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# Deliverable D6.1:

# Report on Lab and First Field Trials

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# Contents

# 1 Scope

This document summarizes results from initial laboratory and field test campaigns performed by the ConVeX project with the C-V2X equipment. Also a summary how to test the C-V2X equipment in a lab environment is provided as well as how to examine that the required functionality is properly in operation after installation of a DP in vehicular and roadside ITS stations.

# 2 References

[1] ConVeX Project Deliverable D2.2, “Final ConVeX System Architecture Description”

[2] ConVeX Project Deliverable D4.1, “Roadside ITS-Station Specification”

[3] ConVeX Project Deliverable D5.1, “Vehicular ITS-Station Specification”

[4] ConVeX Project Deliverable D7.1, “Final Report on Field Tests and Evaluation Report”

[5] See https://www.mobilemark.com/product/mag-59001575/

[6] See https://www.taoglas.com/product/magma-aa170-gpsglonassbeidou-magnetic-mount-antenna-2/

[7] See http://www.hirschmann-car.com/fileadmin/content/downloads/pdf/produkttabellen_5/hirschmann_cc-cellular-communication.pdf

# 3 Definitions and Abbreviations

## 3.1 Definitions

See definitions in the ConVeX System Architecture description [1].

## 3.2 Abbreviations

| | |
|---|---|
| A9 | Motorway A9 |
| ADB | Android Debug Bridge |
| AP | Access Point |
| APQ | Application Processor system |
| BSM | Basic Safety Message |
| CAM | Cooperative Awareness Message |
| CCARD | Communication card (for V2N connectivity) |
| C-ITS | Cooperative Intelligent Transport Systems |
| C-V2X | Cellular V2X Communication |
| DENM | Decentralized Environmental Notification Message |
| DP | Development Platform |
| ETSI | European Telecommunications Standards Institute |
| FAKRA | Fachkreis Automobil (DIN 72594-1 / USCAR-18 standard for coaxial cable antenna connectors) |
| GNSS | Global Navigation Satellite System |
| GPS | Global Positioning System |
| ID | Identifier |
| IRS | ITS Roadside station |
| ITS | Intelligent Transport System |
| IVI | In-Vehicle Information as defined in SAE and CEN/ISO information on current (dynamic) sign display to be sent from infrastructure to vehicles |
| IVS | In-Vehicle Signage |
| JTAG | Joint Test Action Group |
| KPI | Key Performance Indicators |
| LAN | Local Area Network |
| LOS | Line-of-Sight |
| LTE | Long Term Evolution |
| MCS | Modulation and Coding Scheme |
| MDM | C-V2X Modem processor system |
| MPR | Maximum Power Reduction |
| NLOS | Non-Line-of-Sight |
| OEM | Original Equipment Manufacturer |
| PC | Personal Computer |

| | |
|---|---|
| PC5 | ProSe Communication reference point 5. |
| PER | Packet Error Rate |
| PRR | Packet Reception Rate |
| RV | Remote Vehicle |
| RSU | Road Side Unit |
| Rx | Receive |
| SAE | Society of Automotive Engineers |
| SPaT/MAP | Signal Phase and Time / Map Standard |
| SW | Software |
| TCC | Traffic Control Center |
| Tx | Transmit |
| UE | User Equipment |
| USB | Universal Serial Bus |
| USB OTG | USB On-The-Go |
| V2I | Vehicle to Infrastructure |
| V2N | Vehicle to Network |
| V2P | Vehicle to Pedestrian |
| V2V | Vehicle to Vehicle |
| V2X | Vehicle to Everything |
| VRU | Vulnerable Road User |
| WAN | Wide Area Network |
| WiFi | Wireless Fidelity |
| WLAN | Wireless Local Area Network |

# 4 Lab testing of C-V2X Equipment

## 4.1 Software installation and lab test configuration

The C-V2X development platform (DP) consists of several interconnected hardware components. Among the main elements are the MDM9150 modem module (denoted in short *MDM module*) and the application processor APQ8096AU module (denoted in short *APQ module*), as described in Deliverable D2.2 [1].

For initial installation of firmware images on a raw C-V2X DP, a setup as shown in Figure 4.1-1 is used. Firmware and software images which have been downloaded via WAN internet connection to a host PC/laptop are installed via dedicated physical USB connections on the APQ and MDM modules using the Android Debug Bridge (adb) command-line tool.

After connecting the DP to 12 V power supply, the USB cables can be connected with the Host PC and firmware/software installation procedures using adb can be used.

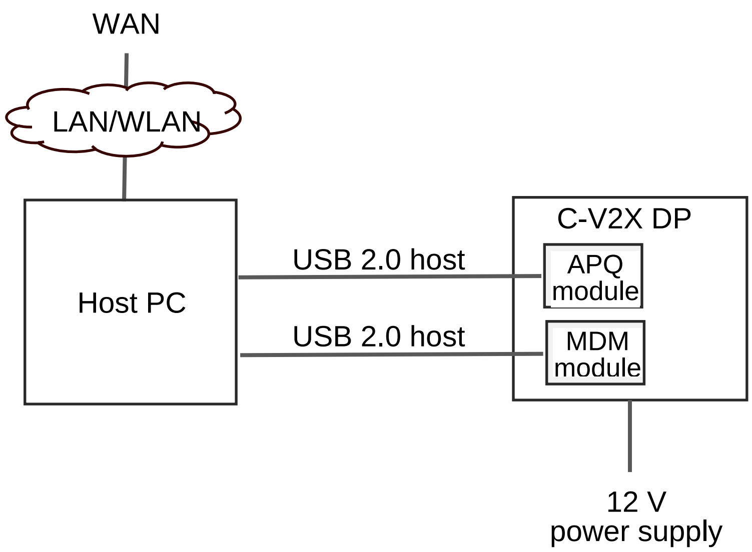



***Figure 4.1-1: Configuration for initial firmware/software image installation***

When re-installing firmware and/or software on a functioning C-V2X DP as well as for general DP lab testing purposes, a setup as shown in Figure 4.1-2 needs to be established. The DP needs to be connected to 12 V power supply and to a GPS antenna. Note that the functioning DP will start tx and rx operation only after reliable acquisition of GPS signals and establishment of time synchronization. If the testing location provides insufficient indoor GPS coverage, the GPS antenna may need to be placed close or even outside of a window.

