



TROOPERS 2026

Dieter Schuster & Nikolai Puch

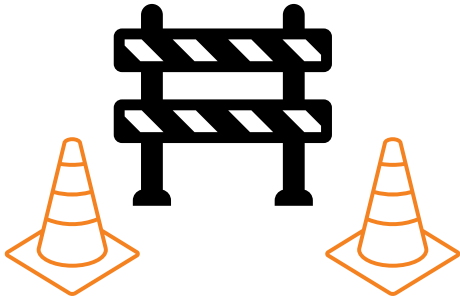
V2X Wardriving - They Drive, We Listen

V2N, V2G, V2I, V2X, ...
V 2 what?

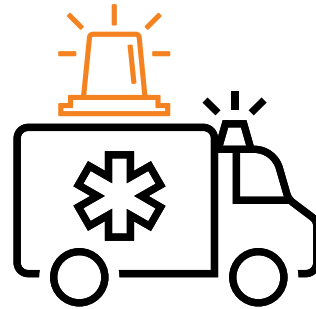
V2X

Use Cases

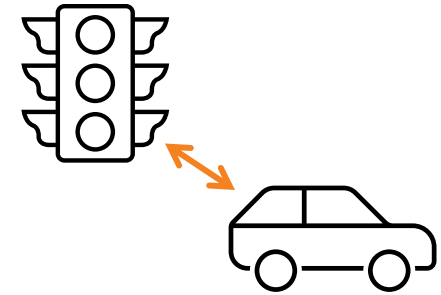
Increase road safety and traffic flow via



Warnings for hazards



Alerts for emergency vehicles



Information exchange
between vehicles and
infrastructure

V2X

Works in Real Live



<https://media.asfinag.at/media/ctbnbtj/verkehrsmeldungen-im-fahrzeug.jpg>



V2X

Acronym Soup

C-ITS, ITS-G5, WAVE
DSRC, C-V2X, 5G, 3GPP, IEEE, RSU
OBU, CAM, DENM, IVI, MAPEM
SPATEM, EA, AA, TLM, C2C-C

So first a short introduction

Vehicle-to-Everything (V2X)

Types

Vehicle-to-grid (V2G) incl. 2Home

e.g. charging planning



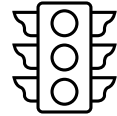
Vehicle-to-network (V2N) incl. 2Cloud

e.g. telematics, OTA



Vehicle-to-infrastructure (V2I)

e.g. traffic lights, road works



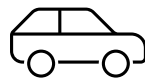
Vehicle-to-pedestrian (V2P)

e.g. vulnerable road user



Vehicle-to-vehicle (V2V)

e.g. end of traffic jam, heavy rain



Vehicle-to-Everything (V2X)

Types

Vehicle-to-grid (V2G) inkl. 2Home

e.g. charging planning



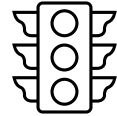
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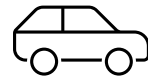
Vehicle-to-pedestrian (V2P)

e.g. vulnerable road user



Vehicle-to-vehicle (V2V)

e.g. end of traffic jam, heavy rain



V2X

C-ITS vs Cellular V2X

C-ITS

- **Cooperative Intelligent Transport System (C-ITS)**
- **Intelligent Transport System Access Layer in 5 GHz (ITS-G5)**
 - IEEE 802.11p WiFi
- Decentralized, peer2peer
- < 1s latency
- EU, US

C-V2X

- **Cellular-V2X (5G, 3GPP)**
- Cellular Networks
 - LTE / 5G
- Centralized, network dependent
- 20 s – 2 min latency
- EU, US, China

V2X

C-ITS vs Cellular V2X

C-ITS

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C-V2X

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C-ITS Architecture

Players



C-ITS



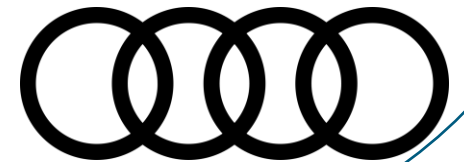
CUPRA



Nutzfahrzeuge



C-V2X



Quelle: [ADAC Hersteller-Umfrage 2024](#)

C-ITS Architecture

Roles

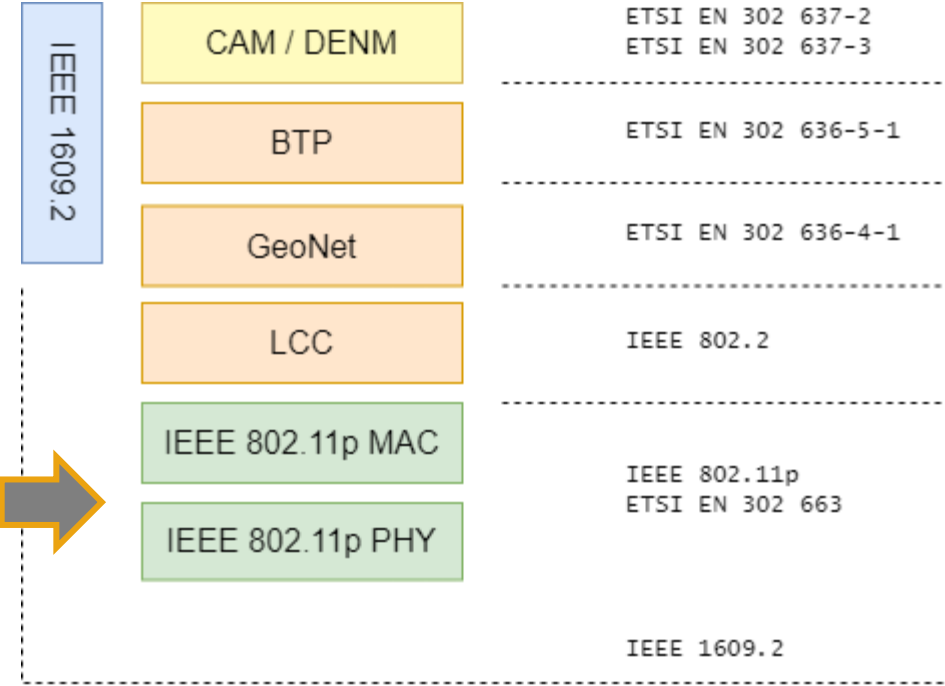
Road Side Unit (RSU)



On-Board Unit (OBU)



C-ITS Architecture Stack

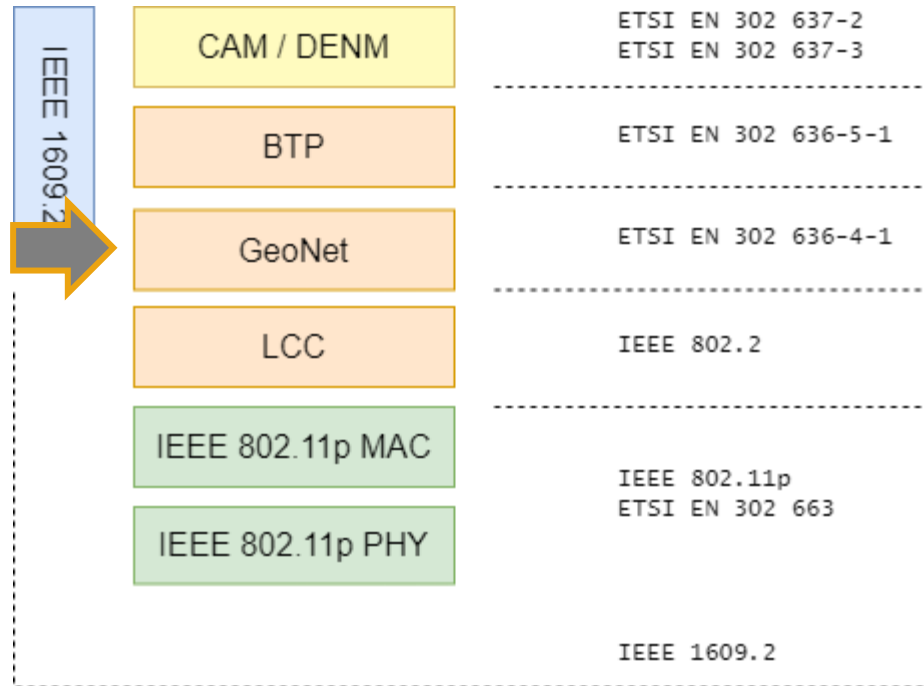


IEEE 802.11p

- 5.9 GHz
- 10 MHz Channels

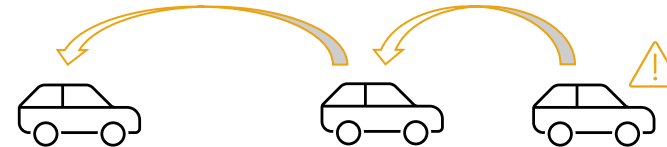
CH 172	CH 174	CH 176	CH 178	CH 180	CH 182	CH 184
5860	5870	5880	5890	5900	5910	5920
				ITS (CCH)		
Non-Safety		Safety-Critical			Future Use	

C-ITS Architecture Stack



GeoNetworking

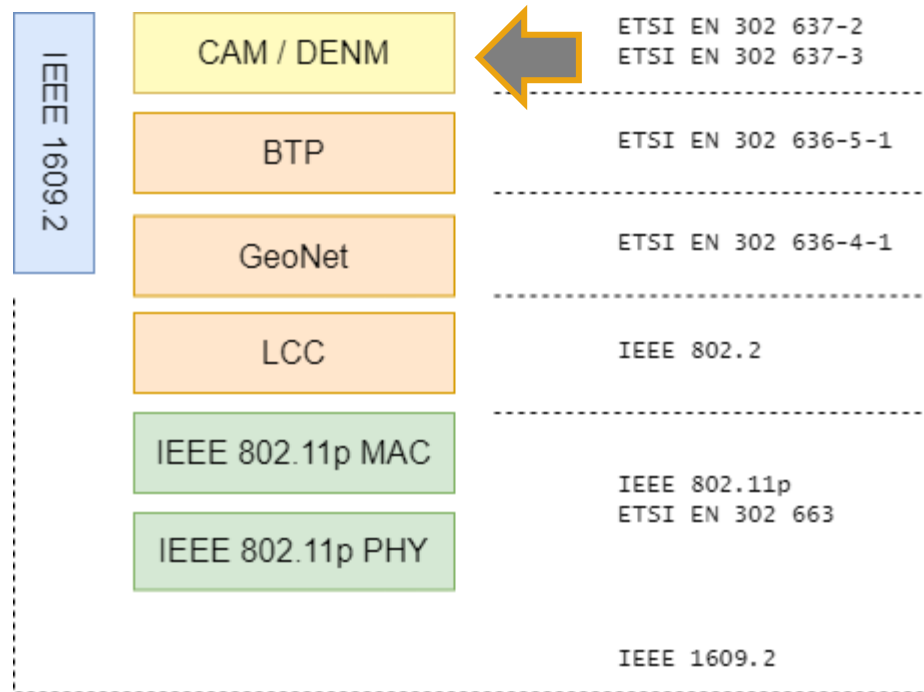
- Direct peer2peer communication



BTP

- Establishing and managing connections

C-ITS Architecture Stack



Message types (ASN.1 UPER encoded):

Cooperative Awareness Message (CAM)

TS 103 900

Decentralized Environmental Notification Message (DENM)

TS 103 831

Map Extended Message (MAPEM)

TS 103 301

Signal Phase and Timing Extended Message (SPATEM)

TS 103 301

Collective Perception Message (CPM)

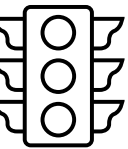
TS 103 324

In-Vehicle Information Message (IVIM)

TS 103 301

Vulnerable-Road-Users Awareness Message (VAM)

TS 103 300-3



C-ITS Message Types

Cooperative Awareness Message (CAM) - ETSI TS 102 637-2



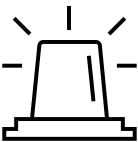
CAM

- Contains basic information
- Cyclic information

ITS PDU Header	Basic Container	HF Container	LF Container	Special vehicle Container
meta-information (version, stationId)	stationType, referencePosition, altitude	Heading, speed, vehicle dimensions, ...	exteriorLights, pathHistory	Use case specific

C-ITS Message Types

Decentralized Environmental Notification Message (DENM) - ETSI EN 302 637-3



DENM

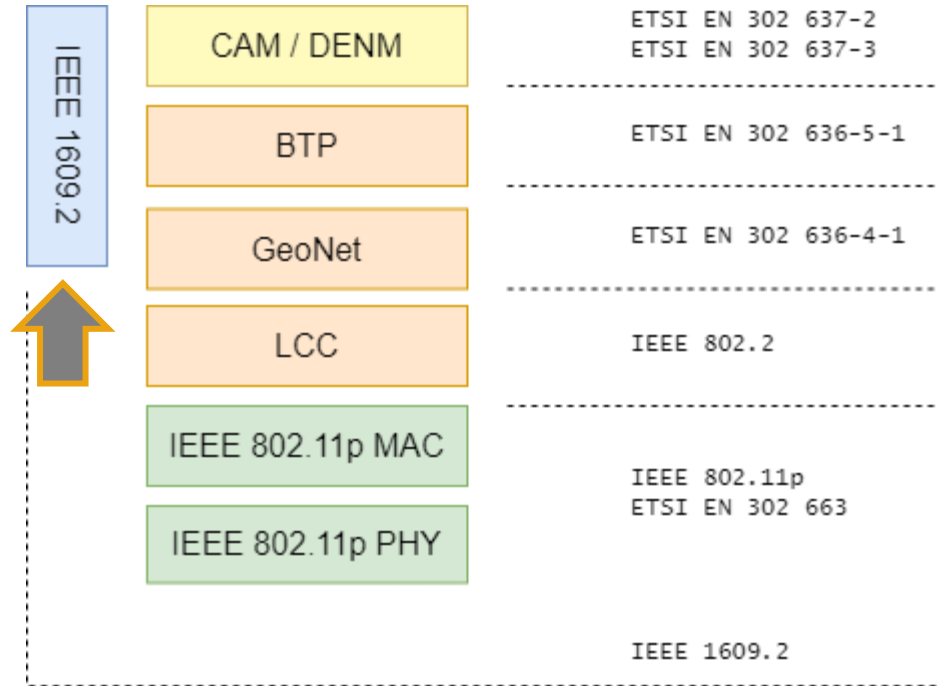
- Event-driven
- Event specific information
 - Accidents, roadwork, hazardous conditions
- Triggering Conditions are condition-specific [1]

