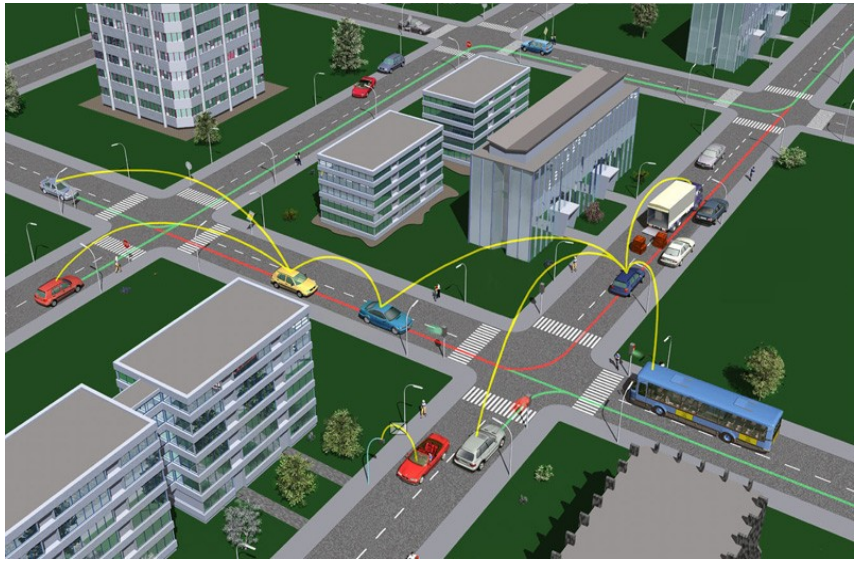


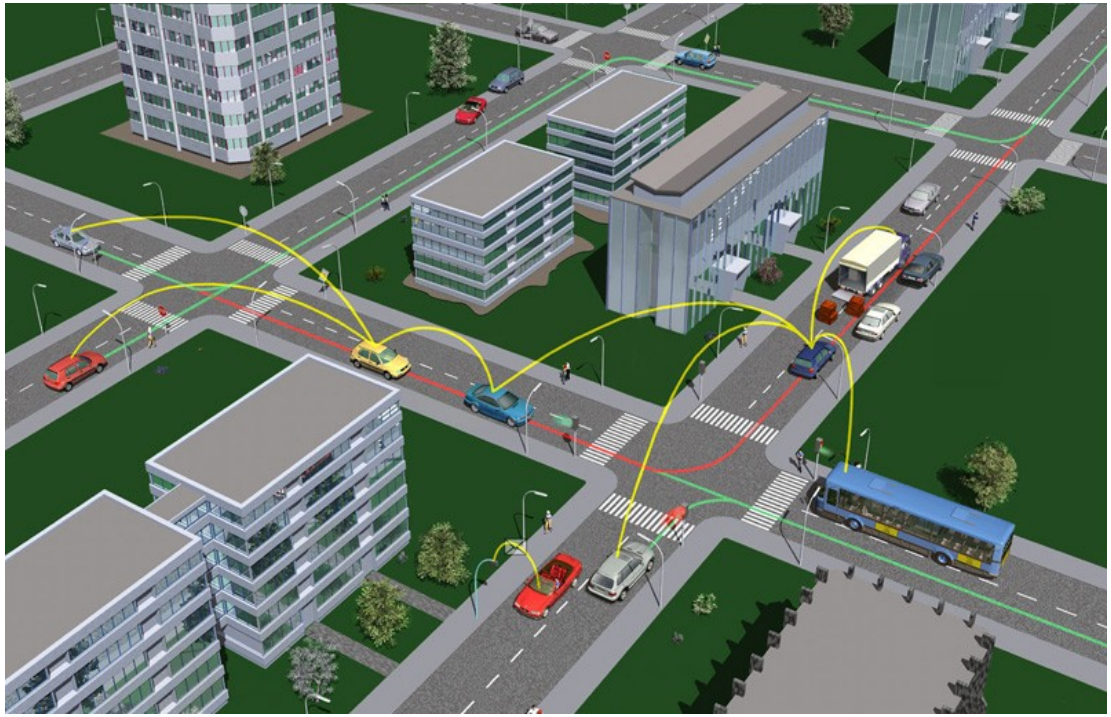
Secure V2X Communications
- According ETSI (Europe) -

Markus Ullmann

Outline

- Secure Vehicle-2-Vehicle Communication (V2V) according to ETSI
  - Communication Model
  - Security - and Privacy Requirements
  - Shortcomings of the existing ETSI Specifications
    - Security, Privacy
- Secure Vehicle-2-Infrastructure Communication (V2X)
  - V2X Pilot Projects in Europe
    - Cooperative Intelligent Transport System (C-ITS) Corridor Project Rotterdam-Frankfurt-Vienna
  - Secure V2X Communication
  - Secure ITS Roadside Station (IRS) messages (DENM)
  - Multi Domain PKI Architecture
- Conclusion/Future Work

Vehicle-2-Vehicle Communication (V2V)

