Mobile Network Testing

SAFER ROADS BY VERIFYING CRITICAL C-V2X INFRASTRUCTURE AND COMMUNICATIONS

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ROHDE&SCHWARZ

Make ideas real

CONTENT

- **C-V2X: the “why” and the “what”**
- C-V2X pain points
- A bit of technology
- Real field measurement results
- C-V2X Test Solutions
- Conclusion

Road safety globally

Global status of road safety:

Source: Global Status Report on Road Safety 2018 (WHO)

World Health Organization

- Each year, 1.35 million people are killed on roadways
- Every day, almost 3,700 people are killed globally in crashes. More than half of those killed are vulnerable road users (pedestrians, motorcyclists, or cyclists).
- Higher “rates of road traffic death” in low- and middle-income countries

- It is estimated that fatal and nonfatal crash injuries will cost the world economy approximately **$1.8 trillion dollars** from 2015–2030.

Source: The global macroeconomic burden of road injuries: estimates and projections for 166 countries (Chen S, Kuhn M, Prettner K, Bloom DE; article 2019)

- 132 (out of 175 participating) countries have national strategies for road safety that are funded
- 109 countries have national targets for the reduction of road traffic deaths
- A true global social objective!

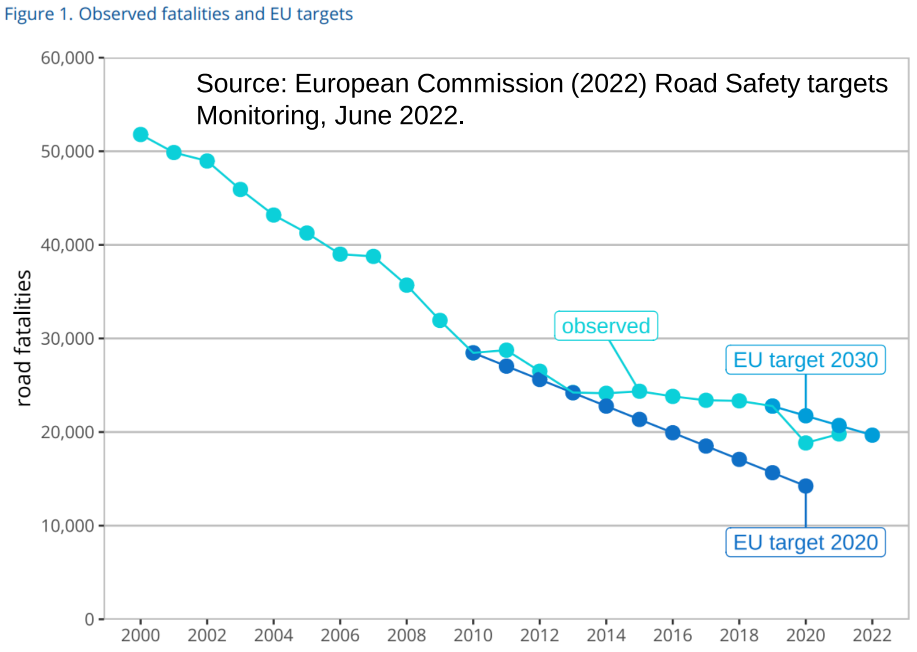
Why C-V2X?

Status in Europe:

Vision Zero:

"Our goal is to reduce road deaths to zero by 2050"

- ► What is the status towards this goal?

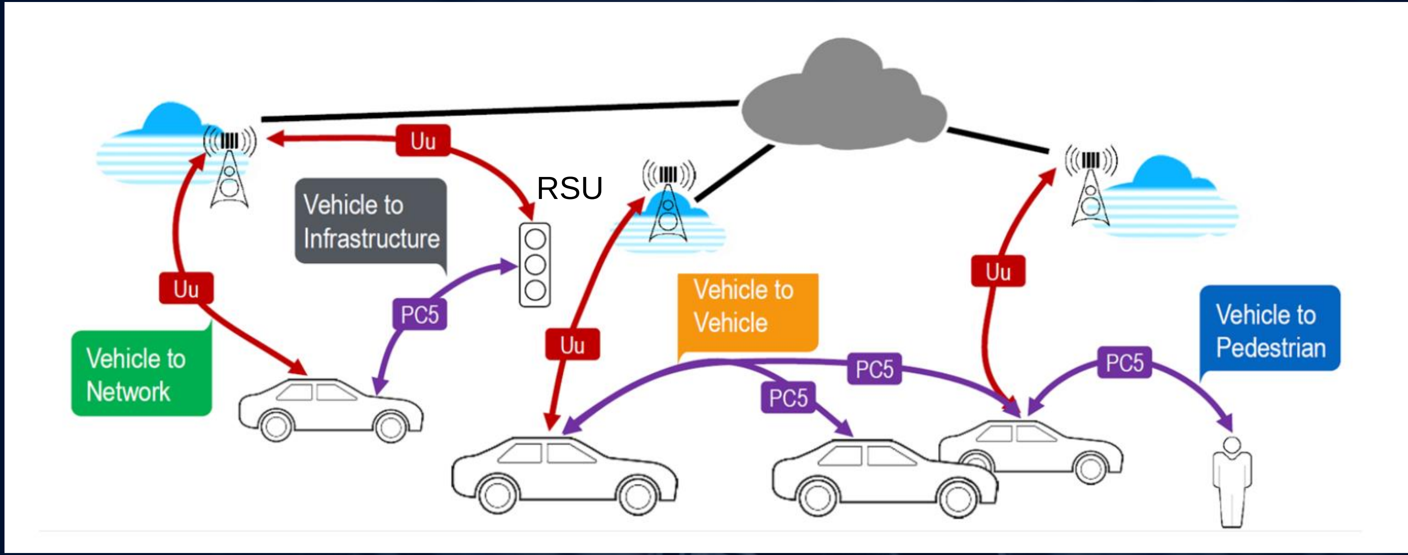


- ► Among other measures C-V2X should contribute to this goal
- ► C-V2X is a governmental task

What is C-V2X (CELLULAR-VEHICLE-TO-EVERYTHING)?
Connected mobility use cases and their key performance indicators

Cars send data to other cars or pedestrians or road infrastructure

C-V2X network architecture - ubiquitous connectivity



RSU: Road Side Unit

V2N: Vehicle to network (Uu interface)

V2V: Vehicle to vehicle (Sidelink, PC5)
V2I: Vehicle to infrastructure (Sidelink, PC5)
V2P: Vehicle to pedestrian (Sidelink, PC5)

TECHNOLOGY SOLUTION FOR C-ITS
MESSAGE TYPES AND SYSTEM REQUIREMENTS

Message Type EU	Message Type USA	Message Type China
Cooperative Awareness Message (CAM) Vehicle status information (ETSI EN 302 637-2) **Decentralized Environment Notification (DENM)** Information about specific event (ETSI EN 302 637-3)	**Basic Safety Message (BSM)** Vehicle status information Optional event flags (SAE J2735, SAE J2945)	**Basic Safety Message (BSM)** Vehicle status information (T/CSAE 53-2017)

End-to-End Latency: 20ms – 500ms, Message Repetition: 1Hz – 10Hz, Maximum Range: 300m – 1km
Maximum Speed: 250km/h (absolute), 500km/h (relative)

