Breaking Mobile Social Networks for Automated User Location Tracking

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Outline

- Location Information Management in Mobile Social Networks
- Our Automated Attack Framework for User Location Discovery
- Our Real-world Attack Experiment and Results
- The Proposed Defense Mechanisms
- Concluding Remarks

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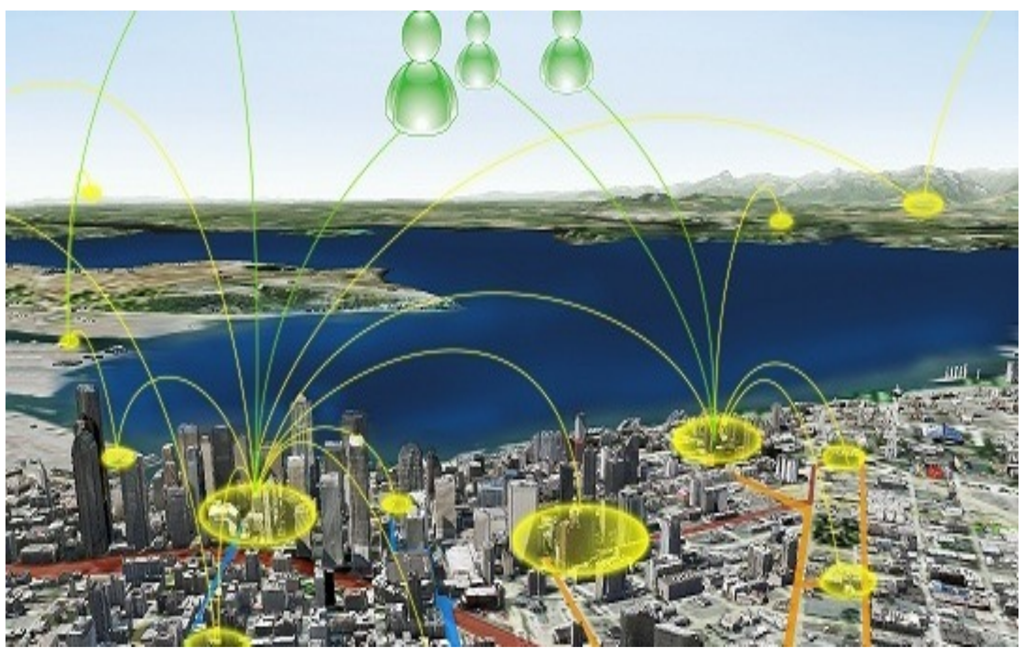
Mobile Social Networks

- The ubiquity of the smartphones has led to the extreme popularity of mobile social networks
- Billions of users are actively using them for social interactions on a daily basis
- Successful examples include Wechat, Facebook, Google+, What’s App, Momo, etc.

Location Based Social Networks (LBSNs)



- Location information is key to user interaction experiences in mobile social networks today
- They are used to enable and facilitate various location-based social interactions

Examples of Location Based Social Interactions

- Checking-in Services
  - Allow users to check in to report their locations: Facebook, Weibo, Foursquare, etc.
- Geotagging
  - Reveal/Redact location data on user posts/messages: Facebook, Weibo, Renren, etc.
- Location-dependent Comments
  - Comment to specific subjects with exact known locations: Yelp, Dianping, etc.
- And most popularly, proximity-based friend discovery
  - The focus of this research

How do LBSNs Acquire Users' Location?

- Mobile users voluntarily report their location via LBSN client App to LBSN servers.
- Various types of location information. i.e., Wi-Fi (80m), GPS (10m) and Cell ID (600m), are being collected in a periodical, on-movement or combined fashion.

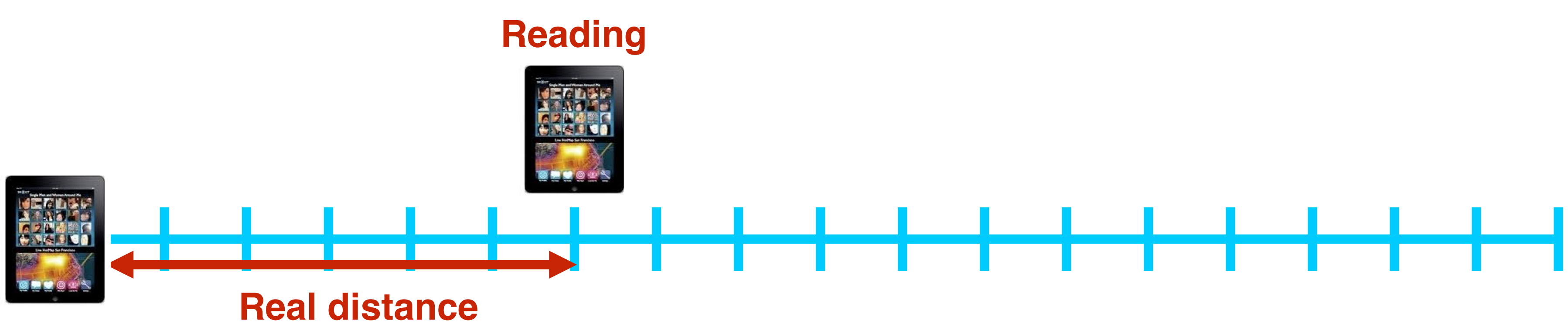
LBSN	Location Retrieval Method
Momo	Rely on Baidu location SDK to fuse inputs from multiple location sources
Wechat/Skout	Select the available one with the highest precision (GPS, Wi-Fi, Cell ID)

How Accurate are the Displayed Location Info?

- The location accuracy displayed in LBSN client App's is reflected by the distance between
  - an user's real physical location (as perceived by the location services according to his/her mobile devices) and
  - the location readings from LBSN App's.
- Location accuracy varies across different LBSNs
  - Depending on both their own internal processing strategy and
  - The available location info sources
- The overall observation is that LBSN location readings are quite accurate.

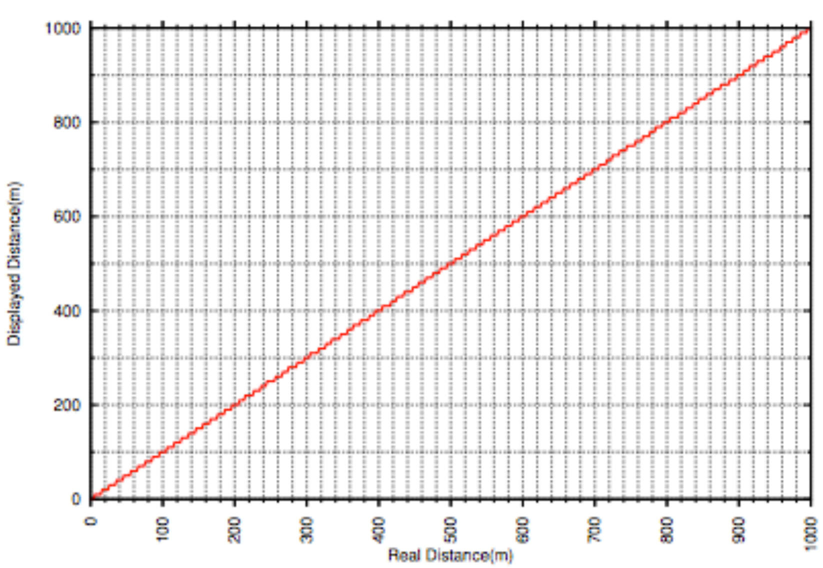
Location Accuracy Testing in Popular LBSNs

- Differences between the real distances and the distance readings on popular LBSNs are studied:
  - Run two instances of the same LBSN in two VMs;
  - Fix one reference point in one instance and move a testing point along a line in the other;
  - Record the actual distances between the testing point and the reference point;
  - Refresh the LBSN App in the VMs and record their distance readings

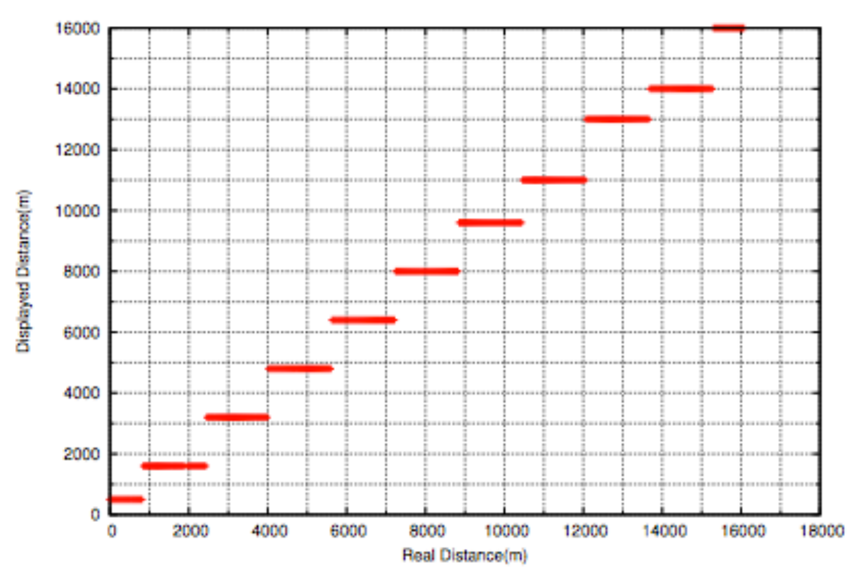


Location Accuracy Testing Results

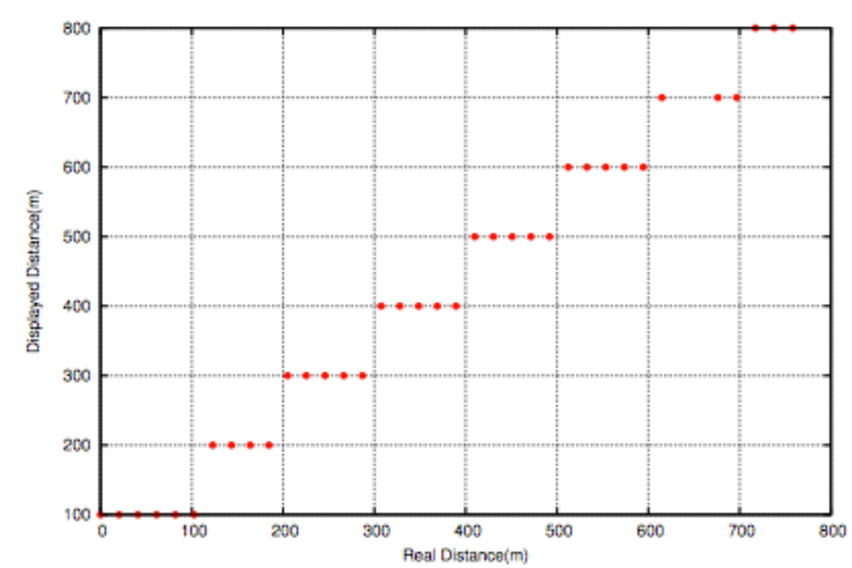
- Momo's distance readings are rounded at 5m;
- Skout rounds up the distance readings every 1.0mi but also indicates when a user is within 0.5mi;
- Wechat answers user's location with the precision of 100m when the distance <1km in metropolitan areas;



