AEIS Lab
Ajou Embedded Internet Systems Laboratory

SAIL: Single Access Point-Based Indoor Localization

Alex Mariakakis, Souvik Sen, Jeongkeun Lee, Kyu-Han Kim

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Seungmin Kim

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PAPER INTRODUCTION

Paper overview(1)

- Topic
  - Introduce SAIL, a Single Access Point Based Indoor Localization system
- Proposed algorithm
  - Hybrid ToF/dead-reckoning estimation of target's location
    - Using kalman filter to reduce distance estimation error and using smartphone's sensors to detect human mobility
- Goal
  - To design accurate single-AP localization system that works with commodity APs and avoids fingerprinting or crowdsourcing

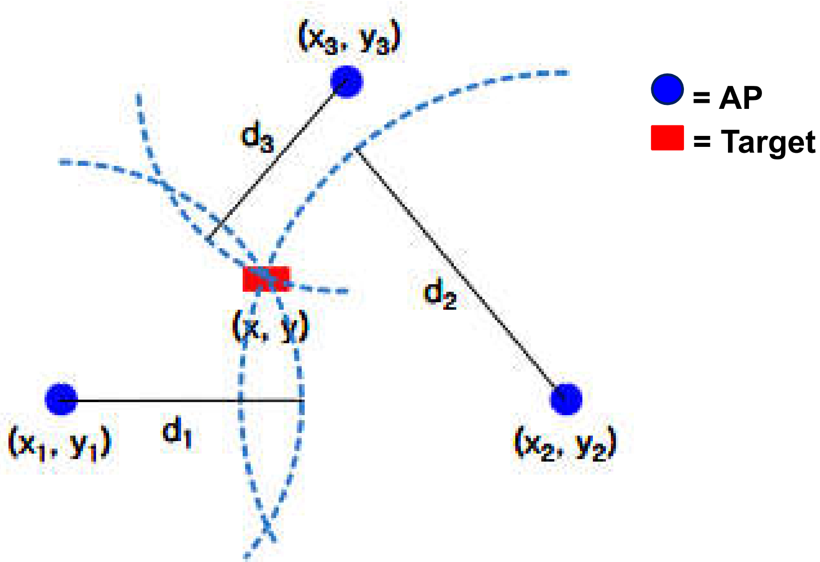
Paper overview(2)

- Contribution
  - Demonstrates how WiFi-based distance estimation can be improved by exploiting human mobility
  - Utilizes channel impulse responses and human mobility to eliminate the effect of multipath in ToF-based distance estimation
  - Identifies the opportunity to improve inertial dead-reckoning techniques using accelerometer hints

BACKGROUND OF PROPOSED SCHEME

Existing localization scheme(1)

- Triangulation or Multilateration
  - Using equals or over than three APs to estimate target's location
  - Distance that between APs and target will be estimated from some information such as RSSI, ToF(Time-of-Flight), AoA(Angle-of-arrival), etc.



