

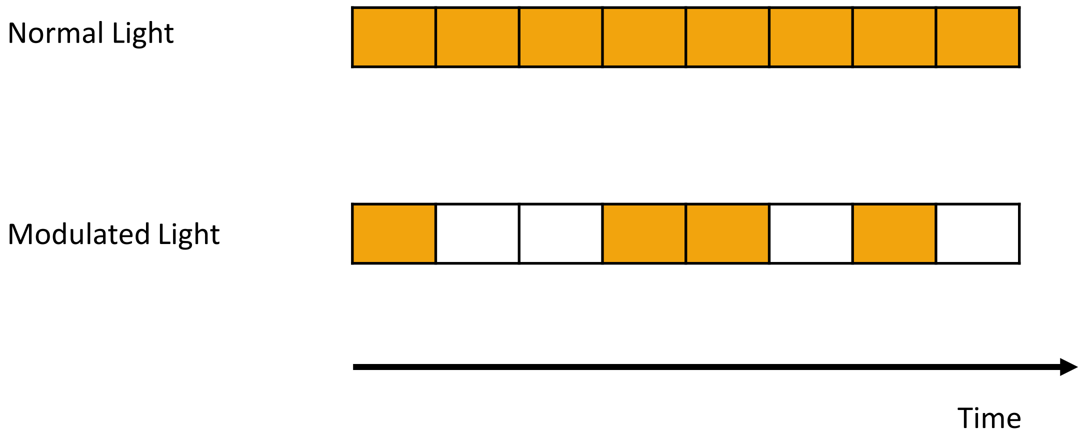


Visible Light Positioning

- Visible Light Positioning (VLP) is an emerging positioning technique that based Visible Light Communication (VLC)
  - Light bulbs are densely deployed
    - ➢ Location anchors are ubiquitous
  - Light beam is very directional
    - ➢ No multipath, localization is simple and accurate
  - More…
    - Light is free of radio wave
    - Positioning through light bulbs is green in energy

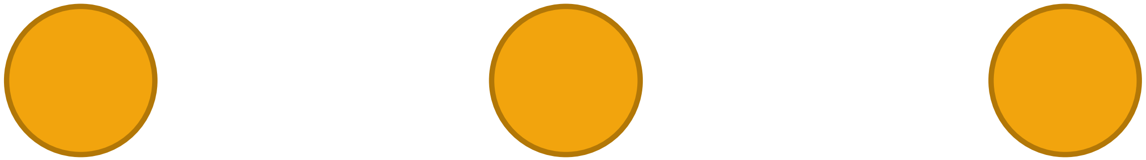
How VLC generally works?

- Modulate Light Intensity



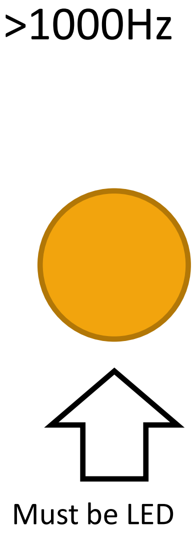
Problem in VLC: Flickering

10Hz 100Hz >1000Hz



Consequence: Overhead in Client

- Additional Receiving Device
  - Using customized light sensor that requires cumbersome calibration[1]
- High Computational Overhead
  - Using very high resolution camera to extract the roller shuttering patterns[2]



These overhead can hardly be afforded in wearables.
Can they be eliminated?

[1] L. Li etc. “Epsilon: A visible light based positioning system” in NSDI’14
[2] Y.-S. Kuo etc. “Luxapose: Indoor positioning with mobile phones and visible light” in Mobicom’14

Idea: Flickering-free Modulation

- Instead of changing the intensity, we modulate information by changing the polarization of light
  - Human eyes CANNOT perceive changes in polarization

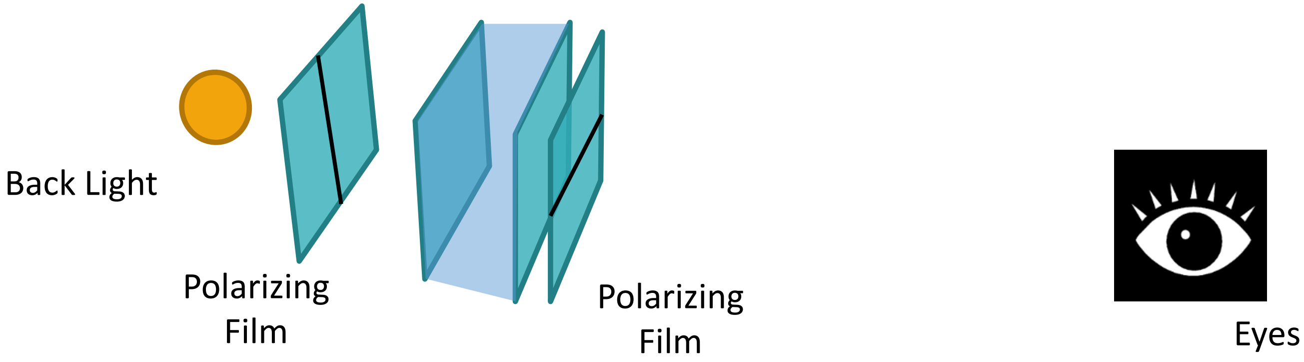
Therefore low baud rate in transmitters

Therefore low decoding overhead in clients

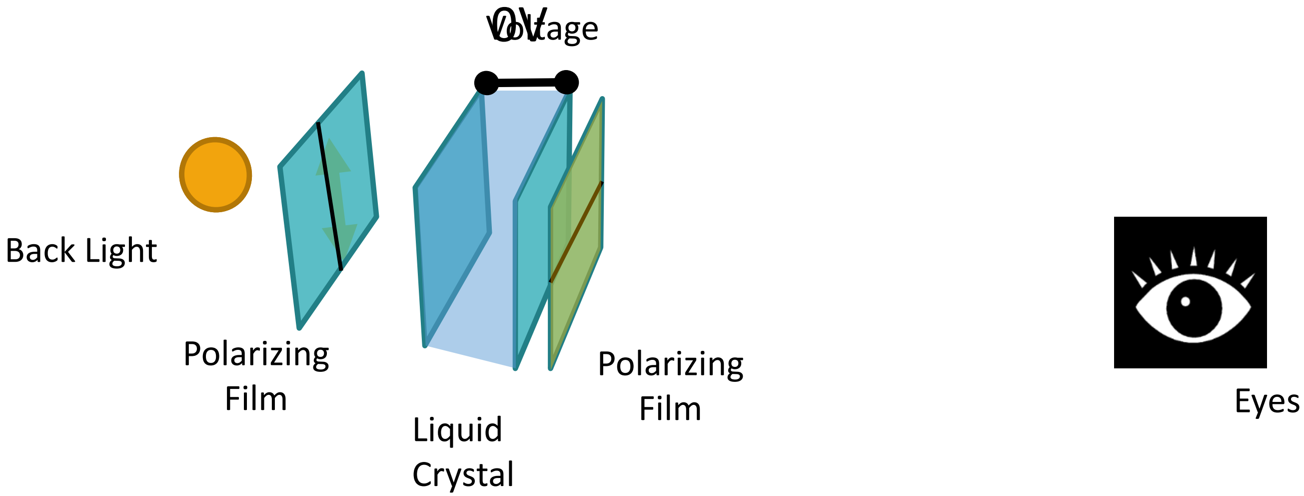
PIXEL

Review the display mechanism of LCD !

