CAMP

Vehicle Safety Communications 3

Intelligent Transportation Systems

A Security Credential Management System for V2V Communications

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Outline of presentation

- Significance of this design
  - There are lots of papers written every year about certificate management for V2V safety, why is this special?
  - If V2V safety communications happen, the design in this presentation is the leading candidate for real-world deployment in the US.
- Overall architecture + privacy by design
- Original features of the design
  - Linkage authorities and linkage values
  - Butterfly keys

Who are we and what are we doing?

- Crash Avoidance Metrics Partnership (CAMP)
  - Founded by Ford and GM, forms and manages project teams for pre-competitive technical research
  - Partner organization, Vehicle Infrastructure Integration Consortium (VIIC), provides coordinated policy statements from automotive OEMs
- CAMP Vehicle Safety Communications 3 (VSC3) Consortium: Ford, General Motors, Honda, Hyundai-Kia, Mercedes-Benz, Nissan, Toyota*, and Volkswagen / Audi
- VSCS Aim: Develop a design for a Secure Credential Management System (SCMS) suitable for deployment across 300 million vehicles
  - Plus potentially aftermarket and nomadic devices
  - Identify full set of functionality that must be supported in day 1 devices

* Toyota is not part of the VSCS Study Team developing the SCMS

Background

- 32,000 deaths on the road in the US in 2012
- Significant reduction may be possible from V2V wireless communications for 360º warning applications.
  - 300 m range, 802.11-derived medium access
  - Basic Safety Message (BSM)
    - Location, velocity, steering angle…
  - Allows receiving unit to predict collisions
    - Forward, longitudinal, intersection
  - Warn driver, driver action can prevent or reduce impact of collision
  - Spectrum reserved for these communications since 1999
- USDOT (NHTSA) currently considering mandating this system for inclusion in new light vehicles
  - Decision on mandate to be made 2013, some years before it takes effect

Security considerations

- Risk of false messages
  - Reduce users' faith in system and cause warnings to be ignored
  - (not safety-related): Messages may affect choice of route or have other mobility/efficiency impacts
  - Requirement: must be able to detect untrustworthy senders or messages and let receivers know not to trust them
- Impact on privacy
  - Don't want the system to be used as a tracking system
    - Tracking is always possible, don't want this option to be the cheapest
  - Prevent eavesdroppers or insiders from collecting Personally Identifiable Information (PII)
  - Conflict with requirement to detect and remove untrustworthy senders
- Design constraints
  - Constraints on available data rate using current V2V system (6 MBps under ideal conditions)
  - Cost-sensitive suppliers: limits on processing power, storage, connectivity, number of 5.9 GHz radios, …

Security concept of operations

- Protect against false messages:
  - Messages are signed and not encrypted
    - Signed using ECDSA over the NISTp256 curve
  - Signed message includes (or references) a certificate that specifies permissions (not identity) of holder
  - Misbehaving units can have their certificates identified and revoked
- Protect privacy:
  - Don’t directly reveal information: No personal information included in broadcast messages
  - Prevent tracking: “Identifiers” at application, network and other levels should be transient
    - Eavesdropper can only track from place to place if they record all your messages
  - Vehicles have a number of simultaneously valid certificates, can choose which certificate to use to sign each message
    - Baseline number of certs =20 per week
    - When cert changes, all other identifiers change too
      - Currently no standardized algorithm for cert change
  - SCMS is split into a number of components so that no individual component knows the full set of certificates that belong to a single device
  - Policy: out of scope for this presentation (and CAMP). Could consider
    - Restricting law enforcement use of the system
    - Data retention rules for storage of BSMs

Privacy by Design, an OEM perspective

- Privacy from attacks by an SCMS insider
  - Don’t link certificates to VIN or require legal process
  - Separate operation of SCMS components:

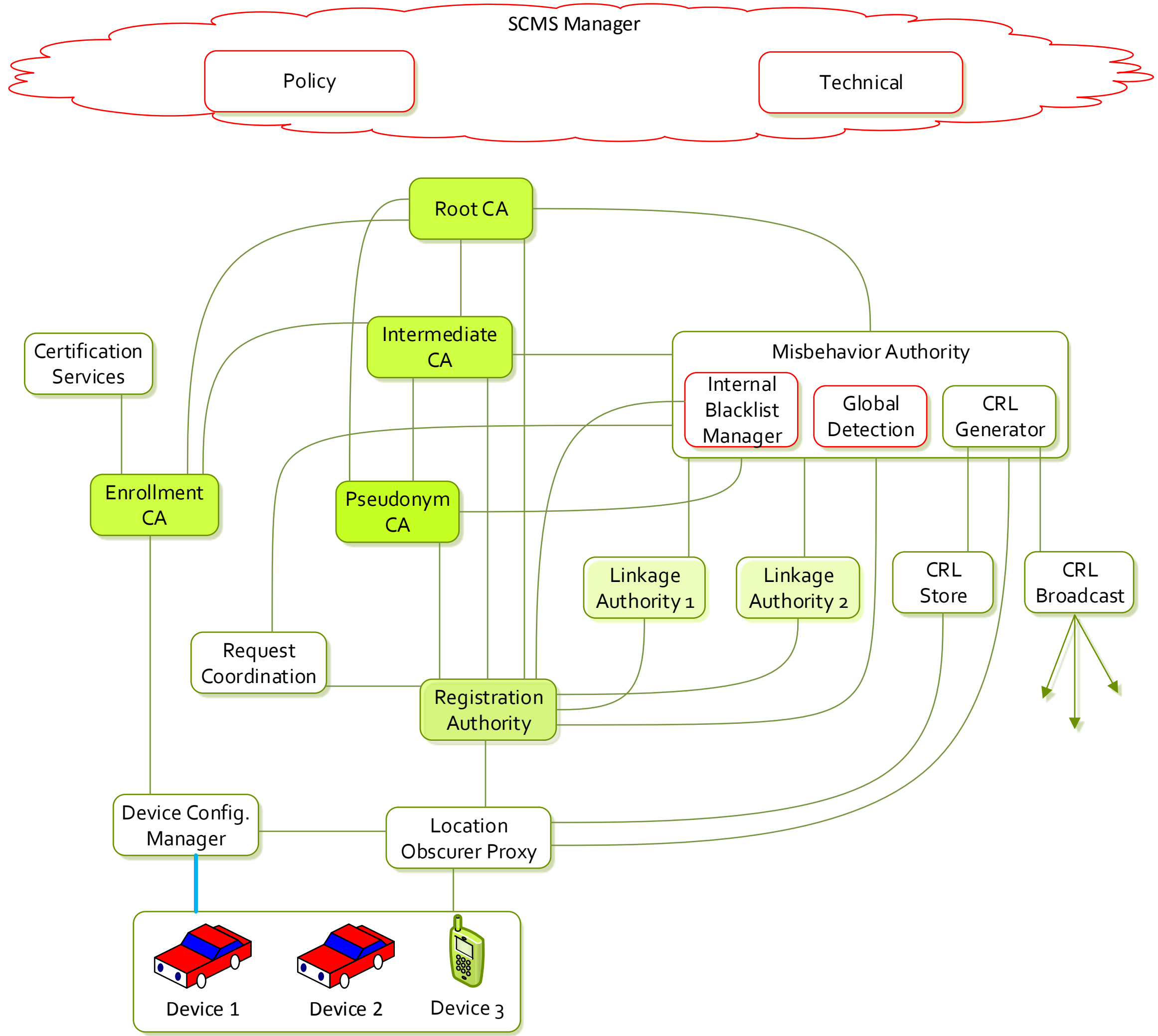
    Two or more components should not be run by the same organization without “proper” separation