ITS PDU Header	Management Container	Situation Container	Location Container	À la carte Container
meta-information (version, stationId)	detection time, event position.	event type, linked cause, ...	event speed, road type	lane position, external temperature

[1] <https://www.car-2-car.org/documents/basic-system-profile>

C-ITS Architecture

Security Stack

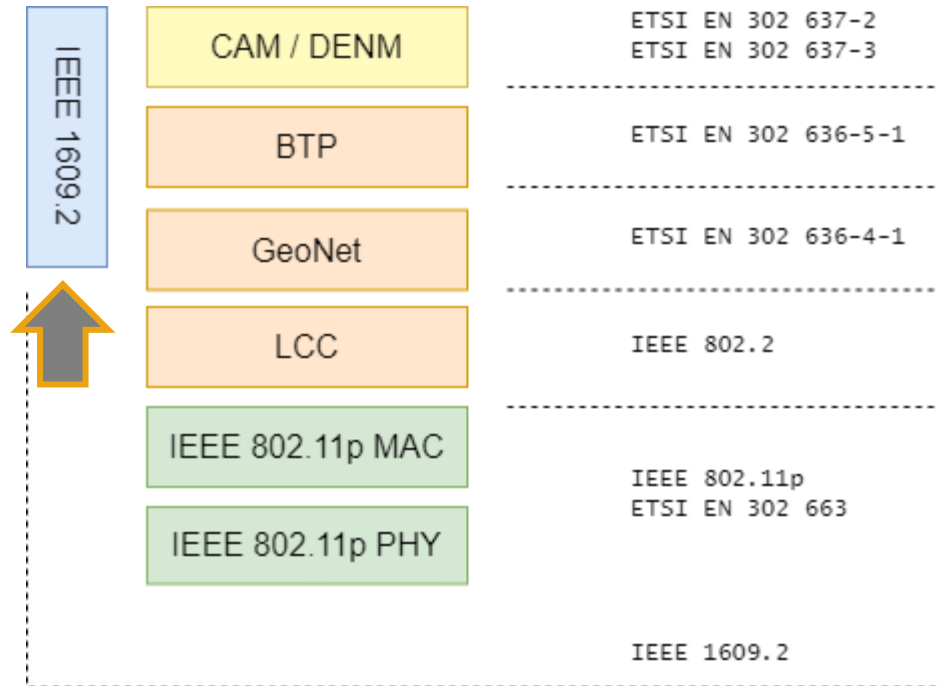


Security in the C-ITS Stack

- Builds upon IEEE 1609.2

C-ITS Architecture

Security Stack



IEEE 1609.2 (ASN.1 OER encoded):

encapsulates payload in Security services Protocol Data Units (SPDUs)

- Unsecured SPDUs
- Signed SPDUs
- Encrypted SPDUs
- Signed certificate request
- Signed X.509 certificate request
- SPDU with multiple layers of cryptographic protection

C-ITS Security & Privacy Considerations

Anonymisation

Standards recommend privacy enhancing measures

However, realisation is vendor specific

ID Rotation

- Certificate: 7d valid
- MAC, StationID, and Certificate: after vehicle slept

Disable Car2X in the Infotainment



C-ITS PKI Hirachy

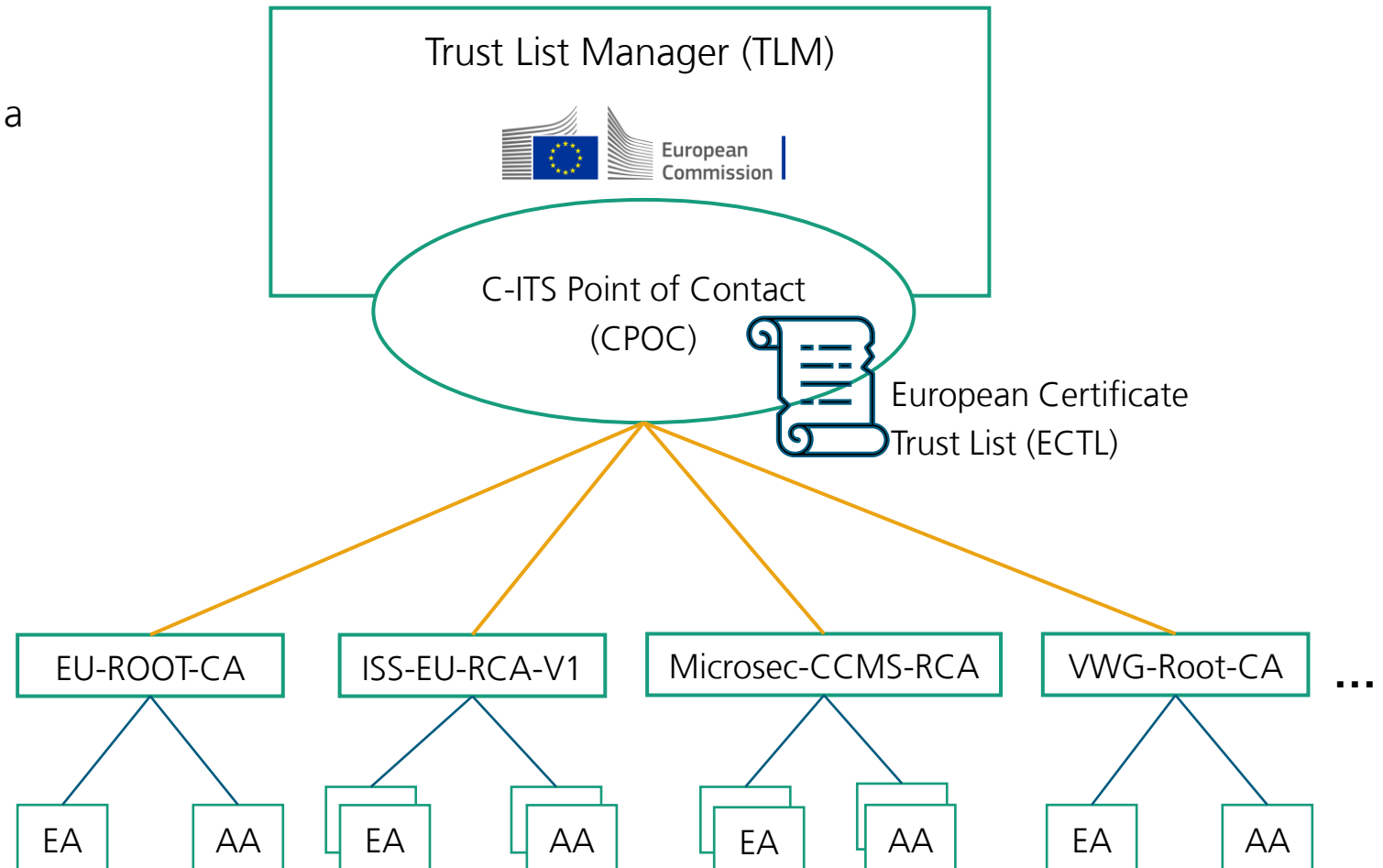
Enrolment Authority (EA)

Issues long-term enrolment certificates binding a station's identity to its key material

Authorization Authority (AA)

Issues short-term authorization tickets

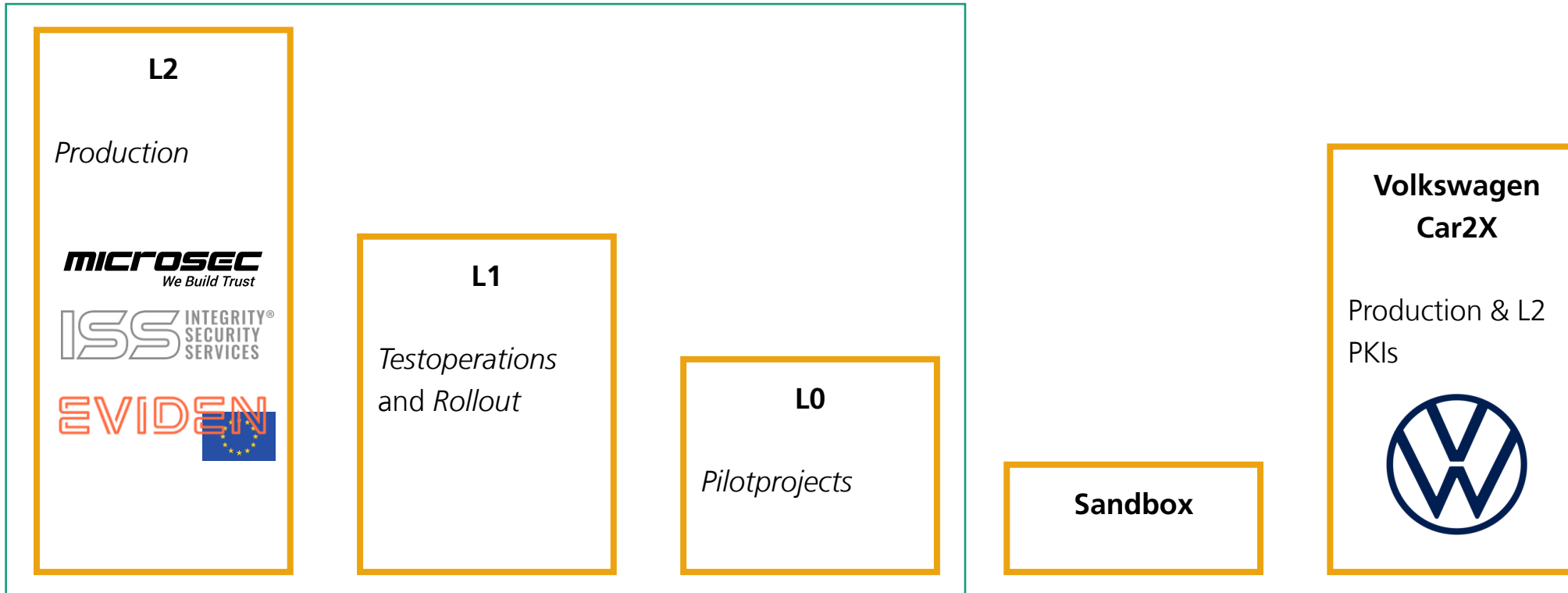
→ Used to sign messages



C-ITS PKI

PKI

EU PKI Landscape



<https://cpoc.jrc.ec.europa.eu/ECTL.html>

V2X Wardriving

Our Roadtrip into C-ITS

Hardware

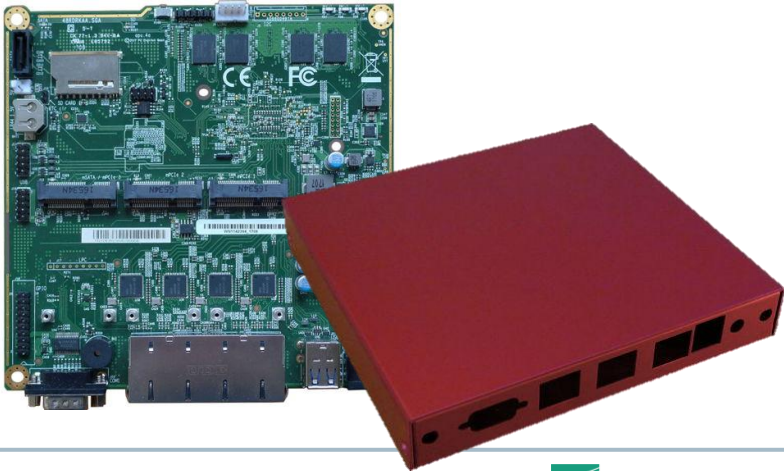
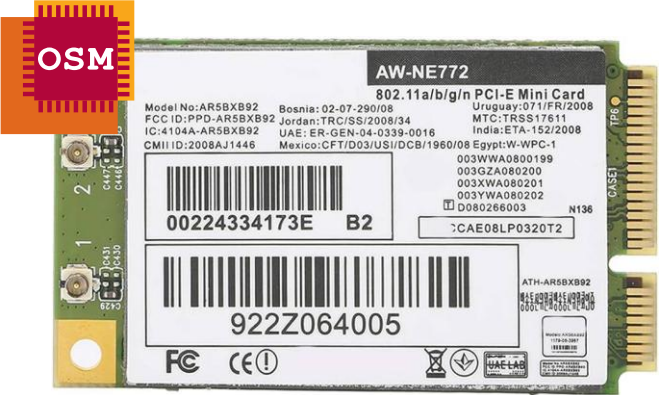
How we started

SDR



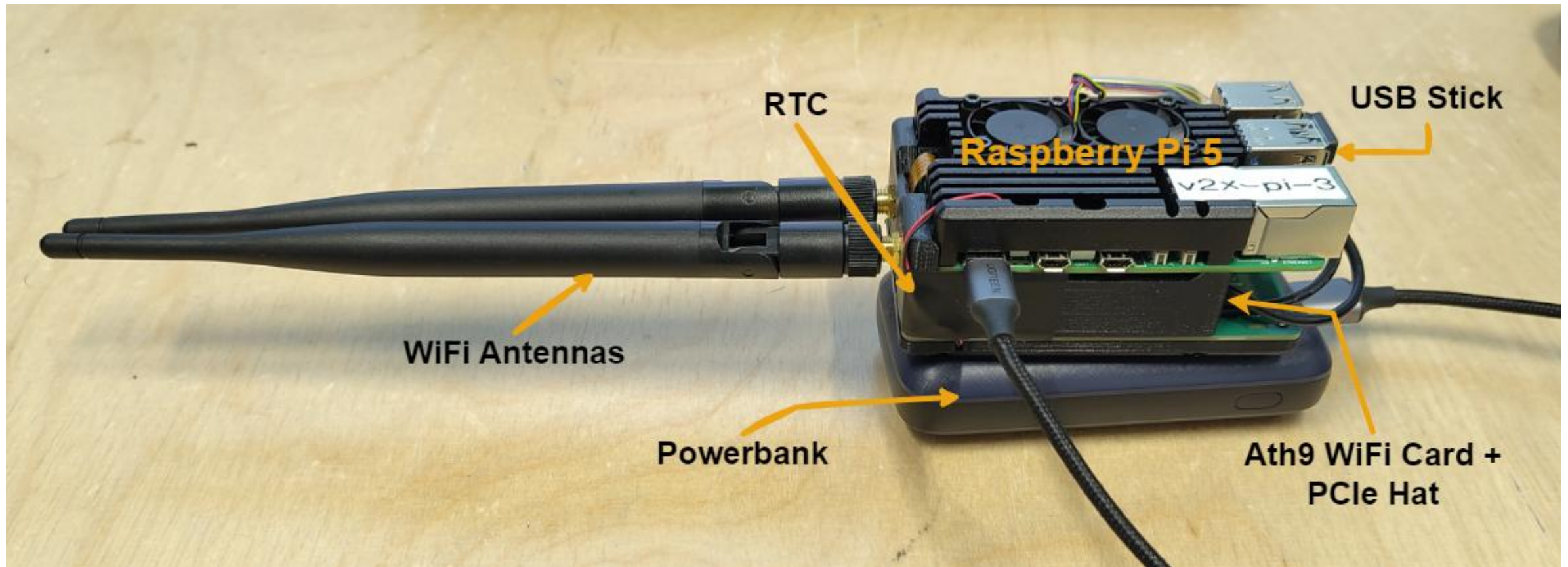
gr-ieee802-11

APU + WiFi Card



Hardware Platform

Our Raspi Setup:



Hardware

WiFi Cards

Building on previous work: ath9k kernel module patch from HPI Potsdam [1]

- Add channels to driver
- Patch wireless-regdb
- Put interface in 802.11p (5.9 GHz) band with OCB

Supported Atheros Cards:

Atheros AR9220 [3]

Atheros AR9280 [2], [3] us

Atheros AR9382 [2], [3]

Atheros AR9462 [1], [2]

Atheros AR9580 [1]

Atheros AR9582 us



[1] GitLab Potsdam, <https://gitlab.com/hpi-potsdam/osm/g5-on-linux/11p-on-linux>

[2] Pastrana, https://github.com/jfpastrana/802.11p/blob/master/Documentation/Wireless_cards.pdf

[3] OpenC2X, <https://www.ccs-labs.org/software/openc2x/>

Software

Capturing C-ITS

First tries with our lab car (VW ID.4)

- No traffic in the lab -> No GPS fix for some time
- Driving around the parking lot yields lots of CAMs
- Provoke DENM (Stationary Vehicle)
 - Warning lights on
 - Open driver's door
- Other vehicles not showing warnings
 - Warnings only displayed when relevant
 - Conditions are OEM specific



Software

Inspecting C-ITS: CAM



Wireshark

```
> Ethernet II, Src: 4e:e4:f9:dc:29:07 (4e:e4:f9:dc:29:07), Dst: Broadcast (ff:ff:ff:ff:ff:ff)
  GeoNetworking
    > Basic Header
    > Secured Packet
    > Common Header
    > Topologically-Scoped Broadcast Packet
  BTP-B
    Destination Port: 2001
    Destination Port info: 0x0000
  Intelligent Transport Systems
    > ItsPduHeader
    > CamPayload
      generationDeltaTime: 49624
      > camParameters
        > basicContainer
        > highFrequencyContainer: basicVehicleContainerHighFrequency (0)
        > lowFrequencyContainer: basicVehicleContainerLowFrequency (0)
```

Software Inspecting C-ITS

Wireshark

IEEE 1609.2 Secured Packet

```

  ▾ Secured Packet
    ▾ Ieee1609Dot2Data
      protocolVersion: 3
      ▾ content: signedData (1)
        ▾ signedData
          hashId: sha256 (0)
          > tbsData
            ▾ signer: certificate (1)
              ▾ certificate: 1 item
                ▾ Item 0
                  ▾ Certificate
                    version: 3
                    type: explicit (0)
                    ▾ issuer: sha256AndDigest (0)
                      sha256AndDigest: 0498fbf3b8b8c249
                    ▾ toBeSigned
                      > id: none (3)
                      cracaId: 000000
                      crlSeries: 0
                      ▾ validityPeriod
                        start: 2026-01-13 03:00:00 (695358005)
                        ▾ duration: hours (4)
                          hours: 168
                      ▾ appPermissions: 2 items
                        ▾ Item 0
                          ▾ PsidSsp
                            psid: psid-ca-basic-services (36)
                            ▾ ssp: bitmapSsp (1)
                              bitmapSsp: 010000
                        ▾ Item 1
                          ▾ PsidSsp
                            psid: psid-den-basic-services (37)
                            ▾ ssp: bitmapSsp (1)
                              bitmapSsp: 01901a25
                      > verifyKeyIndicator: verificationKey (0)
                      > signature: ecdsaNistP256Signature (0)
            > signature: ecdsaNistP256Signature (0)

```



VWG-AA_L2

CAM

DENM

trafficCondition

adverseWeatherCondition-Adhesion

adverseWeatherCondition-Visibility

adverseWeatherCondition-Precipitation

dangerousEndOfQueue

stationaryVehicle

collisionRisk

dangerousSituation

Software Inspecting C-ITS

Wireshark

Cam Payload

```

  CamPayload
    generationDeltaTime: 49624
    camParameters
      basicContainer
        stationType: passengerCar (5)
        referencePosition
          latitude: 48°16'39.387"N (482776074)
          longitude: 11°38'4.579"E (116346053)
          positionConfidenceEllipse
          altitude
        highFrequencyContainer: basicVehicleContainerHighFrequency (0)
        basicVehicleContainerHighFrequency
          heading
          speed
            speedValue: 27.16m/s = 97.8km/h (2716)
            speedConfidence: 0.21m/s (21)
          driveDirection: forward (0)
          vehicleLength
          vehicleWidth: 1.8m (18)
          longitudinalAcceleration
          curvature
            curvatureCalculationMode: yawRateUsed (0)
          yawRate
          accelerationControl: 80 [bit length 7, 1 LSB pad bits, 1000 000. decimal value 64]
          steeringWheelAngle
          lateralAcceleration
        lowFrequencyContainer: basicVehicleContainerLowFrequency (0)
        basicVehicleContainerLowFrequency
          vehicleRole: default (0)
          exteriorLights: 08 [bit length 8, 0000 1000 decimal value 8]
            0... .... = lowBeamHeadlightsOn: False
            .0.. .... = highBeamHeadlightsOn: False
            ..0. .... = leftTurnSignalOn: False
            ...0 .... = rightTurnSignalOn: False
            .... 1... = daytimeRunningLightsOn: True
            .... .0.. = reverseLightOn: False
            .... ..0. = fogLightOn: False
            .... ...0 = parkingLightsOn: False
          pathHistory: 10 items

```



C-ITS Tooling

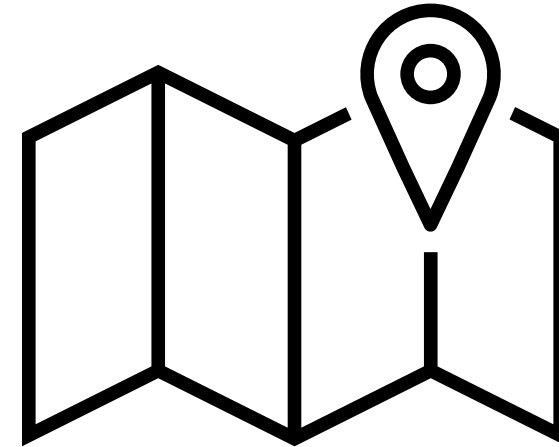
C-ITS Map Monitor

Problem

- Some values are easy to analyse in Wireshark
 - Speed
 - Length
 - Bitfields
- Coordinates, Headings, etc. are rather unintuitive (for us)

Solution

- Visualisation on a map to get an overview
- Enrich visualisation with custom information
- Realtime overview when wardriving

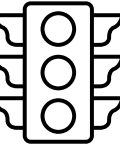




C-ITS Map CAM



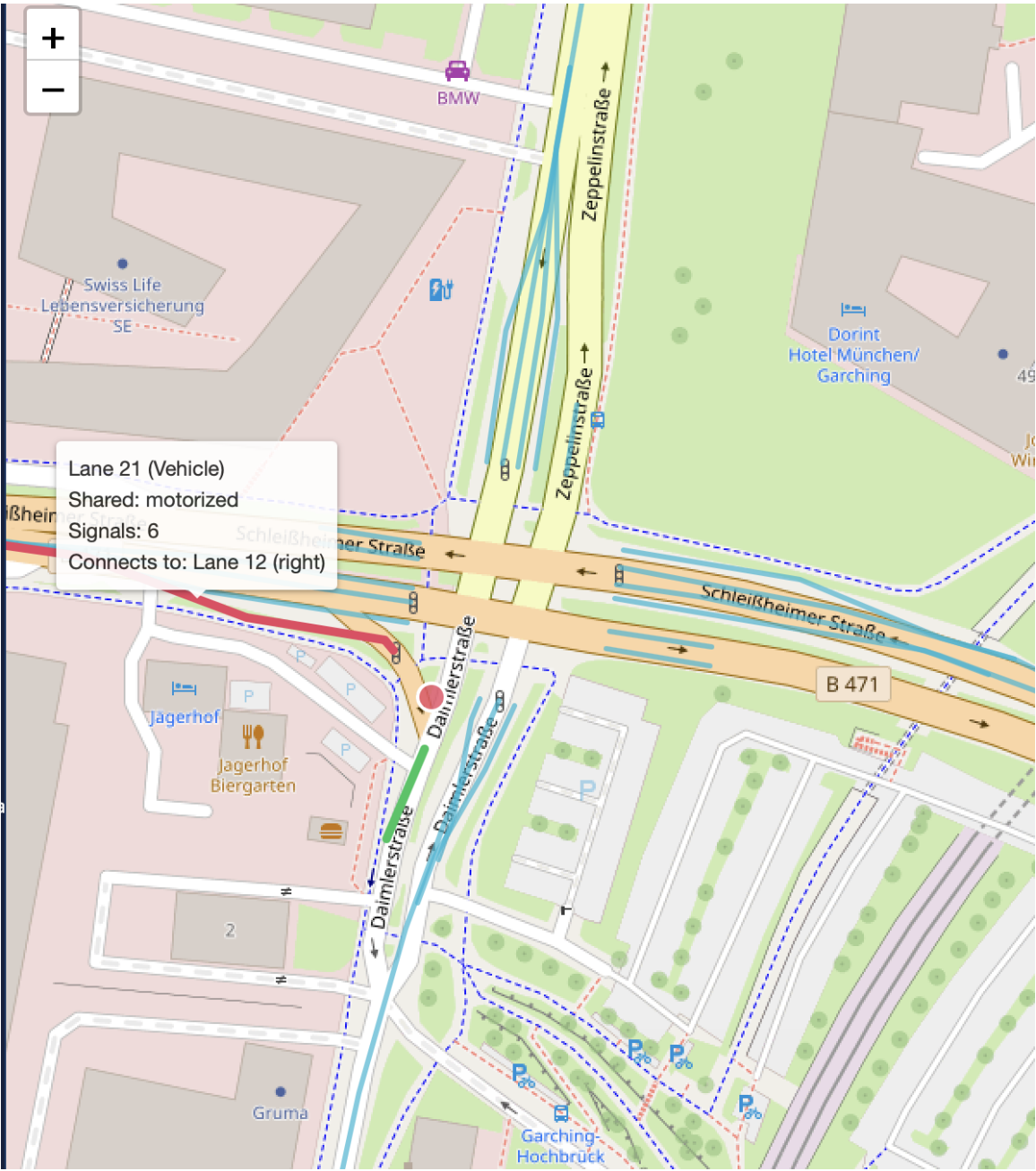
C-ITS Map MAPEM



- ✓ Intelligent Transport Systems
 - > ItsPduHeader
 - ✓ MapData
 - msgIssueRevision: 0
 - ✓ intersections: 1 item
 - ✓ Item 0
 - ✓ IntersectionGeometry
 - name: Garching_2014932_V03_MAP
 - > id
 - revision: 1
 - > refPoint
 - laneWidth: 325
 - > laneSet: 21 items
- ✓ laneSet: 21 items
 - ✓ Item 0
 - ✓ GenericLane
 - laneID: 1
 - ingressApproach: 1
 - ✓ laneAttributes
 - > directionalUse: 80 [bit length 2, 6 LSB pad bits, 10.. decimal value 2]
 - > sharedWith: 1000 [bit length 10, 6 LSB pad bits, 0001 0000 00.. decimal value 64]
 - > laneType: vehicle (0)
 - ✓ nodeList: nodes (0)
 - ✓ nodes: 6 items
 - ✓ Item 0
 - ✓ NodeXY
 - ✓ delta: node-XY4 (3)
 - ✓ node-XY4
 - x: -439
 - y: 2511
 - > Item 1
 - > Item 2
 - > Item 3
 - > Item 4
 - > Item 5
 - ✓ connectsTo: 1 item
 - ✓ Item 0
 - ✓ Connection
 - ✓ connectingLane
 - lane: 16
 - > maneuver: 4000 [bit length 12, 4 LSB pad bits, 0100 0000 0000 decimal value 1024]
 - signalGroup: 1
 - connectionID: 1