The C-V2X DP must be connected to a LAN via Ethernet cable or via WLAN radio for connectivity with a cloud-based measurement server. The LAN/WLAN must provide WAN connectivity to the DP. A host PC/laptop is used to connect to, monitor and remotely control the DP via the (W)LAN (this can also be done via the USB connection to the APQ using adb).

If WLAN is used, the DP needs to be configured with the SSID and passphrase associated with the employed WiFi Access Point. Typically, an ordinary mobile phone may be used as WiFi access point providing WAN access via a cellular network (see more details in Section 4.2.2). In this case, there is no need to configure a CCARD for providing 3G/4G cellular connectivity. V2N messages can be routed via the WAN-enabled WiFi AP, e.g. mobile phone or other portable device.

In cases of critical failure of the DP, e.g. during firmware imaging, a special debug board may be connected to the DP via its debug board port. The debug board can be connected via USB with the Host PC. The debug board may also be used to flash firmware directly on any of the components of the DP (including APQ module, modem module, CAN interface processor and other programmable modules) using a JTAG interface. Also, the adb tool via USB connections as shown in Figure 4.1-1 may be used for DP debugging purposes.

The debug board also allows interacting with the DP via a serial console. There is one serial console port attached to the APQ module and another for the MDM module.

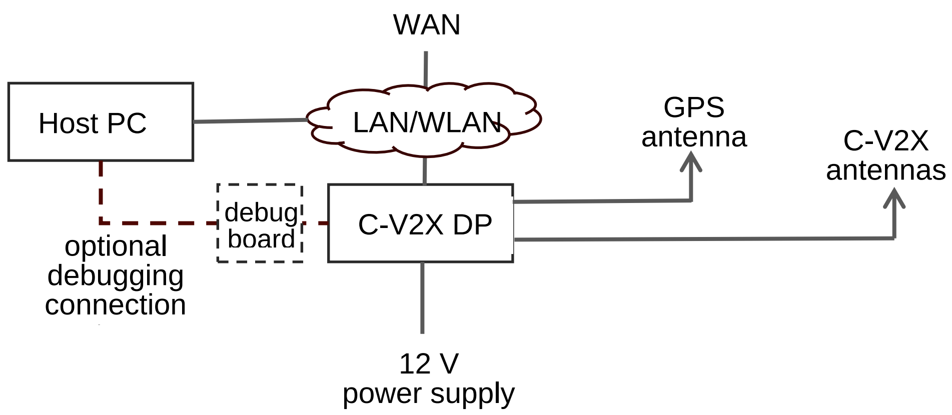



***Figure 4.1-2: Configuration of C-V2X platform for software re-installation and lab test***

The connectors of a DP board are shown in Figure 4.1-3.

When connecting the imaged DP with 12 V power, both APQ and MDM modules should boot independently of each other. The internal connection between the two modules uses the modem host interface (MHI) protocol.

The software in use has sleep current of 130 mA. If 130 mA is not acceptable due to the battery drain rate, an external power supply needs to provide 12 V to the platform.

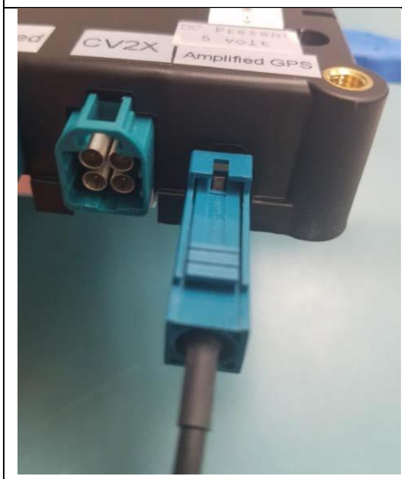
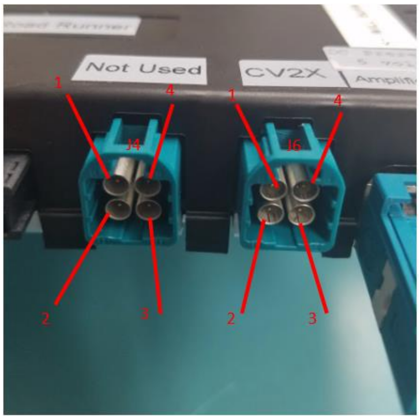
| 12 V power supply: | APQ debug connector and USB ports: |
|---|---|
|  | <br> |
| USB connector for MDM modem and Ethernet port: | |
| <br> | |
| GPS antenna connector (single FAKRA): | C-V2X 5.9 GHz antenna connectors (only right quad-FAKRA connector used), 4: tx and primary rx, 1: rx diversity: |
| <br> | <br> |

**Figure 4.1-3: Connectors of the C-V2X DP**

# 4.2 Test of basic operation of C-V2X DP

## 4.2.1 General

The following sections describe the recommended steps to be executed in a lab environment or in a vehicle to check that the employed C-V2X DPs are working as desired, e.g. after initial software/firmware installation, software update or exchange of any components of the equipment integrated in the vehicles prepared for field testing.

The first step is to establish the configuration as outlined in Figure 4.1-2.

At least two C-V2X DPs need to be configured in the same fashion for a test of C-V2X tx and rx communication functionality.

## 4.2.2 Setup and test of WiFi connectivity

The DP has a Wi-Fi client available through the APQ module. No external Wi-Fi antennas are needed since the DP already includes two internal antennas.

The target external access point needs to be added to a WPA configuration file, which is placed at `/etc/wpa_supplicant/wpa_supplicant-wlan0.conf`.

