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# Secure and Privacy Preserving Vehicular Communication Systems: Identity and Credential Management Infrastructure

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# Outline

# Vehicular Communication (VC) Systems

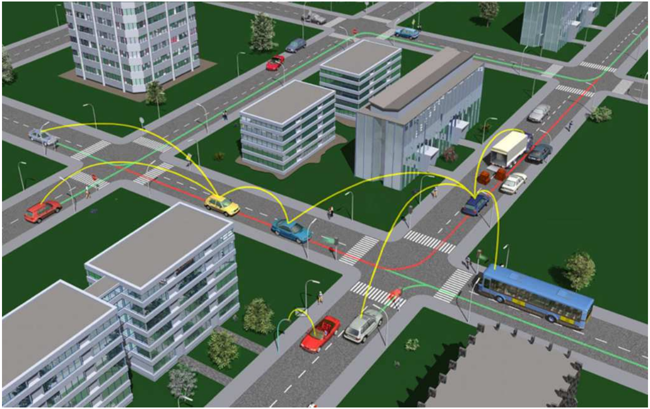
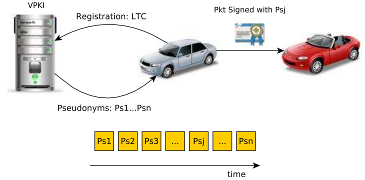


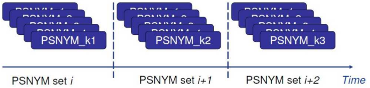
**Figure:** Photo Courtesy of the Car2Car Communication Consortium (C2C-CC)

# Security and Privacy for VC Systems[1]

## Basic Requirements

- Message authentication & integrity
- Message non-repudiation
- Access control
- Entity authentication
- Accountability
- Privacy protection



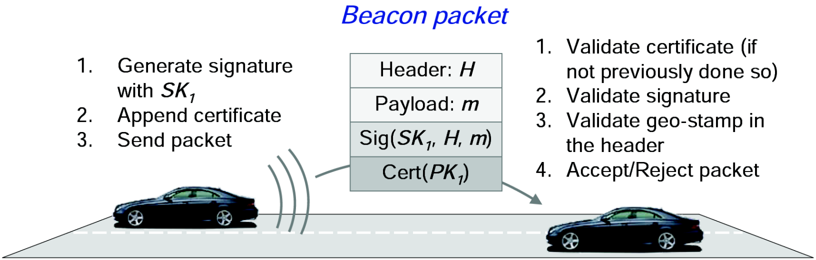




## Vehicular Public-Key Infrastructure (VPKI)

- Pseudonymous authentication
- Trusted Third Party (TTP):
  - Certification Authority (CA)
  - Issues credentials & binds users to their pseudonyms

[1] P. Papadimitratos, et al. "Securing Vehicular Communications - Assumptions, Requirements, and Principles," in ESCAR, Berlin, Germany, pp. 5-14, Nov. 2006.
P. Papadimitratos, et al. "Secure Vehicular Communication Systems: Design and Architecture," in IEEE Communications Magazine, vol. 46, no. 11, pp. 100-109, Nov. 2008.

# Security and Privacy for VC Systems (cont'd)




- Sign packets with the private key, corresponding to the current valid pseudonym
- Verify packets with the valid pseudonym
- Cryptographic operations in a Hardware Security Module (HSM)

## State-of-the-art

### Standardization and harmonization efforts

- IEEE 1609.2 [1], ETSI [2] and C2C-CC [3]
- VC related specifications for security and privacy-preserving architectures

### Projects

- SEVECOM, EVITA, PRECIOSA, OVERSEE, DRIVE-C2X, Safety Pilot, PRESERVE, CAMP-VSC3

### Proposals

- V-Token [4], CoPRA [5], SCMS [6], SEROSA [7], PUCA [8]

