D4.3: Evolved Solution and Verification of Transport Use Case Trials

Revision: v.1.0

<table>
<thead>
<tr>
<th>Work Package</th>
<th>WP4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task</td>
<td>Tasks 4.2 and T4.3</td>
</tr>
<tr>
<td>Due rate</td>
<td>M30 – 30 November 2021</td>
</tr>
<tr>
<td>Submission date</td>
<td>30 November 2021</td>
</tr>
<tr>
<td>Deliverable lead</td>
<td>POLAR</td>
</tr>
<tr>
<td>Version</td>
<td>1.0</td>
</tr>
<tr>
<td>Authors</td>
<td>Jarno Pinola (editor) (VTT), Juhani Kemppainen (editor) (POLAR), Hamidreza Bagheri (UOS), Bastiaan Wissingh (TNO), Valérian Mannoni (CEA), Matthias Gabriel (TUC), Olli Apilo (VTT), Riikka Ahola (POLAR), Grigorios Kakkavas (NTUA), Maria Diamanti (NTUA), Vasileios Karyotis (NTUA), Michalis Mitrou (WINGS), Prageeth Krishnan (EPI), Seiamak Vahid (UOS)</td>
</tr>
<tr>
<td>Reviewers</td>
<td>Tilemachos Doukoglou (ACTA), Meng Lu (DYNNIQ/PEEK), George Fourtinas (OCC), Ruth Anderson (OCC)</td>
</tr>
</tbody>
</table>

Abstract
This deliverable describes the Phase 2 (evolved) trials of the various use case scenarios of the transport vertical. These Phase 2 trials contribute to the milestone MS4 of the project.

Keywords
5G, transport, trials
D4.3: Evolved Solution and Verification of Transport Use Case Trials

Disclaimer
The information, documentation and figures available in this deliverable, are written by the 5G-HEART (5G HEalth AquacultuRe and Transport validation trials) – project consortium under EC grant agreement 857034 and does not necessarily reflect the views of the European Commission. The European Commission is not liable for any use that may be made of the information contained herein.

<table>
<thead>
<tr>
<th>Project co-funded by the European Commission in the H2020 Programme</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nature of the deliverable:</td>
</tr>
<tr>
<td>Dissemination Level</td>
</tr>
<tr>
<td>PU</td>
</tr>
<tr>
<td>CI</td>
</tr>
<tr>
<td>CO</td>
</tr>
</tbody>
</table>

Copyright notice
© 2019 - 2022 5G-HEART Consortium

¹ R: Document, report (excluding the periodic and final reports)
DEM: Demonstrator, pilot, prototype, plan designs
DEC: Websites, patents filing, press & media actions, videos
OTHER: Software, technical diagram
EXECUTIVE SUMMARY

The 5G for HEalth, AquacultuRe and Transport (5G-HEART) validation trials project performs vertical validation trials on top of all three ICT-17 facilities and two national Fifth Generation (5G) test platforms with use cases from three different vertical domains. The selected verticals for 5G-HEART trials are healthcare and transport, both of which have been identified as priority vertical sectors for Europe, and aquaculture, which is seen as an additional high potential application area for ICT-19 by the 5G Infrastructure Association (5G IA). This deliverable describes the Phase 2 trials of the transport vertical use cases from the project. These trials contribute to the milestone MS4 (“Phase 2 trials of multiple verticals”) from the perspective of work package WP4 (“Solutions for Delivery of Transport Vertical”). It provides an update to the status of the implementation and initial validation of the transport vertical use case trials performed at four different 5G test facilities.

The implementation of the vertical validation trials is performed iteratively in three phases. In Phase 1, the initial implementations of the use case service components, i.e., the initial solutions, were tested on top of the 5G test facilities and the performance achieved with the partial implementations of the trial scenarios was measured. In Phase 2, the focus has been on the extended implementations of the use case service components, i.e. evolved solutions, as the work has continued from individual components towards integrated trial deployments. The performance of the extended Phase 2 implementations has again been verified on top of the 5G test facilities. These trials have been conducted per scenario, coordinated by the scenario leaders and utilising the 5GENESIS (Surrey, UK), 5Groningen (Groningen, Netherlands) and 5GTN (Oulu, Finland) trial facilities, except for scenario T2S2, which during Phase 2 has been fully based on simulations, and for T2S3, which has been initially trialled in Chemnitz, Germany. In Phase 3, the full implementations of the use cases will be deployed on top of the 5G test facilities, their performance and functionality will be verified. Through the performance verification of the full implementations, the project will validate the feasibility of 5G as the connectivity platform for its target verticals.

In order to better focus the work for Phases 2 and 3, the trial scenarios under the four main use cases in the transport vertical, i.e. “T1: Platooning”, “T2: Automated/assisted driving”, “T3: Support for remote driving” and “T4: Vehicle data services”, have been divided to core and supplementary scenarios. By focusing the large-scale implementation and in-depth trialling activities to the core scenarios, the key 5G functionalities and KPIs of the transport vertical use cases can be investigated and validated more deeply. The supplementary scenarios will provide additional insight into the 5G performance by providing validation results for specific technology enablers.

The core use case scenarios in the transport vertical are “T2S1: Smart junctions and network assisted & cooperative collision avoidance (CoCa); Trial track”, “T2S4: Human tachograph”, “T3S1: Tele-operated support (TeSo)”, “T4S5: End-to-end (E2E) slicing” and “T4S6: Vehicle sourced high-definition (HD) mapping”. The main Phase 2 achievements in these core scenarios are summarised in the following paragraphs.

In the use case scenario “T2S2: Smart junctions and network assisted & cooperative collision avoidance (CoCa); Trial track”, the Phase 2 trial implementation extended with a Traffic Light Controller (TLC) was on-boarded on top of a 5G Standalone (SA) network architecture. In addition, the implementation of user application messaging was updated. The performance verification of the 5G SA network configuration and updated Intelligent Transport System (ITS) application was done through several measurement campaigns. With a network setup including both 5G SA and Edge Computing support, the achieved Uplink (UL) throughput was approximately 60 Mbps and Downlink (DL) throughput 410 Mbps. In addition, the measured Round-Tip-Trip (RTT) latency was a little bit over 8 ms. and the End-to-End (E2E) application latency was improved by roughly 40-95 % when compared to the baseline measurements performed with Fourth Generation (4G) technologies in Phase 1.

In the use case scenario “T2S4: Human tachograph”, the extended Phase 2 trial implementation included an edge cloud environment and updated 5G Non-Standalone (NSA) network architecture. In addition, the user application architecture was updated with a new streaming software for the wearables sensor
data as well as an edge cloud implementation of the sensor data collection and warning message triggering frameworks. The performance verification of the 5G NSA network configuration and updated user application components was done with laboratory and field measurements. The lowest average UL latencies achieved in the setup were approximately 7 ms, whereas the lowest average DL latencies were approximately 4 ms. In the DL direction, a 11-13 ms latency for the warning messages was achieved with 99.99 % reliability.

In the use case scenario “T3S1: Tele-operated support (TeSo)”, the network architecture for the extended Phase 2 trial configuration was updated. In addition, the design and implementation of the E2E software implementation of the TeSo service was completed. Additionally, a comprehensive assessment of each distinct software component’s operation was performed as well as their coherent cooperation to provide the required E2E service. The baseline performance verification of the Phase 2 E2E service implementation was done on top of a 4G network. The achieved UL throughput was approximately 50 Mbps and DL throughput 70 Mbps. In addition, the measured RTT latency was approximately 28 ms.

In the use case scenario “T4S5: End-to-end (E2E) slicing”, the Phase 2 work focused on the preparation of the extended trial implementations for deployment on top of the 5GENESIS slices. The work has been performed in collaboration between the 5G-HEART and 5GENESIS projects. Due to the access restrictions at the 5G test facility during the Phase 2 work, most performance verification measurements for the deployed extended trial implementations had to be re-scheduled to the beginning of Phase 3.

In use case scenario “T4S6: Vehicle sourced high-definition (HD) mapping”, the Phase 2 work focused on the preparation of the extended trial implementation for further measurements using an optimised 5G network configuration. Due to the access restrictions at the 5G test facility during the Phase 2 work, most performance verification measurements for the extended trial implementation had to be re-scheduled to the beginning of Phase 3.

The supplementary use case scenarios in the transport vertical are “T1S1&T1S2: High bandwidth in-vehicle situational awareness and see-through for platooning”, “T2S1: Smart junctions and network assisted & cooperative collision avoidance (CoCa); Simulation track”, “T2S3: Quality of service (QoS) for advanced driving”, “T4S1: Vehicle prognostics”, “T4S2: Over-the-air (OTA) updates”, “T4S3: Smart traffic corridors”, “T4S4: Location based advertising” and “T4S7: Environmental services”. The main Phase 2 achievements in these supplementary scenarios are summarised in the following paragraphs.

In use case scenario “T1S1&T1S2: High bandwidth in-vehicle situational awareness and see-through for platooning”, the Phase 2 work focused on the preparation of the extended trial implementation for further measurements using a network configuration supporting 4G/5G Cellular Vehicle-to-Everything (C-V2X) functionality. Due to the access restrictions at the 5G test facility during the Phase 2 work, most performance verification measurements for the extended trial implementation had to be re-scheduled to the beginning of Phase 3.

In the use case scenario “T2S1: Smart junctions and network assisted & cooperative collision avoidance (CoCa); Simulation track”, the simulation setup from Phase 1 was extended to evaluate the impact of Long Term Evolution (LTE) – Vehicle-to-Everything (V2X) connectivity performance on the fusion of local occupancy maps and Collective Perception Messages (CPMs). In addition, the setup was used to define the best compromises between the communication configuration and obstacle detection capabilities. It was found that messages size of 1685 Bytes with 4 Bits Per Pixel (BPP) was suitable for global occupancy maps in terms of obstacle misdetection ratio. In addition, the effectiveness of the utilised fusion algorithm was proved in terms of obstacles detection capabilities. Moreover, this algorithm was able to cope with packet loss caused by LTE-V2X connectivity performance degradation.

In the use case scenario “T2S3: Quality of service (QoS) for advanced driving”, the user application architecture was fully implemented for the Phase 2 trials. The verification of the service implementation was done by deploying the implemented application on top of a 4G network. In addition to the verification of the application functionality, a mean RTT latency of 35 was measured for the utilised setup.
In the use case scenario “T4S1: Vehicle prognostics”, performance verification of the updated 5G NSA network configuration was done with mobile users. Depending on the application payload size, the achieved UL latency was approximately 5-7 ms and the theoretical maximum amount of simultaneously supported user was estimated to be 36-380.

In the use case scenario “T4S2: Over-the-air (OTA) updates”, the Phase 2 trials were done to determine the baseline performance of the 4G Evolved Multimedia Broadcast Multicast Service (eMBMS) -based multicasting in a file download scenario. The achieved baseline performance was compared to 5G NSA DL and based on a theoretical estimation, the spectral efficiency of the eMBMS-based multicasting exceeds that of 5G NSA unicasting when the number of simultaneous users requiring the same OTA update data exceeds 6.

In the use case scenario “T4S3: Smart traffic corridors”, the Phase 2 trial implementation was extended with a physical sensor device for initial testing. In the conducted laboratory tests, the mean value of the E2E RTT latency was approximately 1.0 s with a standard deviation of 0.1 s.

In the use case scenarios “T4S4: Location based advertising” and “T4S7: Environmental services” the Phase 2 work focused on the preparation of the trial implementation for further measurements using an optimised 5G network configuration. Due to the access restrictions at the 5G test facility during the Phase 2 work, most performance verification measurements for the extended trial implementation had to be re-scheduled to the beginning of Phase 3.

In general, the focus of the work will shift from testing and performance verification of the extended, but still partial, use case implementations in Phase 2 towards the final trials and demonstrations during Phase 3, which will be performed using the full implementations of the use case scenarios listed above. The next step plans towards Phase 3 are also provided in this document for each use case scenario.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EXECUTIVE SUMMARY</strong></td>
<td>3</td>
</tr>
<tr>
<td><strong>TABLE OF CONTENTS</strong></td>
<td>6</td>
</tr>
<tr>
<td><strong>LIST OF FIGURES</strong></td>
<td>12</td>
</tr>
<tr>
<td><strong>LIST OF TABLES</strong></td>
<td>14</td>
</tr>
<tr>
<td><strong>ABBREVIATIONS</strong></td>
<td>15</td>
</tr>
<tr>
<td><strong>1 INTRODUCTION</strong></td>
<td>19</td>
</tr>
<tr>
<td>1.1 Use cases and Phase 2 trials overview</td>
<td>19</td>
</tr>
<tr>
<td>1.2 Definitions</td>
<td>20</td>
</tr>
<tr>
<td>1.3 Organization of this deliverable</td>
<td>21</td>
</tr>
<tr>
<td><strong>2 TIS1&amp;TIS2: HIGH BANDWIDTH IN-VEHICLE SITUATIONAL AWARENESS AND SEE-THROUGH FOR PLATOONING</strong></td>
<td>23</td>
</tr>
<tr>
<td>2.1 Description and motivation</td>
<td>23</td>
</tr>
<tr>
<td>2.2 Proposed setup</td>
<td>23</td>
</tr>
<tr>
<td>2.2.1 Network architecture</td>
<td>23</td>
</tr>
<tr>
<td>2.2.2 User application architecture</td>
<td>23</td>
</tr>
<tr>
<td>2.2.3 Hardware components</td>
<td>23</td>
</tr>
<tr>
<td>2.2.4 Software components</td>
<td>24</td>
</tr>
<tr>
<td>2.3 Testing and verification</td>
<td>24</td>
</tr>
<tr>
<td>2.3.1 Methodology</td>
<td>24</td>
</tr>
<tr>
<td>2.3.2 List of key performance indicators</td>
<td>24</td>
</tr>
<tr>
<td>2.3.3 Measurement and testing tools</td>
<td>24</td>
</tr>
<tr>
<td>2.3.4 Intermediate results</td>
<td>25</td>
</tr>
<tr>
<td>2.4 Next step plans</td>
<td>25</td>
</tr>
<tr>
<td><strong>3 T2S1: SMART JUNCTIONS AND NETWORK ASSISTED &amp; COOPERATIVE COLLISION AVOIDANCE (COCA); TRIAL TRACK</strong></td>
<td>26</td>
</tr>
<tr>
<td>3.1 Description and motivation</td>
<td>26</td>
</tr>
<tr>
<td>3.2 Proposed setup</td>
<td>26</td>
</tr>
<tr>
<td>3.2.1 Network architecture</td>
<td>26</td>
</tr>
<tr>
<td>3.2.2 User application architecture</td>
<td>27</td>
</tr>
<tr>
<td>3.2.3 Hardware components</td>
<td>29</td>
</tr>
<tr>
<td>3.2.4 Software components</td>
<td>29</td>
</tr>
<tr>
<td>3.3 Testing and verification</td>
<td>29</td>
</tr>
<tr>
<td>3.3.1 Methodology</td>
<td>29</td>
</tr>
<tr>
<td>3.3.2 List of key performance indicators</td>
<td>30</td>
</tr>
<tr>
<td>3.3.3 Measurement and testing tools</td>
<td>30</td>
</tr>
<tr>
<td>3.3.4 Intermediate results</td>
<td>30</td>
</tr>
</tbody>
</table>

© 5G-HEART Consortium 2019-2022
### 4 T2S2: SMART JUNCTIONS AND NETWORK ASSISTED & COOPERATIVE COLLISION AVOIDANCE (COCA); SIMULATION TRACK .......................... 35

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1</td>
<td>Description and motivation</td>
<td>35</td>
</tr>
<tr>
<td>4.2</td>
<td>Proposed setup</td>
<td>35</td>
</tr>
<tr>
<td>4.2.1</td>
<td>Network architecture</td>
<td>35</td>
</tr>
<tr>
<td>4.2.2</td>
<td>User application architecture</td>
<td>36</td>
</tr>
<tr>
<td>4.2.3</td>
<td>Hardware components</td>
<td>36</td>
</tr>
<tr>
<td>4.2.4</td>
<td>Software components</td>
<td>37</td>
</tr>
<tr>
<td>4.3</td>
<td>Testing and verification</td>
<td>42</td>
</tr>
<tr>
<td>4.3.1</td>
<td>Methodology</td>
<td>42</td>
</tr>
<tr>
<td>4.3.2</td>
<td>List of key performance indicators</td>
<td>44</td>
</tr>
<tr>
<td>4.3.3</td>
<td>Measurement and testing tools</td>
<td>45</td>
</tr>
<tr>
<td>4.3.4</td>
<td>Intermediate results</td>
<td>45</td>
</tr>
<tr>
<td>4.4</td>
<td>Next step plans</td>
<td>54</td>
</tr>
</tbody>
</table>

### 5 T2S3: QUALITY OF SERVICE (QOS) FOR ADVANCED DRIVING .................. 55

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1</td>
<td>Description and motivation</td>
<td>55</td>
</tr>
<tr>
<td>5.2</td>
<td>Proposed setup</td>
<td>55</td>
</tr>
<tr>
<td>5.2.1</td>
<td>Network architecture</td>
<td>55</td>
</tr>
<tr>
<td>5.2.2</td>
<td>User application architecture</td>
<td>56</td>
</tr>
<tr>
<td>5.2.3</td>
<td>Hardware components</td>
<td>56</td>
</tr>
<tr>
<td>5.2.4</td>
<td>Software components</td>
<td>56</td>
</tr>
<tr>
<td>5.3</td>
<td>Testing and verification</td>
<td>57</td>
</tr>
<tr>
<td>5.3.1</td>
<td>Methodology</td>
<td>57</td>
</tr>
<tr>
<td>5.3.2</td>
<td>List of key performance indicators</td>
<td>59</td>
</tr>
<tr>
<td>5.3.3</td>
<td>Measurement and testing tools</td>
<td>59</td>
</tr>
<tr>
<td>5.3.4</td>
<td>Intermediate results</td>
<td>59</td>
</tr>
<tr>
<td>5.4</td>
<td>Next step plans</td>
<td>61</td>
</tr>
</tbody>
</table>