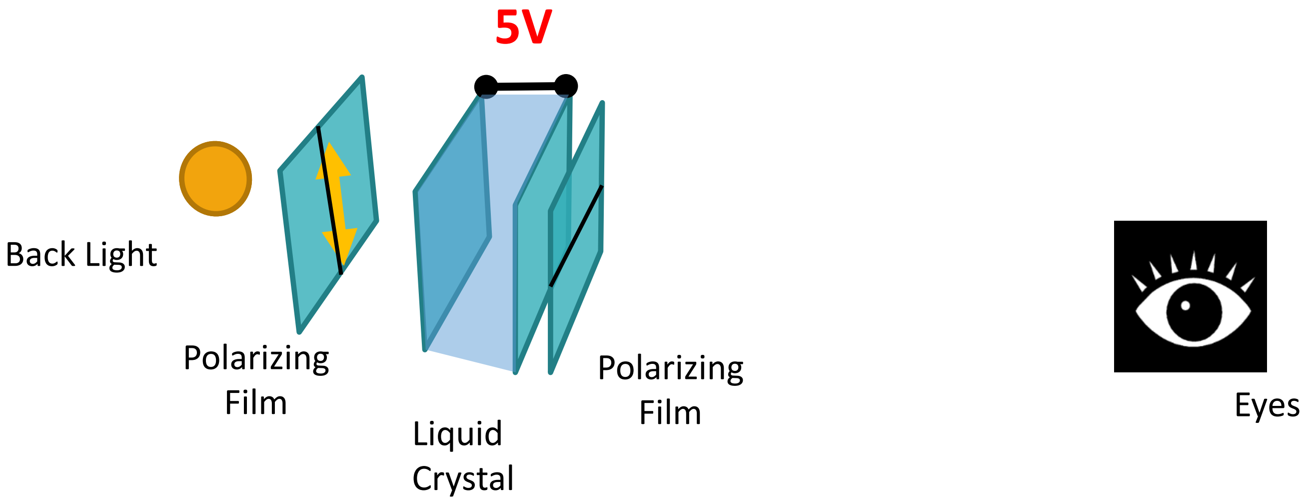
PIXEL: One Pixel from LCD



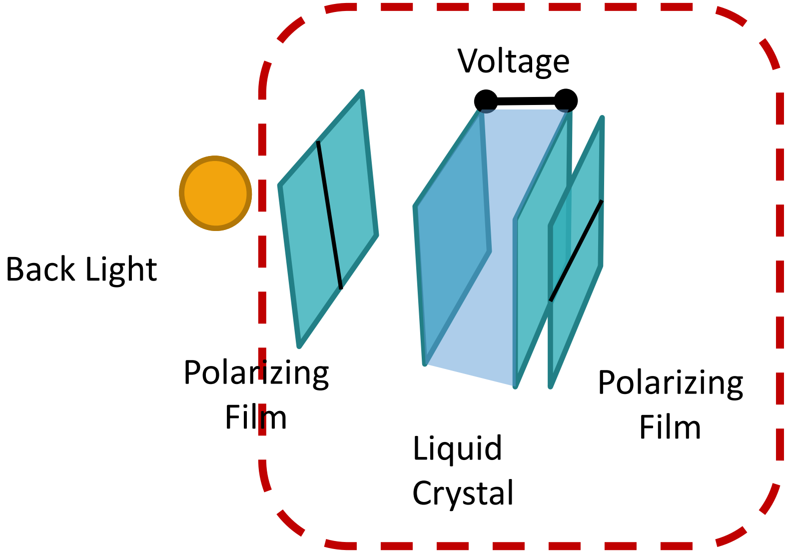
PIXEL: One Pixel from LCD



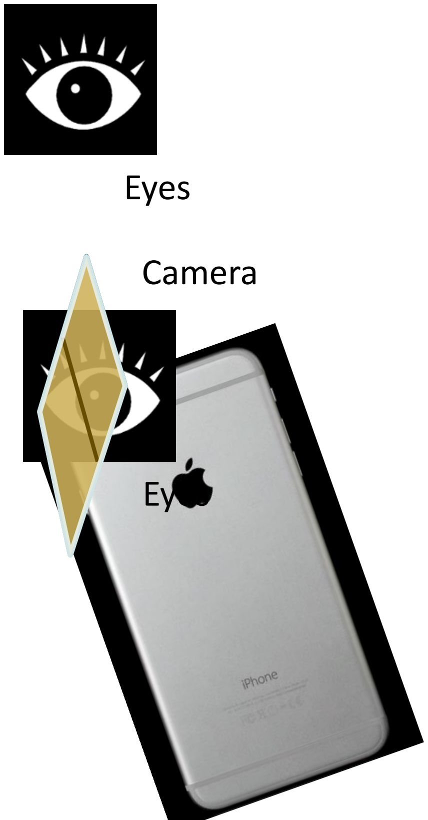
PIXEL: One Pixel from LCD



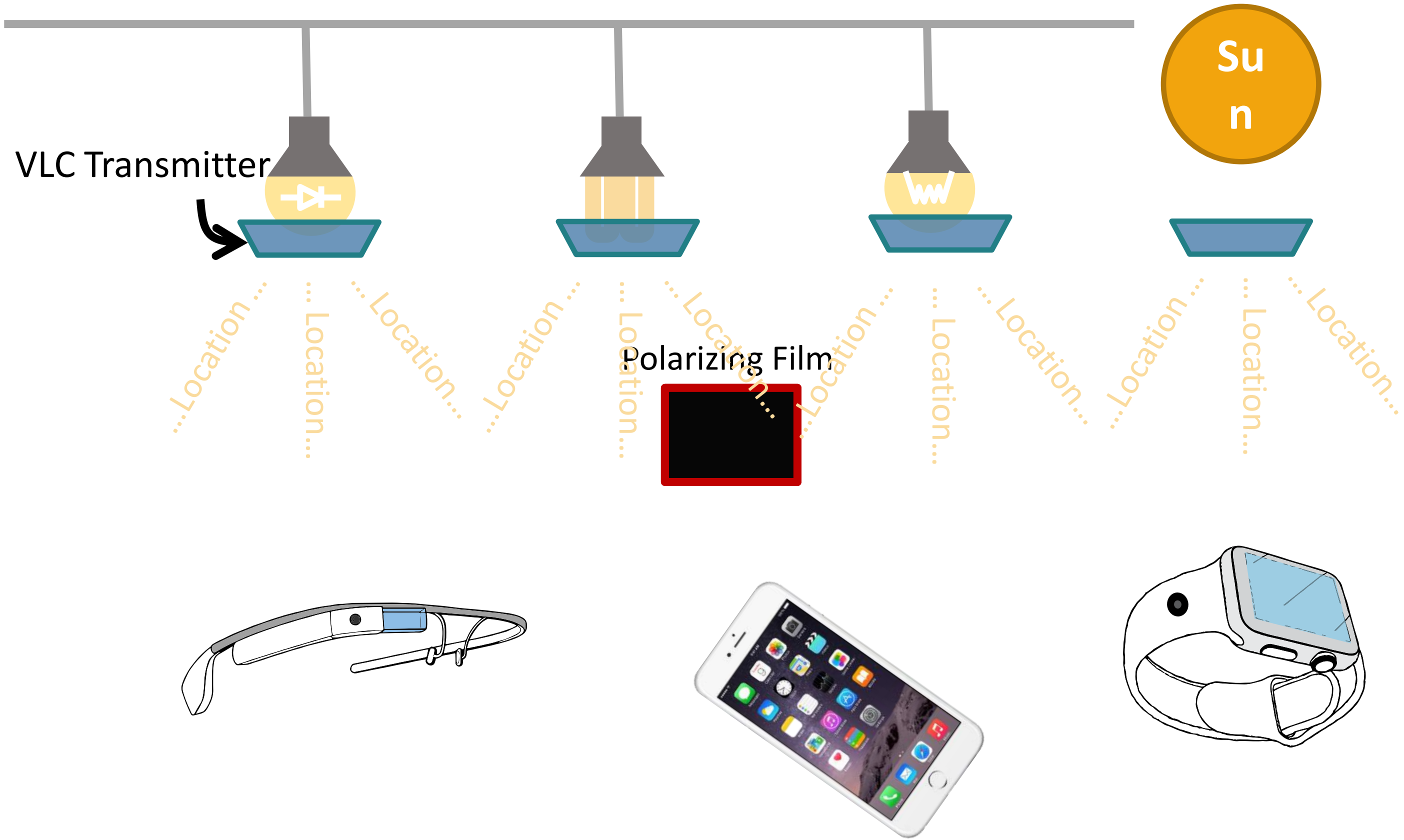
PIXEL: VLC Transmitter



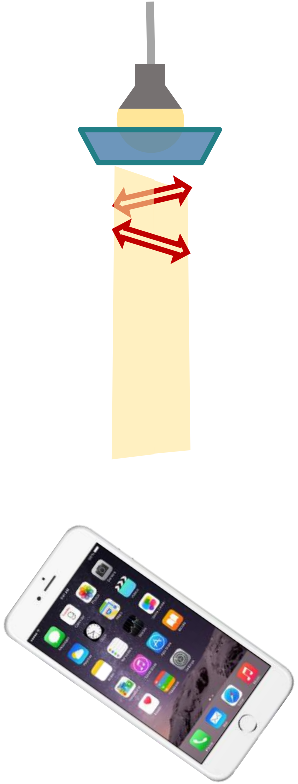
VLC Transmitter



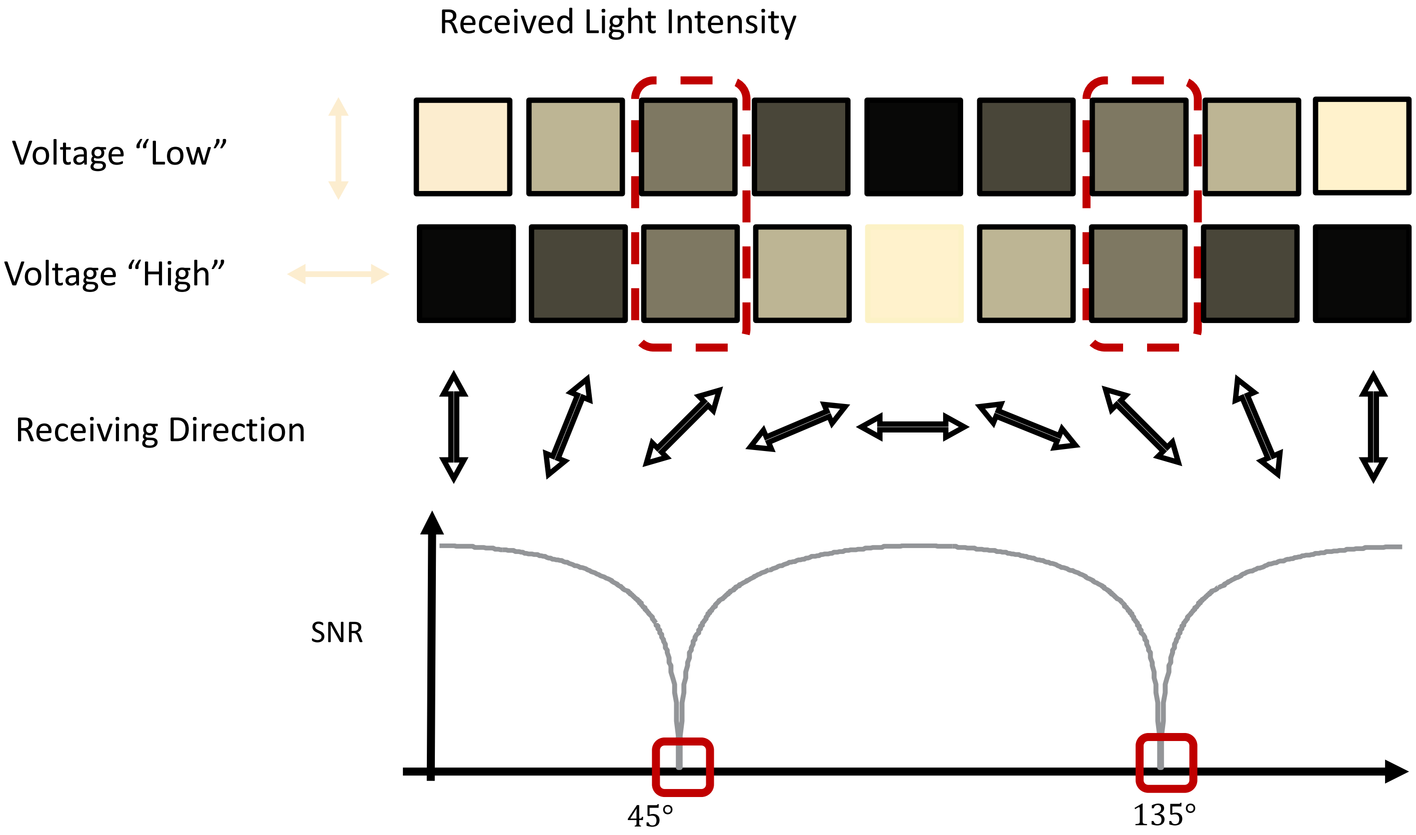
PIXEL: VLP Architecture