    if

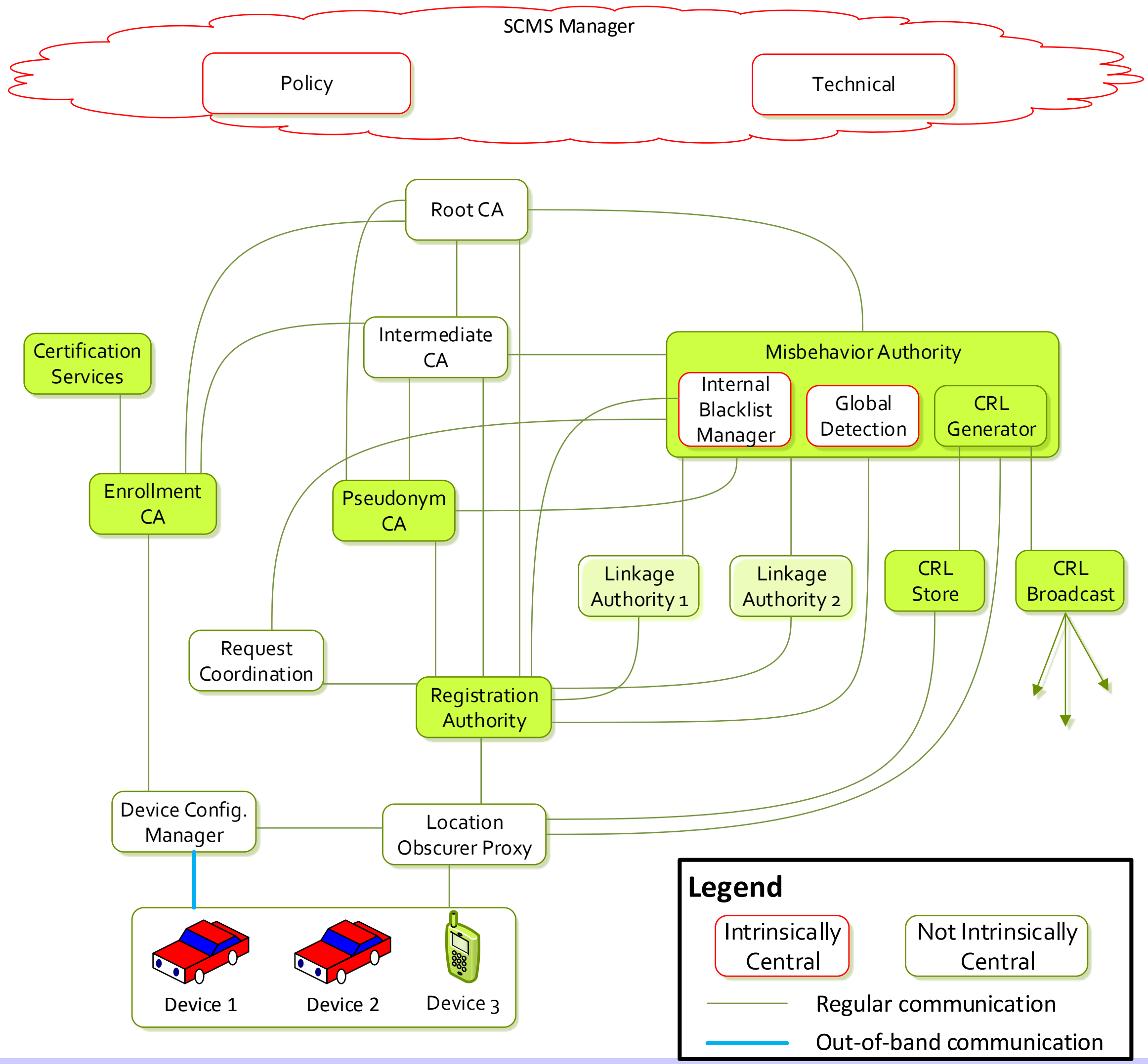
    the combined information held by the components would allow the organization to track* a vehicle

    *predict next pseudonym certificate based on current one or find out whether two certificates belong to the same device
  - Divide functionality between SCMS components as necessary to satisfy this approach