C-ITS: Cooperative Intelligent Transport Systems

C-V2X APPLICATIONS OVERVIEW

Category	Communication type	Abbreviation	Service
safety	V2V	FCW	Forward Collision Warning
	V2V/V2I	ICW	Intersection Collision Warning
	V2V/V2I	LTA	Left Turn Assistant
	V2	BSW	Blind Spot Warning/Lane Change Warning
	V2V	DNPW	Do Not Pass Warning
	V2V	EBW/EEBL	Emergency Brake Warning
	V2V	AVW	Abnormal Vehicle Warning
	V2V	CLW	Control Loss Warning
	V2V/V2I	HLW	Hazardous Location Warning
	V2I	SLW	Speed Limit Warning
	V2I	SVW	Signal Violation Warning
	V2I/V2P (P2X)	VRUCW	Vulnerable Road User Collision Warning
	V2V/V2I	SDS	Sensor Data Sharing
	V2V/V2I	CLC	Cooperative Lane Change
	V2P (P2X)	VRUSP	Vulnerable Road User Safe Passing
	V2I	CVM	Cooperative Vehicle Merge
	V2I	CIP	Cooperative Intersection Passing
efficiency	V2I	GLOSA	Green Light Optimal Speed Advisory
	V2I	IVS	In-Vehicle Signage
	V2I	TJW	Traffic Jam Warning
	V2V/V2I	EVW	Emergency Vehicle Warning
	V2I	CHPVP	Cooperative High Priority Vehicle Passing
	V2I	CVM	Cooperative Vehicle Merge
	V2I	CIP	Cooperative Intersection Passing
	V2I	RTS	Road Tolling Service
	V2I	DLM	Dynamic Lane Management
information and management	V2I	VNFP	Vehicle Near-Field Payment
	V2I	GSPA	Guidance Service In Parking Area
	V2I	DDS	Differential Data Service
	V2I	PDC	Probe Data Collection
	V2I	RTS	Road Tolling Service
	V2I	DLM	Dynamic Lane Management
	V2V	CPM	Cooperative Platooning Management

Note: Applications may vary according to region.

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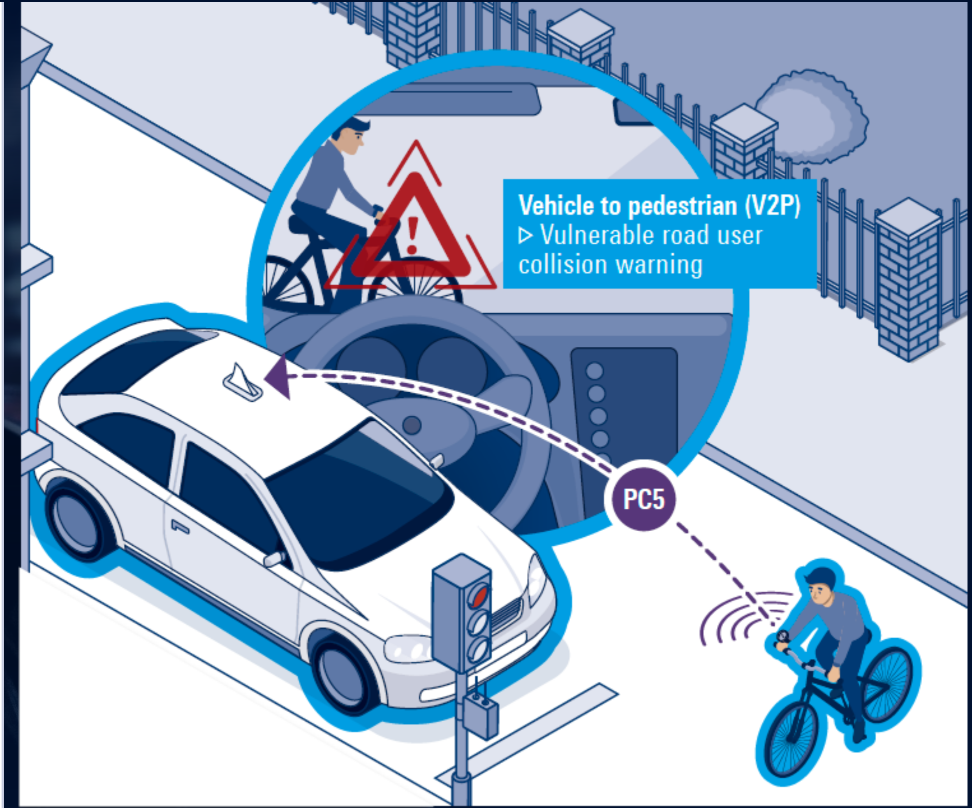

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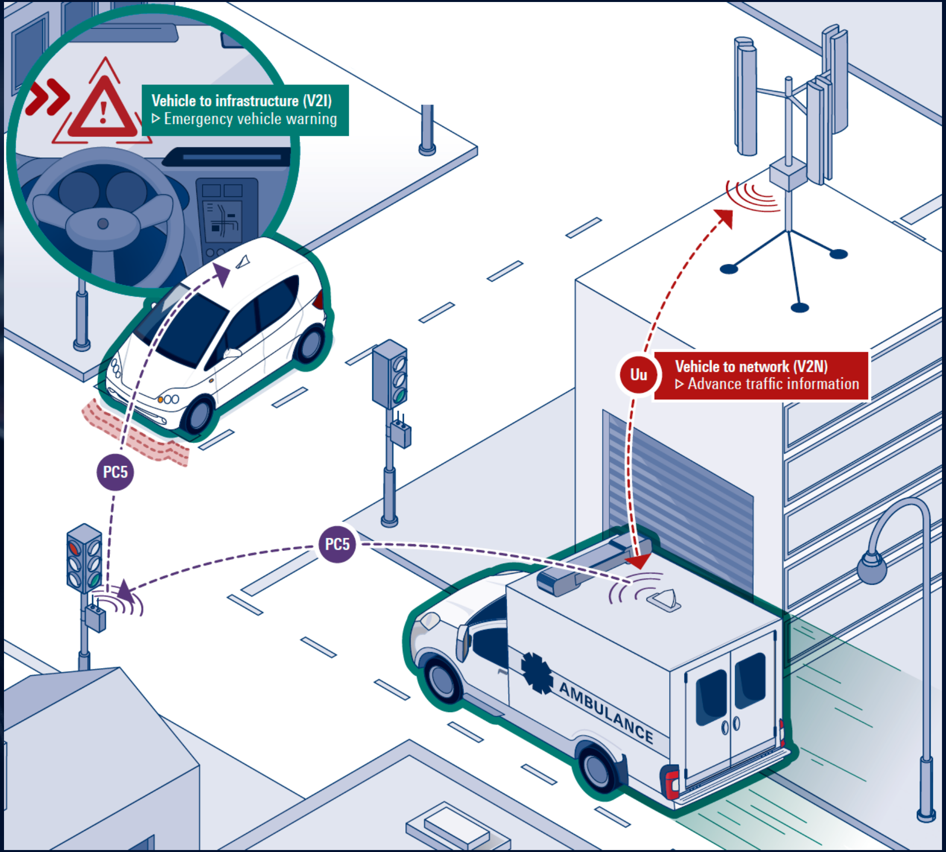
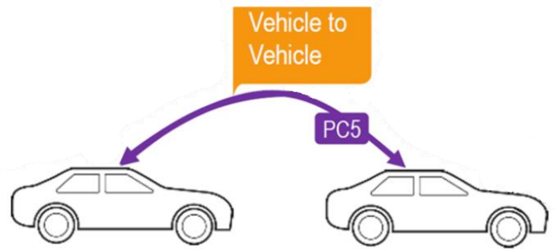


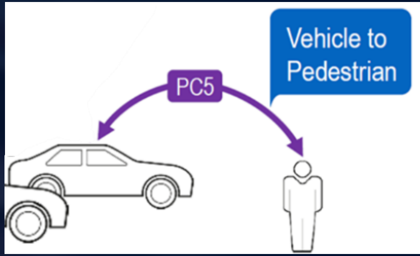
CONTENT

C-V2X / PC5 communication paths and what are the pain points?