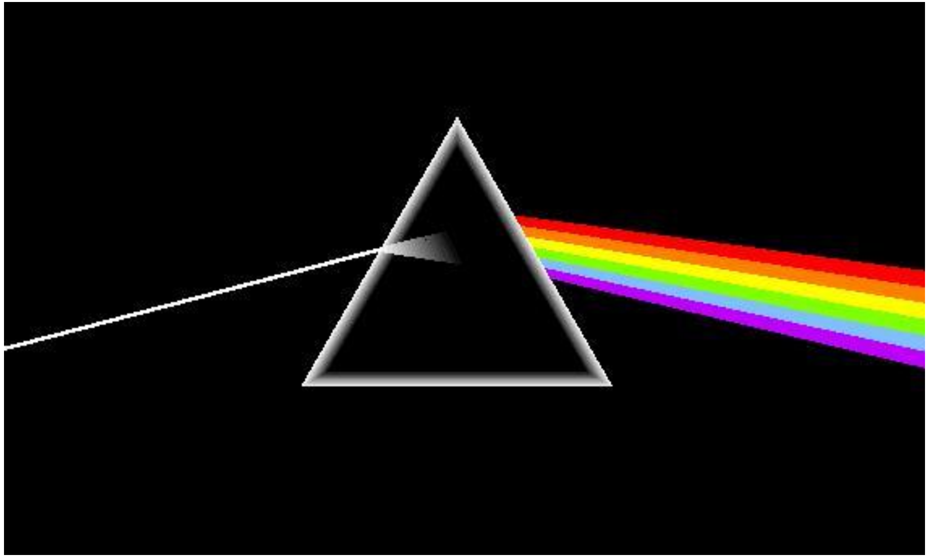
Challenge: User Mobility



Challenge: User Mobility (Cont.)

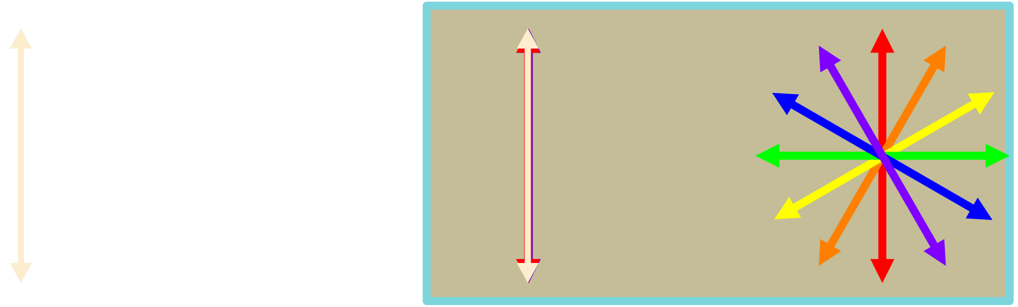


Solution: Dispersion



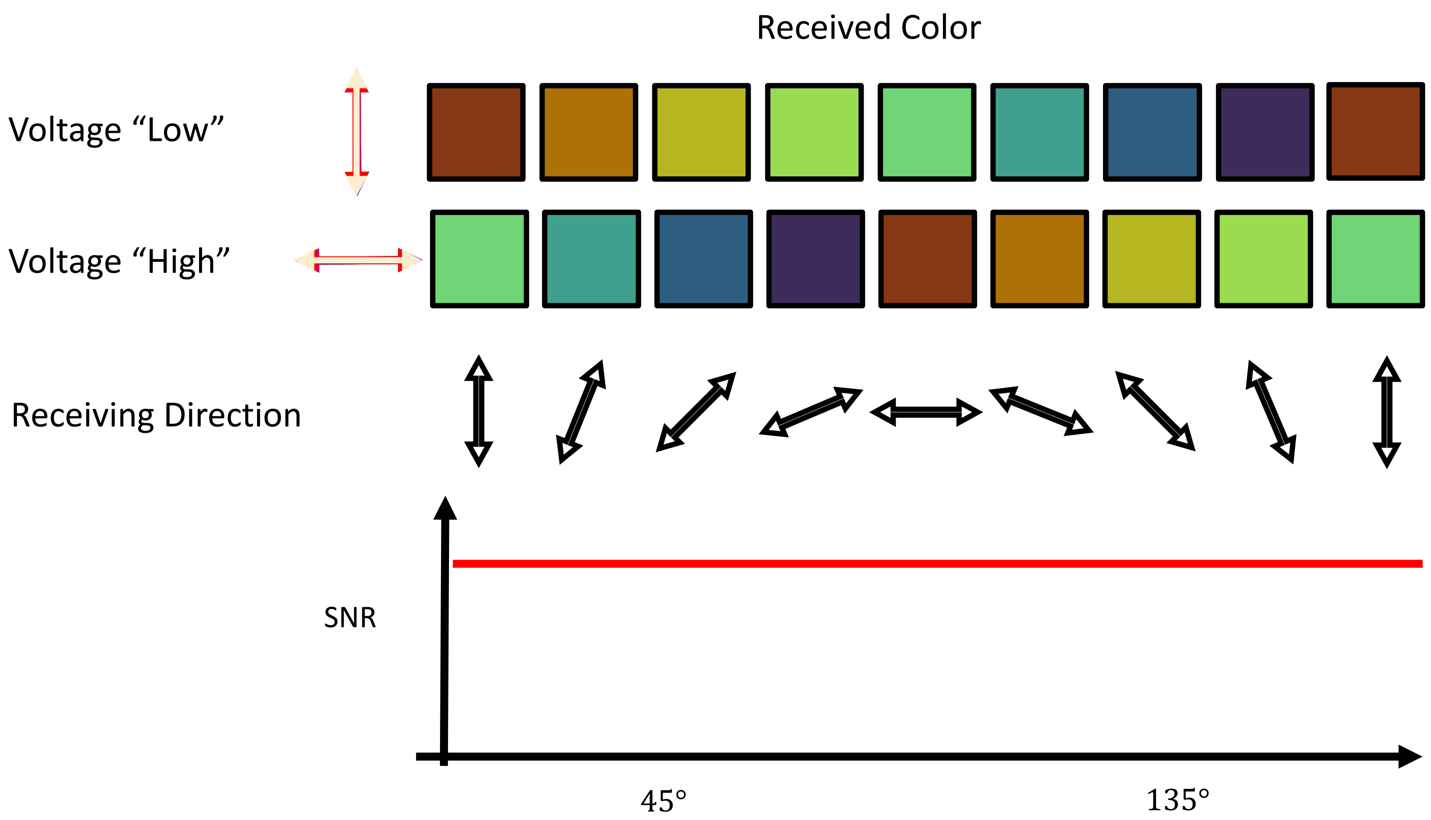
Solution: Dispersion (Cont.)

Disperse the Polarization of Different Colors in to Different Directions



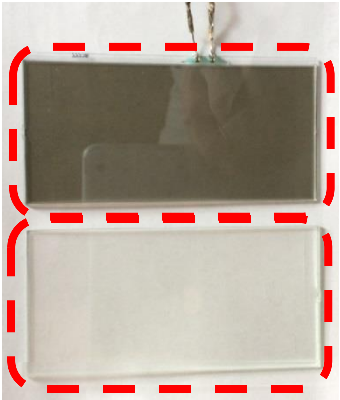
Dispersor

Solution: Dispersion (Cont.)