Momo



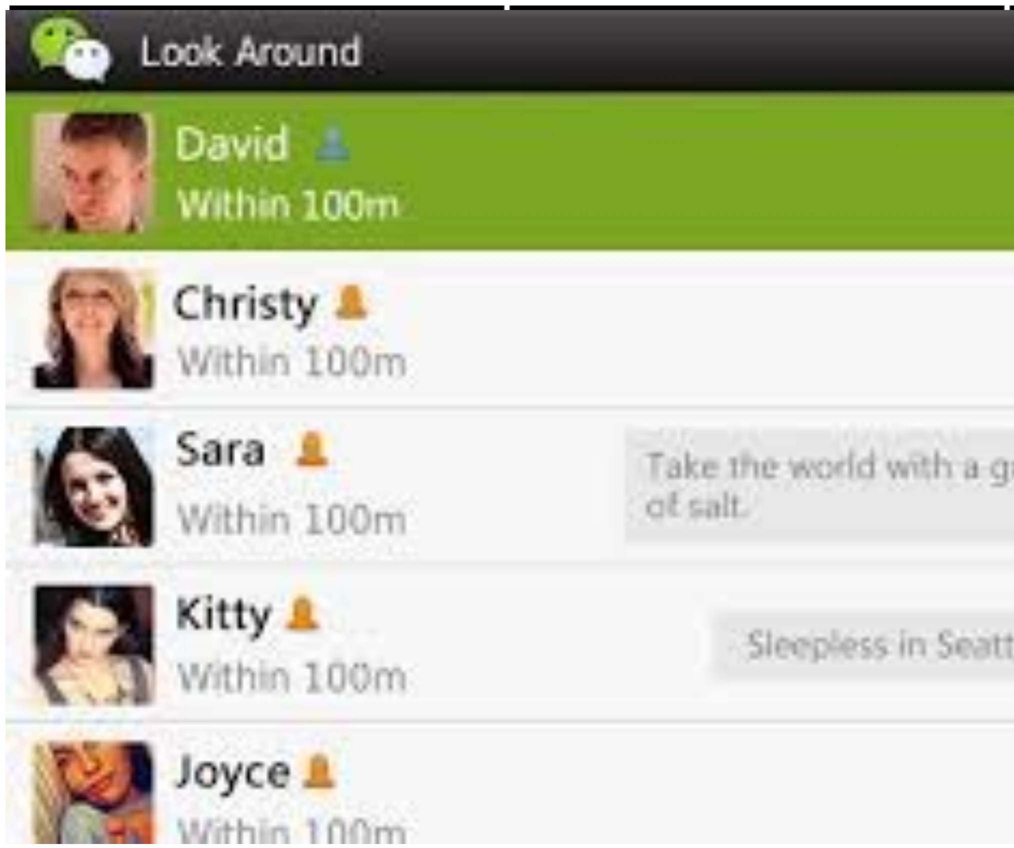
Skout



Wechat

How are the Location Info Shared among LBSN Users?

- Open direct access to any registered users
  - Sharing exact locations among users
- Authorized direct access
  - Sharing locations with authorized friends
- Indirect access with constraints
  - Sharing obfuscated location information according to various constraints

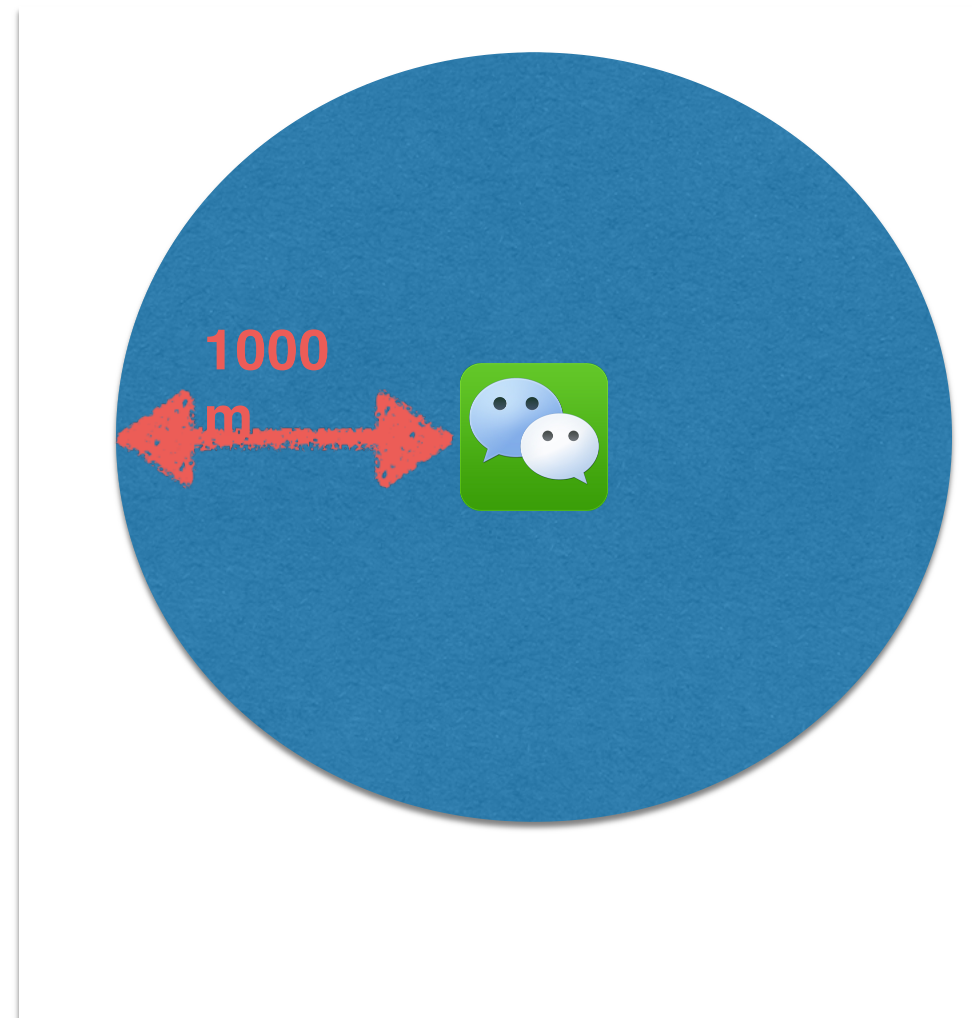


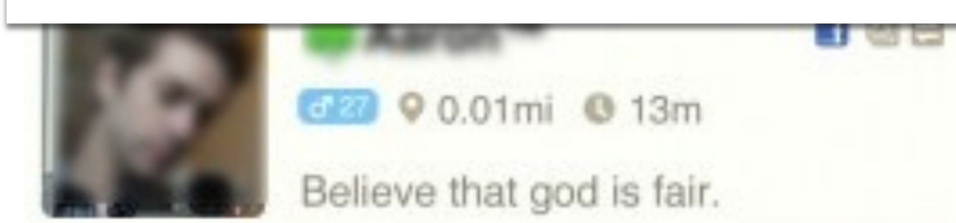
An Overlook of Location Sharing in Popular LBSNs

	Number of users	Classification
Wechat	300 millions	Indirect
Skout	5 millions	Indirect
Momo	30 millions	Indirect
iAround	10 millions	Open direct access
Google+	30 millions	Authorized direct access
Facebook	1.23 billion	Authorized direct access

A Closer Look on Constrained Indirect Access in LBSNs

- Showing the relative distance between users
  - e.g., Momo displays relative distances with the precision of 5m
  - Users see their distances to other users instead of exact location.
- Imposing a minimal location accuracy constraint
  - e.g., Skout shows relative distances no smaller than 0.5 mi;
  - Users see their distances to other users when the distances are larger than 0.5mi with with the precision of 1mi.
- Imposing a maximum distance constraint
  - e.g., Wechat lists only the users within the range of 1km in metropolitan areas with the precision of 100m;
  - Users cannot see others who are more than 1km away.





Location Privacy in Existing LBSNs

- Today, user location privacy achieved relying on indirect & constrained location sharing; Exact location info never shared among users
  - Such utility and privacy trade-offs are today's industry best practices, affecting hundreds of millions of users.
  - Viewed by most popular LBSNs as a desirable middle ground to both protect user location privacy and enable effective location-based services

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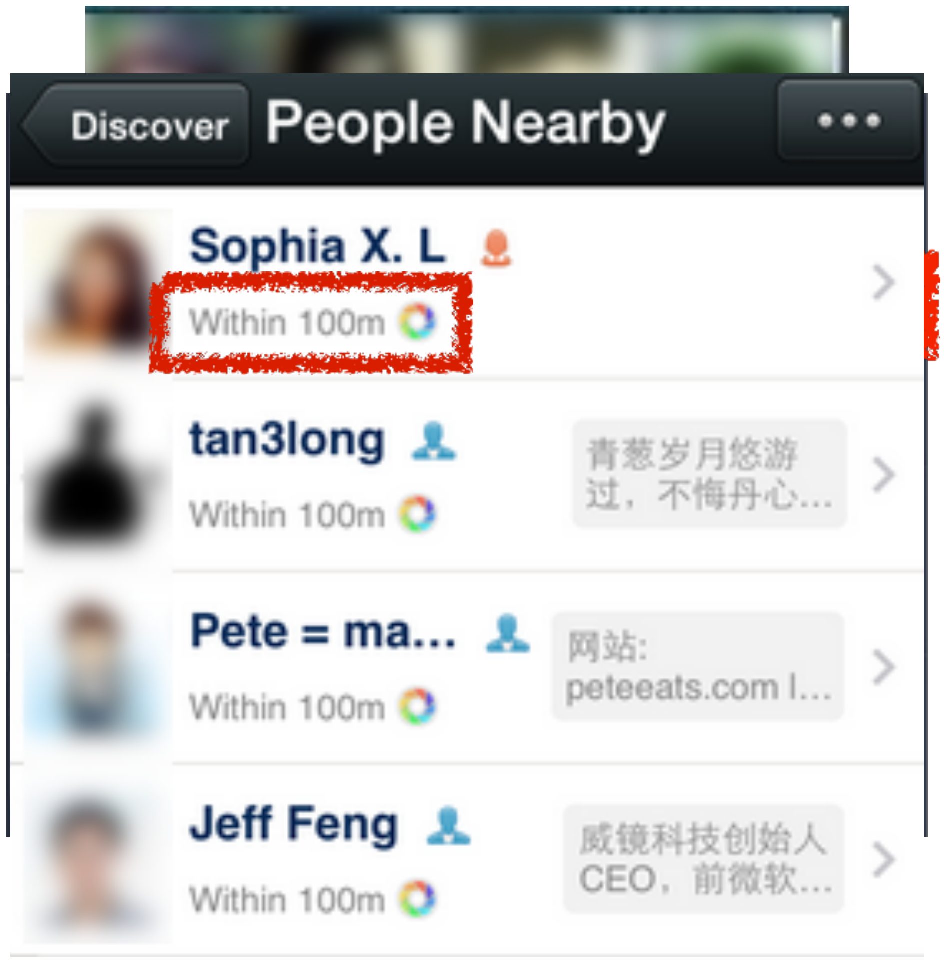
The Attack Goal & Assumptions