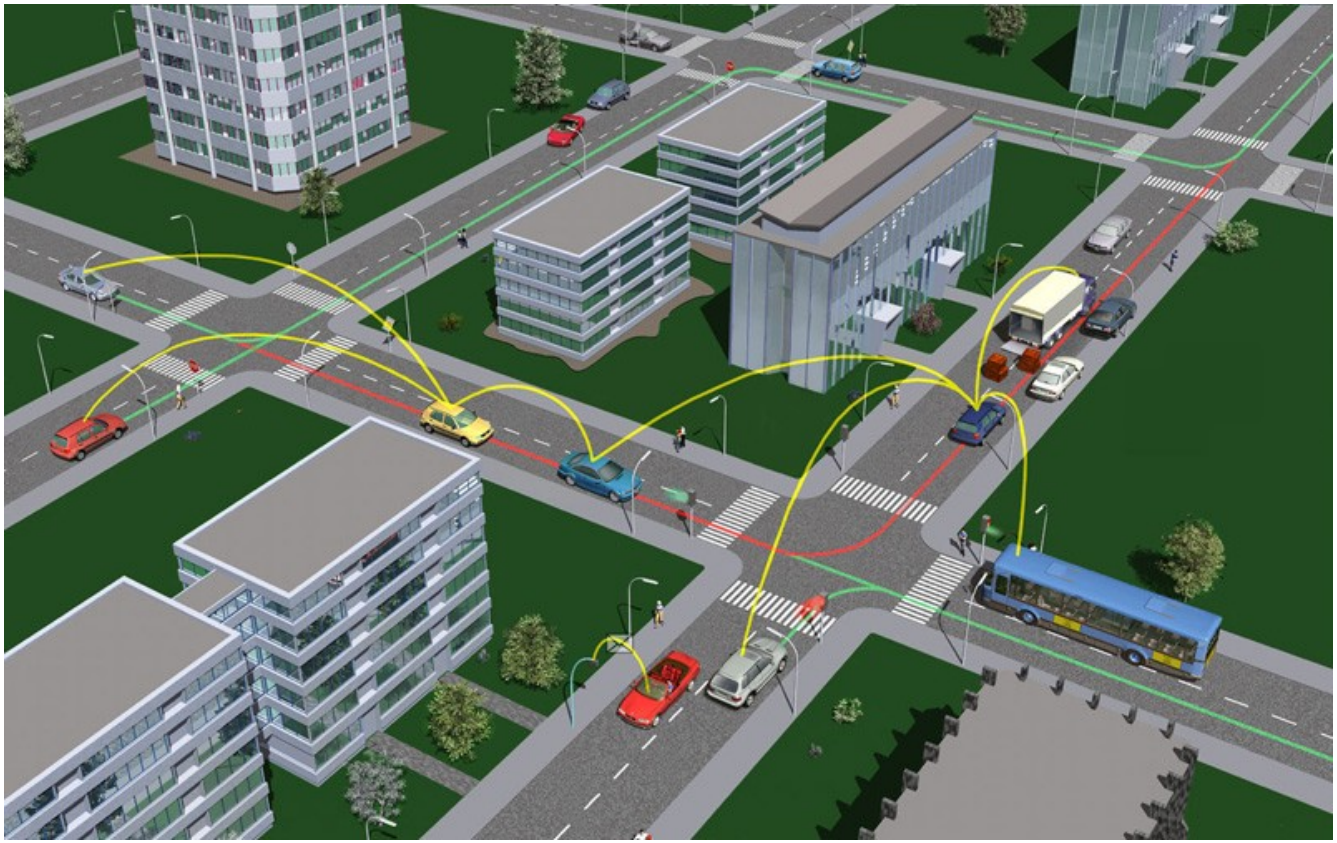


- Aim:
  Enhance Traffic Safety

Status V2V Communication

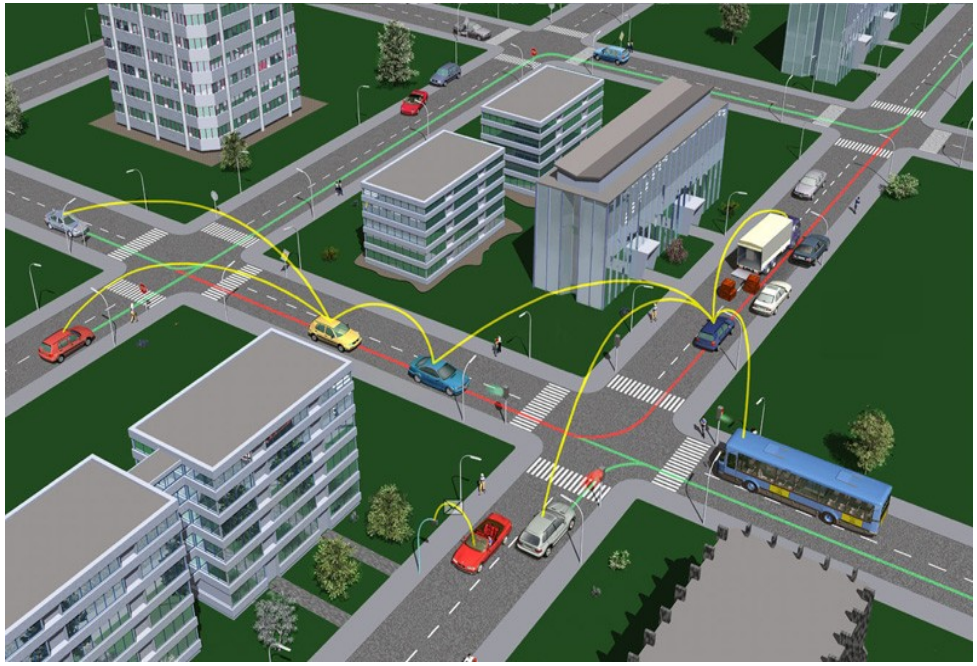
- ~ 1995 – 2005: Basic Research (including Security and Privacy)
- ~ 2005 – 2010: Prototyping
- ~ 2010 – 2015: Standardization Europe: ETSI
  US: IEEE, SAE
- 2018/19: Start Deployment Vehicles with V2V interface in Europe

Vehicle-2-Vehicle Communication



- Broadcast Communication
- IEEE 802.11p
- 5,9 GHz (“G5“)

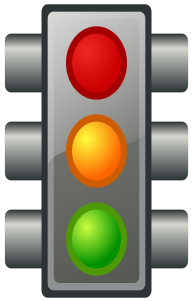
Security and Privacy Requirements for the V2V Communication



- Security Requirements
  - Message Integrity
  - Message Authenticity
- (Location) Privacy
  - Sender Anonymity
  - Message Unlinkability (~ “over longer time periods“)

ETSI ITS Architecture

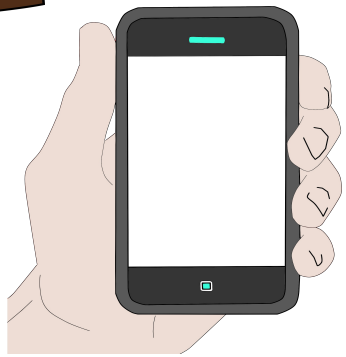
- ITS roadside stations



- ITS vehicle stations

- ITS central stations

- ITS personal stations



Secure Vehicle-2-Vehicle Communication

Broadcast Communication

- ETSI ITS Specifications
  - TS 102 637-2 V 1.2.1: Cooperative Awareness Message (CAM): Location, Speed, Time, … Send Frequency: 100ms

Header	CAM Information	ECDSA Signature	Certificate

  - TS 102 637-3 V 1.1.1: Decentralized Environmental Notification Basis Services (DENM): **Warning**

Header	DENM Information	ECDSA Signature	Certificate

  - TS 103 097 V 1.1.1: Security header and Certificate formats

ECDSA

- Elliptic Curve Digital Signature Algorithm (ECDSA)
  - Digital Signature is a "Cryptographic Fingerprint"
  - In general: Use of Asymmetric Cryptography
    - Here: Elliptic Curve Cryptography (ECC)
  - Entities need:
    - Key Pair: (public key | private key)
    - Certificate (formal attestation of a key pair)

  - Sender: Calculates signature (ECDSA)
  - Receiver: Verifies signature (ECDSA)
  - Elliptic Curves Cryptography
    - Calculation in specific cyclic finite groups (Discret Logarithm Problem on ECC is hard)
    - Elliptic Curve Domain Parameter (according to NIST, Brainpool, …)
      - NIST P-256 (NSA/NIST does not recommend to use this curve any longer)
      - BrainpoolP256r1
      - ...