To configure the needed parameters like the SSID and the passphrase for the respective WLAN, the tool wpa_passphrase can be used, piping its output to the configuration file:

```
$ cd /etc/wpa_supplicant
$ wpa_passphrase <SSID> <passphrase>  > wpa_supplicant-wlan0.conf
```

where <SSID> is the SSID and *<passphrase>* is the passphrase used by the WiFi Access Point, e.g. *wpa_passphrase myWLAN mySecretkey >wpa_supplicant-wlan0.conf*.
Thereafter, the DP can be power-cycled or the new WPA configuration can be enabled with the command

```
$ systemctl restart wpa_supplicant@wlan0
```

The operation of WiFi connectivity can be tested, e.g. by pinging the IP address of the host PC. After this is accomplished, the DP should connect to the configured WiFi network automatically at boot procedure when the WiFi AP is in operation.

The DP may also be configured as Wi-Fi Access Point. Details are described in clause 5.2.6 of DP User Guide **Error! Reference source not found.**.

## 4.2.3 Setup and test of WAN connectivity with measurement server

The application responsible to send messages to the measurement server should come up automatically in the DP boot procedure. Upon availability of WAN internet connectivity, the application will start communication with the measurement server. The communication is based on https. The server configurations are installed by default when installing QC Middleware. Configurations stored in the file /home/root/cv2x/app.ini.

In addition, a unique identifier (DP-UID) of each C-V2X DP needs to be configured on the measurement server in order to generate a token for authentication. DP-UID and token will be saved in the configuration file of each DP.

This way, all transmitted and received messages and warnings are forwarded to the server and can be visualized in a real-time map.

The measurement server configuration is stored in the file /home/root/cv2x/app.ini.

If any of the parameters needs to be changed, this file should be changed with a text editor (e.g. gedit or vi).

When a DP is connected, it appears on a map in the REALTIME tab on the server. The left side panel indicates which other DPs are also connected according to the ID given, as visible in figure 4.2.3-1. Taking the car 1002 as an example, transmitted and received messages are visible on the message panel under the map. This way, one can also verify that the device under test is fully functional.

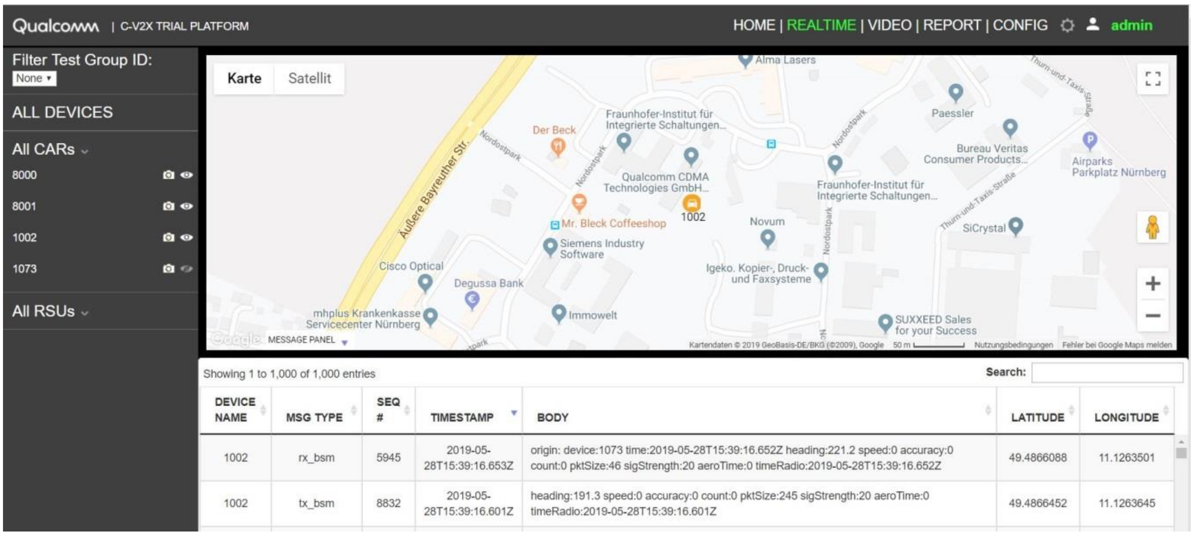



***Figure 4.2.3-1: Example browser view of C-V2X measurement server***

## 4.2.4 Test of V2V transmission and reception

When GPS reception is established, the DP starts transmission and reception. This can be checked using an *adb shell*:

**Test if GPS is in operation**

Open a command window on your Host PC:

```
adb shell
```

Issue following commands in the adb shell:

```
<xxxdev>:/  $ kinematics-sample-client
<xxxdev>:/  $ start
```

Figure 4.2.4-1 shows an example screen when using the above commands

```
root@8x96autocv2x:~# kinematics-sample-client
server ip : 192.168.100.1
Initializing Kinematics API.
Setting the send callback.
----------------------------------------------------
v2x init callback, status=0
----------------------------------------------------

v2x initialized successfully.
***********************************************************
* Command Options:
    start   - starts receiving data from server
    stop    - stops receiving data from server
    set <n> - sets data rate to n Hz [1 <= n <= 10]
    quit    - ends program

***********************************************************
start
cmd=start
start cmd received
----------------------------------------------------
[ 0 ]
v2x newfix listener:
  utc_fix_time                  - 1559124859.5770001
  utc_fix_mode                  - 3
  latitude                      - 49.486643671989441
  longitude                     - 11.126173138618469
  altitude                      - 365.94775390625
  qty_SV_in_view                - 7
  qty_SV_used                   - 6
  gnss_status:
      unavailable               - 0
      aPDOPofUnder5             - 0
      inViewOfUnder5            - 0
      localCorrectionsPresent   - 0
      networkCorrectionsPresent - 0
  SemiMajorAxisAccuracy         - 78
  SemiMinorAxisAccuracy         - 25
  SemiMajorAxisOrientation      - 151.875
  heading                       - 0
  velocity                      - 0
  climb                         - 0
  lateral_acceleration          - 0
  longitudinal_acceleration     - 0
  time_confidence               - 15.056643486022949
  velocity_confidence           - 0.49739319086074829
  leap_seconds                      - 18
----------------------------------------------------
```