# Outline

# Problem Statement and Motivation
## The design of a VPKI

- Resilience
- Stronger adversarial model (than fully-trustworthy entities)
  - User privacy protection against *"honest-but-curious"* entities
  - User privacy enhancement and service unlinkability (inference of service provider or time)
- Pseudonym acquistion policies
  - How should each vehicle interact with the VPKI, e.g., how frequently and for how long?
  - Should each vehicle itself determine the pseudonym lifetime?
- Operation across multiple domains, thus a scalable design
- Efficiency and robustness

# Security and Privacy Requirements for the VPKI Protocols

- Authentication, communication integrity and confidentiality
- Authorization and access control
- Non-repudiation, accountability and eviction (revocation)
- Privacy
  - Anonymity (conditional)
  - Unlinkability
- Thwarting Sybil-based misbehavior
- Availability

# Adversarial Model

## External adversaries

## Internal adversaries

## Stronger adversarial model

Protection against *honest-but-curious* VPKI entities

- Correct execution of protocols but motivated to profile users
- Concealing pseudonym provider identity and acquisition time, and reducing pseudonyms linkability (inference based on time)

Multiple VPKI entities could collude

# Outline

# Secure VC System

- Root Certification Authority (RCA)
- Long Term CA (LTCA)
- Pseudonym CA (PCA)
- Resolution Authority (RA)
- Lightweight Directory Access Protocol (LDAP)
- Roadside Unit (RSU)
- Trust established with RCA, or through cross certification

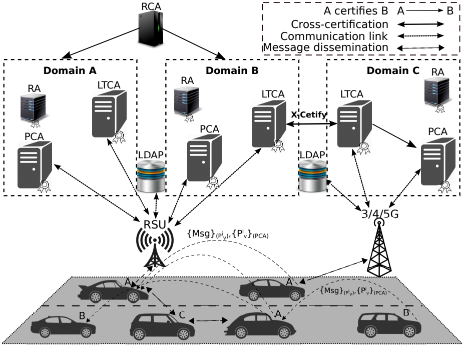



**Figure:** VPKI Overview

# System Model

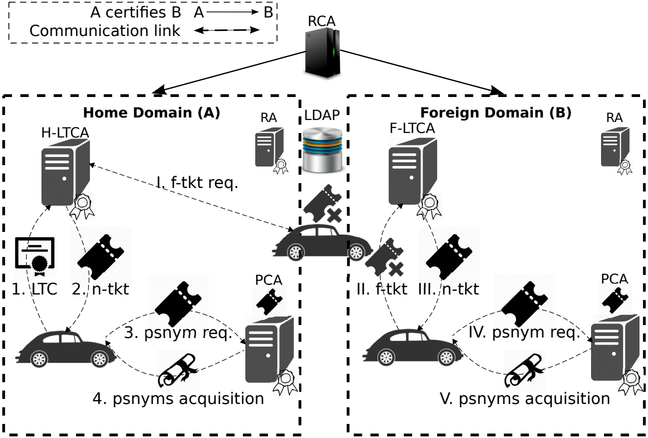
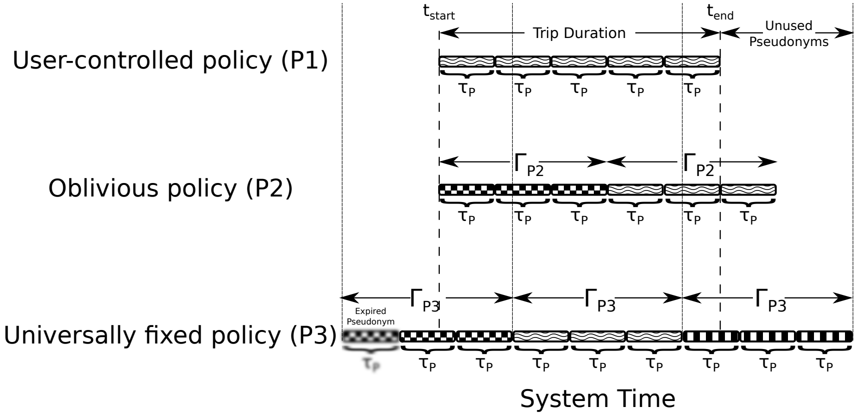
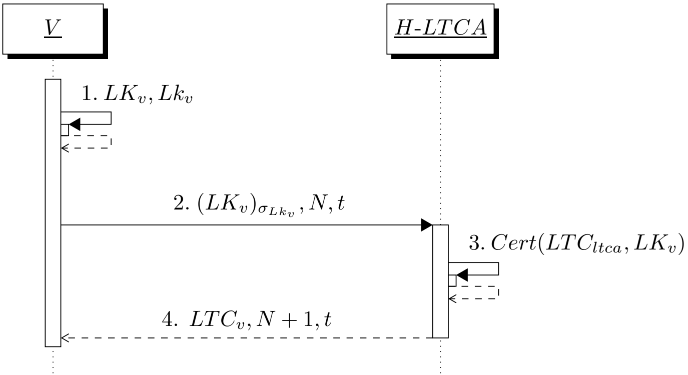



