Privacy-Preserving Implicit Authentication

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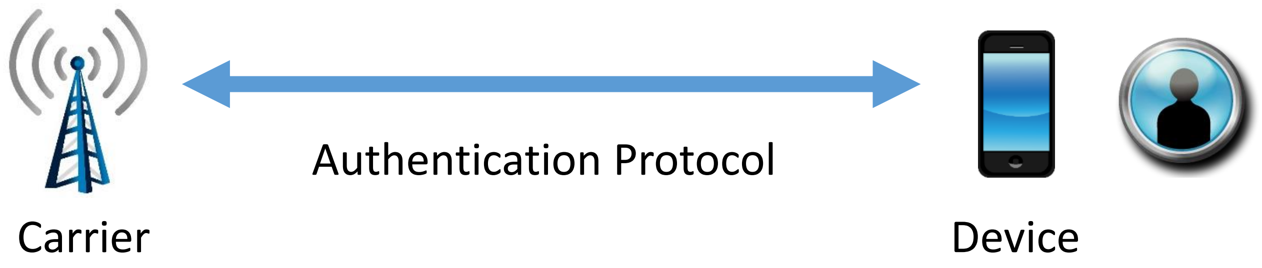
Outline

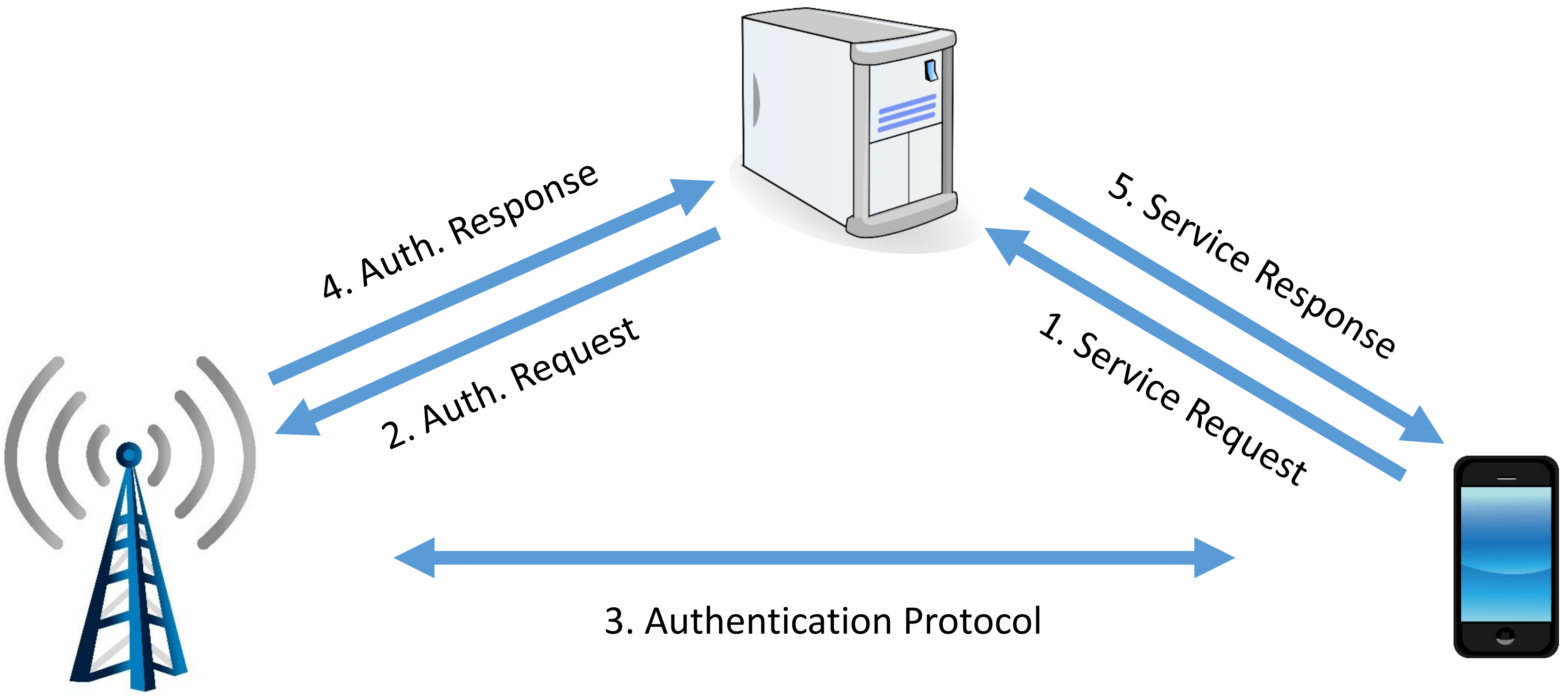
- Device, Implicit Authentication
  - Usage patterns, authentication decision making
  - Cost: privacy!
- Our Basic Protocol
  - Preserves privacy against carrier, benign illegitimate users
- Our Improved Protocol
  - Preserves privacy against malicious illegitimate users as well
- Privacy Guarantees, Computation & Communication Cost
- Concluding Remarks