Overview / Standard PKI Hierarchy



Lifecycle

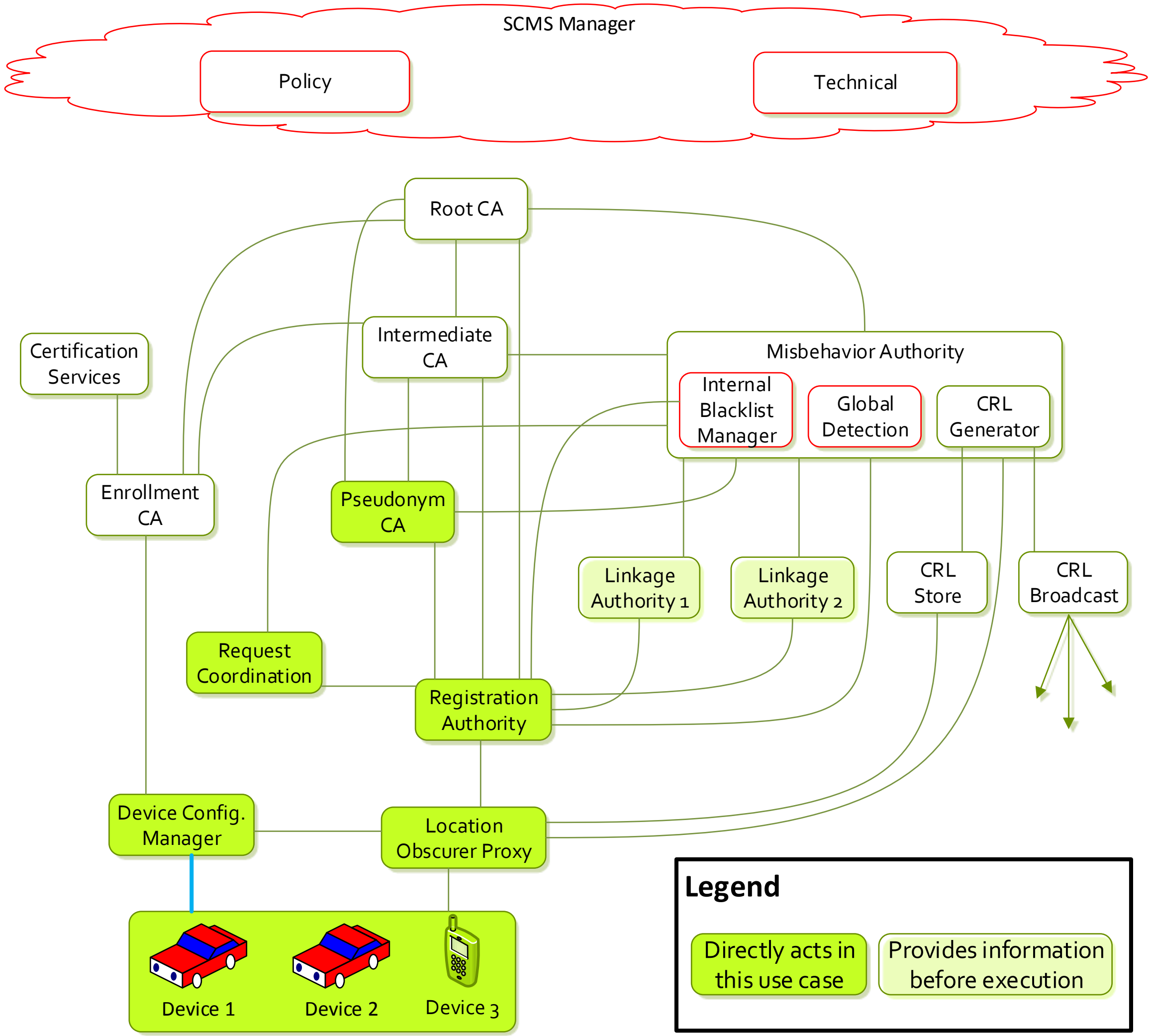


SCMS Manager
Policy
Technical
Root CA
Intermediate CA
Certification Services
Misbehavior Authority
Internal Blacklist Manager
Global Detection
CRL Generator
Enrollment CA
Pseudonym CA
Linkage Authority 1
Linkage Authority 2
CRL Store
CRL Broadcast
Request Coordination
Registration Authority
Device Config. Manager
Location Obscurer Proxy
Device 1
Device 2
Device 3
Legend
Intrinsically Central
Not Intrinsically Central
Regular communication
Out-of-band communication

Unique Features

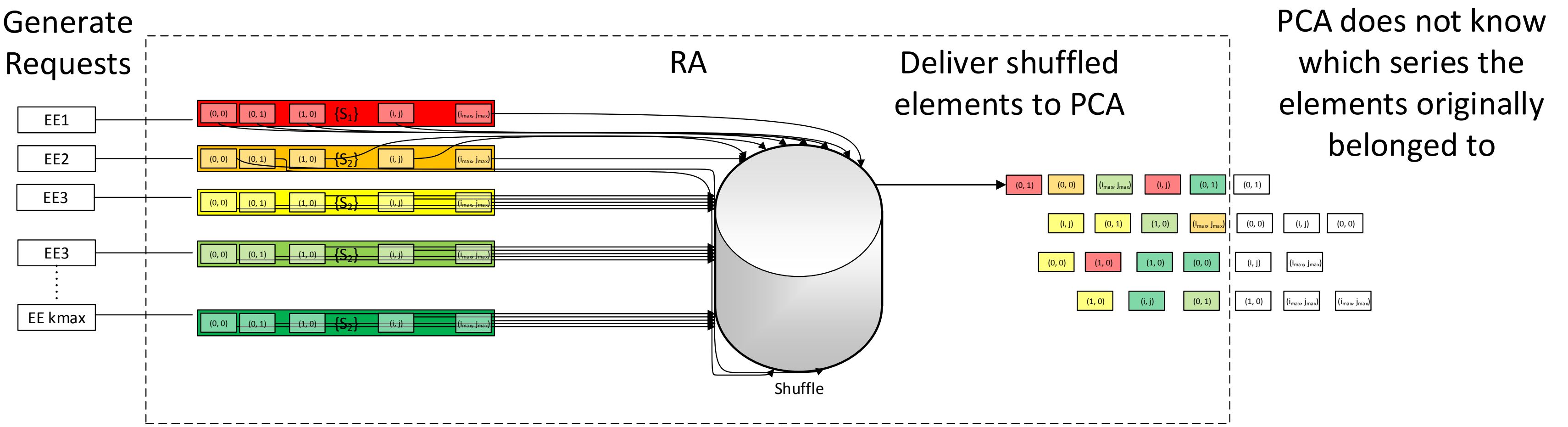
- RA shuffle for privacy
- Certificate request: Butterfly keys
  - Allows more responsiveness & robustness, less work on OBE
- Certificate issuance and revocation: Linkage authorities and linkage values
  - Allows efficient revocation while preventing any SCMS component from tracking non-revoked vehicle
- Misbehavior analysis and revocation
  - Allows certs from misbehaving vehicles to be linked while respecting the privacy of correctly behaving vehicles

Certificate Provisioning



Shuffle at the RA

- RA receives requests from multiple end-entity devices
- Combines requests so that PCA doesn't know that two individual cert requests received at the same time come from the same vehicle

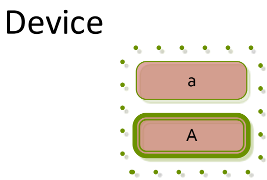


Butterfly keys: Certificate generation goals

- OBE could simply generate a large number of cert requests and send them encrypted to the PCA, but:
  - OBE is constrained
    - Minimum processing on the OBE
    - Minimum wasted processing on the OBE
  - Connectivity is not guaranteed
    - Small uploads
    - Want to request as many certificates as possible at a given time
  - What if the PCA goes out of business?
- Butterfly keys address all these issues
  - Performance and robustness enhancement, not security enhancement as such

Butterfly keys: concept

- Device generates
  - A seed or “caterpillar” keypair
  - An expansion function
  - Cost: ~1 key generation



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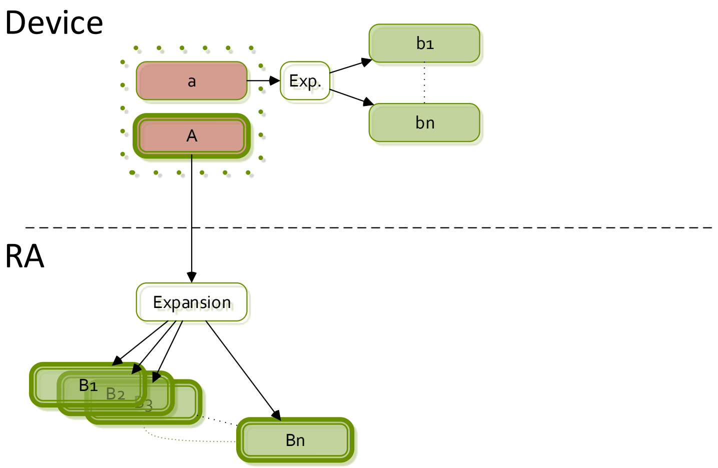
- RA runs the expansion function to generate “cocoon” public keys from the caterpillar public key
  - Cocoon public keys from the same caterpillar keys are not correlated
  - Expansion function lets you generate arbitrarily many cocoon keys
  - RA submits cocoon keys to CA for certification