C-ITS Map

MAPEM

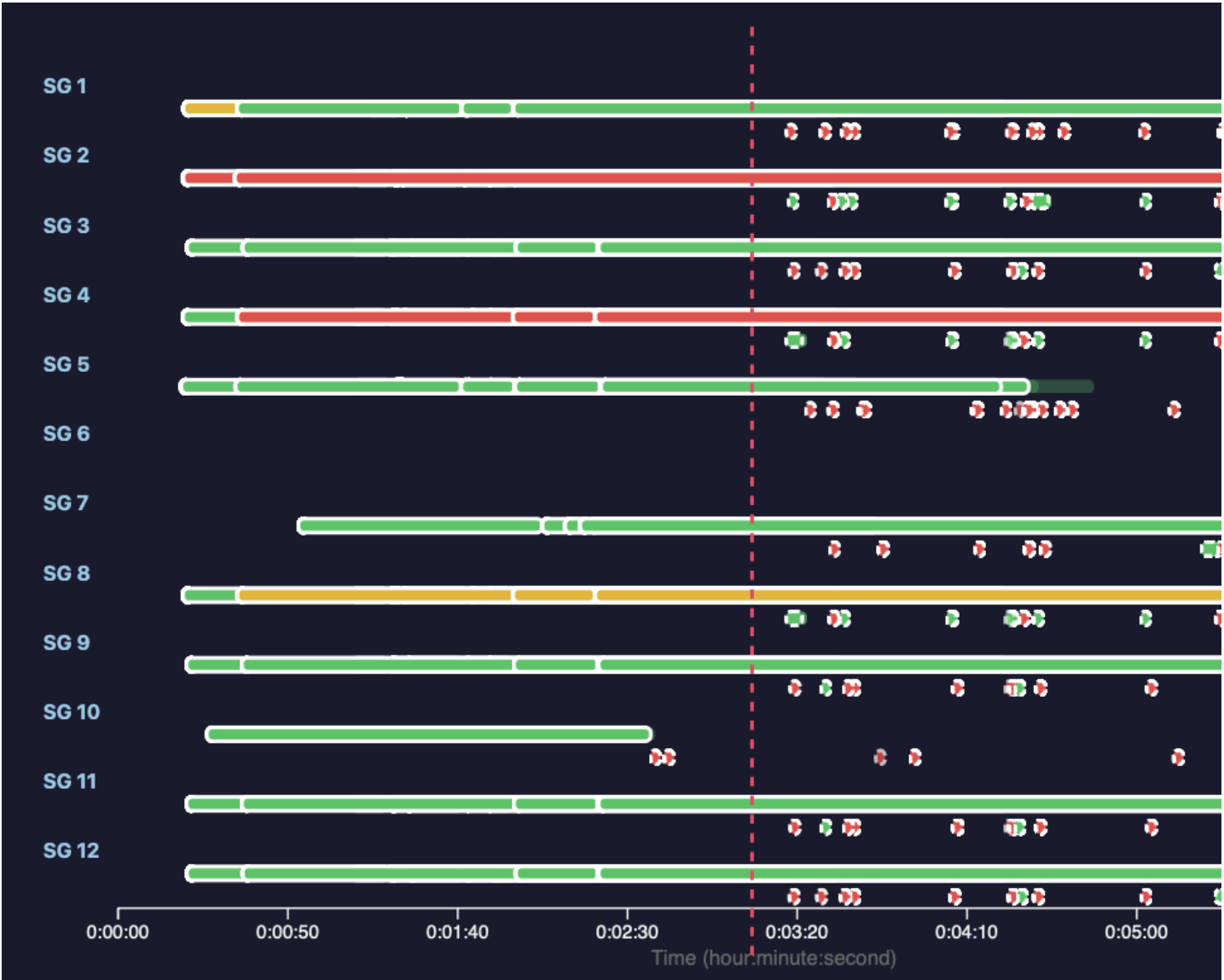


C-ITS Map

SPATEM

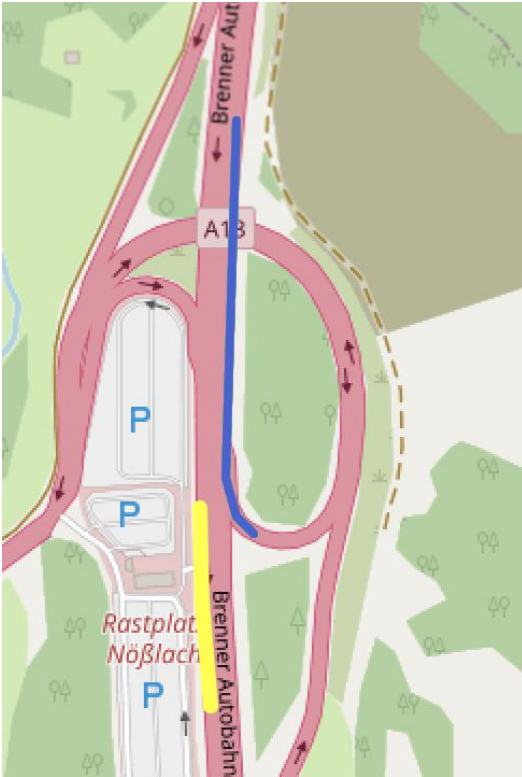
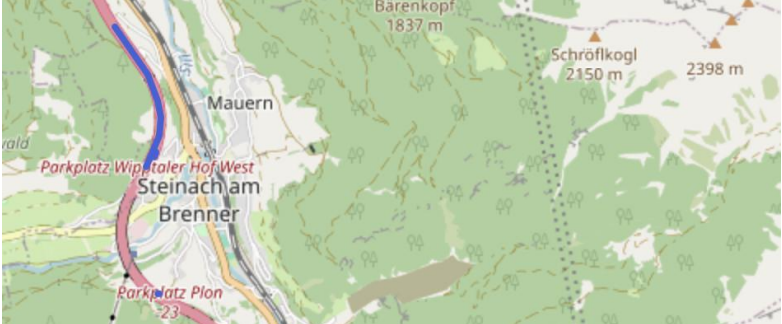
- ✓ SPAT
 - name: 2.2.0
 - ✓ intersections: 1 item
 - ✓ Item 0
 - ✓ IntersectionState
 - name: Garching_2014932_V03_MAP
 - > id
 - revision: 1
 - > status: 0000 [bit length 16, 0000 0000 0000
 - moy: 150d 09:14 (216554)
 - timeStamp: 52.776 (52776)
 - > states: 12 items
- ✓ states: 12 items
 - ✓ Item 0
 - ✓ MovementState
 - movementName: 1
 - signalGroup: 1
 - ✓ state-time-speed: 2 items
 - ✓ Item 0
 - ✓ MovementEvent
 - eventState: stop-And-Remain (3)
 - ✓ timing
 - minEndTime: 15:05.0 (9050)
 - maxEndTime: 18:18.0 (10980)
 - likelyTime: 15:41.0 (9410)
 - confidence: 56% probability (3)
 - ✓ regional: 1 item
 - ✓ Item 0
 - > RegionalExtension
 - ✓ Item 1
 - ✓ MovementEvent
 - eventState: pre-Movement (4)
 - ✓ timing
 - minEndTime: 15:41.0 (9410)
 - maxEndTime: 15:42.0 (9420)
 - likelyTime: 15:42.0 (9420)
 - confidence: 10% probability (15)
 - > Item 1

C-ITS Map SPATEM



C-ITS Map

IVIM



Message Detail

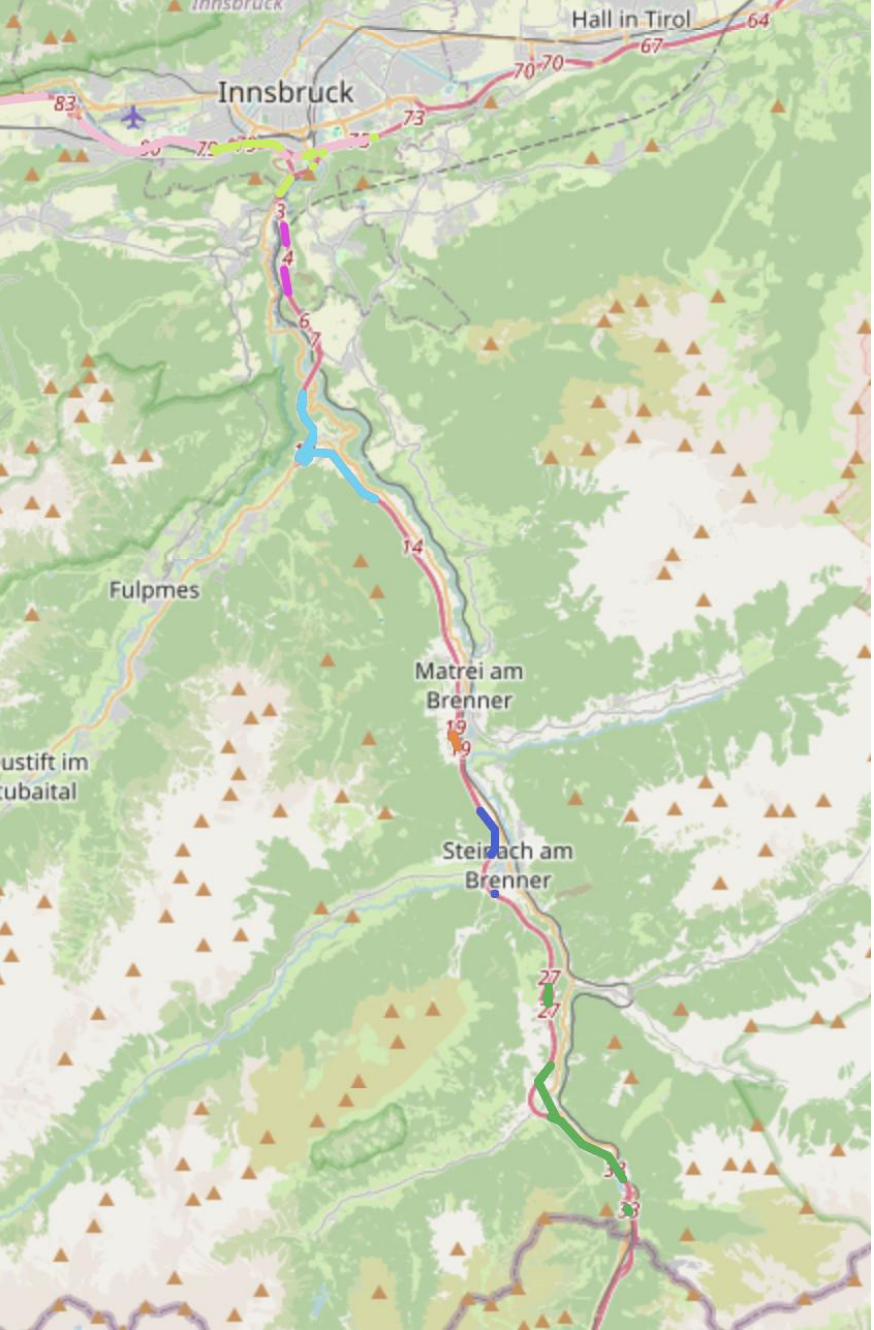
Station: 1020238
IVI ID: 989
Status: new
Provider: AT (769) / 1
Time: 2026-05-09 11:06:56.186
Valid: 2026-05-09 11:06:56.186 → 2026-05-09 11:11:56.186
Ref Pos: 47°3'38.449"N, 11°28'46.752"E
Containers: glc, giv

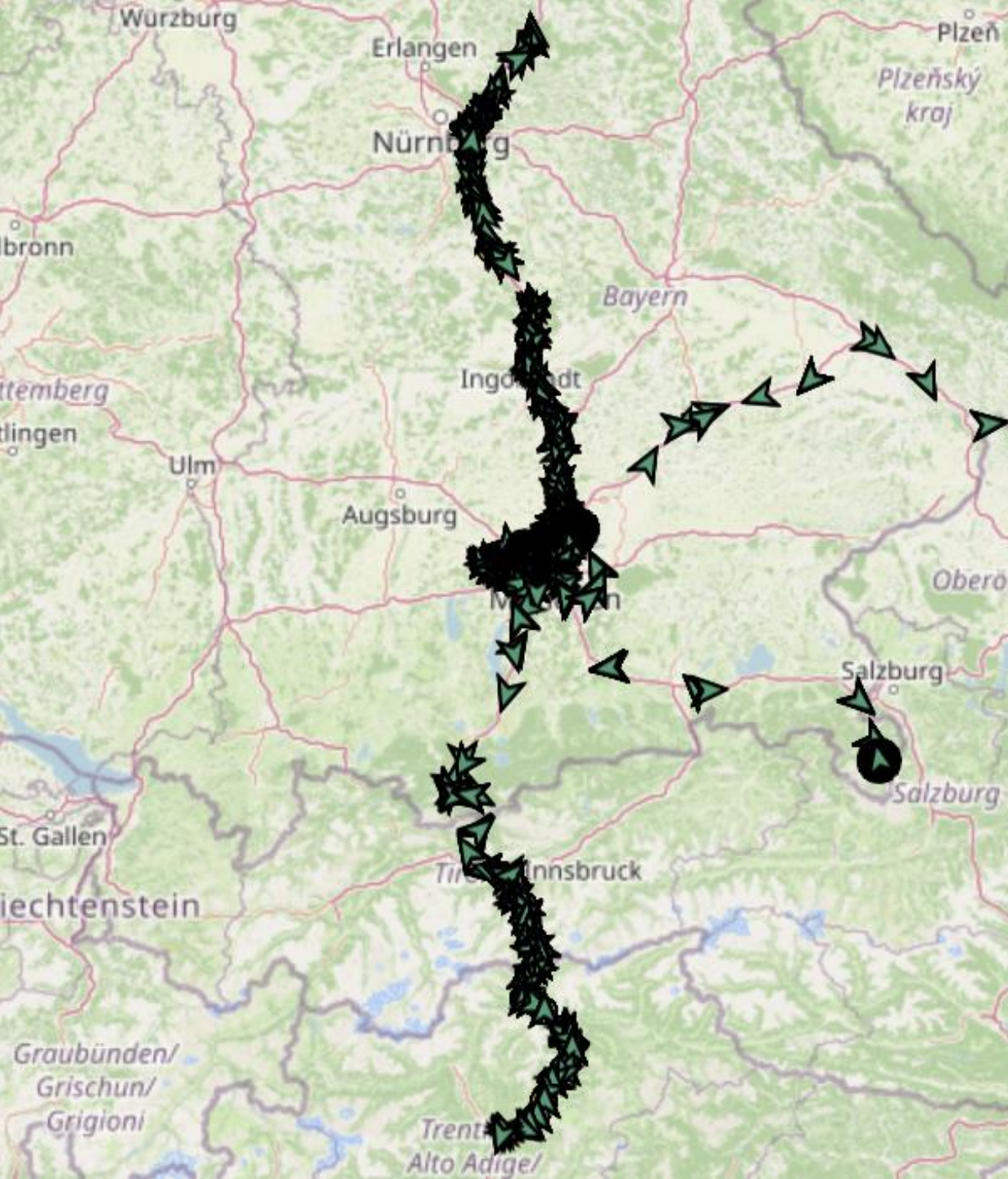
GLC parts: 1

GLC[0] Zone 2 | heading 173° | 2 points

GIV: 1

GIV[0] type:regulatoryMessages speed:40 km/h dir:sameDirection
Maximum speed limited to the figure indicated
zones:[1,2]