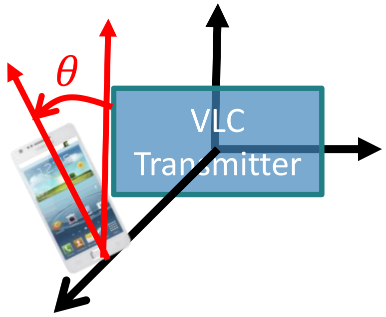
Implementation

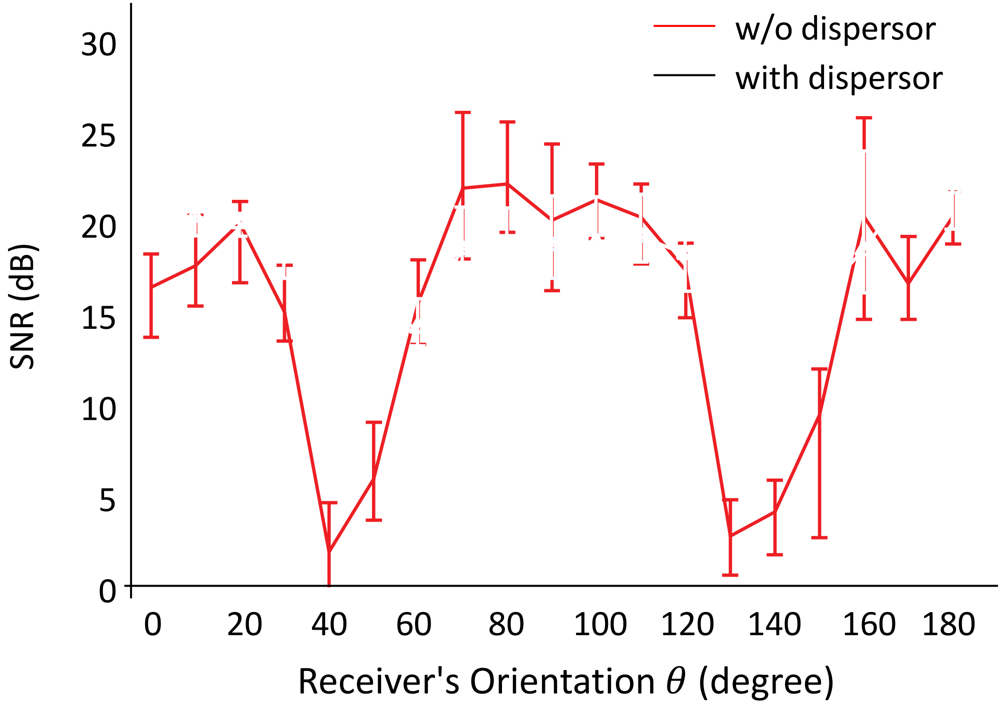
- VLC Transmitter
  - Polarizing film (\$0.001/cm^2)
  - LCD with only one pixel (\$0.03/cm^2)
  - Glass box with optical rotation liquid
  - 14Hz Baud Rate
  - Location Beacon
    - 5bit Preamble + 8bit Location ID + 4bit CRC



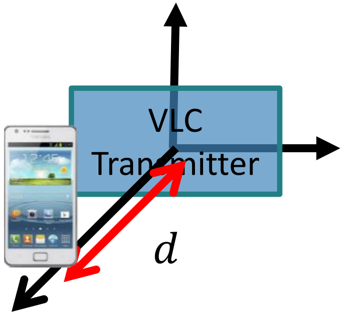
- Client
  - Polarizing film (\$0.001/cm^2)
  - Android App with VLC decoding and VLP algorithm
    - Smart phone: Galaxy S II (1.2GHz CPU, 8 Megapixel Camera)
    - Wearable: Google Glass

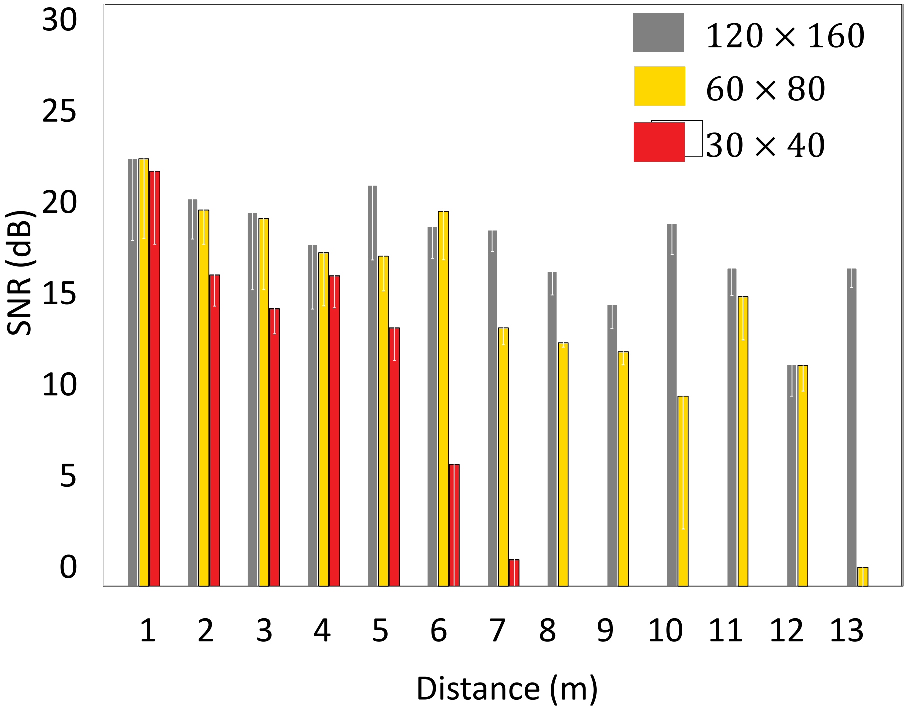
Evaluation-VLC



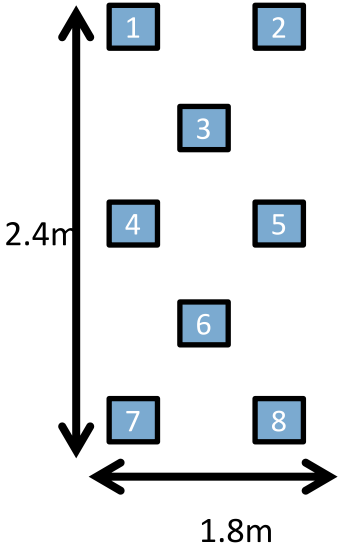


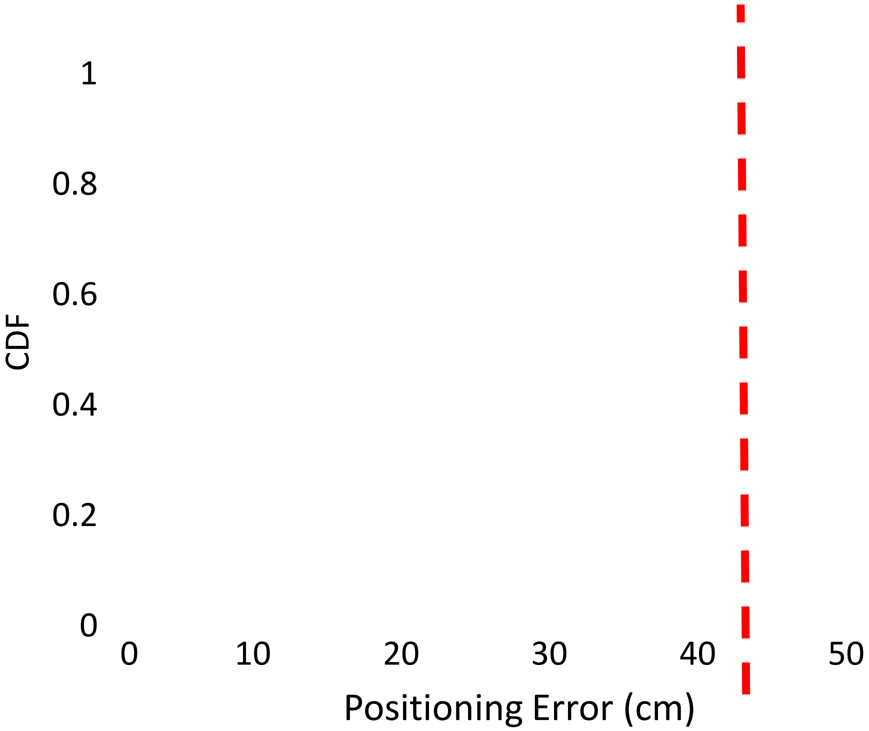
Evaluation-VLC



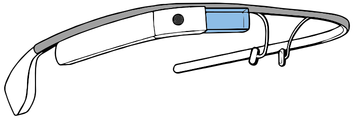


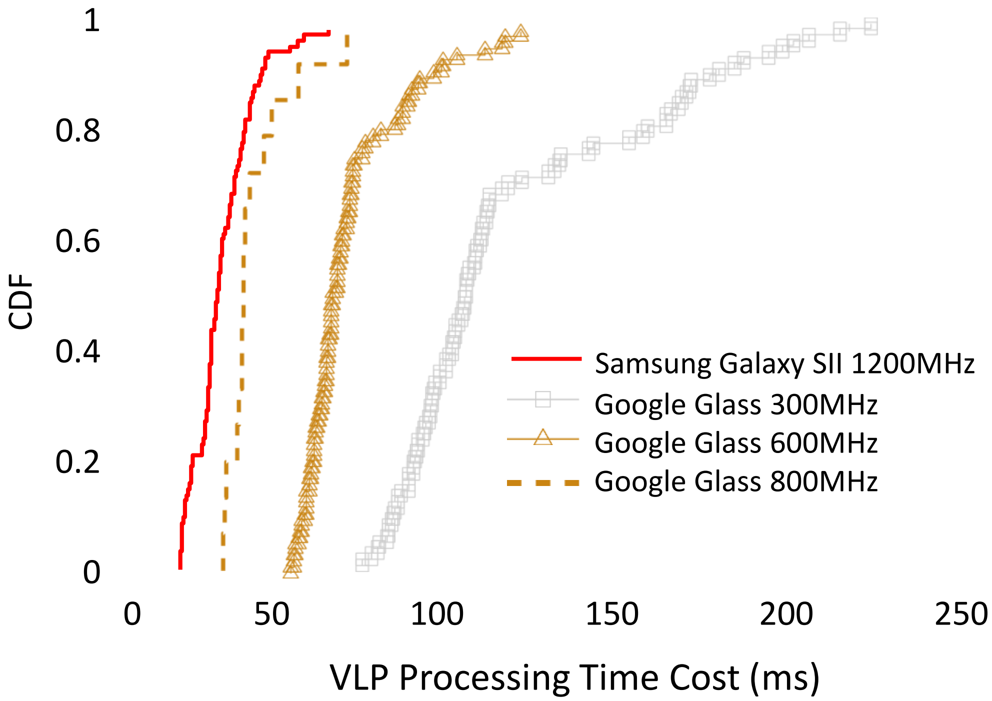
Evaluation-VLP





Evaluation-VLP

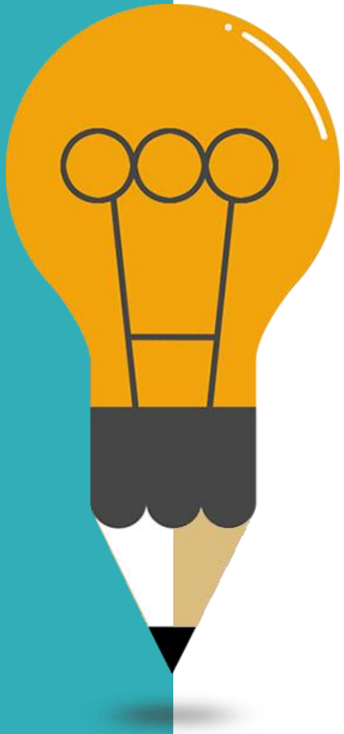




Conclusion

- We introduce a light weight VLC method that based on modulating light’s polarization
- We propose to use optical rotation material/dispersor to hand users’ mobility
- We implement and evaluate the VLP system, and results show submeter accuracy can be achieved in both smart phone and wearables.

