NTNU | Norwegian University of Science and Technology

ABUSE-RESISTANT LOCATION TRACKING: BALANCING PRIVACY AND SAFETY IN THE OFFLINE FINDING ECOSYSTEM

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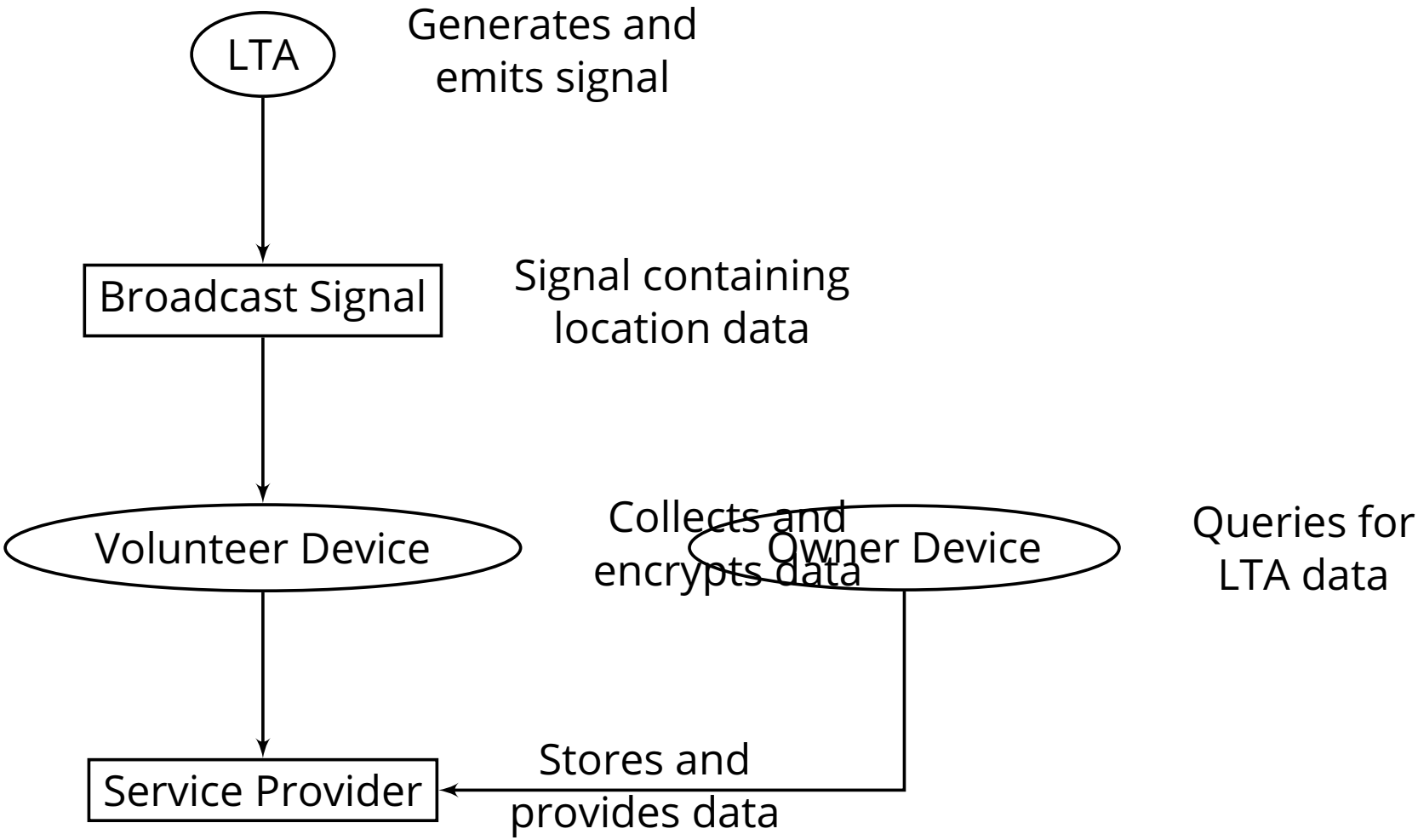
Privacy and Security in Location Tracking Accessories (LTAs)

Picture from: https://www.forbes.com/sites/forbes-personal-shopper/2023/11/30/best-luggage-trackers/

LTAs


LTA
Generates and emits signal
Broadcast Signal
Signal containing location data
Volunteer Device
Collects and encrypts data
Owner Device
Queries for LTA data
Service Provider
Stores and provides data

What can they be used for?