- We assume only a weak outsider adversary:
  - having exactly the same privilege as ordinary users
  - exploiting only publicly available information without hacking into the LBSN servers
- Yet, such adversary is still able to achieve both:
  - localizing an arbitrary user with very high accuracy
  - performing long-term tracking and eventually revealing the user's identity information with high probability

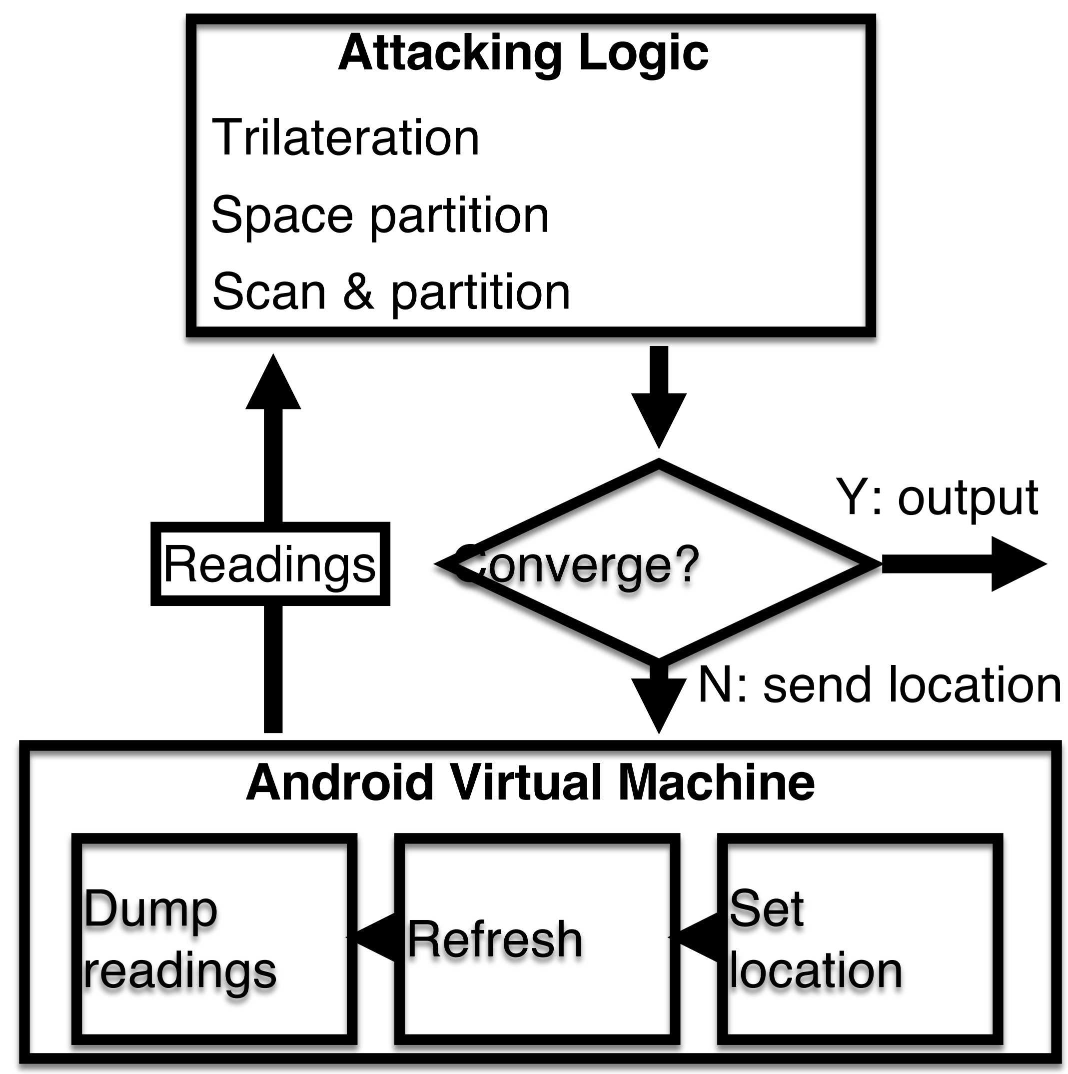
Victim Targeting

- The LBSNs provide query interfaces to retrieve proximity of an arbitrary user without raising the victim's attention:
  - In Momo, proximity can be read when the attacker searches the victim by User ID
  - In Skout, the attacker sends a regular message to the victim and the proximity will be displayed for following queries
  - In Wechat, the attacker searches "People Nearby" and the proximity is shown along with the victim's ID



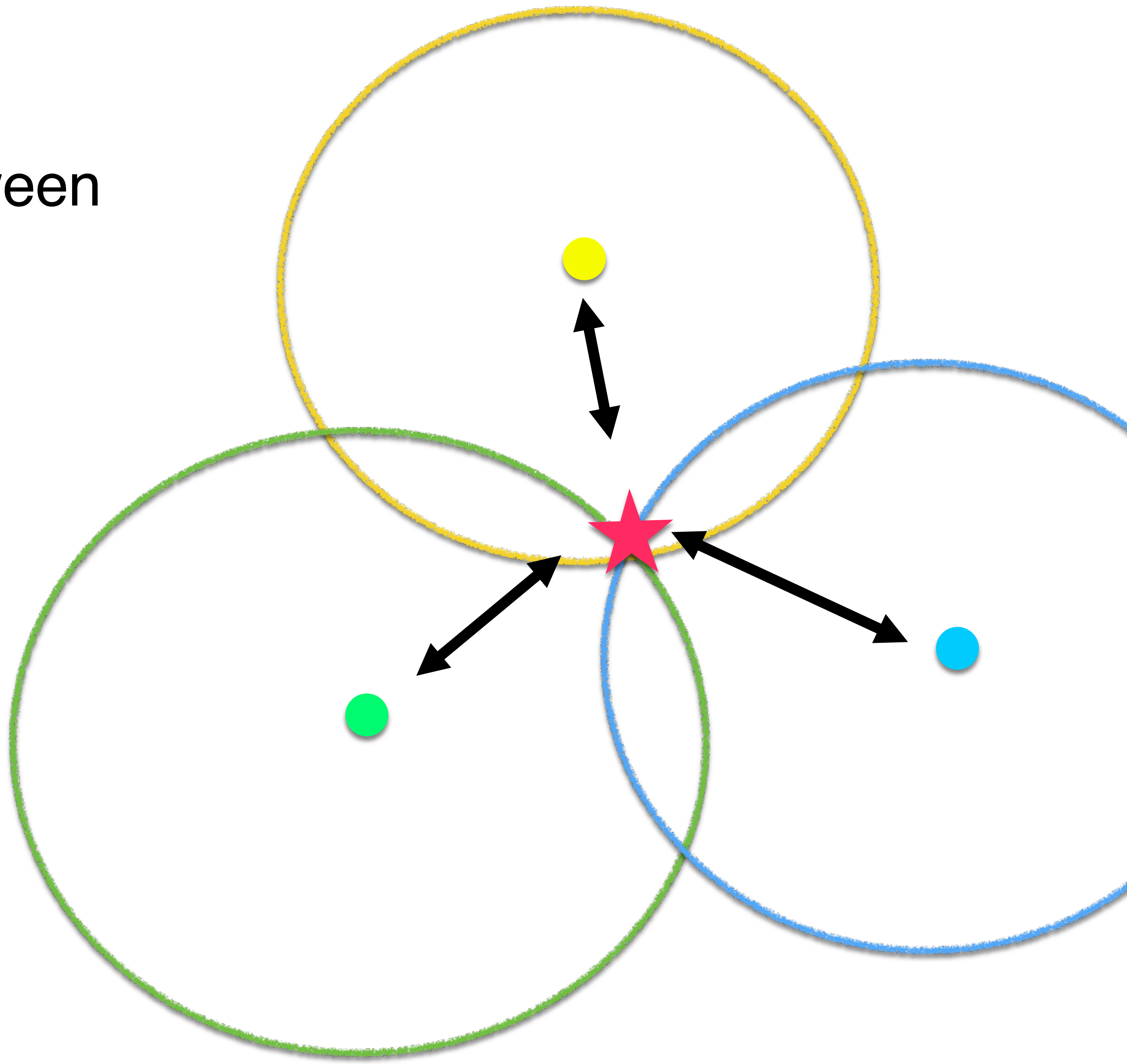
Attack Overview

- Focusing on fooling client side App located on users' mobile devices;
- Developing an automated system which can be easily scaled up:
  - Exploiting the localization service protocols to fake anchor points
  - Modifying Android framework to dump location readings in LBSNs