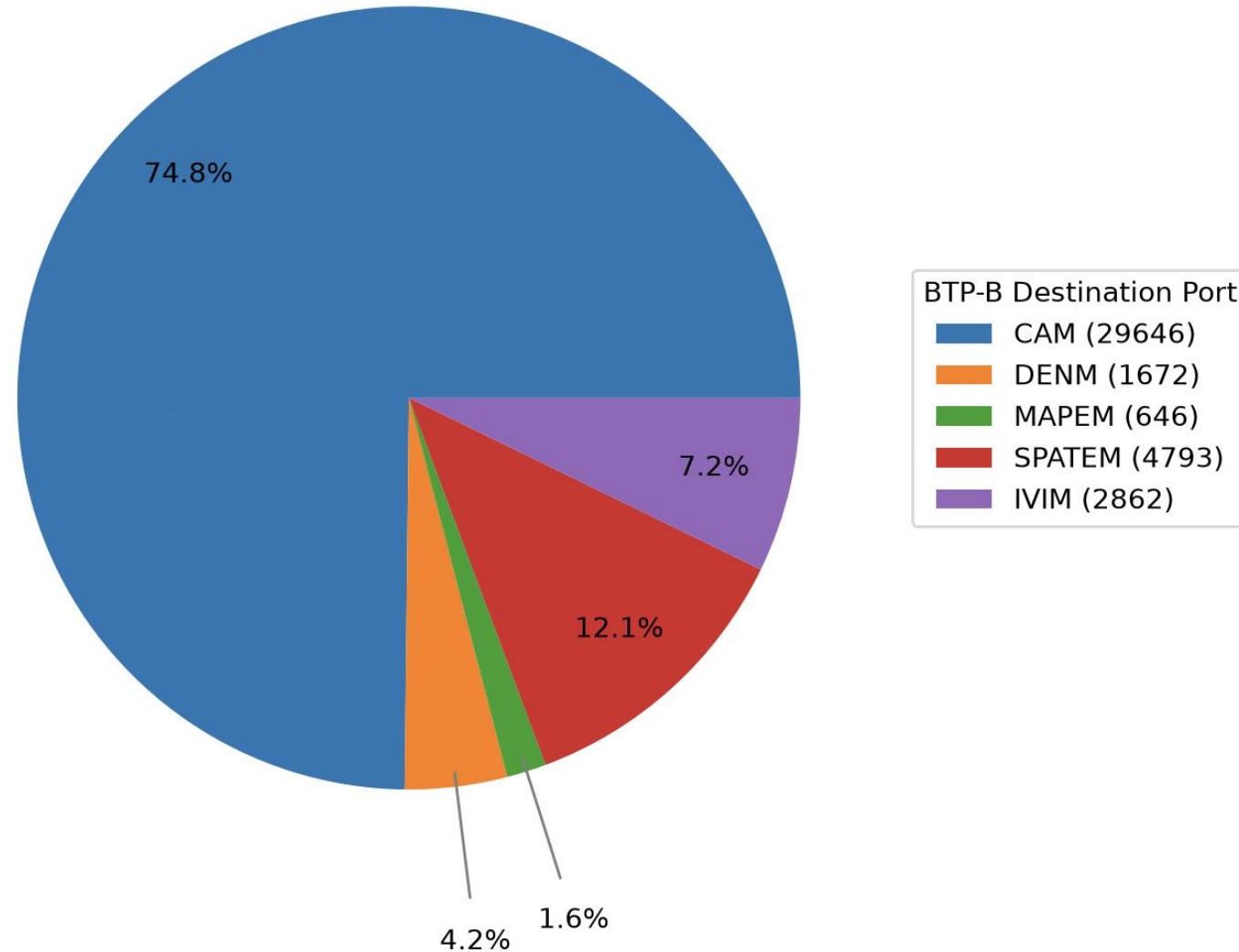




Our dataset

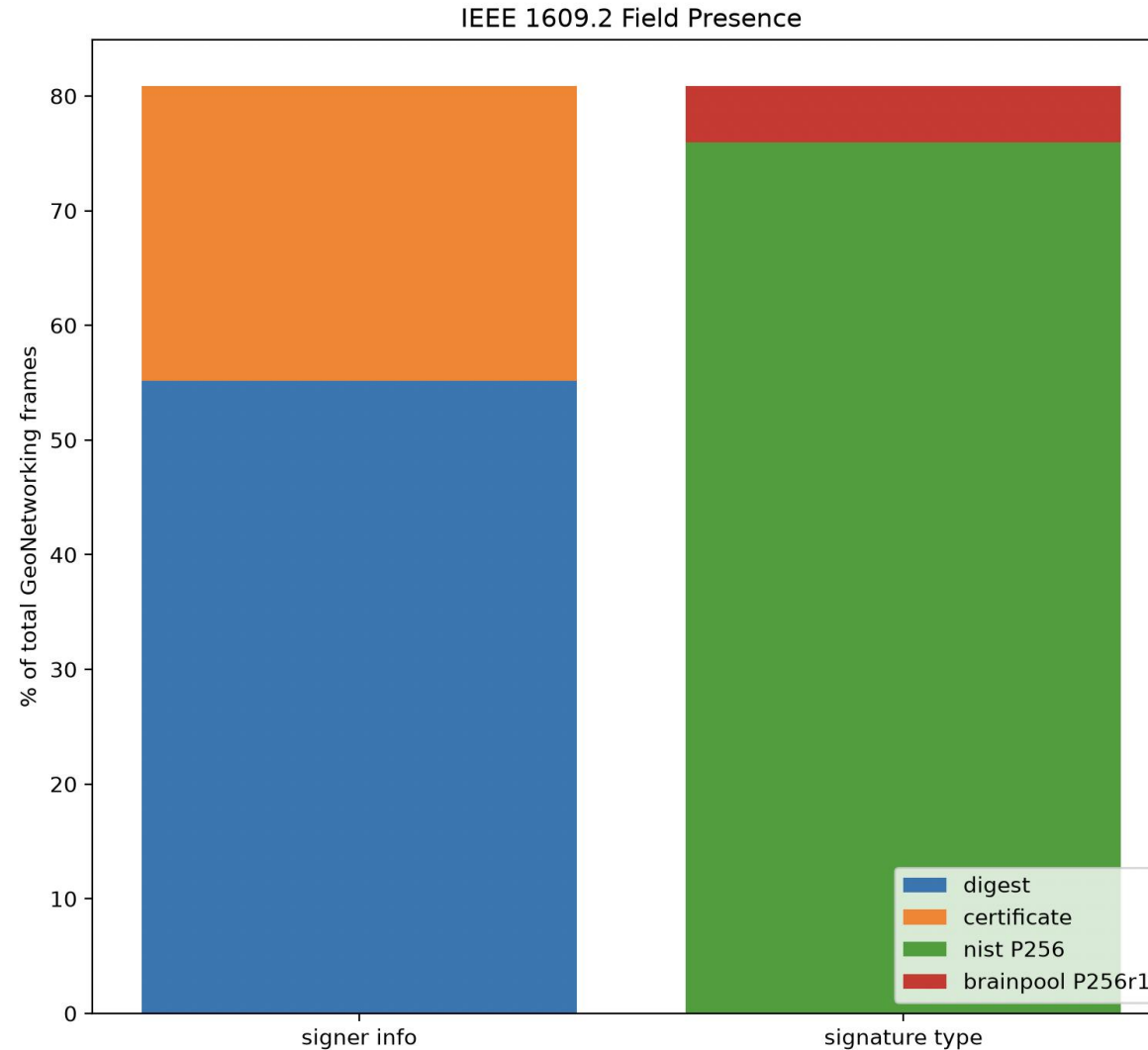
C-ITS Tooling

Dataset – Traffic According to BTP-B Destination Port



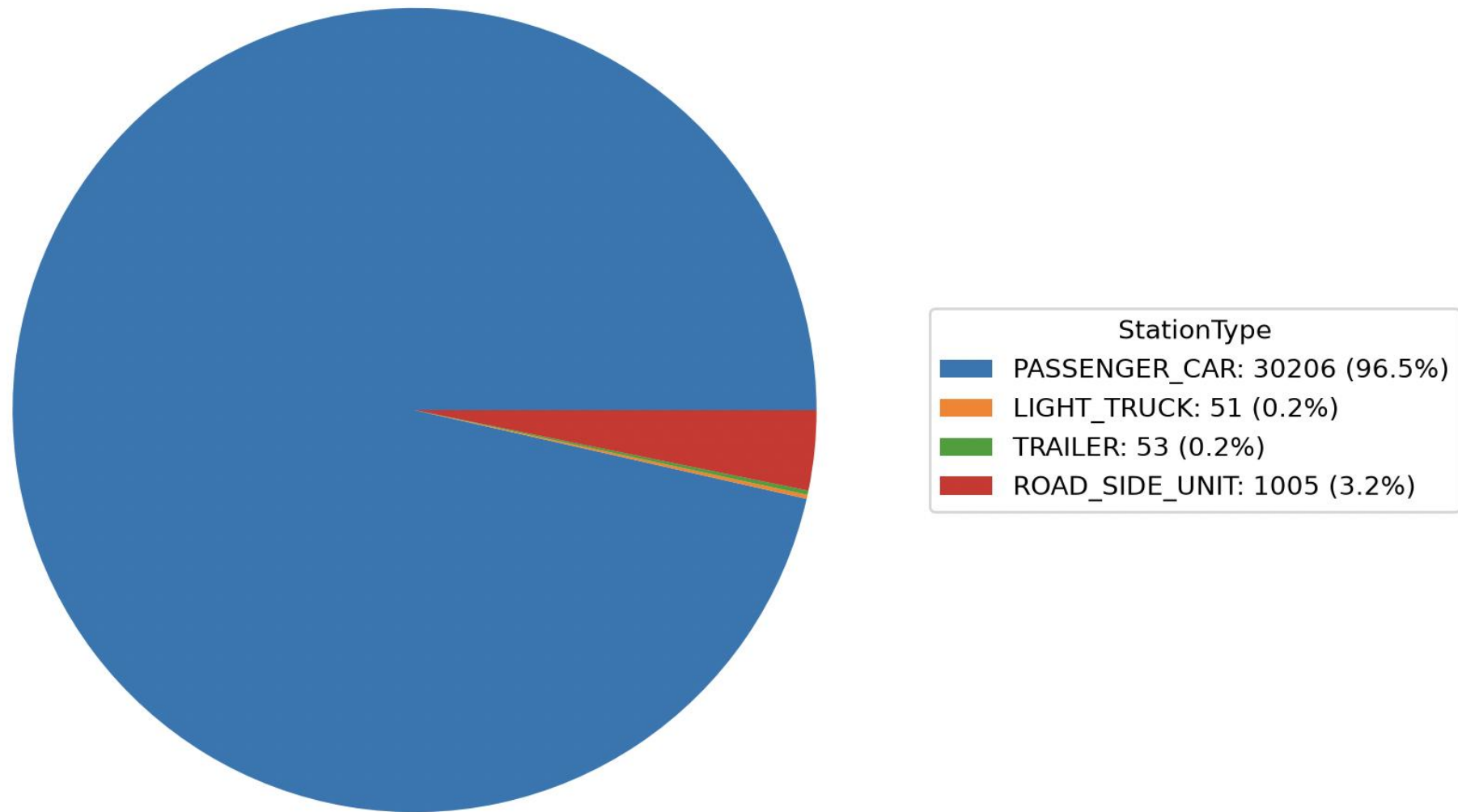
C-ITS Tooling

Dataset – IEEE 1609.2 Security



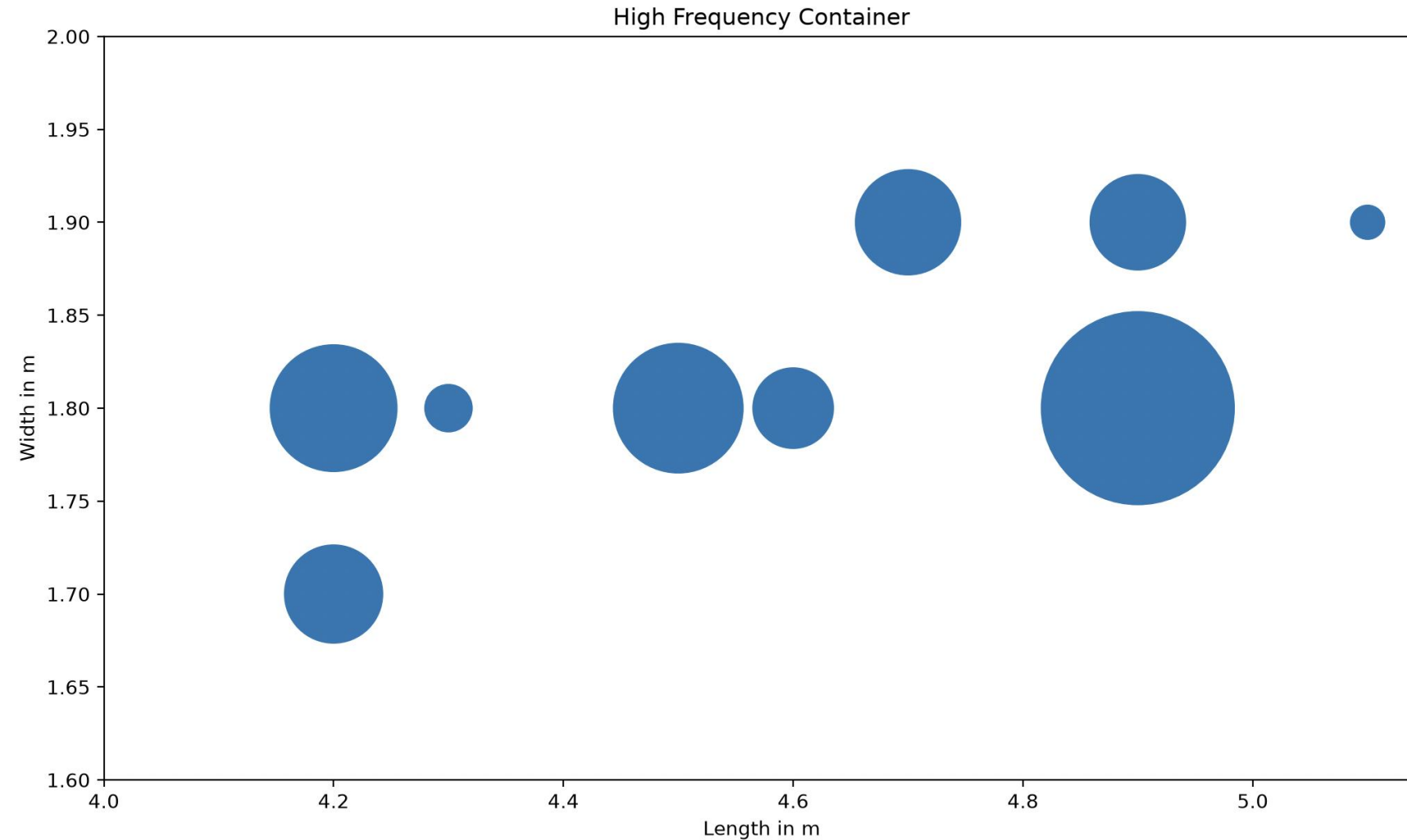
C-ITS Tooling

Dataset – Station Types



C-ITS Tooling

Dataset – Dimensions in CAM



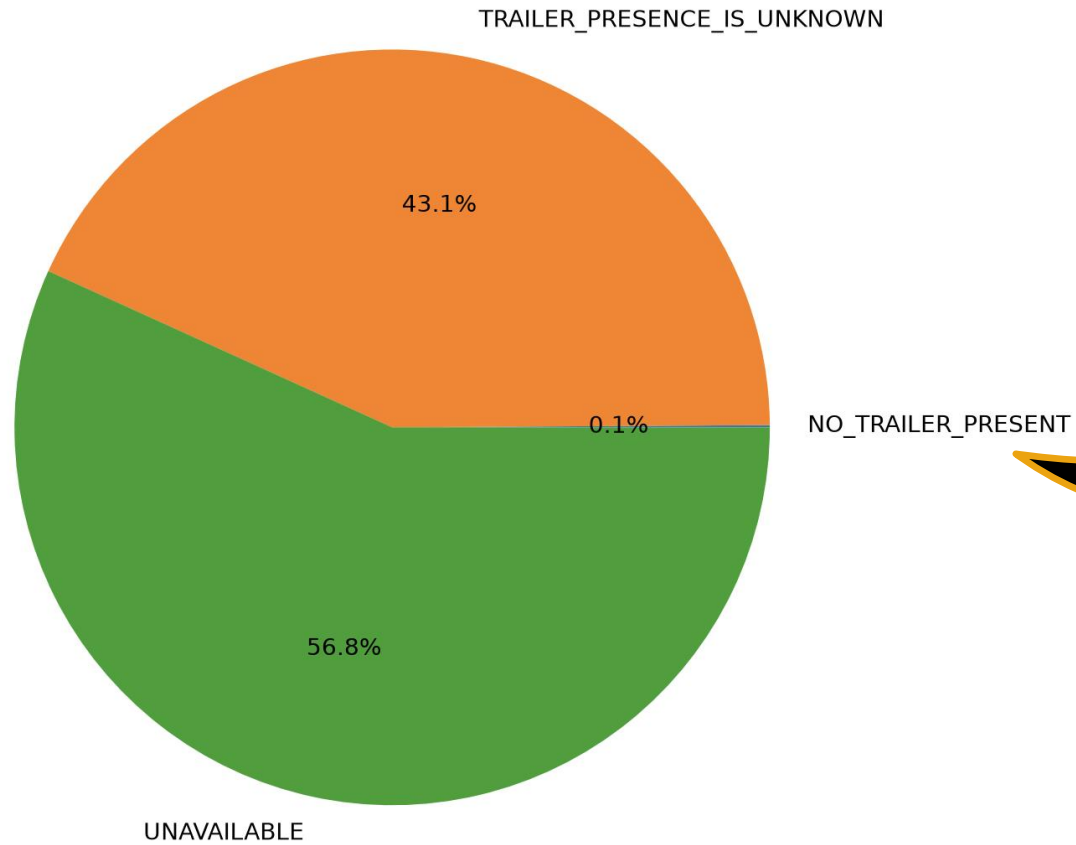
Also:

- One "LightTruck" with 8.4m / 2.3m
- Trailers with vehicleLengthValue "unavailable" (1023)

C-ITS Tooling

Dataset – Dimensions in CAM