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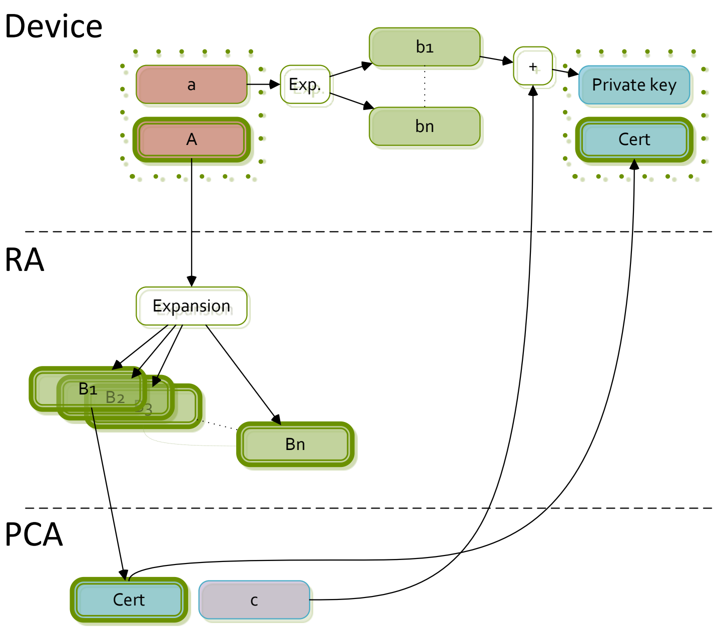
  - RA submits cocoon keys to CA for certification
- CA randomizes each public key separately so the RA can’t recognize them
  - Certs contain the resulting “butterfly” keys
  - CA returns certs and private randomization values to the OBE
- Result: Large number of certs generated from a single initial keypair
  - OBE is the only device that knows private keys
  - Public keys cannot be correlated by any entity
  - Low computational burden on OBE at request time
  - Request once, generate keys for the entire lifetime of the vehicle



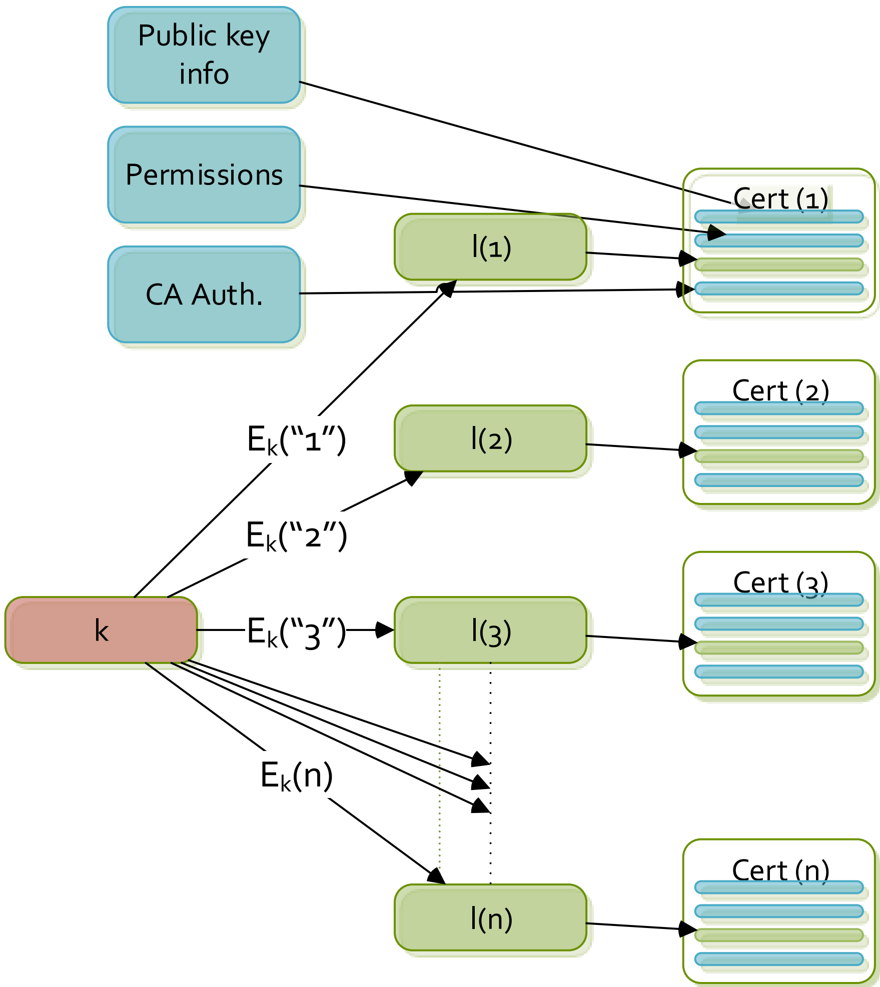
Butterfly keys vs goals

- Minimum processing on the OBE:
  - One cert request from OBE allows generation of arbitrary number of individual certs
- Minimum wasted processing on the OBE:
  - Certs that are not used need not be decrypted
- Small uploads:
  - Upload is two public ECC keys + two expansion functions (= AES keys)
- Want to request as many certificates as possible at a given time
  - One cert request from OBE allows generation of arbitrary number of individual certs
- What if PCA goes out of business?
  - Requests are not encrypted for a particular PCA; any PCA change can be handled on the backend by the RA

Revocation and Linkage Authorities

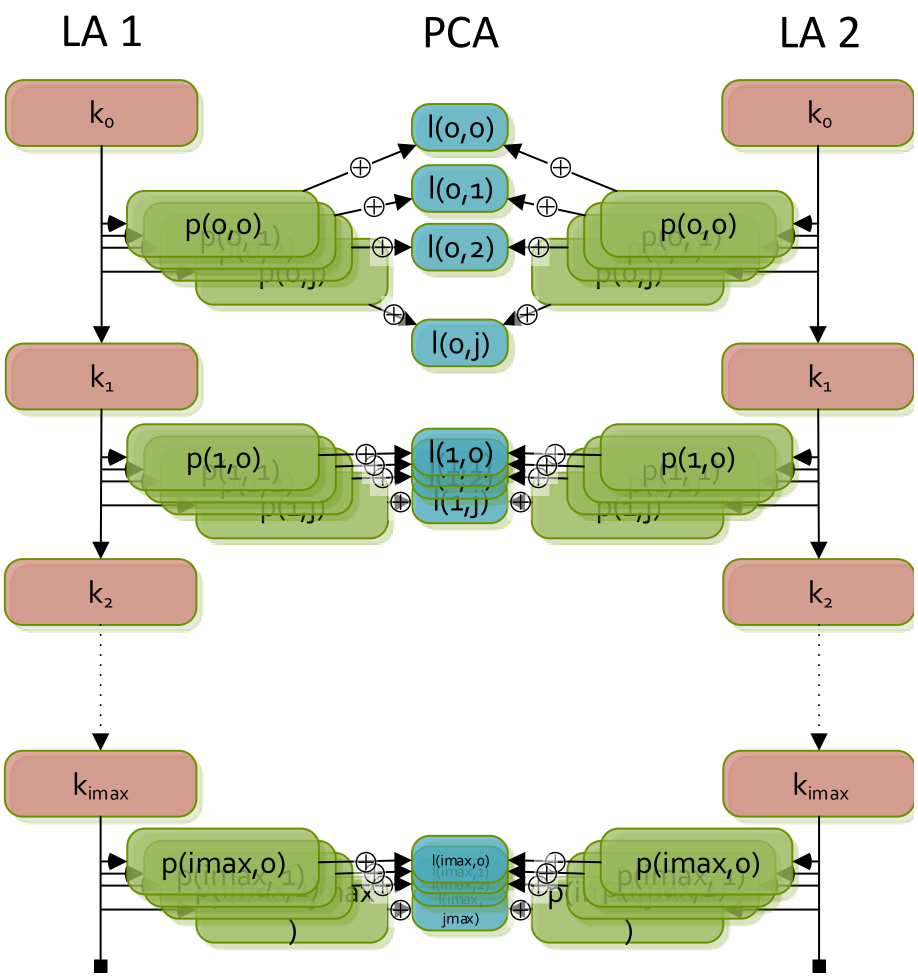
- Why do we need revocation?
  - Why not just choose not to issue new certs to a misbehaving vehicle?
- Not all vehicles will have good data connection
  - Even vehicles that do may be out of coverage
  - Vehicles need to be provisioned with a minimum number of certs in case they are turned off for some time and turned on in an area with no coverage
- If you have a month's worth of certs, you can misbehave for a month
  - If you have three months' worth of certs, you can misbehave for three months
  - If you have three years' worth of certs…
- Revocation must be supported to reduce potential disruption within system, even if in practice it isn't used.
- Need efficient, privacy-preserving revocation