- Tracking personal items

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- Tracking your kids and pets

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What can they be used for?

- Tracking personal items
- Tracking your kids and pets
- Tracking your vehicle
- Tracking PEOPLE! :(

Privacy and Stalking Risks associated with LTAs

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- The challenge is therefore to design a system that both tracks and can be detected if stalking.
- This is hard to do because you don’t want other people tracking your things either.

Contributions

- Development of Abuse-Resistant Private Offline Finding Protocols

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- Experimental Data Collection for Parameter Selection
- Proposing Protocol Optimizations
- Implementation and Efficiency Demonstration

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Current State of LTAs

- Rotate identifiers for privacy

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Current State of LTAs

- Rotate identifiers for privacy
- Use secret keys to generate sequences of identifiers
- Stalker detection becomes harder because of rotating identifiers
- Attempts to balance privacy and stalker detection
- Limited against sophisticated tracking

Balancing User Privacy and Stalker Detection

Apple FindMy

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Apple FindMy

- Pseudonym identifiers

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Apple FindMy

- Pseudonym identifiers
- Secret key mechanism generating IDs

Balancing User Privacy and Stalker Detection

The Paper

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- Using MDDS and list-decodable error-correcting codes to enhance privacy

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- Using MDDS and list-decodable error-correcting codes to enhance privacy
- Better stalking detection

Balancing User Privacy and Stalker Detection

The Paper

- Using MDDS and list-decodable error-correcting codes to enhance privacy
- Better stalking detection
- Requires no more trust than Apple FindMy

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Definitions

Definition (Correctness)

A privacy preserving tracking protocol satisfies correctness if for all authorized owners Owner and compliant service providers SP, $\forall \mathsf{loc}, \mathsf{aux}$ and allowed anonymity epochs i_{epoch}, and $\forall D$ provided by SP.

Definitions

Definition (Detectability)

A privacy preserving tracking protocol is detectable for predicate P' if $\forall$ valid cfg values, $\forall n.u.p.p.t$ algorithms $\mathcal{A}$, $\exists$ a negligible function $negl(\lambda)$ so that $\Pr[\mathsf{Exp}_{\mathcal{A}}^{\mathsf{Det},\mathsf{P}'}(\lambda, \mathsf{cfg}) = 0] \leq negl(\lambda)$.

Tag Detectability Experiment

$Q := \emptyset; L := []; B_{\mathsf{list}} := []; \mathsf{st} = \perp$
$\forall j \in [1, o = poly(\lambda)]:$
  $(\mathsf{id}, i, \mathsf{aux}, \mathsf{loc}, \mathsf{st}) \leftarrow \mathcal{A}(\mathsf{st}, \text{“query”})$
  If $(\mathsf{id}, *) \notin L:$
    $k_{\mathsf{tag}} \leftarrow \mathsf{KeyGen}(1^{\lambda}, \mathsf{cfg})$
    $L := L \cup \{(\mathsf{id}, k_{\mathsf{tag}})\}$
  find k_{tag} so that $(\mathsf{id}, k_{\mathsf{tag}}) \in L$
  $B \leftarrow \mathsf{Beacon}(k_{\mathsf{tag}}, i, \mathsf{aux})$
  $B_{\mathsf{list}} := B_{\mathsf{list}} \cup \{(B, \mathsf{loc})\}$
  $Q := Q \cup \{(\mathsf{id}, i)\}$
$\mathsf{out} \leftarrow \mathsf{Detect}(B_{\mathsf{list}})$
$b = 1$
$\forall (\mathsf{id}, k_{\mathsf{tag}}) \in L,$
  If $P'(\mathsf{cfg}, Q, \mathsf{id}) = 1,$
    $b' = (\exists i, (\mathsf{id}, i) \in Q \wedge$
      $\mathsf{GetTagID}(k_{\mathsf{tag}}, i) \in \mathsf{out})$
    $b = b \wedge b'$
return b

Figure 6: Experiment $\mathsf{Exp}_{\mathcal{A}}^{\mathsf{Det},P'}(\lambda, \mathsf{cfg})$.