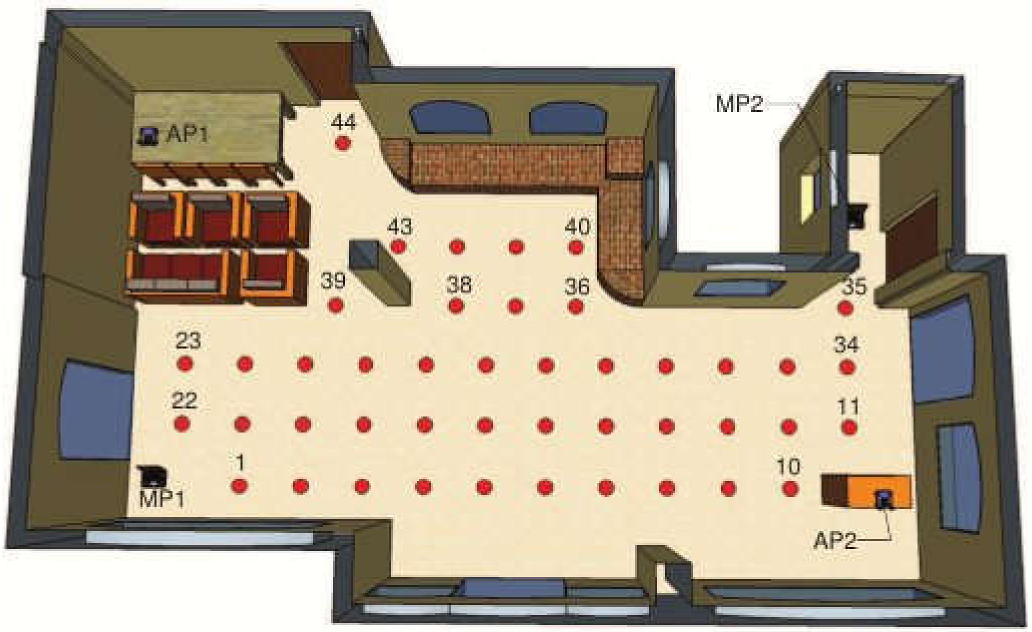
$$d_1^2 = (x - x_1)^2 + (y - y_1)^2$$

$$d_2^2 = (x - x_2)^2 + (y - y_2)^2$$

$$d_3^2 = (x - x_3)^2 + (y - y_3)^2$$

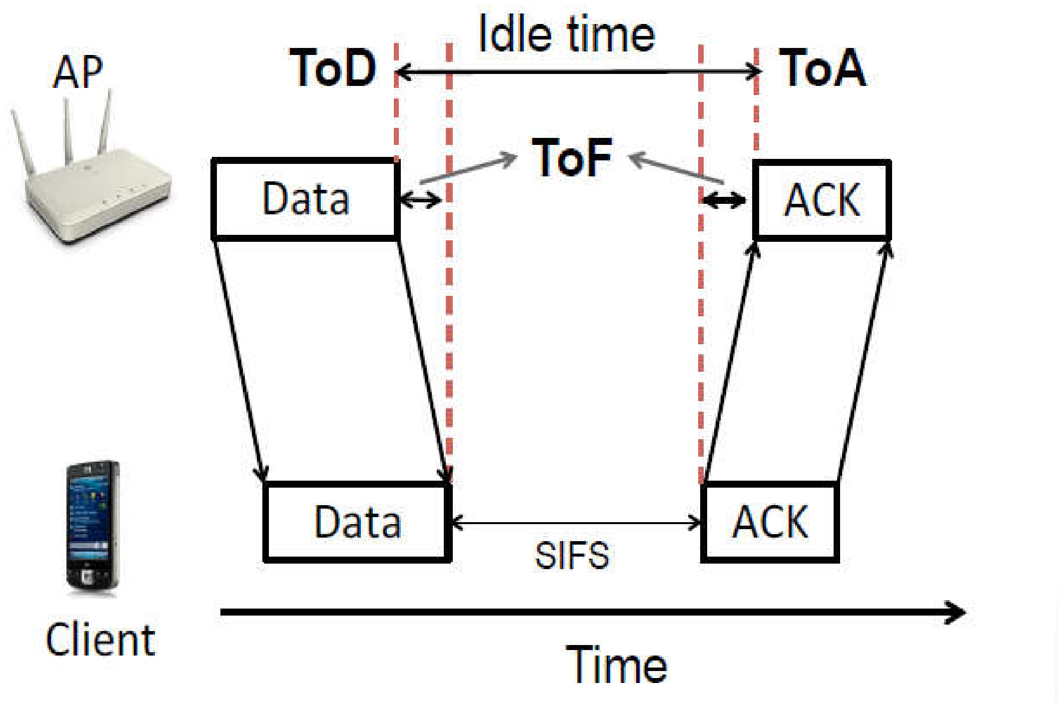
Existing localization scheme(2)

- Fingerprinting
  - Make a virtual map and virtual coordinates based on Aps
  - Each AP's Specific data indicates target's virtual coordinates
  - Construction a map requires a lot of experiments
  - Has low error rate, but is costly



Keywords(1)

- ToF(Time-of-Flight)
  - The round trip propagation time of a signal transmitted between the AP and the mobile device



Keywords(2)

- Dead-reckoning
  - The process of estimating the value of any variable quantity by using an earlier value and adding changes in the meantime
  - In this paper, authors use smartphone motion sensor includes accelerometer, compass, gyroscope sensors.

- Using sensors in proposed scheme
  - **Accelerometer**
    - To compute walking distance estimation and detecting user's turns
  - **Compass**
    - To determine user's absolute heading orientation
  - **Gyroscope**
    - To determine phone's orientation and user's absolute heading orientation

Keywords(3)

- Channel Impulse Response(CIR)
  - Captures the energy of the different wireless propagation paths
  - Can detect the presence of a stronger reflected path and correct the ToF value to obtain the arrival time of the direct path
  - In this paper, the authors use this to identify direct path from multipath
- Channel State Information(CSI)
  - Channel properties of a communication link
  - Describes how a signal propagates from the transmitter to the receiver
  - Represents combined effect like fading, power decay with distance
  - In this paper, the authors use Inverse Fast Fourier Transform to get CIR(Frequency domain to time domain)

Keywords(4)

- Kalman filter
  - An algorithm that uses a series of measurement containing statistical noise and other inaccuracies observed over time
  - Produces estimates of unknown variables that tend to be more precise
  - Basically works well in linear systems, and estimate with normal distribution recursively
  - In this paper, the authors uses past distance and relative speed estimations to correct the errors in current estimations.