### 6 T2S4: HUMAN TACHOGRAPH ..................................................... 62

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1</td>
<td>Description and motivation</td>
<td>62</td>
</tr>
<tr>
<td>6.2</td>
<td>Proposed setup</td>
<td>62</td>
</tr>
<tr>
<td>6.2.1</td>
<td>Network architecture</td>
<td>62</td>
</tr>
<tr>
<td>6.2.2</td>
<td>User application architecture</td>
<td>63</td>
</tr>
<tr>
<td>6.2.3</td>
<td>Hardware components</td>
<td>64</td>
</tr>
<tr>
<td>6.2.4</td>
<td>Software components</td>
<td>65</td>
</tr>
<tr>
<td>6.3</td>
<td>Testing and verification</td>
<td>65</td>
</tr>
<tr>
<td>6.3.1</td>
<td>Methodology</td>
<td>65</td>
</tr>
</tbody>
</table>
6.3.2 List of key performance indicators ................................................................. 67
6.3.3 Measurement and testing tools .................................................................... 67
6.3.4 Intermediate results ..................................................................................... 68
6.4 Next step plans ............................................................................................... 70
7 T3S1: TELE-OPERATED SUPPORT (TESO) .................................................. 72
  7.1 Description and motivation ........................................................................... 72
  7.2 Proposed setup .............................................................................................. 72
  7.2.1 Network architecture ................................................................................ 73
  7.2.2 User application architecture .................................................................. 74
  7.2.3 Hardware components ............................................................................. 75
  7.2.4 Software components ................................................................................ 76
  7.3 Testing and verification ................................................................................ 76
  7.3.1 Methodology ............................................................................................ 76
  7.3.2 List of key performance indicators ............................................................ 77
  7.3.3 Measurement and testing tools ................................................................ 78
  7.3.4 Intermediate results ................................................................................ 78
  7.4 Next step plans ............................................................................................. 83
8 T4S1: VEHICLE PROGNOSTICS ................................................................. 84
  8.1 Description and motivation ........................................................................... 84
  8.2 Proposed setup .............................................................................................. 84
  8.2.1 Network architecture ................................................................................ 84
  8.2.2 User application architecture .................................................................. 84
  8.2.3 Hardware components ............................................................................. 85
  8.2.4 Software components ................................................................................ 85
  8.3 Testing and verification ................................................................................ 85
  8.3.1 Methodology ............................................................................................ 85
  8.3.2 List of key performance indicators ............................................................ 86
  8.3.3 Measurement and testing tools ................................................................ 86
  8.3.4 Intermediate results ................................................................................ 87
  8.4 Next step plans ............................................................................................. 88
9 T4S2: OVER-THE-AIR (OTA) UPDATES .................................................. 89
  9.1 Description and motivation ........................................................................... 89
  9.2 Proposed setup .............................................................................................. 89
  9.2.1 Network architecture ................................................................................ 89
  9.2.2 User application architecture .................................................................. 89
  9.2.3 Hardware components ............................................................................. 90
<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.2.4</td>
<td>Software components</td>
<td>90</td>
</tr>
<tr>
<td>9.3</td>
<td>Testing and verification</td>
<td>90</td>
</tr>
<tr>
<td>9.3.1</td>
<td>Methodology</td>
<td>91</td>
</tr>
<tr>
<td>9.3.2</td>
<td>List of key performance indicators</td>
<td>91</td>
</tr>
<tr>
<td>9.3.3</td>
<td>Measurement and testing tools</td>
<td>91</td>
</tr>
<tr>
<td>9.3.4</td>
<td>Intermediate results</td>
<td>92</td>
</tr>
<tr>
<td>9.4</td>
<td>Next step plans</td>
<td>92</td>
</tr>
<tr>
<td>10</td>
<td>T4S3: SMART TRAFFIC CORRIDORS</td>
<td>94</td>
</tr>
<tr>
<td>10.1</td>
<td>Description and motivation</td>
<td>94</td>
</tr>
<tr>
<td>10.2</td>
<td>Proposed setup</td>
<td>94</td>
</tr>
<tr>
<td>10.2.1</td>
<td>Network architecture</td>
<td>94</td>
</tr>
<tr>
<td>10.2.2</td>
<td>User application architecture</td>
<td>94</td>
</tr>
<tr>
<td>10.2.3</td>
<td>Hardware components</td>
<td>94</td>
</tr>
<tr>
<td>10.2.4</td>
<td>Software components</td>
<td>95</td>
</tr>
<tr>
<td>10.3</td>
<td>Testing and verification</td>
<td>95</td>
</tr>
<tr>
<td>10.3.1</td>
<td>Methodology</td>
<td>95</td>
</tr>
<tr>
<td>10.3.2</td>
<td>List of key performance indicators</td>
<td>96</td>
</tr>
<tr>
<td>10.3.3</td>
<td>Measurement and testing tools</td>
<td>96</td>
</tr>
<tr>
<td>10.3.4</td>
<td>Intermediate results</td>
<td>96</td>
</tr>
<tr>
<td>10.4</td>
<td>Next step plans</td>
<td>97</td>
</tr>
<tr>
<td>11</td>
<td>T4S4: LOCATION BASED ADVERTISING</td>
<td>98</td>
</tr>
<tr>
<td>11.1</td>
<td>Description and motivation</td>
<td>98</td>
</tr>
<tr>
<td>11.2</td>
<td>Proposed setup</td>
<td>98</td>
</tr>
<tr>
<td>11.2.1</td>
<td>Network architecture</td>
<td>98</td>
</tr>
<tr>
<td>11.2.2</td>
<td>User application architecture</td>
<td>98</td>
</tr>
<tr>
<td>11.2.3</td>
<td>Hardware components</td>
<td>98</td>
</tr>
<tr>
<td>11.2.4</td>
<td>Software components</td>
<td>98</td>
</tr>
<tr>
<td>11.3</td>
<td>Testing and verification</td>
<td>99</td>
</tr>
<tr>
<td>11.3.1</td>
<td>Methodology</td>
<td>99</td>
</tr>
<tr>
<td>11.3.2</td>
<td>List of key performance indicators</td>
<td>99</td>
</tr>
<tr>
<td>11.3.3</td>
<td>Measurement and testing tools</td>
<td>99</td>
</tr>
<tr>
<td>11.3.4</td>
<td>Intermediate results</td>
<td>99</td>
</tr>
<tr>
<td>11.4</td>
<td>Next step plans</td>
<td>99</td>
</tr>
<tr>
<td>12</td>
<td>T4S5: END-TO-END (E2E) SLICING</td>
<td>100</td>
</tr>
<tr>
<td>12.1</td>
<td>Description and motivation</td>
<td>100</td>
</tr>
<tr>
<td>12.2</td>
<td>Proposed setup</td>
<td>100</td>
</tr>
</tbody>
</table>
12.2.1 Network architecture ................................................................. 100
12.2.2 User application architecture ......................................................... 100
12.2.3 Hardware components ................................................................. 100
12.2.4 Software components ................................................................. 100
12.3 Testing and verification ................................................................. 100
12.3.1 Methodology ........................................................................ 100
12.3.2 List of key performance indicators ................................................. 101
12.3.3 Measurement and testing tools ....................................................... 101
12.3.4 Intermediate results ................................................................ 101
12.4 Next step plans ........................................................................... 101
13 T4S6: VEHICLE SOURCED HIGH-DEFINITION (HD) MAPPING .............. 102
13.1 Description and motivation .............................................................. 102
13.2 Proposed setup ........................................................................... 102
13.2.1 Network architecture ................................................................. 102
13.2.2 User application architecture ......................................................... 102
13.2.3 Hardware components ................................................................. 102
13.2.4 Software components ................................................................. 103
13.3 Testing and verification ................................................................. 103
13.3.1 Methodology ........................................................................ 103
13.3.2 List of key performance indicators ................................................. 103
13.3.3 Measurement and testing tools ....................................................... 103
13.3.4 Intermediate results ................................................................ 103
13.4 Next step plans ........................................................................... 103
14 T4S7: ENVIRONMENTAL SERVICES .................................................... 104
14.1 Description and motivation .............................................................. 104
14.2 Proposed setup ........................................................................... 104
14.2.1 Network architecture ................................................................. 104
14.2.2 User application architecture ......................................................... 104
14.2.3 Hardware components ................................................................. 104
14.2.4 Software components ................................................................. 105
14.3 Testing and verification ................................................................. 105
14.3.1 Methodology ........................................................................ 105
14.3.2 List of key performance indicators ................................................. 105
14.3.3 Measurement and testing tools ....................................................... 105
14.3.4 Intermediate results ................................................................ 105
14.4 Next step plans ........................................................................... 105
LIST OF FIGURES

Figure 1. Network architecture of Phase 2 of the Smart Junctions trials.........................................................27
Figure 2. Phase 2 Data flow of CPM data through the 5GRONINGEN network...........................................28
Figure 3. Phase 2 Data flow of Traffic Light Controller data through the 5GRONINGEN network..................28
Figure 4. Phase 2 CPM-based latency performance results, without Edge Computing..............................32
Figure 5. Phase 2 CPM-based latency performance results, with Edge Computing.......................................32
Figure 6. SPAT-based latency performance results (Cloud connection)...........................................................33
Figure 7. SPAT-based latency performance results (Edge connection)...........................................................34
Figure 8. Overall architecture of the CoCA system based on V2X communications.....................................36
Figure 9. Simulation Framework to evaluate the performance of a CoCA system..........................................37
Figure 10. Intersection scenario simulated in SUMO (left figure). Local occupancy map example (right figure). ........................................................................................................................................38
Figure 11. Simulation representation of CoCA in NS-3. .......................................................................................38
Figure 12. Simulation modules and the interaction among them.................................................................40
Figure 13: CPM structure .................................................................................................................................40
Figure 14: CPM Fusion Algorithm.................................................................................................................42
Figure 15: PDR of V2I for different MCS. .......................................................................................................46
Figure 16. (a) OMR for different maps resolutions under perfect connectivity conditions with 360° angle. (b) OMR for different maps resolutions under perfect connectivity conditions with 110° angle. ..............................................................................................................................47
Figure 17. (a) OMR with and without packets loss with 360° angle. (b) OMR with and without packets loss with 110° angle. ........................................................................................................................................48
Figure 18. PDR at RSU (UL) with different values of T ....................................................................................49
Figure 19. (a). OMR with different values of T with 360° angle. (b). OMR with different values of T with 110° angle. ........................................................................................................................................50
Figure 20. Mean CPM period ..........................................................................................................................51
Figure 21. Occurrence rate of CPMs Frequency ...............................................................................................51
Figure 22: PDR of V2I communication ..........................................................................................................52
Figure 23. (a) OMR with Th=1m, (b) OMR with Th=2m, (c) OMR with Th=4m...........................................53
Figure 24. Position error with T_{CPM}=200ms. .................................................................................................54
Figure 25. Network architecture for T2S3. ......................................................................................................55
Figure 26. Use application architecture for T2S3. ............................................................................................56
Figure 27. Message flow between the vehicle (client) and Edge (server) in T2S3.............................................56
Figure 28. Experimentation area at TUC premises, Chemnitz (N50.814°, E12.928°). Green path denotes the track the vehicle travels; orange cross marks the base station location. Map: © OpenStreetMap contributors. .........................................................................................................................58
Figure 29. Derived map for the trajectory planner (black), ideal track for the automated vehicle (gray), virtual obstacles (red) as well as the ego vehicle with the planned trajectory (blue). .........................................................................................................................58
Figure 30. Planned trajectory for a single use case..........................................................................................59
D4.3: Evolved Solution and Verification of Transport Use Case Trials

Figure 31. RTT measurements from the measurement campaign in milliseconds ........................................60
Figure 32. Average throughput over time in bits/s ..................................................................................60
Figure 33. Network architecture for the Phase 2 trials of the human tachograph use case scenario.......62
Figure 34. User application architecture for the Phase 2 trials of the human tachograph use case scenario. .................................................................64
Figure 35. Human tachograph trial setup for the Phase 2 laboratory measurements. .........................66
Figure 36. Human tachograph trial setup for the Phase 2 outdoor measurements ..............................67
Figure 37. Outdoor measurement route for the human tachograph Phase 2 trials with the RSRP (dBm) values. ..............................................................................................................................................68
Figure 38. CDF of the biosignal reporting latency in the UL direction. ..................................................69
Figure 39. CDF of the warning message delivery latency in the DL direction. .......................................69
Figure 40. Reliability as a function of time constraint for the biosignal reporting in the UL direction. 70
Figure 41. Reliability as a function of time constraint for the warning message delivery in the DL direction. ..............................................................................................................................................70
Figure 42. High-level overview of the TeSo service’s network and user application architecture and setup. ..............................................................................................................................................72
Figure 43. Detailed overview of the TeSo service’s network architecture .................................................73
Figure 44. ROC GUI application ..........................................................................................................75
Figure 45. Overview of the hardware equipment at the vehicle’s (left) and ROC’s (right) side ..........75
Figure 46 TeSo service’s testing and verification methodology ....................................................................77
Figure 47. RTT of GPS position TCP stream. .......................................................................................79
Figure 48. RTT of front camera TCP stream. .......................................................................................80
Figure 49. RTT of back camera TCP stream. .......................................................................................80
Figure 50. RTT of right camera TCP stream. .......................................................................................81
Figure 51. RTT of left camera TCP stream. .............................................................................................81
Figure 52. RTT of steering wheel control TCP stream. .................................................................82
Figure 53. RTT of vehicle state TCP stream. ............................................................................................82
Figure 54. RTT of automation state TCP stream. ..................................................................................83
Figure 55. Network architecture for the Phase 2 trials of the vehicle prognostics use case scenario. ...84
Figure 56: Measurement setup for the Phase 2 trials of the vehicle prognostics use case scenario. .....86
Figure 57: CDC of the vehicle prognostics message delivery latency. ..................................................86
Figure 58. Network architecture for the Phase 2 trials of the OTA updates use case scenario. ............87
Figure 59. User application architecture for the Phase 2 trials of the OTA updates use case scenario. 90
Figure 60: Measurement setup for eMBMS multicasting. .................................................................91
Figure 61: Web dashboard to visualize the proposed route to the end-user. ......................................95
Figure 62. End-to-end response latencies. .............................................................................................96
LIST OF TABLES

Table 1: Planned trial locations and involved partners of the transport use case scenarios ............19
Table 2: Target KPIs for T1S1&T1S2 ..................................................................................24
Table 3: Target KPIs for T2S1, trial track ...........................................................................30
Table 4: Phase 1 (4G/LTE) Network layer performance results ............................................30
Table 5: Phase 2 Network layer performance results ..............................................................31
Table 6: Phase 1 (4G/LTE) CPM-based latency performance results .....................................31
Table 7: Phase 2 CPM-based latency performance results, with and without Edge Computing ...31
Table 8: SPAT-based latency performance results (Cloud connection) .................................33
Table 9: SPAT-based latency performance results (Edge connection) ....................................33
Table 10: Image compression techniques evaluation .............................................................44
Table 11: Configuration settings ............................................................................................45
Table 12: Target KPIs for T2S3 ............................................................................................59
Table 13: Target KPIs for T2S4 ............................................................................................67
Table 14: Parameterization of USRPs and antennas ..............................................................74
Table 15: Target KPIs for T3S1 ............................................................................................78
Table 16: Network layer reference measurements ..................................................................79
Table 17: Target KPIs for T4S1 ............................................................................................86
Table 18: Average throughput, goodput, and latency from the vehicle prognostics Phase 2 trials .....87
Table 19: Target KPIs for T4S2 ............................................................................................91
Table 20: Average performance of the eMBMS-based cellular multicast for file download ..........92
Table 21: Target KPIs for T4S3 ............................................................................................96
Table 22: Target KPIs for T4S4 ............................................................................................99
Table 23: Target KPIs for T4S6 ..........................................................................................103
Table 24: Target KPIs for T4S7 ..........................................................................................105
### ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2D</td>
<td>Two-Dimensional</td>
</tr>
<tr>
<td>3GPP</td>
<td>Third Generation Partnership Project</td>
</tr>
<tr>
<td>4G</td>
<td>Fourth Generation</td>
</tr>
<tr>
<td>5G</td>
<td>Fifth Generation</td>
</tr>
<tr>
<td>5G IA</td>
<td>5G Infrastructure Association</td>
</tr>
<tr>
<td>5G NR</td>
<td>5G New Radio</td>
</tr>
<tr>
<td>5G PPP</td>
<td>5G Infrastructure Public Private Partnership</td>
</tr>
<tr>
<td>5GC</td>
<td>5G Core</td>
</tr>
<tr>
<td>ACC</td>
<td>Accelerometer</td>
</tr>
<tr>
<td>API</td>
<td>Application Programming Interface</td>
</tr>
<tr>
<td>AQI</td>
<td>Air Quality Index</td>
</tr>
<tr>
<td>AQMA</td>
<td>Air Quality Management Area</td>
</tr>
<tr>
<td>AR</td>
<td>Augmented Reality</td>
</tr>
<tr>
<td>AV</td>
<td>Automated Vehicle</td>
</tr>
<tr>
<td>BLE</td>
<td>Bluetooth Low Energy</td>
</tr>
<tr>
<td>BM-SC</td>
<td>Broadcast-Multicast Service Center</td>
</tr>
<tr>
<td>BPP</td>
<td>Bits Per Pixel</td>
</tr>
<tr>
<td>BSI</td>
<td>British Standards Institution</td>
</tr>
<tr>
<td>BW</td>
<td>Bandwidth</td>
</tr>
<tr>
<td>C-V2X</td>
<td>Cellular Vehicle-to-Everything</td>
</tr>
<tr>
<td>CAM</td>
<td>Cooperative Awareness Message</td>
</tr>
<tr>
<td>CBR</td>
<td>Channel Busy Ratio</td>
</tr>
<tr>
<td>CDF</td>
<td>Cumulative Distribution Function</td>
</tr>
<tr>
<td>CLI</td>
<td>Command Line Interface</td>
</tr>
<tr>
<td>CN</td>
<td>Core Network</td>
</tr>
<tr>
<td>CO</td>
<td>Carbon Monoxide</td>
</tr>
<tr>
<td>CoCA</td>
<td>Cooperative Collision Avoidance</td>
</tr>
<tr>
<td>CPE</td>
<td>Customer Premises Equipment</td>
</tr>
<tr>
<td>CPM</td>
<td>Collective Perception Message</td>
</tr>
<tr>
<td>CR</td>
<td>Compression Ratio, Channel Occupancy Ratio</td>
</tr>
<tr>
<td>DCC</td>
<td>Decentralised Congestion Control</td>
</tr>
<tr>
<td>DENM</td>
<td>Decentralised Environmental Notification Message</td>
</tr>
<tr>
<td>DL</td>
<td>Downlink</td>
</tr>
<tr>
<td>E2E</td>
<td>End-to-End</td>
</tr>
<tr>
<td>ECG</td>
<td>Electrocardiogram</td>
</tr>
<tr>
<td>eMBMS</td>
<td>Evolved Multimedia Broadcast Multicast Service</td>
</tr>
<tr>
<td>eNB</td>
<td>Evolved NodeB</td>
</tr>
<tr>
<td>EPC</td>
<td>Evolved Packet Core</td>
</tr>
<tr>
<td>ETSI</td>
<td>European Telecommunications Standards Institute</td>
</tr>
<tr>
<td>FDD</td>
<td>Frequency Division Duplex</td>
</tr>
<tr>
<td>GLOSA</td>
<td>Green Light Optimal Speed Advice</td>
</tr>
<tr>
<td>gNB</td>
<td>Next Generation NodeB</td>
</tr>
<tr>
<td>GNSS</td>
<td>Global Navigation Satellite System</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>GSM</td>
<td>Global System for Mobile Communications</td>
</tr>
<tr>
<td>GUI</td>
<td>Graphical User Interface</td>
</tr>
<tr>
<td>GW</td>
<td>Gateway</td>
</tr>
<tr>
<td>HD</td>
<td>High-Definition</td>
</tr>
<tr>
<td>HLS</td>
<td>Hypertext Transfer Protocol Live Streaming</td>
</tr>
<tr>
<td>HR</td>
<td>Heart Rate</td>
</tr>
<tr>
<td>----------</td>
<td>------------------------------------------------</td>
</tr>
<tr>
<td>HTTP</td>
<td>Hypertext Transfer Protocol</td>
</tr>
<tr>
<td>HW</td>
<td>Hardware</td>
</tr>
<tr>
<td>ID</td>
<td>Identifier</td>
</tr>
<tr>
<td>IoT</td>
<td>Internet of Things</td>
</tr>
<tr>
<td>IOP</td>
<td>Independent Opinion Poll</td>
</tr>
<tr>
<td>IP</td>
<td>Internet Protocol</td>
</tr>
<tr>
<td>ITS</td>
<td>Intelligent Transport System</td>
</tr>
<tr>
<td>ITS-S</td>
<td>Intelligent Transport System - Station</td>
</tr>
<tr>
<td>KPI</td>
<td>Key Performance Indicator</td>
</tr>
<tr>
<td>LDM</td>
<td>Local Dynamic Map</td>
</tr>
<tr>
<td>LIDAR</td>
<td>Light Detection and Ranging</td>
</tr>
<tr>
<td>LoA</td>
<td>Level of Automation</td>
</tr>
<tr>
<td>LoS</td>
<td>Line of Sight</td>
</tr>
<tr>
<td>LTE</td>
<td>Long-Term Evolution</td>
</tr>
<tr>
<td>LWA</td>
<td>Long-Term Evolution – Wireless Local Area Network Aggregation</td>
</tr>
<tr>
<td>MAC</td>
<td>Medium Access Control</td>
</tr>
<tr>
<td>MBMS</td>
<td>Multimedia Broadcast Multicast Service</td>
</tr>
<tr>
<td>MCE</td>
<td>Multicast Coordination Entity</td>
</tr>
<tr>
<td>MCS</td>
<td>Modulation and Coding Scheme</td>
</tr>
<tr>
<td>MEC</td>
<td>Multi-access Edge Computing</td>
</tr>
<tr>
<td>MIMO</td>
<td>Multiple Input Multiple Output</td>
</tr>
<tr>
<td>ML</td>
<td>Machine Learning</td>
</tr>
<tr>
<td>MQTT</td>
<td>Message Queuing Telemetry Transport</td>
</tr>
<tr>
<td>MSE</td>
<td>Mean Square Error</td>
</tr>
<tr>
<td>MTU</td>
<td>Maximum Transmission Unit</td>
</tr>
<tr>
<td>NB-IoT</td>
<td>Narrowband Internet of Things</td>
</tr>
<tr>
<td>NLoS</td>
<td>Non-Line of Sight</td>
</tr>
<tr>
<td>NMEA</td>
<td>National Marine Electronics Association</td>
</tr>
<tr>
<td>NO</td>
<td>Nitrogen Monoxide</td>
</tr>
<tr>
<td>NO2</td>
<td>Nitrogen Dioxide</td>
</tr>
<tr>
<td>NSA</td>
<td>Non-Standalone</td>
</tr>
<tr>
<td>NTP</td>
<td>Network Time Protocol</td>
</tr>
<tr>
<td>O3</td>
<td>Ozone</td>
</tr>
<tr>
<td>OAI</td>
<td>OpenAirInterface</td>
</tr>
<tr>
<td>OBD-II</td>
<td>On-Board Diagnostics – Second Generation</td>
</tr>
<tr>
<td>OBU</td>
<td>On-Board Unit</td>
</tr>
<tr>
<td>OLoS</td>
<td>Obstructed Line of Sight</td>
</tr>
<tr>
<td>OMR</td>
<td>Obstacle Misdetection Rate</td>
</tr>
<tr>
<td>OS</td>
<td>Operating System</td>
</tr>
<tr>
<td>OSI</td>
<td>Open Systems Interconnection</td>
</tr>
<tr>
<td>OTA</td>
<td>Over-the-Air</td>
</tr>
<tr>
<td>PC</td>
<td>Personal Computer</td>
</tr>
<tr>
<td>PDCP</td>
<td>Packet Data Convergence Protocol</td>
</tr>
<tr>
<td>PDR</td>
<td>Packet Delivery Ratio</td>
</tr>
<tr>
<td>PDU</td>
<td>Protocol Data Unit</td>
</tr>
<tr>
<td>PHP</td>
<td>Personal Home Page</td>
</tr>
<tr>
<td>PHY</td>
<td>Physical</td>
</tr>
<tr>
<td>PM</td>
<td>Particulate Matter</td>
</tr>
<tr>
<td>POC</td>
<td>Perceived Object Container</td>
</tr>
<tr>
<td>PPP</td>
<td>Point-to-Point Protocol</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>-------------</td>
</tr>
<tr>
<td>PPS</td>
<td>Pulse Per Second</td>
</tr>
<tr>
<td>PSNR</td>
<td>Peak Signal to Noise Ratio</td>
</tr>
<tr>
<td>PTP</td>
<td>Precision Time Protocol</td>
</tr>
<tr>
<td>QoE</td>
<td>Quality of Experience</td>
</tr>
<tr>
<td>QoS</td>
<td>Quality of Service</td>
</tr>
<tr>
<td>RADAR</td>
<td>Radio Detection and Ranging</td>
</tr>
<tr>
<td>RAN</td>
<td>Radio Access Network</td>
</tr>
<tr>
<td>RAT</td>
<td>Radio Access Technology</td>
</tr>
<tr>
<td>RB</td>
<td>Resource Block</td>
</tr>
<tr>
<td>RDBMS</td>
<td>Relational Database Management System</td>
</tr>
<tr>
<td>RF</td>
<td>Radio Frequency</td>
</tr>
<tr>
<td>RLC</td>
<td>Radio Link Control</td>
</tr>
<tr>
<td>ROC</td>
<td>Remote Operations Centre</td>
</tr>
<tr>
<td>RSRP</td>
<td>Reference Signal Received Power</td>
</tr>
<tr>
<td>RSU</td>
<td>Road Side Unit</td>
</tr>
<tr>
<td>RTT</td>
<td>Round-Trip Time</td>
</tr>
<tr>
<td>SA</td>
<td>Standalone</td>
</tr>
<tr>
<td>SAE</td>
<td>Society of Automotive Engineers</td>
</tr>
<tr>
<td>SC-FDMA</td>
<td>Single Carrier Frequency Division Multiple Access</td>
</tr>
<tr>
<td>SDK</td>
<td>Software Development Kit</td>
</tr>
<tr>
<td>SDR</td>
<td>Software-Defined Radio</td>
</tr>
<tr>
<td>SIC</td>
<td>Sensor Information Container</td>
</tr>
<tr>
<td>SISO</td>
<td>Single Input Single Output</td>
</tr>
<tr>
<td>SLA</td>
<td>Service Level Agreement</td>
</tr>
<tr>
<td>SO2</td>
<td>Sulphur Dioxide</td>
</tr>
<tr>
<td>SoC</td>
<td>System on a Chip</td>
</tr>
<tr>
<td>SoA</td>
<td>State-of-the-Art</td>
</tr>
<tr>
<td>SPAT</td>
<td>Signal Phase and Timing</td>
</tr>
<tr>
<td>SRM</td>
<td>Signal Request Message</td>
</tr>
<tr>
<td>SSM</td>
<td>Signal State Message</td>
</tr>
<tr>
<td>SUMO</td>
<td>Simulation of Urban Mobility</td>
</tr>
<tr>
<td>SW</td>
<td>Software</td>
</tr>
<tr>
<td>TCP</td>
<td>Transmission Control Protocol</td>
</tr>
<tr>
<td>TDD</td>
<td>Time Division Duplex</td>
</tr>
<tr>
<td>TeSo</td>
<td>Tele-operated Support</td>
</tr>
<tr>
<td>TLC</td>
<td>Traffic Light Controller</td>
</tr>
<tr>
<td>TTI</td>
<td>Transmission Time Interval</td>
</tr>
<tr>
<td>UDP</td>
<td>User Datagram Protocol</td>
</tr>
<tr>
<td>UE</td>
<td>User Equipment</td>
</tr>
<tr>
<td>UL</td>
<td>Uplink</td>
</tr>
<tr>
<td>URLLC</td>
<td>Ultra-Reliable Low-Latency Communication</td>
</tr>
<tr>
<td>USB</td>
<td>Universal Serial Bus</td>
</tr>
<tr>
<td>USRP</td>
<td>Universal Software Radio Peripheral</td>
</tr>
<tr>
<td>UTM</td>
<td>Universal Traverse Mercator</td>
</tr>
<tr>
<td>V2I</td>
<td>Vehicle-to-Infrastructure</td>
</tr>
<tr>
<td>V2N</td>
<td>Vehicle-to-Network</td>
</tr>
<tr>
<td>V2P</td>
<td>Vehicle-to-Pedestrian</td>
</tr>
<tr>
<td>V2V</td>
<td>Vehicle-to-Vehicle</td>
</tr>
<tr>
<td>V2X</td>
<td>Vehicle-to-Everything</td>
</tr>
<tr>
<td>VM</td>
<td>Virtual Machine</td>
</tr>
<tr>
<td>VRU</td>
<td>Vulnerable Road User</td>
</tr>
<tr>
<td>ZMTP</td>
<td>ZeroMQ Message Transport Protocol</td>
</tr>
</tbody>
</table>
1 INTRODUCTION