Revocation and Linkage Authorities



- Revoke all *n* of a device's certs with just one entry on the CRL
- Multiple certs valid in one time period
- Backwards unlinkability
- No component in the SCMS knows the chain

Revocation and Linkage Authorities



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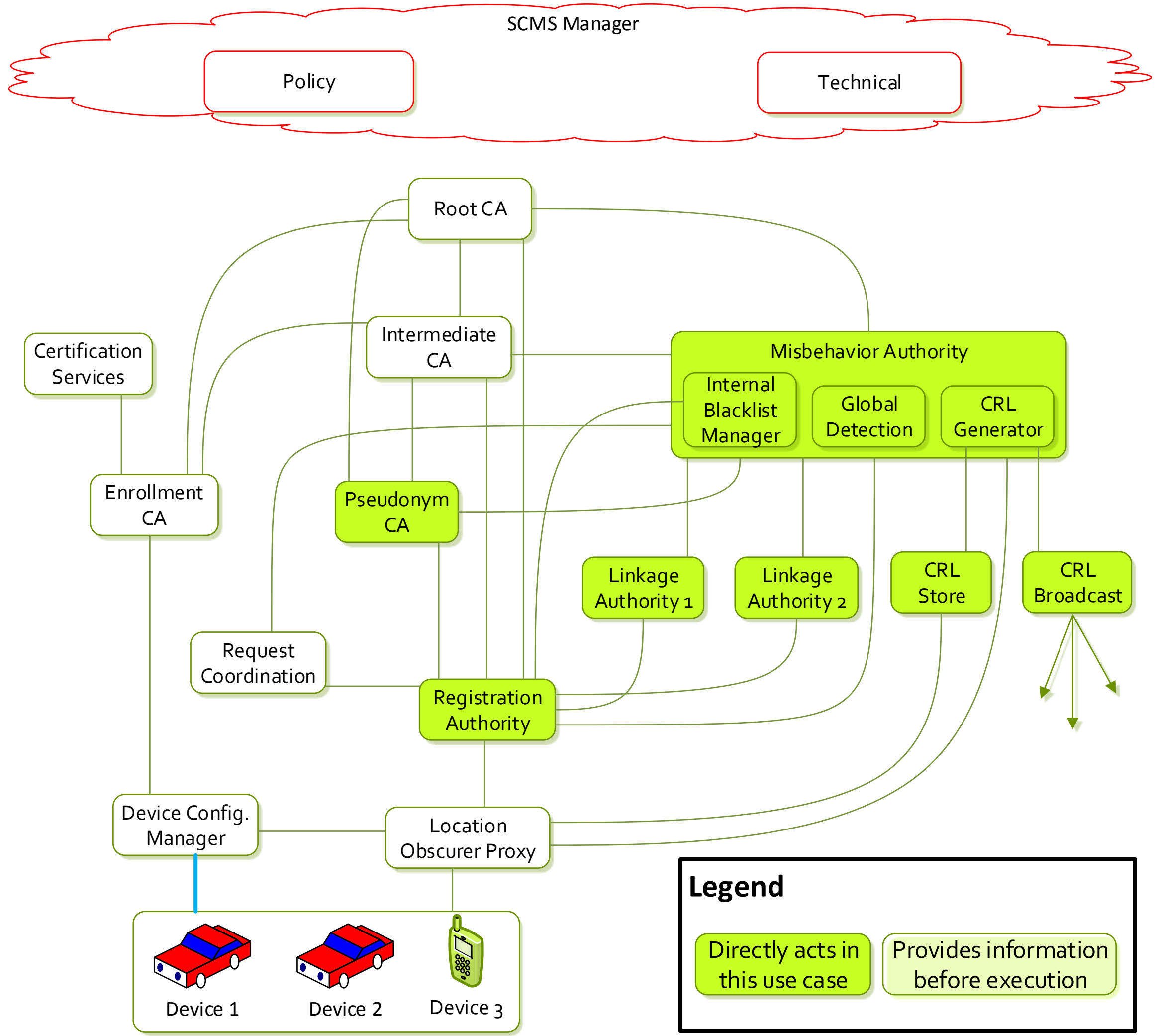
  - LAs encrypt chain for PCA
    - Send to RA
  - RA groups
  - PCA decrypts, XORs

Revocation



SCMS Manager
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CRL Generator
Enrollment CA
Pseudonym CA
Linkage Authority 1
Linkage Authority 2
CRL Store
CRL Broadcast
Request Coordination
Registration Authority
Device Config. Manager
Location Obscurer Proxy
Device 1
Device 2
Device 3
Legend
Directly acts in this use case
Provides information before execution

Misbehavior investigation

- Misbehavior reporting:
  - OBE -> MA
- Misbehavior analysis:
  - MA by itself
- Misbehavior investigation:
  - MA asks PCA if two certs belong to same vehicle
  - PCA asks LAs
  - Yes/no answer
  - Interfaces can be defined to require evidence to be presented at each stage
  - Interfaces protect privacy – only yes/no answer, linkage seeds are not revealed
  - If a vehicle misbehaves often enough it can be revoked
- Revocation:
  - Linkage seed from each LA goes on the CRL
  - CRL recipients at each time period:
    - Hash linkage seeds forward to that time period
    - Calculate 20 pre-linkage values for each
    - XOR to get linkage value
    - Compare to received cert and reject if match

Outlook and Ongoing Projects

- VSCS Study One: Design Optimization and Cost Analysis of Connected Vehicle Security System
- Period of Performance: April 3, 2013 – January 3, 2014
- Activities:
  - Define baseline security model and baseline OBE requirements
  - Develop security system cost model
  - Perform cost analysis on baseline security model
  - Analyze potential simplifications to the deployment model
  - Analyze alternative device-SCMS connectivity approaches
  - Identify technical approaches to linking enrollment certificates to batches of devices to aid defect investigations
  - Provide design recommendations for V2V Security System

Extra slides

Butterfly Keys: Elliptic Curve background

Alice	Bob	
a, A = aG	G, A	a = private key, A = public key, G = base point
		Alice uses a to sign
		Bob knows A and G but can't find a
		Bob can use A to verify Alice's signatures
	b, B = bG	"ephemeral keypair"
a+b, A+B	b, A+B	A+B = (a+b) G
		Only Alice knows a+b although Bob has contributed to key
		Alice can sign with (a+b) just as with any private key; no-one else can
		Bob and others can verify with A+B just as with any public key

Why does this matter?