Protocol Overview

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- MDSS extends secret sharing by allowing multiple dealers, each with their own secrets, to distribute shares independently.
- Unlinkability - It’s hard to determine if two shares comes from the same dealer or not.
- Multi-Dealer correctness - Secrets can be accurately reconstructed even with multiple dealers

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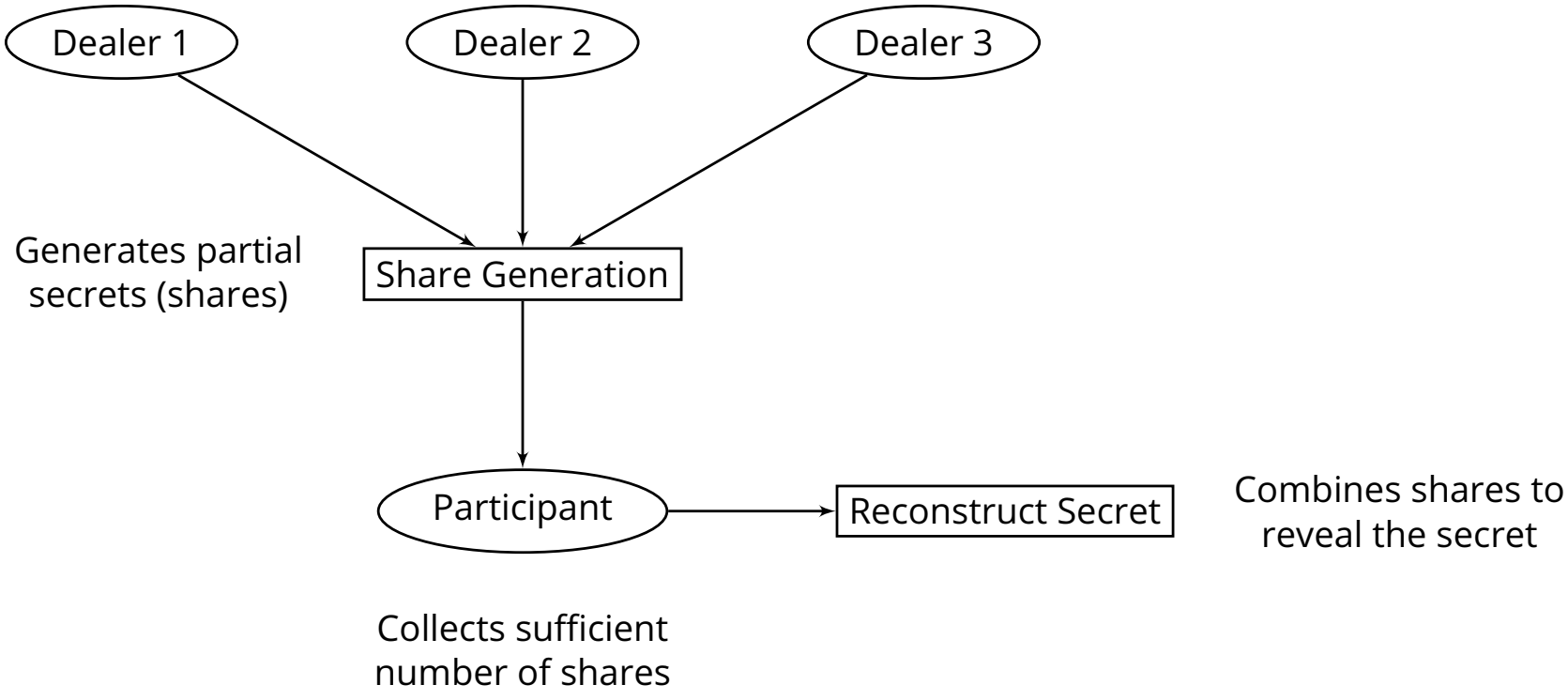
Application in LTAs: Enables stalker-detection algorithms to function effectively despite identifier rotation.