**Figure:** VPKI Architecture

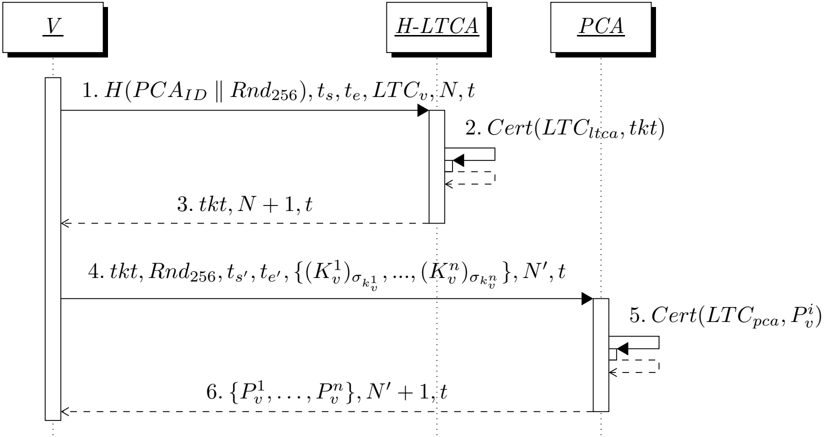
# Pseudonym Acquisition Policies



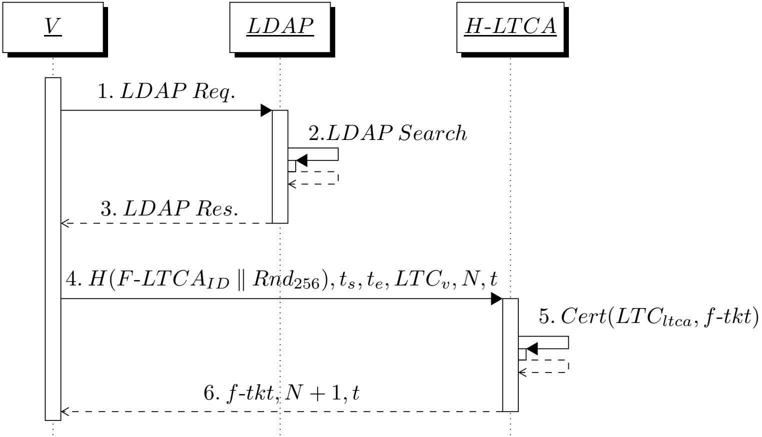
# Vehicle Registration and Long Term Certificate (LTC) Update