Cooperative Awareness Message (CAM)

- "~ Beacon Message" -

Complete Message			
	Header	Signer_Info	
		Generation_Time	
		its_aid ITS-AID for CAM	
	CAM Information	Basis Container	ITS-Station Type
			Last Geographic Position
		High Frequency Container	Speed
			Driving Direction
			Longitudinal Acceleration
			Curvature
			Vehicle Length
			Vehicle Width
			Steering Angle
			Lane Number
			…
		Low Frequency Container	Vehicle Role
			Lights
			Trajectory
		Special Container	Emergency
			Police
			Fire Service
			Road Works
			Dangerous Goods
			Safety Car
			…
	Signature	ECDSA Signature of this Message	
	Certificate	According Certificate for Signature Verification	

CAM Send Frequency: 10 Hz

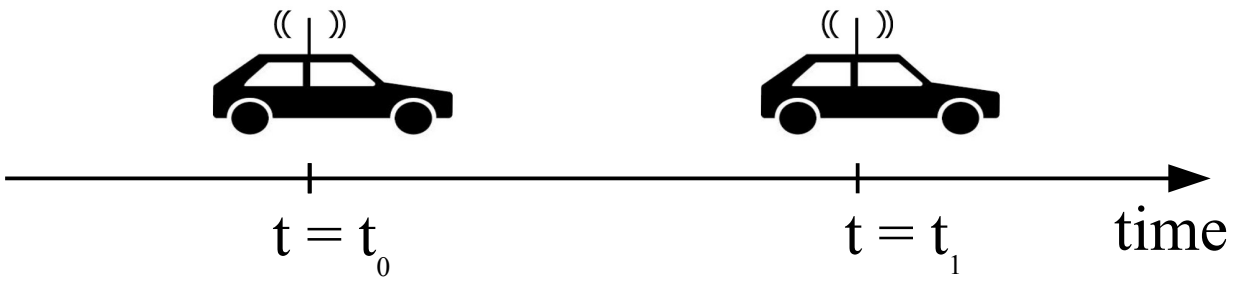
Privacy: Pseudonym Concept

Complete Message			
	Header	Signer_Info	
		Generation_Time	
		its_aid ITS-AID for CAM	
	CAM Information	Basis Container	ITS-Station Type
			Last Geographic Position
		High Frequency Container	Speed
			Driving Direction
			Longitudinal Acceleration
			Curvature
			Vehicle Length
			Vehicle Width
			Steering Angle
			Lane Number
			...
		Low Frequency Container	Vehicle Role
			Lights
			Trajectory
		Special Container	Emergency
			Police
			Fire Service
			Road Works
			Dangerous Goods
			Safety Car
			...
	Signature	ECDSA Signature of this Message	
	Certificate	According Certificate for Signature Verification	

1

Complete Message			
	Header	Signer_Info	
		Generation_Time	
		its_aid ITS-AID for CAM	
	CAM Information	Basis Container	ITS-Station Type
			Last Geographic Position
		High Frequency Container	Speed
			Driving Direction
			Longitudinal Acceleration
			Curvature
			Vehicle Length
			Vehicle Width
			Steering Angle
			Lane Number
			...
		Low Frequency Container	Vehicle Role
			Lights
			Trajectory
		Special Container	Emergency
			Police
			Fire Service
			Road Works
			Dangerous Goods
			Safety Car
			...
	Signature	ECDSA Signature of this Message	
	Certificate	According Certificate for Signature Verification	

2



- Concept
  - Pseudonymous key pairs / certificates
- Privacy Requirements
  - Sender Anonymity
  - Message unlinkability

CAM Data Volume

- Basis Container + High Frequency Container + Low Frequency Container: ~200 bits
- Header + Signature: ~750 bits
- Certificate: ~1000 bits

Complete Message			
	Header	Signer_Info	
		Generation_Time	
		its_aid ITS-AID for CAM	
	CAM Information	Basis Container	ITS-Station Type
			Last Geographic Position
		High Frequency Container	Speed
			Driving Direction
			Longitudinal Acceleration
			Curvature
			Vehicle Length
			Vehicle Width
			Steering Angle
			Lane Number
			…
		Low Frequency Container	Vehicle Role
			Lights
			Trajectory
		Special Container	Emergency
			Police
			Fire Service
			Road Works
			Dangerous Goods
			Safety Car
			…
	Signature	ECDSA Signature of this Message	
	Certificate	According Certificate for Signature Verification	

Decentralized Environmental Notification Basis Services (DENM)

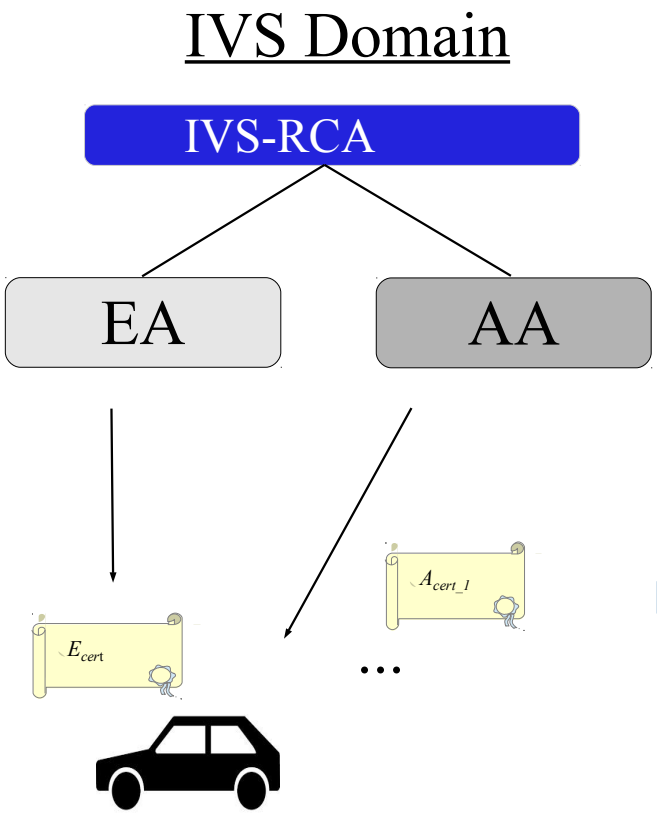
- Warning (event driven) -

Complete Message	Header	Signer_Info	
		Generation_Time	
		its_aid ITS-AID for DENM	
	DENM Information	Management Container	Last Vehicle Position (GPS)
			Event Identifier
			Time of Detection
			Time of Message Transmission
			Event Position (GPS)
			Validity Period
			Station Type (Motor Cycle, Vehicle, Truck)
			Message Update / Removal
			Relevant Local Message Area (geographic)
			Traffic Direction (forward, backwards, both)
			Transmission Interval
			….
		Situation Container	Information Quality (low -high, tbd)
			Event Type (Number)
			Linked Events
			Event Route (geographical)
		Location Container	Event Path
			Event Speed
			Event Direction
			Road Type
		A la carte Container	Road Works (Speed Limit, Lane Blockage….)
			….
	Signature	ECDSA Signature of this message	
	Certificate	According Certificate for Signature Verification	