This deliverable describes the Phase 2 trials of the transport vertical use cases of the 5G-HEART project. These trials contribute to the milestone MS4 (“Phase 2 trials of multiple verticals”) from the perspective of WP4 (“Solutions for Delivery of Transport Vertical”). The described trials are based on the transport vertical use case scenarios defined in the 5G-HEART project deliverable D4.1 [1]. The contents of this deliverable are an update to the Phase 1 trials described in deliverable D4.2 [2]. The verification of the evolved solutions during Phase 2 of the project is performed against the scenario specific Key Performance Indicators (KPIs) originally defined in deliverable D2.2 [3].

The implementation of the vertical validation trials is performed iteratively in three phases. In Phase 1, the initial implementations of the use case service components, i.e., the initial solutions, were tested on top of the 5G test facilities and the performance achieved with the partial implementations of the trial scenarios was measured. In Phase 2, the focus has been on the extended implementations of the use case service components, i.e. evolved solutions, as the work has continued from individual components towards integrated trial deployments. The performance of the extended Phase 2 implementations has again been verified on top of the 5G test facilities. In Phase 3, the full implementations of the use cases will be deployed on top of the 5G test facilities, their performance and functionality will be verified. Through the performance verification of the full implementations, the project will validate the feasibility of 5G as the connectivity platform for its target verticals.

Due to COVID-19, access to the transport trial facilities has been significantly restricted or even completely blocked during the Phase 2 activities. Subsequently, for most use case scenarios, significantly more performance verification measurements have been scheduled to the beginning of Phase 3 than what was originally planned. This has been taken into consideration while planning the Phase 3 activities and all remaining measurements will be reported in the subsequent deliverable D4.4 at the end of the project.

1.1 Use cases and Phase 2 trials overview

Based on the initial transport vertical trial results reported in [2], the implementation work towards the final trials has been prioritised as shown in Table 1. In order to achieve in-depth validation of the identified key Fifth Generation (5G) functionalities for the use cases, five core scenarios have been selected as the main focus of the transport vertical. In parallel with the five core scenarios, the work around the supplementary scenarios focuses on individual technology enablers and extends the knowledge gained from the large-scale trials of the core scenarios. Table 1 presents an overview of the transport vertical use case scenarios which are going to be investigated and trialled during the 5G-HEART project, including the planned trial facilities, locations and list of involved partners.

Table 1: Planned trial locations and involved partners of the transport use case scenarios

<table>
<thead>
<tr>
<th>Use case scenario</th>
<th>Planned trial facility</th>
<th>Planned trial location</th>
<th>Scenario owner (and partners in alphabetical order)</th>
<th>Other collaboration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core use case scenarios</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T2S1: Smart junctions and network assisted &amp; cooperative collision avoidance (CoCa); Trial track</td>
<td>5Groningen</td>
<td>Groningen, Netherlands</td>
<td>TNO (CEA, DYNNIQ, EPI, TUC, UOS)</td>
<td>Potential collaboration with healthcare trials</td>
</tr>
</tbody>
</table>
## 1.2 Definitions

The following terminology and definitions are consistently being used across this document:

- **Road Side Unit (RSU):** A stationary infrastructure entity equipped with V2X capabilities. It can exchange messages with other entities supporting V2X applications. The RSU could be...
implemented in a Fourth Generation (4G) Evolved NodeB (eNB), 5G Next Generation NodeB (gNB) or in a stationary User Equipment (UE) [4].

- **Vehicle-to-Infrastructure (V2I):** The UEs, when equipped with V2I capabilities, can exchange messages containing V2I application information with an RSU or locally relevant application server.
- **Vehicle-to-Network (V2N):** The UEs supporting V2N applications can communicate with an application server via a Third Generation Partnership Project (3GPP) packet network.
- **Vehicle-to-Pedestrian (V2P):** The UEs supporting the V2P functionality can transmit messages containing V2P application information. Such information can be transmitted either by a UE in a vehicle (e.g., warning to pedestrian), or by a UE associated with a Vulnerable Road User (VRU) (e.g., warning to vehicle). The 3GPP transport of this information could be direct between UEs and/or via an infrastructure supporting V2X communication (e.g., On-Board Unit (OBU), RSU and application server).
- **Vehicle-to-Vehicle (V2V):** The UEs supporting the V2V functionality can transmit messages containing V2V application information (e.g. location, dynamics, and attributes). The 3GPP transport of these messages is predominantly broadcast-based. It may be direct between UEs and/or via an infrastructure supporting V2X communication (e.g., OBU, RSU and application server).
- **Vehicle-to-Everything (V2X):** V2X is an umbrella term that covers all 4 types mentioned above, i.e., V2I, V2N, V2P and V2V.
- **SAE levels:** The Society of Automotive Engineers (SAE) defines the following six levels of driving automation [5].
  0 – No Driving Automation,
  1 – Driver Assistance,
  2 – Partial Driving Automation,
  3 – Conditional Driving Automation,
  4 – High Driving Automation,
  5 – Full Driving Automation.

The classification is based on the degree of human involvement. For the lower automation levels (i.e., 0-2), the human operator is the main responsible for monitoring the driving environment and taking actions accordingly. For higher automation levels (i.e., 3-5), the automated system takes over the control of these tasks as the human operator becomes less involved.

### 1.3 Organization of this deliverable

Sections 2-14 provide a detailed description of the Phase 2 trials for each of the considered scenarios, including the proposed trial setup, intermediate testing and verification results, and next-step plans:

- **Section 2:** T1S1&T1S2: High bandwidth in-vehicle situational awareness and see-through for platooning
- **Section 3:** T2S1: Smart junctions and network assisted & Cooperative Collision Avoidance (CoCA); Trial track
- **Section 4:** T2S2: Smart junctions and network assisted & Cooperative Collision Avoidance (CoCA); Simulation track
- **Section 5:** T2S3: Quality of Service (QoS) for advanced driving
- **Section 6:** T2S4: Human tachograph
- **Section 7:** T3S1: Tele-operated Support (TeSo)
- **Section 8:** T4S1: Vehicle prognostics
- **Section 9:** T4S2: Over-The-Air (OTA) updates
- **Section 10:** T4S3: Smart traffic corridors
- **Section 11:** T4S4: Location based advertising
- **Section 12:** T4S5: End-to-End (E2E) slicing
D4.3: Evolved Solution and Verification of Transport Use Case Trials

- Section 13: T4S6: Vehicle sourced High-Definition (HD) mapping
- Section 14: T4S7: Environmental services

Concluding remarks are given in Section 15.
2 T1S1&T1S2: HIGH BANDWIDTH IN-VEHICLE SITUATIONAL AWARENESS AND SEE-THROUGH FOR PLATOONING

2.1 Description and motivation

When driving in platoons, the drivers will most likely feel more secure when they can see what is happening ahead of the lead vehicle. This can be achieved by the see-through functionality that characterises the front scene (i.e., as seen by the lead vehicle) via an Augmented Reality (AR) video stream communicated to the following vehicles. This could also extend the object/event detection to the trailing vehicles for increased safety (via redundancy) and/or comfort by anticipating manoeuvres of the lead vehicle in response to the driving conditions.

While situational awareness and see-through have been previously applied to warn individual drivers about hazardous driving situations ahead, they have not been considered to support the switch between platooning and individual driving modes. As partial automation levels (e.g., SAE Level-3 and Level-4) may govern the operation of platoons, the human driver of a platooned vehicle would need to be updated to get ready to take over the control of the vehicle whenever needed. The identified objects ahead and/or real-time video representing the front scene could be used as a visual alert that a given platoon is about to be split for safety and/or efficiency reasons, thus keeping the drivers’ anxiety levels low.

2.2 Proposed setup

This use-case scenario is being trialled on the 5GENESIS trial facility located in Surrey, UK. Due to the access restrictions at the facility during the Phase 2 work, most performance verification measurements for the extended trial implementation have been re-scheduled to the beginning of Phase 3.

2.2.1 Network architecture

On the network side, the see-through functionality will be supported by the slicing-as-a-service functionality of the 5GENESIS trial facility. The Radio Access Network (RAN) part of the configuration is a set of experimental setups based on OpenAirInterface (OAI) and Software-Defined Radios (SDRs). More details on the network architecture can be found from Section 3.2.1 of the deliverable D4.2 [2].

2.2.2 User application architecture

On the user application side, the functionalities offered by this scenario (i.e., situational awareness and see-through) would need to be supported on top of the basic platooning operation. On the trial facility side, an experimental (i.e., OAI+SDR) setup has been integrated to support Cellular Vehicle-to-Everything (C-V2X) communications. To this end, an incremental methodology has been followed to test each of the required components and functionalities, starting with a baseline 4G setup and moving eventually to a 5G setup. More details on the user application architecture can be found from Section 3.2.2 of the deliverable D4.2 [2].

2.2.3 Hardware components

The required Hardware (HW) components to conduct the Phase 2 trials are the following:

- 4G and Long-Term Evolution – Wireless Local Area Network Aggregation (LWA) experimental setups
  - 5x Universal Software Radio Peripheral (USRP) 2954R
  - DELL OPTIPLEX 7050 (OAI UE)
  - DELL OPTIPLEX 7040 (OAI eNB)
  - PCIe card and PCIe x4 cable
  - DELL OPTIPLEX 9020 for (OAI Evolved Packet Core (EPC))
2.2.4 Software components

The baseline 4G OAI provides a Software (SW) implementation of all key components (i.e., UE, eNB and EPC) of the Long-Term Evolution (LTE) system architecture.

2.3 Testing and verification

2.3.1 Methodology

The setup is planned to be installed inside two vehicles and used to stream video from one to another via their V2V link. In Phase 1 test presented in Section 3.3.4 of the deliverable D4.2 [2], aggregating LTE and WiFi (i.e., LWA) was shown to sustain video streaming with a resolution that may suffice for see-through in a controlled environment (i.e., lab). However, it may not sustain such resolution in less controlled dynamic environments and, furthermore, LWA cannot meet the Ultra-Reliable Low-Latency Communication (URLLC) requirements associated with the platooning operation. As such, 5G is highly needed to fully support this scenario and tests with 4G/5G C-V2X functionality, based on the OAI+USRP experimental setups, are the next step towards the full trial implementation of the use case scenario.

2.3.2 List of key performance indicators

The key target KPIs for Phase 2 are listed in Table 2, which are a subset of the full target KPIs list presented in Section 3.3.2 of the deliverable D4.2 [2].

<table>
<thead>
<tr>
<th>Network requirements</th>
<th>Target values</th>
</tr>
</thead>
<tbody>
<tr>
<td>User experienced downlink (DL) throughput</td>
<td>High (25-80 Mbps)</td>
</tr>
<tr>
<td>User experienced uplink (UL) throughput</td>
<td>High (25-80 Mbps)</td>
</tr>
<tr>
<td>Latency requirements</td>
<td>Medium (5 ms)</td>
</tr>
<tr>
<td>Reliability</td>
<td>High (99.99999%)</td>
</tr>
</tbody>
</table>

2.3.3 Measurement and testing tools

On the experimental (i.e., OAI+USRP) setup side, the OAI built-in tools (e.g., T tracer\(^2\)) will be used to debug and monitor the performance of the OAI communication links.

On the network side, the measurement and testing tools of the 5GENESIS trial facility will be exploited. In particular, the following components will be used:

\(^2\) [https://gitlab.eurecom.fr/oai/openairinterface5g/wikis/T](https://gitlab.eurecom.fr/oai/openairinterface5g/wikis/T)
• Infrastructure Monitoring, which focuses on the collection of data that synthesize the status of architectural components, e.g., end-user devices, radio access and networking systems, computing and storage distributed units.
• Performance Monitoring, which is devoted to the active measure of performance indicators.
• Storage and Machine Learning (ML) Analytics, which enables efficient management of large sets of heterogeneous data and drives the discovery of hidden values and correlation among them.
• InfluxDB (storage).
• Grafana (visualization).

On the vehicle side, the methodology described in Section 2.2.2 of the deliverable D4.2 [2] will be utilised to capture the end-user perception and assess the contribution of the on-board components to the overall performance.

2.3.4 Intermediate results

The initial baseline results for the use case scenario have been presented in Section 3.3.4 of the deliverable D4.2 [2]. Further tests with 4G/5G C-V2X functionality have been scheduled to the beginning of Phase 3.

2.4 Next step plans

The next step is to perform the pending the 4G/5G C-V2X tests with the extended trial implementation. In addition, once the 4G/5G C-V2X support becomes available on the commercial nodes of the 5GENESIS trial facility, the experimental setup will evolve to a mixed one where both USRPs and commercial 4G/5G modems will be used with their performances compared.
3 T2S1: SMART JUNCTIONS AND NETWORK ASSISTED & COOPERATIVE COLLISION AVOIDANCE (COCA); TRIAL TRACK

3.1 Description and motivation

As introduced in Deliverable D4.1 [1] and D4.2 [2], this use case focuses on providing time critical safety information at intersections as well as improving the overall traffic efficiency at intersections and amongst corridors. The safety information at the intersection involves the exchange of precise traffic signal status information, vehicle information (e.g., location, speed and trajectory), as well as location information of VRUs.

This scenario can be implemented in multiple ways. At the Dutch 5GRONINGEN test facility for example, the earlier mentioned safety information is stored in a Local Dynamic Map (LDM) [6] running at the RSU. The intersection controller is hosted separately from the RSU and is, amongst others, responsible for controlling the traffic lights at the intersection.

LDM information will be sent to the vehicles periodically or on demand using European Telecommunications Standards Institute (ETSI) Collective Perception Messages (CPM) [7]. This information will be needed both in the vehicles as well as at the intersection controller to know the current intersection situation and control or convey messages to Automated Vehicles (AVs) (SAE Levels 1 to 3). This service can be provided by a so-called Intersection Safety Information System, which consists of road Radio Detection and Ranging (RADAR), traffic signal information, an LDM server and an RSU application. An application running on top of the LDM server monitors the current road situation at the intersection based on multiple sensors like the road RADAR and traffic signals and generates LDM information which can be delivered to UEs through the RSU application.

A special case is when an individual vehicle, for example an ambulance on its way to an accident, requests priority. This disrupts the default operation of dynamically creating green waves for the larger traffic flow. The vehicle can send a Signal Request Message (SRM) [8] to request priority, which will be answered by the RSU with a Signal State Message (SSM) [9]. To fill the SSM, an interaction with the traffic light controller is required. Moreover, several authorisation steps must be taken to verify the authenticity of the priority request. Due to the disruptive nature of such requests, it is very important to restrict access to vehicles that really need it.

For the Phase 2 trials at the Dutch 5GRONINGEN test facility, an implementation with both CPM messages [7] as well as and implementation with MAP and Signal Phase and Timing (SPAT) messages has been used. The next sections will describe the Phase 2 architecture in more detail.

3.2 Proposed setup

This use case scenario is being trialled on the 5GRONINGEN trial facility located in Groningen and Helmond, the Netherlands. The following section describes the architectures of the Phase 2 trial setup.

3.2.1 Network architecture

During the course of Phase 2, the network architecture of the 5GRONINGEN test facility has been upgraded and reconfigured to support 5G. To that extend the 4G eNB has been replaced by a 5G gNB supporting 5G Stand-Alone (SA) on the 3.6 GHz frequency with a bandwidth of 100 MHz. Also the 4G Core network has been replaced by a 5G Core network with additional support for end-to-end Slicing and Edge Computing.

After the network was upgraded, a Traffic Light Controller (TLC) from Dynniq has been connected to the edge of the 5GRONINGEN network. Via the 5G network, the TLC can now provide Traffic Light data towards the vehicles that are approaching the intersection. The updated architecture is depicted in the below figure.
In what follows, the Phase 2 components will be described in more details together with the associated results.

### 3.2.2 User application architecture

For the Phase 2 trials at the Dutch 5GRONINGEN test facility, the implementation with CPM messages [7] has been extended and an implementation with intersection topology and traffic light signal status information via ETSI SPAT messages and ETSI MAP messages has been added.

**Architecture with ETSI CPM messages**

Figure 2 depicts the updated architecture of the CPM based application. Within this architecture, the infrastructure is equipped with Internet Protocol (IP) based camera’s capable of doing object detection and recognition, e.g. detecting and tracking trajectories of vehicles and VRUs. The information of the detections of these IP based camera’s, e.g. location, direction, speed, are put into CPM messages and published on a service running in the Edge of the 5GRONINGEN platform.

The vehicles used for this project, connected to the network via OBUs with 5G New Radio (5G NR) modules, can subscribe to the service running in the Edge in order to receive these CPM messages, store them in their local LDM and act upon the information accordingly. For example, a vehicle could slow down, after receiving detections of a VRU on its trajectory.

Figure 2 shows the information flow of CPM messages going through the network. The Message Queuing Telemetry Transport (MQTT) back-office server running in the Edge of the 5G network acts as a message broker for the sending and receiving applications. The object detections are published as ETSI CPM messages by the cameras to the message broker. The vehicles can subscribe to the message broker to receive ETSI CAM and ETSI CPM messages, while also publishing ETSI CAM messages.

Appendix A shows an example of the contents of an ETSI CPM message.
D4.3: Evolved Solution and Verification of Transport Use Case Trials

Architecture with ETSI MAP, SPAT, SRM and SSM messages

Next to the upgraded architecture of the CPM based application as described above, for the Phase 2 trials also an intelligent TLC has been connected to the 5GRONINGEN network. This facilitates the delivery of intersection topology and traffic light signal status information to the vehicles connected to the 5G network.

This traffic light signal status and intersection topology information is provided to the vehicles via ETSI SPAT messages and ETSI MAP. Next to that we also implemented green wave priority request via ETSI SRM and SSM messages for special vehicles like ambulances and fire engines.

This facilitates special cases when an individual vehicle, for example an ambulance or fire engine is on its way to an accident, requests priority to gain green wave on passing intersections. This disrupts the default operation of dynamically creating green waves for the larger traffic flow. The vehicle can send a SRM [8] to request priority, which will be answered by the RSU with a SSM [9]. To fill the SSM, an interaction with the traffic light controller is required. Moreover, several authorisation steps must be taken to verify the authenticity of the priority request. Due to the disruptive nature of such requests, it is very important to restrict access to vehicles that really need it.

Figure 2. Phase 2 Data flow of CPM data through the 5GRONINGEN network.

Figure 3. Phase 2 Data flow of Traffic Light Controller data through the 5GRONINGEN network.
Figure 3 shows the information flow of Traffic Light Controller data going through the network. The MQTT back-office server running in the edge of the 5G network acts as a message broker for the sending and receiving applications.

The vehicle position information and priority requests are published as ETSI CAM and ETSI SRM messages respectively to the message broker. Via the message broker this information is forwarded to the corresponding Traffic Light Controller to be processed.