EVALUATING THE PAPER IN 6 STEPS

1. What does the paper try to solve?

- Indoor positioning system satisfies both low cost and accurate for real-world deployment
  - The current proposed indoor positioning schemes need some restrictions for accurate estimation
    - Fingerprinting requires a lot of cost to estimate for accuracy
    - Crowdsourcing is slow to adapt to changes in environment and depends on willingness of users
    - Without fingerprint or crowdsourcing, they needs high density of APs

- SAIL using CIR to estimate the distance between the AP and users

2. What was the problem before?

- Recent WiFi-based Localization system has practical limitations
  - Requires distance estimation from at least 4-5 reasonably strong WiFi APs with known locations
    - Unavailable in the edge of the enterprise network
  - Difficult to find 4-5 strong APs on the same channel
    - Because after the advent of the IEEE 802.11ac standard, nearby APs reside on different channels
  - Regular data communication cannot happen during the AP scanning operation
    - Impacting user experience for real-time traffic such as VoIP

- We need a positioning system that avoiding channel switching and network disruptions at the client

3. What are its ideas?

- Combines **dead-reckoning** and **ToF** scheme to estimate in the real world
  - To avoid costly scheme such as fingerprint, crowdsourcing

- Goal and Purpose
  - Using single AP and smartphone's sensors to estimate user's location
  - In terms of accuracy, the proposed scheme would be better than recent single AP localization systems

Proposed localization Scheme

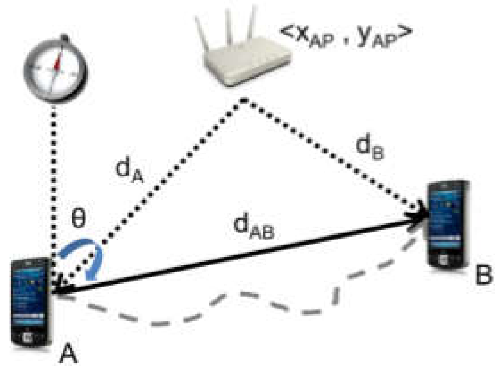


Figure 1: The triangle formed between an AP and a user walking from location A to location B

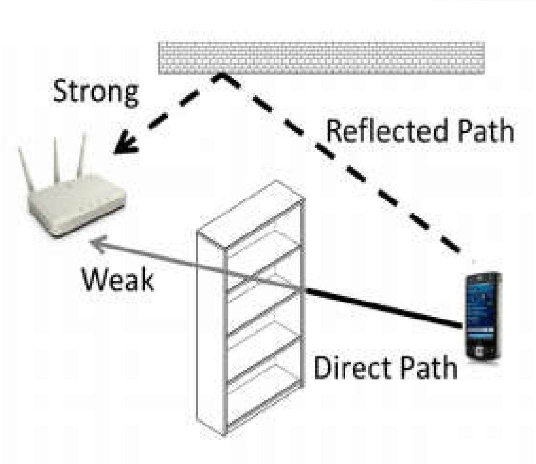
- Localization procedure with single AP and smartphone.
  1. Assume AP with a known location connected to a user's smartphone, and user walks location A to B(in Figure 1)
  2. It is possible to estimate the distance of the user from the AP to A and B(d_A and $d_B$in figure 1)
  3. Also, d_{AB} can be estimated by dead-reckoning.
     - By using his/her phone's sensor.
  4. d_A , d_B and d_{AB} makes unique triangle(in figure 1) that can be rotated any direction, so using smartphone's compass to determine the orientation(θ) of the triangle

To realize the proposed scheme(1)

- What information we use to estimate distance between APs and smartphone?
  - AoA(Angle-of-Arrival)
    - The angle estimation granularity
  - ToF(Time-of-Flight)
    - It is susceptible to multipath
      - Use CIR to capture direct path
    - ToF = ToD - SIFS duration**(16μs)** - ToA

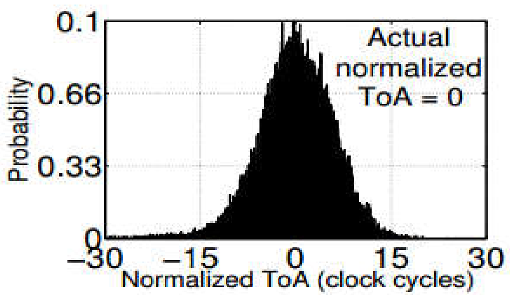
$$distance = c * ToF/2$$

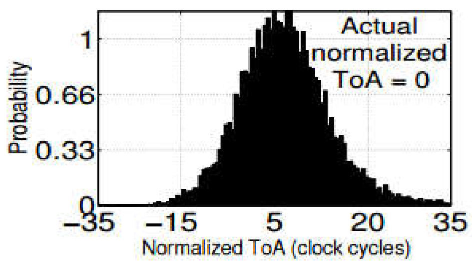
    - ToD is computed when a data packet sent out in the air at the PHY layer
    - ToA is determined based on preamble detection in the PHY layer