Comparison V2X in Europe / US

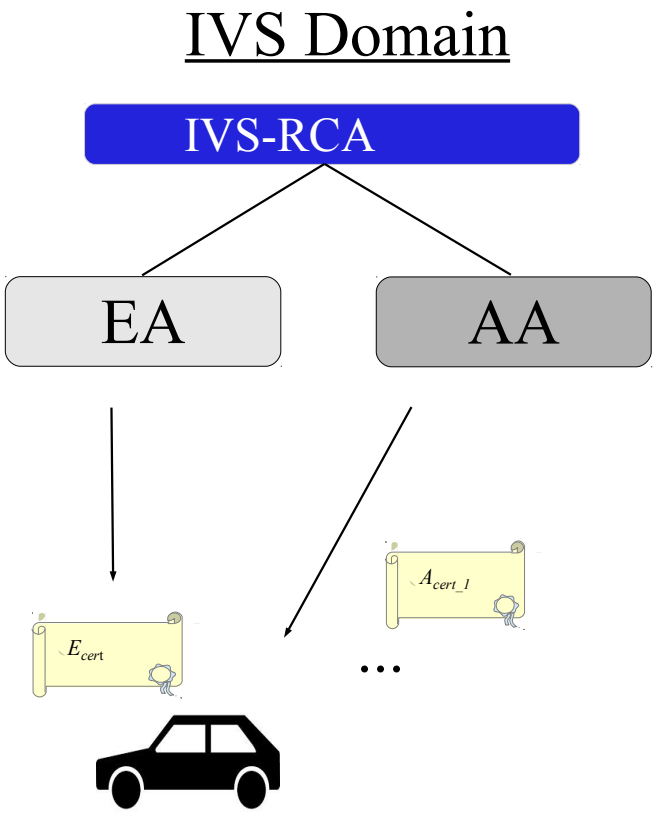
	Europe	US
Standards:	ETSI 102637 1-3	SAE J 2735
	ETSI 102 943	IEEE 1609.2
	ETSI 103 097 (Naming derived from IEE 1609.2)	
	further ETSI standards possible	
Accepted ECC Curves:	NIST P-256r1	NIST P-256r1
	BrainpoolP256r1 (in discussion)	BrainpoolP256r1 (in discussion)
Message Types:	CAM	BSM
	DENM	RSA
		EVA
	"unlimited" number of types possible	limited number of types
Minimal Message Size without Signature and Certificate:	186 bit	275 bit
Minimal Message Size with Signature and Certificate:	~2 Kbit	~2 Kbit

Secure Vehicular Communication - Keys, Certificates, PKI

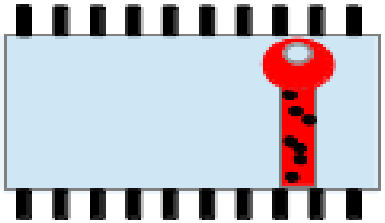


- Identification and Authentication of Vehicles
  - Long term cryptographic key pair (certificate) based on Elliptic Curves (NIST P-256)
    - ETSI Certificate format (not widely used)
  - Issued by Long Term Certification Authority (LTCA)
    [ETSI]: Enrolement CA
- Message Security / Location Privacy
  - Pseudonymous key pairs (certificates) (ECC NIST P-256)
    - ETSI Certificate Format
  - Issued by Pseudonym Certification Authority (PCA)
    [ETSI]: Authorization CA

Secure Vehicular Communication - Key Generation, Key Storage -



- Private keys are generated at random (within the order of the ECC group)
  - Long term -, pseudonymous keys are distinct
  - No key duplicates
- Typically secret keys will be generated and stored within secure elements in the vehicle



Outline

- Secure Vehicle-2-Vehicle Communication (V2V) according to ETSI
  - Communication Model
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  - Shortcomings of the existing ETSI Specifications
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    - Cooperative Intelligent Transport System (C-ITS) Corridor Project Rotterdam-Frankfurt-Vienna
  - Secure V2X Communication
  - Secure ITS Roadside Station (IRS) messages (DENM)
  - Multi Domain PKI Architecture
- Conclusion/Future Work

Shortcomings of the ETSI specifications

- Cryptographic Setting
  - Cryptography ages over time (e.g., due to better computer attack capabilities)
  - Missing mechanism for cryptographic update (crypto agility)
    - Elliptic Curve Domain Parameter
    - Hash Function, Signature Algorithms, …
- Adapations
  - Crypto agility concept is needed

Linkability of CAMs (BSMs)

- Static Information
  - Certificate
  - Length/Width
  - Confidence Level
  - (Geographic position)
- Linkability based on the Pseudonym Certificate
- Linkability based on CAM data
  - Length / Width
  - Confidence Level
  - (Geographic position)

Complete Message			
	Header	Signer_Info	
		Generation_Time	
		its_aid ITS-AID for CAM	
	CAM Information	Basis Container	ITS-Station Type
			Last Geographic Position
		High Frequency Container	Speed
			Driving Direction
			Longitudinal Acceleration
			Curvature
			Vehicle Length
			Vehicle Width
			Steering Angle
			Lane Number
			…
		Low Frequency Container	Vehicle Role
			Lights
			Trajectory
		Special Container	Emergency
			Police
			Fire Service
			Road Works
			Dangerous Goods
			Safety Car
			…
	Signature	ECDSA Signature of this Message	
	Certificate	According Certificate for Signature Verification	