V2V / V2P direct communiction (no infrastructure involved)

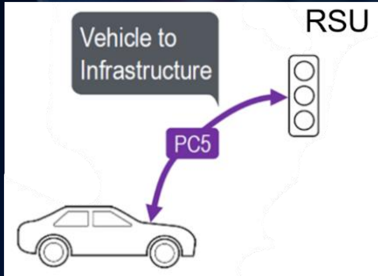
- How far the vehicles can see each other? Coverage – RSRP?
- What PC5 messages the cars transmit?
- PC5 message sent/received in time?
- Do the vehicles (TCUs) behave correctly in field compared to a reference?





V2I communication (via infrastructure – road side units (RSU))

- What is the coverage of the RSU – RSRP?
- Is there any interference?
- Are the RSU PC5 messages correct?



RSU locations: Intersections (traffic lights), construction sites, …

Business pain points: who is paying for what? $?

V2V / V2P direct communication

- HW/SW: Telematics Control Units (TCU) embedded in vehicles incl. antenna system
- Buyers of vehicles may pay for enhanced safety features (and efficiency and convenience)
- But V2V will probably not happen without V2I

V2I communication via RSUs

- HW/SW: Road Side Units (RSU) connected to traffic management systems
- Who should pay for this critical C-V2X infrastructure?
  - No RSU operator gets money from subscribers / vehicles
  - Ecosystem ?

Ecosystem: who are the players in C-V2X?

TCU Supplier	RSU Supplier	Certification	OEM / Car Manufacturer	RSU Operator
▶ Bosch ▶ Continental ▶ Denso ▶ Ford ▶ Harman ▶ Huawei ▶ LG ▶ ZTE ▶ …and many others	▶ Askey ▶ Cohda Wireless ▶ Commsignia ▶ Harman ▶ Huawei ▶ Kapsch ▶ Siemens ▶ ZTE ▶ …and many others	▶ CATARC ▶ Dekra ▶ TÜV ▶ …	▶ Audi ▶ BMW ▶ Daimler ▶ GM ▶ Fiat ▶ Ford ▶ Honda ▶ Jaguar-Landrover ▶ Nissan ▶ Renault ▶ Toyota ▶ Volvo ▶ VW ▶ …	▶ Government entity (e.g. in China) ▶ Virginia Department of Transportation ▶ City municipality ▶ American Tower ▶ Road operator (e.g. Autostrade Italy) ▶ … Different company types Different reach Business cases? ?

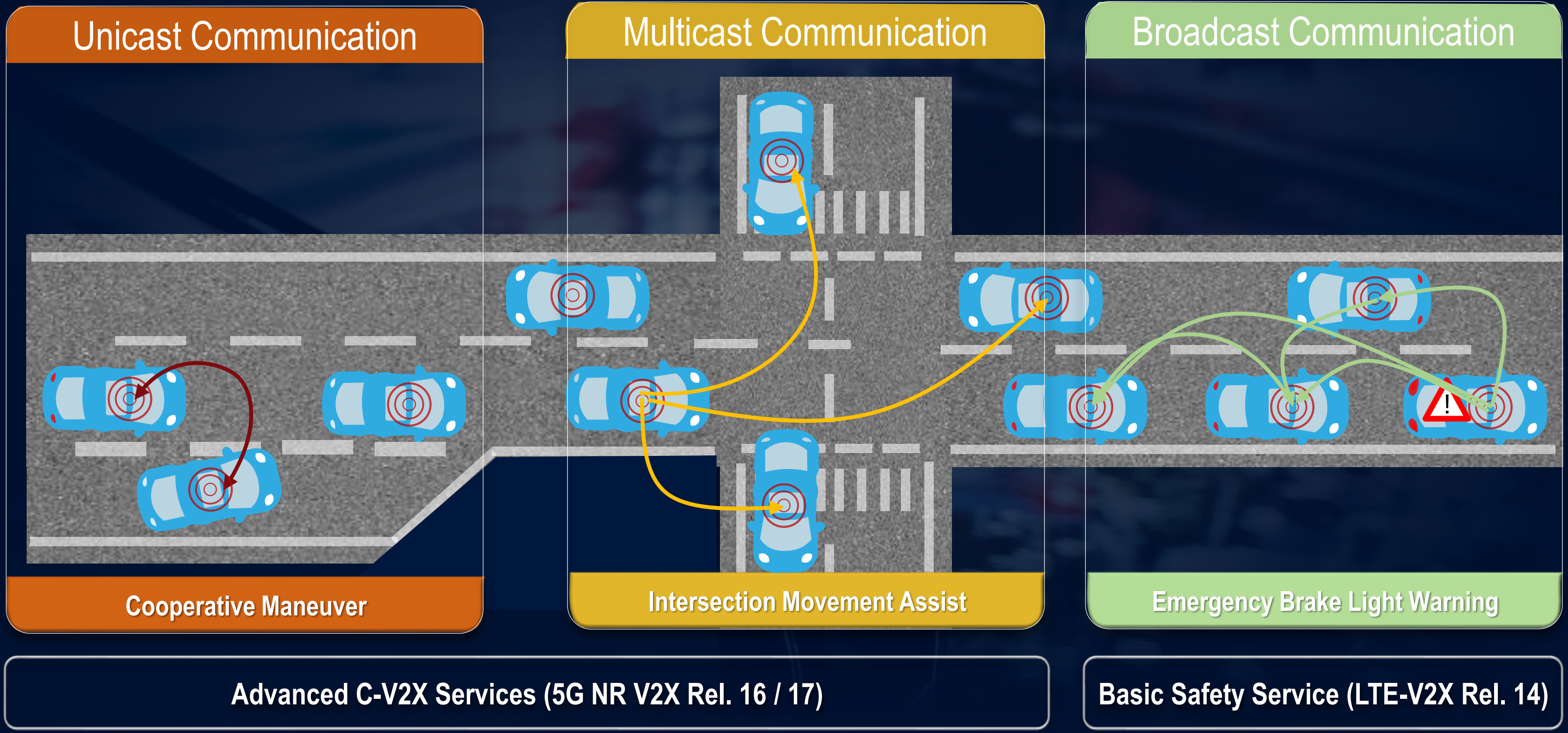
Lab tests / R&D and production tests

System Verification / test grounds / in-field verification

▶ Road Safety is a governmental task (like traffic lights) – maybe indirect payment via taxes

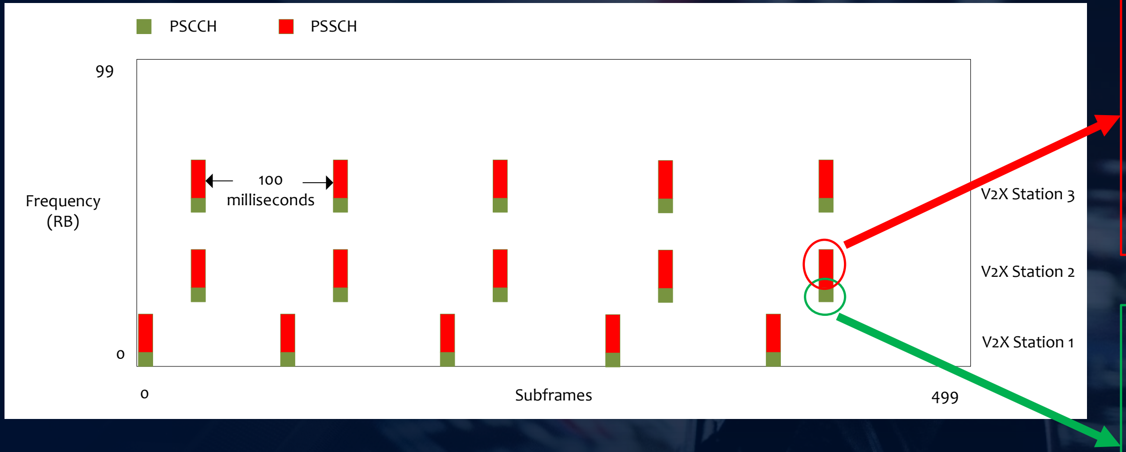
CONTENT

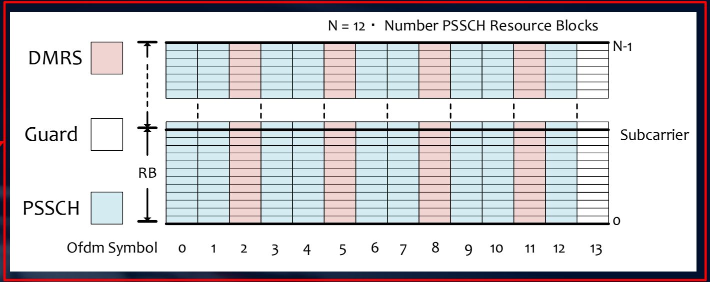
Communications types in 4G LTE and 5G NR to support automated driving