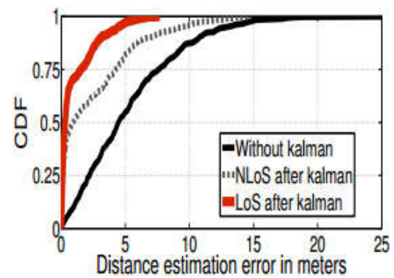


To realize the proposed scheme(2)

- It is difficult to precisely detect the arrival of the preamble with nanosecond precision in the PHY layer
  - Because of the limited bandwidth of the WLAN chipset
  - Especially in NLoS(Non-LoS), signals are affected by noise
    - Use two-state Kalman filter that tracks the estimated distance and also user’s relative speed with regard to the AP to minimize the effect of noise



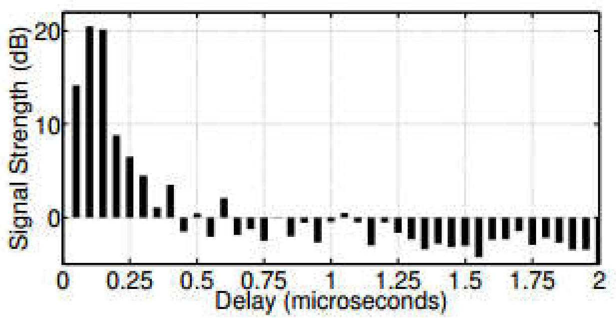




  - Kalman filter uses its relative speed estimate to predict the distance of the client
    - Uses the current ToF-based distance value to update its distance and relative speed estimate

To realize the proposed scheme(3)

- The PHY layer reports the ToA value corresponding to the strongest arriving signal path, not necessarily the direct path
  - Need to determine the arrival time of only the direct path
    - The direct path signal can be identified by a PHY layer information called CIR
    - But the resolution of the CIR is only 25ns for an ACK packet received over a 40MHz bandwidth, causing distance estimation errors of up to 7.5m

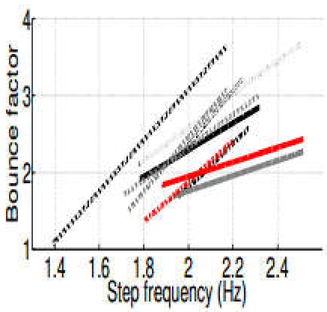


To realize the proposed scheme(4)

- To overcome the limitation of coarse CIR resolution
  - Exploiting multiple antennas
    - A mobile device typically transmits an ACK packet by using a single antenna
      - Most APs are MIMO capable and hence receive the ACK over multiple antennas
    - To avoiding the multipath error by this technique, the authors determine the relative arrival time of the strongest component across all the CIRs over all of antennas
  - Exploiting human mobility
    - Whenever the mobile device moves, the direct-path is usually stable
    - Multipath coherence time under mobility is typically more than 10ms
    - Space the same measurements equally within a short time(1s) interval

To realize the proposed scheme(4)

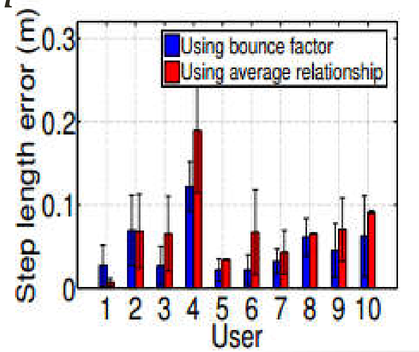
- Dead-Reckoning to estimate user's displacement
  - Distance Estimation
    - Step detection
      - BF(bounce factor) = the standard deviation of the projections of the total acceleration onto the gravity vector



$$BF = \text{std}\left(\frac{\langle a_x, a_y, a_z\rangle \cdot \langle g_x, g_y, g_z\rangle}{\langle g_x, g_y, g_z\rangle}\right)$$

$< a_x, a_y, a_z > = total\ acceleration\ experienced\ by\ the\ phone$

$< g_x, g_y, g_z > = the\ gravity\ vector$



    - Step length
      - Only consideration of acceleration data
      - New user is tracked for the first time by SAIL, a constant step length is assumed

To realize the proposed scheme(5)

- Dead-Reckoning to estimate user's displacement
  - Gyroscope orientation
    - Phone's orientation tracking
      - Gyroscope reports the relative angular velocity of the phone
      - Because affected by noise, they define a ***pose change*** as an event during which user changes her phone's orientation without taking a physical turn
      - Checks drastic change of the direction of the gravity vector to detect pose change

