V2V Communication Security: A Privacy Preserving Design for 300 Million Vehicles

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Disclaimer

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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
  • The U.S. Department of Transportation estimates that V2V technology, if widely deployed, could provide warnings to drivers in as many as 76 percent of potential multi-vehicle collisions, with the level of benefit depending on the extent of deployment and the effectiveness of V2V warnings in eliciting appropriate driver responses
Deployment

- NHTSA, February 3rd 2014: “The U.S. Department of Transportation's (DOT) National Highway Traffic Safety Administration (NHTSA) announced today that it will begin taking steps to enable vehicle-to-vehicle (V2V) communication technology for light vehicles.”

- The security system in this presentation presents the leading candidate for 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

Digital signatures to guarantee integrity

Security Credential Management Server (SCMS) as trust anchor

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

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 certs
- 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.
- Further approaches available, such as mix-zones
  - Vehicles change certificates in a coordinated way (e.g. at an intersection)
  - However, mix-zones seem to interfere with the idea of safety systems
Implicit Certificates

- Messages are signed using ECDSA over the NISTp256 curve with ECQV certificates
- “Implicit” certificates replace signature with public key reconstruction value
- Save 64 bytes per certificate
- Speed up the first verification of a certificate chain
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 anonymizer proxy
- Butterfly keys to minimize effort of device
- Efficient privacy-preserving revocation
Certificate Provisioning
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
Butterfly Keys

- **Device:**
  - Generates signing keypair: $a, A = aG$ and encryption keypair: $h, H = hG$
  - Creates expansion functions $f_s(i), f_e(i)$

- **RA:**
  - Generates signing public value $B_i = A + f_s(i) G$ and encryption public key $L_i = H + f_e(i) G$

- **PCA:**
  - Creates signing public key $C_i = B_i + c_i G$ for random $c_i$ (so that RA cannot learn final public key)
  - Issues $<C_i>$, the cert containing $C_i$,
  - Encrypts $(<C_i>, c_i)$ with $L_i$ to Device
  - Signs encrypted value (to avoid MitM attack by RA)

- **Device, and only Device, knows private key of $C_i$: $a + f_s(i) + c_i$**

- **OBE and only OBE knows private decryption key (similar argument)**

- **RA does not know certificate’s public key and cannot link certificates**
Privacy against Insider: Shuffle at the RA

- RA receives requests from multiple end-entity devices/vehicles
- RA shuffles requests and delivers shuffled elements to PCA. PCA doesn’t know to which device the request belongs.
- RA combines responses from PCA and forwards to proper device. PCA encrypts the response so that RA cannot learn certificate content.
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 certs 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
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 LA₁ and LA₂

- LA₁ calculates pv₁ and encrypts for PCA
- LA₂ calculates pv₂ and encrypts for PCA
- PCA calculates lv = pv₁ XOR pv₂
How to Revoke an OBE

- Reporter provides misbehavior report with certificate of suspicious device
  - Known: certificate with linkage value
- PCA knows certificates that were issued. It looks up an identifier and provides identifier to RA and LAs
- RA can link identifier to device’s credentials
  - RA includes device’s credentials in blacklist and will deny any further requests
- LAs can link identifier to used hash chain value.
  - SCMS will add hash chain values to CRL

➢ All entities have to collaborate!
Group Revocation

- Use a mechanism similar to the above but with a public "salt" value
- Revoke all $n$ of a device’s certs with just one entry on the CRL
- Backwards unlinkability
- Group membership is secret until revocation
What Else Was Considered?

- Group signatures for V2V message authentication
  - Large signature size (channel congestion)
  - Not standardized
  - Problematic revocation
- Group signatures for Device-SCMS requests
  - Additional program code in vehicle
  - Non-standardized
What Else Was Considered? (2)

• Blind signatures so that SCMS does not know certificate
  • High complexity and high over-the-air bandwidth requirements
  • Not standardized
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
# Vehicle Platform Types

<table>
<thead>
<tr>
<th>Function</th>
<th>Integrated Systems</th>
<th>Retrofit / Aftermarket Devices</th>
<th>Vehicle Awareness Devices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broadcasts to others</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Receives broadcasts, Issues Alerts to Drivers</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Integrated with vehicle data bus &amp; systems; OEM interface</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Vehicles in Test</td>
<td>67</td>
<td>319</td>
<td>2450</td>
</tr>
</tbody>
</table>

| Source of Vehicles                           | Recruited drivers, USDOT-CAMP vehicles from 8 OEMs | Recruited drivers & vehicles Cars, trucks, buses | Recruited vehicles. Cars, trucks, buses, fleets. |
| Data Logging                                 | Full FOT-style data acq system (DAS)              | Some FOT DAS, some device logs                    | Device log files |
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
DEVICE SECURITY

Acknowledgement: The device’s security requirements have been developed by the CAMP VSC3 VSCS Team.
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

• Sending
  • Digitally sign 10 messages per second
Secure Processing Platform (2)

- Receiving
  - Digitally verify messages as required: Verify-on-Demand. Actual numbers depend on supported applications.
- Should sensor input (e.g. GPS, speed, etc.) be protected?
  - Depends on applications
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

Remaining Research

- Epidemic distribution of CRLs
- Misbehavior detection algorithms (both local algorithms running in vehicle and global algorithm running in backend)
- Secure in-vehicle implementations
- Privacy models to determine proper certificate change strategies
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Standards and Projects

- V2V and V2I is specified in IEEE 1609.2
  - Latest version is from April 26th, 2013 (IEEE Std. 1609.2 – 2013)
  - 1609.2 will be further developed
- V2V security credential management
  - Specification of first version available at
    http://www.priorartdatabase.com/pubView/IPCOM000210877D (September 14th, 2011)
  - Version of 2011 was deployed in Safety Pilot Model Deployment:
    http://safetypilot.umtri.umich.edu
  - Refined design, shown in this presentation, was published at IEEE VNC 2013: W. Whyte, A. Weimerskirch, V. Kumar, T. Hehn, “A Security Credential Management System for V2V Communications“
  - The European design was published at ITS World Congress 2011: N. Bißmeyer, H. Stübbing, E. Schoch, S. Götz, J.P. Stolz, B. Lonc, „A generic public key infrastructure for securing Car-to-X communication“.
References


[EVITA] http://www.evita-project.org


[OVERSEE] http://www.oversee-project.org