Agenda



01 Wireless-based Solution

02 VLC-based Solution

03 Multi-Source based Solution

SurroundSense: Mobile Phone Localization via Ambience Fingerprinting

Ionut Constandache, Martin Azizyan and Romit Roy Choudhury

Context

Pervasive wireless connectivity

+

Localization technology

=

Location-based applications

Location-Based Applications (LBAs)

- For Example:
  - GeoLife shows grocery list when near Walmart
  - MicroBlog queries users at a museum
  - Location-based ad: Phone gets coupon at Starbucks

- iPhone AppStore: 3000 LBAs, Android: 500 LBAs

Location-Based Applications (LBAs)

- For Example:
  - GeoLife shows grocery list when near Walmart
  - MicroBlog queries users at a museum
  - Location-based ad: Phone gets coupon at Starbucks

- iPhone AppStore: 3000 LBAs, Android: 500 LBAs

- Location expresses context of user
  - Facilitates content delivery

As if Location is an IP address for content delivery

Thinking about Localization

from an application perspective…

Emerging location based apps need
place of user, not physical location

Starbucks, RadioShack, Museum, Library

Latitude, Longitude

We call this Logical Localization …

Can we convert from

Physical to Logical Localization?

Can we convert from Physical to Logical Localization?

State of the Art in Physical Localization:

1. GPS	Accuracy: 10m
2. GSM	Accuracy: 100m
3. Skyhook (WiFi+GPS+GSM)	Accuracy: 10m-100m

Can we convert from Physical to Logical Localization?

State of the Art in Physical Localization:

1. GPS	Accuracy: 10m
2. GSM	Accuracy: 100m
3. Skyhook (WiFi+GPS+GSM)	Accuracy: 10m-100m

Widely-deployable localization technologies have errors in the range of several meters

Several meters of error is inadequate to logically localize a phone

Several meters of error is inadequate
to logically localize a phone

The dividing-wall problem

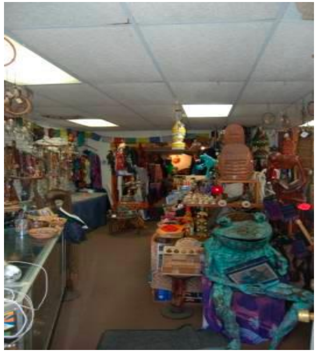
Contents

- SurroundSense
- Evaluation
- Conclusion

Hypothesis

It is possible to localize phones by sensing the ambience

such as sound, light, color, movement, WiFi …



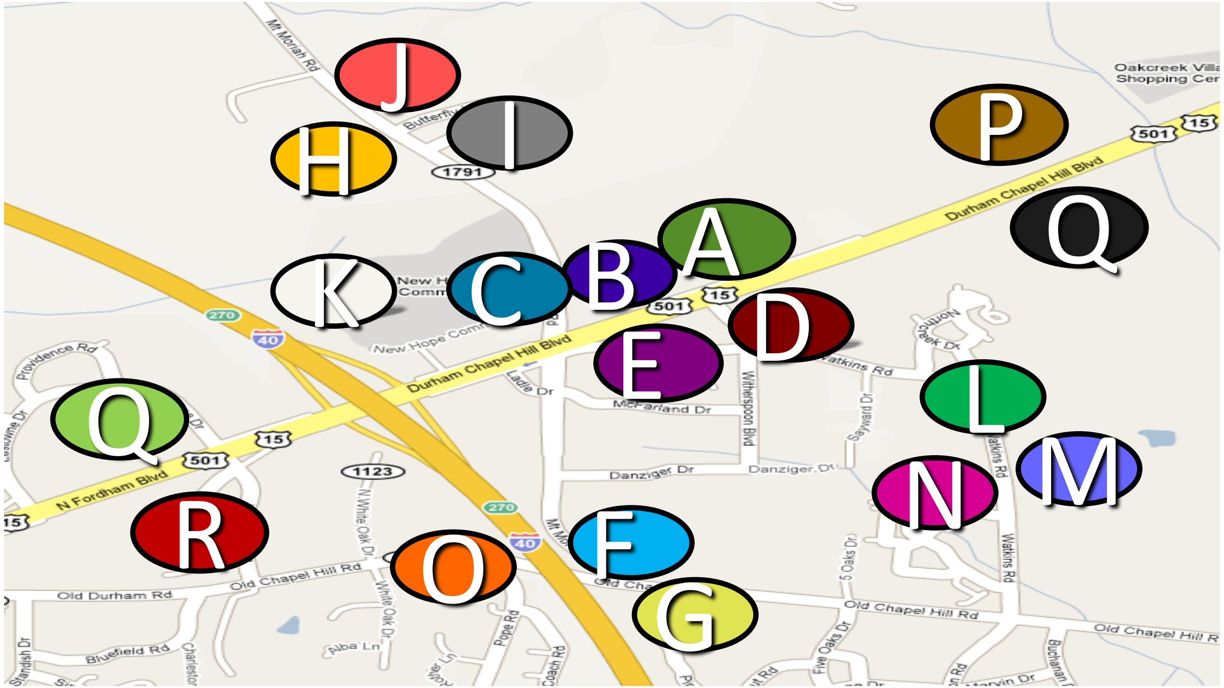
Sensing over multiple dimensions extracts more information from the ambience

Each dimension may not be unique,

but put together, they may provide a

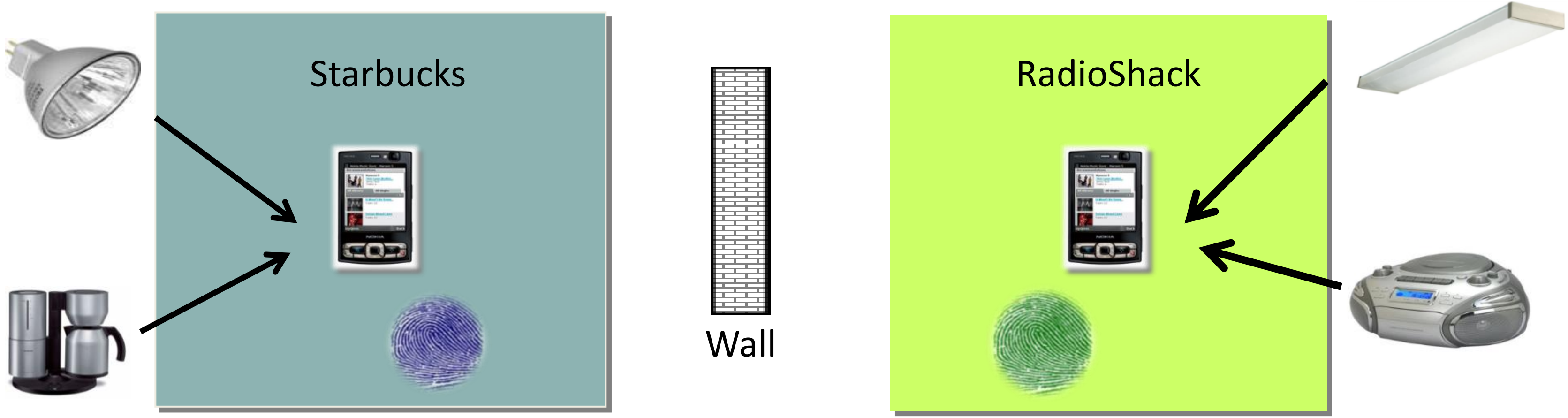
unique fingerprint

Should Ambiences be Unique Worldwide?