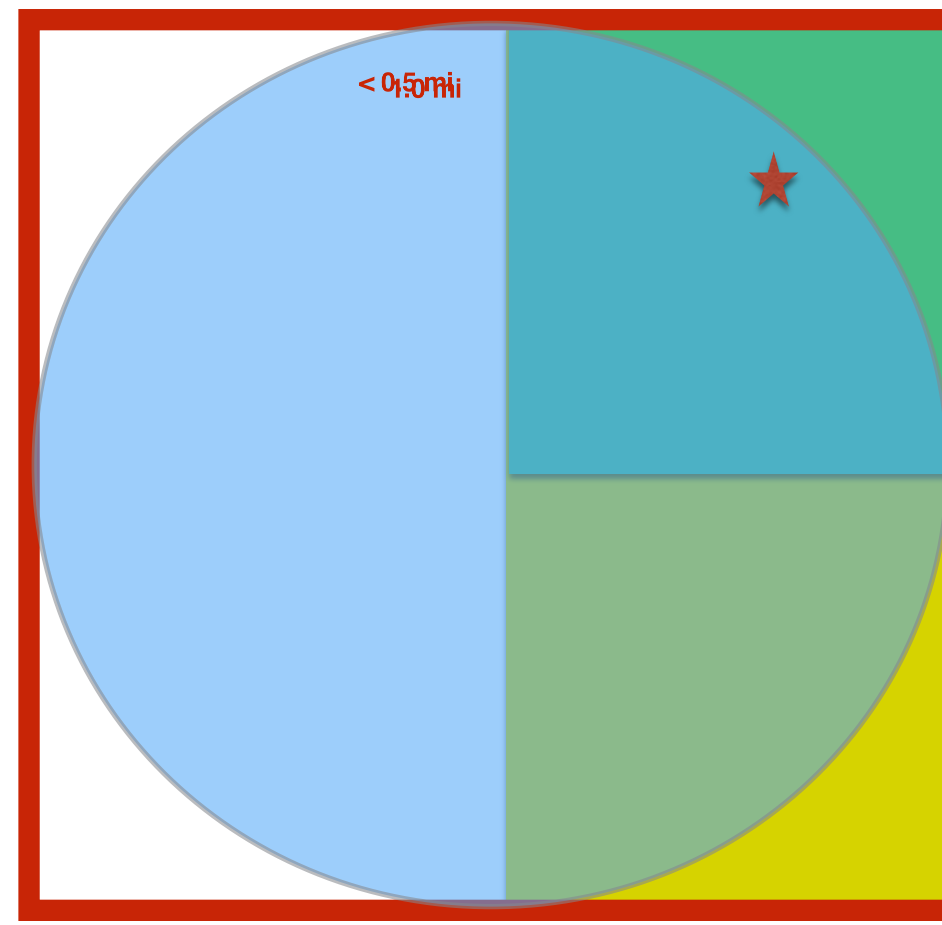
Attack Logic: Trilateration

- Momo shows relative distances between users:
  - Set up 3 anchor points
  - Trilateration the location of the victim
  - Iterate multiple rounds of trilateration to improve accuracy



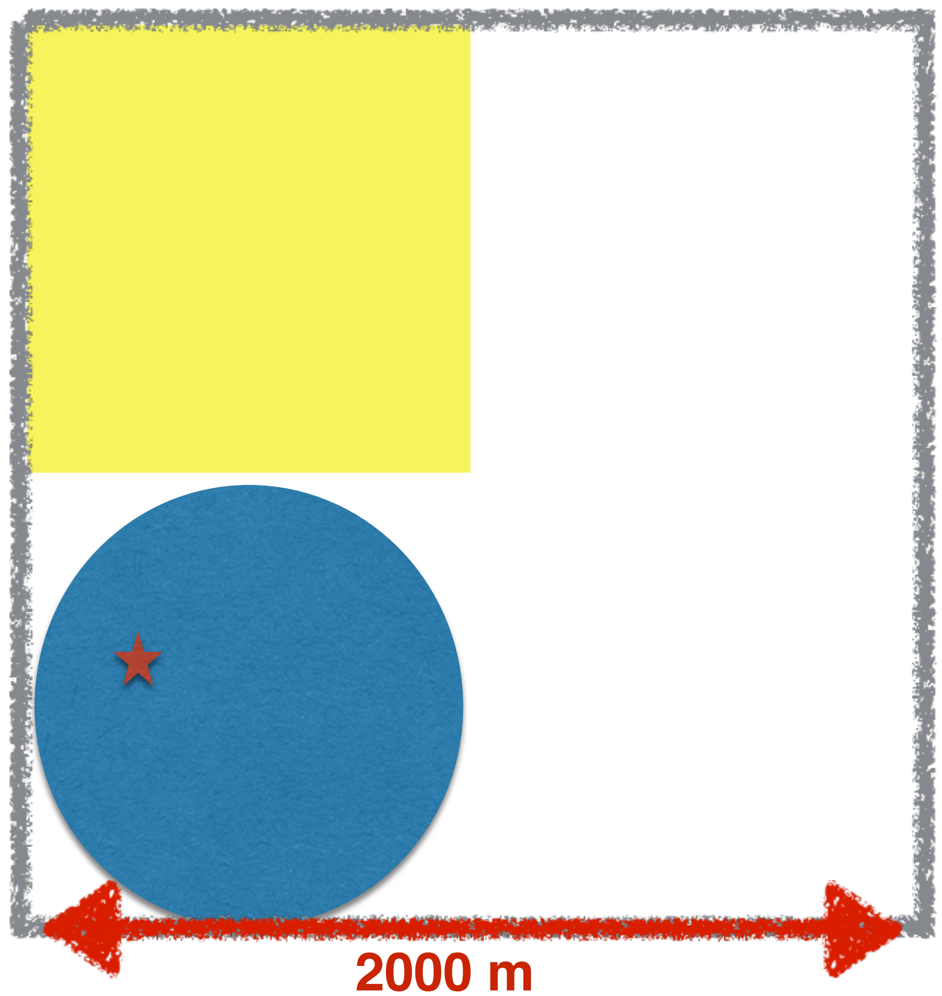
Attack Logic: Space partition

- Skout displays “< 0.5mi” instead of showing real distances when 2 users are within 0.5mi
- Partition the space based on this information to estimate the user’s location



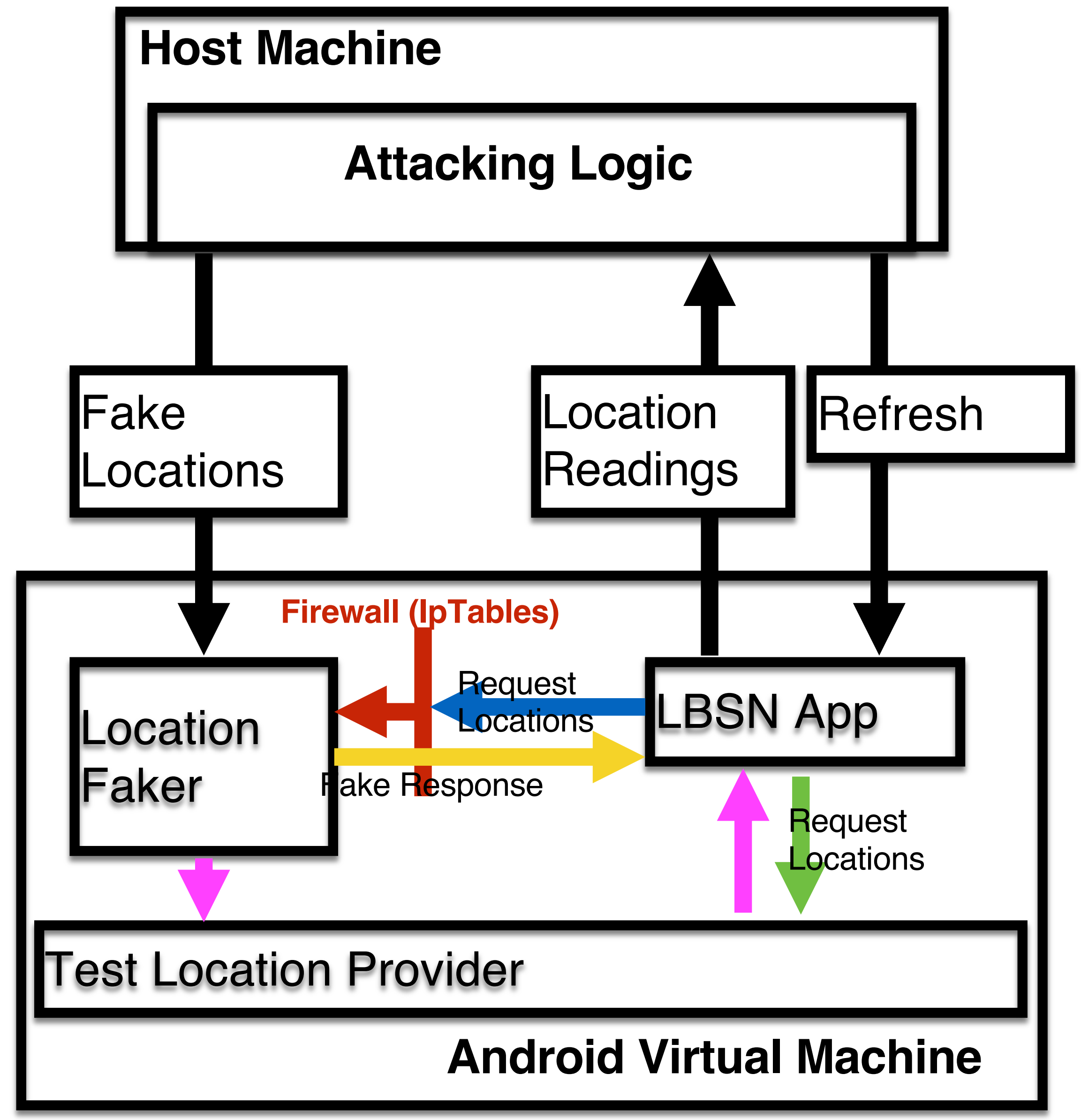
Attack Logic: Scan & Partition

- Wechat restricts visibility to 1km only
- Scan through the possible area with a 1km-step-size
- Then launch space partition to further improve precision