VehicleLengthConfidenceIndication



C-ITS Analysis Features

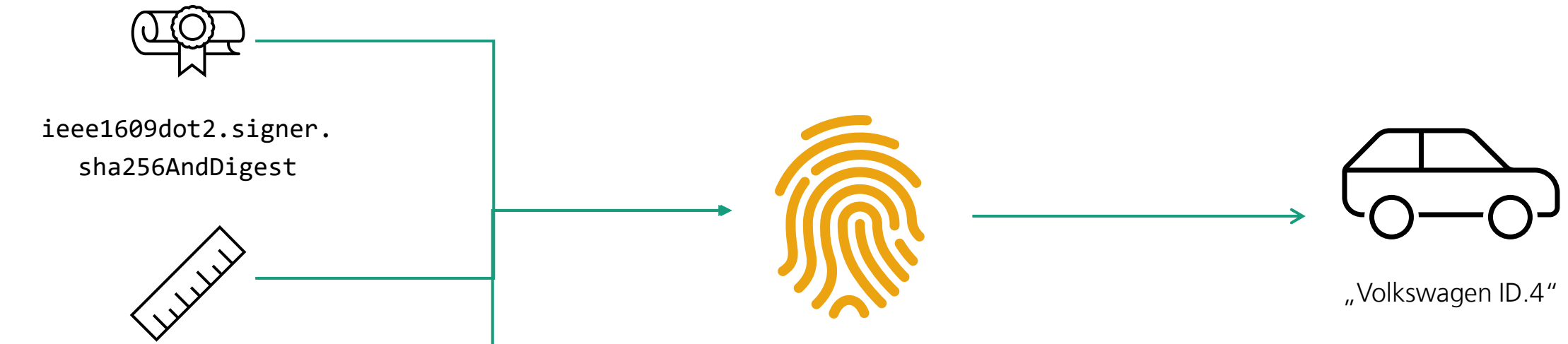
Goal

- Supplement with additional information
 - Correlate information
- Derive new insights for map view



C-ITS Analysis Features

Vehicle Type Fingerprinting



Appeal to the masses:

- Provide Fingerprint Information
 - Confirmed Vehicle Dimensions
 - PKI AA Digests (other than VW)



C-ITS Analysis Features

Speeding



No! (at least we think so)

- Legal
- Localized

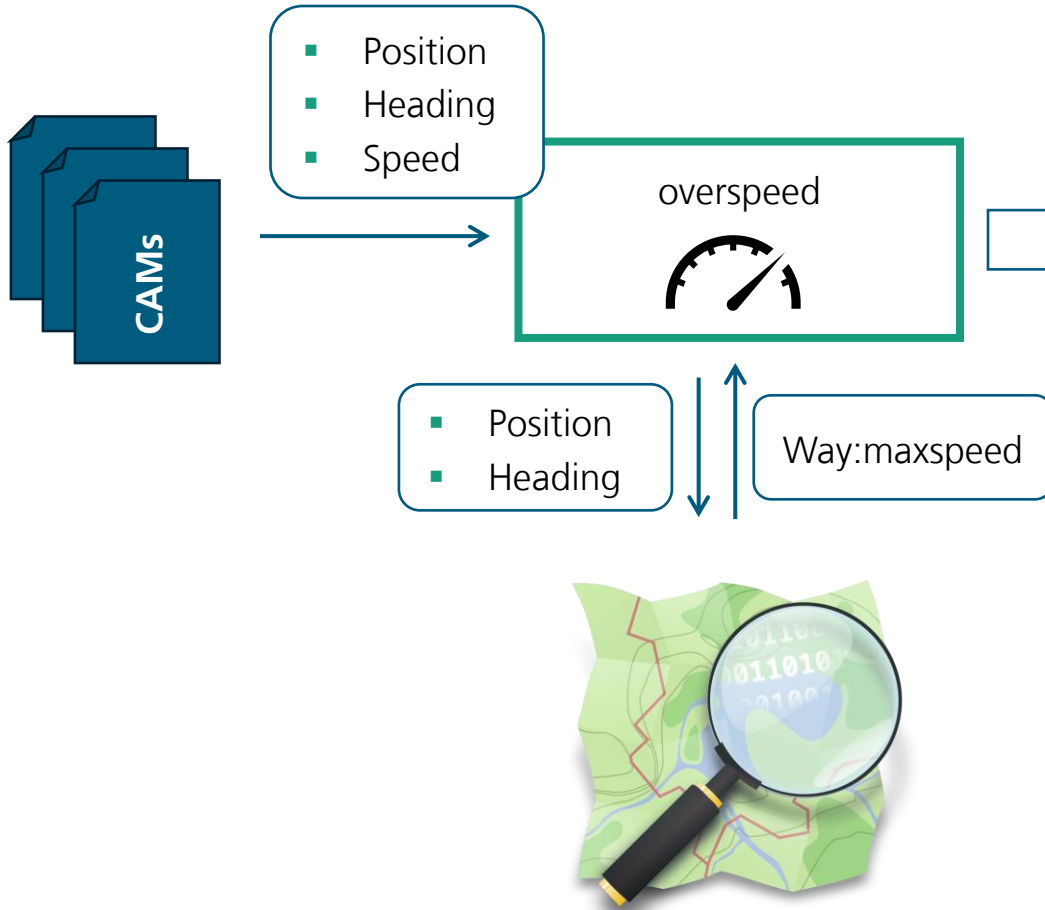
→ Existing tech works in this conditions