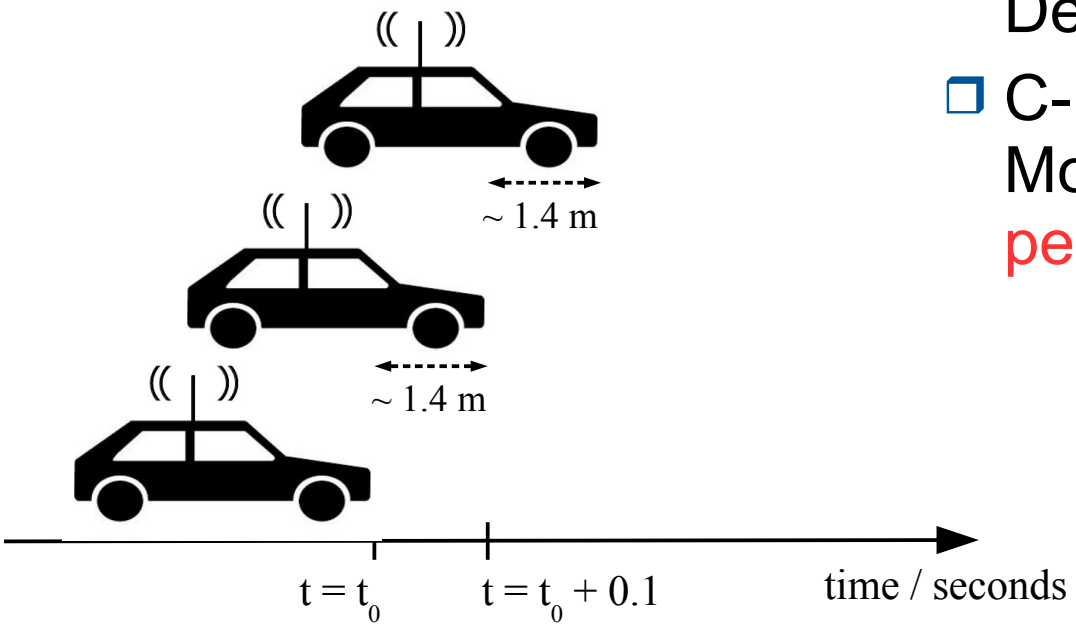
CAM: Static Informations

- Vehicle Length (CAM: in 10 cm intervals)
- Vehicle Width (CAM: in 10 cm intervals)
- High Frequency Container: Confidence Level

	Value Range	Confidence Level Range
Heading	0, . . . , 3601 (12 bit)	1, . . . , 127 (7 bit)
Speed	0, . . . , 16383 (14 bit)	1, . . . , 127 (7 bit)
Acceleration	0000000, . . . 1111111 (7 bit)	0, . . . , 102 (7 bit)
Curvature	-30000, . . . , 30000 (16 bit)	0, . . . , 7 (3 bit)
Yaw Rate	-32766, . . . , 32767 (16 bit)	0, . . . , 9 (4 bit)

Movement of the Geographic Position

Assumptions:
- Speed: 50 km / h
- CAM transmission frequency: 10 Hz



- Secondary vehicular identities: e.g., Bluetooth Device Address (48 bit), ...
- C-ITS Platform EC DG Move: „CAM / DENM: personal data“

Location Privacy
- Attacker Models -

- „Big Brother“ Attacker
  - Monitoring traffic in a specific region
    - Static: e.g., roadside stations
    - Dynamic: class of vehicles (e.g., trucks)
- Local Attacker
  - Monitoring specific vehicle (driver)

Shortcomings of the Pseudonym Concept

Observation Device: e.g., Future Smart Phone

- IEEE 802.12 Interface (5G)
- Storage
- Prozessor
- GPS
- LTE

- Observation Device:
  - Stores „CAM Trace“ (location, time, speed, …)
    ==> **Non-disputable observation**
    Due to the (ECDSA) Signature

Link a “CAM Trace“ to a Vehicle

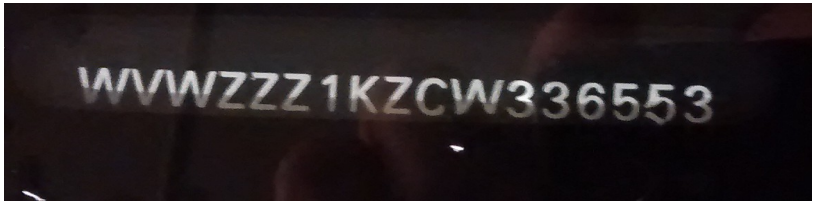
Observation Devive: e.g., Future Smart Phone

- IEEE 802.12 Interface (5G)
- Storage
- Prozessor
- GPS
- LTE
- WLAN/Bluetooth

- If one CAM of the whole “CAM Trace“ can be linked to a vehicle then the whole CAM Trace can be linked
- Linkability
  - Limited Vehicles with V2V Interface
  - Based on Second Level Vehicle Identifier
  - ...

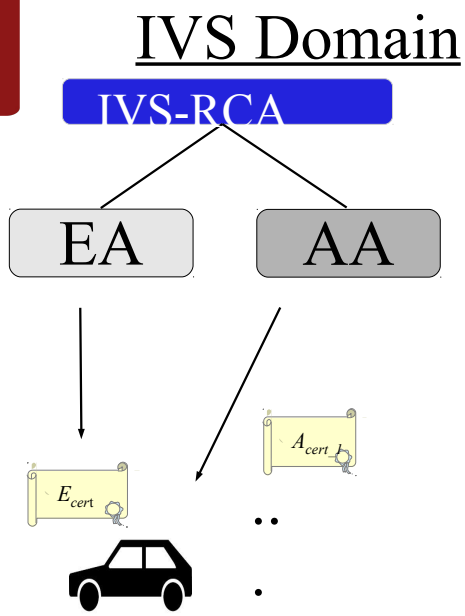
Vehicle Identifier (1)

- First Level Identifier (formal/official)
  - Vehicle Identification Number (VIN)



  - Licence plate

  - Enrolement certificate (long term)



Vehicle Identifier (2)

- Second Level Identifier (arise with wireless vehicle communication interfaces)
  - Vehicular multimedia device:
    - 48 bit static Bluetooth MAC ID (24 bit manufacturer || 24 bit bluetooth device)
    - ``User-friendly-name''
  - WiFi access point:
    - WLAN MAC ID
    - Service Set Identifier (SSID)
  - Active Tyre Pressure Monitoring System (TPMS):
    - RFID-ID
  - Mobile:
    - IMEI

Individual Driver Identification

- Do humans have individual driveability properties ?
- Are driveability properties deducible from send CAM data ?
- Open Research Issues
  - Driver identification based on a small driver set (1 : N) ?
  - Driveability Features ?
  - Matching Algorithm ?
  - …

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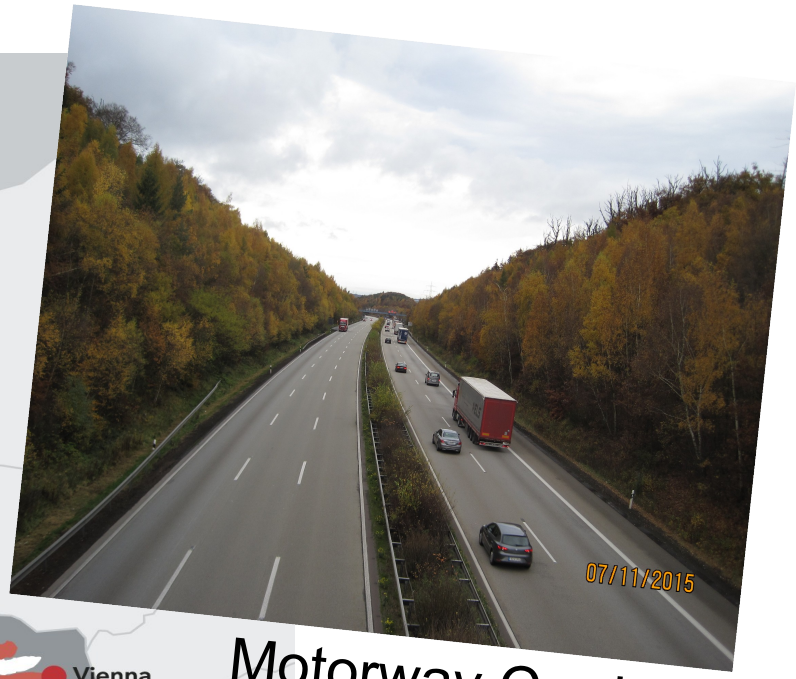
  - Secure V2X Communication
  - Secure **I**TS **R**oadside **S**tation (IRS) messages (DENM)
  - Multi Domain PKI Architecture
- Conclusion/Future Work

