Resilient Collaborative Privacy for Location-Based Services

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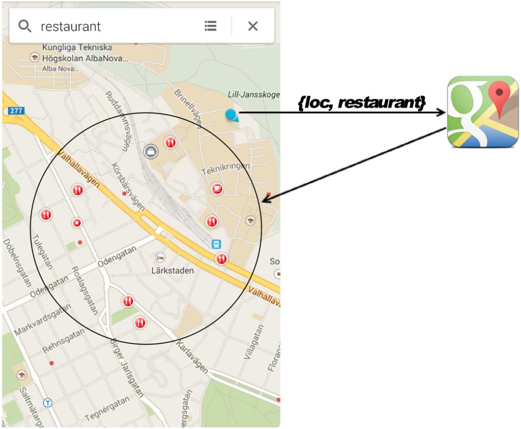
Background

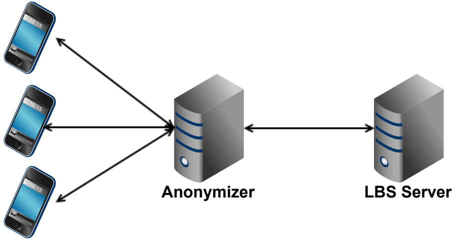


- **Privacy issue** - Expose users (and their queries) to honest-but-curious Location-based Service (LBS) servers

What can go wrong?

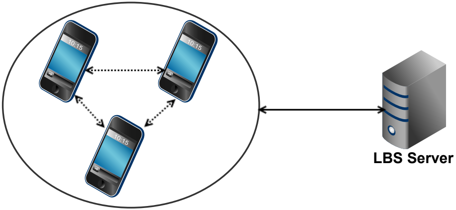
- Location information used to reconstruct user trajectories
- Profile users' activities and infer their interests
- Push advertisements to users

Centralized Privacy Protection Scheme



- Scheme
  - All the queries are sent to the anonymizer
  - Apply privacy-enhancing technologies on the anonymizer
- Advantages
  - Effective
  - Transparent to client
- Problem
  - Why couldn't an anonymizer also breach the user privacy the same way?

Decentralized Scheme

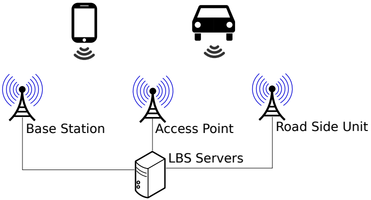


- Objectives
  - Rely on neighbors/peers
  - Contact the LBS server directly, but with protected (anonymized) information
- Example (MobiCrowd [Sho+14])
  - Cache signed results from LBS server
  - Query neighbors first, and query LBS server if no result from neighbors
- Challenge
  - Expose users to faulty or misbehaving nodes

Security and Privacy Requirements

- Authentication and Integrity
- Non-repudiation and Accountability
- Anonymity/Pseudonymity and Unlinkability
- Confidentiality (optioanlly) - might be required for subscriber-based LBSs

System Model

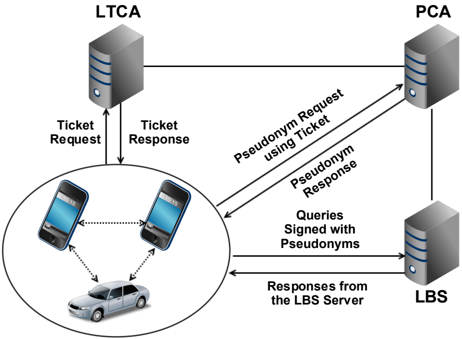


- Nodes (smartphones or On-board Units) are interested in POI information
- Nodes request POI information from LBS servers through the Internet
- Nodes are able to exchange information in an wireless ad-hoc network

Adversary:

- LBS servers are honest-but-curious
- Any trusted-third-party introduced could also be honest-but-curious, including the ones we introduce in our scheme
- Nodes can be honest-but-curious
- Nodes can be malicious: deviate from the collaborative protocol functionalities and policies

Our Scheme



- Client registration with a Long-Term Certification Authority (LTCA)
- Ticket and pseudonym acquisition from LTCA and Pseudonymous Certification Authority (PCA) [Kho+14]
- Leverage information sharing in wireless ad-hoc network
- Pseudonymous authentication for queries and responses
- Pseudonym resolution in case of misbehavior (conditional anonymity)