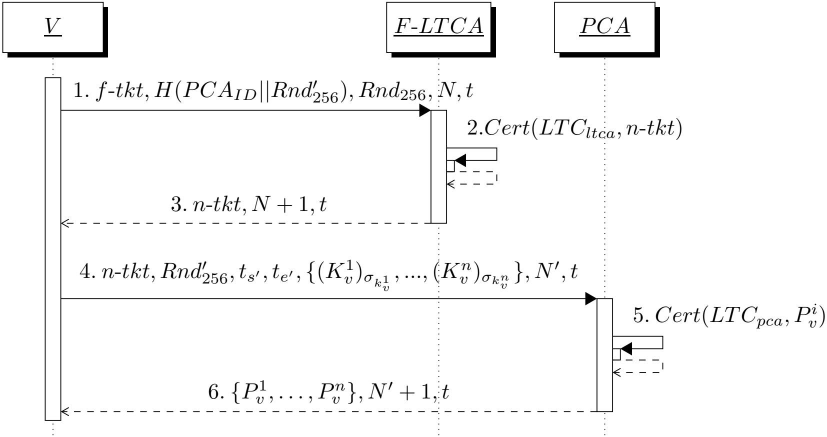
# Ticket and Pseudonym Acquisition



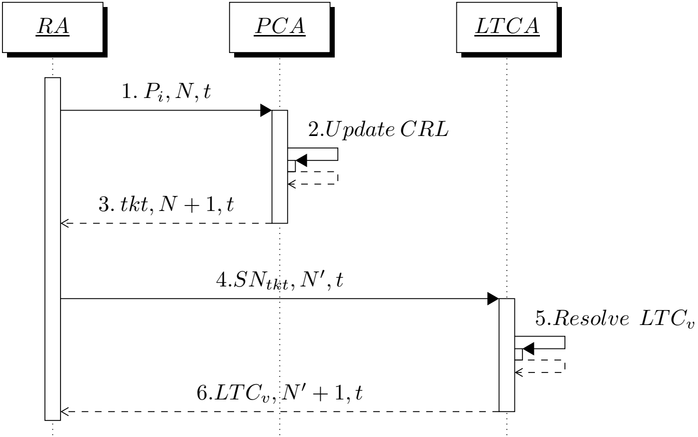
# Roaming User: Foreign Ticket Authentication



# Native Ticket and Pseudonym Acquisition in the Foreign Domain



# Pseudonym Revocation and Resolution

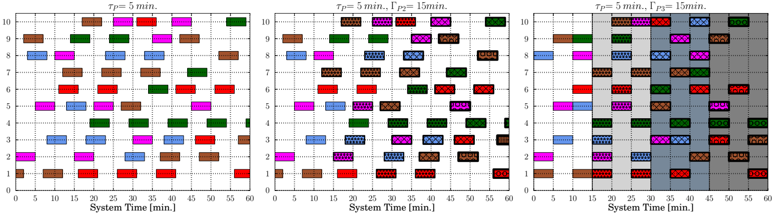


# Outline

## Security and Privacy Analysis

- Communication integrity, confidentiality, and non-repudiation
  - Certificates, TLS and digital signatures
- Authentication, authorization and access control
  - LTCA is the *policy decision and enforcement point*
  - PCA grants the service
  - Security association discovery through LDAP
- Concealing PCAs, F-LTCA, actual pseudonym acquisition period
  - Sending $H(PCA_{id} \| Rnd_{256})$, $t_s$, $t_e$, $LTC_v$ to the H-LTCA
  - PCA verifies if $[t'_s,\ t'_e] \subseteq [t_s,\ t_e]$
- Thwarting Sybil-based misbehavior
  - LTCA never issues valid tickets with overlapping lifetime (for a given domain)
  - A ticket is bound to a specific PCA
  - PCA keeps records of ticket usage

# Linkability based on Timing Information of Credentials




(a) P1: User-controlled policy (b) P2: Oblivious policy (c) P3: Universally fixed policy

- Non-overlapping pseudonym lifetimes from eavesdroppers' perspective
- P1 & P2: Distinct lifetimes per vehicle make linkability easier (requests/pseudonyms could act as user *'fingerprints'*)
- P3: Uniform pseudonym lifetime results in no distinction