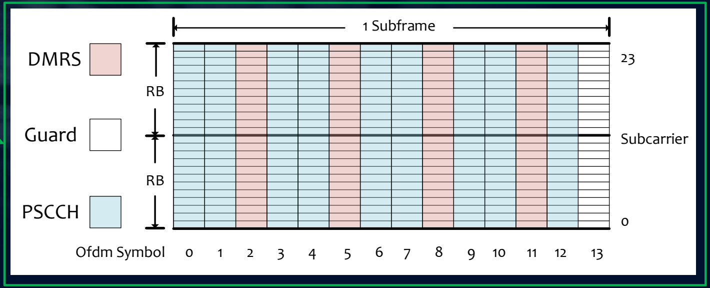


C-V2X / PC5 measurements for each PSCCH / PSSCH occurance

- LTE-based: Broadcast, no bi-directional communication
- Example of V2X stations broadcasting messages with a period of 100 ms







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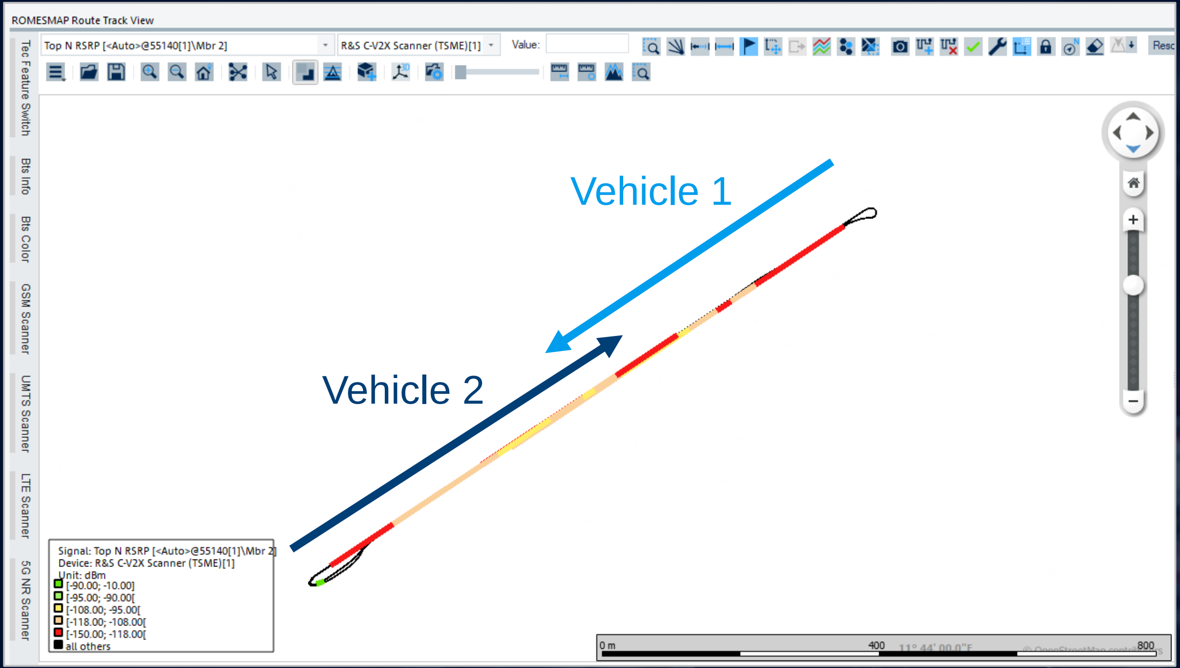
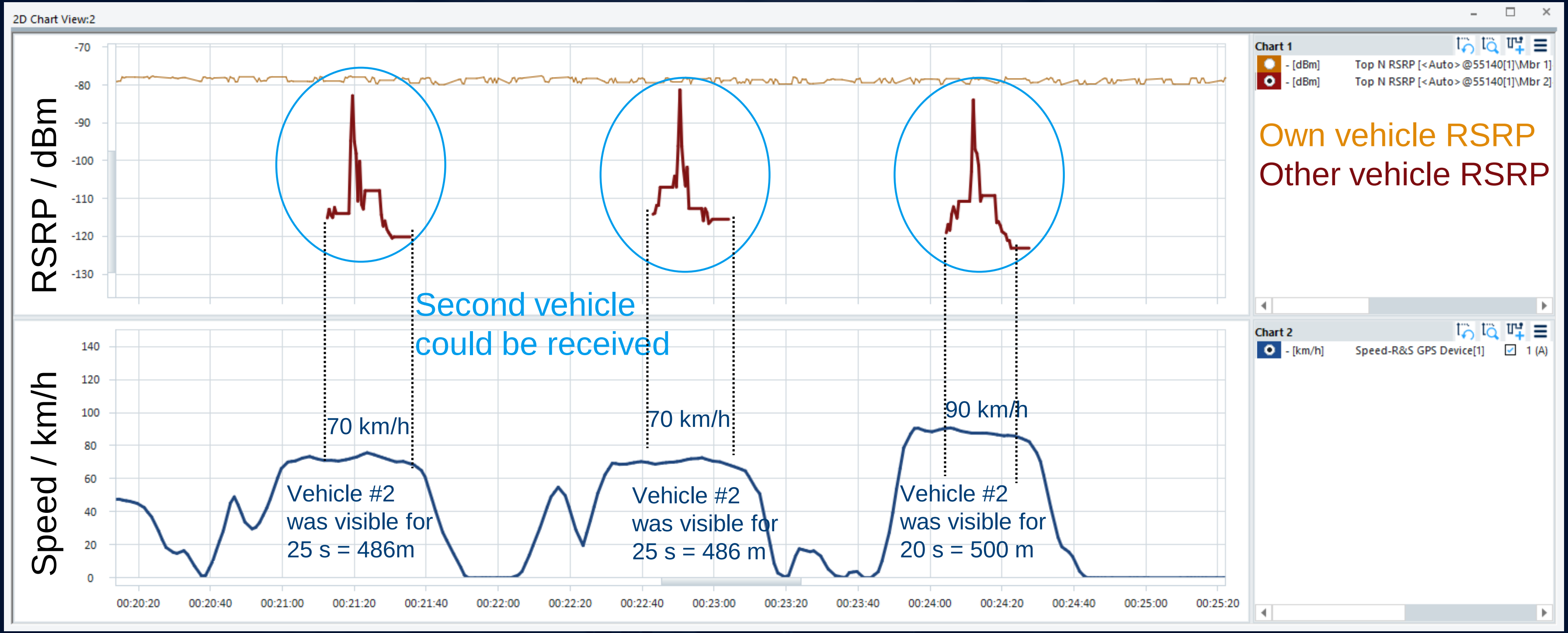
Vehicle approaching scenario on proving ground - RSRP analysis