... but we could

C-ITS Tooling

Speeding Check



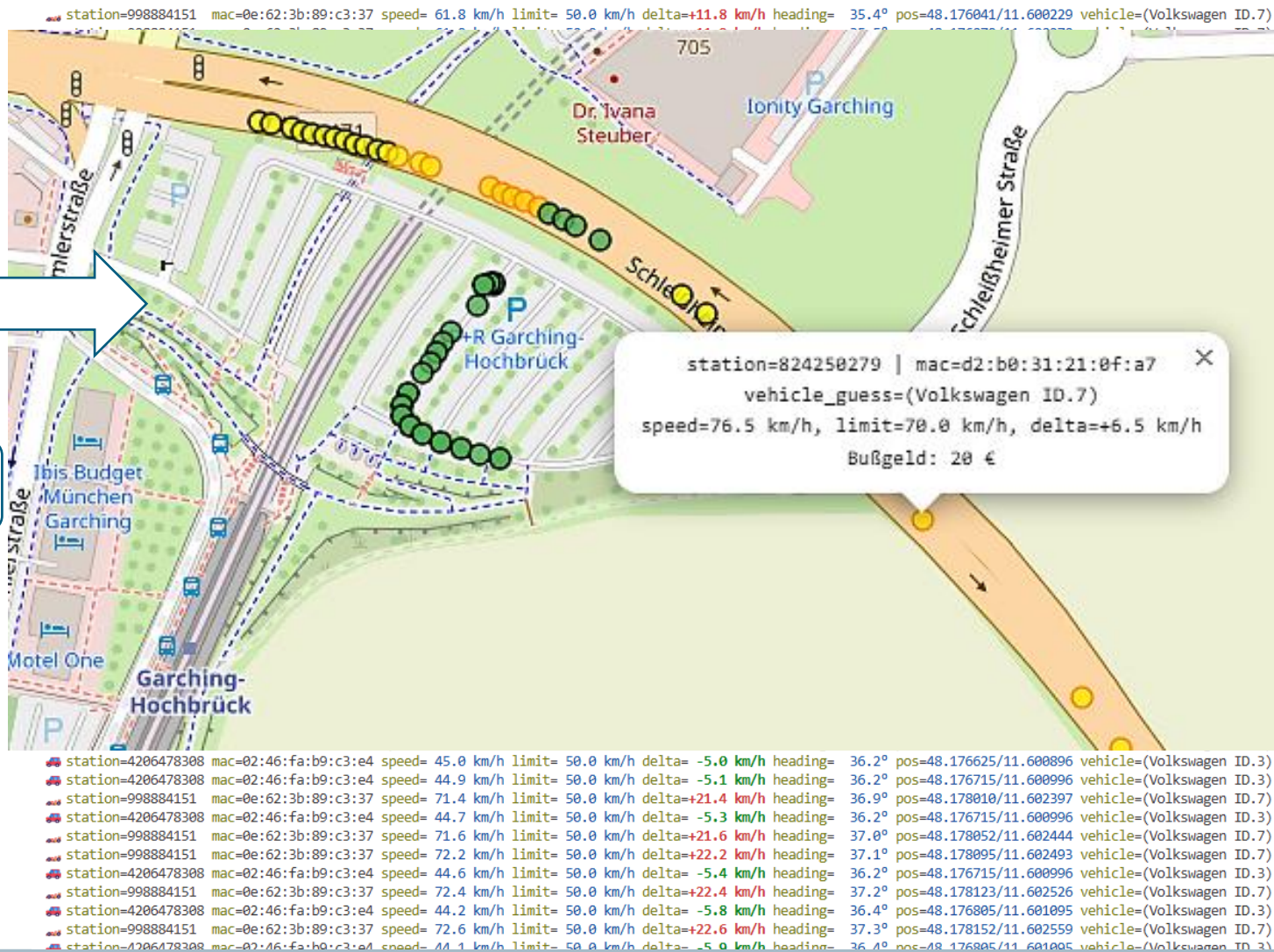
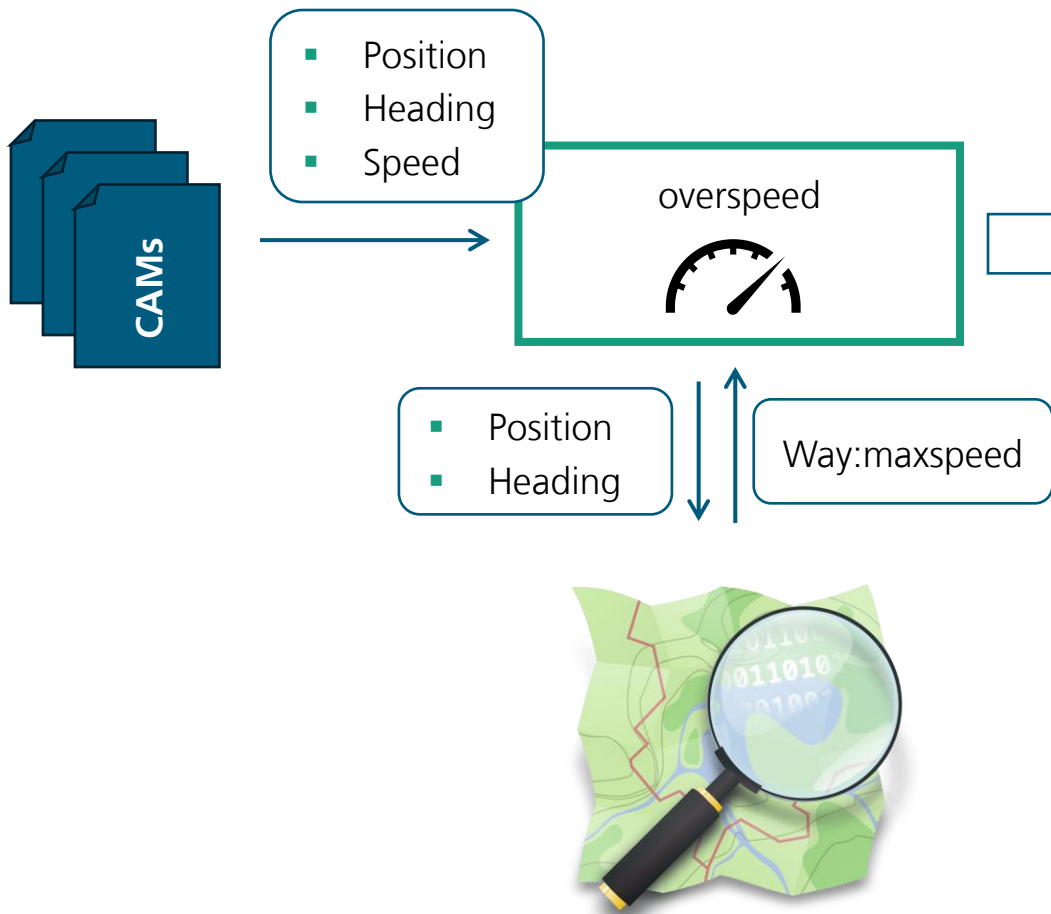
```

station=998884151 mac=0e:62:3b:89:c3:37 speed= 61.8 km/h limit= 50.0 km/h delta=+11.8 km/h heading= 35.4° pos=48.176041/11.600229 vehicle=(Volkswagen ID.7)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 61.9 km/h limit= 50.0 km/h delta=+11.9 km/h heading= 35.5° pos=48.176079/11.600270 vehicle=(Volkswagen ID.7)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 61.7 km/h limit= 50.0 km/h delta=+11.7 km/h heading= 35.8° pos=48.176192/11.600390 vehicle=(Volkswagen ID.7)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 61.7 km/h limit= 50.0 km/h delta=+11.7 km/h heading= 36.3° pos=48.176416/11.600633 vehicle=(Volkswagen ID.7)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 61.9 km/h limit= 50.0 km/h delta=+11.9 km/h heading= 36.5° pos=48.176528/11.600757 vehicle=(Volkswagen ID.7)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 62.0 km/h limit= 50.0 km/h delta=+12.0 km/h heading= 36.6° pos=48.176565/11.600798 vehicle=(Volkswagen ID.7)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 62.1 km/h limit= 50.0 km/h delta=+12.1 km/h heading= 36.7° pos=48.176602/11.600840 vehicle=(Volkswagen ID.7)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 62.2 km/h limit= 50.0 km/h delta=+12.2 km/h heading= 36.7° pos=48.176639/11.600881 vehicle=(Volkswagen ID.7)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 62.1 km/h limit= 50.0 km/h delta=+12.1 km/h heading= 36.7° pos=48.176714/11.600965 vehicle=(Volkswagen ID.7)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 61.0 km/h limit= 50.0 km/h delta=+11.0 km/h heading= 36.7° pos=48.176787/11.601046 vehicle=(Volkswagen ID.7)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 58.6 km/h limit= 50.0 km/h delta= +8.6 km/h heading= 36.6° pos=48.176823/11.601086 vehicle=(Volkswagen ID.7)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 57.8 km/h limit= 50.0 km/h delta= +7.8 km/h heading= 36.5° pos=48.176858/11.601125 vehicle=(Volkswagen ID.7)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 56.4 km/h limit= 50.0 km/h delta= +6.4 km/h heading= 36.5° pos=48.176892/11.601162 vehicle=(Volkswagen ID.7)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 55.0 km/h limit= 50.0 km/h delta= +5.0 km/h heading= 36.5° pos=48.176925/11.601199 vehicle=(Volkswagen ID.7)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 54.4 km/h limit= 50.0 km/h delta= +4.4 km/h heading= 36.5° pos=48.176958/11.601235 vehicle=(Volkswagen ID.7)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 54.2 km/h limit= 50.0 km/h delta= +4.2 km/h heading= 36.5° pos=48.176991/11.601272 vehicle=(Volkswagen ID.7)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 54.8 km/h limit= 50.0 km/h delta= +4.8 km/h heading= 36.6° pos=48.177024/11.601308 vehicle=(Volkswagen ID.7)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 57.1 km/h limit= 50.0 km/h delta= +7.1 km/h heading= 36.7° pos=48.177092/11.601384 vehicle=(Volkswagen ID.7)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 58.9 km/h limit= 50.0 km/h delta= +8.9 km/h heading= 36.6° pos=48.177162/11.601462 vehicle=(Volkswagen ID.7)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 60.2 km/h limit= 50.0 km/h delta=+10.2 km/h heading= 36.5° pos=48.177199/11.601502 vehicle=(Volkswagen ID.7)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 61.0 km/h limit= 50.0 km/h delta=+11.0 km/h heading= 36.4° pos=48.177236/11.601543 vehicle=(Volkswagen ID.7)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 62.1 km/h limit= 50.0 km/h delta=+12.1 km/h heading= 36.4° pos=48.177273/11.601584 vehicle=(Volkswagen ID.7)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 63.5 km/h limit= 50.0 km/h delta=+13.5 km/h heading= 36.1° pos=48.177350/11.601668 vehicle=(Volkswagen ID.7)
station=4206478308 mac=02:46:fa:b9:c3:e4 speed= 45.8 km/h limit= 50.0 km/h delta= -4.2 km/h heading= 35.7° pos=48.176258/11.600494 vehicle=(Volkswagen ID.3)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 63.9 km/h limit= 50.0 km/h delta=+13.9 km/h heading= 36.1° pos=48.177389/11.601710 vehicle=(Volkswagen ID.7)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 64.7 km/h limit= 50.0 km/h delta=+14.7 km/h heading= 36.1° pos=48.177428/11.601753 vehicle=(Volkswagen ID.7)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 65.3 km/h limit= 50.0 km/h delta=+15.3 km/h heading= 36.1° pos=48.177467/11.601796 vehicle=(Volkswagen ID.7)
station=4206478308 mac=02:46:fa:b9:c3:e4 speed= 45.5 km/h limit= 50.0 km/h delta= -4.5 km/h heading= 36.0° pos=48.176351/11.600594 vehicle=(Volkswagen ID.3)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 65.8 km/h limit= 50.0 km/h delta=+15.8 km/h heading= 36.1° pos=48.177507/11.601839 vehicle=(Volkswagen ID.7)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 66.6 km/h limit= 50.0 km/h delta=+16.6 km/h heading= 36.1° pos=48.177547/11.601883 vehicle=(Volkswagen ID.7)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 67.1 km/h limit= 50.0 km/h delta=+17.1 km/h heading= 36.1° pos=48.177588/11.601928 vehicle=(Volkswagen ID.7)
station=4206478308 mac=02:46:fa:b9:c3:e4 speed= 45.4 km/h limit= 50.0 km/h delta= -4.6 km/h heading= 36.2° pos=48.176444/11.600695 vehicle=(Volkswagen ID.3)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 67.6 km/h limit= 50.0 km/h delta=+17.6 km/h heading= 36.2° pos=48.177628/11.601971 vehicle=(Volkswagen ID.7)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 68.5 km/h limit= 50.0 km/h delta=+18.5 km/h heading= 36.2° pos=48.177669/11.602016 vehicle=(Volkswagen ID.7)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 69.6 km/h limit= 50.0 km/h delta=+19.6 km/h heading= 36.3° pos=48.177712/11.602063 vehicle=(Volkswagen ID.7)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 70.6 km/h limit= 50.0 km/h delta=+20.6 km/h heading= 36.4° pos=48.177754/11.602110 vehicle=(Volkswagen ID.7)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 71.1 km/h limit= 50.0 km/h delta=+21.1 km/h heading= 36.4° pos=48.177796/11.602157 vehicle=(Volkswagen ID.7)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 71.2 km/h limit= 50.0 km/h delta=+21.2 km/h heading= 36.5° pos=48.177839/11.602204 vehicle=(Volkswagen ID.7)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 71.5 km/h limit= 50.0 km/h delta=+21.5 km/h heading= 36.7° pos=48.177897/11.602269 vehicle=(Volkswagen ID.7)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 71.1 km/h limit= 50.0 km/h delta=+21.1 km/h heading= 36.7° pos=48.177925/11.602300 vehicle=(Volkswagen ID.7)
station=4206478308 mac=02:46:fa:b9:c3:e4 speed= 45.0 km/h limit= 50.0 km/h delta= -5.0 km/h heading= 36.2° pos=48.176625/11.600896 vehicle=(Volkswagen ID.3)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 44.9 km/h limit= 50.0 km/h delta= -5.1 km/h heading= 36.2° pos=48.176715/11.600996 vehicle=(Volkswagen ID.3)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 71.4 km/h limit= 50.0 km/h delta=+21.4 km/h heading= 36.9° pos=48.178010/11.602397 vehicle=(Volkswagen ID.7)
station=4206478308 mac=02:46:fa:b9:c3:e4 speed= 44.7 km/h limit= 50.0 km/h delta= -5.3 km/h heading= 36.2° pos=48.176715/11.600996 vehicle=(Volkswagen ID.3)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 71.6 km/h limit= 50.0 km/h delta=+21.6 km/h heading= 37.0° pos=48.178052/11.602444 vehicle=(Volkswagen ID.7)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 72.2 km/h limit= 50.0 km/h delta=+22.2 km/h heading= 37.1° pos=48.178095/11.602493 vehicle=(Volkswagen ID.7)
station=4206478308 mac=02:46:fa:b9:c3:e4 speed= 44.6 km/h limit= 50.0 km/h delta= -5.4 km/h heading= 36.2° pos=48.176715/11.600996 vehicle=(Volkswagen ID.3)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 72.4 km/h limit= 50.0 km/h delta=+22.4 km/h heading= 37.2° pos=48.178123/11.602526 vehicle=(Volkswagen ID.7)
station=4206478308 mac=02:46:fa:b9:c3:e4 speed= 44.2 km/h limit= 50.0 km/h delta= -5.8 km/h heading= 36.4° pos=48.176805/11.601095 vehicle=(Volkswagen ID.3)
station=998884151 mac=0e:62:3b:89:c3:37 speed= 72.6 km/h limit= 50.0 km/h delta=+22.6 km/h heading= 37.3° pos=48.178152/11.602559 vehicle=(Volkswagen ID.7)
station=4206478308 mac=02:46:fa:b9:c3:e4 speed= 44.1 km/h limit= 50.0 km/h delta= -5.9 km/h heading= 36.0° pos=48.176805/11.601095 vehicle=(Volkswagen ID.3)

```

C-ITS Tooling

Speeding Check

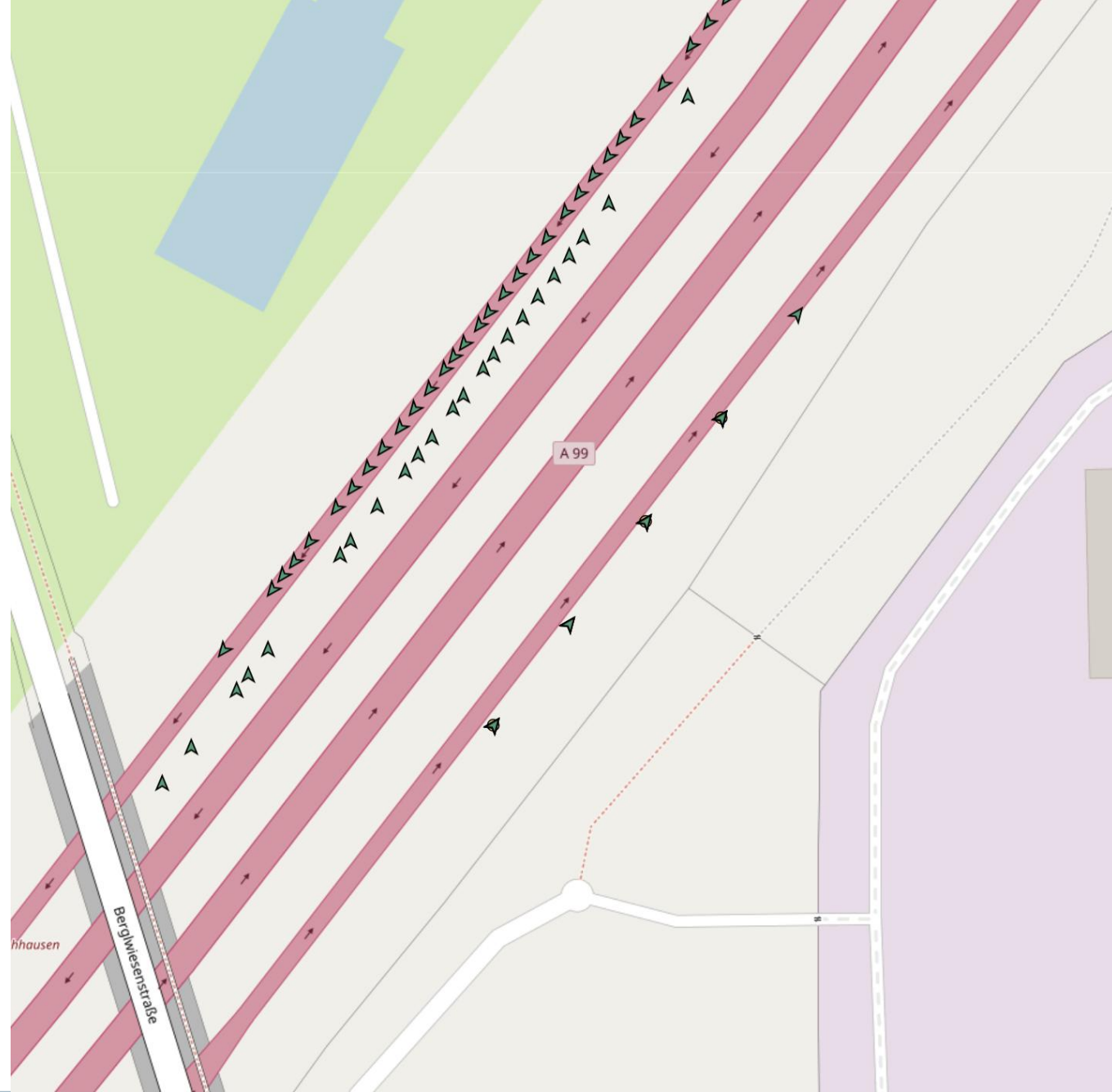


C-ITS Tooling

Overspeed

This led to some interesting findings:

An ID.4 driving down the A99 motorway



C-ITS Tooling

Overspeed

This led to some interesting findings:

An ID.4 driving down the A99 motorway

- Over 580 km/h
- Against the flow of traffic
- Between lanes
- Drifting



C-ITS Tooling

Demo

Demo – War driving through Heidelberg



C-ITS Tooling

Demo

Demo – War driving jogging through Heidelberg



What's Next:

Security Testing C-ITS

C-ITS Tooling

Scapy

How to craft packets ourselves?