# Outline

# Experimental Setup (#1)

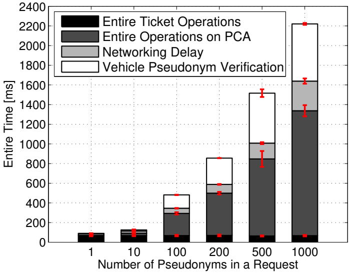
- **VPKI testbed**
  - Implementation in C++
  - OpenSSL: Transport Layer Security (TLS) and Elliptic Curve Digital Signature Algorithm (ECDSA)-256 according to the standard [1]
- **Network connectivity**
  - Varies depending on the actual OBU-VPKI connectivity
  - Reliable connectivity to the VPKI (e.g., RSU, Cellular, opportunistic WiFi)

**Table:** Servers and Clients Specifications

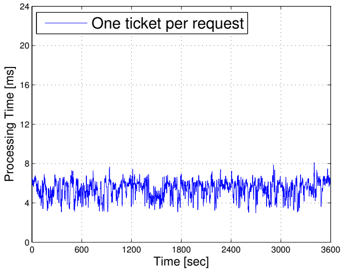
| | LTCA | PCA | RA | Clients |
|---|---|---|---|---|
| VM Number | 2 | 5 | 1 | 25 |
| Dual-core CPU (Ghz) | 2.0 | 2.0 | 2.0 | 2.0 |
| BogoMips | 4000 | 4000 | 4000 | 4000 |
| Memory | 2GB | 2GB | 1GB | 1GB |
| Database | MySQL | MySQL | MySQL | MySQL |
| Web Server | Apache | Apache | Apache | - |
| Load Balancer | Apache | Apache | - | - |
| Emulated Threads | - | - | - | 400 |

- **Use cases**
  - Pseudonym provision
  - Performing a DDoS attack

# Client and LTCA Performance Evaluation



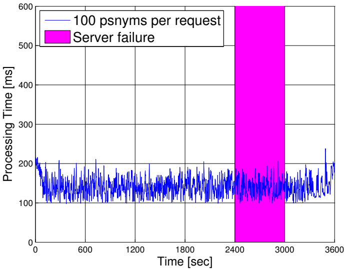

Client processing time



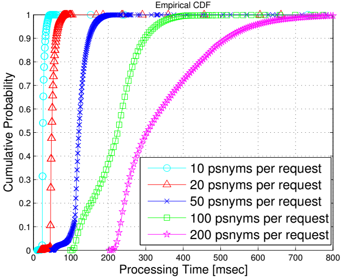

LTCA performance

- Delay to obtain pseudonyms
- LTCA response time to issue a ticket

# PCA Performance Evaluation



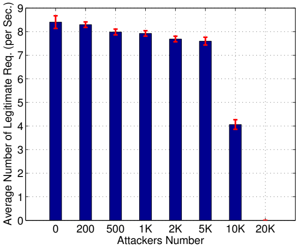

Issuing 100 pseudonyms per request



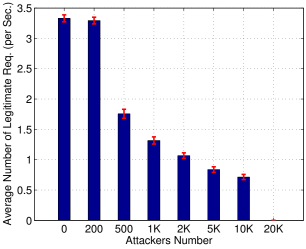

PCA performance under different configuration

- PCA response time, including a *crash* failure
- Efficient provision for pseudonyms, with different configurations
- Obtaining 200 pseudonyms: $F_x$(t=500)=0.9 or Pr{t$\leq$500}=0.9

# The VPKI Servers under a DDoS Attack




LTCA performance




PCA performance

- 10K legitimate vehicles, requesting 100 pseudonyms every 10 minutes
- Up to 20K attackers, sending requests every 10 seconds
- An LTCA is more resistant to DDoS than a PCA