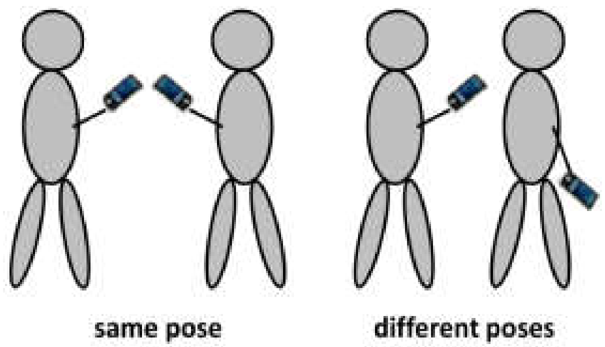


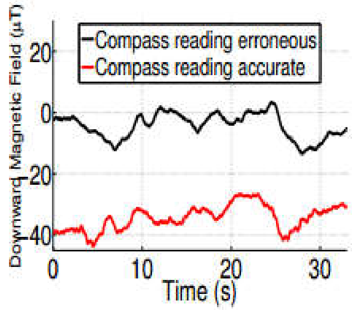
Figure 10: Pose changes occur during specific user initiated changes in phone orientation.

	Different poses				
	Head	Ear	Swinging	Purse	Pocket
Hand	X	100%	100%	100%	100%
Ear	100%	X	100%	100%	100%
Swinging	100%	100%	X	95%	100%
Purse	100%	100%	95%	X	100%
Pocket	100%	100%	85%	90%	X%

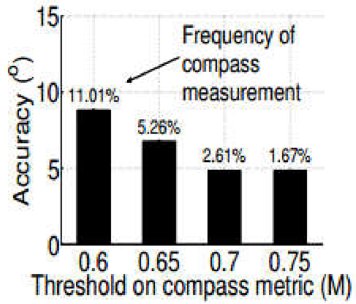
Table 1: Accuracy results for transitions between five different poses.

To realize the proposed scheme(6)

- Dead-Reckoning to estimate user's displacement
  - Compass orientation
    - User's heading estimation
      - The magnetic field was weak, the compass was unreliable
      - Something is disturbing nearby magnetic field, rendering any measurements useless



$$M = \frac{1}{2}\left(\mu_1^{\frac{dm_{meas}}{dt}} + \mu_2^{|m_{meas} - m_{exp}|}\right)$$

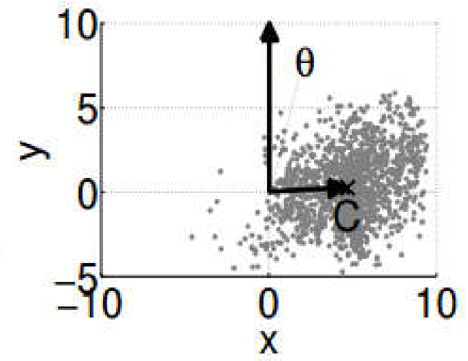


      - When the threshold is increased to 0.75, the median error for compass readings becomes 5°

M : ***Compass confidence metric*** that ranges from 0 to 1
m_{meas} : The magnitude of reported by the magnetometer
m_{exp} : Ideal magnitude of the geomagnetic field according to the World Magnetic Model
u_1&u_2 : empirically determined constants

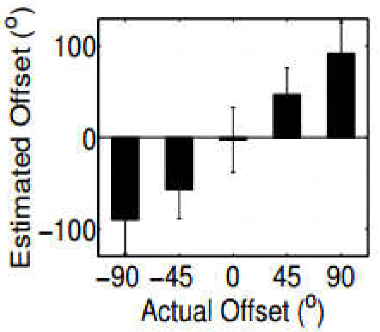
To realize the proposed scheme(7)

- Dead-Reckoning to estimate user's displacement
  - Compass offset correction
    - When the user holds phone in landscape mode, compass estimated error occurs.
    - When the phone is in a more arbitrary orientation, need to find the offset(compass offset) between the phone's and the user's heading orientation
    - SAIL addresses this issue by exploiting the smartphone's accelerometer
    - Because when the user walks forward, he/she exerts a force that manifests itself on the accelerometer



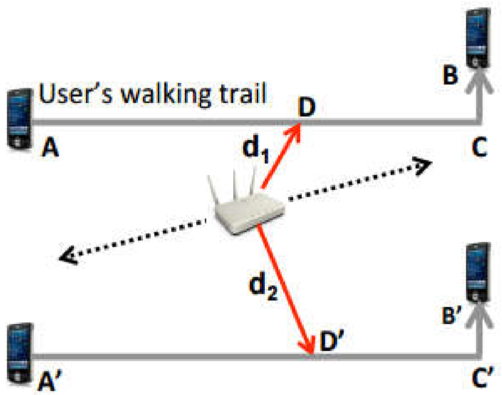
$\theta = user's\ heading\ vector$
$C = phone's\ heading\ vector$