The intersection topology and traffic light signal status information are published to the message broker via ETSI MAP messages and ETSI SPAT messages. The Traffic Light Controller response and status of the vehicle’s priority request is published to the message broker via ETSI SSM messages. The vehicles can subscribe to the message broker at the edge of the network to receive the corresponding information.

### 3.2.3 Hardware components

The Phase 2 trial network architecture contains the following components:

- One OBU configured for both 5G SA and LTE-V2X.
- 5G SA gNB:
  - Running 5G SA @ 3650 MHz with a Bandwidth (BW) of 100 MHz.
- 5G Core (5GC) network.
- IP based security cameras with object detection, e.g. vehicle and VRU tracking.
- Intelligent Traffic Light Controller with support for Emergency Vehicle priority request.
- Back-office edge server running an MQTT broker, hosting the object detections and traffic light status information.

### 3.2.4 Software components

The Phase 2 trial application architecture consists of components both on the vehicle side, residing within the OBU, and at the infrastructure side, running the IP based cameras, the intelligent Traffic Light Controller and a back-office server platform.

On the vehicle side, the OBU is functioning as a UE connecting to the network via 5G Stand Alone. The OBU runs three applications, one application generating and publishing ETSI CAM [10] messages to the network and another application consuming ETSI CPM messages from the network. The third application consumes the ETSI MAP, SPAT and SSM messages from the network, while publishing the ETSI SRM messages to the network.

On the infrastructure side, the back-office server is running an MQTT platform at which the IP based cameras publish their object detections in the form of ETSI CPM messages, the intelligent Traffic Light Controller publishes its traffic light information in the form of ETSI MAP, ETSI SPAT and ETSI SSM messages and the vehicles publish their position information in the form of ETSI CAM messages.

### 3.3 Testing and verification

#### 3.3.1 Methodology

In Phase 2, the architectures presented in Section 3.2.2 are tested. The focus of the trials will be on the initial 5G Stand Alone measurements for both the general network latency when introducing Edge Computing and the throughput of the 5G Stand Alone network, as well as the CPM application layer and TLC application layer E2E latency.

These different entities will be tested separately with the tools described in Section 3.3.3, from the same stationary OBU connected to the network via a gNB. For the general delay and throughput measurements, the OBU will be using Ping and iPerf tools to measure the performance to different
components within the network. For the CPM application layer E2E latency measurements on the other hand, the OBU will run a CPM application which retrieves CPM messages from an edge service, as shown in Figure 2.

3.3.2 List of key performance indicators

The Intersection Safety Information System is an application based on V2X communications to improve safety at intersections. As the Phase 2 trials aim to test the connectivity, functionality, and performance of the integrated 5G capable equipment to be compared with the baseline State-of-the-Art (SotA) (3GPP Rel-14 LTE) measurements of the Phase 1 trials, the key KPIs listed in Table 3 were measured. The full target KPIs list for the use case scenario is presented in Section 5.3.2 of the deliverable D4.2 [2].

Table 3: Target KPIs for T2S1, trial track

<table>
<thead>
<tr>
<th>Network requirements</th>
<th>Target values</th>
</tr>
</thead>
<tbody>
<tr>
<td>User experienced DL throughput</td>
<td>Medium (10 Mbps)</td>
</tr>
<tr>
<td>User experienced UL throughput</td>
<td>Medium (10 Mbps)</td>
</tr>
<tr>
<td>Broadband connectivity / peak data rate</td>
<td>DL: Low (20 Mbps)</td>
</tr>
<tr>
<td></td>
<td>UL: Low (20 Mbps)</td>
</tr>
<tr>
<td>Latency requirements</td>
<td>Low (200 ms)</td>
</tr>
<tr>
<td>Interactivity</td>
<td>High (1000 transactions/sec)</td>
</tr>
</tbody>
</table>

3.3.3 Measurement and testing tools

As with the trials for Phase 1 presented in [2], also for the Phase 2 trials, both network and application layer performance were measured. The measurement and testing tools utilised for this are:

- Ping for measuring the Round-Trip Time (RTT) at the network layer
- iPerf for measuring network layer throughput
- ETSI CPM-based application, to measure application layer E2E latency
- Green Light Optimal Speed Advice (GLOSA) application to measure Traffic Light status information application E2E latency.

3.3.4 Intermediate results

In order to perform the necessary measurements to evaluate the network performance, multiple trial days were scheduled. During the first trials, the network layer performance has been measured and evaluated, e.g. only measurement at the network layer were conducted there was not yet an Intelligent Transport System (ITS) application involved. During the following trials, the focus was on evaluating the ITS application as described in Section 3.2.2.

As a reference, Table 4 shows the averages of multiple runs of both the latency and throughput measurements at the network layer for Phase 1 of the project, based on 4G/LTE.

Table 4: Phase 1 (4G/LTE) Network layer performance results

<table>
<thead>
<tr>
<th>Tool</th>
<th>From</th>
<th>To</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ping</td>
<td>UE</td>
<td>Cloud</td>
<td>RTT: 36ms</td>
</tr>
<tr>
<td>iPerf</td>
<td>UE</td>
<td>Cloud</td>
<td>Upload: 8.49 Mbits/s</td>
</tr>
<tr>
<td>iPerf</td>
<td>Cloud</td>
<td>UE</td>
<td>Download: 10.5 Mbits/s</td>
</tr>
</tbody>
</table>
As described above, the network performance has also been evaluated by using the ETSI CPM-based application and the traffic light application to determine the E2E latency.

The latency shown in the tables below represents the one-way latency between the CPM message being generated at the server side, and the moment of receiving the CPM message within the UE. Table 6 shows the results of the Phase 1 measurements, using 4G without edge computing. Table 7 shows the results of the Phase 2 measurements using 5G SA, both with and without Edge Computing.

Table 5: Phase 2 Network layer performance results

<table>
<thead>
<tr>
<th>Tool</th>
<th>From</th>
<th>To</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ping</td>
<td>UE</td>
<td>Edge</td>
<td>RTT: 8.33ms</td>
</tr>
<tr>
<td>iPerf</td>
<td>UE</td>
<td>Edge</td>
<td>Upload Avg: 58.58 Mbits/s</td>
</tr>
<tr>
<td>iPerf</td>
<td>Edge</td>
<td>UE</td>
<td>Download Avg: 412.17 Mbits/s</td>
</tr>
</tbody>
</table>

Table 6: Phase 1 (4G/LTE) CPM-based latency performance results

<table>
<thead>
<tr>
<th>Log_stationid</th>
<th>Count</th>
<th>Min (ms)</th>
<th>Max (ms)</th>
<th>Avg (ms)</th>
<th>Stddev</th>
</tr>
</thead>
<tbody>
<tr>
<td>123169</td>
<td>968</td>
<td>19</td>
<td>52</td>
<td>21.4969008264462810</td>
<td>2.9866976195472903</td>
</tr>
</tbody>
</table>

Table 7: Phase 2 CPM-based latency performance results, with and without Edge Computing

<table>
<thead>
<tr>
<th>Log_stationid</th>
<th>Count</th>
<th>Min (ms)</th>
<th>Max (ms)</th>
<th>Avg (ms)</th>
<th>Stddev</th>
<th>Edge Computing enabled</th>
</tr>
</thead>
<tbody>
<tr>
<td>3101</td>
<td>30499</td>
<td>12</td>
<td>135</td>
<td>18.6891373487655</td>
<td>4.4551956244479</td>
<td>No</td>
</tr>
<tr>
<td>3101</td>
<td>32580</td>
<td>6</td>
<td>103</td>
<td>13.4217925107428</td>
<td>4.28241104918258</td>
<td>Yes</td>
</tr>
</tbody>
</table>

As can be seen in the above tables, making use of a 5G SA network greatly improves the overall E2E application latency compared to 4G/LTE. Especially when also configuring Edge Computing within the network setup, the average latency improves by roughly 40%. These results are also shown in Figure 4 and Figure 5 below.
Figure 4. Phase 2 CPM-based latency performance results, without Edge Computing.

Figure 5. Phase 2 CPM-based latency performance results, with Edge Computing.

The latency shown in the tables below represents the one-way latency between the SPAT message being generated at the server side, and the moment of receiving the SPAT message within the UE. Table 8 shows the results of the Phase 2 measurements of the UE connecting to the cloud platform for Traffic Light status information using 5G SA. Table 9 on the other hand, shows the results of the Phase 2 measurements of the UE connecting via Edge Computing directly to the Traffic Light controller for Traffic Light status information.
As can be seen in the above tables, introducing Edge Computing (connecting the Intelligent Traffic Light Controller to the Edge of the 5G SA Network) into the application architecture of the Traffic Light status information application, greatly improves the overall E2E application latency, roughly 95%. These results are also shown in Figure 6 and Figure 7 below.

Table 8: SPAT-based latency performance results (Cloud connection)

<table>
<thead>
<tr>
<th>Log_stationid</th>
<th>Count</th>
<th>Min (ms)</th>
<th>Max (ms)</th>
<th>Avg (ms)</th>
<th>Stddev</th>
</tr>
</thead>
<tbody>
<tr>
<td>3101</td>
<td>4143</td>
<td>62</td>
<td>1734</td>
<td>133.107892831282</td>
<td>60.1860883211668</td>
</tr>
</tbody>
</table>

Table 9: SPAT-based latency performance results (Edge connection)

<table>
<thead>
<tr>
<th>Log_stationid</th>
<th>Count</th>
<th>Min (ms)</th>
<th>Max (ms)</th>
<th>Avg (ms)</th>
<th>Stddev</th>
</tr>
</thead>
<tbody>
<tr>
<td>3101</td>
<td>823</td>
<td>1</td>
<td>58</td>
<td>5.66950182260024</td>
<td>5.1266329658561</td>
</tr>
</tbody>
</table>

Figure 6. SPAT-based latency performance results (Cloud connection)
Next step plans

Extend the Phase 2 measurements by further evaluating the Traffic Light status information application with regards to the Green Wave Priority request mechanism.

Beyond retrieving Traffic Light Status information with ETSI SPAT and ETSI MAP messages, emergency vehicles like ambulances and fire trucks would also like to request vehicle priority when approaching an intersection. This disrupts the default operation of dynamically creating green waves for the larger traffic flow. The vehicle can send an SRM [8] to request priority, which will be answered by the RSU with an SSM [9]. In order to fill the SSM, an interaction with the TLC is required. Moreover, several authorisation steps must be taken to verify the authenticity of the priority request. Due to the disruptive nature of such requests, it is very important to restrict access to this priority request service.

Further evaluate the potential benefits of Slicing for the ETSI CPM-based application with regards to latency and availability.
4 T2S2: SMART JUNCTIONS AND NETWORK ASSISTED & COOPERATIVE COLLISION AVOIDANCE (COCA); SIMULATION TRACK

4.1 Description and motivation

The current scenario—related to the CoCA service—consists in the exchange of sensor information to ensure efficient navigation through different driving situations, such as lane changing, overtaking or entering/exiting highways and intersections. In this context, the CoCA system provides network-assisted safety information to connected/automated vehicles via the available infrastructure to announce a risk of collision and/or the location of other vehicles and vulnerable users on the road (such as pedestrians or cyclists). In this work, we propose two use cases to evaluate this track through simulations.

In the first use case, we consider that vehicles can exchange information about their surrounding environment via occupancy maps. In this case, it is necessary that the connected vehicles and the infrastructure facilities possess a minimum number of on-board sensors (e.g. RADAR, Light Detection and Ranging (LIDAR), camera) to detect and integrate obstacles in the generated occupancy map. To do so, the connected vehicles will use their on-board LDM application to calculate a local occupancy map using the measurements coming from their sensors. This local occupancy map models the local scene perceived by the vehicle with pixels representing a zone occupied by an obstacle, another vehicle or a VRU with an associated probability.

In the second use case, connected vehicles can improve their perception capabilities by exchanging traffic safety messages including sensor information via wireless technologies (ITS-G5 [11] and LTE-V2X [4]). This is known as collective perception which consists of the exchange of messages between vehicles and/or RSU) in order to reveal any hidden obstacles. More precisely, ETSI Technical committee [11] has designed CPM that allow vehicles to exchange information about detected obstacles. ETSI standard describes then the generation rules of CPM messages while taking into account detection capabilities and wireless connectivity performance.

In both use cases, the connected vehicles broadcast the local occupancy maps / CPMs in the network. Thus, the RSUs/eNB/gNB can gather all available information from vehicles to build the global occupancy map/ merged CPM and recreate the whole scene of the evaluated zone. At this stage, the RSU/eNB/gNB can either share the global map / merged CPM or send a simple Decentralised Environmental Notification Message (DENM) to warn the vehicles in case of collision risk.

This work aims to complement the field trials described in Section 3 by evaluating large-scale simulations. In this first contribution, we focus on the evaluation of the connectivity of a CoCA system based on 4G LTE-V2X network communication in the intersection scenario. The main objective is to evaluate the impact of LTE-V2X connectivity performance on the fusion of local occupancy maps and CPMs and to define the best compromises between the communication configuration and obstacle detection capabilities.

4.2 Proposed setup

4.2.1 Network architecture

Figure 8 shows the overall system architecture supporting a CoCA system based on V2X communications, as defined by the ETSI for the ITS architecture. We consider both UEs and RSUs as ITS-Stations (ITS-S) following an ITS protocol architecture:

- Facilities Layer to enable the CoCA, LDM, Cooperative Awareness Message (CAM), CPM and DENM related services.
- Access layer for the Physical (PHY) and Medium Access Control (MAC) based on V2X communication systems such as cellular 4G/5G, the LTE-V2X PC5 mode 3-4 or 5G sidelink.
The architecture described in Figure 8 is common to Scenario 1 and Scenario 2. In both cases, information collected by vehicles is stored and processed by the on-board LDM system. In the first scenario, physical sensors (e.g. RADAR, camera, LIDAR) and navigation system are used to build local occupancy maps. In the second scenario, a list of obstacles is extracted from sensors data and included in CPMs. Then, this high-level information is sent through the V2X communication system.

RSUs can also be equipped with physical sensors and a V2X communication system. However, an RSU has a more powerful LDM system capable of fusion of all the information coming from the network and possibly from its own sensors, to generate a global occupancy map or a merged CPM. Thus, the LDM of RSU predicts potential trajectories of each vehicle and detects obstacles or vulnerable users. Then, depending on the use case, RSUs can either broadcast event-DENM messages in case of risk of collision or broadcast messages to share the global occupancy map/ CPM with the UEs. Note that UEs are assumed to have an on-board CoCA system to interpret the global occupancy map/ merged CPMs or the warning messages sent from the RSUs.

4.2.2 User application architecture

N/A

4.2.3 Hardware components

N/A
4.2.4 Software components

First use case: Fusion of occupancy maps

A road intersection scenario has been considered, where vehicles can generate local occupancy maps and broadcast them to a RSU that plays the role of a fusion center (i.e., in practice, the RSU at stake is endowed or connected with computation and storage means devoted to the fusion process). The latter executes the fusion of local occupancy maps and broadcast the generated global occupancy map to all connected vehicles under its coverage. Note that an alternative architecture would be to perform the fusion directly by the vehicles themselves (on-board fusion). However, in this study, we have focused on the RSU as the fusion center because of its privileged position in the near center of the intersection which facilitates communication links. In order to simulate this scenario, we consider a simulation model with four modules as shown in Figure 9.

Module 1: Physical Mobility Module

Module 1 models realistic road traffic mobility using Simulation of Urban Mobility (SUMO). Resulting mobility traces are fed into NS-3 (module 2) in order to simulate messages exchange between vehicles and also the fusion center, via LTE-V2X connectivity. At the same time, SUMO mobility traces are used by our Matlab® application (module 3) to generate local occupancy maps. Module 4 extracts successfully received packets from NS-3 traces and subsequently executes the fusion of local occupancy maps generated by module 3.

In the following, we present each simulation module in details.

Module 1: Physical Mobility Module

The road traffic of a real-life urban intersection (Figure 10- left) is simulated using SUMO. The generated output contains a timestamped vector with the Two-Dimensional (2D) coordinates, speed and heading of both vehicles and pedestrians. Note that these mobility traces are generated offline and can be replayed from both NS-3 and Matlab®. In fact, since we are mainly interested in assessing the information flow till the elaboration of global maps, no control feedback to vehicles mobility (and thus, no tight co-simulation between mobility and connectivity modules) is really needed in our simulations.
Module 2: V2X Connectivity Module

This module simulates LTE-V2X connectivity in NS-3 with a cross-layer simulation approach between the physical and higher layers to exploit SUMO mobility traces (Cf Figure 11). LTE-V2X operates using the Single Carrier Frequency Division Multiple Access (SC-FDMA) waveform with Turbo-code. Channel occupation is defined by three main elements: sub-frames defining the Transmission Time Interval (TTI), subcarriers defining the Resources Blocks (RBs) and sub-channels defining the group of RBs in a sub-frame to transmit user and control information. A TTI has a fixed duration of 1 ms and a RB has a bandwidth of 180 kHz (12 subcarriers). LTE-V2X standard gives different Modulation and Code Scheme (MCS), leading to a trade-off between throughput, range and capacity [12]. UEs/RSUs can transmit packets every 100 subframes (100 ms) or in multiples of 100 ms. To do so, LTE-V2X PC5 mode 4 lets UEs/RSUs autonomously select their radio resources following the Sensing-based Semi-Persistent Scheduling.

In this module, we consider a 10 MHz bandwidth divided in 50 RBs using the ITS 5.9 GHz band with a power transmission $P_{\text{Tx}} = 23$ dBm. For the propagation model, we consider the path loss model Winner B1 (in Line of Sight (LoS), Non Line of Sight (NLoS) and Obstructed Line of Sight (OLoS) condition) and the fast fading model based on the 3GPP Extended Vehicular A Model (See [12]).

Module 3: Local Occupancy Maps Calculation Module

Module 3 implements LIDARs sensors model in Matlab® relying on both so-called measurement and beam sensor models. For the measurement model, the measurements collection is defined based on the range, azimuth angle and frequency cycle. The measurement output corresponds to a (distance; angle) set. The beam sensor model is represented by probabilistic curves that compute the probability of existence/absence of obstacles in each beam direction.

Figure 10. Intersection scenario simulated in SUMO (left figure). Local occupancy map example (right figure).

Figure 11. Simulation representation of CoCA in NS-3.
According to these models, equipped vehicles can generate local probabilistic occupancy maps based on a grid-based approach [13]. The local scene, representing a predefined zone of interest, is perceived by each vehicle with pixels (also referred to as cells in this report) associated with a probability value; those pixels represent a zone possibly occupied by an obstacle (another vehicle or a vulnerable user). For more details about the probabilistic beam sensor model considered for LiDARs, and local occupancy maps construction, readers may refer to [14]. Figure 10 (right) gives an example of a generated local map.

**Module 4: Fusion Algorithm Module**

This module implements the fusion algorithm in Matlab®. The fusion center gathers successfully received local maps (generated by module 3) to build the global occupancy map. More precisely, as explained previously, we use NS-3 traces files in order to determine at each transmission period (T) vehicles maps that are successfully received by the fusion center (RSU). The fusion is then achieved by means of the Independent Opinion Poll (IOP) algorithm [15], [16]. For instance, given a cell $i$ of the occupancy map, the occupancy probability $P_i$ obtained by the fusion of 2 occupancy maps, with indexes 1 and 2 (e.g., two local maps from two first vehicles, or one local map from a vehicle and the latest version of the global map, resulting from a previous fusion step) with IOP is given as follows:

$$
P_i = \frac{P_1^i P_2^i}{P_1^i P_2^i + (1 - P_1^i)(1 - P_2^i)}
$$

where $P_j^i$ is the $j$th occupancy probability in cell $i$, $j \in \{1,2\}$. The fusion of $n$ maps can thus be performed iteratively, even if maps are not received simultaneously. For a third vehicle with occupancy probability $P_3^i$, the fusion is computed with $P_4^i$.

**Second Use Case: Fusion Algorithm for Collective Perception Messages**

In this second scenario, we propose a fusion algorithm for CPMs that contain a list of obstacles with their corresponding information such as speed, position, heading, type, etc. More specifically, we consider the scenario where vehicles transmit CPMs to a fusion center via LTE-V2X connectivity. The latter will perform the proposed fusion algorithm to generate a merged CPM that will be broadcast, every $T_{CPM} = 100\text{ms}$, to all vehicles in range. The fusion of CPMs obstacles is important in order to maximize perception gains and obstacles detection capabilities. The proposed fusion algorithm presents a low complexity and can process CPMs according to the ETSI generation rules, while considering the impact of V2X connectivity on the CPM fusion.

In order to simulate this scenario, we consider a simulation framework (shown in Figure 12) that consists of four module:

- Physical mobility module: models realistic road traffic of a real-life urban intersection using SUMO.
- V2X connectivity module: NS-3 simulation of messages exchange between vehicles and fusion center, via LTE-V2X connectivity, based on mobility traces generated in SUMO. Details about LTE-V2X standard and simulation setup are explained in the description of the first use case above.
- CPM generation module: generates CPMs (following ETSI generation rules), based on LiDAR sensor model.
- CPM fusion module: the local generated CPMs will be gathered by the fusion center while taking into account V2X connectivity. The fusion center executes the fusion algorithm then as explained in details in the following.
CPM Structure

According to ETSI standard [11], CPM messages (illustrated in Figure 13) include an ITS Protocol Data Unit (PDU) header and 4 containers: Management Container, Station Data Container, Sensor Information Containers (SICs), and Perceived Object Containers (POCs). The ITS PDU header includes data such as the message Identifier (ID) and the vehicle ID. The Management Container is mandatory and provides basic information such as the position of the transmitting vehicle. SIC is optional and includes additional information about the transmitting vehicle (e.g. its speed, heading, etc.). Finally, the POCs provide information about the detected obstacles; their speed, type and dimensions.