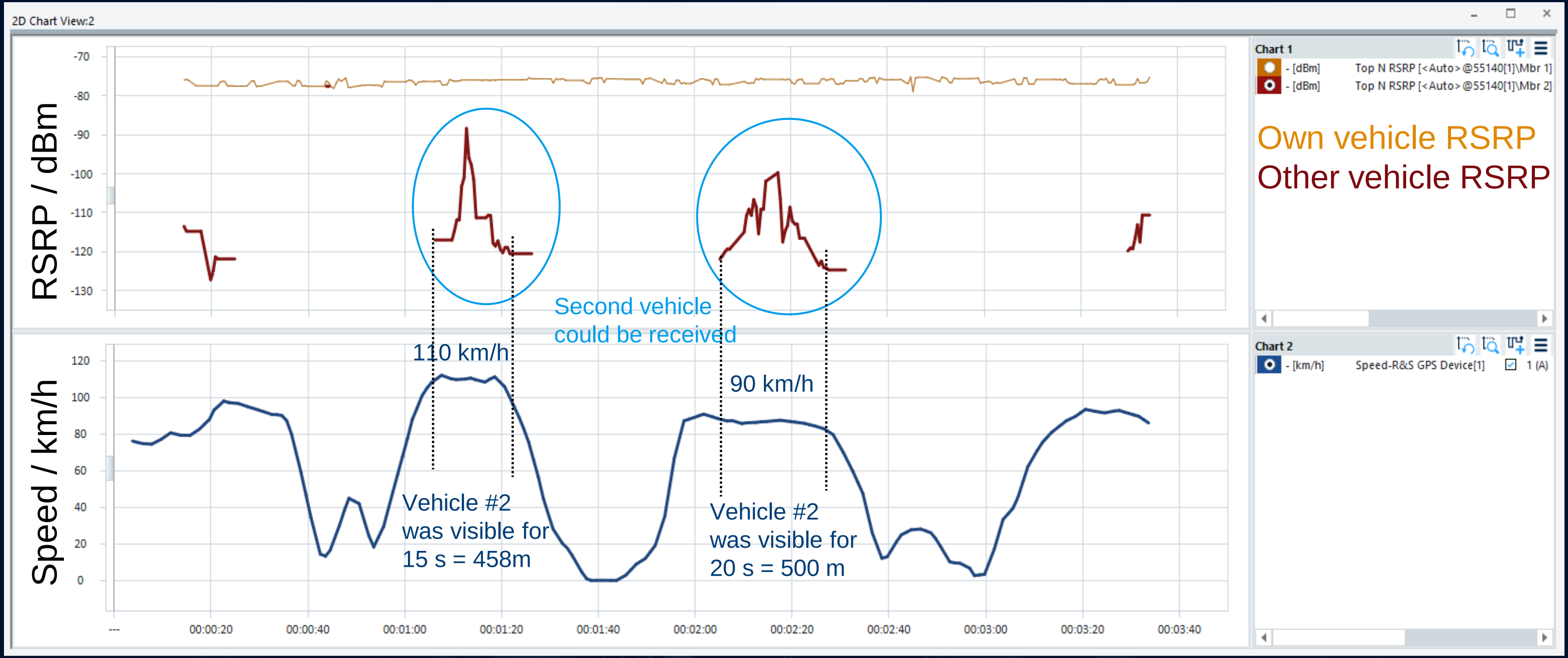
- Scanner was placed in vehicle #1 with RX antenna on the top of the roof
- The trial was conducted with different car driving speeds (same speed for both cars)
- High doppler shift due to opposite driving directions of the vehicles

- Question: What is the C-V2X / PC5 coverage?

Vehicle approaching scenario 90 / 70 kmph - RSRP Analysis



Vehicle approaching scenario 110 / 90 kmph - RSRP Analysis



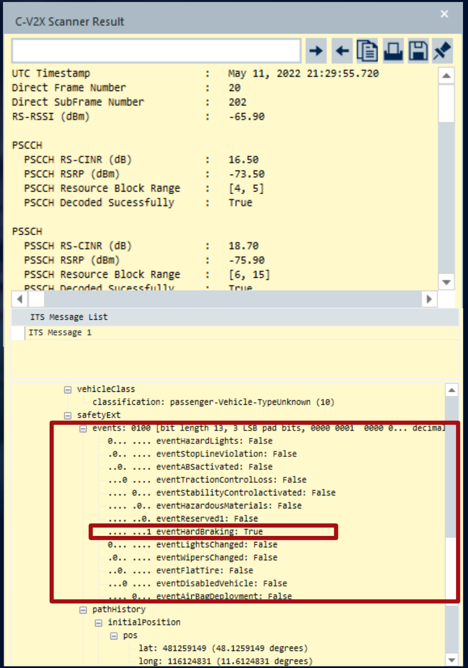
- Approaching vehicle C-V2X messages can be received in the range of 450 to 500m (line of sight)
- Non-line of sight scenarios (street canyons) to be analyzed

Support of C-V2X Scanning in ROMES4
C-V2X scanner message view and ITS message decoding

- Every scanner measurement is represented by a line in the C-V2X Scanner Message View
- By double-clicking on one line, message details will open in a dedicated window

C-V2X Scanner Message View

	UTC Timestamp	L2 Mac Source ID	RSSI (dBm)	PSCCH CINR (dB)	PSCCH RSRP (dBm)	PSSCH CINR (dB)	PSSCH RSRP (dBm)
2341	Apr 11, 2022 09:54:4...	45007	-77.10	12.37	-104.19	12.37	-105.23
2342	Apr 11, 2022 09:54:4...	45001	-66.30	19.83	-96.43	19.83	-94.08
2343	Apr 11, 2022 09:54:4...	45002	-66.55	17.54	-96.57	17.54	-94.34
2344	Apr 11, 2022 09:54:4...	45003	-66.77	17.47	-96.43	17.47	-94.55
2345	Apr 11, 2022 09:54:4...	45004	-76.68	11.71	-105.96	11.71	-104.69
2346	Apr 11, 2022 09:54:4...	45005	-85.21	0.18	-116.70	0.18	-114.92
2347	Apr 11, 2022 09:54:4...	45006	-67.51	17.35	-95.89	17.35	-95.35
2348	Apr 11, 2022 09:54:4...	45007	-72.77	15.18	-100.91	15.18	-100.68
2349	Apr 11, 2022 09:54:4...	45001	-73.93	14.07	-102.98	14.07	-101.81
2350	Apr 11, 2022 09:54:4...	45002	-74.19	13.14	-103.19	13.14	-102.08
2351	Apr 11, 2022 09:54:4...	45003	-74.36	13.99	-103.48	13.99	-102.25
2352	Apr 11, 2022 09:54:4...	45004	-83.47	4.36	-113.36	4.36	-112.33
2353	Apr 11, 2022 09:54:4...	45006	-75.12	12.08	-104.75	12.08	-103.04
2354	Apr 11, 2022 09:54:4...	45007	-80.10	6.94	-110.34	6.94	-108.33
2355	Apr 11, 2022 09:54:4...	45001	-69.32	18.35	-97.41	18.35	-97.17
2356	Apr 11, 2022 09:54:4...	45002	-69.30	18.68	-97.59	18.68	-97.15
2357	Apr 11, 2022 09:54:4...	45003	-69.21	17.24	-97.67	17.24	-97.04
2358	Apr 11, 2022 09:54:4...	45004	-78.64	9.60	-107.89	9.60	-106.77
2359	Apr 11, 2022 09:54:4...	45005	-86.35	-1.19	-117.73	-1.19	-117.31
2360	Apr 11, 2022 09:54:4...	45006	-68.77	16.76	-97.58	16.76	-96.61