C-ITS Corridor Project
- Secure Vehicle-2-Infrastructure Communication -

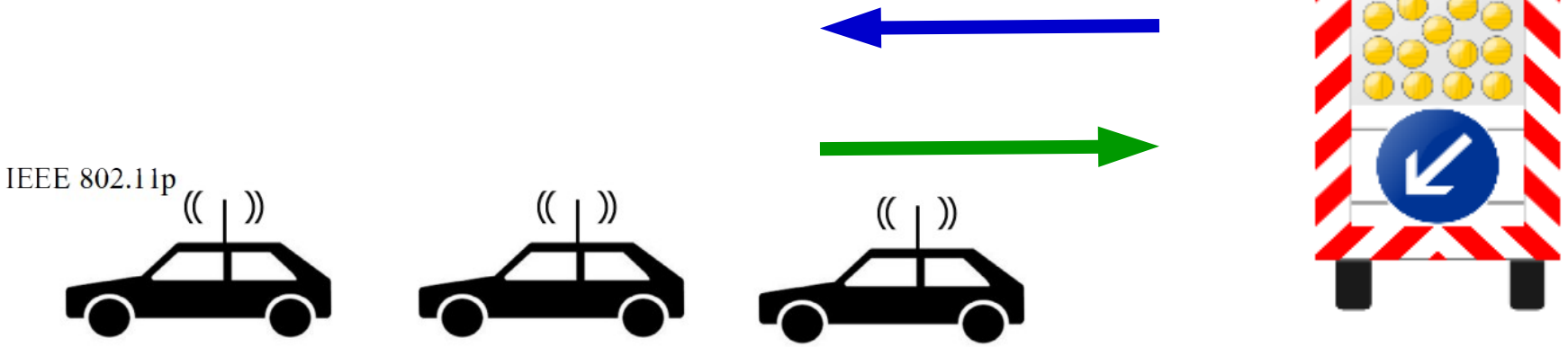


Motorway Corridor

Attention: Short Term Site

C-ITS Corridor Project
- Secure V2X Communication -

- Cooperative ITS Corridor Project Rotterdam-Frankfurt-Vienna (NL-G-AU)
  - Joint Project of:
    - Austria: Federal Ministry of Transport, Innovation and Technology
    - Netherlands: Ministry of Infrastructure and the Environment
    - Germany: Federal Ministry of Transport and Digital Infrastructure
  - Digitalization of Road Works Warning
  - Use Cases (Broadcast Communication)
    - Send DENM messages to the crossing vehicles
    - Receive CAM / DENM messages of crossing vehicles



Further V2X Pilot Projects in Europe

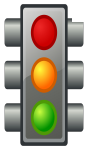
- France: Scoop@F

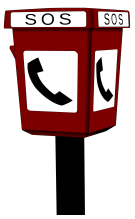
SCOOP@F

- Danmark, Finland, Norway, Sweden: NordicWay

Nordic WAY

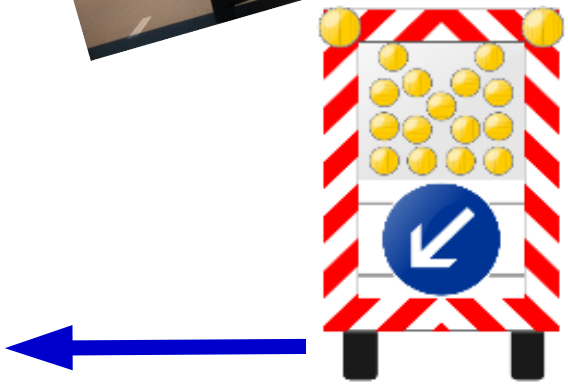
Secure ITS Roadside Stations (1)

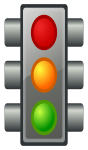




- Integration of an electronic gateway
- Threats to incoming/outgoing messages
  - Availability
    - Jamming, ...
  - Authenticity
    - Masquerading, …
  - Integrity
    - Injection of forged messages, ...
  - Confidentiality
    - Extraction of sensitive information (e.g., cryptographic keys)
- Threats concerning the integrity of the electronic gateway itself
  - Malicious software
  - Extraction of cryptographic keys, ...

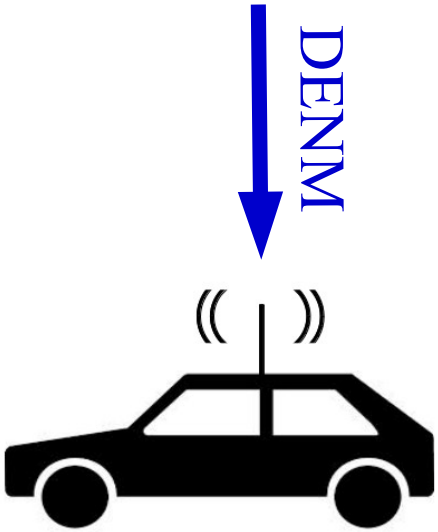
Secure ITS Roadside Stations (2)





- Location Privacy
  - ITS roadside stations are not controlled by a user
  - No Privacy Requirements ==> no pseudonym certificates are needed
  - Instead: Credential Certificate (short validity period [~ days] to avoid CRLs)
- Security Requirements
  - DENM-Security: Message integrity and authentication
  - „Protection of the gateways“ → Protection Profile (PP)
    - Identification and authentication (roles)
    - Access Control, …
    - Short time authorization (credential certificate)
    - ...