CPM Generation Rules

CPM generation rules, standardized by ETSI, define when vehicles should transmit a CPM, and what is the information, i.e. the list of obstacles and sensors information, that should be included in a CPM. Two generation rules have been considered: the periodic and dynamic rules. First, the periodic method, which is a reference method, is used to compare with other policies. It indicates that CPMs are generated every $T_{CPM}$ and they include all the detected objects. The CPM should be transmitted even if no objects are detected. With the dynamic generation rule, the transmitting vehicle checks every $T_{CPM}$ if the environment has changed in order to transmit a new CPM. More precisely, a vehicle generates a new CPM if it has detected a new object, or any of the following conditions are satisfied for any of the previously detected obstacles:

1) The obstacle’s absolute position has changed by more than 4m since the last time ($T_{update}$) it was included in a CPM.

2) The obstacle’s absolute speed has changed by more than 0.5m/s since the last $T_{update}$.
3) The last time the object was included in a CPM was 1 second ago ($T_{update} > 1$ sec).
4) The obstacle is classified as VRU or an animal.

**Fusion algorithm overview**

The algorithm proceeds mainly with three steps. The first step occurs in case the fusion center receives CPMs at iteration $t$. In this case, the fusion center will check if the obstacles included in the CPMs are new obstacles or an update about already existent obstacles. Moreover, the fusion center will consider also already existent obstacles that are not updated but are still valid ($T_{update} < 1$ sec). The second step of this algorithm takes place in case the fusion center does not receive any CPM at iteration $t$. In this case, the fusion includes all valid already existent obstacles without changing their information. The third step of this algorithm consists of analyzing the list of obstacles by first associating obstacles according to their position and by giving a reliability value for each obstacle.

According to the proposed CPM fusion algorithm (shown in Figure 14), at each time iteration $t$, the fusion center executes the following steps, in order to generate a temporary list of obstacles $\text{List\_Obstacles\_Temp}(t)$ (LOT($t$)). This list will be treated in order to determine the final list of obstacles, which includes obstacles that should be integrated in the merged CPM.

1. Every $T_{CPM}$, the fusion center gathers successfully received CPM in order to generate a merged CPM. CPM fusion proceeds as follows:
   - First, the fusion center checks if the received CPM includes new obstacles. More precisely, a CPM includes a tuple (vehicle_ID; obstacle_ID), if this tuple is not included in the LOT($t$-1), then the obstacle is considered to be new.
   - Second, the fusion center checks if already existent obstacles in LOT($t$-1) are updated. An already existent obstacle is defined as an obstacle with the tuple (vehicle_ID; obstacle_ID) included in LOT($t$-1). In this case, the fusion center update the information of these obstacles.
   - If there is remaining obstacles in LOT($t$-1) that are not updated or processed, the fusion center will check if $T_{update} < 1$sec, and include the obstacles in LOT($t$) without changing $T_{update}$ nor the obstacles information.
2. In case of no received CPMs at $t$, the fusion center will search for already existent obstacles in LOT($t$-1). If this list is not empty, the fusion center adds only obstacles with $T_{update} < 1$sec to LOT($t$). This is the case of obstacles that are already present in the scenario, but do not follow the conditions listed in the CPM dynamic generation rules.
3. The final step of the fusion algorithm consists of processing the LOT($t$) in order to define the final list included in the PoC of the merged CPM. This is achieved by the following steps:
   a. The first step is responsible of merging obstacles with close positions. Given two obstacles in LOT($t$), one can calculate the best objects association by computing the difference between their positions and checking if it is lower than a predefined threshold.
      An important challenge appears when handling ambiguous cases. For example in case two different trajectories followed by two vehicles intersect and/or get close enough, this leads to suggest a merging erroneously. In this case, using only the distance between the current object observations may not be sufficient, and may lead to wrong associations. To overcome this, we consider that the detected obstacles in the final list will be assigned an identifier $\text{merged\_obstacle\_id}$. Each tuple in LOT($t$) is associated to the corresponding $\text{merged\_obstacle\_id}$. This will avoid merging tuples corresponding to different $\text{merged\_obstacle\_id}$. Concerning new obstacles in LOT($t$), the association is done based on the position only.
   b. Second, by giving identified obstacles a reliability value: $\text{reliability value} = 1 - \left(\frac{t - T_{update}}{T_{max}}\right)$; where $T_{max}$ is a design parameter defining the maximum valid object age before it is discarded ($T_{max} = 1$sec). This is achieved in order to let vehicles know about the possibility of finding an obstacle in a certain position at time $t$. 

© 5G-HEART Consortium 2019-2022
Algorithm advantages

The proposed algorithm is simple to deploy and presents low costs in terms of run time and processing. Moreover, this algorithm presents accuracy in obstacles detection. In fact, the fusion considers obstacles individually, which reduces the probability of obstacle missing. Furthermore, the proposed algorithm avoids problems resulting from the interpretation of the occupancy maps. More precisely, in case of ambiguous cases, for example when two vehicles have close positions, the interpretation of occupancy maps may lead to consider both vehicles as one object, leading thus to obstacle missing and errors on the type of the detected object.

4.3 Testing and verification

In the following, we present the evaluation methodology and Key Performance Indicators (KPIs).

4.3.1 Methodology

For both considered scenario, we consider the real intersection of two main streets located in Lyon (France). Each street is four lanes wide, with two lanes in each direction. This intersection constitutes the center of a 400mx 400m area. The RSU, placed at the north-west corner of the intersection, plays the role of the fusion center. Simulated vehicles can reach a maximum speed of 50 km/h.

Concerning the first use case scenario, we consider that the period of sending messages T is a multiple of 100 ms. Besides, we assume that vehicles arriving to the intersection are all equipped with ranging sensors, and are thus able to generate probabilistic occupancy maps. In Matlab®, we setup a 2D LIDAR with a horizontal field of view of 110° and 360° (azimuth aperture) for all equipped vehicles. The complete setup of LIDAR sensors can be found in [15]. We have set decision thresholds as follows: $P_{\text{min}} = 0.3$ and $P_{\text{max}} = 0.7$. The occupancy maps represent a zone of interest of 100m x 100m.

We calculate the link condition for all vehicles using the SUMO traces at each timestamp. We consider that the antennas are placed at the top of vehicles at a height of 1.7m from the ground and the RSU at a...
height of 5m from the ground. Thus, we consider three types of link condition as described with more details in D4.2: LoS, NLoS and OLoS.

Regarding the second use case scenario evaluation, we setup a 2D LIDAR with a horizontal field of view of 110° (azimuth aperture) for all equipped vehicles. According to the dynamic generation rule policy, CPMs present variable size based on the number of obstacles included in the POCs and other containers included in the CPM. In this work, containers are included in CPMs according to ETSI dynamic generation rule. Moreover, concerning packets headers, due to the use of PC5 mode 4, we are considering MAC, Radio Link Control (RLC) and Packet Data Convergence Protocol (PDCP) layers headers with a respective size of 10, 3 and 2 Bytes; this gives an overhead of 15 Bytes to CPM packets.

For each considered scenario, we run 10 NS-3 simulations with a duration of 60 seconds each.

**First use case evaluation methodology**

In the performance evaluation of the first use case, we consider that occupancy maps are represented by pixels that have a certain probability value \( P_{\text{occ}} \in [0; 1] \). In order to determine whether a cell (pixel) is occupied or not, we should define a priori thresholds values. For instance, the cell is considered to be occupied if its occupancy probability \( P_{\text{occ}} \geq P_{\text{max}} \), free if \( P_{\text{occ}} \leq P_{\text{min}} \), and unknown for \( P_{\text{min}} < P_{\text{occ}} < P_{\text{max}} \). We note that unknown cells result from the fact that some regions might not be covered by ranging sensors. First, we conduct a study to define the most suitable maps format for V2X connectivity (size, resolution, and quantization). Second, we investigate the impact of messages periodicity.

**Maps size and resolution**

The exchange of traffic safety messages in vehicular networks can be ensured by broadcasting periodic awareness messages such as CAM. In D4.2, we have considered 800 Bytes as maximal CAM size. However, exchanged local maps require larger packets size, since they carry a considerable amount of information, depending on the retained local map representation. Furthermore, the constraints of transmitting a packet through a single TTI with a reasonable MCS urge us to study the message format of occupancy maps. To this end, we consider that local probabilistic maps generated by vehicles are pre-processed before being sent to the fusion center. Accordingly, we consider two cases of images quantization with two values of the number of Bits Per Pixels (BPP): 3 and 4 BPP. In the following, we conduct a study about different image compression techniques and show that a minimum compression rate of 1/3 can conserve a good image quality and avoid losses.

The quality of compressed image can be measured by several image quality parameters. The most used image quality parameters are Mean Square Error (MSE), Peak Signal to Noise Ratio (PSNR) and Compression Ratio (CR). The PSNR value used to measure the difference between a compressed image and its original image. Normally, the larger PSNR value, will give the better quality of compressed image. We define the following parameters:

**Mean Square Error (MSE)**

Mean square error is one of the parameters to evaluate the quality of compressed image. If the value of MSE is less, then the quality of compressed image will increase. The equation for MSE can be given as:

\[
MSE = \frac{1}{MN} \sum_{x=1}^{M} \sum_{y=1}^{N} (f(x, y) - f'(x, y))^2
\]

, where \( f(x, y) \) is the original input image, \( f'(x, y) \) is compressed image and \( M, N \) are the dimensions of the images.

**Peak Signal to Noise Ratio (PSNR)**

PSNR is ratio between sizes of the input image to the square of MSE. If PSNR is high then the quality of compressed image is also increased.

\[
PSNR = 10 \log_{10} \left( \frac{M \times N}{MSE^2} \right)
\]
where, $M \times N$ is the size of an input image.

**Compression Ratio**

Compression ratio is a useful parameter in Image Compression. This CR can be defined as the ratio between the uncompressed image size and compressed image size. Table 10 shows the evaluation of different image compression techniques. From this table, we can see that with a compression rate of minimum 1/3 we can obtain a relatively good PSNR and no losses in the occupancy probability values.

<table>
<thead>
<tr>
<th>Method</th>
<th>Compression Ratio</th>
<th>MSE</th>
<th>PSNR (dB)</th>
<th>Probability pixels values loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>JPEG</td>
<td>3</td>
<td>40.042</td>
<td>32</td>
<td>0</td>
</tr>
<tr>
<td>Wavelet level 1 Universal thresholding</td>
<td>3.49</td>
<td>1.218</td>
<td>47.27</td>
<td>0</td>
</tr>
<tr>
<td>Wavelet level 1 Hard thresholding ( th=15)</td>
<td>3.489</td>
<td>1.187</td>
<td>47.38</td>
<td>0</td>
</tr>
<tr>
<td>Wavelet level 1 Soft thresholding ( th=15)</td>
<td>3.489</td>
<td>56.97</td>
<td>30.57</td>
<td>0</td>
</tr>
<tr>
<td>Vector Quantization</td>
<td>3</td>
<td>101.8</td>
<td>28</td>
<td>0.0015</td>
</tr>
</tbody>
</table>

**Messages periodicity**

As mentioned earlier, vehicles are assumed to send maps to the fusion center periodically every T ms. Obviously, the value of T can have a strong impact on both V2X connectivity performance and global map quality. Indeed, LTE-V2X link performance is expected to increase with higher values of T. However, increasing messages periodicity may lead to a higher number of mis-detected obstacles due to the fact that the information can be outdated (not enough consistent in terms of space/time coherence to be merged with the latest global fusion result). Thus, the choice of a suitable value of T is crucial and should be carefully studied.

**Second use case evaluation methodology**

In order to demonstrate the efficiency of the second use case fusion algorithm, we compare the following scenarios:

1. Dynamic generation rule with perfect connectivity and with V2X connectivity, i.e, in this scenario, packets losses induced by V2X connectivity are considered and calculated based on simulated NS-3 traces.
2. Periodic generation rule with perfect connectivity and with V2X connectivity.
3. Scenario with local occupancy maps considered for the first use case scenario, where vehicles exchange local occupancy maps of 1685 Bytes packets size every 100 ms and every 200 ms. The goal here is to show the importance of using CPM instead of occupancy maps. To this end, we consider that vehicles send maps to the fusion center. The latter extracts the list of obstacles, performs the fusion algorithm and retransmits a merged global occupancy map.

**4.3.2 List of key performance indicators**

The full list of target KPIs for the use case scenario has been presented in Section 6.3.2 of deliverable D4.2 [2]. To specifically assess the impact of maps/CPMs processing, messages periodicity and LTE-V2X radio configuration in the Phase 2 simulations, we consider as KPIs, both Packet Delivery Ratio (PDR) and Obstacle Misdetection Rate (OMR):

- Packets Delivery Ratio: The PDR of V2I is calculated: first we study the communication link from vehicles to RSU (denoted by UL for simplicity), to evaluate the capacity of the RSU to
collect local occupancy maps/CPMs from the vehicles, and second we evaluate the communication link from RSU to vehicles (DL), to evaluate the capacity of the RSU to share global maps/merged CPMs with all the vehicles in the intersection. We define the PDR in UL as the ratio between the number of packets received by the RSU and the number of packets sent by the vehicles. The PDR in DL is the number of vehicles actually receiving a packet over the total number of active vehicles in the intersection for each transmission from the RSU.

- **Obstacle Misdetection Rate:** For the first use case scenario, changes made on the local maps may affect the global map occupancy probability values which may engender some obstacles misdetection. More precisely, changing the value of \( P(i) \) in a pixel \( i \), due to image processing, might lead to consider this pixel as free. In our study, we assume that the typical dimension of vehicles (resp. other VRUs such as pedestrians) is about 2m x 4m (resp. 0.8m x 0.8m). Thus, for a map with a 1m x 1m resolution, misdetecting an obstacle on one pixel may cause a risk of collision. To this end, we will assess the OMR: the ratio between the number of misdetected pixels and the number of truly occupied cells on a real map: ground-truth binary map of free and occupied cells. A misdetection occurs when a really occupied cell is considered as free or unknown. It is defined by the following expression:

\[
OMR = 1 - \frac{N_{TP}}{N_{TrueOcc}}
\]

where \( N_{TP} \) is the number of true detected obstacles, and \( N_{TrueOcc} \) is the number of truly occupied cells.

For the second use case scenario, the OMR accounts the number of misdetected obstacles compared to the real scenario. An obstacle is considered as misdetected if it is missing compared to the real scenario or whenever the difference between the detection position and the real obstacle position is higher than a predefined threshold \( Th \).

### 4.3.3 Measurement and testing tools

N/A

### 4.3.4 Intermediate results

**First use case results**

**Maps Size and Resolution**

We evaluate the impact of changing messages size on LTE-V2X performance and on the global occupancy maps. Table 11 presents the considered sizes of the messages and the associated MCS to transmit a message through one TTI (1ms) and 48 RBs.

<table>
<thead>
<tr>
<th>Packets size (Bytes)</th>
<th>MCS</th>
<th>Quantization level (BPP)</th>
<th>Map Resolution (cell size in meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1190</td>
<td>11</td>
<td>3</td>
<td>1.02m x 1.02 m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>1.18m x 1.18m</td>
</tr>
<tr>
<td></td>
<td>1520</td>
<td>13</td>
<td>1.04m x 1.04m</td>
</tr>
<tr>
<td></td>
<td>1685</td>
<td>14</td>
<td>0.86m x 0.86m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>0.99m x 0.99m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>
First, we evaluate the PDR in each case and we compare the results to those obtained with 700-Bytes messages and MCS 5 as considered in D4.2 (Cf Figure 15). Note that a period of $T = 100$ ms was considered for this evaluation. We can then observe that the PDR decreases for all the MCS when vehicles density increases (from 83% to 50% in UL for MCS11 with 1190 Bytes). Moreover, with larger packets size (and so with higher MCS), the probability of losing packets sent to the RSU (UL) is higher, which may have an impact on the fusion result (PDR decreases from 58% to 43% for 100 vehicles). It is noteworthy that, in this case, packets sent from RSU to vehicles (DL) present a higher packet loss ratio. This may be critical in case of a collision warning.

![Figure 15. PDR of V2I for different MCS.](image)

In order to evaluate the impact of changing messages size on global maps, we calculate local maps resolution, for each considered packet size according to two probability quantization levels (as indicated in Table 11). We assess the OMR, as illustrated in Figure 16, and compare the results to that of a high resolution map with 8 BPP and 0.5m x 0.5m resolution. We note that in this evaluation, the fusion algorithm is executed every $T = 100$ ms, without considering packet losses induced by V2X connectivity, so as to isolate uniquely the effect of quantization/compression on the global map. Furthermore, in order to shed the light on the interest of cooperation between vehicles, we add to the results the OMR in case of standalone mode (i.e., accounting for the detection capabilities of vehicles while relying only on their own on-board sensors). The latter is obtained by calculating the mean of OMR values over all local occupancy maps (i.e., prior to fusion). Figure 16 illustrates the impact of cooperation between vehicles. A significant gain can then be observed through cooperative approach compared to the standalone mode. Certainly, with a standalone mode, each vehicle presents a limited field view. This is critical since it increases the possibility of misdetecting obstacles. It can also be observed that the OMR decreases as the number of vehicles increases. In addition, the best performance in terms of OMR is obtained for high-resolution maps. Indeed, performing a quantization of probability levels on occupancy maps leads to a loss of precision that can lead to considering some occupied pixels as free. We can also note that the OMR is relatively constant as soon as the number of vehicles in the intersection is greater than 20. This is due to the high vehicles density at the intersection that causes field view obstruction.

To summarize, as expected in idealized cases, the best performance in terms of obstacle detection would be obviously obtained with the maps with the best resolution and therefore with the largest packet size. However, using large packet sizes and in combination with high MCS, is expected to degrade LTE-V2X connectivity performance. Thus, we evaluate next the impact of LTE-V2X connectivity on obstacle detection performance, while trying to determine practical operating trade-offs between the two.
Impact of V2X Connectivity on Obstacle Detection

To evaluate the impact of LTE-V2X connectivity on the quality of the merged occupancy map and thus on obstacle detection performance, we compare for $T = 100$ ms: 1) occupancy maps without packets loss ("genie-aided") and 2) occupancy maps with packets loss (due to the LTE-V2X connectivity). Results are then illustrated in Figure 17 with the evaluation of the OMR as the function of the number of vehicles in the intersection.

Figure 17 shows the impact of V2X connectivity on obstacle detection performance and we can observe an OMR degradation of about 10% compared to the ideal case without packet loss. Besides, in contrast to the no packet loss case, the OMR first decreases with the number of vehicles but then increases after reaching a critical number of vehicles (typically 20 in our case). This exhibits the correlation with PDR (UL) values that decrease with a higher vehicle density (Figure 15). Indeed, the increase in the number of vehicles leads to an augmentation in the number of packet collisions and thus their loss. Furthermore, we notice the effect of images quantization on occupancy maps and we conclude that the configuration using a packet size of 1685 Bytes, a quantization level of 4 BPP associated with the MCS 14 has the best performance in terms of obstacle misdetection.
4.3: Evolved Solution and Verification of Transport Use Case Trials

Figure 17. (a) OMR with and without packets loss with 360° angle. (b) OMR with and without packets loss with 110° angle.

Impact of Messages Period

In the following, we evaluate the impact of messages period on the global occupancy maps and the V2X connectivity performance. To do so, we assess the PDR (Figure 18) and OMR (Figure 19) for different values of $T$.

Figure 18 gives the PDR in UL versus the number of vehicles for different configurations (packets size, MCS, application period $T$). We can then observe an improvement in the PDR as the message period increases. Indeed, the increase of the period automatically decreases the number of packet collisions. For the configuration 1685 Bytes / MCS14, at 100 vehicles the PDR increases from 43% for $T$=100 ms to 65% for $T$=300 ms. Furthermore, for high vehicle densities, we can notice that $T$=200 ms and $T$=300 ms present close performance in terms of PDR. However, with $T$=100 ms, V2X connectivity performance decreases significantly.
Figure 18. PDR at RSU (UL) with different values of T.

Figure 19 illustrates OMR for different values of T. For this study, simulations were performed with the best configuration identified previously, i.e. packet size of 1685 Bytes packets, MCS 14 and 4 BPP for the quantization. Packet loss has also been considered. We can see in Figure 19 that the OMR increases with higher values of T. Indeed, increasing messages period will lead to extra latency (i.e., injecting outdated information) and thus, to a lack of coherence among the merged local maps, which can harm the quality of the global map. This will mechanically increase the probability of missing an obstacle present at instant t in certain locations. Furthermore, we can observe that, due to the impact of V2X connectivity performance, the OMR is better with T=200 ms when the number of vehicles is higher than 70. Indeed, as demonstrated in Figure 18, with the increase of vehicles density, PDR values decrease with T=100 ms. This is correlated with a higher packets loss rate caused by a high number of vehicles trying to transmit every 100ms and the resulting collisions. Consequently, despite the fact that increasing the refresh rates of local maps leads to high precision in terms of obstacle detection at each time instant, it appears that the value of T should be doubled in case of a high vehicles density due to LTE-V2X performance degradation. Moreover, the Channel Occupancy Ratio (CR) based on the Channel Busy Ratio (CBR), as specified in [17], has been assessed for our scenario. It turns out that the Decentralized Congestion Control (DCC) mechanism should then be applied with T =100 ms only when the number of vehicles is superior to 85. Accordingly, in order to respect the CR limitation, one should double the refreshment period of the messages (i.e., T =200 ms) when exceeding this number of vehicles. In that case, the application of DCC is not expected to degrade obstacle detection performance.

From this study, we can conclude that messages size of 1685 Bytes with 4 BPP is suitable for global occupancy maps in terms of obstacle misdetection ratio. Moreover, in the considered scenario, message periodicity should be set to 100 ms whenever the number of vehicles does not exceed 70, and to 200 ms otherwise.
4.3: Evolved Solution and Verification of Transport Use Case Trials

Figure 19. (a). OMR with different values of T with 360° angle. (b). OMR with different values of T with 110° angle.