In landscaping mode



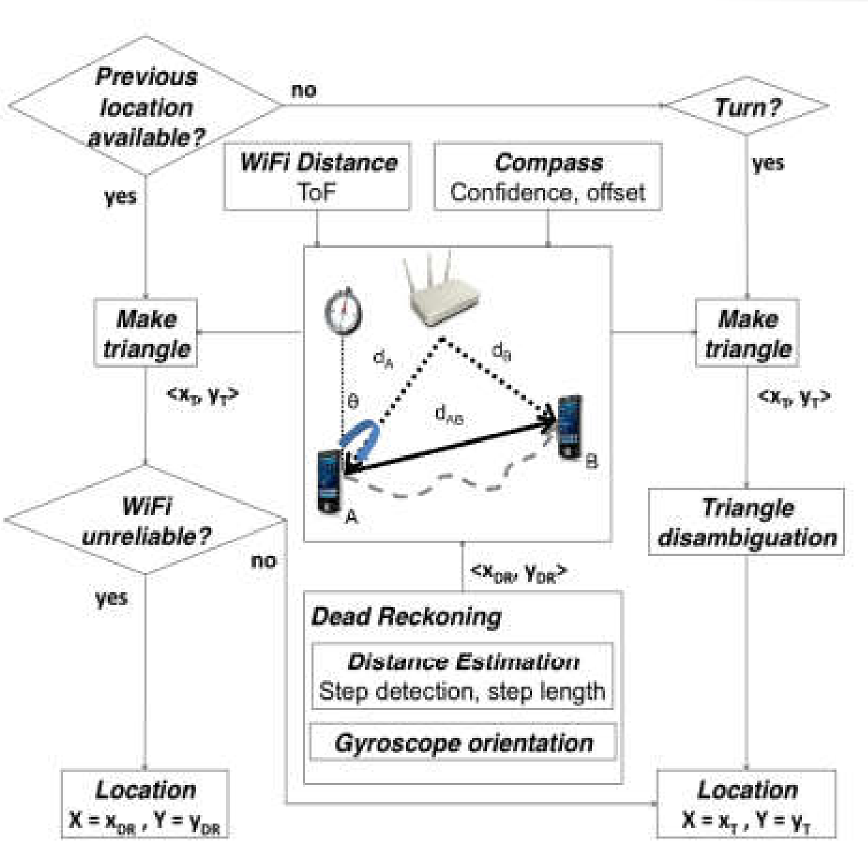
To realize the proposed scheme(8)

- Location estimation using triangles
  - There are 2 candidate triangles when the user is walking straight
    - But once user turns, this indicates that the distance of an intermediate point D from the AP will be different for the two candidate triangles
    - The ambiguity can be broken by inspecting the WiFi distance at the intermediate point D and picking the triangle that satisfies this distance
    - SAIL considers the intermediate instance when the WiFi distance measurement has the highest confidence



Overall the architecture of SAIL

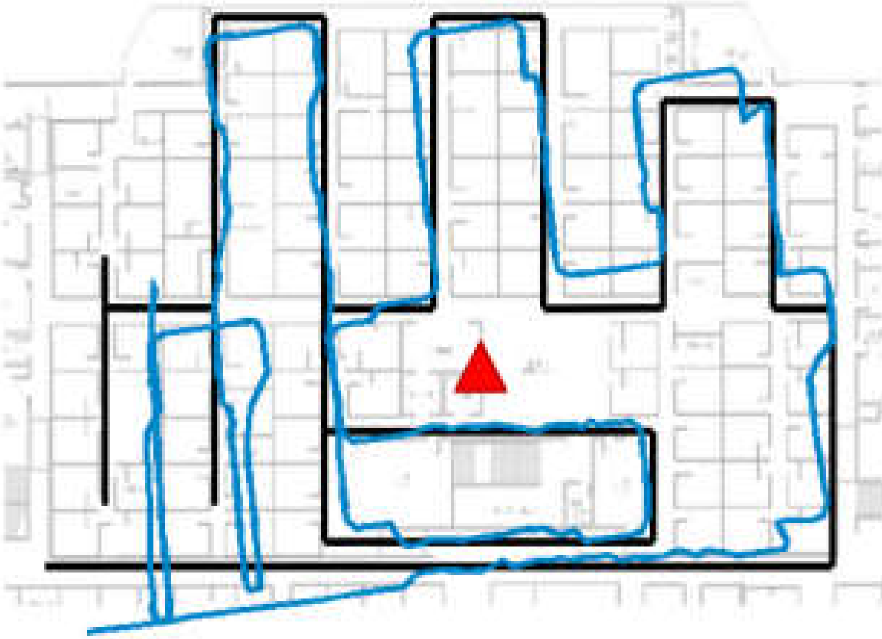
- Initially, SAIL can only track the change in the user's location like physical turn