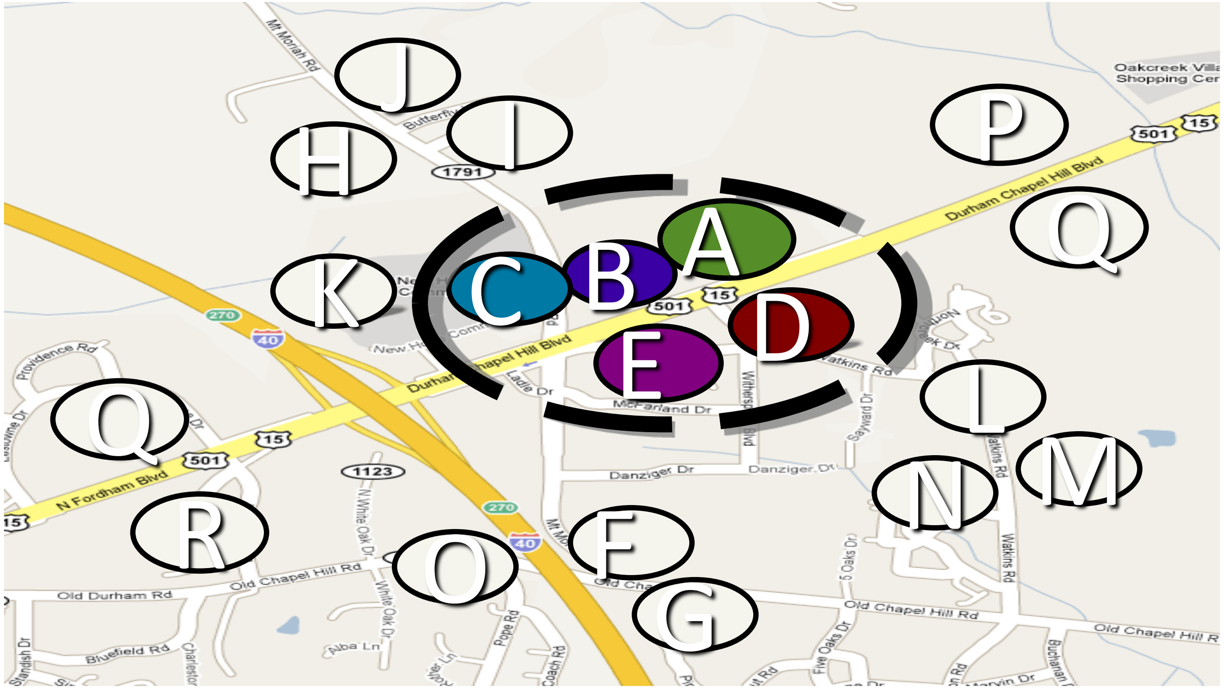
SurroundSense

- Multi-dimensional fingerprint
  - Based on ambient sound/light/color/movement/WiFi

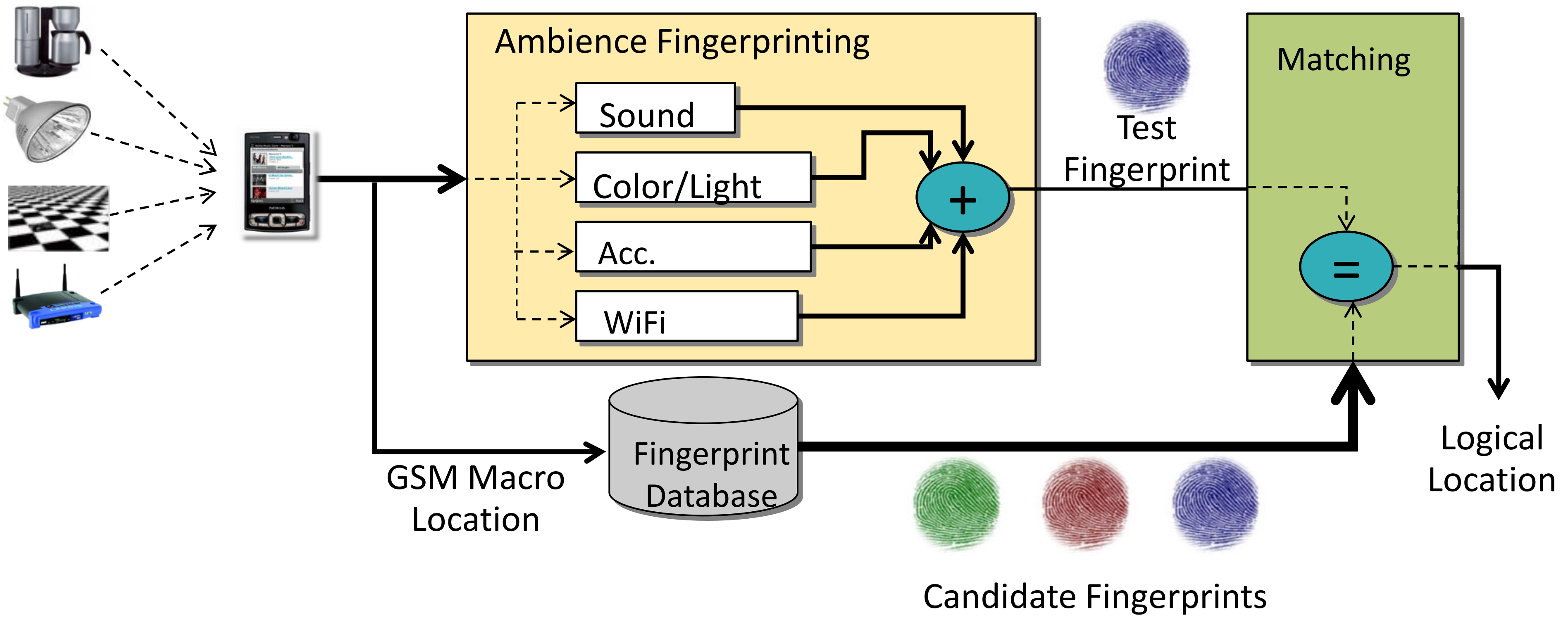


GSM provides macro location (strip mall)

SurroundSense refines to Starbucks



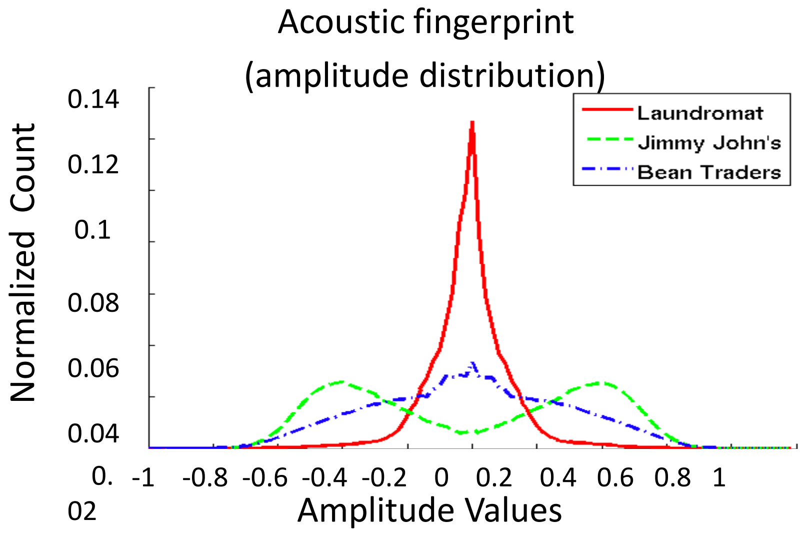
SurroundSense Architecture



Fingerprints

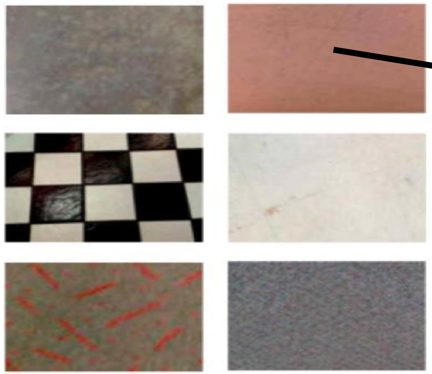
- Sound:

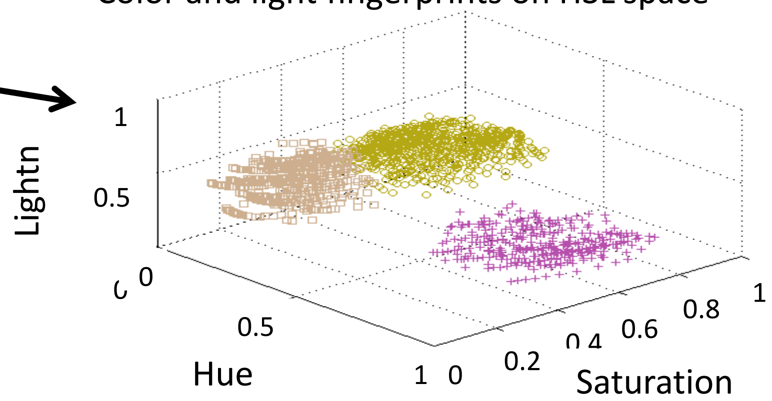
(via phone microphone)



- Color:

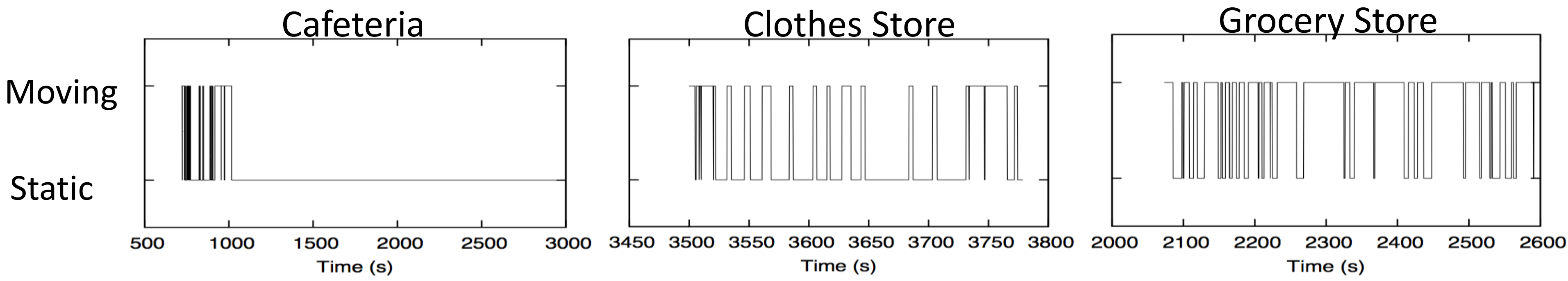
(via phone camera)