Optimizations for Query Processing

- Certificate omission [Cal+11]
  - Omit attaching pseudonyms to reduce communication overhead
- Cache responses to popular queries
  - Such information is likely to become useful later, thus avoid duplicated work
- Set a threshold, N, for the number of responses needed
  - Overhear open transmissions and respond in case less than N response are overheard
  - Send an ACK when enough responses are received

Security and Privacy Analysis

- **Authentication, Integrity, and Confidentiality**
    - Pseudonymous authentication
    - Session key negotiation
- **Non-repudiation and Accountability**
    - Pseudonym resolution
- **Unlinkability**
    - Messages only linkable over pseudonym lifetime, τ

Security and Privacy Analysis (cont'd)

- **Node Authentication and Exposure to the LBS Server**
  - Pseudonymous authentication
  - Reduced exposure to the LBS server due to collaboration
- **Non-verifiable Responses**
  - Redundant (N) responses can help for cross-checking
- **Thwarting Clogging Attacks**
  - Limit the usage of pseudonym
  - Prevent Sybil attack from the infrastructure (PKI) [Kho+14]

Security and Privacy Analysis (cont'd)

- **Exposure to the Security Infrastructure and Collusion with the LBS**
  - A single LTCA or PCA cannot trace a user's actions [Kho+14]
  - LTCA + LBS: no extra information
  - PCA + LBS: link the batch of pseudonyms obtained from one pseudonym request and the messages authenticated with them
  - Only the collusion of the LBS server, the LTCA and the PCA would expose users

Performance Evaluation

- **Specifications**
  - Sony Xperia Ultra Z with Quad-core 2.2 GHz Krait 400 CPU
  - Bouncy Castle library for crypto operations (only one available in Android for ECDSA)

Processing delay of cryptographic operations

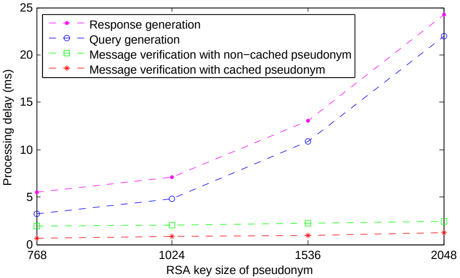
Key Type	Security Level (bits)	Generation (ms)	Sign (ms)	Verify (ms)	Signature Size (bytes)
RSA-1024	80	400.86	4.63	0.78	128
RSA-2048	112	2104.59	21.18	1.21	256
ECDSA-192	96	214.65	210.01	286.44	56
ECDSA-224	112	251.66	251.91	345.95	63

- **Key choice - RSA-1024**
  - 80-bit security level
  - Unoptimized ECDSA crypto operations in the library
  - Longer pseudonym lifetime due to lower message rate, implies less key generation

Performance Evaluation (cont'd)

Processing overhead for different operations

Operation	Processing Overhead
Message verification with cached pseudonym	Message Verification
Message verification with non-cached pseudonym	Pseudonym Verification, Message Verification
Query generation	Message Signing
Response generation	Database Query, Message Signing



Processing delay of different operations, assuming RSA-2048 certificate of the PCA

- 3000 mobile phone users per km^2 in Barcelona [Lou+14]
- Around 100 neighbors assuming Wi-Fi radio range of 100 m
- 1.7 *queries/sec* received assuming 1 *query/min* per user

Conclusions

- Decentralized secure and privacy protection scheme for LBSs
- Leverage information sharing in P2P systems
- High resiliency to different attacks and high practicality for deployment
- Can be extended in terms of proposed optimizations

References

R. Shokri, G. Theodorakopoulos, P. Papadimitratos, E. Kazemi, and J.-P. Hubaux. "Hiding in the Mobile Crowd: Location Privacy through Collaboration". In: *IEEE TDSC* (2014).

G. Calandriello, P. Papadimitratos, J.-P. Hubaux, and A. Lioy. "On the performance of secure vehicular communication systems". In: *IEEE TDSC* (2011).

M. Khodaei, H. Jin, and P. Papadimitratos. "Towards deploying a scalable & robust vehicular identity and credential management infrastructure". In: *IEEE VNC*. Paderborn, Germany, Dec. 2014.

T. Louail, M. Lenormand, O. G. Cantu Ros, M. Picornell, R. Herranz, E. Frias-Martinez, J. J. Ramasco, and M. Barthelemy. "From mobile phone data to the spatial structure of cities". In: *Scientific Reports* (June 2014).