4. How does the paper evaluate?

- Evaluation environments
  - HP MSM 460 APs using Atheros 9590 chipset
  - 5.805GHz frequency using a 40MHz bandwidth
  - 88MHz WLAN clock
  - 10 users to evaluate SAIL
  - 20 different types of smartphones(Android-based, iOS-based)

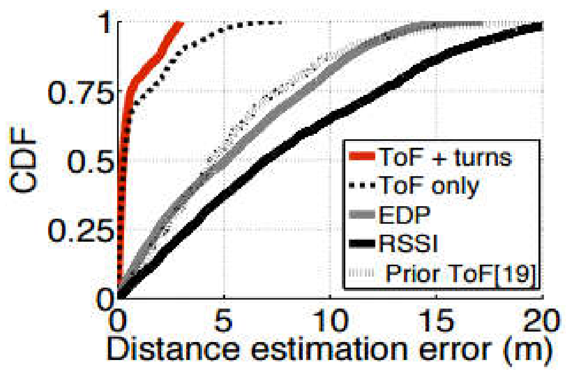
Evaluation. in the building



- A single AP installed at a known location(red triangle)
  - The black line is the ground truth as user walks
  - The blue line is SAIL's estimated location

WiFi-based Distance Estimation

- The performance of SAIL's distance estimation error by using 10 packets per second
  - Correct the multipath infused error
    - Using CIRs from 3 antennas at the AP
  - Correct the relative speed
    - Using Kalman filter whenever the user takes a physical turn
- Reduces the average distance estimation error to 0.8m
  - EDP is the energy of direct path that the author used this data in previous proposed scheme but worse than ToF



Effect of Device Heterogeneity

- Evaluation to find a manufacturer dependent constant value
  - Same type mobile devices have very similar estimation error

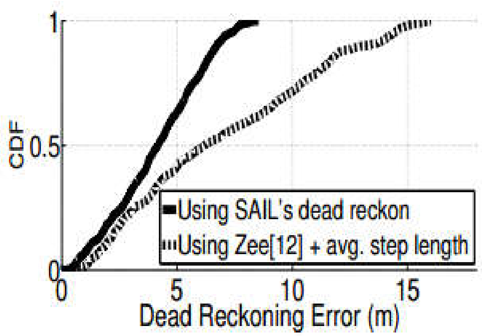
	Distance estimation error (meters)			
Samsung Galaxy S4	0.71	0.68	0.75	0.63
iPhone 5	0.9	0.81	0.83	0.94

  - If the predetermined offset is correct, the average distance estimation error is less than a meter

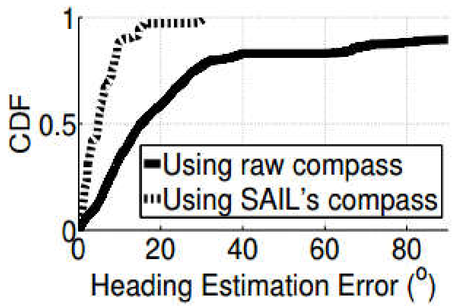
Galaxy S3	Xperia Z	iPhone 5S	HTC One	Nexus 4
0.93m	0.64m	0.82m	0.7m	0.9m

Dead-Reckoning Performance

- The performance of dead-reckoning
  - Compare to existing approaches using map matching techniques

