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.

<table>
<thead>
<tr>
<th>LBSN</th>
<th>Location Retrieval Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Momo</td>
<td>Rely on Baidu location SDK to fuse inputs from multiple location sources</td>
</tr>
<tr>
<td>Wechat/Skout</td>
<td>Select the available one with the highest precision (GPS, Wi-Fi, Cell ID)</td>
</tr>
</tbody>
</table>
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's Graph]
![Skout's Graph]
![Wechat's Graph]
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

<table>
<thead>
<tr>
<th></th>
<th>Number of users</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wechat</td>
<td>300 millions</td>
<td>Indirect</td>
</tr>
<tr>
<td>Skout</td>
<td>5 millions</td>
<td>Indirect</td>
</tr>
<tr>
<td>Momo</td>
<td>30 millions</td>
<td>Indirect</td>
</tr>
<tr>
<td>iAround</td>
<td>10 millions</td>
<td>Open direct access</td>
</tr>
<tr>
<td>Google+</td>
<td>30 millions</td>
<td>Authorized direct access</td>
</tr>
<tr>
<td>Facebook</td>
<td>1.23 billion</td>
<td>Authorized direct access</td>
</tr>
</tbody>
</table>
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 0.5mi;
  • Users see their distances to other users when the distances are larger than 0.5mi 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

Attacking Logic

- Trilateration
- Space partition
- Scan & partition

Android Virtual Machine

- Dump readings
- Refresh
- Set location

Converge?

Y: output
N: send location
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
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) …
Log.d(text) …

<0.5 mi

Adb Logcat
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
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
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)
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

Top-N Location Coverage

- Top-N location coverage rate is defined as:

\[
TNR = \frac{|Top_N(G) \cap Top_N(I)|}{N},
\]

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]

<table>
<thead>
<tr>
<th>Top locations</th>
<th>1 week</th>
<th>2 weeks</th>
<th>3 weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Momo</td>
<td>Skout</td>
<td>Wechat</td>
</tr>
<tr>
<td>1</td>
<td>92.3%</td>
<td>20.0%</td>
<td>50.0%</td>
</tr>
<tr>
<td>2</td>
<td>46.1%</td>
<td>0.0%</td>
<td>21.4%</td>
</tr>
<tr>
<td>3</td>
<td>30.7%</td>
<td>20.0%</td>
<td>21.4%</td>
</tr>
<tr>
<td>4</td>
<td>23.0%</td>
<td>20.0%</td>
<td>35.7%</td>
</tr>
<tr>
<td>5</td>
<td>23.0%</td>
<td>0.0%</td>
<td>21.4%</td>
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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.