Benefit: Improves the balance between user privacy (through identifier rotation) and effective stalker detection.

Multi Dealer Secret Sharing (MDSS)



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Reconstruct($\{sh_1, \ldots, sh_{max}\}$)

1. Return $CH^* - MDSS(\{sh_1, \ldots, sh_w\})$

CH* Construction

- What does it do? - Lattice based polynomial recovery

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  2. Creates a lattice basis
  3. Reduces the basis
  4. Solution is based on the shortest vector

Algorithm 1: CH*

Input : $\lambda, k, n, \{(\alpha_i, \beta_{i,1}, \ldots, \beta_{i,c})\}_{i=1}^{n}$
Output: None, Multiple, or a single solution $(p_1 \ldots p_c)$

forall $j \in [c]$ **do**
  $f_j(z) = \mathsf{LagrInterpol}(\{(\alpha_1, \beta_{1,j}), \ldots, (\alpha_n, \beta_{n,j})\})$
end
$N(z) = \prod_{i=1}^{n}(z - \alpha_i)$
construct the matrix $M \in \mathbb{F}[z]^{(c+1)\times(c+1)}$:

$$M = \begin{bmatrix} z^k & f_1(z) & f_2(z) & \ldots & f_c(z) \\ & N(z) & & & \\ & & N(z) & & \\ & & & \ddots & \\ & & & & N(z) \end{bmatrix}$$

$M_{\mathsf{red}} \leftarrow \mathsf{LatticeReduce}(M)$
if *there is one shortest vector* $\vec{v} = (v_0 \ldots v_c)$ *that has a length* $\leq \lambda$ **then**
  return $(v_1 \cdot z^k/v_0, \ldots, v_c \cdot z^k/v_0)$
end
if *there are multiple vectors with the shortest length and the shortest length* $\leq \lambda$ **then**
  return Multiple
else
  return None
end

CH*-MDSS Construction

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  2. If multiple solutions are found, modify ws to isolate a single solution
  3. Does this with random deletion of coordinates

Algorithm 2: CH*-MDSS Construction

Input : $k, t, n, \{(\alpha_i, \beta_{i,1}, \ldots, \beta_{i,c})\}_{i=1}^{n}$
Output: a list $\{(p_1^i \ldots p_c^i)\}_{i=1}^{z}$ or $\perp$

```
1  solns := [], ws := [n], fail := False
2  while |ws| ≥ t and not fail do
3      res ← CH*(k + (|ws| − t), k, n, {(α_i, β_{i,1} ... β_{i,c})}_{i∈ws}).
4      if res = None then
5          return solns
6      else if res = Multiple then
7          s ← ⌊|ws| / t⌋, found ← False
8          while not found: do
               // randomly remove points until a single solution is found
9              pts ← ws.pop(2(s − 1))
10             res ← CH*(k + (|ws| − t), k, n, {(α_i, β_{i,1} ... β_{i,c})}_{i∈ws})
11             ws ← ws ∪ pts
12             if res can be parsed as (p_1 ... p_c) then
13                 found ← True
14                 add (p_1 ... p_c) to solns, remove agreeing points from ws
15             end
16         endw
17     else
18         parse res as (p_1 ... p_c), add (p_1 ... p_c) to solns, remove agreeing points from ws
19     end
20 endw
21 return solns
```

Abuse-resistant Offline Finding Protocol

$\mathsf{KeyGen}(1^\lambda, \mathsf{cfg}) \to k_{\mathsf{tag}}$ In: required params, out: a secret key.

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$\mathsf{Detect}(\mathsf{cfg}, \{(B_1, \mathsf{loc}_1), \ldots, (B_n, \mathsf{loc}_n)\}) \to \{\mathsf{id}_{\mathsf{tag}_i}\}$ In: set of broadcasts, out: one or more identifiers.