Butterfly key process

(Notation is different from paper for space reasons)

OBE	RA	PCA		
a, A = aG f_s(i, j)	A, f_s			f_s = "pseudorandom permutation" = AES_k(i || j) for some k
	$B_{1,1}$ = A + f_s(1,1)*G $B_{1,2}$ = A + f_s(1,2)*G $B_{1,3}$ = A + f_s(1,3)*G …			a+f_s(1,1) is private key for $B_{1,1}$ a+f_s(1,2) is private key for $B_{1,2}$ a+f_s(1,3) is private key for $B_{1,3}$ …
	$B_{1,1}$	c, C = cG Issue Cert($B_{1,1}$+C)		c is randomly generated & distinct for each received B
		$\mathcal{E}$ = Enc_{OBE}(Cert, c, "1,1")		Encrypt response so that RA can't see cert contents Response encryption key is butterfly key formed from (H, f_e)
(Cert, c, "1,1")		$Sign_{CA}$($\mathcal{E}$)		Signing proves that CA encrypted message, not RA
a+f_s(1,1)+				a + f_s(1,1) + c is private key for

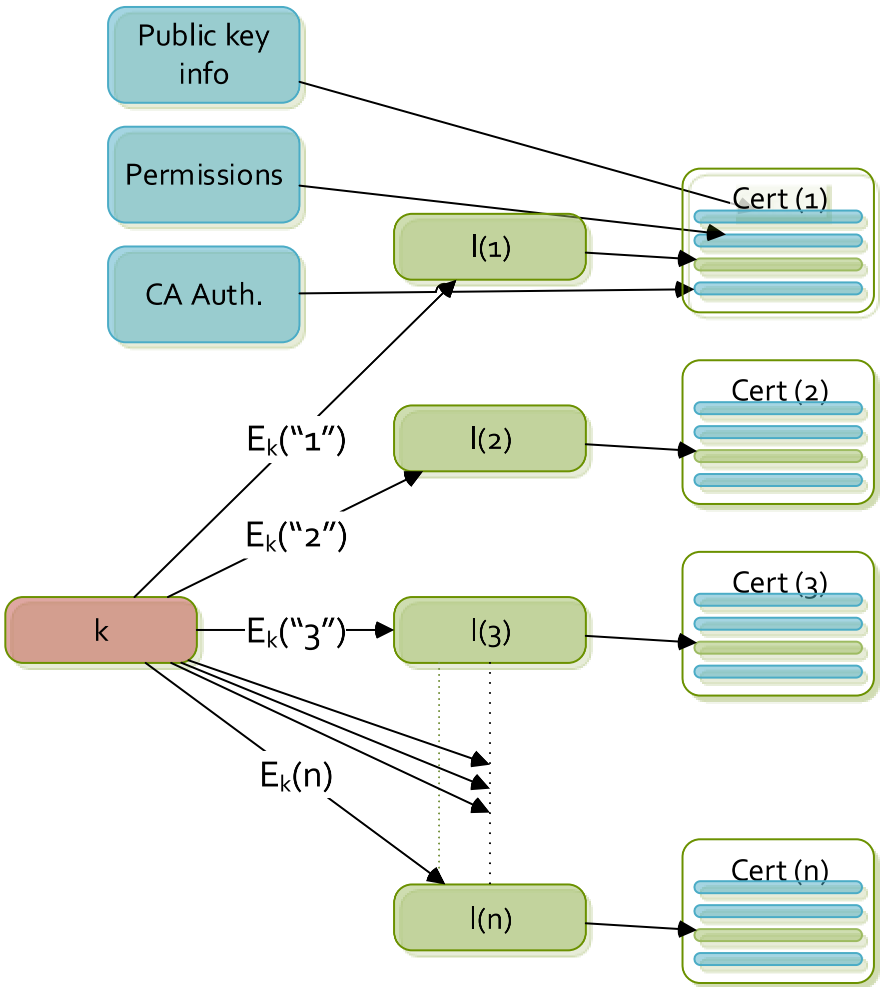
Butterfly keys: OBE to RA

- Start with a single “caterpillar” public key A in a cert request
  - $A = aG$, a = private key (integer) mod p, G = Elliptic Curve Base Point
  - Given A & G, very hard to find the value a
  - $(a+b)*G = aG + bG$
- Want to expand this to certs for time period (i, j)
  - OBE defines *expansion function* $f_s(i, j)$ that takes (i, j) to (pseudo)random integer mod p
    - Pick AES key k
    - $f_s(i, j) = AES_k(\ 0^{128}\ XOR\ [i_{32} \,||\, j_{32}\ ])\ ||\ AES_k(\ 1^{128}\ XOR\ [i_{32} \,||\, j_{32}])$
  - Shares $f_s(i, j)$ with RA (i.e. shares k)
  - Then RA can calculate $B_{ij} = A + f_s(i, j)*G$
    - f_s is pseudorandom, so the PCA cannot determine that B_{ij}s from the same A are related
  - Corresponding private key is $a + f_s(i, j)$ which *only OBE knows*
- So:
  - A single cert request from the OBE to the RA leads to…
  - Multiple individual uncorrelated public keys from the RA to the PCA
  - These can be shuffled together, protecting OBE privacy against PCA

Butterfly keys: RA to PCA

- One more requirement: RA must not know the public keys in the certs
  - But RA has put the public keys in the requests
- PCA generates an offset
  - Integer c, point $C = cG$, generated freshly at random for each request
  - PCA receives request containing B_{ij}, signs cert containing $B_{ij} + C$
    - B_{ij} = "coccoon" public key, $B_{ij}+C$ = "butterfly" public key
  - PCA returns (c, Cert) to RA to return to OBE
    - Encrypted under a separate butterfly encryption key
    - Ciphertext signed by PCA to prevent MITM attack by RA
    - Encrypted response includes indication of the request it is associated with so RA can return it to the right OBE
- Now:
  - Shuffle prevents PCA from knowing which certs go together
  - Offset prevents RA from knowing which certs go together
  - Only the OBE knows the contents of its certs
  - OBE knows a, $f_s(i, j)$, receives c:
    - $(a + f_s(i,j) + c) * G = A + f_s(i,j)G + C = B_{ij} + C$ ← public key in cert
    - … so $a + f_s(i,j) + c$ = private key for cert

Revocation and Linkage Authorities



- Revoke all *n* of a device's certs with just one entry on the CRL
  - Include linkage value $l(i) = E_k(i)$ in the cert
  - Include key *k* on CRL; in each time period *i*, vehicles calculate $E_k(i)$ for all entries and compare to the linkage value in the cert.

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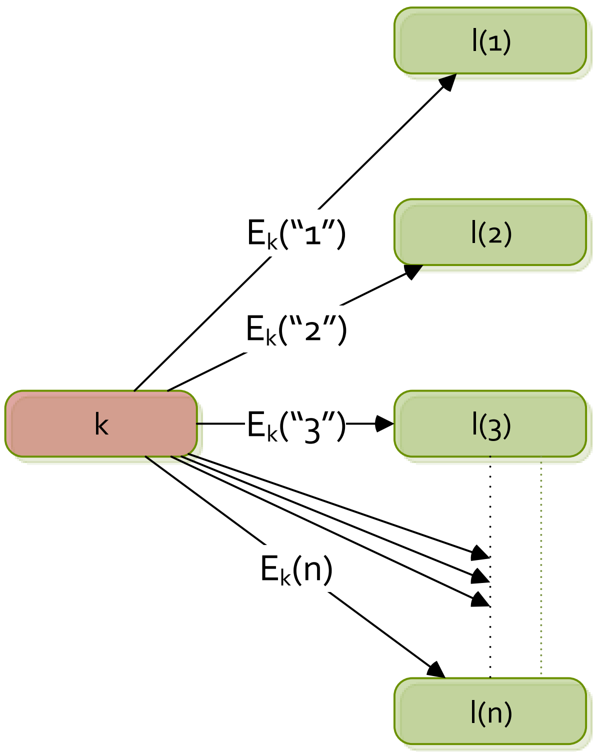