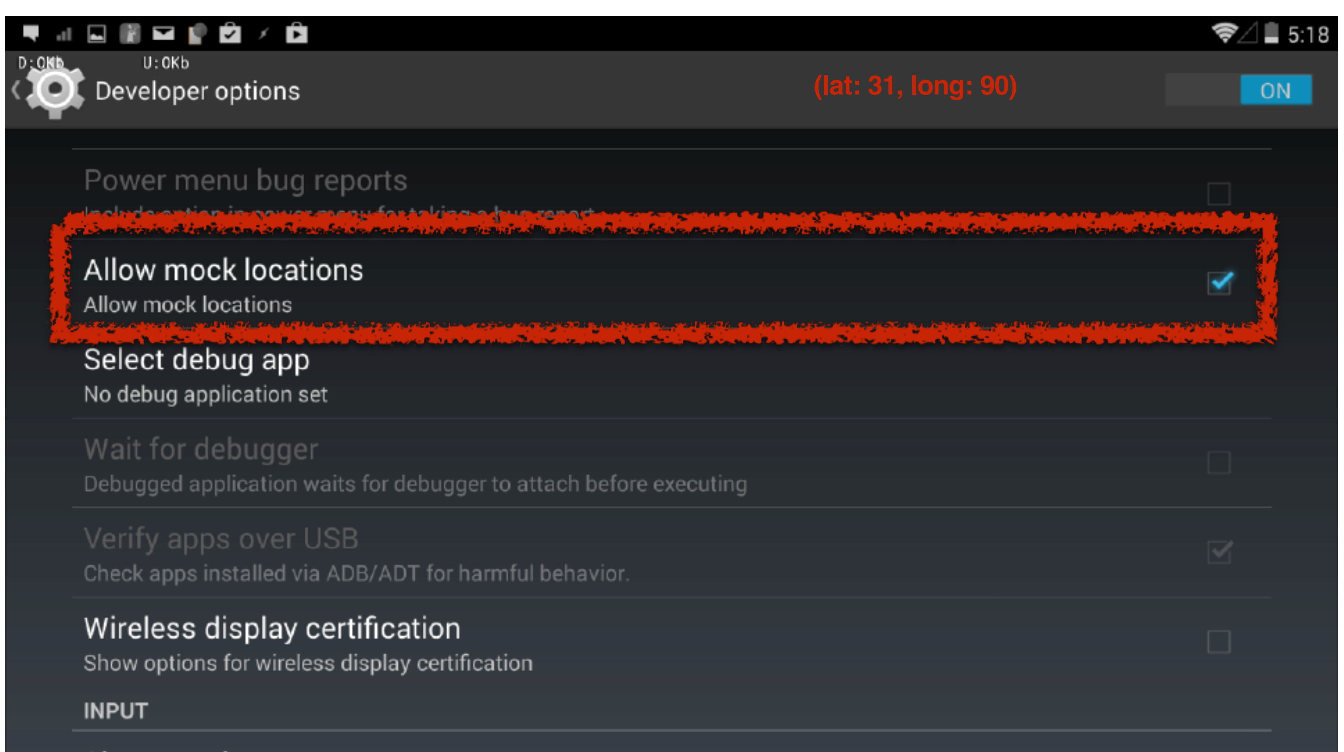
System Implementation

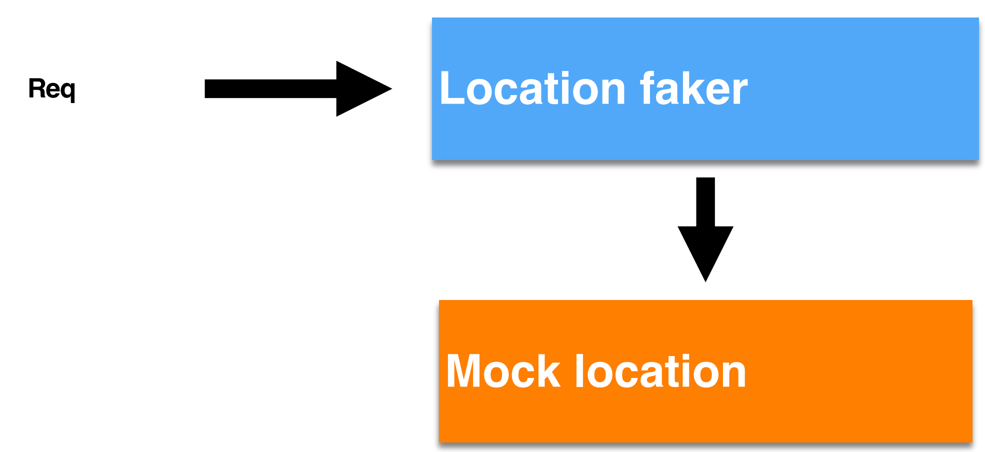
- The attacking logic runs inside the host machine:
  - Carry out localization calculations
  - Communicate with the location faker app in the VM to set fake locations
  - Trigger location updates in LBSN apps and retrieve location readings from Android's ADB logs
- The location faker app in the VM sets fake locations by:
  - Use Android's mock location provider
  - Act as a location server that answers the location requests from LBSN apps



Generating Testing Points: Mock Location

- Android system allows setting mock location via the test location provider for the debugging purpose
- Our Location Faker implements a test location provider
- The Location Faker can accept requests from the attacking logic unit to update locations

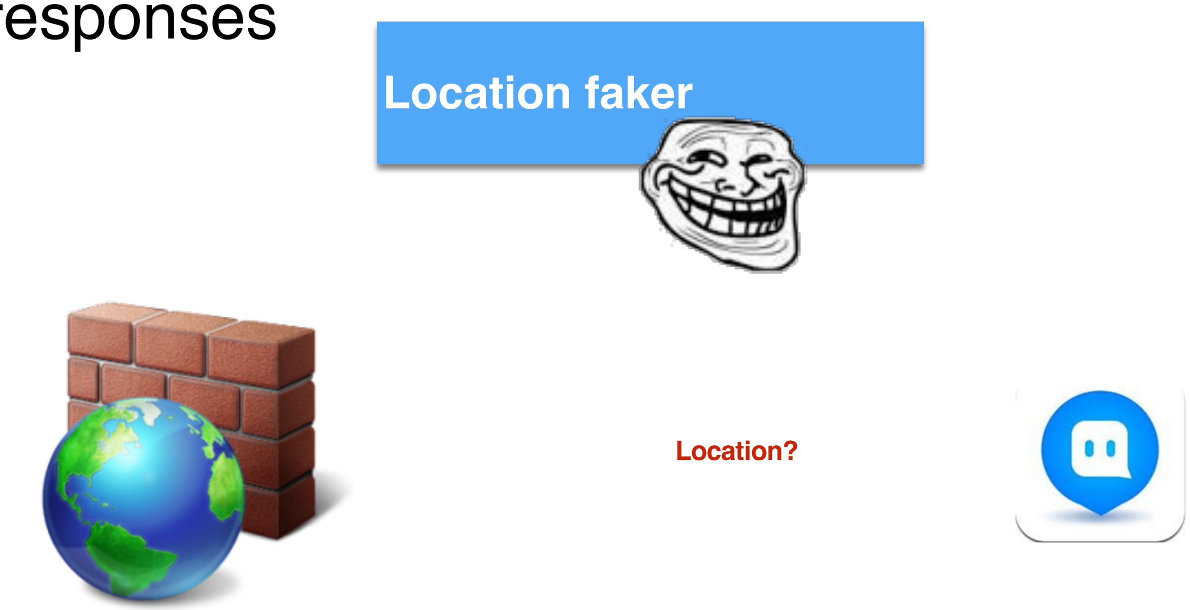




Generation of Test Points: Spoofing the Localization Protocol

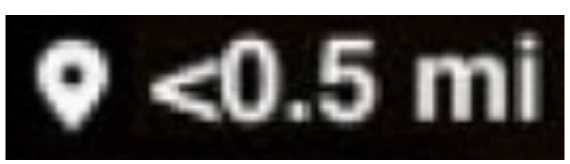
- Momo uses Baidu location API that does not allow taking in mock locations in VMs
- We intercept the network traffic and send fake response:
  - using the kernel firewall (IpTables) to intercept and redirect the location requests to Baidu location API servers
  - using our Location Faker to send fake responses

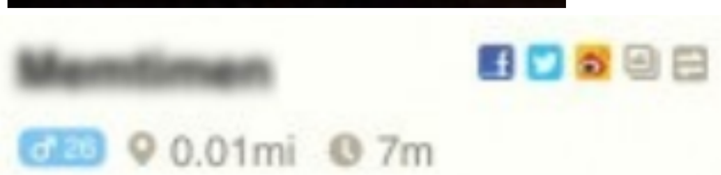
{"content":{"addr":{"detail":""},
"bldg":"","floor":"",
"point":{"y":"90","x":"31"},
"radius":""},
"result":{"error":,"time":""}}



Reading Locations from Apps in Android Framework

- All text related information is displayed in a widget called TextView provided by the Android framework
- The widget has an interface “TextView.SetText”, which is called by the apps to show texts
- We insert code in TextView.SetText function to dump text to the ADB log buffer





SetText(text)
SetText(text)
Log.d(text)
…

0.5 mi

Automating Mobile Location Updating Operations in LBSN Apps

- The location updating operation in LBSN apps consists of multiple tapping / dragging due to the screen size of the mobile devices
- We simulate these inputs to refresh the locations of the LBSN apps
- We mimic screen scrolling with multiple drags to deal with long user lists to read back all distance readings

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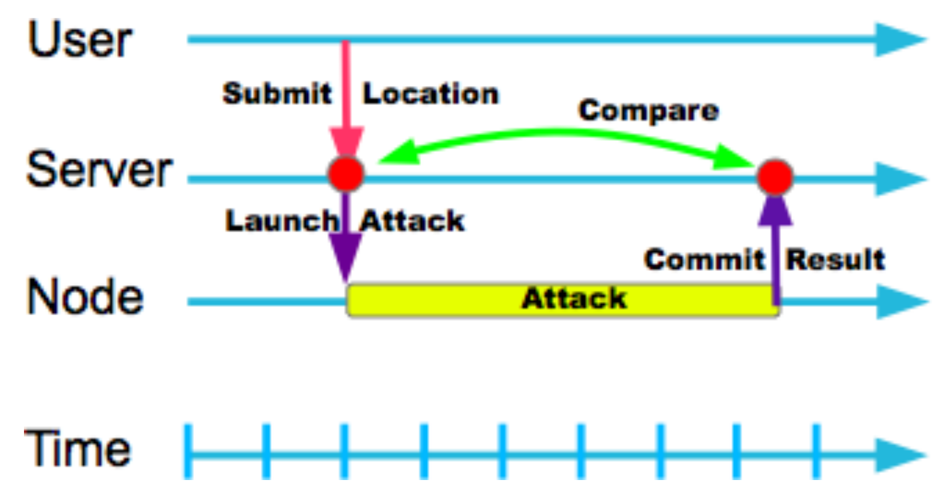
Evaluation Overview

- We perform 3-week long evaluations with 30 volunteers from China, Japan, and U.S and focus on
  - Tracking accuracy:
    - Synchronous tracking accuracy measures the effectiveness of our localization strategy
    - Asynchronous tracking accuracy measures the effectiveness of the strategy in real world scenario
  - Localization efficiency and possible improvements
  - Effectiveness of long term tracking