Implicit Authentication

- Idea: authentication by device usage pattern
  - Implicit: does not need user interaction, runs in the background
- Usage pattern is compared with history
  - If conforming: no action
  - If not conforming: user asked to provide the first factor for authentication
- Result: legitimate user not burdened much, illegitimate user caught



Example Scenario



Jakobsson, Shi, Golle, Chow – USENIX 2009

Storage of Usage Pattern History

Usage pattern history needs to be stored on the carrier side!

- Otherwise, loss of device = loss of usage pattern history

  = ability to mimic (physically or artificially) the usage pattern

  = loss of authentication security!

  = loss of privacy!

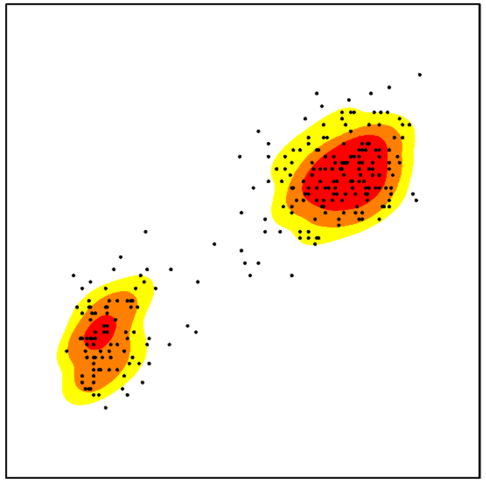
Usage Pattern Data

- 3 categories of usage pattern data:
  - 3rd party (App server / cloud) data: app usage pattern, app data, …
  - Carrier data: call, sms, data usage patterns, location pattern, …
  - Device data: WiFi usage pattern, sensor data, device usage pattern, …
- Device (, 3rd party) data needs to be shared with carrier for effective implicit authentication
- We claim this is unnecessary!
- and propose “privacy-preserving implicit authentication”
- Idea: store *encrypted* usage pattern data

User Profiles & Authentication

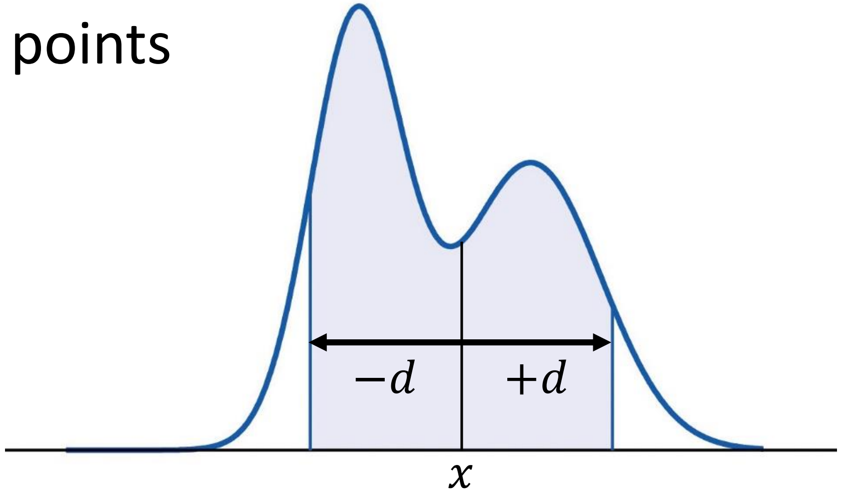
- User profile: vector of features
- Each feature belongs to a user-specific distribution
- Feature distributions are approximated by feature history
- On a new reading, a decision is made if it belongs to the distribution

- Observation: often the distribution is
  a collection of clusters
  e.g. based on time of day