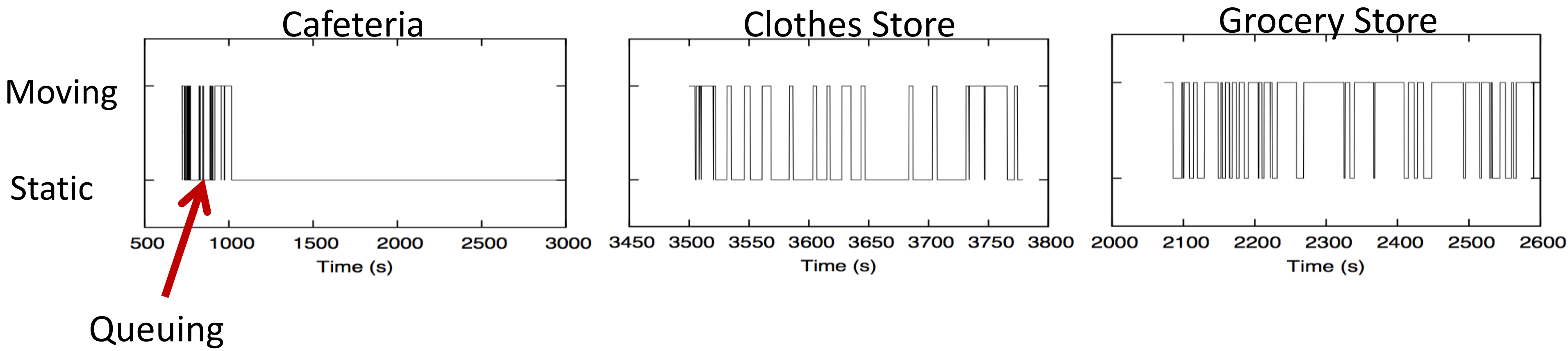
Fingerprints

- Movement: (via phone accelerometer)



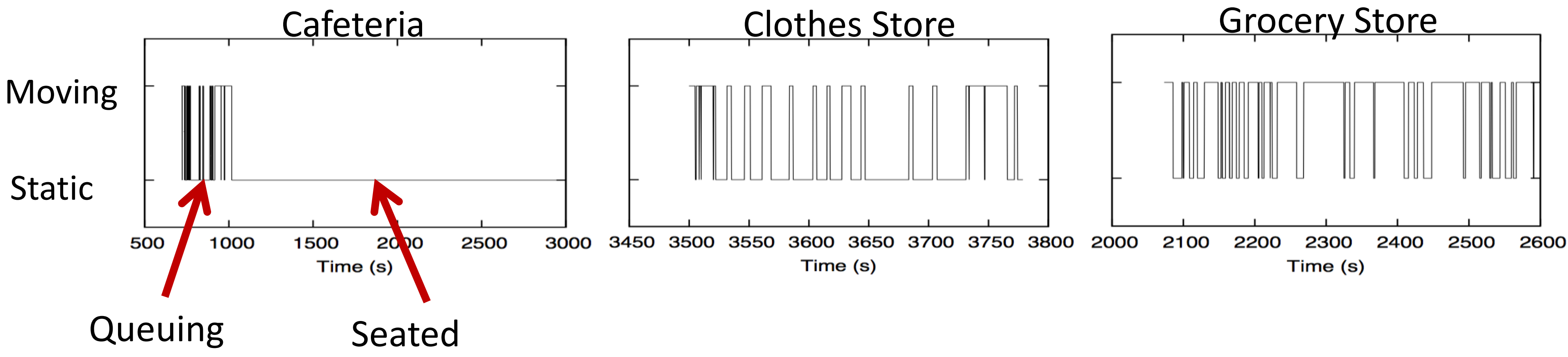
Fingerprints

- Movement: (via phone accelerometer)



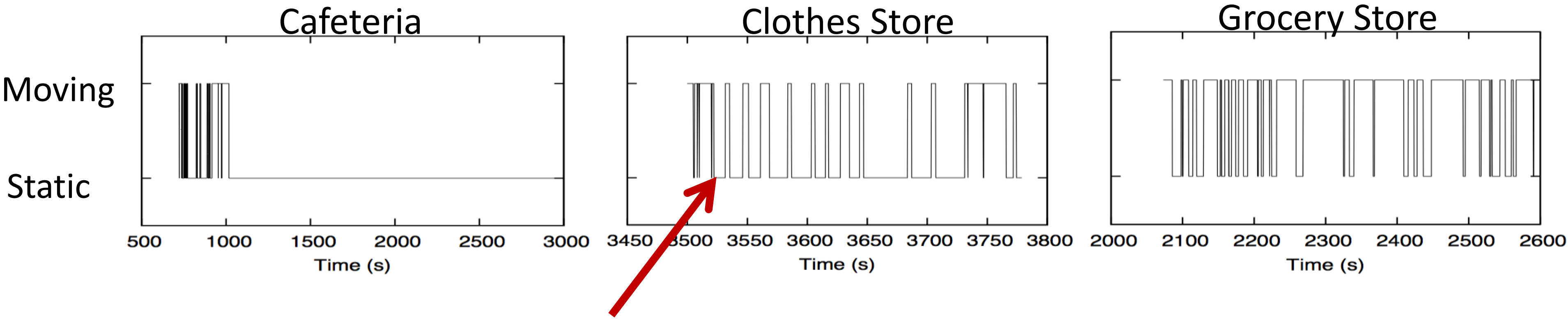
Fingerprints

- Movement: (via phone accelerometer)



Fingerprints

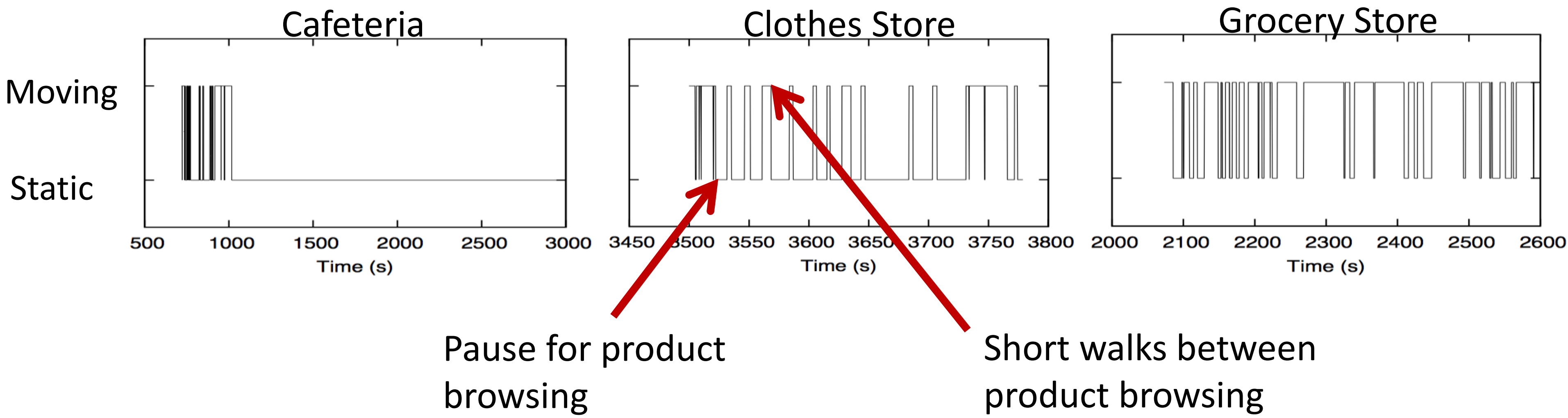
- Movement: (via phone accelerometer)



Pause for product browsing

Fingerprints

- Movement: (via phone accelerometer)

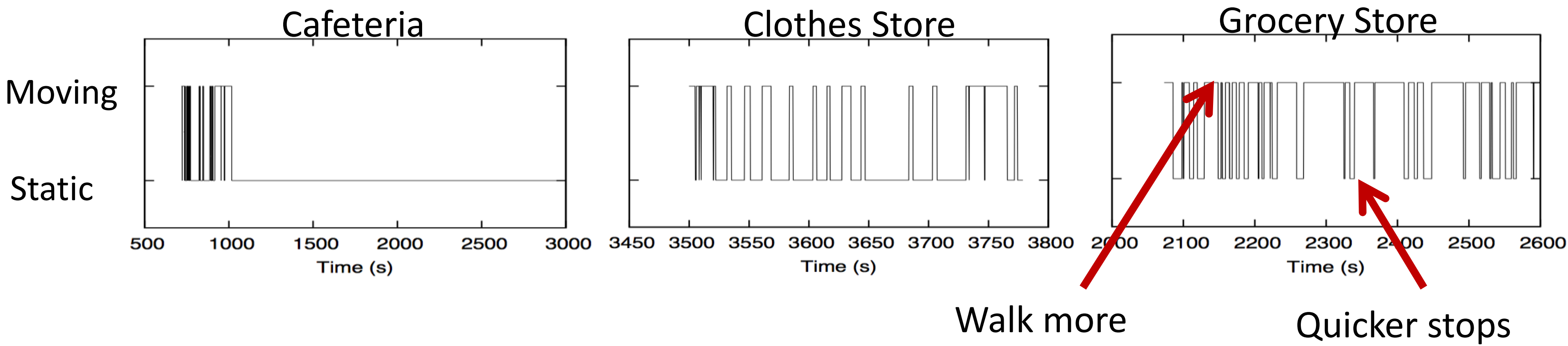


Fingerprints

- Movement: (via phone accelerometer)