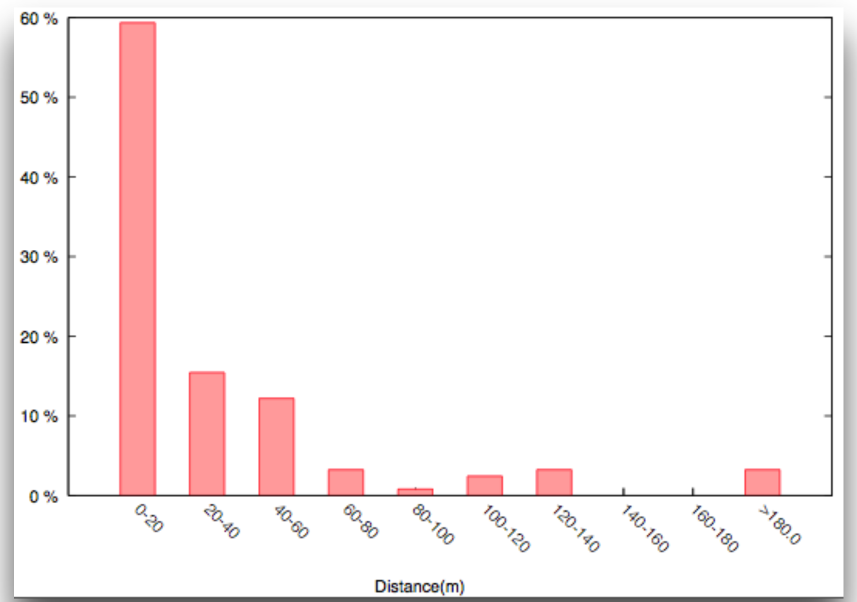
Accuracy: Synchronous Tracking

- Synchronous tracking measures the effectiveness of the localization strategy without the interferences from users' mobility
- Users refresh the location readings on LBSN apps and report their locations to the server
- Upon receiving a report, server launches an attack immediately
- The accuracy is measured as distance between the inferred location and the user's real location

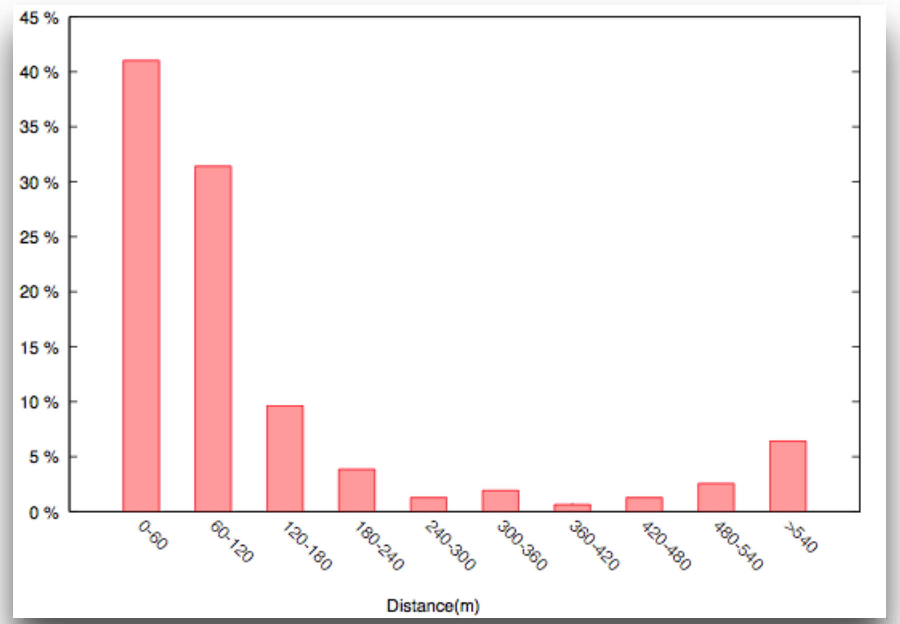


Synchronous Tracking Results

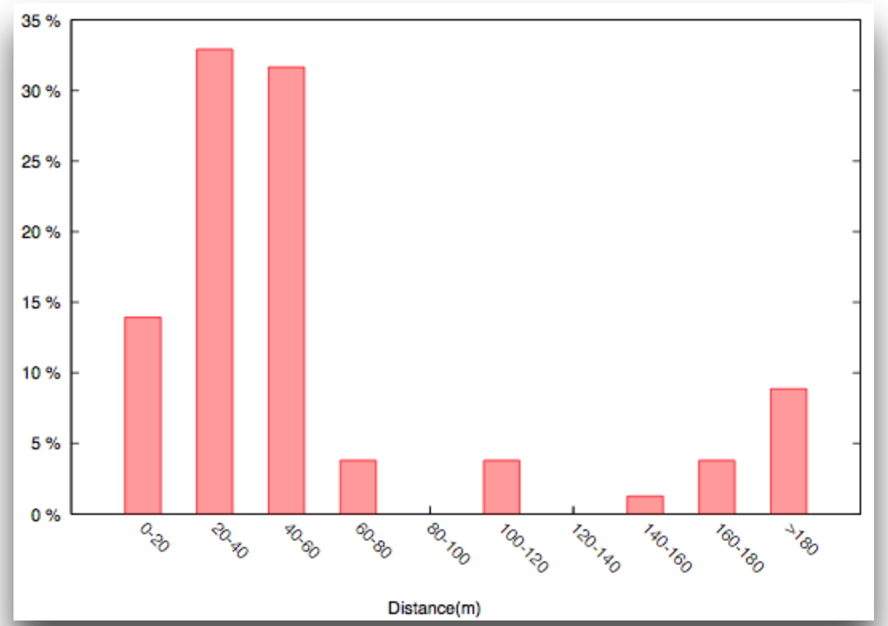
- Our tracking method achieves high accuracy for each of the LBSN applications
- It dramatically improves the accuracy compares to the location protection strategies



Momo



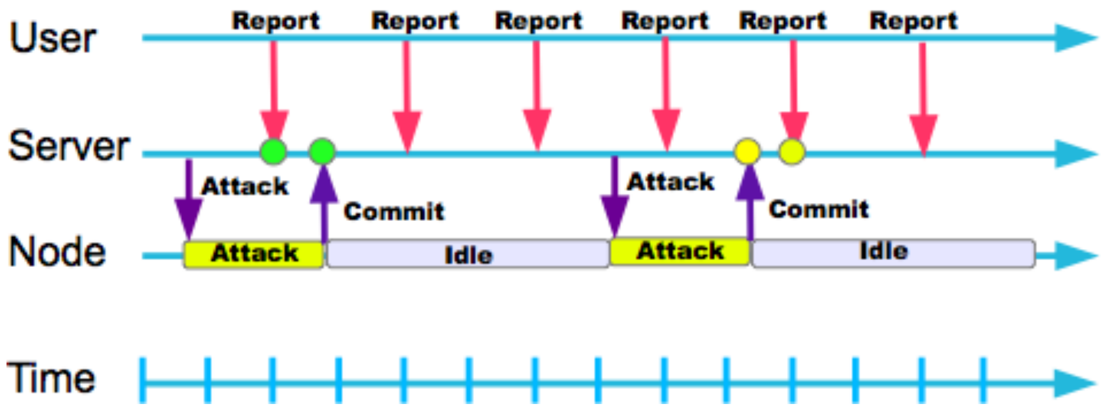
Skout



Wechat

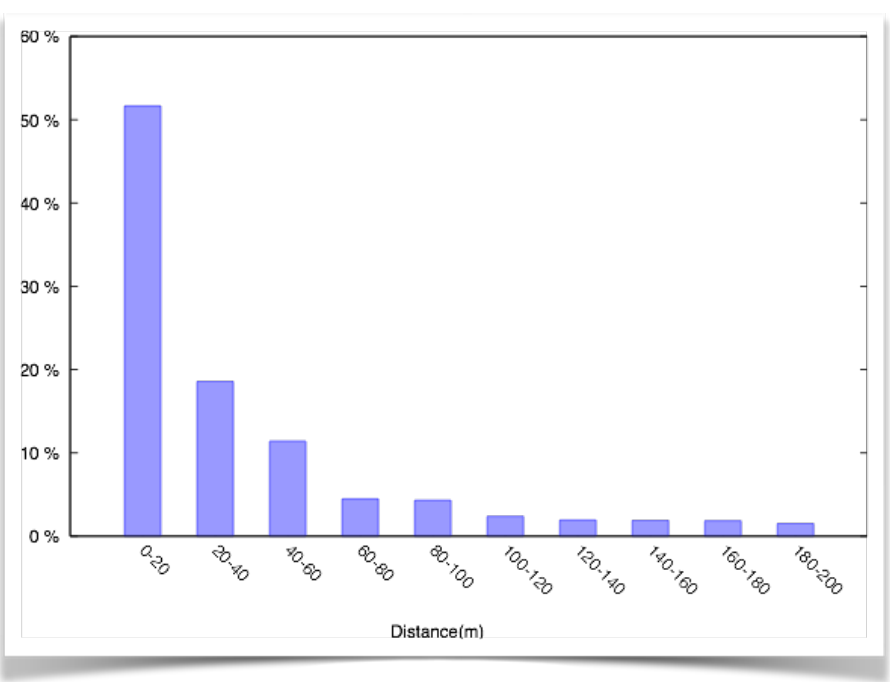
Accuracy: Asynchronous Tracking

- An user may move after refreshes location readings in LBSNs and before the attack
- The volunteers carry an app that automatically reports locations periodically
- Attacks are scheduled at a lower frequency
- We match the closest points in timeline and compare their distances to evaluate the tracking accuracy