***Figure 4.2.4-1: Example use of the kinematics-sample-client command***

**Verification of transmitted messages**

This is done by issuing a command to display the ITS stack statistics. The counter of tx and rx is updated, i.e. increases as they occur:

When using ETSI ITS stack, enter following command:

```
etsifacility_stats -a
```

When using SAE ITS stack, enter following command:

```
asd_stats -b
```

Figure 4.2.4-2 shows an example screen when using the above `etsifacility` command.

```
root@8x96autocv2x:~# etsifacility_stats -a
CAM stats:
        Transmit channel:                180
        Transmit Interval:               1000
        Transmit count:                  28
        Receive count:                   0
        Encode fail:                     0
        Decode fail:                     0
        RV Count:                        0
        Prerec file replay:              0
        Last Transmit Timestamp:         28/05/2019-15:27:38
        Last Receive Timestamp:
        Pre LF Transmit Timestamp:       28/05/2019-15:27:37
        Last LF Transmit Timestamp:      28/05/2019-15:27:38
        CAM security enabled:            0
        CAM sec sign failed:             0
        CAM sec verification failed:     0
        CAM cert change Count:           0
```

***Figure 4.2.4-2: Example use of the etsifacility command***

Another way to verify that tx has started is to check whether the ITS messages generated are being forwarded from APQ to MDM. This can be done by taking a dump of the packets on the interface named rmnet_data1.

```
<xxxdev>:/  $ tcpdump -i rmnet_data1
```

Figure 4.2.4-2 shows an example screen when using the above `tcpdump` command.

```
root@8x96autocv2x:~# tcpdump -i rmnet_data1
tcpdump: WARNING: rmnet_data1: no IPv4 address assigned
tcpdump: verbose output suppressed, use -v or -vv for full protocol decode
listening on rmnet_data1, link-type LINUX_SLL (Linux cooked), capture size 65535 bytes
15:27:13.620716 IP6 80f8:f80:f80f:80f8:4d2:697c:9317:c148.2008 > ip6-allnodes.9000: UDP, length 91
15:27:14.618485 IP6 80f8:f80:f80f:80f8:4d2:697c:9317:c148.2008 > ip6-allnodes.9000: UDP, length 102
15:27:15.618718 IP6 80f8:f80:f80f:80f8:4d2:697c:9317:c148.2008 > ip6-allnodes.9000: UDP, length 102
15:27:15.718837 IP6 80f8:f80:f80f:80f8:4d2:697c:9317:c148.2008 > ip6-allnodes.9000: UDP, length 91
15:27:15.818310 IP6 80f8:f80:f80f:80f8:4d2:697c:9317:c148.2008 > ip6-allnodes.9000: UDP, length 91
15:27:16.819301 IP6 80f8:f80:f80f:80f8:4d2:697c:9317:c148.2008 > ip6-allnodes.9000: UDP, length 102
15:27:17.818988 IP6 80f8:f80:f80f:80f8:4d2:697c:9317:c148.2008 > ip6-allnodes.9000: UDP, length 102
15:27:18.818769 IP6 80f8:f80:f80f:80f8:4d2:697c:9317:c148.2008 > ip6-allnodes.9000: UDP, length 102
15:27:19.818675 IP6 80f8:f80:f80f:80f8:4d2:697c:9317:c148.2008 > ip6-allnodes.9000: UDP, length 102
15:27:20.818289 IP6 80f8:f80:f80f:80f8:4d2:697c:9317:c148.2008 > ip6-allnodes.9000: UDP, length 102
15:27:21.818460 IP6 80f8:f80:f80f:80f8:4d2:697c:9317:c148.2008 > ip6-allnodes.9000: UDP, length 102
```

***Figure 4.2.4-3: Example use tcpdump on `rmnet_data1`***

**Validation that processes required for normal operation are running**

Check with the `ps` command that following processes are running on the APQ:

```
SavariCANd -t generic_can_frames -T -d can0
qcrr-gnss-cand
AeroLinkv2xd.bin
GNd -k -K 100
mosquitto -c /home/root/cv2x
```

```
blackbox -o ../logs/
wpa_supplicant
its_adp_dp
v_app
```

It can happen that the mosquitto process does not come up during boot and any MQTT type of communication will be affected. Therefore restart of the `trial` system process needs to be entered:`<xxxdev>:/  $ systemctl restart trial`

# 4.3 Test of interfaces in the vehicle

## 4.3.1 General

In addition to the configuration shown in Figure 4.1-2, the DP installed in a vehicle is provided with connectivity to the Human-Machine Interface (HMI) of the vehicle and to the onboard CAN network. The HMI connection is established via the LAN/WLAN as in Figure 4.1-2 using MQTT communication. The MQTT broker for this purpose is implemented on the APQ processor together with the MQTT clients. The Vehicle HMI is emulated with a laptop PC which produces audio-visual information that is presented on the dashboard of the vehicle.
The CAN bus connection is established via a CAN-USB adapter device (“PCAN Adapter”) which is connected to a USB port of the DP.
Since the used V2X SW on the DP expects a specific set of CAN messages an adapter gateway is needed to translate the individual CAN messages from the vehicle bus into the expected format.