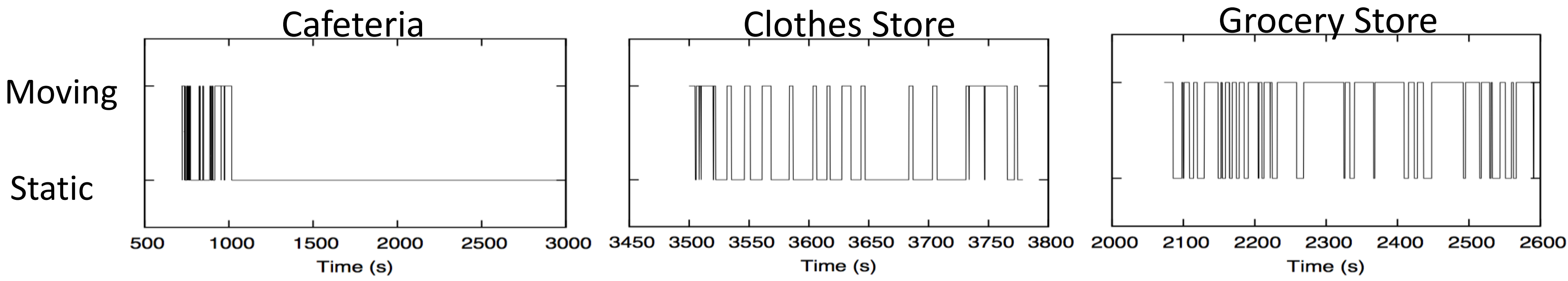
Fingerprints

- Movement: (via phone accelerometer)



Fingerprints

- Movement: (via phone accelerometer)



- WiFi: (via phone wireless card)

f(overheard WiFi APs)

Discussion

- Time varying ambience
  - Collect ambience fingerprints over different time windows

- What if phones are in pockets?
  - Use sound/WiFi/movement
  - Opportunistically take pictures

- Fingerprint Database
  - War-sensing

Contents

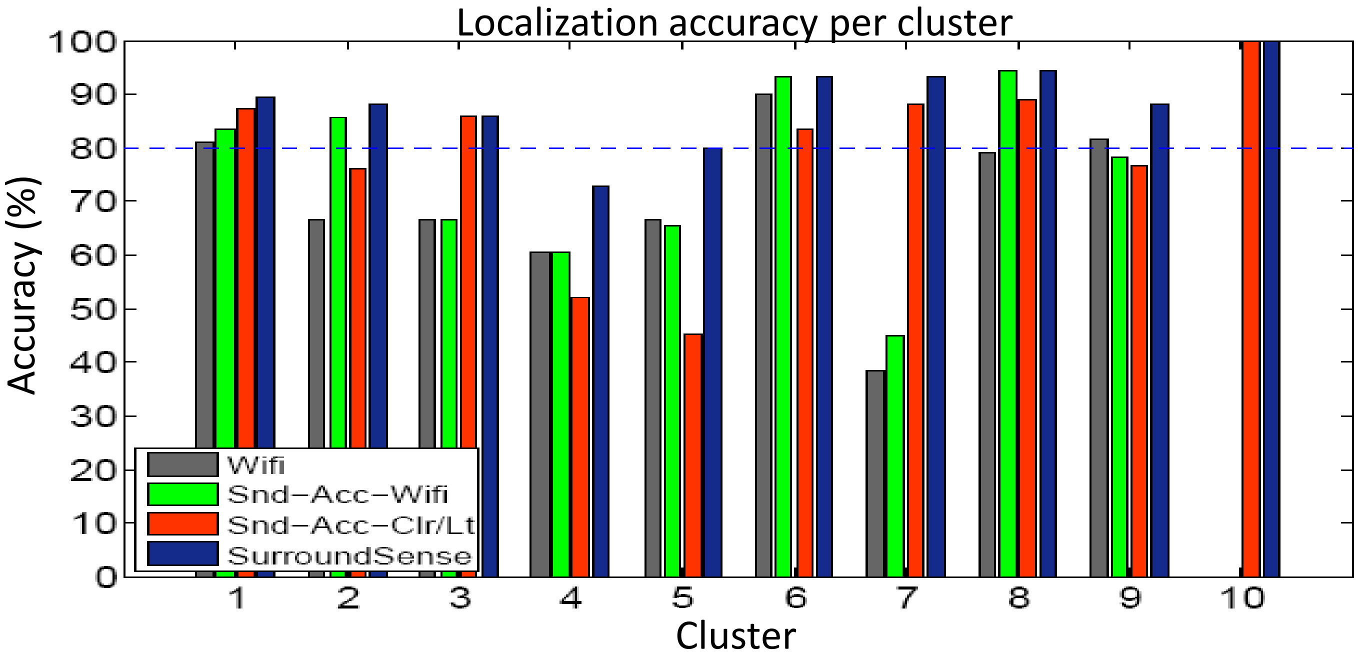
- SurroundSense
- Evaluation
- Conclusion

Evaluation Methodology

- 51 business locations
  - 46 in Durham, NC
  - 5 in India
- Data collected by 4 people
  - 12 tests per location
- Mimicked customer behavior

Evaluation: Per-Cluster Accuracy

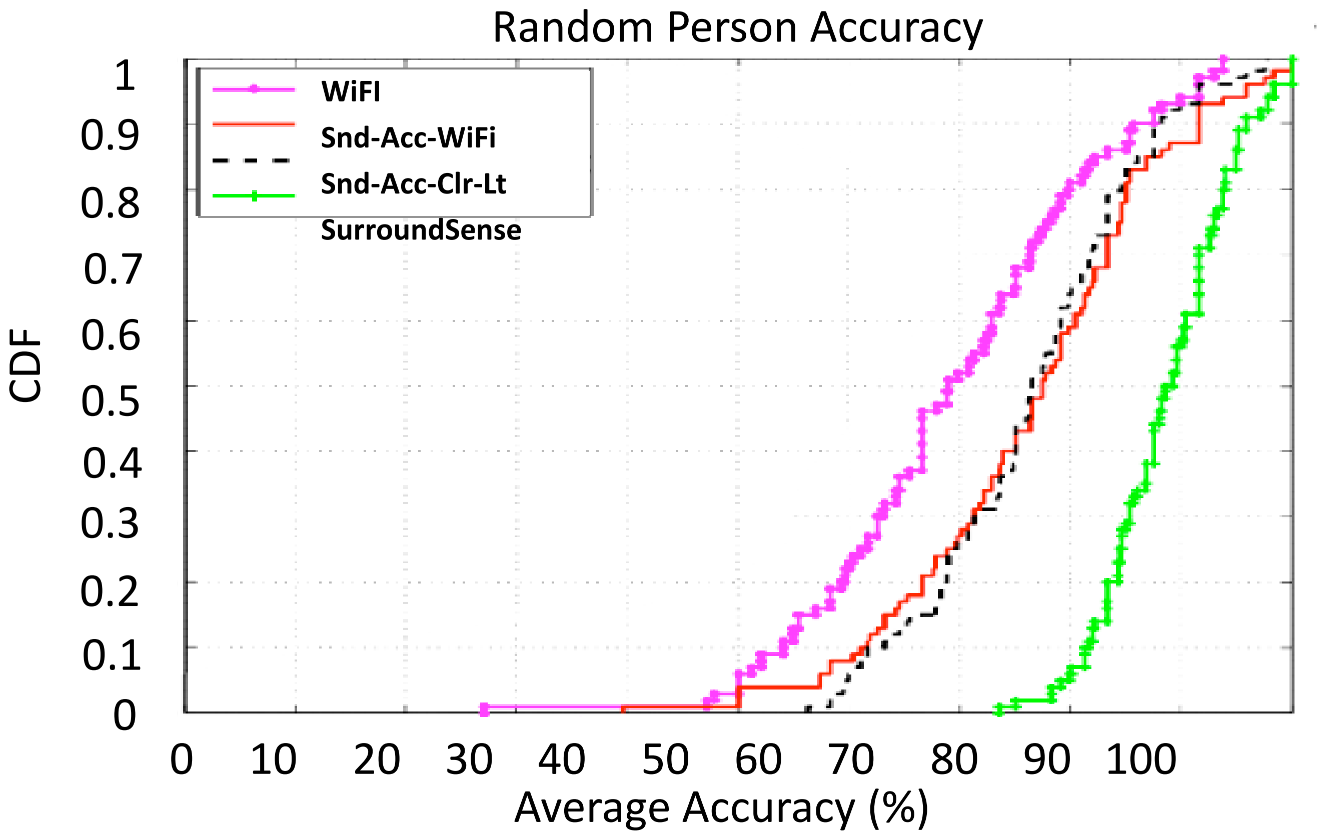
Cluster	1	2	3	4	5	6	7	8	9	10
No. of Shops	4	7	3	7	4	5	5	6	5	5



Evaluation: Per-Scheme Accuracy

Mode	WiFi	Snd-Acc-WiFi	Snd-Acc-Lt-Clr	SS
Accuracy	70%	74%	76%	87%

Evaluation: User Experience



Why does it work?

The Intuition:

Economics forces nearby businesses to be different

Not profitable to have 3 coffee shops
with same lighting, music, color, layout, etc.

SurroundSense exploits this ambience diversity

Contents

- SurroundSense
- Evaluation
- Conclusion

SurroundSense

- Today's technologies cannot provide logical localization
- Ambience contains information for logical localization
- Mobile Phones can harness the ambience through sensors
- Evaluation results:
  - 51 business locations,
  - 87% accuracy

- SurroundSense can scale to any part of the world

Homework

- Paper review:
  - Ubiquitous Acoustic Sensing on Commodity IoT Devices: A Survey, IEEE Surveys and Tutorials, 2022
  - Go through the above paper and select one paper in the reference to conduct paper review. Please indicate why you select this paper to review.

End of This Chapter