Vehicle to Vehicle Safety Application using ECC PKI

NIST Workshop on Elliptic Curve Cryptography Standards

June 11, 2015

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V2V Significance

Safety

33,561 highway deaths in 2012
5,615,000 crashes in 2012
Leading cause of death for ages 4-27

Mobility

5.5 billion hours of travel delay
$121 billion cost of urban congestion

Environment

2.9 billion gallons of wasted fuel
56 billion lbs. of additional CO_2

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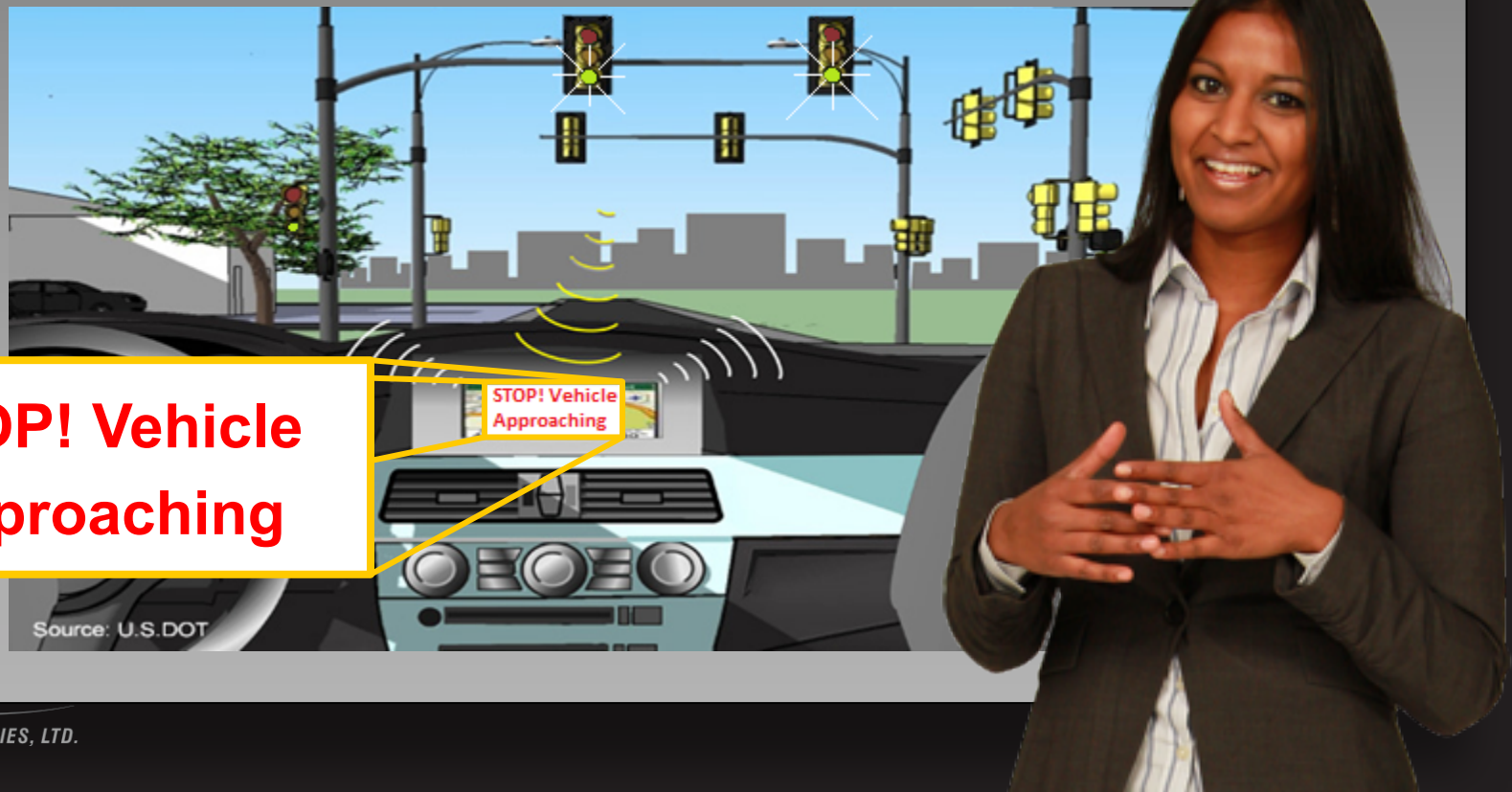
V2X Capabilities

- V2X has the potential to avoid 80% of crashes involving unimpaired drivers
- Greater situational awareness:
  - Your vehicle can “see” nearby vehicles and knows roadway conditions you cannot see
  - 360-degree “visibility”
- Reduce or even eliminate crashes through:
  - Driver advisories
  - Driver warnings
  - Vehicle control

Safety Applications: V2V Scenario

Lauren is driving home with her son after school. She is stopped at a red light. When the light turns green, she is about to move through the intersection when she is warned of a vehicle crossing the path in front of her. She quickly brakes to avoid a T-bone crash.