- **All ITS stacks (China, US, Europe) supported in ROMES4**

ITS message decoding is available

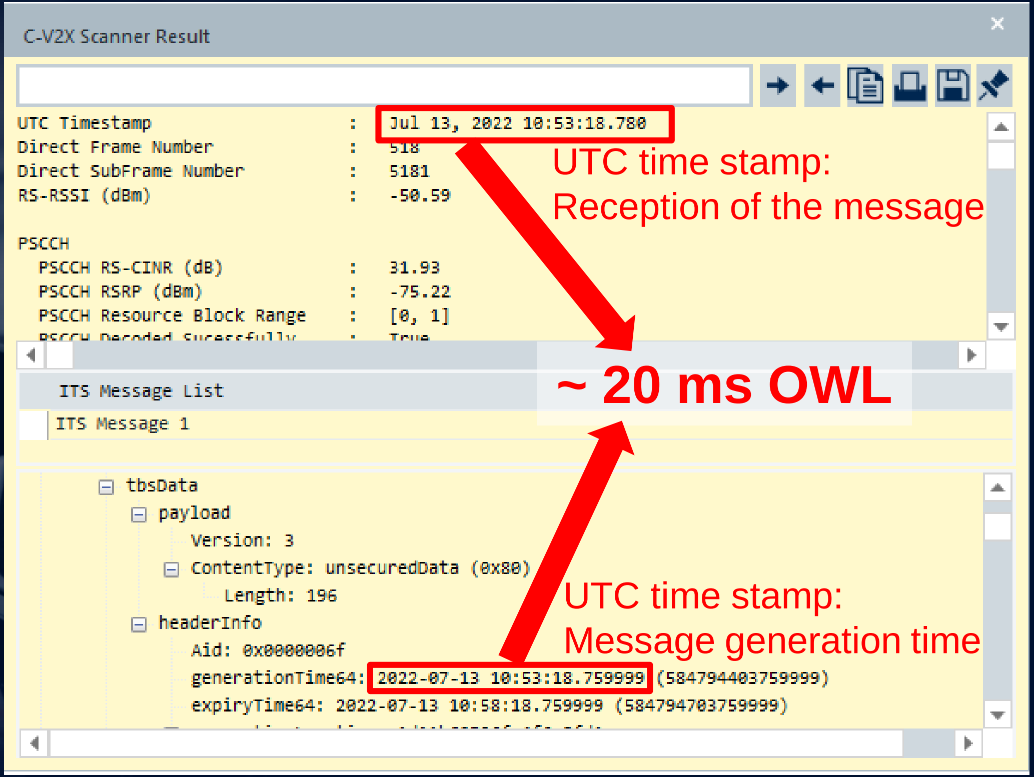
```
⊟ vehicleClass
    classification: passenger-Vehicle-TypeUnknown (10)
⊟ safetyExt
  ⊟ events: 0100 [bit length 13, 3 LSB pad bits, 0000 0001  0000 0... decimal
      0... .... eventHazardLights: False
      .0.. .... eventStopLineViolation: False
      ..0. .... eventABSactivated: False
      ...0 .... eventTractionControlLoss: False
      .... 0... eventStabilityControlactivated: False
      .... .0.. eventHazardousMaterials: False
      .... ..0. eventReserved1: False
      .... ...1 eventHardBraking: True
      0... .... eventLightsChanged: False
      .0.. .... eventWipersChanged: False
      ..0. .... eventFlatTire: False
      ...0 .... eventDisabledVehicle: False
      .... 0... eventAirBagDeployment: False
  ⊟ pathHistory
    ⊟ initialPosition
```

```
⊟ pos
    lat: 481259149 (48.1259149 degrees)
    long: 116124831 (11.6124831 degrees)
    elevation: 0 (0.0 m)
  transmission: unavailable (7)
  speed: 0 (0.00 m/s, 0.00 mph)
  heading: 10841 (135.51 degrees)
⊟ accelSet
    long: 2001 (unavailable)
    lat: 2001 (unavailable)
    vert: -127 (unavailable)
    yaw: 32767 (327.67 degree/s)
⊟ brakes
    brakePadel: unavailable (0)
    traction: unavailable (0)
    abs: unavailable (0)
    scs: unavailable (0)
    brakeBoost: unavailable (0)
    auxBrakes: unavailable (0)
⊟ size
    width: 190 (1.90 m)
    length: 480 (4.80 m)
```

- ITS message decoding in combination with RF measurements helps verifying C-V2X communication

One-way-latency reference measurements

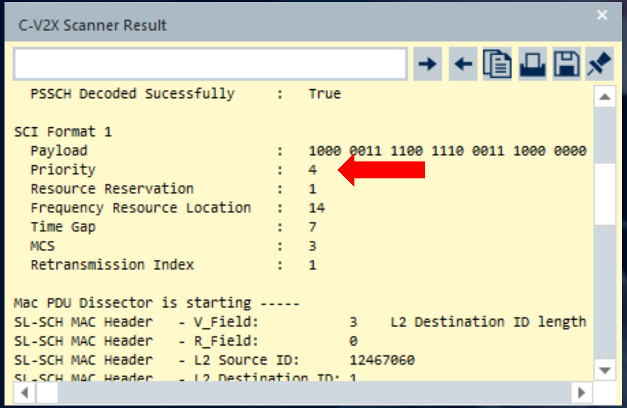
- ▶ Delay between message generation (car 1) and reception (car 2)?
- ▶ Time delay can vary due to message queuing on the TCU and multipath propagation (RF level)



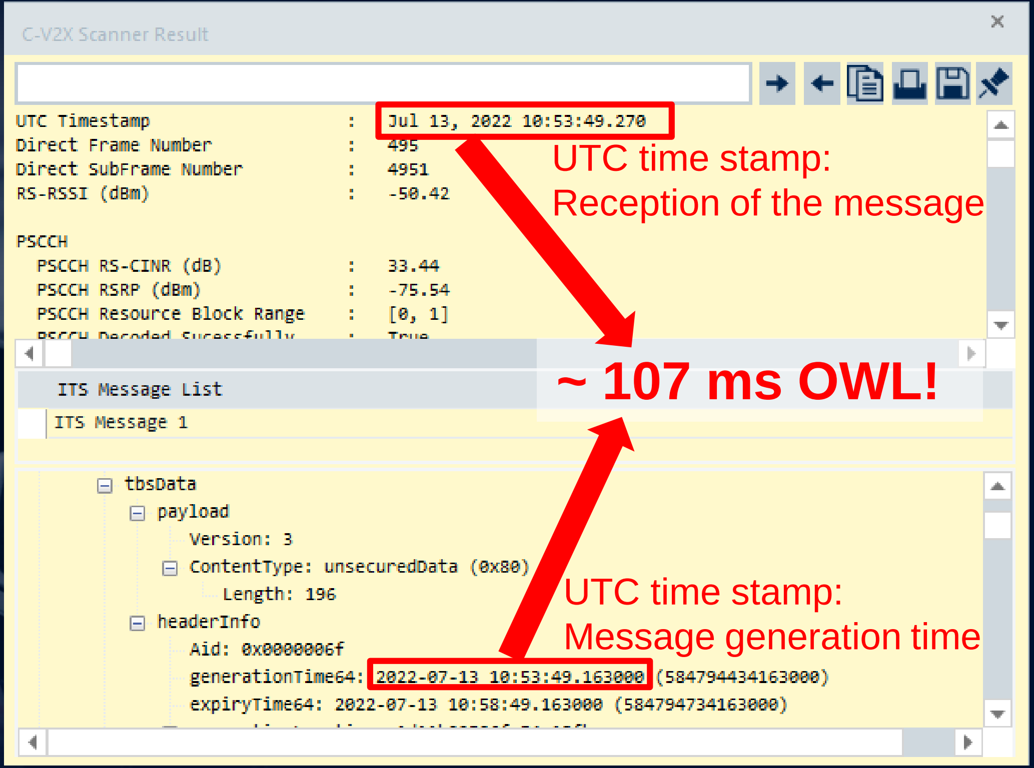
▶ C-V2X is safety relevant and latency shall be under control!