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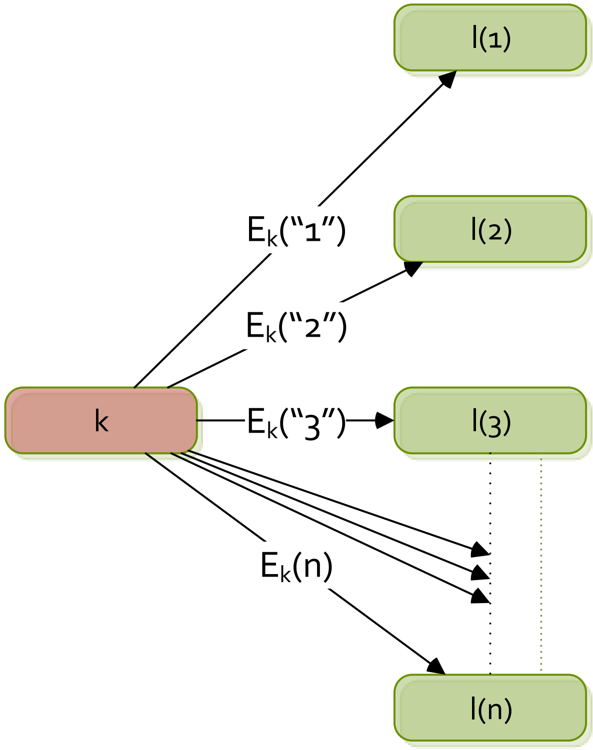

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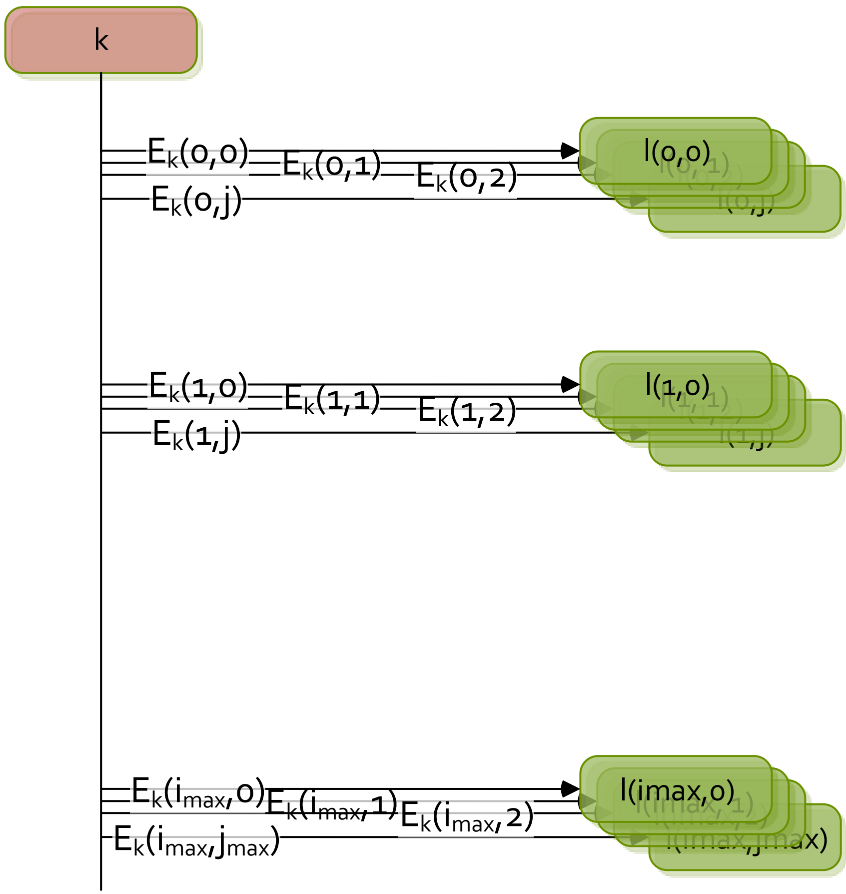

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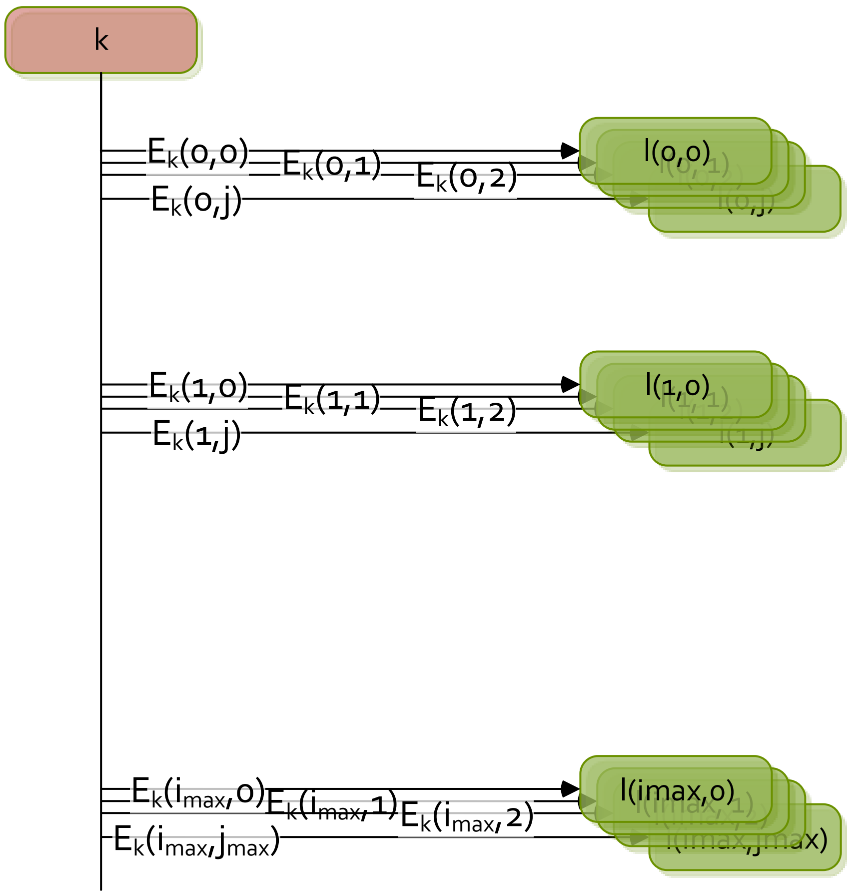