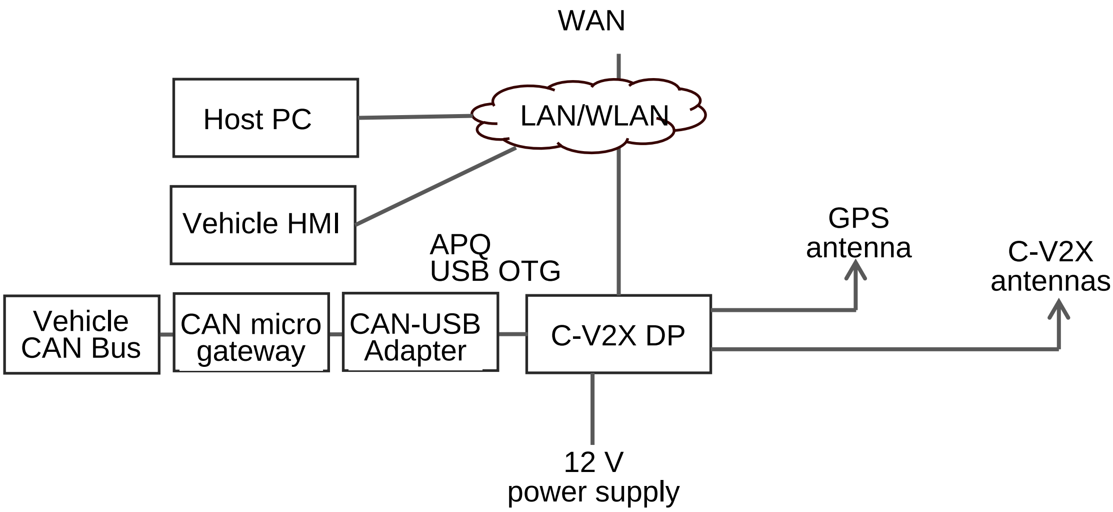



*Figure 4.1-2: Configuration of C-V2X platform in a vehicle used for field testing*

## 4.3.2 Setup and test of HMI connectivity

The configuration needed here is the IP address of the DP which hosts the MQTT broker as well as the port number (per default 1883). The program on the host PC shows successful establishment of the connection. The connection enables subscribing to certain topics in order to receive data from the DP (like alerts related to use cases etc.).

### 4.3.3 Setup and test of CAN bus connectivity

For validation of CAN verification execute following commands from an adb shell on the APQ processor:

- **Display of raw CAN messages received from the vehicle:**

```
cantap -p can<x> -t1
```

where x is the ID of the CAN interface used (can<x> = can0 for physically connecting the CAN to the DP, can2 if a PCAN adapter is used instead).

- **Display of decoded CAN messages:**

```
v2x_veh_test
```

If all is connected properly, and the car is running, e.g. the operation of the indicators shall be reflected in the output of the tool (e.g. “vehicle speed”, “break indicator”, “right indicator”, “left indicator”).

### 4.3.4 Test of V2V communication

If two cars are equipped and the DPs are up and running, the verification of the communication can be done in a similar way as for the lab setup:

```
etsifacility_stats -c
```

shows the send and receive statistics of the CAM. So, if the command is issued repeatedly, the send and receive values should increase.

## 4.4 Test of interfaces in the RSU

### 4.4.1 General

For tests the same configuration as in Figure 4.1-2 is employed. The optional debugging connection should not be needed, assuming that the employed C-V2X DP is booting correctly.

### 4.4.2 Setup and test of WAN connectivity with virtual TCC

In general, there are two common ways to connect roadside equipment with a TCC: a dedicated wire-based network and a VPN-secured mobile connection via modem or mobile router. Both cases make use of the RJ45 equipped Ethernet port of the DP.

Therefore, it is necessary to configure the eth0 interface. For a temporary setup, execute the command

```
Ifconfig eth0 <IP_ADDR> <NETMASK>
```

A long-term setting requires editing of the file “`/etc/systemd/network/wired.network`”, e.g.

```
[Match]
Name=eth* en*

[Network]
DHCP=no
Address=10.45.81.66/28
Gateway=10.45.81.65
```

Then, the connection can be tested using the `ping` command or login on the DP via `ssh`.

### 4.4.3 Test of V2I communication

V2I-, like V2V-, messages are communicated through the rmnet_data1 interface on the DP. Therefore, the easiest way to check for in- and out-bound traffic is to listen to this interface by:

```
tcpdump -i rmnet_data1
```

An advantage of this method is that it only needs one transmitting device, but of course, it works for two or more, too. The payload can be decoded online, e.g. at https://asn1.io/asn1playground/, or in a future version of the “wireshark” tool.

Obviously, to send and receive V2I messages, the ETSI-stack by Savari needs to be running, which can be checked on the RSU by:

```
root@8x96autocv2x:~# ps | grep GNd
 2833 root       103m S    /usr/bin/GNd -k -K 100
 4782 root       2940 S    {grep} /bin/busybox.nosuid /bin/grep
GNd
```

Note that incoming messages will pass the ETSI-stack after being received by this interface and that the presence of messages in the output of tcpdump doesn’t guarantee a correct syntax or content.

An alternative way to check the communication is by using the Savari command line tool `sample_v2x_btp`. This tool accesses the stack while sending and receiving. Usage:

Receiving: `sample_v2x_btp –R – p <port>`

Transmitting: `sample_v2x_btp –T <Tx_File> -p <port>`

`<Tx_File>` is an ASCII-text file, which is transmitted line wise.

## 4.5 Test of DP board configuration settings

### 4.5.1 Server and device configuration

Execute the /home/root/cv2x/devconfig script to configure:

- Measurement Server address
- Authentication Token
- Device ID

This needs only to be done in case of a new installation, or some needed change (e.g. token validity did expire and a new one was generated on the server).

Select the ITS stack variant to be used (ETSI ITS stack or US SAE ITS stack) with following command:

```
echo "US" > /home/root/testing/conf/stack_in_use
echo "EU" > /home/root/testing/conf/stack_in_use
```

### 4.5.2 Playback of recorded data

The DP contains pre-recorded data in format of csv files for bench testing. Those files are located under /home/root/cv2x/CSV and are used to provide the position coordinates for the ITS messages. GNSS timing still comes from the physical connection to the board, therefore GPS antennas need to be connected. For playback of recorded measurement data files, use following commands:

On both DPs: `$ cd /home/root/cv2x/CSV`

On DP01: `$ ./hv_eebl start`

On DP02: `$ ./rv_eebl start`

Observation: after the playback from files, live mode starts with: *systemctl start savari*

Inspect logging files at following file directory:

- `/home/root/testing/logs`

# 5 Initial Field Test Results

## 5.1 Communication between Vehicles (V2V)

### 5.1.1 General information

This section describes the default settings of the C-V2X DP and other measurement conditions applied in the field tests described in this document. Any differences from these default settings will be explicitly mentioned.