One-way-latency reference measurements – example 2

- Depending on the message priority (ProSe Per Packet Prioritiy – PPPP) a certain latency needs to be ensured → 5G AA / SAE / …



- Latency evaluation essential for proper C-V2X verification



Bit Error Rate (BER) reference measurements

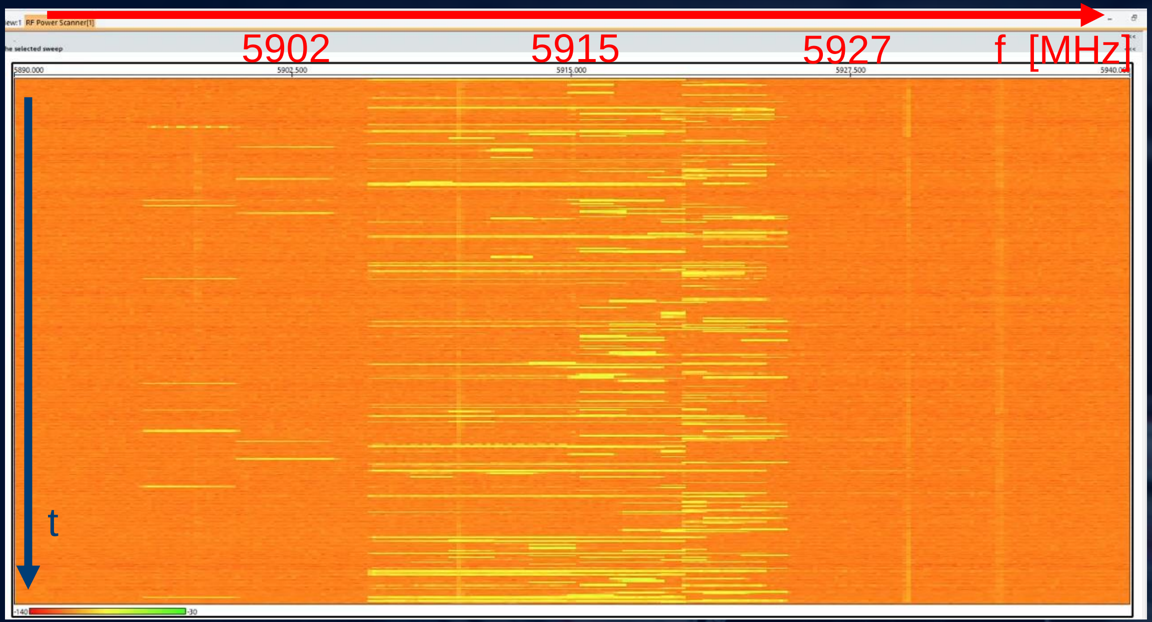
C-V2X Scanner Message View

	UTC Timestamp	L2 Mac Source ID	RSSI (dBm)	PSSCH CINR (dB)	PSSCH RSRP (d...	PSSCH BER (%)
153	Okt 20, 2022 07:50:03.320	890570	-91.60	8.22	-118.36	4.65
154	Okt 20, 2022 07:50:03.379	9379573	-77.56	24.13	-100.54	7.33
155	Okt 20, 2022 07:50:03.383	9379573	-69.13	30.20	-91.01	9.13
156	Okt 20, 2022 07:50:14.201	890570	-93.61	3.28	-122.99	14.28
157	Okt 20, 2022 07:50:14.279	9379573	-73.77	26.91	-96.04	7.33
158	Okt 20, 2022 07:50:14.283	9379573	-67.09	30.85	-88.95	9.13
159	Okt 20, 2022 07:50:25.158	9379573	-75.02	25.84	-98.01	6.85
160	Okt 20, 2022 07:50:25.172	9379573	-69.29	30.17	-91.58	9.13
161	Okt 20, 2022 07:50:25.177	890570	-93.25	4.07	-121.92	10.65
162	Okt 20, 2022 07:50:35.915	9379573	-66.48	31.47	-87.77	6.97
163	Okt 20, 2022 07:50:35.923	9379573	-63.91	28.68	-89.82	9.25
164	Okt 20, 2022 07:50:46.817	9379573	-68.25	32.26	-89.91	9.01
165	Okt 20, 2022 07:50:46.865	890570	-93.57	3.89	-122.92	12.56
166	Okt 20, 2022 07:50:46.908	16670963	-70.71	30.70	-92.25	7.21
167	Okt 20, 2022 07:50:57.389	16670963	-73.21	28.98	-95.73	9.37
168	Okt 20, 2022 07:50:57.446	890570	-93.76	2.58	-123.60	14.66
169	Okt 20, 2022 07:50:57.481	16670963	-74.93	26.27	-98.10	6.73
170	Okt 20, 2022 07:51:10.981	16670963	-83.87	17.96	-108.30	7.33
171	Okt 20, 2022 07:51:10.989	16670963	-73.72	28.47	-95.82	9.13
172	Okt 20, 2022 07:51:23.208	16670963	-68.37	31.54	-89.76	6.85

- ▶ BER [%] per message = received bits with errors / total number of bits
- ▶ Bit errors can occur due to bad radio conditions such as low power level or signal to interference ratio

▶ Monitoring the BER helps evaluating whether TCU can still decode the message

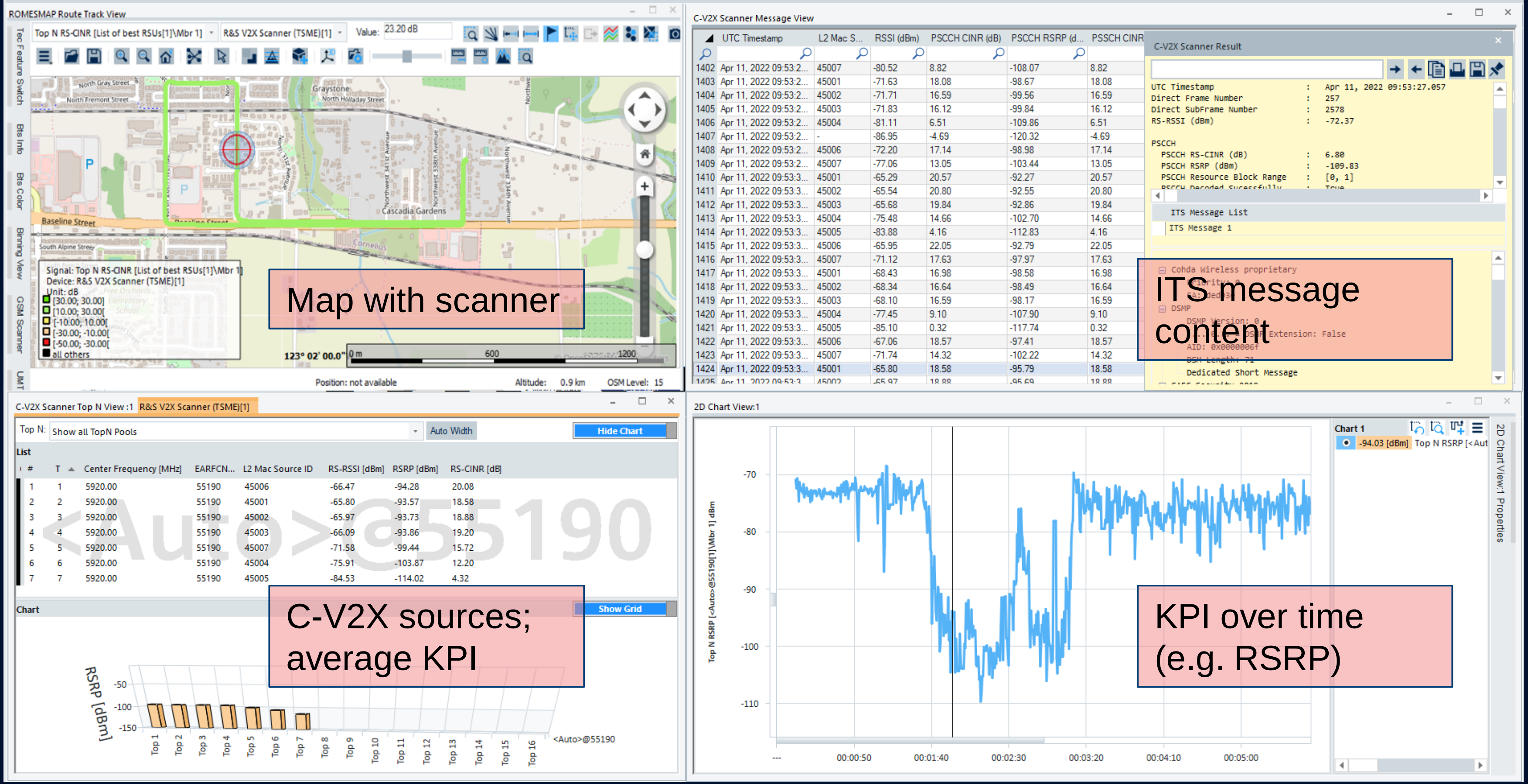
Spectrum measurements – monitoring C-V2X spectrum