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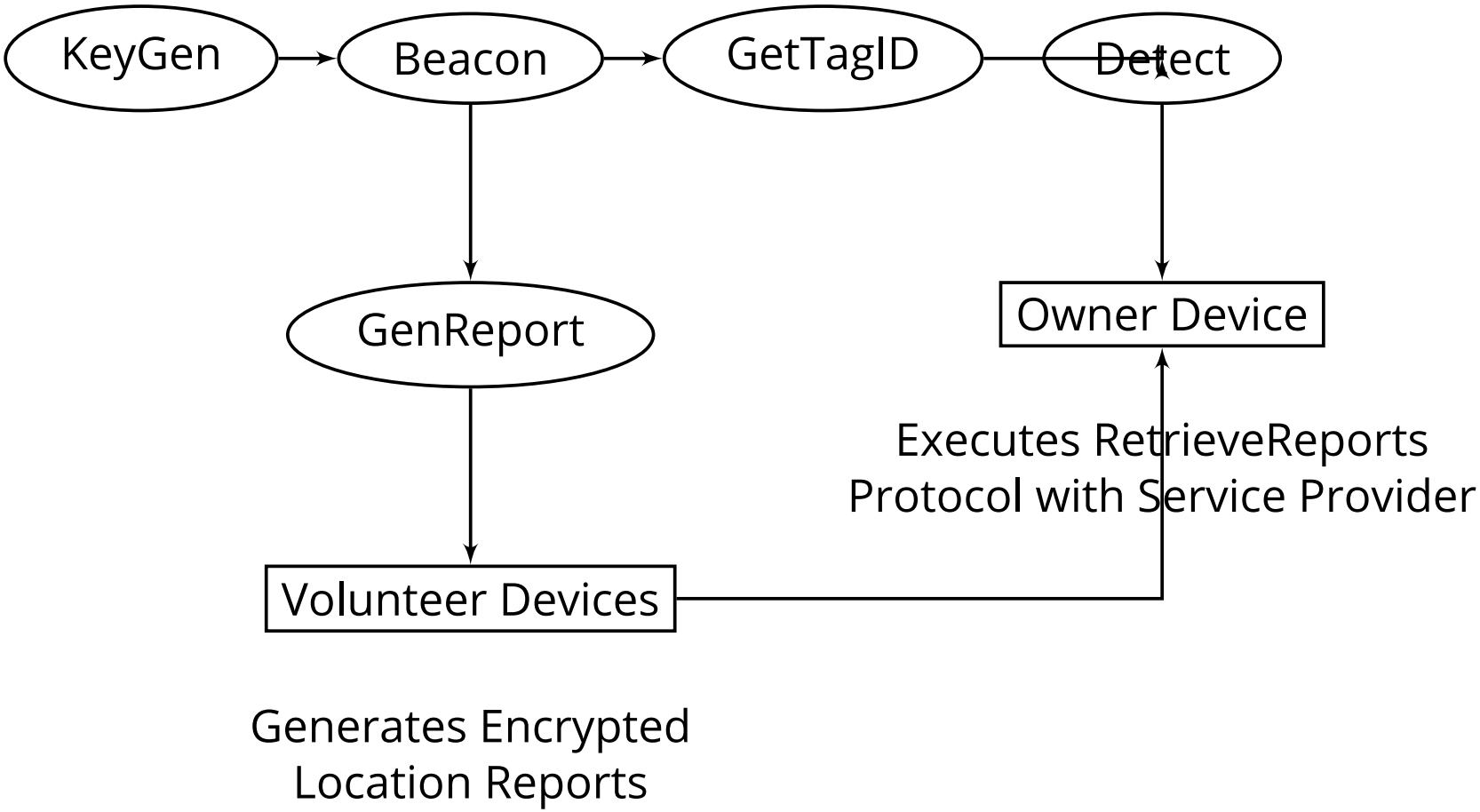
$\mathsf{RetrieveReports}(\mathsf{Owner}(k_{\mathsf{tag}}, i_{\mathsf{epoch}}), \mathsf{SP}(\mathcal{D}))$ Executed between 2 parties, Owner provides a tag key and epoch, SP uses a database $\mathcal{D}$, ouputting a list of reports.