Second use case results

CPM Generation Analysis

We proceed first by evaluating the CPM frequency (Figure 20) and CPM periodicity (Figure 21) using the dynamic generation rule. To this end, we consider three cases of traffic density: low density (20 vehicles), medium density (50 vehicles) and high density (100 vehicles). Figure 20 demonstrates that the percentage of low CPM frequency increases with the traffic density. Indeed, in case of high vehicle density, the speed will decrease and thus the frequency of changing the position and speed will decrease accordingly. It is to be noticed that the maximum speed is 50 km/h. Thus, the vehicle will detect the change 3.44 times per second in average. However, in this case, we observe a non-negligible percentage of vehicles that transmit between 6 and 10 CPM per second. This is the case of vehicles that generate CPM as soon as the detect changes in obstacles position more than 4m. If the detected vehicle is changing its position more than 4m at different times, the vehicle will need to generate different CPMs. This explains the presence of non-negligible percentage of 10 Hz in case of high density. Regarding low and medium densities, we can observe that the percentage of 1 Hz is lower because vehicles will send more messages per second, due to high speed. Vehicles satisfy more frequently the condition of the changing environment (i.e. change in position more than 4m and speed more than 0.5 m/s). Figure 21 shows that messages are sent in average every of 390 ms in case of 20 vehicles. This period increases to reach 600 ms in case of 100 vehicles. This is correlated with the frequency values in Figure 20. In
case of low density of vehicles, messages periodicity will be low because the frequency is high (high percentage of 6 and 7 Hz compared to medium and high densities). However, in case of 100 vehicles, the percentage of 1 Hz is the highest, which justifies the average period of 600 ms.

![Figure 20. Mean CPM period.](image)

![Figure 21. Occurrence rate of CPMs Frequency.](image)

**Packet Delivery Ratio**

As shown in Figure 22, the PDR decreases with the increase of vehicles density. Moreover, we can notice the gains brought by the dynamic generation rules compared to periodic generation rules. With the dynamic policy, PDR is high even with high vehicle density (91% of PDR for 100 vehicles for the dynamic policy instead of 65% in case of the periodic policy). A lower channel load explains this. Indeed, in the dynamic case the average message periodicity for 100 vehicles is 600ms compared to 100 ms for the periodic generation rule. Furthermore, in the periodic scenario, CPM messages include all obstacles which implies an increase in packet size and therefore the use of higher MCS to transmit in 1 TTI. This results in a degradation of the connectivity performance [18]. For the occupancy maps scenario, where packets present larger size compared to CPMs, the probability of losing packets sent to the RSU (UL) is higher, which may have an impact on the fusion result (PDR decreases from 71% to 43% for 100 vehicles). Figure 22 shows that the PDR in DL is high because the RSU is strategically located in visibility of all the road users. It is noteworthy that, in case of occupancy maps, PDR DL is the lowest because packets sent from RSU to vehicles (DL) present a higher packet loss ratio. This may be critical in case of a collision warning.
Obstacle Misdetection Ratio (OMR)

OMR is assessed in order to demonstrate the effectiveness of the proposed algorithm and to show the impact of LTE-V2X connectivity on the merged list of obstacles. Results are illustrated in Figure 23 for different values of obstacles position error threshold $Th$. This threshold can be seen as a tolerance on the position error.

Figure 23 highlights the fusion algorithm advantages in terms of obstacles detection capabilities. Moreover, compared to the occupancy maps scenario, results confirm that the use of CPMs improves the communication performance. The use of large packets (1685 Bytes), for occupancy maps exchange and sent every 100 ms explains this. This induces packets loss due to high channel load. Indeed, sending occupancy maps every 200 ms presents improved results compared to 100 ms periodicity, however, we notice that using occupancy maps present a higher OMR than the use of CPMs.

For the case of periodic scenario with V2X connectivity losses, with low traffic density, OMR is lower than the dynamic policy. In fact, with the periodic generation rules, vehicles are sending CPMs every 100 ms and include all detected obstacles. This enhances the detection capabilities. However, with a higher number of vehicles, packets collision is more frequent as confirmed by Figure 22 where PDR decreases to reach 67%. This explains the increase of OMR values for higher traffic densities. For the dynamic policy, in case of perfect connectivity, OMR increases by 20% for $Th=1$ m compared to the periodic scenario, that is 20% of obstacles are given with a position shifted by 1 m to 2 m from their real positions. For $Th=2$ m (Figure 23 (b)), one can notice that few obstacles are misdected by more than 2 m. Moreover, $Th=4$ m is considered (Figure 23 (c)) in order to show that the fusion algorithm works correctly. In fact, with the dynamic policy, information about obstacles are included in a CPM each time the obstacle changes its position by 4 m or more. Therefore, in case of perfect connectivity, all obstacles should be updated, and no obstacle should be misdetected. Figure 23 (c) shows that OMR in this case is null, which confirms our analysis and highlights the effectiveness of the proposed algorithm. For the dynamic policy with V2X connectivity, the OMR is higher by 10% than the scenario of perfect connectivity. This is in accordance with the PDR values given in Figure 22.
Position Error

In the following, we will give an idea about the average position error obtained in each case. It is to be noted that this work considers a perfect GPS positioning. Figure 24 shows that the mean error for dynamic policy with perfect connectivity is close to zero at first, then this error increases with high vehicles density to reach 0.5m due to vision obstruction. For the dynamic policy with V2X connectivity, the mean error is 1.25m. While for the periodic policy with loss, the error is low at first with low density.
since packet loss is low. However, with the increase of traffic density this error increases to reach 3m due to packets losses and PDR decrease.

![Graph showing position error with T_{CPM}=200ms.]

From this study, we proved the effectiveness of our fusion algorithm in terms of obstacles detection capabilities. Moreover, this algorithm can cope with packet loss caused by LTE-V2X connectivity performance degradation. In addition, we showed that the use of CPM is more advantageous than occupancy maps in our scenario.

### 4.4 Next step plans

In the next phase, V2X connectivity will be based on cellular 5G NR (V2N). Thus, we will study and evaluate 5G NR for the CoCA system (based on CPM messages). We will highlight the best 5G NR configurations for this application and we will be able to compare the performance obtained with sidelink C-V2X communication system.
5 T2S3: QUALITY OF SERVICE (QOS) FOR ADVANCED DRIVING

5.1 Description and motivation

This scenario involves the dynamic selection of the appropriate driving mode based on the context at-hand. According to [19], the driving mode is mainly characterised by the Level of Automation (LoA), which reflects the functional aspects of the technology and affects the system performance requirements. While each driving mode has its own merits and advantages, there exist non-trivial traffic scenarios where using an inappropriate driving mode may result in traffic hazards and/or collisions. For instance, automated driving may be allowed only on certain roads (e.g., strategic roads, such as motorways) or prevented on others (e.g., due to adverse weather conditions). As such, the best LoA for a given scenario should be selected based on all the relevant factors (e.g., the operating conditions of the vehicle, design decisions made by manufacturers and regulation in-force).

While the original T2S3 scenario is quite generic, it has been decided to work on a specific instance that exhibits a much higher business value. This instance considers the situation where an AV cannot guarantee safe manoeuvre and requests assistance from the Edge of the network. Depending on the connectivity and associated QoS levels that can be guaranteed, the request may be accepted (i.e., the Edge starts assisting the AV by monitoring how the scenario evolves and reporting changes and/or instructions) or rejected (i.e., the Edge does not get involved in the manoeuvre).

5.2 Proposed setup

This use case scenario will be trialled at Chemnitz, Germany. At the time of submitting deliverable D4.2, the pandemic situation that evolved as a result of COVID-19 made travelling temporarily impossible and the perspective of shipping the Carai vehicles to Surrey, UK became very unclear. Therefore, development to implement our own trial facilities started at TUC with the goal of hosting smaller-scale trials involving the Carai vehicles directly at the TUC premises and thus removing the need for travelling and shipping. In the process, gNBs/eNBs and UEs have been developed and deployed and adequate spectrum licenses have been acquired. As of now, the pandemic situation and the bureaucratic difficulties of shipping the vehicles to Surrey, due to Brexit, are still unsolved and therefore the trials leading to this deliverable have been conducted at TUC premises using the equipment we purchased for this purpose.

5.2.1 Network architecture

The network architecture for T2S3 is depicted in Figure 25. It consists of two USRP N321 that model the UE, gNB/eNB respectively. Further it hosts two Personal Computers (PCs) involved, one for the server application at the Edge (Multi-access Edge Computing (MEC)) and one on the user side for the client application.

![Network architecture for T2S3](image)
5.2.2 User application architecture

The user application architecture of the T2S3 scenario is described in Figure 26. A trajectory planning, running at the Edge, interacts via the 5G network with the vehicle through a client/server architecture.

![User application architecture for T2S3](image)

In the following subsections, the HW and SW blocks of the considered architecture will be described.

5.2.3 Hardware components

The following hardware is used and deployed as part of the experimentation setup at the TUC facilities in Chemnitz, Germany and have been used for the trials of this scenario.

- **Base Station**
  - N321 USRP
  - Dell OptiFlex 7070; Server software is deployed here
- **Carai 3 vehicle (BMW i3)**
  - N321 USRP
  - Dell OptiFlex 7070; Client software is deployed here
  - OBU Nuvo industrial
  - uBlox NEO M8T Global Navigation Satellite System (GNSS) receiver

5.2.4 Software components

The used software consists of a client and a server part that are deployed to the vehicle and the Edge respectively. While the client contains the interface to the on-board unit, the server application contains a trajectory planning algorithm to derive safe trajectories in case assistance is required. The messaging scheme is shown in Figure 27 and will be explained subsequently.

![Message flow between the vehicle (client) and Edge (server) in T2S3](image)
When a vehicle requires the assistance to perform a manoeuvre, the client sends a request to the server containing the current position and the destination in Universal Traverse Mercator (UTM) coordinates. The server then processes the request by trying to derive a safe trajectory for the vehicles trip. If this is successful, it then checks whether the network can provide a minimum level of QoS along the derived path. It then responds the derived trajectory back to the vehicle (OK) and indicates it to use that trajectory. In case no safe trajectory was found or the needed QoS level cannot be provided, it answers negatively (NOK).

If the client receives a positive response, it starts the manoeuvre by travelling the provided trajectory. In this phase, it continuously monitors the connection by sending frequent pings (PING) containing its current position and waits for acknowledgements. If these acknowledgements do not arrive timely, it cancels the maneuverer and moves to a lower level of automation by involving the driver. Once the vehicle reaches the final position of the trajectory, the manoeuvre is finished by sending FIN.

The communication between the vehicle and Edge is implemented based on ZeroMQ “Radio-Dish” sockets\(^3\) with User Datagram Protocol (UDP) protocol. These sockets bind to UDP ports and use one publisher/subscriber pair per participant with data encoded with FlatBuffer\(^4\).

The trajectory planning applications, hosted by the Edge, determines an optimal and collision-free trajectory on a given map subject to the existence of some obstacles. The details of the trajectory planning application are presented in Section 7.2.4.3 of the deliverable D4.2 [2].

### 5.3 Testing and verification

#### 5.3.1 Methodology

The capability of 5G to support Edge-assisted automated manoeuvres will be trialled. A preliminary setup will be considered, where a trajectory planning application, deployed at the Edge, assists vehicles to maintain high automation levels. The setup will initially integrate a simplified and static form of QoS level estimation to cope with potential changes. It will be later extended to exploit advanced predictive QoS mechanisms based on the latest 3GPP progress. During the final project trials, the Edge-assisted automated manoeuvre functionality will be combined with the T3S1 use case scenario (i.e., tele-operated support) to switch between different modes of teleoperation (e.g., from manoeuvring to trajectory provision) depending on the operating conditions.

The described functionality has been fully implemented and preliminary trials using 4G have been performed at TUC’s premises. The experimentation setup consists of a base station with the Edge service and the Carai 3 as client as shown in Figure 28.

The base station consists of a USRP-based eNB which is configured to use Single Input Single Output (SISO) on 3700MHz with a bandwidth of 10MHz. At the Edge, the Server software is deployed and run for minimum latency. It continuously listens for requests for manoeuvre assistance for the specified area by nearby vehicles. Upon request it plans a trajectory and responds accordingly. If the assistance has been granted, server and client exchange continuous pings until finalization.

---

\(^3\) [https://rfc.zeromq.org/spec/48/](https://rfc.zeromq.org/spec/48/)

\(^4\) [https://google.github.io/flatbuffers/](https://google.github.io/flatbuffers/)
4.3: Evolved Solution and Verification of Transport Use Case Trials

Figure 28. Experimentation area at TUC premises, Chemnitz (N50.814°, E12.928°). Green path denotes the track the vehicle travels; orange cross marks the base station location. Map: © OpenStreetMap contributors.

A map of the experimentation facility has been created and deployed to the server application. On this map, a virtual obstacle has been placed to simulate the need for edge assistance. The final map, the obstacle and a sample planning step has been depicted in Figure 29.

Figure 29. Derived map for the trajectory planner (black), ideal track for the automated vehicle (gray), virtual obstacles (red) as well as the ego vehicle with the planned trajectory (blue)

The Carai 3 vehicle is equipped with a USRP-based UE and connected to the base station. The assisted manoeuvre client is deployed to the OBU of the vehicle and communicates with the server. Upon triggered, it emits a request for assistance and if a positive reply is received monitors the state with continuous pings until finalization.

After completing the described setup, the trail was performed and measurement data with a total length of 83 minutes were taken. Travelling the path, the vehicle requested edge assistance when encountering the virtual obstacles, monitoring the connection via continuous pings and finalising the trip once reaching the end of the provided trajectory.
5.3.2 List of key performance indicators

The key target KPIs for Phase 2 are listed in Table 12, which are a subset of the full target KPIs list presented in Section 7.3.2 of the deliverable D4.2 [2].

Table 12: Target KPIs for T2S3

<table>
<thead>
<tr>
<th>Network requirements</th>
<th>Target values</th>
</tr>
</thead>
<tbody>
<tr>
<td>User experienced DL throughput</td>
<td>High (10-50 Mbps)</td>
</tr>
<tr>
<td>User experienced UL throughput</td>
<td>High (0.25-10 Mbps)</td>
</tr>
<tr>
<td>Latency requirements</td>
<td>Low SAE automation levels: Low (100 ms)</td>
</tr>
<tr>
<td></td>
<td>High SAE automation levels: Medium (5 ms)</td>
</tr>
</tbody>
</table>

5.3.3 Measurement and testing tools

For capturing the KPIs, the computer’s clocks are continuously synchronized using Precision Time Protocol (PTP). Then while executing the scenario, traces of the involved communication are taken at the client and server PC endpoints. The measurements are repeated and evaluated statistically.

Traces are taken using “tcpdump” on the probe points (Ethernet interfaces). This captures traffic on layers 2-7 of the Open Systems Interconnection (OSI) model and provides high-resolution timestamps. Additionally, each UDP message carries a timestamp that can be used to trace the packages. By performing round trip measurements, the effect of sub-optimal time synchronisation can be mitigated. Both measurements for the latency KPI are evaluated statistically by combing KPIs of multiple trials.

5.3.4 Intermediate results

When the vehicle requests edge assistance and the request has been accepted, both partners exchange continuous pings and acknowledgements. These pings carry timestamps which can be used to estimate RTTs. The distribution of the measured RTTs is shown in Figure 31. A mean of 35ms RTT has been achieved, which is in accordance with the expected performance of LTE Rel. 10 that was used.
Figure 31. RTT measurements from the measurement campaign in milliseconds

The bandwidth required by the application was measured by taking samples of the traffic flow at the server side and evaluating it with Wireshark. The derived throughput is displayed in Figure 32. The peak observed throughput was 110 kbit/s. Note, that this trial did not include any sensor data yet, which explains the very low observed value. In a further step, the actual throughput will be increased.

Figure 32. Average throughput over time in bits/s

The main goal of the trials was to deploy and verify that the full setup is working. Further, baseline measurements using 4G have been derived that will serve for comparison with the 5G measurements, once they become available. The results show a performance in the expected range.
5.4 Next step plans

Up until now, the trials have been performed using 4G technology. With the upcoming release 21.10 of srsRAN\(^5\) in November 2021, 5G Non-Standalone (NSA) is expected to be available for gNB. Together with the already existing support for the 5G NSA UE we will be able leverage that functionality for additional trials in Q1/2022. For the final demonstration it is expected, that full 5G SA support will land with the release 22.04. of srsRAN in Q2/2022. Alternatives like OAI or commercial Customer Premises Equipment (CPE) are investigated.

During the remainder of the project, the setup will be extended to include a more advanced trajectory planning application relying on sensor data from the vehicles and thus increasing the bandwidth demand as well as employing a predictive QoS mechanisms based on the latest 3GPP progress. For the final project trials, it is envisaged to combine the Edge-assisted automated manoeuvre functionality with the T3S1 use case scenario (i.e., tele-operated support) to switch between different modes of teleoperation (e.g., from manoeuvring to trajectory provision) depending on the operating conditions.

6 T2S4: HUMAN TACHOGRAPH

6.1 Description and motivation

The trialled human tachograph service utilises driver’s biosignals and provides guidance to prevent fatigue and improve wellbeing. Unlike most of the existing driver fatigue detection systems, the human tachograph tracks both live biosignals as well as sleep and physical activity in long-term. The information from the tachograph application can also be shared with other drivers and vehicles. For this purpose, a 5G-based traffic warning system has been implemented, which triggers warning messages towards other road users and road traffic safety systems based on the human tachograph driver condition analysis.

This section presents the Phase 2 measurements for the overall human tachograph service and assesses the achieved performance individually in the 5G NR uplink (collection of driver biosignals) and downlink (dissemination of warning messages) directions. The performance of the overall service is measured in the 5GTN VTT Oulu test facility in terms of communication latency and reliability. The measurements are performed in both laboratory and field conditions.

6.2 Proposed setup

6.2.1 Network architecture

Figure 33 presents the high-level network architecture for the Phase 2 trials of the human tachograph use case scenario. The driver monitoring data in the form of live biosignals is collected using wearable sensor devices (heart rate monitors on chest belts and/or sports watches) and streamed to the network in the uplink direction using a 5G smartphone as Gateway (GW) device. The sensor data is received in the edge cloud to be used as a live biosignal data in the driver condition assessment and it is also forwarded to the remote cloud to be used in the long-term analysis. In addition to the live sensor data analysis and visualisation, the edge cloud environment can be used for data fusion between the live and long-term sensor data. Furthermore, the edge cloud environment hosts the warning message triggering framework, which is used to notify the other road users in the area about increased risk caused by driver fatigue. The warning messages are distributed to the road user in the downlink direction of the same 5G cell that is used to collect the wearable sensor data from the professional drivers. As an additional component to the warning messages distribution in 5G NSA networks, the Evolved Multimedia Broadcast Multicast Service (eMBMS) -based multicasting/broadcasting can be used to deliver the notifications to a large group of recipients. The performance of the 4G LTE cellular broadcast/multicast and comparison against 5G NR is done in the OTA updates use case scenario trials discussed in Section 9.

Figure 33. Network architecture for the Phase 2 trials of the human tachograph use case scenario.
All architectural components depicted in Figure 33 are running locally at the 5GTN-VTT test facility in Oulu, Finland. The only remote component (available, but not yet utilised in the measurements) is the wearables services ecosystem running on Polar’s research servers. The hardware and software related to collection and forwarding of the sensor data to the network is implemented and provided by Polar as is the software related to the analysis of the data at the remote wearables services servers. All the 5G network components and user devices as well as the warning message triggering framework is implemented and provided by VTT.

6.2.2 User application architecture

The user application architecture for the human tachograph service can be device-centric or network-centric. The device-centric architecture, discussed in Section 8.2.2 of [2], relies on the user devices for the sensor data processing. This is the traditional way to deploy wearable-based services where either the wearable devices themselves or the smartphones they are connected to handle the time sensitive operations related to the provided service. In the human tachograph scenario, the analysis of the live biosignals, data fusion with the historical data and triggering of the warning messages would all be handled at the user devices if the service is deployed using a device-centric architecture as shown in [2]. While this kind of deployment could be more straightforward when compared to a network-centric approach as there are less interacting components participating to the processing of the sensor and warning message data, it would be really dependent on the capabilities of the user devices for the data processing. In addition, it would be more difficult to make the human tachograph related information available to other services which hinders the possibilities for service integration with network-based road safety systems such as CoCA.

Taking into consideration the shortcomings of the device-centric architecture and enhanced performance provided by 5G, the most promising deployment approach for the human tachograph service is to shift the sensor data processing from the user devices into the network. The network-centric architecture, depicted in Figure 34, is still divided in two distinct braches. In the live sensor data streaming branch, the service components include the wearable sensor devices with integrated software, which forwards the sensor data measurement data from the wearable sensor device to the smartphone as a continuous stream. In the smartphone, the sensor data stream received from the wearable sensor device is further forwarded to the 5G network edge cloud and Polar’s research server in the remote cloud using Polar Sensor Data Logger software. In the historical data analysis branch, the server side algorithms are running in the remote cloud as well as the API utilised to access the analysed historical data have been developed to support the specific parameters and information required to assess the driver status. Combining the two branches in the 5G network edge cloud is the current driver status analysis and warning message trigger framework, which takes in both the live biosignal data as well as the pre-analysed historical data and generates warning messages when the driver’s ability to drive safely becomes impaired.

In parallel with the Phase 2 laboratory and field trials presented in Section 6.3, the live sensor streaming and historical data analysis branches have been combined in order to enable data fusion for the final trials in Phase 3. In the human tachograph service, the status of the driver is to be assessed and shown based on data from both live biosignals and history data. Based on this combined analysis, warning messages and alert are generated and sent to the from the edge cloud back to the driver and also to other road users.
6.2.3 Hardware components

The Phase 2 trial network architecture contains the following hardware components:

- **Wearable sensor devices:**
  - Polar H10 heart rate monitor measures the biosignals including Heart Rate (HR), Electrocardiogram (ECG), and Accelerometer (ACC) and broadcasts them continuously over a Bluetooth Low Energy (BLE) link.

- **UEs:**
  - OnePlus 8 Pro for receiving biosignals from Polar H10 and streaming them to the network. The same phone is also running Nemo Handy SW for debugging purposes.
  - Huawei H112-370 5G CPE is used as the 5G UE in the measurements. It is visible as a conventional Ethernet interface for the measurement laptop.