**Antenna system**
By default, field tests are performed with a reference antenna system installed at the vehicle as described in Deliverable D5.1 [3], and briefly recapped below.

Antennas for C-V2X PC5 (5.9 GHz) communication:

- 2x MobileMark MAG6 5900/1575 (see [5] for details), mounted on vehicle rooftop as shown in Figure 5.1.1-1,
- Non-removable connector cables attached to the antennas with attenuation of 2.44 dB,
- Omnidirectional peak antenna gain of 6.5 dB.

Antenna for GPS signal reception:

- 1x Taoglas AA.170.301111 (see [6] ) mounted on vehicle rooftop as shown in Figure 5.1.1-1.

Antenna for cellular connectivity:

- When cellular connectivity is required for transmission of measurement data, video and voice communication the ordinary in-build antenna of a mobile phone is used.

When V2N use case specific information is transmitted, a Hirschmann CEL 7026 RD M/series antenna is used (see), which is installed on the rooftop or trunk (if available) of the vehicle.

A typical antenna setting is shown in Figure 5.1.1-1. It should be noted that the exact location of the GPS antenna on the rooftop (in this example placement in the middle between the MAG6 C-V2X antennas) has no impact on C-V2X performance.

*Figure 5.1.1-1: Installation of C-V2X reference and GPS antennas on vehicle rooftop*

**Transmit power**
The default setting of PA output power is 21.5 dBm (i.e. nominal peak power of 23 dBm reduced by 1.5 dB MPR backoff). Given a cable and connector loss 2.44 dB and peak antenna gain of 6.5 dB

The resulting maximal EIRP is

21.5 dBm – 2.44 dB + 6.5 dB = 25.56 dBm

**Other Parameters**

The default ITS message size (CAM/BSM) is fixed to 69 bytes per message on ITS layer.

Retransmission and HARQ are enabled, i.e. each ITS message is transmitted twice on physical layer.

## 5.1.2 LOS communication range

The range of V2V communication under line-of-sight (LOS) radio conditions represents the admissible distance between V2V transmitters and receivers while complying a given target message reception rate (e.g. of 90 %).

Ideally, LOS V2V communication range should be assessed under open-space and flat terrain conditions such as e.g. an airport runway, a long and wide plain road or a big empty car park. In reality however, it is rather difficult to identify places which are suitable and accessible for these kind of measurements due to the quite large communication range of up to 2000 meters which can be achieved at the typical transmit power levels (see transmit power assumptions below).

**Test Procedure**

A first car is placed stationary at a fixed position. A second car is driving at a speed of about 10 km/h until to the end of the road. There, the moving car makes a U-turn and return towards the stationary first car.

C-V2X DP is transmitting/receiving CAMs/BSMs with 100 ms periodicity (i.e. 10 CAMs per second).

Assessment of the V2V communication range have been performed at various locations. The figures below show some example results. Note that it is in practice very difficult to identify a suitable location for this kind of experiments as it ideally requires a flat road in an open environment of up to 3 km length. An ideal location would be a sufficiently long airport runway. At this time, the ConVeX project is still trying to obtain access to more suitable locations such as e.g. Ingolstadt-Manching airport for replications of range measurement campaigns under LOS and NLOS conditions.

Figure 5.1.2-1 shows a location in the Nuremberg area where field evaluations of LOS range have been conducted. This road is flat over a distance of 1.2 km. Beyond that distance the terrain becomes uneven such that LOS conditions are lost.


***Figure 5.1.2-1: Example driving route for LOS range test (Nuremberg area)***
***Picture source: Google Maps, © 2009 GeoBasis-DE/BKG. ©2019 Google***

Figure 5.1.2-2 shows a typical example PER measurement obtained for a single drive run of the moving vehicle over that 1.2 km stretch of the road. The result shows that there are only extremely rare occasions where packet losses occur at all. Each spike in the PER measurement curve corresponds to a single lost messages per second. In this campaign it could be observed that the packet reception rate (PRR) is better than 99.5 % under LOS conditions for a range of 1.2 km.

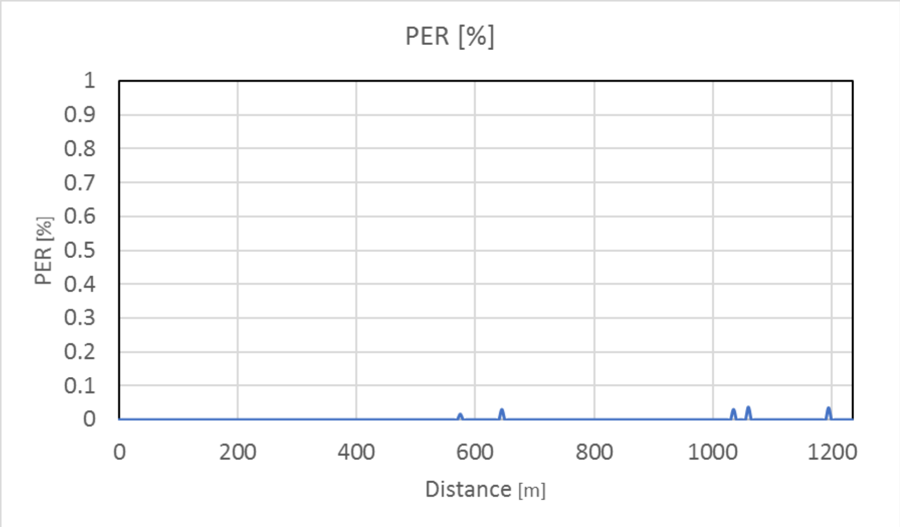



*Figure 5.1.2-2: Measured PER during LOS on drive route in Figure 5.1.2-1*

Figure 5.1.2-3 shows another location in the Ingolstadt area where range measurements have been conducted. In this case, the terrain is not completely flat within the drive distance. In this example, retransmission has been disabled (i.e. the effective power per message is reduced by 3 dBs).