A Simple Decision Maker

- For a distribution D, calculate a measure of dispersion d
  - E.g. standard deviation, average absolute deviation (AAD)
- On a new reading x, calculate the area under the distribution curve between $x - d$ and $x + d$
  - This *'similarity measure'* is between 0 and 1
  - Can be approximated by the number of points recorded in the history
- Only needs comparison, addition, calculation of dispersion d



Calculation in the Ciphertext Space

- *Homomorphic Encryption (HE):* enables addition in ciphertext space
  - $H.Enc(a+b) = H.Enc(a) \oplus H.Enc(b)$
  - Hence, $H.Enc(c \cdot a) = c \odot H.Enc(a)$
- Comparison in the ciphertext space
  - Possible using homomorphic encryption, but needs interaction
  - *Order-Preserving Symmetric Encryption (OPSE)*   Boldyreva et al. EuroCrypt'09
    - $a > b \Leftrightarrow OP.Enc(a) > OP.Enc(b)$

Our Protocol: Idea, Pre-computation

Basic idea:

- Device sends *encrypted* readings to carrier periodically, which are stored on the carrier side as history:

$$H.Enc\big(v(t_i)\big),\ \ OP.Enc\big(v(t_i)\big)$$

Pre-computation:

- Carrier finds order in history using order-preserving encryptions, finds encrypted median, calculates average absolute deviation (AAD):

$$H.Enc\big(AAD(v)\big)$$

Our Protocol: Authentication, Update

Authentication:

- Carrier calculates, sends them to device:

$$H.Enc\big(v(t_i) - AAD(v)\big), \qquad H.Enc\big(v(t_i) + AAD(v)\big)$$

- Device decrypts, calculates OP encryptions, sends back:

$$OP.Enc\big(v(t_i) - AAD(v)\big), \qquad OP.Enc\big(v(t_i) + AAD(v)\big)$$

- Carrier locates values, counts no. of ciphertexts within the range

Update:

- If authentication succeeds (either implicit or explicit), update AAD
  - Only needs a few calculations to account for the difference

Privacy of our Protocol

- Definition based on secure two-party computation guarantees:
  - Device only learns AAD of history
  - Carrier only learns order of current reading compared to history
- Proven our protocol secure against an *honest-but-curious* device, an *honest-but-curious* carrier
  - User privacy is preserved against carrier
  - If device stolen or lost, user privacy preserved against illegitimate users, as long as the device is not ‘hacked’
  - For ‘hacked’ devices, need to consider privacy against *malicious* devices

Improving Security

- To achieve security against malicious devices:
  - Device required to send a *proof of knowledge* of plaintext with the ciphertext $H.Enc\left(v(t_i)\right)$ Baudron et al. PODC'01
  - Order-preserving encryption replaced by interaction with device to compare ciphertexts
    - Compare $OP.Enc\left(v(t_i) \pm AAD(v)\right)$ with history records via binary tree search
    - $\log \ell$ rounds of interaction for a history of size ℓ
- Proven our protocol secure against a *malicious* device
  - If device stolen or lost, user privacy preserved, even if device 'hacked'

Comparing Homomorphic Ciphertexts

- Goal: compare a, b given $H.Enc(a), H.Enc(b)$, device has key
- Naïve: send to device, get response, but device learns a, b, might cheat
- Equivalent: Calculate $H.Enc(a-b)$, compare with zero
- Randomise: $H.Enc(r(a-b))$, so device does not learn $a-b$, but still might cheat
- Mix with $k-1$ other values $H.Enc(c_i)$ for known c_i, now device might still cheat, but will be caught with high probability

Computation & Communication Cost

Cost of privacy for device: encryption

- Basic protocol:
  - 3 homomorphic, 3 order-preserving encryptions
  - Authentication: *300ms* on 2.66 GHz single-core processor
  - Only 2 rounds of communication
- Improved protocol:
  - $k \log \ell$ homomorphic encryptions for security parameter k
  - Authentication failure discovered *4 seconds* with $k = 2, \ell = 100$
  - $\log \ell$ rounds of communication

Final Remarks

- Implicit authentication improves security without degrading usability
- However it requires giving up on privacy! Is this necessary?
- We proposed privacy-preserving implicit authentication
- Guarantees privacy against carrier, also illegitimate users in case of loss of device
- Does not incur prohibitive extra computation, communication cost
- A step towards showing that

the trade-off between privacy & security is a false one!

Thank you!

Full version: eprint.iacr.org/2014/203

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