- **eNBs:**
  - LTE Frequency Division Duplex (FDD) @ 2600 MHz (band 7), BW = 5+10 MHz (anchor for macro 5G gNB).
  - LTE FDD @ 2100 MHz (band 1), BW = 10 MHz (anchor for pico 5G gNB).

- **gNBs:**
  - 5G NR Time Division Duplex (TDD) Rel-15 NSA @ 3.5 GHz (band n78), BW = 60 MHz.
    - Pico gNB for laboratory testing.
    - Macro gNB for field trials with a grid of 6 horizontal beams.
    - The only supported numerology is 30 kHz subcarrier spacing, which corresponds to 0.5 ms slot duration.
The configuration is optimised for UL performance with the 3/7 DL/UL time slot ratio and UL proactive scheduling enabled [20].

The Multiple Input Multiple Output (MIMO) configuration is 4x4 in the DL and 1x4 in the UL direction.

- EPC and 5GC:
  - Emulated core network services.
- Wearables services:
  - A Virtual Machine (VM) server receiving the streaming sensor data in VTT’s edge cloud environment.
  - A server receiving the streaming sensor data and history data in Polar’s remote cloud.

### 6.2.4 Software components

The following software components are utilised in the T2S4 Phase 2 trial setup:

- Polar Mobile Software Development Kit (SDK) enables to read live data (streamed through BLE) directly from Polar sensors, including ECG data, ACC data and HR broadcast.
- Polar Sensor Logger Android application implements decoding of the H10 BLE signalling using the Polar SDK and visualization of the biosignal measurements. During the Phase 2 it was also updated to include an MQTT publisher for the measurement and trial purposes. Polar Sensor Logger publishes the sensor data from a smartphone to the brokers at the network edge cloud in the 5GTN-VTT test facility and Polar’s remote research server.
- Polar Open Test Application Programming Interface (API) provides a direct information sharing link between the Polar ecosystem and research server as well as between the Polar research server and 5G network edge cloud environment for historical data.
  - Estimation of fatigue levels for the day based on user’s sleep history (recent sleep amount and timing in relation to circadian rhythm) is calculated on the research server.
  - Fatigue level prediction also takes into account daytime napping (not currently available in history data, but through manual notation).
- MQTT client (publisher) for publishing the biosignal data packets to the network.
- MQTT broker running in the edge cloud for initial reception and forwarding of the published biosignal data packets.
- MQTT client (subscriber) for receiving the published biosignal data packets in the network.

### 6.3 Testing and verification

In Phase 2, we evaluated the feasibility of a 5G-based traffic warning system, which triggers warning messages towards other road users and road traffic safety systems based on the human tachograph driver condition analysis. The performance is measured in terms of communication latency and reliability using a 5G NSA network configuration in the 5GTN VTT Oulu test facility. The setup and the results for the indoor laboratory measurements were published in [21].

#### 6.3.1 Methodology

As a first step, the setup for the human tachograph based warning system was built in the laboratory using a 5G NR small cell. This allowed simple synchronization of the measurement end points using PTP over Ethernet. In addition, long measurements over several days were possible in the indoor environment with stationary users, which enables estimating the upper bound for the reliability based on the latency measurements. The setup for the laboratory measurements is shown in Figure 35. Polar H10 heart rate sensor measures the biosignals and sends them over the BLE connection to an Android phone running the Polar Sensor Logger app. The phone publishes all the biosignals to a MQTT broker. The Mosquitto MQTT broker is running in the same server rack as the EPC to avoid any extra delays. The processing of the human tachograph data and warning message triggering is also done at the network
D4.3: Evolved Solution and Verification of Transport Use Case Trials

edge. The MQTT packets are captured by Qosium Probes which send the relevant metadata to a Qosium Scope for processing. This allows measuring of one-way latencies when the Probe measurement points are accurately synchronised with PTP.

Figure 35. Human tachograph trial setup for the Phase 2 laboratory measurements.

As a second step, to verify that the mobility of the users do not have any significant effect on the results achieved in the laboratory conditions, similar measurements were performed outdoors around the VTT Oulu premises using 5G NR macrocell provided by the test facility. In this case, all the available 5G NR devices synchronized their clocks using the Network Time Protocol (NTP) signal sent from the gNB. The accuracy of mobile NTP synchronization is in the order of 10 ms [22], which is clearly not enough for any one-way latency measurements with 5G NR. To overcome this issue, we setup an external Global Positioning System (GPS) receiver as a clock reference for the laptop through which the Polar Sensor Logger traffic is forwarded. The setup for the outdoor measurements is shown in Figure 36. When compared to Figure 35, the following modifications were needed to the setup to accurately synchronize the measurement points:

- Any phone in a (public) LTE network provides general connectivity for the Probe A laptop in order to enable its WiFi hotspot.
- Probe A laptop provides WiFi connectivity for the Polar Sensor Logger phone.
- The biosignal data received at the Probe A laptop over WiFi is forwarded to the 5G network.
- Clock reference for Linux laptops in the field is provided using NTP that is synchronized with GPS National Marine Electronics Association (NMEA) timestamp and the Pulse Per Second (PPS) signal from the GPS receiver.

This kind of setup can provide even ~10 µs synchronization accuracy for different Qosium Probes with stationary vehicles. The synchronization accuracy is somewhat decreased with moving vehicles but is still below ~100 µs, which adequate for Rel-15 5G NSA measurements.
6.3.2 List of key performance indicators

The key target KPIs for Phase 2 are listed in Table 13, which are a subset of the full target KPIs list presented in Section 8.3.2 of the deliverable D4.2 [2]. The Phase 2 trials aim to verify the 5G NSA performance for both the DL and UL traffic profiles of the human tachograph use case scenario with both stationary and mobile end users. Reliability is defined as the percentage of application packets that are successfully received within the pre-defined timeframe.

<table>
<thead>
<tr>
<th>Network requirements</th>
<th>Target values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latency requirements</td>
<td>Medium (5 ms)</td>
</tr>
<tr>
<td>Reliability</td>
<td>Low (99.99%)</td>
</tr>
</tbody>
</table>

6.3.3 Measurement and testing tools

The measurement and testing tools utilised in the indoor and outdoor trials:

- Qosium for E2E passive QoS / Quality of Experience (QoE) measurements and monitoring. Qosium Probes capture the MQTT traffic at the publisher, broker, and subscriber. The metadata, such as packet timestamps, from the captured traffic is sent to Qosium Scope, which calculates the latencies based on the timestamps.
- Garmin GPS18x LVC is used as the external GPS receiver for synchronising the laptops used as UEs (together with the 5G CPEs) in the field measurements. Its main feature for the field trials purposes is that in addition to conventional NMEA GPS signal, it also gives a PPS pulse, which is synchronized to the GPS time reference, as an output. The PPS signal is fed into the serial port of the measurement laptop to avoid any inaccuracies from Universal Serial Bus (USB) processing. The combined NMEA and PPS signals are then used as the only timing reference for the measurement laptop6.

---

- Trimble Thunderbolt PTP GM200 with an external GPS antenna is used as PTP master for the server running the MQTT broker. This ensures the same timing reference for the both ends of the measurement path.

6.3.4 Intermediate results

Polar Sensor Logger was configured to publish approximately 6 ACC, 2 ECG and 1 HR messages per second with an average bit rate of 50 kbps during the measurements. The biosignal reporting latency over 5G NR (from Probe A to Probe B) as well as the warning message delivery latency (from Probe B to Probe C) are measured over approx. 100 000 packets. The high number of packets allows evaluating the tail of the latency Cumulative Distribution Function (CDF) needed for reliability measurements. The outdoor measurement route around VTT Oulu premises is shown in Figure 37. The maximum vehicle speed during the measurements was 40 km/h.

![Image of outdoor measurement route](image)

Figure 37. Outdoor measurement route for the human tachograph Phase 2 trials with the RSRP (dBm) values.

The CDF of the biosignal reporting latency in the UL direction is shown in Figure 38. The measured average latencies are 7.04 ms, 8.98 ms, and 22.8 ms for 5G outdoor, 5G indoor, and LTE, respectively. It is somewhat surprising that better results are achieved from the outdoor measurements than indoor stationary measurements. However, it should be noted that the indoor laboratory measurements were performed in December 2020 – January 2021 while the outdoor measurements were done in September-October 2021. However, there has been several 5G gNB software updates between the measurement campaigns that is likely to explain the differences in latency. In the network-centric deployment of the human tachograph service, the UL is only used for biosignal reporting and not for the warning messages, so the isolated UL latency is not so critical from the end-to-end performance perspective. In addition, the achieved latency levels can fulfil the one-way latency requirements for this particular use case.

The CDF of the warning message delivery latency in the DL is shown in Figure 39. The average latencies are 3.96 ms, 4.10 ms, and 5.38 ms for 5G outdoor, 5G indoor, and LTE, respectively. Again, the 5G outdoor measurements achieve slightly lower latency than earlier indoor measurements, which is most likely due to the 5G gNB software updates performed at the test facility during the long time period between the measurement campaigns. The achieved average DL latencies are already on a very good average level for traffic warning services. However, it is the tail of the latency CDF that defines the reliability of the warning message delivery services.
Figure 38. CDF of the biosignal reporting latency in the UL direction.

Figure 39. CDF of the warning message delivery latency in the DL direction.

The reliability in the human tachograph measurements is defined as the number of packets successfully delivered to the destination within the specified time constraint. The achieved reliability as a function of time constraint is shown in Figure 40 and Figure 41 for biosignal reporting and warning message delivery, respectively. It can be seen that many of the UL reliability issues in the 5G indoor measurements reported in [21] have been fixed for the newer gNB software releases, because the 5G outdoor reliability in Figure 40 is at a much better level. The 5G indoor and outdoor measurements showed that ~11-13 ms latency can be achieved for the warning messages with reliability of 99.99%. This is already close to the target level for cooperative collision avoidance for automated driving, i.e.
10 ms latency with a reliability of 99.99%. It is expected that the reliability levels will significantly improve when the URLLC features will be released for the gNBs utilised in the 5GTN VTT Oulu test facility.

![Graph showing reliability as a function of time constraint for biosignal reporting in the UL direction.]

**Figure 40.** Reliability as a function of time constraint for the biosignal reporting in the UL direction.

![Graph showing reliability as a function of time constraint for warning message delivery in the DL direction.]

**Figure 41.** Reliability as a function of time constraint for the warning message delivery in the DL direction.

### 6.4 Next step plans

Based on the available test network development roadmaps, it is expected that 5G SA and RAN slicing support becomes available in the 5GTN VTT Oulu test facility in the end of 2021 or beginning of 2022.
These functionalities will be utilised in the final human tachograph trials and their effect to the overall 5G and service performance will be evaluated and validated during Phase 3. Another upgrade on the development roadmap of the 5GTN VTT Oulu test facility is a hardware-based UE emulator, which enables generation of multiple artificial UEs and traffic for different network slices. The UE emulator will be utilised for evaluating the scalability of the human tachograph service in 5G networks. Finally, in parallel with the validation trials and measurements, the implementation of the final demonstration for the human tachograph use case scenario will be finalised. In addition to the measurement tools utilised in the trials, the demonstration implementation will include additional 5G performance monitoring as well as data analysis and visualisation components, which can be used to show the progress of the trial scenario to the demonstration viewers in real time.
7 T3S1: TELE-OPERATED SUPPORT (TESO)

7.1 Description and motivation

The use-case scenario of tele-operated support for remote driving refers to the remote control of a vehicle using the available mobile communication infrastructure. A human operator located remotely sends control commands to the vehicle over the network, while at the same time, information about the vehicle’s state and its surroundings is properly transferred and visualized back to the operator. Tele-operated support can be utilized as a standalone service to support various applications and scenarios, ranging from mission critical situations under harsh environmental conditions to every-day automated transportation or industrial services. More importantly though, the application of remote driving can be complimentary or serve as a back-up service of the autonomous/assisted driving mode. This form of remote driver fallback authority can help to bring autonomous vehicles’ technology to the consumer earlier by providing the desired advanced security and safety level.

To realize the communication chain from the vehicle to the remote operator and then, back to the vehicle, a V2N connection is established between the remotely controlled vehicle and the Remote Operations Center (ROC), where the remote human operator is located. Through the V2N wireless link the secure transmission of real-time data feed from the on-board vehicle's instrumental sensors and High Definition HD cameras, as well as the GNSS position, is achieved. These data are properly visualized by the appropriately designed and developed user application’s Graphical User Interface (GUI), and, ultimately, utilized by a remote human operator to maneuver the vehicle. At this time, the control commands are transmitted via the V2N connection in the opposite direction of the communications, realizing in this way the TeSo service.

7.2 Proposed setup

A high-level overview of the end-to-end TeSo service’s user application and network architecture and setup is illustrated in Figure 42, below. As can be seen, the main components are a remotely controlled vehicle, the mobile network infrastructure and the ROC located at the edge of the network. The vehicle is equipped with the appropriate sensors and actuators to measure and control, respectively, its speed, acceleration, steering angle and brake position. Also, four cameras are mounted on each side of the vehicle (i.e., at the front, back, right and left side) to allow for video streaming to the ROC. An OBU, which interfaces with the sensors and the cameras, is used to capture operational and ambient data. It also makes the data available to other hardware or software components that are integrated into and operate in the vehicle. In addition to the sensors, the OBU is used as an interface towards the vehicle’s actuators and is responsible for translating the received commands from other hardware or software components to appropriate signals compatible with the vehicle’s actuators.

Figure 42. High-level overview of the TeSo service’s network and user application architecture and setup.
The general idea behind the overall TeSo service’s architecture has not changed since the previous deliverable D4.2 [2]. However, specific details regarding the wireless network connectivity between the vehicle and the ROC, as well as the network equipment used have been modified, owing to the finalization of the user application’s integration to the research vehicles and the establishment of the wireless connection with the edge network. In the following subsections, a more elaborate description of the network and user application architecture, is provided, along with the required hardware and software components.

7.2.1 Network architecture

In this section, we emphasize on the network architecture of the overall proposed setup, which essentially extends from the srsUE to the srsENB and srsEPC components of Figure 42. A more detailed overview of the network-related components and their in-between connections is provided in Figure 43.

![Detailed overview of the TeSo service’s network architecture.](image)

In more detail, a USRP device lies at each side of the communications, i.e., the vehicle’s and the ROC’s side, and is connected with the appropriate antennas for the transmission and reception of the wireless signals from the one side to the other. Both sides bear an omnidirectional wideband antenna (e.g., MGRM-WHF antenna) for transmitting instrumental data and control commands, in the uplink and downlink direction, respectively, while at the same time a GPS antenna is used to receive real-time feed from GNSS satellites at both the vehicle and the ROC. At the vehicle’s side, the USRP device is connected to a personal computer, indicated as “srsUE”, which hosts a full-stack software radio UE implementation of the srsRAN [1] open-source platform – appropriate for 4G LTE and 5G NR communications. Considering the communication between the USRP and the srsUE personal computer, the 10 Gigabit Ethernet standard is adopted. In a similar manner, at the ROC’s side, the USRP device is connected to a personal computer that hosts the srsENB and srsEPC, implementing the software radio eNB and Core Network (CN), respectively, via the use of the srsRAN platform. Once again, the communication between the USRP and the srsENB + srsEPC personal computer is realized by adopting the 10 Gigabit Ethernet standard.

The specific parameterization of the USRPs and antennas used to setup the communications is provided in Table 14, below.
Table 14: Parameterization of USRPs and antennas

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>eNB Maximum Tx Power</td>
<td>-7 dBm (USRp gain = 60 dB) + 30 dB (Power Amplifier)</td>
</tr>
<tr>
<td>Antenna Gain</td>
<td>3 dBi</td>
</tr>
<tr>
<td>Cable Loss (3 Meters)</td>
<td>2.5 dB</td>
</tr>
<tr>
<td>Tx Center Frequency</td>
<td>DL: 2400 MHz, UL: 5800 MHz</td>
</tr>
<tr>
<td>BW</td>
<td>20 MHz</td>
</tr>
<tr>
<td>Transmission Mode</td>
<td>SISO</td>
</tr>
<tr>
<td>Duplex Mode</td>
<td>FDD</td>
</tr>
<tr>
<td>No. of Antennas</td>
<td>4 (2 for each channel)</td>
</tr>
<tr>
<td>Antenna Height</td>
<td>1.5 m</td>
</tr>
<tr>
<td>USRP Noise Figure</td>
<td>6 dB</td>
</tr>
</tbody>
</table>

7.2.2 User application architecture

The user application architecture has not significantly changed from what has been presented in deliverable D4.2 [2]. To summarize, the overall application has two main endpoints which communicate over the 5G network—the ROC-GW node at the vehicle and the ROC GUI at the remote location. Both these components, incorporate the following three functionalities:

- Video streaming from the four cameras that are mounted on the vehicle (at the front, back, right and left side).
- Transmission/Reception of sensor and instrumentation data describing the current state of the vehicle and automation system.
- Remote control with appropriate commands based on the input of the human operator.

The ROC-GW node is constructed using the DRAIVE Link2 framework and it is a Command Line Interface (CLI) application. The required configuration is provided in the form of a JSON file (instance.json) that is given as an argument to the CLI application. The most relevant information is the IP address of the ROC that is needed for establishing the ZeroMQ sockets between the two endpoints and the JPEG compression quality (an integer between 1 and 100, with 100 being the best) corresponding the cameras’ frames. The ROC GUI application is the interface with the human operator. Although it has been only slightly modified compared to what has been previously presented, since it is the only real point of interaction with the end-user, we once again provide a screenshot with sample output and we briefly explain the layout.

As can be seen in Figure 44, the four widgets displaying the video streams from the on-board cameras of the vehicle comprise the bulk of the application’s main window. In the upper right corner, a 2D map illustrates the trace of the vehicle that is constructed based on the received GPS coordinates. In the upper left corner, telemetry data describing the current state of the automation system and the vehicle is updated according to the information received from the ROC-GW. Finally, the bottom part of the window is dedicated to the remote control. In the middle, there are four push buttons for entering the desired brake/throttle and steering input (alternatively, input can be given via the arrow keys of the keyboard). To the left, the user-provided angle is displayed in degrees, along with the respective selected increment step. To the right, a bar displays the user-provided throttle (or brake) percentage in green (or red) color, together with the respective selected increment step.
7.2.3 Hardware components

In the following, the specific hardware that is used to realize different components, as described in previous sections, are listed, while Figure 45 presents the complete installation of this hardware at both the vehicle (left subfigure) and the ROC (right subfigure).

- **OBU**: Nuvo industrial PC
- **Research experimentation vehicle**: Carai 3 (BMW i3)
- **2x Laptops** running srsRAN: Dell OptiFlex 7070
- **2x USRPs**: USRP N321
  - 2 RX, 2 TX channels
  - 3 MHz to 6 GHz frequency range
  - Up to 200 MHz bandwidth per channel
- **2x MGRM-WHF antenna**
- **2x GPS antenna**

Figure 44. ROC GUI application.

Figure 45. Overview of the hardware equipment at the vehicle’s (left) and ROC’s (right) side.
7.2.4 Software components

The design of the overall software architecture, consisting of the ROC-GW node at the vehicle side and the ROC GUI application at the remote location, has remained unchanged and is described in detail in deliverable D4.2 “Initial Solution and Verification of Transport Use Case Trials”. However, based on the insights gained during the integration of the software into the vehicle and the first validation trials, the implementation of the modules has been further fine-tuned. More precisely, the changes are mainly located at the ROC GUI application and can be summarized as follows:

- There is now a separate thread for the reception of the video frames of each camera via a ZeroMQ SUB socket (i.e., four threads in total). After the ZeroMQ message containing the frame is received and the necessary data conversions are performed, a suitable signal that is connected to the appropriate display slot of the main window’s widget corresponding to the examined camera is emitted and the frame is displayed. This approach was selected to increase the robustness of the application by decoupling the four video streams. In that way, if there is an error/malfunction with some of the cameras (e.g., the right camera has been unexpectedly turned off or lost connection), the remaining streams (e.g., the streams from the front, left and back cameras) continue to be received and displayed to the operator without an issue.

- Apart from displaying only the received frames of each camera, the timestamps corresponding to the moments when the frames were captured at the vehicle are also presented as a text overlay in the upper left corner of the respective widgets. This is a simple and straightforward way to enhance the situation awareness of the operator and to visually supervise the status of the streams (e.g., the operator can relatively quickly realize that a particular video stream has been stopped or exhibits a long delay with respect to the others).

- In order to increase compatibility with the actuators of the vehicle, the remote control mechanism has been modified both with regards to the frequency of the sent remote control commands, as well as the way in which input is received from the human operator. Regarding throttle and brake control, taking into account that the actuators remember and maintain the last received value, input is obtained from the operator and transmitted to the vehicle in the appropriate data type by adding or subtracting a predetermined increment every time the respective buttons or arrow keys are pressed. Regarding the steering wheel control, the current (desired) angle is continuously transmitted every 100ms. When the respective button or arrow key is pressed, the angle is increased (for the left direction) or decreased (for the right direction) at a predetermined rate. Finally, when no button/key is pressed the angle is moving towards 0 at a fix rate.

7.3 Testing and verification

In Phase 2, we designed and completed the end-to-end software implementation of the TeSo service. Additionally, we performed a comprehensive assessment of each distinct software component’s operation, as well as their coherent cooperation to provide the required end-to-end service. In Phase 3, we go one step further and finalize both the integration of the user application and the network equipment into the research vehicle. At this stage, we are able to showcase the effectiveness of the proposed end-to-end setup, for both the network and the user application perspective, by providing initial measurements and results.