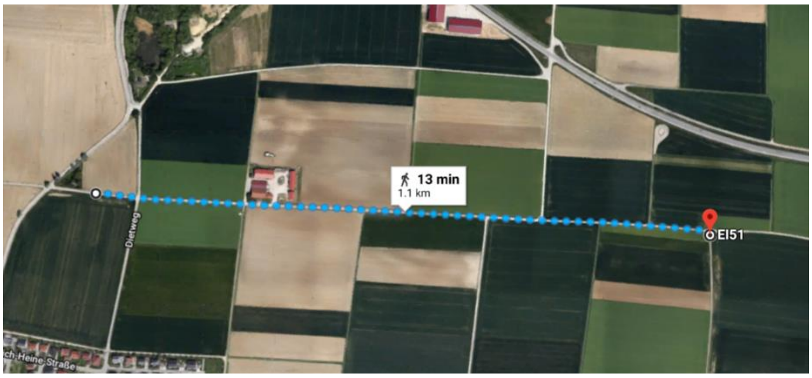



*Figure 5.1.2-3: Example driving route for LOS range test (Ingolstadt area)*
*Picture source: Google Maps, © 2009 GeoBasis-DE/BKG. ©2019 Google*

A typical example PRR measurement obtained for a single drive run along this route is shown in Figure 5.1.2-4. Reception is perfect up to a distance of 1050 meters. Beyond that distance communication degrades quickly. Note that in this example this is mostly due to elevation characteristics of the terrain which causes loss of LOS conditions beyond 1050 meters.

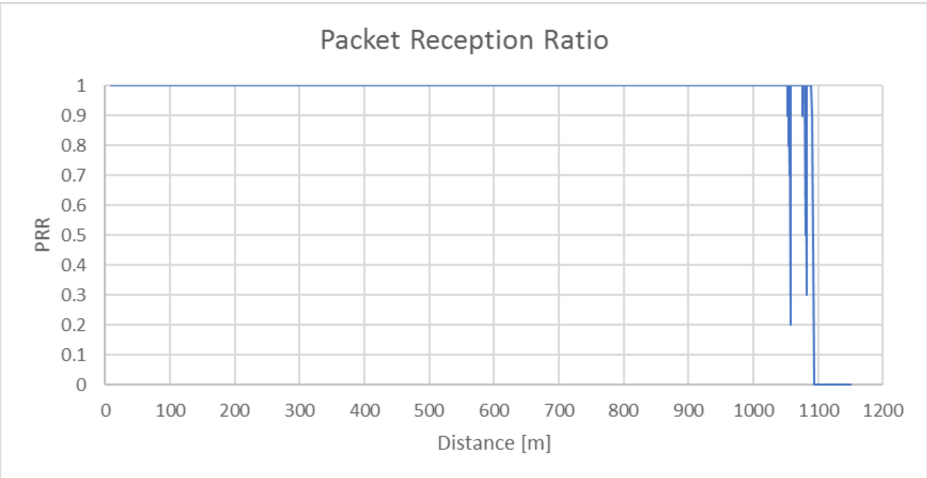



*Figure 5.1.2-4: Measured PER during LOS on drive route in Figure 5.1.2-3*

The overall conclusion from the range evaluations under LOS conditions executed so far is that at a distance of up to 1200 meters, reliable V2V communication is possible under the default parameter conditions as described in section 5.1.1 (which includes retransmission).

### 5.1.3 NLOS communication range

Evaluation results for this scenario will be presented in Deliverable D7.1 [4].

# 5.1.4 Communication range in real traffic scenarios

## 5.1.4.1 Highway

### 5.1.4.1.1 Dependency on relative vehicle speed

In this section we evaluate the potential dependency of C-V2X communication range on the relative vehicle speed. In this scenario two vehicles are driving in opposite directions towards each other on a highway. At a certain point the vehicles run across each other at opposite sides of the highway and then depart from each other. Such drive tests have been conducted at various sections of the A9 highway on rather straight segments of the road. However, this has been done under real traffic conditions. Due to obstacles such as bridges, other cars and big vehicles (trucks and busses) on the road, it is impossible to expect ideal LOS conditions. To achieve performance results at high relative speeds, both vehicles try to drive at a speed as high as possible while driving each in the leftmost lanes. Figure 5.1.4.1-1 shows maps of two locations where such experiments were conducted.  In case a) the two cars were commuting between the highway junction “Nürnberg” and A9 exit “Lauf/Hersbruck”. In case b) the two cars were commuting between A9 exits “Hilpoltstein” and “Greding”.

Case a) Case b)

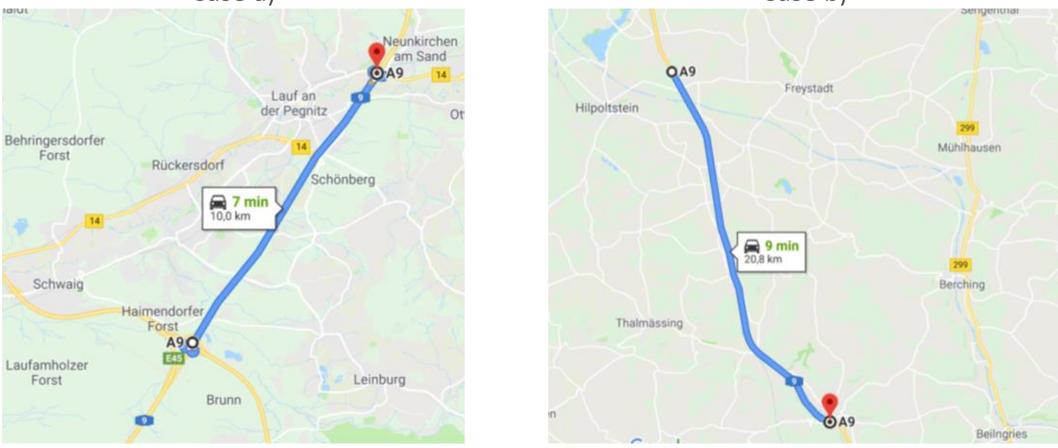



*Figure 5.1.4.1-1: Driving route for range evaluation at high relative vehicle speeds*

To give an impression of the scenarios and environment, Figure 5.1.4.1-2 shows driver views of the stretch of the route where range measurements have been evaluated. Note that videos have been recorded for each test run from one of the two involved vehicles, in order to enable correlation of measurements with actual situations on the road.