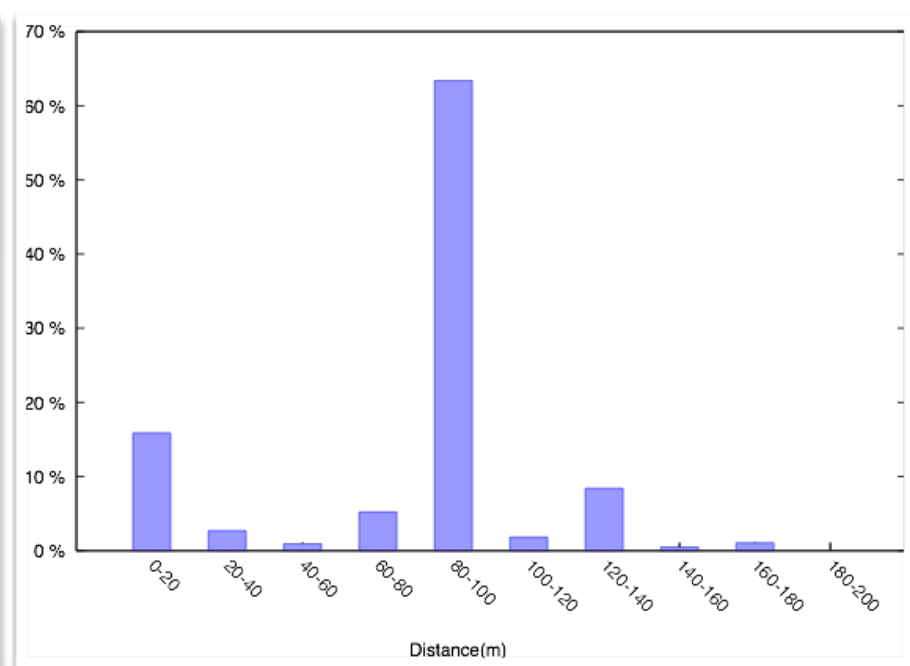


Asynchronous Tracking Results

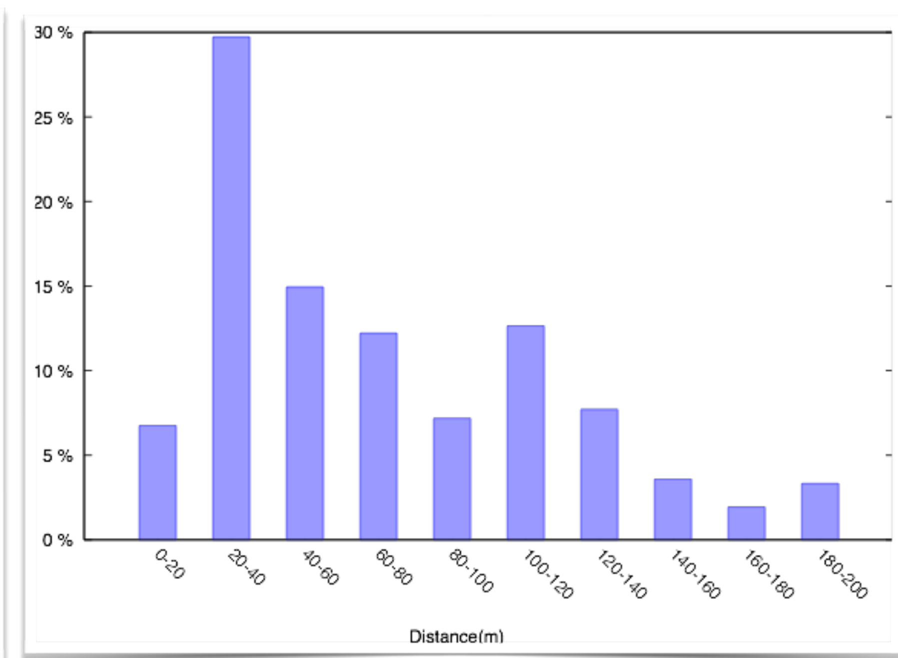
- Our tracking method is still significantly more accurate than the location protection constraints with user's mobility



Momo



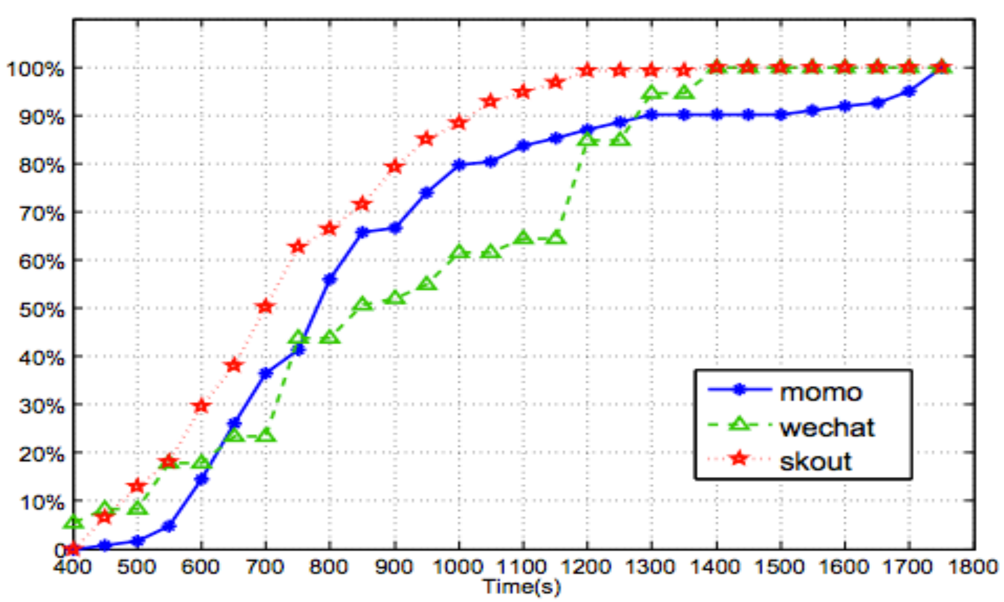
Skout



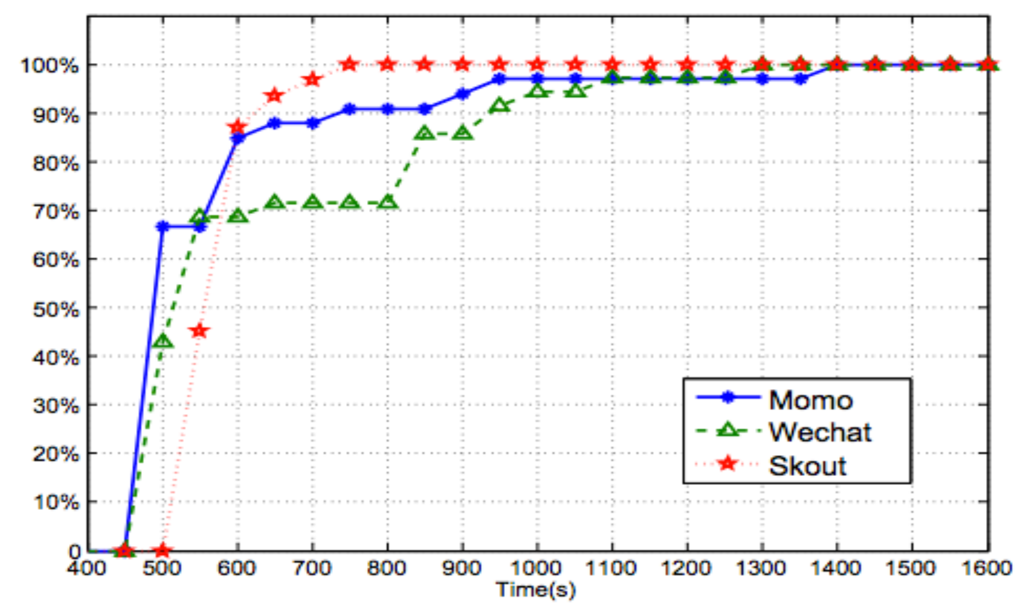
Wechat

Tracking Efficiency

- 80% of the attacks take < 900s to complete when anchor points are randomly chosen globally
- Most of the time is spent on waiting for network responses
- Efficiency can be dramatically improved with a little prior knowledge (e.g. the city in which the user is in and popularity distribution of the area)



CDF of Tracking Efficiency



CDF of Improved Tracking Efficiency

Effectiveness of Long-term Tracking

- Top-N locations refer to users N most frequently visited locations
- Existing works show that Top-N locations are closely related to a user's identity [1]
- We evaluate how many Top-N locations are revealed in our 3-week tracking

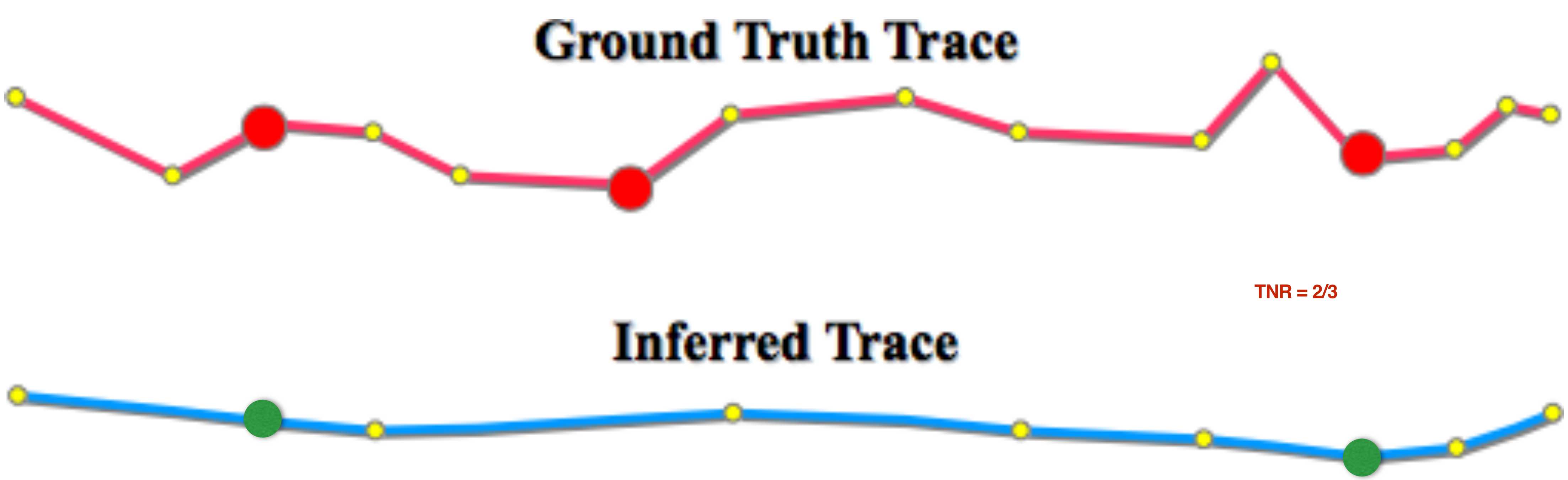
[1] Unique in the Crowd: The privacy bounds of human mobility. de Montjoye et. al. Nature. 2013