→ Build on Scapy

- Custom layers for C-ITS

ASN.1 troubles

- Only BER and DER are implemented and used in Scapy
- C-ITS also uses OER, (U)PER

Current solution

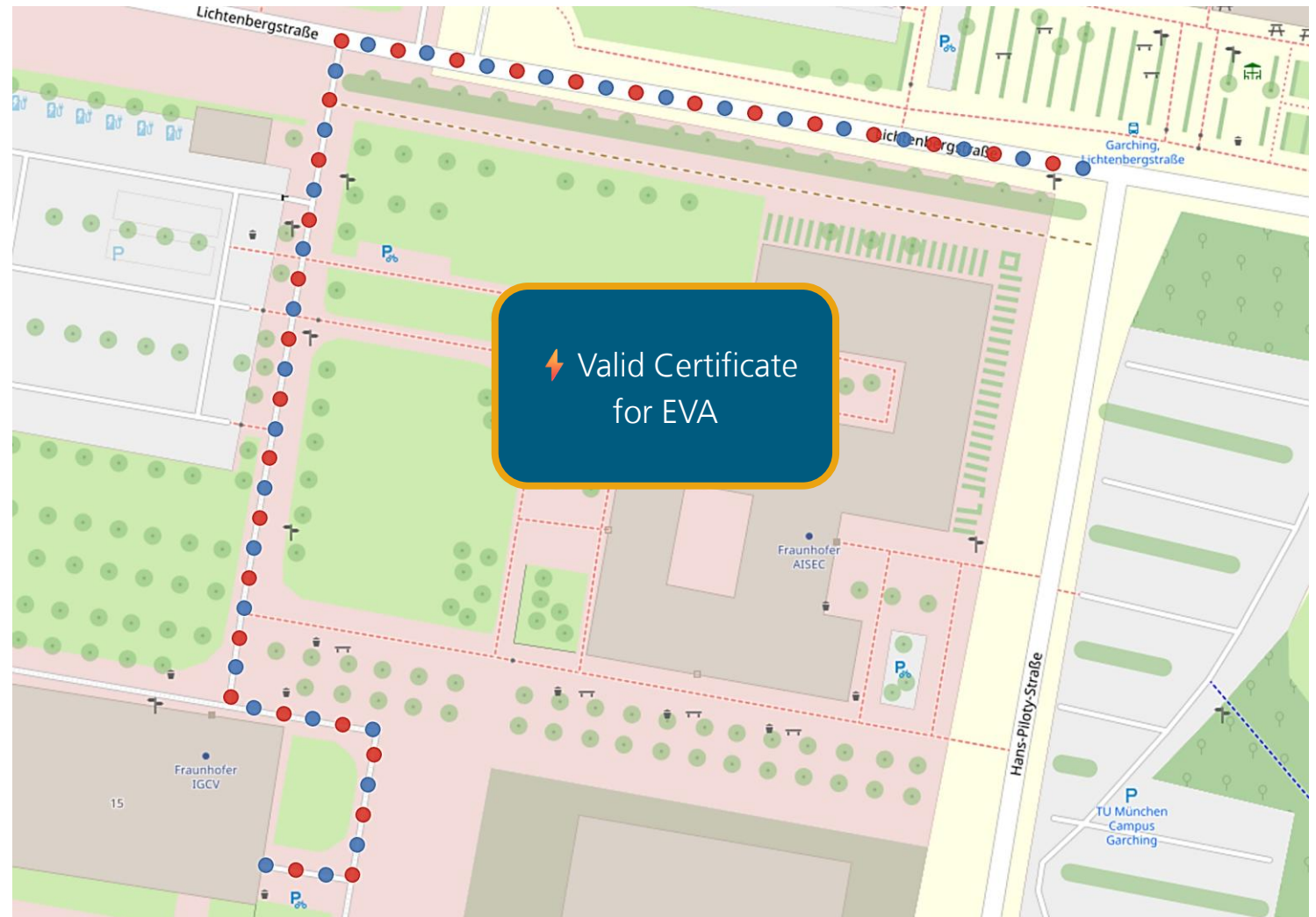
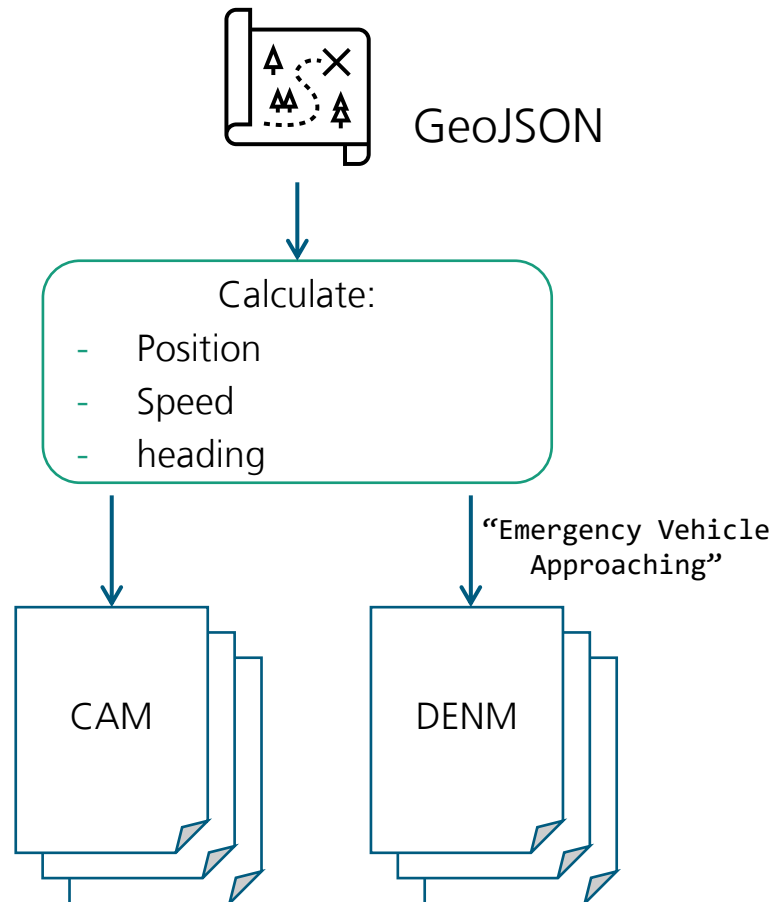
- Use `asn1tools` for coding
 - Adapt ASN.1 definitions for `asn1tools`
- Handle ASN.1 fields as dict of dicts
- Not desirable, but works for first tests



Spoofing

Emergency Vehicle Spoofing

Simulates the continuous behavior of a moving emergency vehicle



Approaches for Protocol Fuzzing

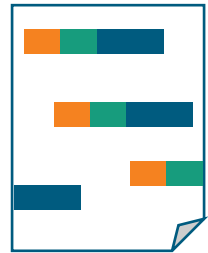
Fuzzing Strategies

Naive Fuzzing



ASN.1 Fuzzing

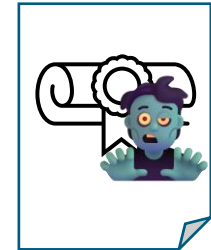
TLV-Fields



Payload Fuzzing

IEEE 1609.2 Fuzzing

- Mutate Certificates



Message Payload Fuzzing

- Target C-ITS Payload
- ⚡ Requires a valid certificate!

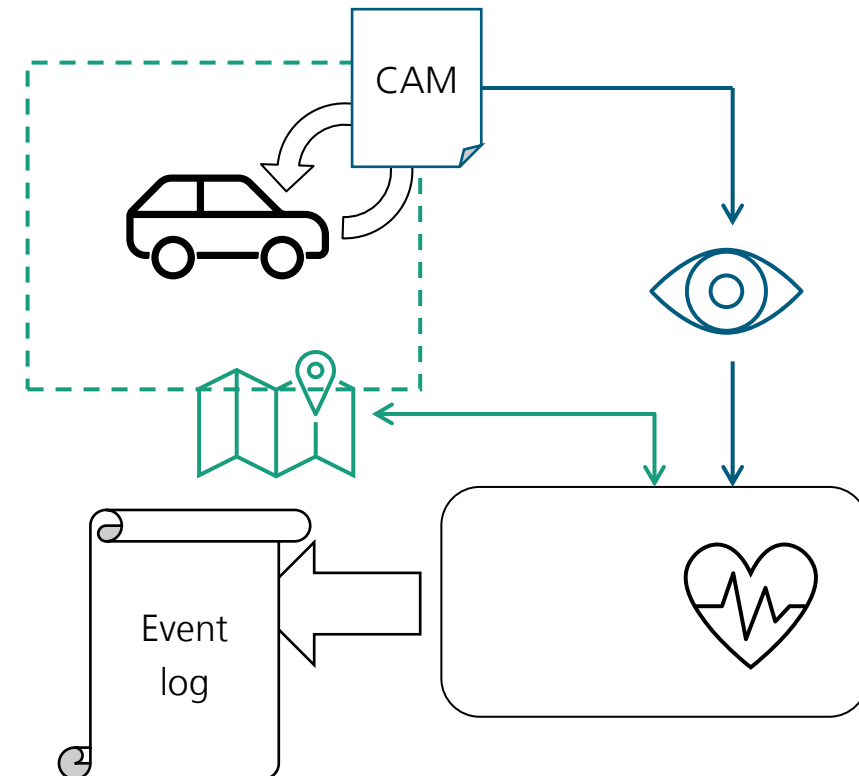


Approaches for Protocol Fuzzing Backchannel

How do we know if we hit something (in black-box testing)?

→ Backchannel

1. Get the car to send CAMs
2. Look for our vehicle type in **bounding box**
3. **Track** the cyclic CAMs
4. If CAM is missing raise flag
 - Go to 2.
 - Else 3.



Limitations

Fuzzing depth

- Multiple stacked parsers (ASN.1, IEEE 1609.2, C-ITS)
 - Many payloads require valid certificates
 - Access to the PKI is limited
- Targeting deeper layers is not trivial



Z-Image Turbo

Disclaimer

Radio Emissions

Mind your local regulation!

- For Germany c.f. *Allgemeinzuteilung*
 - *Funkanwendungen intelligenter Verkehrssysteme* ([Vfg. 102 / 2025](#))

We operate indoors and limit our tx power

- Use at your own digression

```
v2x-tester@v2x-pi-1:~ $ iw dev  
phy#2  
  
    Interface wlan1  
        ifindex 5  
        wdev 0x200000001  
        addr 04:f0:21:91:7f:2c  
        type outside context of a BSS  
        channel 180 (5900 MHz), width: 10 MHz, center1: 5900 MHz  
        txpower 3.00 dBm
```



Conclusion

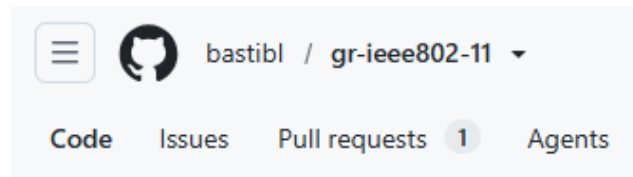
Standing on the Shoulders of Giants

Other Noteworthy C-ITS projects

HPI Potsdam / Operating Systems and Middleware Group / ETSI ITS-G5 on Linux

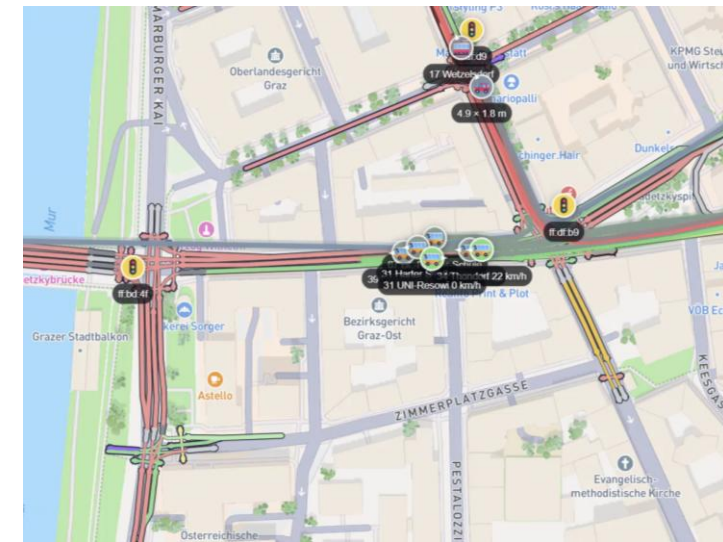
IEEE 802.11p on Linux

<https://gitlab.com/hpi-potsdam/osm/g5-on-linux/11p-on-linux>



gr-ieee802-11 Public

<https://github.com/bastibl/gr-ieee802-11>



opentrafficmap

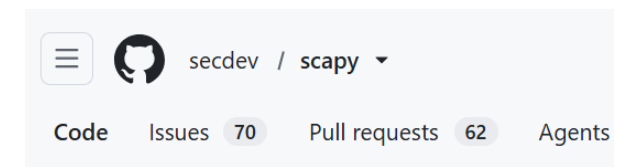
Grazer Linuxtage 2026 talk recording (youtube): <https://www.youtube.com/watch?v=gje6RnskBNA>

Grazer Linuxtage 2026 talk recording (media.ccc.de): <https://media.ccc.de/v/glt26-688-c-its-mit-einem-esp32-ampeln-straenbahnen-und-autos-tracken>

<https://codeberg.org/opentrafficmap>



scapy



scapy Public

<https://github.com/secdev/scapy>

Conclusion

- Only small introduction
 - A lot more to talk about
 - A lot more to explore
- Hopefully got you interested

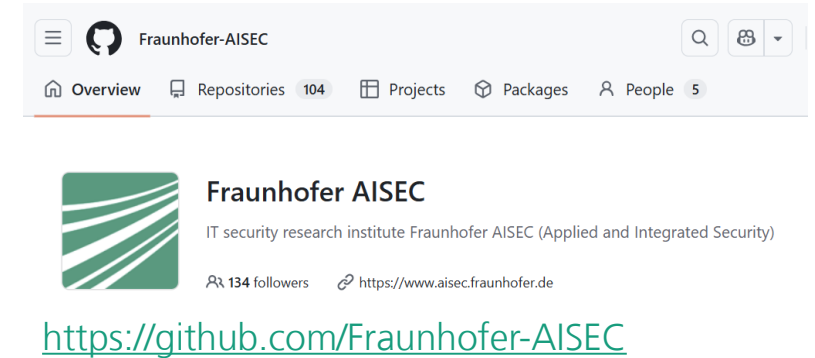
Talk to us:

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Nikolai.Puch@aisec.fraunhofer.de





Thank you for you attention