Offline Finding Protocol Flow



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3. $k_3 \leftarrow \mathsf{PRF}_3.\mathsf{KeyGen}(1^\lambda)$
4. return $(k_1, k_2, k_3, \mathsf{cfg})$

Main Construction: $\mathsf{Beacon}(k_{\mathsf{tag}}, i_{\mathsf{epoch}}, \mathsf{aux})$

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7. $\mathsf{sh}_0^e \ldots \mathsf{sh}_{L-1}^e \leftarrow \mathsf{Share}(\mathsf{id}_{\mathsf{tag}}, I; \mathsf{PRG}(\mathsf{PRF}_2.\mathsf{Eval}(k_2, e)))$

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8. Return $\mathsf{pk}||\mathsf{sh}_i^e||\mathsf{aux}$

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2. Return $\Pi.\mathsf{Reconstruct}(S)$

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Achieving Privacy Goals

- Unlinkability and threshold privacy from MDSS

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- Unlinkability and threshold privacy from MDSS
- Ensure identifiers change periodically
- Should need a copy of the secret key to re-derive the correct sequence to obtain location reports

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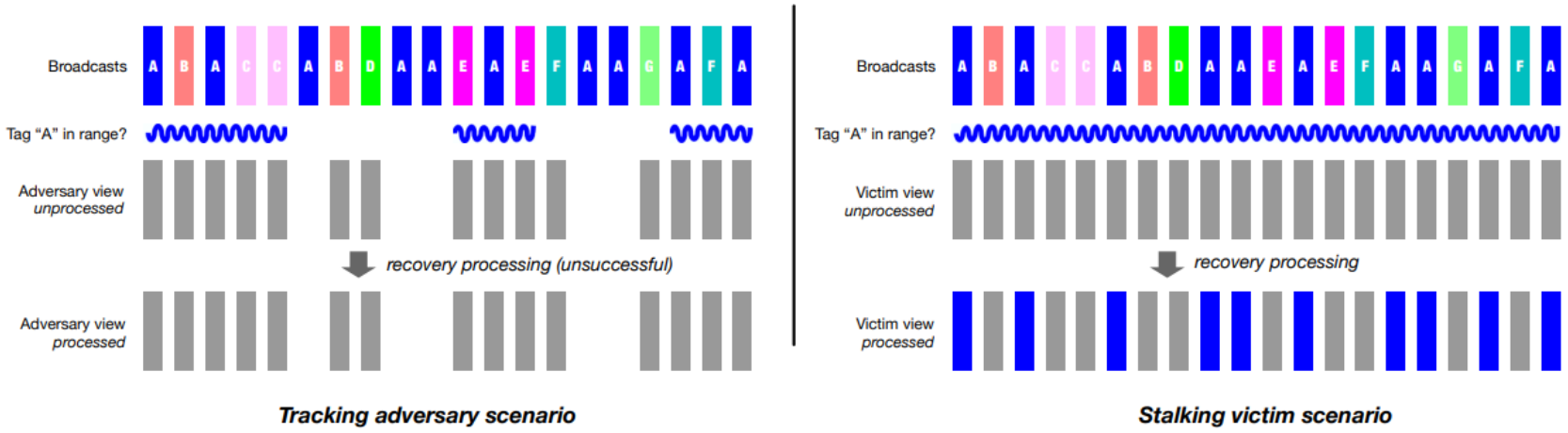
- LTA generates pseudonym for each Beacon call and appends one secret share to be broadcast by LTA.
- These secret shares are only used locally for stalker detection.

Contents

FindMy vs. This Construction

Protocol	Epoch duration	Broadcasts per epoch	Stalker detection?	Tracking privacy	Continuous Proximity	Stalker detection
Apple FindMy [2] / IETF [32]:						
Near-owner mode	15 min	450	✗	n/a	n/a	
Separated mode	24 hrs	43,200	●	n/a	✗	15-60 min†
This work (§4):						
2-second epochs / 1-hour window	2 sec	1	●	40 – 46 min*	●	60 min
4-second epochs / 1-hour window	4 sec	1	●	39 – 46 min*	●	60 min
1-minute epochs / 1-hour window	60 sec	15	●	41 – 47 min*	●	60 min

2 Detection Scenarios



Questions?