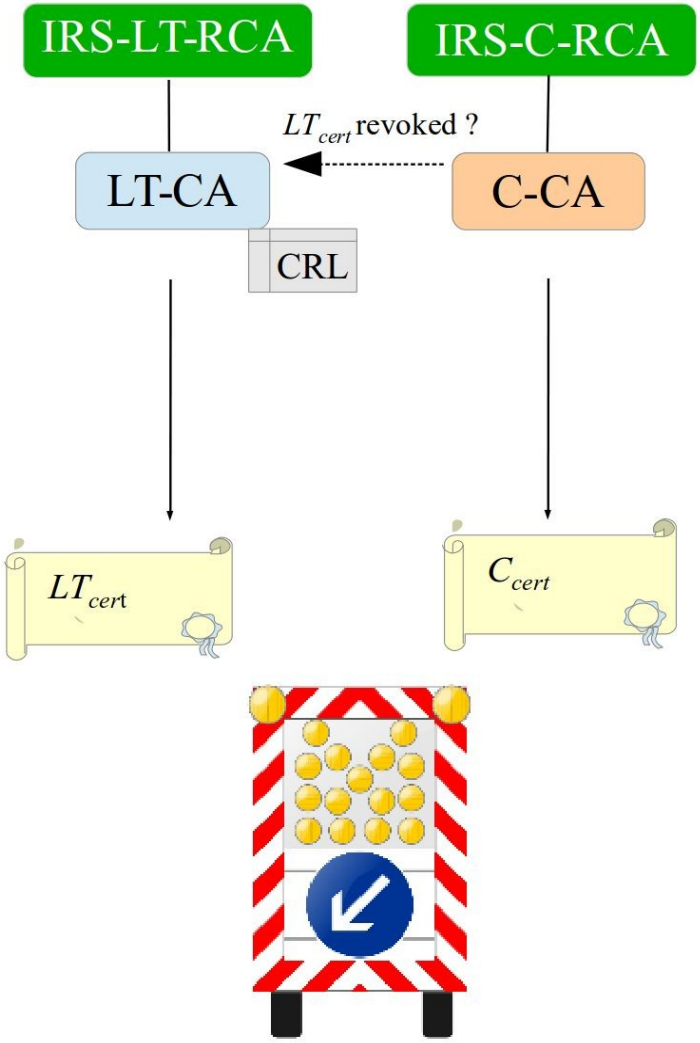
C-ITS Use Case: Sending DENM messages



- Short Term Credential Certificate
- Usage
  - Authorization of ITS roadside station
  - Message integrity and authentication of DENM messages
- ETSI Certificate format

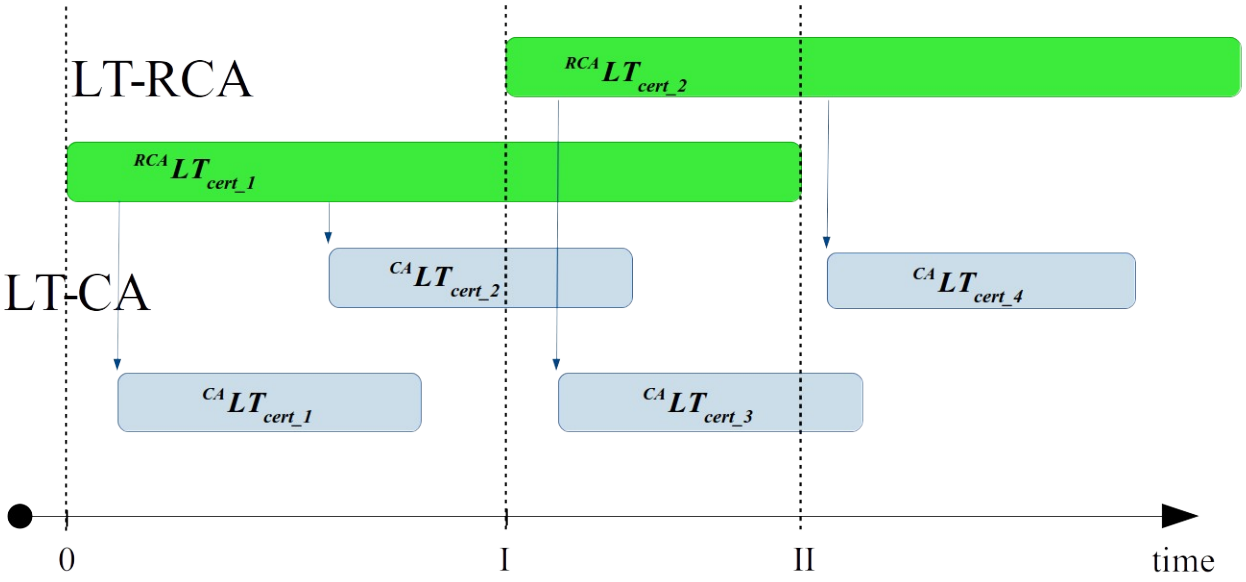
Complete Message	Header	Signer_Info	
		Generation_Time	
		its_aid ITS-AID for DENM	
	DENM Information	Management Container	Last Vehicle Position (GPS)
			Event Identifier
			Time of Detection
			Time of Message Transmission
			Event Position (GPS)
			Validity Period
			Station Type (Motor Cycle, Vehicle, Truck)
			Message Update / Removal
			Relevant Local Message Area (geographic)
			Traffic Direction (forward, backwards, both)
			Transmission Interval
			….
		Situation Container	Information Quality (low -high, tbd)
			Event Type (Number)
			Linked Events
			Event Route (geographical)
		Location Container	Event Path
			Event Speed
			Event Direction
			Road Type
		A la carte Container	Road Works (Speed Limit, Lane Blockage….)
			….
	Signature	ECDSA Signature of this message	
	Certificate	According Certificate for Signature Verification	

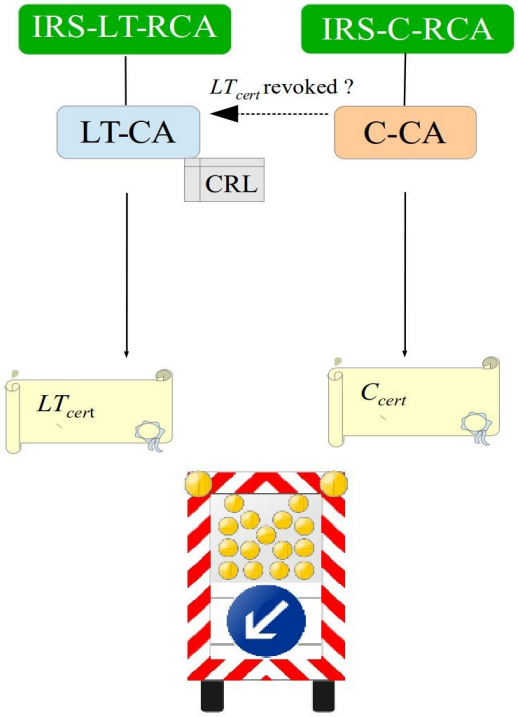
IRS PKI Domain (Infrastructure)



