Connected Vehicle Security and Privacy

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Connected Vehicles – V2X
Introduction

- 32,000 deaths on the road in the US in 2012
- Day-1 applications will likely be:
  - USA: V2V driver notifications safety applications
  - Europe: mobility applications, supported by infrastructure (e.g. temporary highway construction site)
- V2V wireless communications for 360° warning applications.
  - 300+ m range
- Basic Safety Message (BSM)
  - Contains position, velocity, acceleration …
  - Transmitted up to 10 times per second
- Allows receiving unit to predict collisions and warn driver
Deployment

- NHTSA released an advanced notice of proposed rulemaking (ANPRM) and research report on V2V on August 18th, 2014.

- Cadillac announced deployment of V2V on select 2017 models (CTS) in September 2014.

- The security system in this presentation presents the leading candidate for V2V and V2I deployment.
Security Overview

To enforce security in V2X systems we need to ensure that

- A message originates from a trustworthy and legitimate device
- A message was not modified between sender and receiver
- Misbehaving units are removed from the system

Frequently change certificates to prevent linking BSMs to one-another for tracking purposes

Security Credential Management Server (SCMS) as trust anchor

Digital signatures to guarantee integrity

Option to verify-on-demand: only verify messages that will result in driver’s warning
Risk Analysis

- It can be assumed that V2X will be used for driver warnings and notifications only
  - It is reasonable to assume that V2X will only support control applications, i.e., all control applications will use V2X only as an additional sensor on top of radar or camera sensor input.
- Successful attacks do not pose a safety threat
  - However, applications must be designed in a careful manner (known from radar and camera based control applications such as assisted braking)
- Messages may affect choice of route or have other mobility/efficiency impacts (not safety-related)
  - Higher motivation for attack, however, no safety-related risk
- Actual Risk: lack of security will result in a high number of false warnings that will reduce acceptance of V2X significantly and loss of user acceptance
Security Considerations

- Impact on privacy
  - Don’t want the system to be used as a tracking system
  - Prevent eavesdroppers or insiders from collecting Personally Identifiable Information (PII)
- Additional attack surface
  - New wireless interface adds another surface to hack into car (similar to Bluetooth, cellular and Wi-Fi).
Design Constraints

- *Data rate using current V2X system*: transmits at 6 Mbps under ideal conditions.
  - Typical data rates usually below theoretic optimum
- *Cost*: limits in car on processing power and storage
- *Life-cycle*: solutions designed today will be deployed in a decade and will then be used for several decades.
Design Constraints (2)

- **Connectivity**: During the early years of deployment, only limited connectivity of the vehicles to Internet available
  - Road-side units at intersections, gas stations, dealerships, etc., that allow communication for a few seconds while vehicle drives by
  - Embedded modems installed in a few cars that allow regular communication with these cars and use them as seed for epidemic spreading of data (e.g. distribution of CRLs)
V2V MESSAGE AUTHENTICATION

Acknowledgement: Many of these concepts have been developed by the CAMP VSC-A Team, the CAMP VSC3 VSCS Team, and the IEEE 1609.2 group.
V2V Authentication

- Messages are signed
  - ECDSA-256 with NISTp256 curve
- Signed messages include time and location
  - Signer adds time and location before signature
  - Allows to detect relay and replay attacks
- Optionally verify messages on demand: only verify messages that will result in a driver’s warning
  - E.g. do not verify message that was broadcast from a vehicle that is 300m away
Protect Privacy

- No personal information included in broadcast messages
- Prevent tracking: “Identifiers” at application, network and other levels should be transient and change simultaneously
  - Vehicles are provisioned with three years’ worth of certificates
- Vehicles have $k$ simultaneously valid BSM certificates,
  - Dynamically choose which certificate to use to sign (e.g. rotate every 5 minutes). More research required to determine proper change strategies.
  - Baseline number of certs $k = 20$ per week (but car makers can choose to use more certificates per week)
  - For three years’ worth of certificates, at least 3,120 certificates are loaded at Day-1.
SECURITY CREDENTIAL MANAGEMENT SYSTEM (SCMS)

Acknowledgement: These concepts have been developed by the CAMP VSC3 VSCS Team.
SCMS Overview

- Privacy against insiders and outsiders
  - Separation of SCMS duties and information: a single SCMS component cannot link any two certificates to the same device (no tracking)
  - No information stored within SCMS that links certificates to a particular device, vehicle, or owner
  - Registration Authority (RA) shuffles all requests from device
  - Location Obscurer Proxy (LOP) acts as an anonymizer proxy
- Butterfly keys to minimize effort of device
- Efficient privacy-preserving revocation
Certificate Provisioning