STOP! Vehicle Approaching

V2X Capabilities

- V2V effectiveness increases with *deployment saturation*
- V2I can improve initial performance:
  - e.g. Stoplights can use sensors to detect oncoming vehicles and warn V2I equipped drivers of oncoming vehicles likely to run through a red light.
- V2V's PKI is in a Proof Of Concept (POC) phase

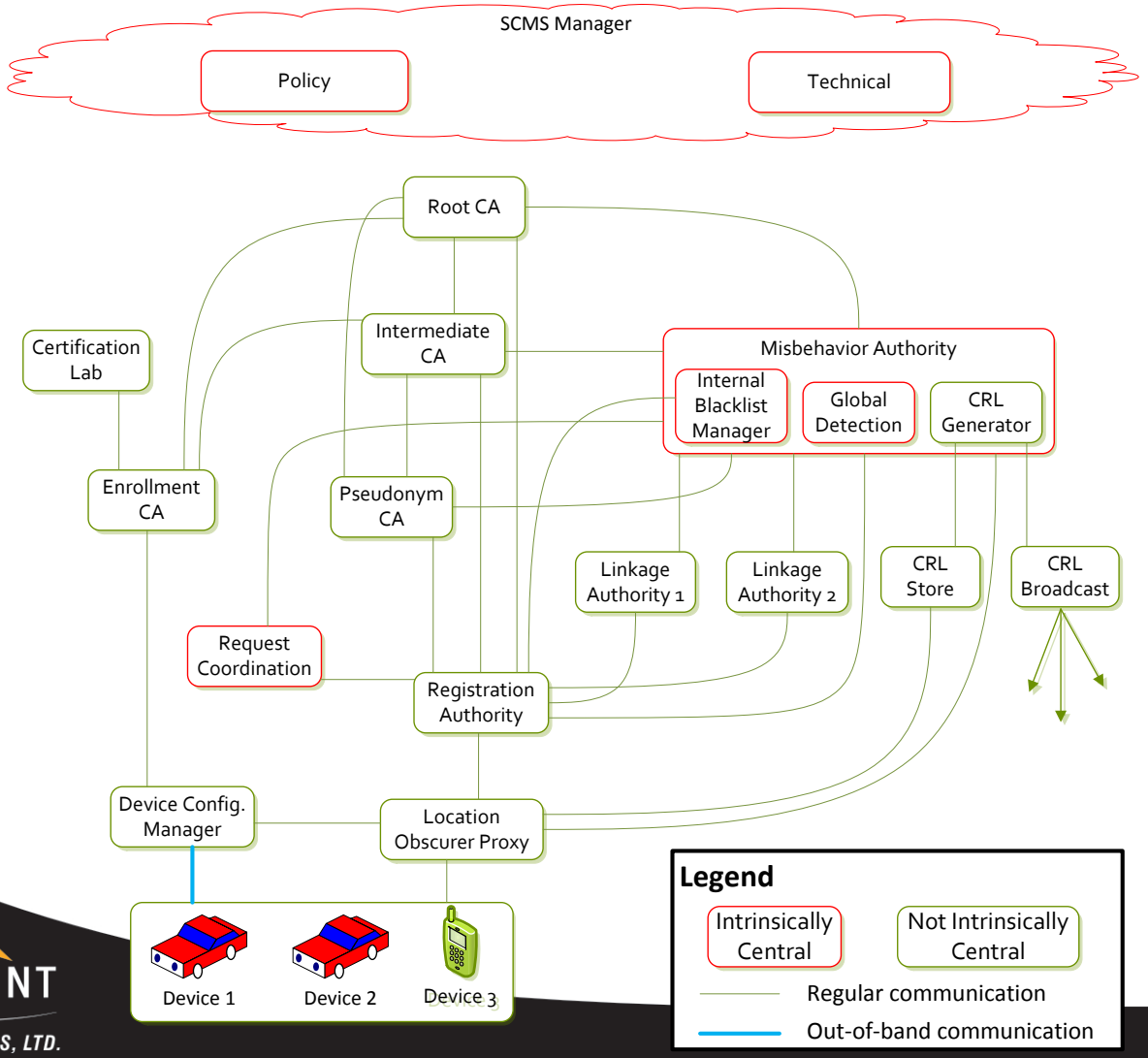
Complex Security Design

- System mandates:
  - Privacy for users: No Personal Ident Information (PII)
  - Prevent tracking by insiders & outsiders
  - Assume errors and hackers
  - Detect and remove misbehaving systems
  - Minimize over the air messaging bandwidth
- Tricky to Achieve:
  - Need high volume of small anonymous short lived certificates
  - … and still be able to revoke the certs when needed