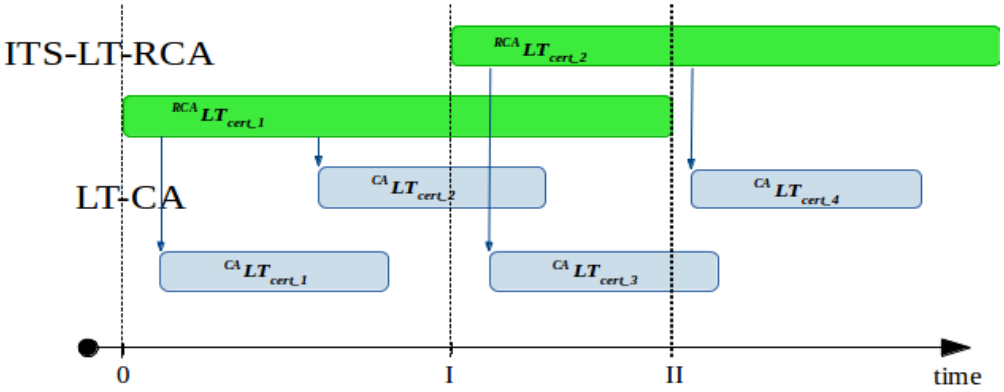
- Identification and Authentication of ITS Roadside station
  - Long term key pair (certificate) based on Elliptic Curves
    - BrainpoolP256r1 curve
    - X.509 V3 certificate format
  - Issued by Long Term Certification Authority (LT-CA)
    [ETSI: Enrolement CA]
- **Authorization** and Message Authentication
  - Short term key pair (credential certificate) based on Elliptic Curves
    - BrainpoolP256r1 curve
    - ETSI Certificate format
  - Issued by Credential Certification Authority (C-CA)
    [ETSI: Authorization CA]

Certificate Shell Model



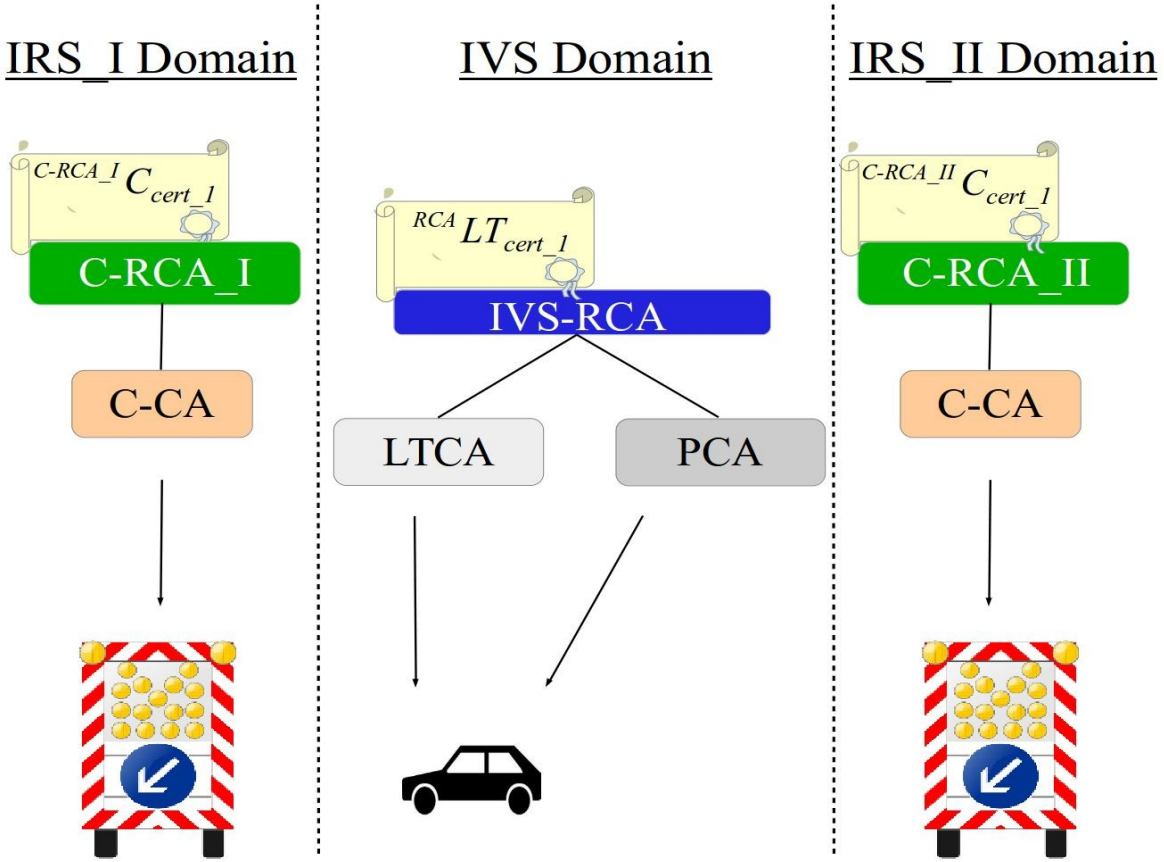


Crypto Agility



- Adaptation of Cryptographic Parameters
  - Key Length → ECC Domain Parameter
  - Crypto Algorithms
  - ...
- Performed by a IRS-LT-RCA **link certificate** (signed with the previous root key)

Multi Domain PKI Architecture



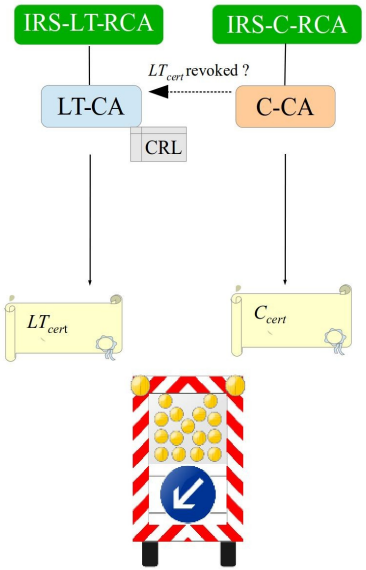
- Trust Relation
  - Local Trust Lists (LTL)
- Benefits
  - Flexibility (Requirements)
  - RSU under control of infrastructure authority
- Drawback
  - Managing of LTLs within each PKI

Outline

- Secure Vehicle-2-Vehicle Communication (V2V) according to ETSI
  - Communication Model
  - Security - and Privacy Requirements
  - Shortcomings of the existing ETSI Specifications
    - Security, Privacy
- Secure Vehicle-2-Infrastructure Communication (V2X)
  - V2X Pilot Projects in Europe
    - Cooperative Intelligent Transport System (C-ITS) Corridor Project Rotterdam-Frankfurt-Vienna
  - Secure V2X Communication
  - Secure **I**TS **R**oadside **S**tation (IRS) messages (DENM)
  - Multi Domain PKI Architecture
- Conclusion/Future Work

Conclusion V2X

- Next steps C-ITS Corridor Project (2016)
  - Setup PKI for ITS roadside stations (RWWG)
  - Equip RWW gateways with keys/certificates
  - Test secure Vehicle-2-X communication with real vehicles within the C-ITS corridor
  - ...
- Secure V2X Communication
  - Security Concept for ITS Roadside stations and V2X is sound
- C-ITS Platform (EC DG MOVE): Common C-ITS PKI Policy in preparation for Europe



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Kontact

Thanks for listening

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