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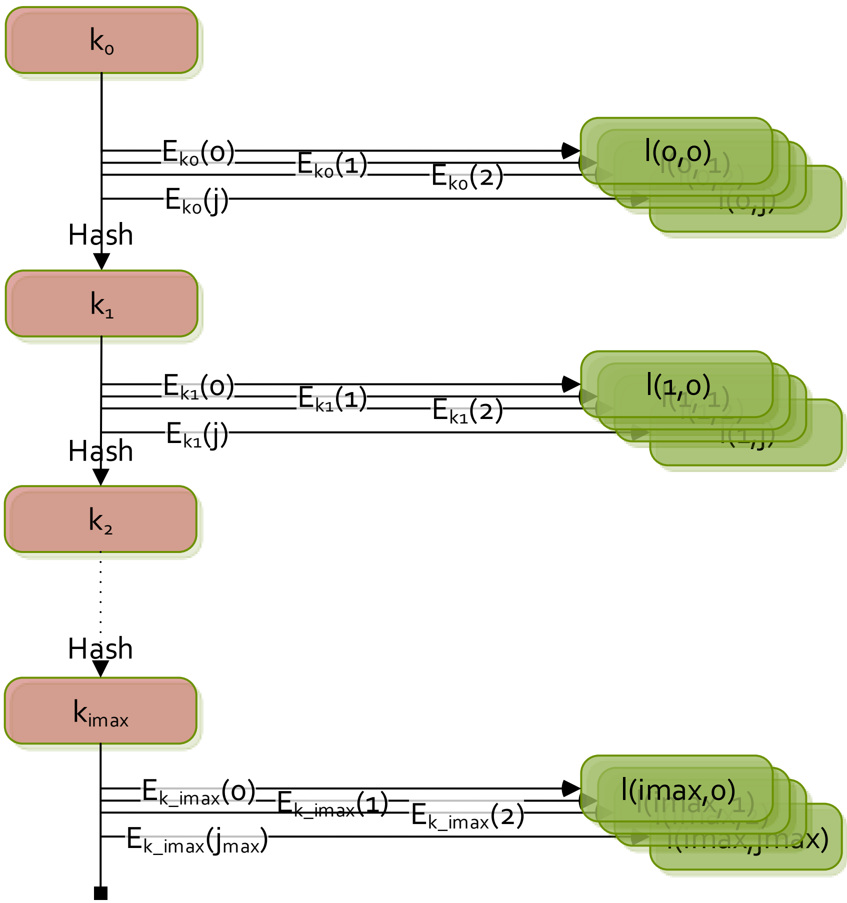

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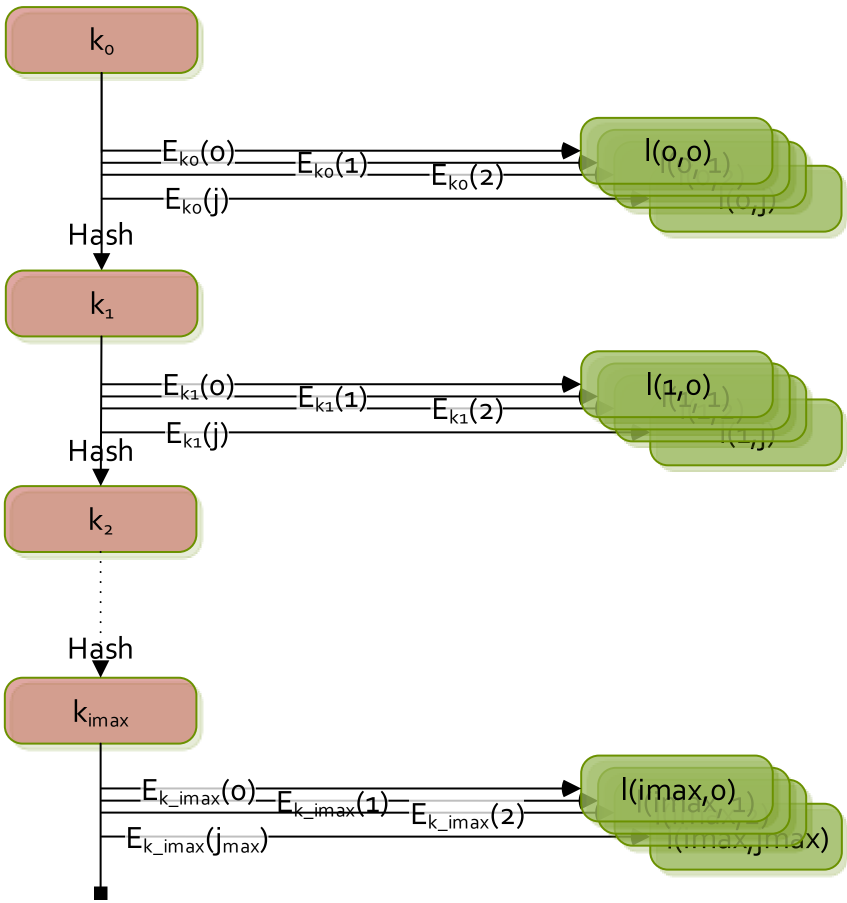

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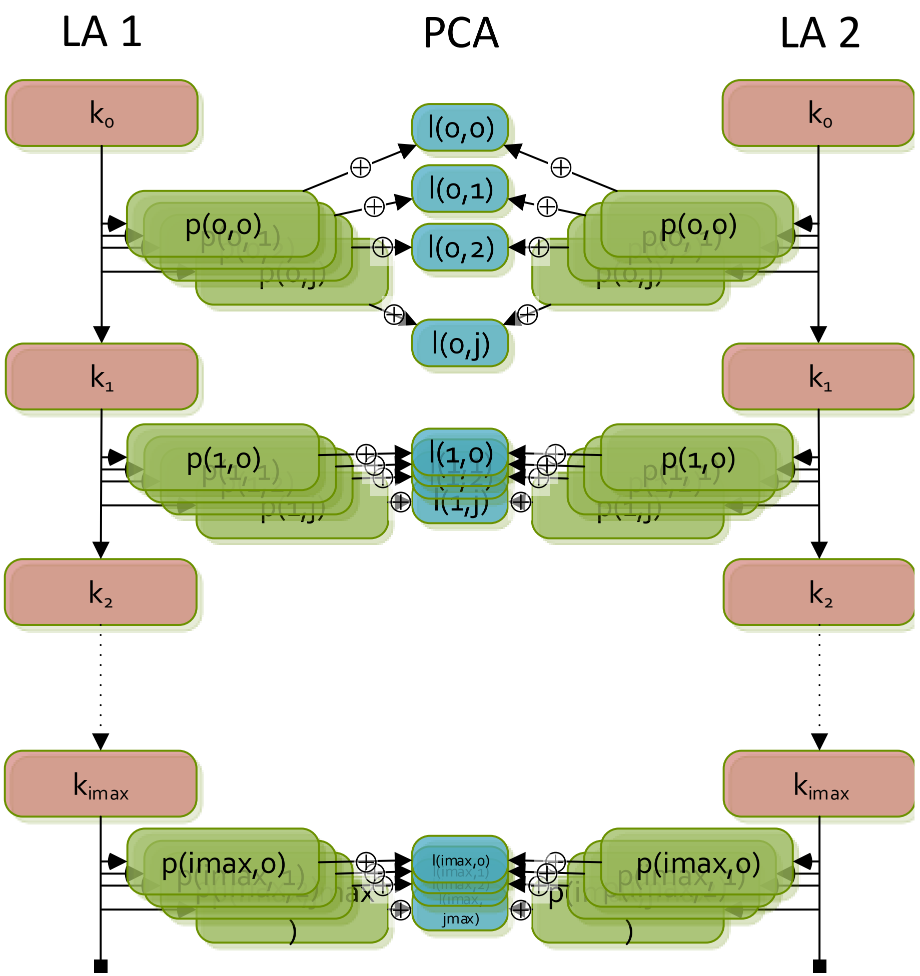

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