ECC PKI Required

- Challenging embedded environment
  - 10x messages per vehicle per second
  - Up to 300 vehicles in range
  - memory and limited bandwidth
  - Each vehicle provisioned with 1000s of certs
  - Some vehicles may be offline for long periods
- Large Volume of Certificates
  - 45,000 x the largest CA to date (full deployment)
  - Volume driven by short-lived certificate design

V2X PKI Architecture



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System Parameters

- Standards
  - NIST P-256 curve
  - ECDSA (FIPS 186-3)
  - ECIES (IEEE 1363a)
  - SHA-256 (FIPS 180-3)
  - AES-CCM (NIST SP 800-38C)
  - IEEE 1609.2 messaging (ASN.1)
- Interesting Exceptions
  - ECQV (*SEC4, no NIST standard yet)
  - Butterfly key expansion (*unique to V2V, no standard)

Stylized ECQV

U		CA
$k_U \in_R [1, n)$		
$R_U := k_U G$	$\xrightarrow{U, R_U}$	
		$k \in_R [1, n)$
		$P_U := R_U + kG$
		$Cert_U := Encode(P_U, U, *)$
		$e := H_n(Cert_U)$
		$r := ek + d_{CA} \bmod n$
$e := H_n(Cert_U)$	$\xleftarrow{r, Cert_U}$	
$d_U := ek_U + r \bmod n$		

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Hash for ECQV

$H_n : \{0, 1, \ldots, 255\}^* \to [0, n)$
maps octet strings to integers modulo n.

Input:

1. An arbitrary length octet string S.
2. H hash function output length *hashlen*.
3. An integer n.

Actions:

1. Compute $h = H(S)$ (*hashlen* bits).
2. Set e to leftmost $\lfloor \log_2 n \rfloor$ bits of h.

Output: Integer e in $[0, n)$.

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Private/Public Correspondence

$$
\begin{aligned}
d_U &= ek_U + r \pmod{n} \\
&= ek_U + ek + d_{CA} \pmod{n}
\end{aligned}
$$

$$
\begin{aligned}
Q_U &= eP_U + Q_{CA} \\
&= e(R_U + kG) + Q_{CA} \\
&= e(k_U G + kG) + d_{CA} G \\
&= (ek_U + ek + d_{CA})G
\end{aligned}
$$

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Reconstruction

Private:

$$d_U := ek_U + r \bmod n$$

Public:

$$e := H_n(Cert_U)$$
$$Q_U := eP_U + Q_{CA}$$

Here Q_{CA} a system parameter, similar to curve.

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Pros/Cons

Certificate components:

- ECDSA: P, r, s: $3 + \epsilon$ finite field elements.
- ECQV: P_U: $1 + \epsilon$ finite field elements.

This size difference is crucial in V2V, where many messages must traverse a low bandwidth channel.

However, we now must delay our assurance until the private key has been *used*.

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Butterfly Expansion (William Whyte)

Certificate components:

- Base point: $R_U = k_U G$.
- Keyed Index: $f_K(i)$ keyed indexed function producing an EC private key.
- Expansion: $R_{U,i} = R_U + f_K(i)G$.

Expansion at the RA produces multiple public keys from one request.
Request value R_U is expanded to $R_{U,i}$
Each $R_{U,i}$ processed by the CA as R_U before.

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Butterfly Expansion (William Whyte)

- V2V-unique feature for certificate requests
  - Each vehicle requests 3000 certs initially (1000 annual)
  - Desire to reduce the volume of requests on the uplink
- Butterfly expansion actors
  - Client sends one public key and a keyed expansion function
  - RA expands the public keys into a series
  - RA shuffles requests from multiple clients
  - CA contributes to the client private key series
  - CA generates certs for derived public keys
  - CA encrypts certificates to client (privacy)
  - Client generates matching private keys.

Anonymous Revocation

- Critical to privacy and robustness
  - Vehicles change certificates frequently
  - Certificates do not contain identifying information
  - Yet, all of a vehicle's current and future certificates can be revoked by placing information on the CRL
  - Revocation destroys privacy for vehicle, but only forward in time, not backward

Linkage Values

- Anonymous revocation achieved with a pair of hash chains, seeded uniquely to a vehicle (Linkage Authorities)
- XOR of hash chain values used as cert pseudonym
- Hash chains advance at a defined system rate
  - All vehicles re-compute current revoked pseudonyms at each new time period
  - CRL's are periodically updated to current time periods
- Linkage Authorities operated separately for security and privacy protection

Relevance to NIST

- The largest PKI ever deployed will be ECC based
- Butterfly key expansion, Linkage Authorities
- The ECQV algorithm would benefit from NIST certification/compliance testing
- US Gov funded project, using US Gov curves for the POC, would like to know NIST's intentions for future curves to prepare for deployment