# Experimental Setup (#2)

**Table:** Mobility Traces Information

| | TAPASCologne | LuST |
|---|---|---|
| Number of vehicles | 75,576 | 138,259 |
| Number of trips | 75,576 | 287,939 |
| Duration of snapshot (hour) | 24 | 24 |
| Available duration of snapshot (hour) | 2 (6-8 AM) | 24 |
| Average trip duration (sec.) | 590.49 | 692.81 |
| Total trip duration (sec.) | 44,655,579 | 102,766,924 |

- **Main metric**
  - End-to-end pseudonym acquisition latency from the initialization of ticket acquisition protocol till successful completion of pseudonym acquisition protocol

**Table:** Servers & Clients Specifications

| | LTCA | PCA | Client |
|---|---|---|---|
| Number of entities | 1 | 1 | 1 |
| Dual-core CPU (Ghz) | 2.0 | 2.0 | 2.0 |
| BogoMips | 4000 | 4000 | 4000 |
| Memory | 2GB | 2GB | 1GB |
| Database | MySQL | MySQL | MySQL |

- N.B. PRESERVE Nexcom boxes specs: dual-core 1.66 GHz, 2GB Memory

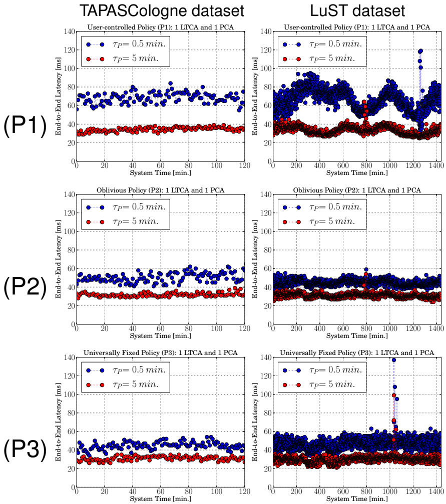
# End-to-end Latency for P1, P2, and P3

**Choice of parameters:**

- Frequency of interaction and volume of workload to a PCA
- $\Gamma$=5 min., $\tau_P$=0.5 min., 5 min.

**LuST dataset ($\tau_P = 0.5\ min$):**

- P1: $F_x(t = 167\ ms) = 0.99$
- P2: $F_x(t = 80\ ms) = 0.99$
- P3: $F_x(t = 74\ ms) = 0.99$



# The VPKI Servers under a DDoS Attack

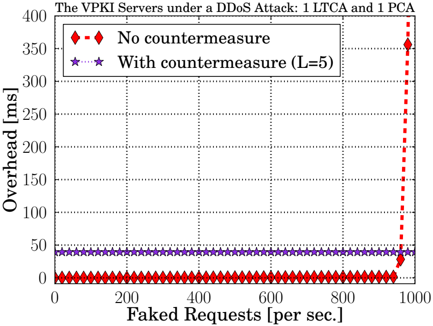



**Figure:** Overhead to obtain pseudonyms, LuST dataset with P1 ($\tau_P$ = 5 min.)

# Outline

## Summary of Contributions

1. Facilitating multi-domain operation
2. Offering increased user privacy protection
   - Honest-but-curious system entities
   - Eliminating pseudonym linking based on timing information
3. Eradication of Sybil-based misbehavior
4. Proposing multiple generally applicable pseudonym acquisition policies
5. Detailed analysis of security and privacy protocols
6. Extensive experimental evaluation
   - Efficiency, scalability, and robustness
   - Achieving significant performance improvement
   - Modest VMs can serve sizable areas or domain

# Future Steps

## VPKI enhancements

- Evaluation of the level of privacy, i.e., unlinkability, based on the timing information of the pseudonyms for each policy
- Evaluation of actual networking latency, e.g., OBU-RSU
- Rigorous analysis of the security and privacy protocols

## Efficient distribution of revocation information

- *How to disseminate pseudonyms validity information without interfering with vehicles operations?*