Case a) Case b)

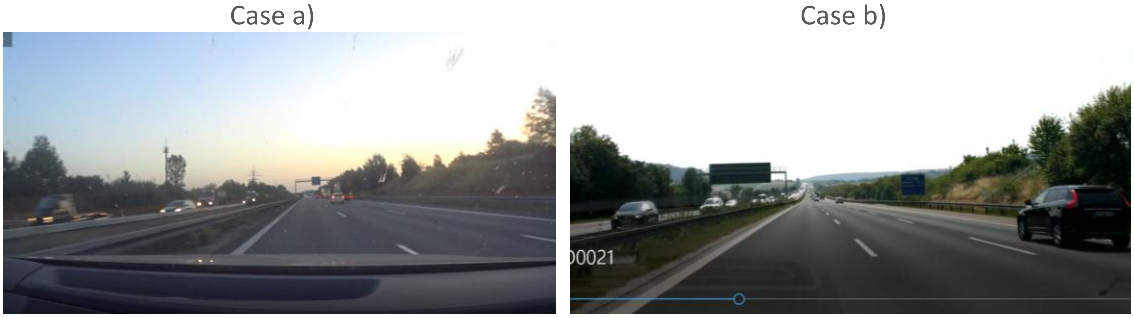


*Figure 5.1.4.1-2: Example driver views during tests*

Figure 5.1.4.1-3 shows in an example of a case a) drive run,

- the absolute individual speeds of each of the two vehicles and the relative speed between the vehicles which is between 400 and 430 km/h.
- the observed PER averaged over 1-second intervals
- the distance between the two vehicles.

The result demonstrates that even at relative vehicle speeds of 400 km/h the communication range is in the order of 1000 meters in a realistic traffic scenario. This result is mostly independent of the actual relative vehicle speed, i.e. when the relative speed is lowered to 200 km/h communication range is essentially the same.

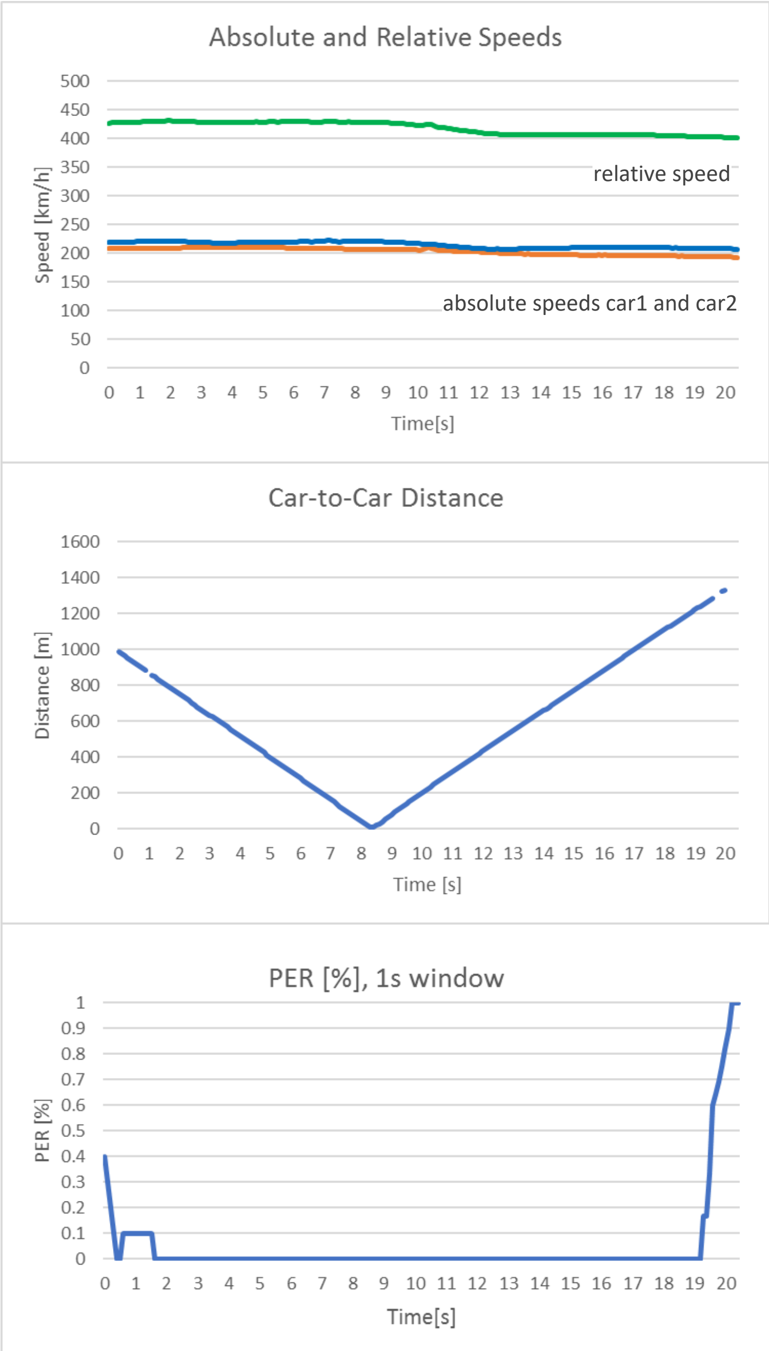



***Figure 5.1.4.1-3: Observed measurements for a drive run case a)***

# 6 Summary and conclusions

This document summarizes how to test the C-V2X equipment in a lab environment as well as how to examine that all required functions are working properly after installation of a DP in vehicular and roadside ITS stations. It further documents initial results from field experiments, primarily with regard to message reception performance in dependence of communication range, speed of vehicles and some environmental factors.

Note that an exhaustive presentation and evaluation on C-V2X performance is planned to be provided in the *Final Report on Field Test and Evaluation Results*, Deliverable D7.1.