SCMS Manager

Policy

Technical

Root CA

Intermediate CA

Pseudonym CA

Certification Services

Enrollment CA

Request Coordination

Registration Authority

Device Config. Manager

Location Obscurer Proxy

Misbehavior Authority

Internal Blacklist Manager

Global Detection

CRL Generator

CRL Store

CRL Broadcast

Legend

Directly acts in this use case

Provides information before execution
Shift Effort from Device to Server: Butterfly Keys

• Generating a lot of keys for requests is a burden at the OBE side
  • It might not need all of them
  • It needs to store the private keys
  • Increases request size and risk that request doesn’t make it through the network
• Device generates a private/public seed value and expansion function
• Server expands public seed to create many public keys (without knowing the corresponding private keys)
• Server does most of the work, but only device knows the private keys
Revocation
Revocation

- Two ways of revocation
  - Publish certificate revocation lists (CRL) to devices
  - Deny renewal of certificates
- Vehicles need to be provisioned with a minimum number of certificates in case they are turned off for some time and turned on in an area with no coverage
  - If you have, say, a month’s worth of certs, you can misbehave for a month
- Revocation by CRL must be supported to reduce potential disruption within system
- Revocation by denying renewal of certificates will be implemented on top
  - Need efficient, privacy-preserving revocation
Efficient Revocation: Linkage Values

• Remember: each device holds 20 certificates per week, more than 1,000 certificates per year

• Revoke all $n$ of a device’s certificates with just one entry on the CRL

• Backwards unlinkability
  • If a device is revoked, its privacy for past events is still protected

• After revocation, privacy cannot be protected
**Linkage Values**

- Create one hash chain value $s(i)$ per week
- Encrypt values $j=1$ to 20 with hash chain values as key to obtain pre-linkage values:
  \[ plv(i, j) = Enc_{s(i)}(j) \]
- Embed $i$ and $plv$ in certificate ($i$ is a global unit)
- To revoke, publish current week’s hash chain value $s(i)$
- Backward privacy is preserved
Linkage Values: Avoid Inside Attacks

- **Problem**: if a single entity calculates the linkage values, then this entity can link certificates.
  - Introduce Linkage Authorities $LA_1$ and $LA_2$

- $LA_1$ calculates $pvl_1$ and encrypts for PCA
- $LA_2$ calculates $plv_2$ and encrypts for PCA
- PCA calculates $lv = plv_1 \text{ XOR } plv_2$
SAFETY PILOT MODEL DEPLOYMENT

Acknowledgement: The underlying security design has been developed by the CAMP VSC3 VSCS Team. Safety Pilot Model Deployment has been conducted by UMTRI.
Safety Pilot Model Deployment

- Conducted by UMTRI
- 2,836 vehicles equipped with DSRC wireless communication devices in a concentrated geographic area (Ann Arbor)
- August 2012 – February 2014
- One year deployment period.
- Equipped roadside units.
Model Deployment Geographic Area

- Ann Arbor, Michigan
Security

- 1st version of Security Credential Management Server designed in 2011 was deployed in Model Deployment, operated under a separate USDOT contract.
- 105,000 certificates per year per on-board unit (i.e., almost 300 million certificates per year were issued)
- Certificates were either loaded manually or they were updated over-the-air during road-side unit drive-by.
- Security was deployed for V2V basic safety messages and for road-side unit applications (e.g. Signal Phase and Timing broadcast messages that announce when a traffic light will turn red).
- Note: the previously presented security design is a refined version
AUTOMOTIVE SECURITY
Secure Wireless Interface

- Recent research results from various parties suggest that data security in vehicle becomes safety issue
  - Successful penetration via Bluetooth and cellular connections
- DSRC would be a standardized wireless interface
- DSRC is a safety system and requires communication with powertrain systems by design
  - DSRC interface of cars must be carefully protected
Secure Processing Platform

• Secure hardware
  • Message signature generation and handling of private keys only in secure hardware
  • Store certificates only encrypted and only decrypt within secure hardware

• Sensor input
  • Should sensor input be authenticated?
Conclusions

- The US DOT announced they are moving forward with a V2V communication regulation.
- The presented design is the leading candidate for deployment in the US. This will be a security system for 300 million vehicles.
- Privacy against inside and outside attackers was included in the design.
- Feedback about design highly welcome! More details available in

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