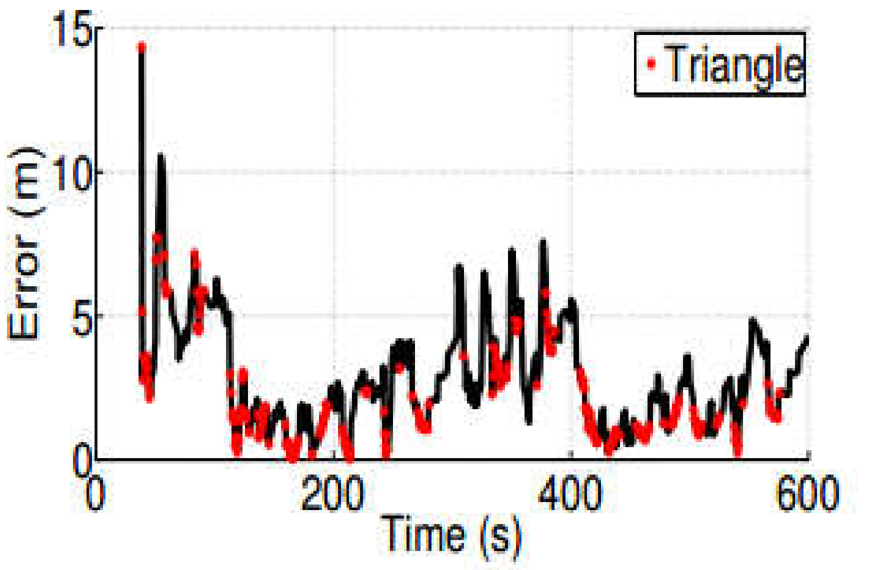


  - Compare to raw compass for heading estimation



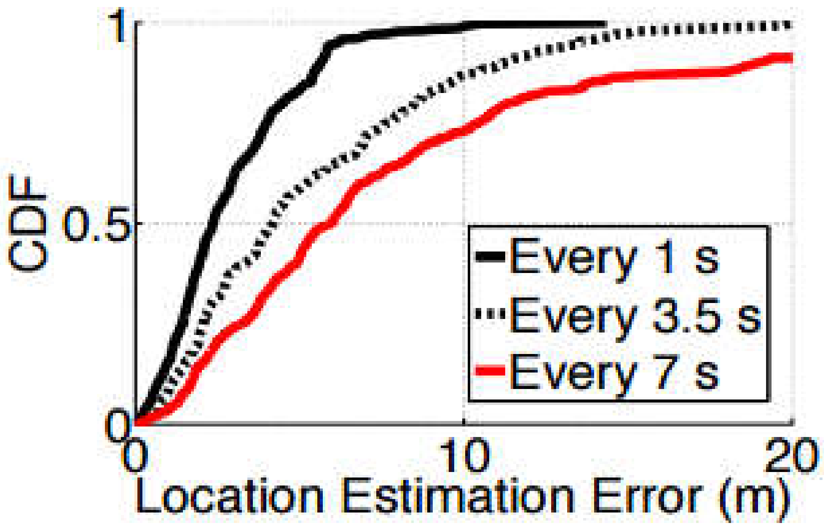
Location Estimation(1)

- The localization performance of the system
  - SAIL computes the triangle only when the WiFi distance is deemed reliable (RSSI > 10dB)
    - Otherwise, it continues to dead-reckon from past estimated location
  - The errors are typically less than 5m except the client is far away from the AP



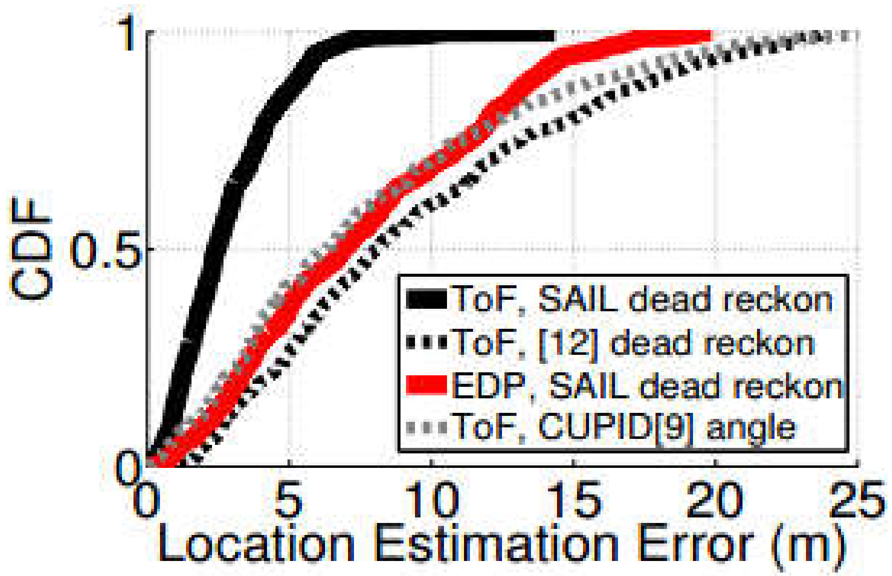
Location Estimation(2)

- Impact of periodic WiFi probing
  - Each such probe consists of 10 measurement packets resulting into a background traffic overhead of approximately 0.2% per client
    - Since the number of clients can grow quickly, overhead problem is important
  - Studied the possibility of reducing the frequency of probing



Location Estimation(3)

- Comparison with existing schemes
  - The performance of several schemes
    - Existing schemes often get confused by erroneous compass measurements



Conclusion

- SAIL achieved methodically addresses many of the challenges towards practical WiFi-based positioning only a single AP
- The techniques proposed in SAIL are now operational in an enterprise network and achieve a median error of 2.3m

5/6. Limitation & Opinion

- Limitation
  - Restriction that user can be tracked after physical turns
    - If user walks straight to outside the range to communicate, then AP cannot know user's location forever
- Opinion
  - Proposed scheme seems to be achieved good accurate localization system even they are using a single AP
  - How is going to add AoA scheme to eliminate one of candidate triangle when the user walks straight? I think it is helpful for higher accuracy in distance estimation, and consequently, location estimation will also get higher accuracy.

Thank you for listening.

Any Questions?