Top-N Location Coverage

- Top-N location coverage rate is defined as:

$$TNR = \frac{|Top_N(\mathbb{G}) \cap Top_N(\mathbb{I})|}{N},$$

G: Ground truth traces
I: Inferred traces



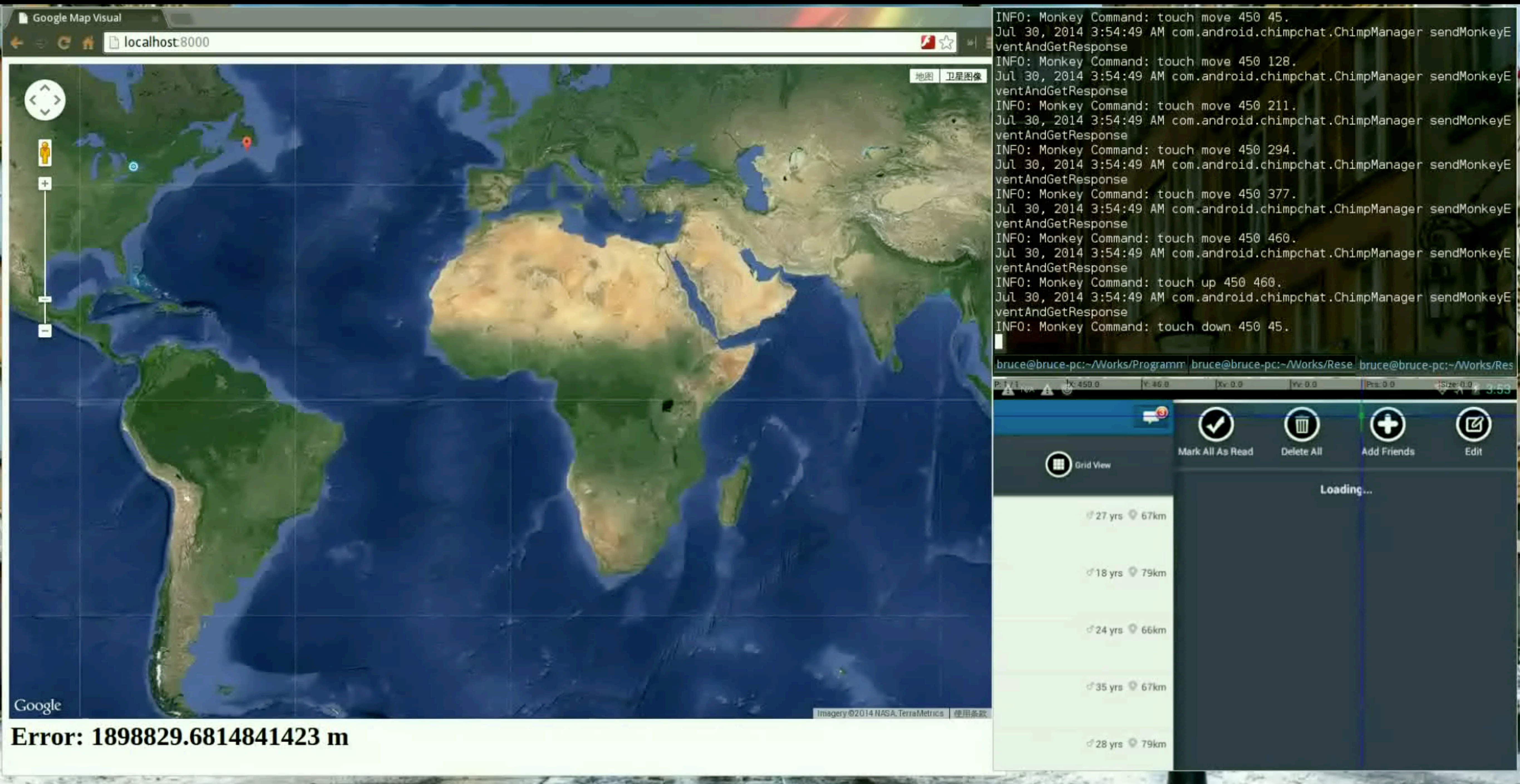
Top-N location coverage

- Top-N location coverage rate grows in 3-week experiments
- For all 3 apps, we achieve high Top 1 location coverage rate
- Our top locations are much finer-grained than existing works [1][2]

Top locations	1 week			2 weeks			3 weeks		
	Momo	Skout	Wechat	Momo	Skout	Wechat	Momo	Skout	Wechat
1	92.3%	20.0%	50.0%	100.0%	60.0%	57.1%	100.0%	60.0%	71.4%
2	46.1%	0.0%	21.4%	46.1%	40.0%	21.4%	69.2%	40.0%	21.4%
3	30.7%	20.0%	21.4%	46.1%	60.0%	28.5%	38.4%	80.0%	28.5%
4	23.0%	20.0%	35.7%	30.7%	40.0%	35.7%	38.4%	40.0%	35.7%
5	23.0%	0.0%	21.4%	15.3%	40.0%	21.4%	15.3%	40.0%	14.2%

[1] Unique in the Crowd: The privacy bounds of human mobility. Y. Montjoye et al. Nature. 2013
[2] Anonymization of Location Data Does Not Work: A Large-Scale Measurement Study. H. Zang et al. MobiCom'13.

Attack Demo



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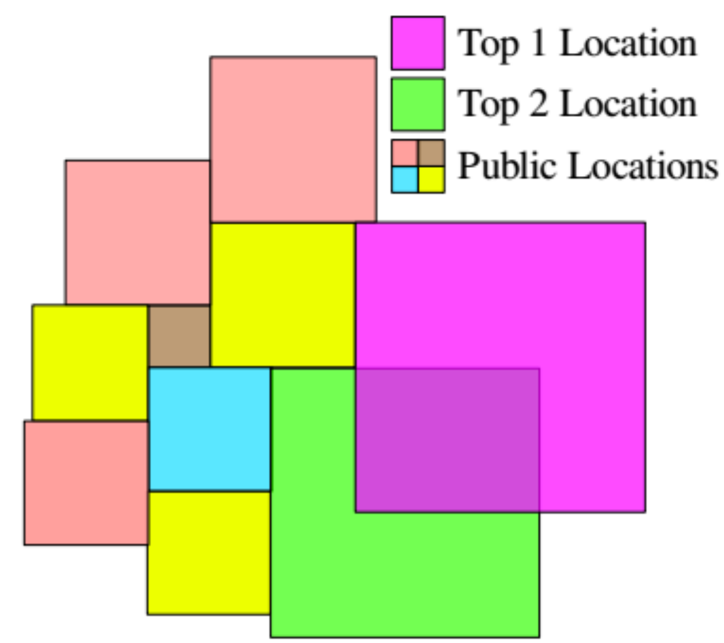
Defense Mechanism Overview

- One possible defense mechanism is to use location obfuscation
- We outlined a user-centric location obfuscation mechanisms to achieve a good balance between utility and effectiveness:
  - More obfuscation when users are at their Top-N locations
  - Less obfuscation when users are at public places
- We implement this technique as an Android location service

User-Centric Location Obfuscation

- We record users' location profiles and identity Top-N locations

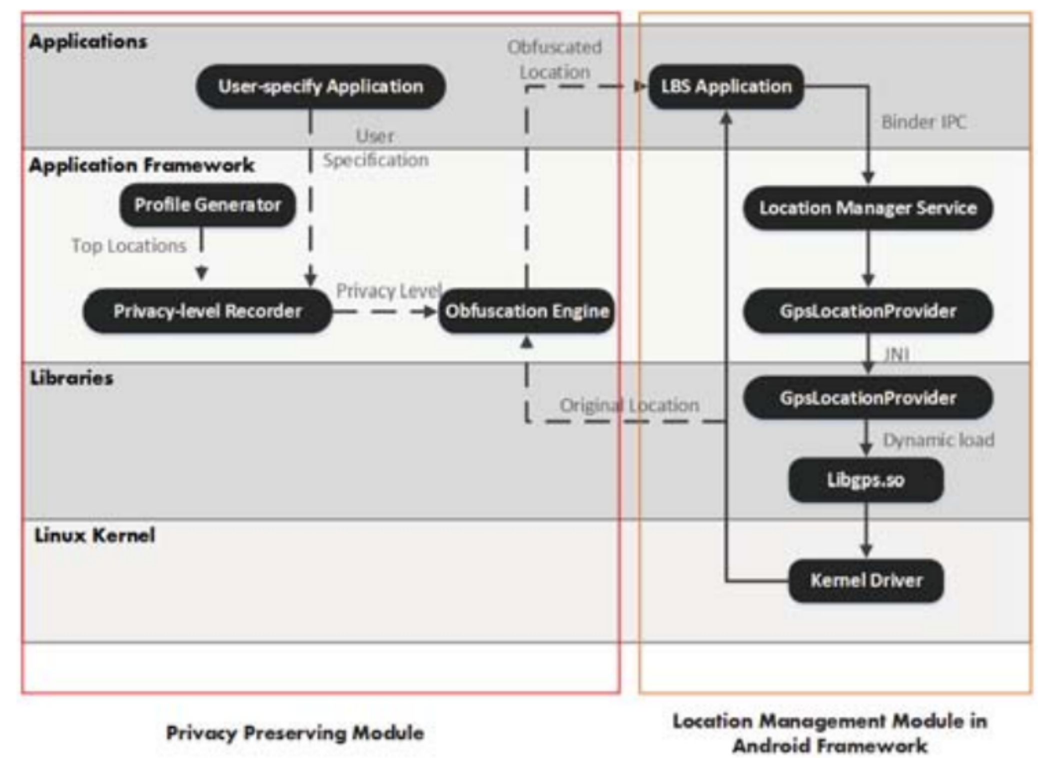
- Users selectively apply:
  - more obfuscation to Top-N locations
  - less obfuscation to public places



Implementation as Android Location Service

- The profile generator collects and identifies Top-N locations

- The obfuscation middleware intercepts location requests from the applications and replies with obfuscated locations



Concluding Remarks

- We have developed automated attacks for the first time against popular LBSNs with hundreds of millions of users
- Proximity-based friend discovery poses serious threats to users' location privacy
- Automated tracking attacks without hacking into LBSN services can be carried out without much technical difficulty and resource.

Concluding Remarks

- It is very important to protect users' location privacy in today's world
- We believe that people should be able to take the control of their own personal location data
- Open-source "personal location obfuscater" controlled only by the user him/herself is desired:
  - Continuously learn his/her own location profile
  - Perform adaptive location obfuscation on-demand to all mobile apps that request user location info based on
    - the nature of the app and
    - his/her own location profile

Q & A