# Original Work


- N. Alexiou, M. Laganà, S. Gisdakis, M. Khodaei, and P. Papadimitratos, *"VeSPA: Vehicular Security and Privacy-preserving Architecture,"* in ACM HotWiSec, Budapest, Hungary, Apr. 2013.
- 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.
- M. Khodaei and P. Papadimitratos, *"The Key to Intelligent Transportation: Identity and Credential Management in Vehicular Communication Systems,"* IEEE VT Magazine, vol. 10, no. 4, pp. 63-69, Dec. 2015.
- M. Khodaei and P. Papadimitratos, *"Evaluating On-demand Pseudonym Acquisition Policies in Vehicular Communication Systems,"* in ACM MobiHoc, Workshop on Internet of Vehicles and Vehicles of Internet (IoV-VoI), Paderborn, Germany, July 2016.
- M. Khodaei, H. Jin, and P. Papadimitratos, *"SECMACE: Scalable and Robust Identity and Credential Management Infrastructure in Vehicular Communication Systems,"* Submitted to the IEEE Transactions on Intelligent Transportation Systems.

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[4] F. Schaub, F. Kargl, Z. Ma, and M. Weber, "V-tokens for Conditional Pseudonymity in VANETs," in *IEEE WCNC*, NJ, USA, Apr. 2010.

[5] N. Bißmeyer, J. Petit, and K. M. Bayarou, "CoPRA: Conditional Pseudonym Resolution Algorithm in VANETs," in *IEEE WONS*, Banff, Canada, pp. 9–16, Mar. 2013.

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[6] W. Whyte, A. Weimerskirch, V. Kumar, and T. Hehn, “A Security Credential Management System for V2V Communications,” in *IEEE VNC*, Boston, MA, pp. 1–8, Dec. 2013.

[7] S. Gisdakis, M. Laganà, T. Giannetsos, and P. Papadimitratos, “SEROSA: SERvice Oriented Security Architecture for Vehicular Communications,” in *IEEE VNC*, Boston, MA, USA, Dec. 2013.

[8] D. Förster, H. Löhr, and F. Kargl, “PUCA: A Pseudonym Scheme with User-Controlled Anonymity for Vehicular Ad-Hoc Networks (VANET),” in *IEEE VNC*, Paderborn, Germany, Dec. 2014.

[9] M. Khodaei, “Secure Vehicular Communication Systems: Design and Implementation of a Vehicular PKI (VPKI),” Master’s thesis, Lab of Communication Networks (LCN), KTH University, Oct. 2012.

[10] N. Alexiou, M. Laganà, S. Gisdakis, M. Khodaei, and P. Papadimitratos, “VeSPA: Vehicular Security and Privacy-preserving Architecture,” in *Proceedings of the 2nd ACM workshop on Hot topics on wireless network security and privacy*, Budapest, Hungary, pp. 19–24, Apr. 2013.

# Bibliography III


[11] M. Khodaei, H. Jin, and P. Papadimitratos, "Towards Deploying a Scalable & Robust Vehicular Identity and Credential Management Infrastructure," in *IEEE Vehicular Networking Conference (VNC)*, Paderborn, Germany, pp. 33–40, Dec. 2014.

[12] M. Khodaei and P. Papadimitratos, "The Key to Intelligent Transportation: Identity and Credential Management in Vehicular Communication Systems," *IEEE VT Magazine*, vol. 10, no. 4, pp. 63–69, Dec. 2015.

[13] ——, "Evaluating On-demand Pseudonym Acquisition Policies in Vehicular Communication Systems," in *Proceedings of the First International Workshop on Internet of Vehicles and Vehicles of Internet*, Paderborn, Germany, pp. 7–12, July 2016.

[14] "Preparing Secure Vehicle-to-X Communication Systems - PRESERVE." [Online]. Available: http://www.preserve-project.eu/

# Secure and Privacy Preserving Vehicular Communication Systems: Identity and Credential Management Infrastructure

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