- Identification of interferers
- How busy is the C-V2X spectrum?
- Real-time spectrum analysis / waterfall diagram beneficial

► Qualitative status of load in the C-V2X system at the measurement location

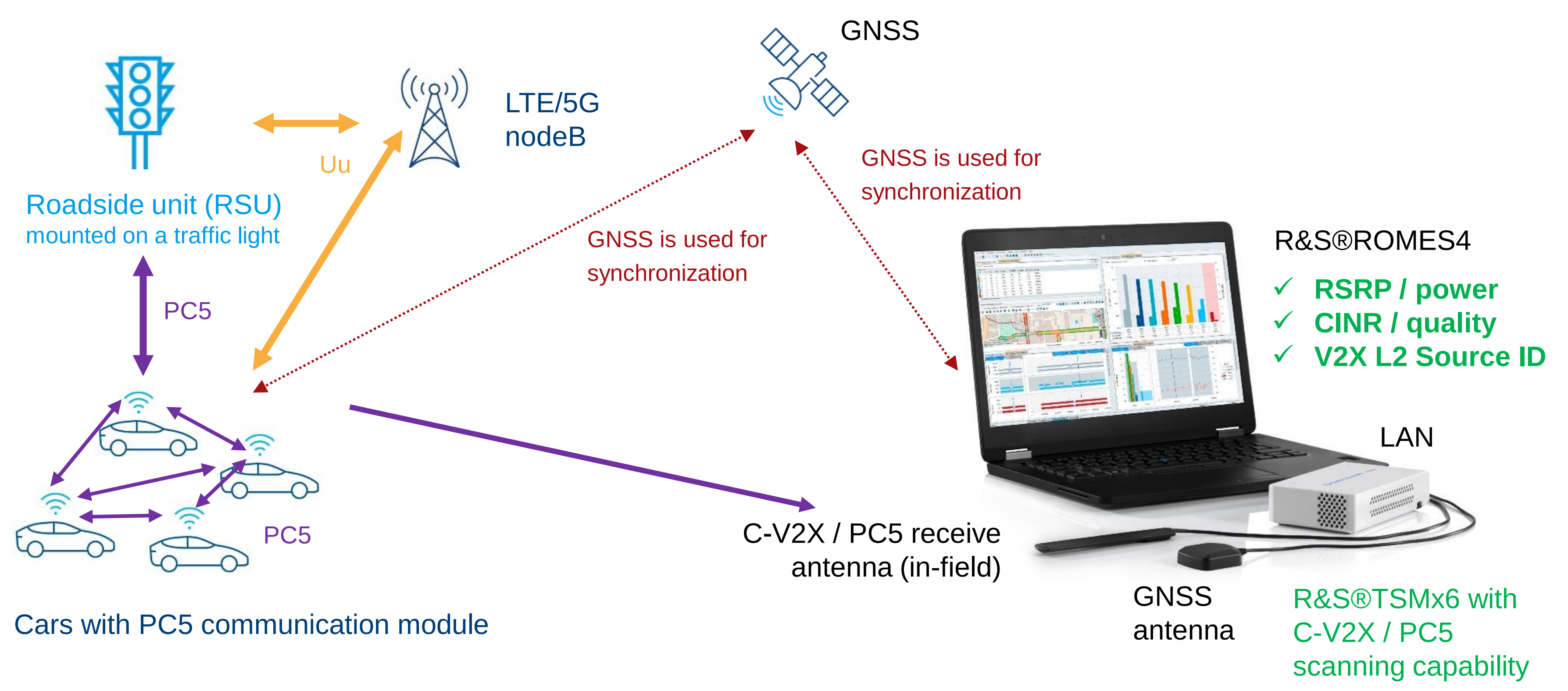
WHAT WILL YOU SEE? – ROMES4 VIEWS - SUMMARY



CONTENT

- C-V2X: the "why" and the "what"
- C-V2X pain points
- A bit of technology
- Real field measurement results
- **C-V2X Test Solutions**
- **Conclusion**

C-V2X / PC5 scanner – field test scenario



Extensive R&S offerings for testing of C-V2X use cases
From lab, R&D, production to field test

Scalable

Precise & Repeatable

Performance optimized

3GPP RF

Allows customer to validate hardware using Rx and Tx measurements capability based on 3GPP 36.521-1

3GPP PROTOCOL

3GPP Protocol Test Cases leveraging CMW500 protocol testing features and test automation tools

CAICT TESTING

CAICT ITS Conformance Test package from Neusoft for the China Market focused on Message, Network and Application Security.

Neusoft东软

TCU APPLICATION

Testing using CMW500 and Vector CANOE.Car2X system. Simulated environment allows real TCU software to be used with key interfaces (Ethernet, CAN) and protocols (AutoSAR etc.)

E2E APPLICATION

Enables OEM to test complete Car, offering a quick transition from lab to proving ground, simulating 150+ Cars

	3GPP RF	3GPP PROTOCOL	CAICT TESTING	TCU APPLICATION	E2E APPLICATION
E2E Application					●
TCU Application				●	○
ITS Stack			●	○	○
3GPP Stack		●	○	○	○
3GPP PHY	●	○	○	○	○

● Test Focus
○ Required functionality

SUMMARY

www.rohde-schwarz.com/v2x
www.rohde-schwarz.com/mnt

C-V2X should contribute to the global goal to reduce the number of road traffic deaths

C-V2X is more a governmental task than a clear financial business case. C-V2X ecosystem e.g. for road infrastructure is complex and country-/region-dependent.

ITS message decoding + RF reference measurements is a unique combination for C-V2X communication verification → very important for RSUs, too!

Message latency + BER + spectrum measurements add more value to characterizing C-V2X communication → very important for RSUs, too!

Network Scanners TSMx6 offer this unique combination for RSU site acceptance and as reference measurements what the TCUs can achieve

► **Rohde & Schwarz is your One-Stop-Shop for C-V2X lab, R&D, production tests and in-field performance verification**

Find out more

www.rohde-schwarz.com/v2x

www.rohde-schwarz.com/mnt

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Make ideas real