7.3.1 Methodology

Following the description of the proposed setup and architecture, as analytically presented in Section 7.2, the end-to-end chain of the remote driving application can be divided into three main parts, each of them illustrated in Figure 46 using different color. In more detail, the first part (green color) regards the integration and (inter)connection of the vehicle’s sensors/actuators with the OBU and ultimately the ROC-GW. The second part (grey color) is the network application over the 5G network for the communication between the vehicle (in particular ROC-GW) and ROC. Finally, the third part (orange
color) is the inclusion of the human in the control-loop of the vehicle that is realized via the ROC GUI application. The human operator processes the information presented to them in the form of video streams and sensor/instrumentation data, decides the appropriate course of action, and gives as input the corresponding control commands, which will be transmitted back to the vehicle over the network. To give a more concrete example, a typical end-to-end sequence is the following:

1. The four cameras that are mounted on the vehicle record a specific scene. After the necessary format conversions, the corresponding frames are transferred to the OBU, and from there they ultimately reach the ROC-GW (vehicle integration).
2. Using the ZeroMQ messaging library, the frames are transferred over the 5G network from the ROC-GW to the ROC application (network application).
3. The frames are displayed to the human operator in the ROC GUI application, who then processes this information, decides the actions that must be taken, and provides the respective control commands input (human cognitive process).

Vehicle integration depends on the specific employed strategy at a hardware level and can be considered a constant, since all the involved components are hardwired. Series vehicles typically have lower latency values due to the manufacturer’s tight integration. Experimental setups, like the one employed here, tend to have higher latency values, but offer greater flexibility. Moreover, the human operator’s cognitive process and reaction time are outside of the scope of this study and cannot be directly measured. On the other hand, the network application performance varies over time and space, since it depends on the 5G connection, network coverage and overall link conditions. The conducted trials focus on measuring and providing suitable KPIs of this variable part of the operation chain.

In particular, taking into account that it is not possible to map the exact data (e.g., video stream frames) that instigates a specific reaction from the operator and generates the respective remote-control commands, we will take measurements separately for each type of data on the downstream and on the upstream between the ROC-GW and ROC (points 1-2 and 3-4 in Figure 21). The overall end-to-end (or even round-trip if so desired) delay can then be estimated by adding the corresponding upstream and downstream components with the constant representing the vehicle integration and the estimate/bound regarding the human reaction time found in the literature. At this point it should be noted that the mean human’s reaction time is estimated to be around 1 sec [23], [24], [25].

7.3.2 List of key performance indicators

Primarily relying on the mobile network connectivity, the TeSo service imposes strict requirements in terms of the delay, loss, reliability, availability, and channel security. As a result, the main KPIs that are scrutinized to reassure the sustainability of TeSo service are: latency, which can significantly affect cognitive functions such as spatial cognition, sense of presence, and awareness, throughput, which is directly related to the ability of the operator to accurately perceive the vehicle’s environment and state and packet loss that constitutes, also, a measure of the service’s reliability and availability. The targeted
values of the KPIs under investigation are listed in Table 15, below. The full list of target KPIs for the use case scenario can be found from Section 9.3.2 of the deliverable D4.2 [2].

<table>
<thead>
<tr>
<th>Network requirements</th>
<th>Target values</th>
</tr>
</thead>
<tbody>
<tr>
<td>User experienced DL throughput</td>
<td>Low to Medium (1-5 Mbps)</td>
</tr>
<tr>
<td>User experienced UL throughput</td>
<td>High (16-20 Mbps)</td>
</tr>
<tr>
<td>Latency requirements</td>
<td>Medium (5-20 ms)</td>
</tr>
<tr>
<td>Packet Loss (%)</td>
<td>1/10000</td>
</tr>
</tbody>
</table>

### 7.3.3 Measurement and testing tools

As described in Section 7.3.1, in order to evaluate the achieved performance, the outgoing and incoming traffic at the two devices hosting the ROC-GW node and ROC GUI application is captured. To that end, we employ the tcpdump packet analyzer on the appropriate network interfaces with a Boolean expression that indicates the underlying port range used by the application, and we record the matching traffic in two PCAP files.

In order to post-process these captured files we leverage the capabilities and features of the network protocol analyzer Wireshark. More precisely, we make use of the ZMTP Wireshark Dissector\(^7\) to decode the ZeroMQ Message Transport Protocol (ZMTP) that is used for the communications between ROC-GW and ROC. Then, using the PyShark\(^8\) Python packet parser we write a script to identify the corresponding ZeroMQ messages and compute the respective latencies. Throughput and retransmission/lost packet analysis are realized over the underlying TCP streams using the Wireshark integrated statistics tools.

### 7.3.4 Intermediate results

The aim of these intermediate reference measurements is to determine the best case performance of the employed network setup, described in Section 7.2.1, and assess how well it is able to fulfill the requirements of the considered tele-operated support service by comparing the achieved performance with the target values of the KPIs. To that end, we utilize Ping to measure the RTT and iPerf3 to measure the Transmission Control Protocol (TCP) throughput at both UL and DL between the devices (i.e., laptops) hosting the ROC-GW node (mounted on the vehicle) and the ROC GUI app (“remote” location). The measurements were realized under ideal conditions, i.e., inside the garage at TUC premises and with a very small distance between the two endpoints.

More precisely, the iperf client is running on the device hosting the ROC-GW node (mounted on the vehicle) and the iperf server is running on the device hosting the ROC GUI application (“remote” location). By default, the client is the sender and the server is the receiver of the test data, therefore in that mode we can measure the performance of the uplink (i.e., the upload speed of the client). By specifying the -R flag these roles can be reversed (i.e., the test data is sent from the server to the client) and we can measure the performance of the downlink (i.e., the download speed from the server). Table 16 presents the RTT and TCP throughput measurements at the network layer.

\(^7\) [https://github.com/whitequark/zmtp-wireshark](https://github.com/whitequark/zmtp-wireshark)

\(^8\) [https://kiminewt.github.io/pyshark/](https://kiminewt.github.io/pyshark/)
Table 16: Network layer reference measurements

<table>
<thead>
<tr>
<th>KPIs</th>
<th>Tool</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Round-Trip-Time (ms)</td>
<td>Ping</td>
<td>27.61</td>
</tr>
<tr>
<td>UL TCP Throughput (Mbps)</td>
<td>iPerf3</td>
<td>48.5</td>
</tr>
<tr>
<td>DL TCP Throughput (Mbps)</td>
<td>iPerf3</td>
<td>69.9</td>
</tr>
</tbody>
</table>

Apart from the reference measurements presented above, we also realized actual validation trials performing several simple maneuvers (i.e., turn right, turn left, lane change left, lane change right) at a controlled open space at TUC premises with a line-of-sight setup, and we captured the incoming and outgoing traffic at the ROC-GW and ROC measurement points (see Figure 46). From these capture files, we analyzed the underlying TCP streams (identified by the pre-determined port numbers) using the tools provided by Wireshark. As a representative example, the following figures present the TCP RTT for the various data types transferred from ROC-GW to ROC and vice versa for the case of a right turn. Each plotted point on the graph represents the RTT of a segment. The x-axis corresponds to the sequence numbers of the segments and the y-axis to the RTT values in milliseconds.

The latency requirement presented in Table 15 corresponds to the one-direction wireless transmission (i.e., UL or DL) from the ROC-GW to the ROC, or vice versa. Contrary to that, the Round-Trip-Time (RTT) graphed in Figure 47 - Figure 54 is the amount of time it takes for a packet to be sent plus the amount of time it takes for the acknowledgement (ACK) of that packet (which determines its successful delivery) to be received. This time delay includes propagation times for the paths between the two communication endpoints. The total time that is consumed from the transfer of the packet to the corresponding ACK is called round-trip-time. Of course, this is only an estimate as the receiver is free to delay ACKs for a short period if it feels it can respond to multiple incoming packets with a single reply. Furthermore, as can be observed in the graphs, RTT frequently changes over the duration of the session due to changing network conditions. The effect is (obviously) more pronounced the further away the endpoints. Taking into account the above, we observe that generally the measured delay is within the targeted range, albeit closer to the upper limit.

![Figure 47. RTT of GPS position TCP stream.](image-url)
Figure 48, RTT of front camera TCP stream.

Figure 49. RTT of back camera TCP stream.
D4.3: Evolved Solution and Verification of Transport Use Case Trials

Figure 50. RTT of right camera TCP stream.

Figure 51. RTT of left camera TCP stream.
Figure 52. RTT of steering wheel control TCP stream.

Figure 53. RTT of vehicle state TCP stream.
7.4 Next step plans

Our immediate next step is to achieve precise clock synchronization between the devices hosting the ROC-GW node (inside the vehicle) and the ROC GUI application (“remote” location), which is necessary for realizing accurate one-way latency measurements. This will enable us to evaluate the actual performance of the developed remote driving application when in use, following the methodology described in Section 7.3.1 and utilizing the tools listed in Section 7.3.3. After these two steps, we plan to update the network setup from the currently used 4G LTE to the 5G protocol stack and perform once again the same type of reference measurements and TeSo application performance evaluation.
8 T4S1: VEHICLE PROGNOSTICS

8.1 Description and motivation

In trials for the vehicle prognostics use case focus on the validation of the 5G NR uplink performance with test traffic based on typical On-Board Diagnostics – Second Generation (OBD-II) message sizes. By emulating the service with software and/or hardware-based traffic generators, the validation trials can be flexibly configured to focus on uplink data throughput, end-to-end latency of the data path and scalability of the trialled service. The Phase 2 measurement results presented in this section are focusing on the uplink throughput and latency in field conditions using a single mobile end user. In the Phase 1 measurements presented in [2], similar tests have been performed for fixed end users in laboratory conditions.

8.2 Proposed setup

8.2.1 Network architecture

Figure 55 presents the network architecture for the Phase 2 trials of the vehicle prognostics use case scenario. The utilised test traffic is generated at the 5G UE and transmitted to the network through the 5G NR uplink. The services receiving the emulated test traffic is running on a VM server in the edge cloud environment. The role of the edge cloud server is to also emulate the placement of the RSU application in the network architecture, as the RSU application acting as the local proxy towards the remote cloud where the actual vehicle repair centre service is running, is part of the high-level use case scenario description in [2]. From the point of view of the end user, the most critical part of the data transfer is the upload of the vehicle status data from the moving vehicle to RSU application at the network edge, as the vehicle is inside the coverage area of the RSU only for a limited period of time. The network architecture components related to the generation, transmission and reception of the test traffic are developed and configured for the trials by VTT. Other network architecture components are provided for the trials by the 5GTN VTT Oulu test facility.

![Network Architecture Diagram](image)

Figure 55. Network architecture for the Phase 2 trials of the vehicle prognostics use case scenario.

8.2.2 User application architecture

The user application in the Phase 2 vehicle prognostics use case scenario trials was emulated with a software-based traffic generator, which generates test traffic based on the OBD-II message format and sizes. All test traffic was transferred between the 5G UE (publisher) and edge cloud server (subscriber) using the MQTT protocol.
8.2.3 Hardware components

The Phase 2 trial network architecture contains the following hardware components:

- **UE:**
  - Huawei H112-370 5G CPE (visible as a conventional Ethernet interface for the measurement laptop) for UL throughput and latency measurements.

- **eNB:**
  - LTE FDD @ 2600 MHz (band 7), BW = 5+10 MHz (anchor for macro 5G gNB).

- **gNB:**
  - 5G NR TDD Rel-15 NSA @ 3.5 GHz (band n78), BW = 60 MHz
    - Macro gNB for field trials with a grid of 6 horizontal beams.
    - The only supported numerology is 30 kHz subcarrier spacing, which corresponds to 0.5 ms slot duration.
    - The configuration is optimized for UL performance with the 3/7 DL/UL time slot ratio and UL proactive scheduling enabled [5GPPP21].
    - The MIMO configuration is 1x4 in the UL direction.

- **EPC and 5GC:**
  - Emulated core network services.

8.2.4 Software components

The following software components are utilised in the Phase 2 trial setup:

- MQTT client (publisher) for publishing the generated test traffic data packets to the network.
- MQTT broker running in the edge cloud for initial reception and forwarding of the published test traffic data packets.
- MQTT client (subscriber) for receiving the published test traffic data packets in the network.

8.3 Testing and verification

8.3.1 Methodology

During Phase 2 trials, the measurements reported in [2] were extended to an outdoor mobile scenario similar to the human tachograph use case scenario descriptor in Section 6.3. The same drive route as in human tachograph trials (see Figure 37) was also used during the measurements. The test traffic data packets related to the emulated vehicle prognostic service were transmitted using MQTT. As in [2], three different packet payload sizes were used for the measurements. The smaller payload sizes correspond with typical OBD-II message lengths, i.e., 12 B and 255 B, and the largest payload size of 1400 B was used to assess the link performance with near-Maximum Transmission Unit (MTU) sized packets. A random data packet with the given payload size was published from the 5G UE via MQTT with a frequency 10 packets/s. Each measurement run collected QoS statistics related to the use case scenario KPIs from approximately 10 000 packets. The measurement setup is shown in Figure 56.
4.3: Evolved Solution and Verification of Transport Use Case Trials

Figure 56: Measurement setup for the Phase 2 trials of the vehicle prognostics use case scenario.

8.3.2 List of key performance indicators

The key target KPIs for Phase 2 are listed in Table 17, which are a subset of the full target KPIs list presented in Section 11.3.2 of the deliverable D4.2 [2]. The Phase 2 trials aim to verify the 5G NSA performance for the UL traffic profile of the vehicle prognostics use case scenario with mobile end users.

Table 17: Target KPIs for T4S1

<table>
<thead>
<tr>
<th>Network requirements</th>
<th>Target values</th>
</tr>
</thead>
<tbody>
<tr>
<td>User experienced UL throughput</td>
<td>Medium (1-10 Mbps)</td>
</tr>
<tr>
<td>Latency requirements</td>
<td>Low (&gt; 100 ms)</td>
</tr>
</tbody>
</table>

8.3.3 Measurement and testing tools

The measurement and testing tools utilised in the outdoor trials:

- Qosium for E2E passive QoS/QoE measurements and monitoring. Qosium Probes capture the MQTT traffic at the publisher, broker, and subscriber. The metadata, such as packet timestamps, from the captured traffic is sent to Qosium Scope, which calculates the latencies based on the timestamps.

- Garmin GPS18x LVC is used as the external GPS receiver for synchronising the laptops used as UEs (together with the 5G CPEs) in the field measurements. Its main feature for the field trials purposes is that in addition to conventional NMEA GPS signal, it also gives a PPS pulse, which is synchronized to the GPS time reference, as an output. The PPS signal is fed into the serial port of the measurement laptop to avoid any inaccuracies from USB processing. The combined NMEA and PPS signals are then used as the only timing reference for the measurement laptop⁹.

- Trimble Thunderbolt PTP GM200 with an external GPS antenna is used as PTP master for the server running the MQTT broker. This ensures the same timing reference for the both ends of the measurement path.

8.3.4 Intermediate results

The average measured packet throughput, goodput, and latency are given in Table 18. The differences in throughput and goodput are due to the combined header offset of 76 B. Based on the Phase 1 measurements, the 60 MHz outdoor 5G NSA cell used in measurements can support up to 62 Mbps UL throughput with stationary users. Thus, based on the results in Table 18, the upper bound on the simultaneous low-latency vehicle prognostics transmissions can be estimated to be 380 (12 B payload), 157 (255 B payload), and 36 (1400 B payload). However, the packet scheduling algorithms typically do not allocate resources for hundreds of UEs for the same time slot. Thus, the average packet latencies are expected to increase already with a significantly lower number of simultaneous prognostics transmissions. In addition, TCP, on top of which MQTT protocol is running, has an additional negative impact on the communication latencies when the amount of traffic increases or the quality of the communication channel decreases, as can already be seen in the single user latency figures presented Table 18. In order to assess the scalability of the vehicle prognostics service in a more realistic manner, the measurements described here for a single user will be repeated in the upcoming Phase 3 trials using multiple emulated users as the sources for the test traffic.

<table>
<thead>
<tr>
<th>Payload size [B]</th>
<th>12</th>
<th>255</th>
<th>1400</th>
</tr>
</thead>
<tbody>
<tr>
<td>Throughput [kbps]</td>
<td>163</td>
<td>394</td>
<td>1720</td>
</tr>
<tr>
<td>Goodput [kbps]</td>
<td>23</td>
<td>303</td>
<td>1630</td>
</tr>
<tr>
<td>Latency [ms]</td>
<td>4.7</td>
<td>7.0</td>
<td>7.2</td>
</tr>
</tbody>
</table>

The cumulative distribution function of the vehicle prognostic message delivery latency for a single user is shown in Figure 57. It can be seen that below-10 ms latencies can be achieved with high probability for all tested payload sizes.
8.4 Next step plans

During Phase 3, the performance of the 5G SA uplink will be measured and validated using the vehicle prognostics traffic profile. In addition, the scalability of the service will be evaluated using the hardware-based UE emulator to generate additional UEs and transmit test traffic in the utilised 5G NR cell.
9 T4S2: OVER-THE-AIR (OTA) UPDATES

9.1 Description and motivation

The Phase 2 trials of the OTA updates use case scenario assesses the achievable downlink performance when, instead of 5G NR unicast used for a single user in [2], the software update packages delivered to the vehicles are distributed as cellular multicast based on eMBMS in the utilised 5G NSA test network setup. The purpose of these intermediate tests is to provide the initial data on the multicast performance so that the full analysis of the potential gains to switch over to the lower capacity 4G network can be performed after the upcoming Phase 3 trials. In the Phase 3 trials, the actual downlink capacity of the 5G NR will be measured with multiple emulated users receiving the test traffic simultaneously via unicast.

9.2 Proposed setup

9.2.1 Network architecture

Figure 58 presents the network architecture for the Phase 2 trials of the OTA updates use case scenario. The multicast service is configured and scheduled at the Broadcast-Multicast Service Center (BM-SC), which offers the generated multicast traffic to the users with eMBMS-enabled UEs through the Multimedia Broadcast Multicast Service (MBMS) gateway component. The content streamed by the gateway component is processed at the eNB before it is delivered to the users as cellular multicast transmission over the LTE downlink. The service configurations at the BM-SC are designed and tailored specifically for the OTA updates trials by VTT. Other network architecture components are provided for the trials by the 5GTN VTT Oulu test facility. In Figure 58, the data path utilised in the measurements is presented with a solid black line between the network components. The data paths presented with a dashed line are available in the 5G NSA network configuration, but not active during the Phase 2 trials.

![Network Architecture Diagram]

Figure 58. Network architecture for the Phase 2 trials of the OTA updates use case scenario.

9.2.2 User application architecture

Figure 59 presents the user application architecture for the Phase 2 trials. The use case scenario specific software consists of the eMBMS middleware and client application required in the UE to receive the cellular multicast traffic. The utilised software is configured and provided for the trials by the 5GTN VTT Oulu test facility and VTT.
9.2.3 Hardware components

The Phase 2 trial network architecture contains the following hardware components:

- **UE:**
  - Samsung Galaxy S7 for multicast traffic reception.

- **eNB:**
  - The indoor pico eNB is configured to support eMBMS multicasting. eNB is operating at band B7 with BW of 10 MHz. 40% of the time-frequency resources are reserved for eMBMS that is using spatial diversity and MCS 25 by default. This results in a theoretical maximum bit rate of approx. 11.4 Mbps. The Multicast Coordination Entity (MCE) is integrated as part of the eNB.

- **EPC:**
  - Emulated core network services.

- **eMBMS:**
  - Enensys eMBMS server for multicast traffic transmission.

9.2.4 Software components

The following software components are utilised in the Phase 2 trial setup:

- Enensys MediaCast Mobile LTE Broadcast delivery server includes the BM-SC and MBMS gateway eMBMS components. For the testing and measurements purposes in the Phase 2 trials, a file download service is configured with continuous multicasting of the same 10 MB file.

- Enensys CubeAgent Mobile includes the eMBMS middleware for controlling the modem and a test app for file reception at the UE.

9.3 Testing and verification

Our purpose was to evaluate if a commercial cellular multicast system optimized for video broadcasting can also be used for delivering OTA updates for vehicles. Since native 5G multicasting for vehicular communications is not yet available at VTT’s 5GTN network, we used the existing LTE broadcast (eMBMS) system and compared its performance to conventional 5G unicasting.
9.3.1 Methodology

The measurements were done in laboratory conditions using the 5GTN-VTT test facility. A 10 MB file was continuously broadcasted to all eMBMS-capable UEs in a single cell with a target bit rate of 10 Mbps. The received eMBMS traffic was monitored using Qosium. Based on the packet inspection results, both the total data amount and the time difference between the reception of a first and last packet of a burst corresponding to a single file were measured. The measurement setup is shown in Figure 60. The LTE broadcast server components are BM-SC and MBMS gateway while MCE is integrated as part of eNB.

Figure 60: Measurement setup for eMBMS multicasting.

9.3.2 List of key performance indicators

The key target KPIs for Phase 2 are listed in Table 19, which are a subset of the full target KPIs list presented in Section 11.3.2 of the deliverable D4.2 [2]. However, as the Phase 2 trials aim to determine the baseline performance of the eMBMS-based multicasting in a file download scenario, the 5G KPIs listed in Table 19 are not directly in the focus. Instead, when combined with the baseline 5G NR DL unicast results measured in Phase 1 and presented in Section 11.3.4 of the deliverable D4.2 [2], the Phase 2 results act as the starting point for the scalability assessment of the OTA updates service in Phase 3. In addition, the results can be used in the analysis of the potential benefits of eMBMS-based broadcast/multicast in 5G NSA network.

Table 19: Target KPIs for T4S2

<table>
<thead>
<tr>
<th>Network requirements</th>
<th>Target values</th>
</tr>
</thead>
<tbody>
<tr>
<td>User experienced DL throughput</td>
<td>High (10-100 Mbps)</td>
</tr>
<tr>
<td>Latency requirements</td>
<td>Low (&gt; 100 ms)</td>
</tr>
</tbody>
</table>

9.3.3 Measurement and testing tools

The measurement and testing tools utilised in the multicast trials:

- Qosium Probe is installed to the rooted measurement smartphone for packet capturing and analysis. It should be noted that in the eMBMS case, the high-accuracy two-way Qosium measurements from the MBMS gateway to the phone were not possible because the packet identification at the receiving end was not successful due to the extensive processing of the cellular multicast traffic at the eNB.
9.3.4 Intermediate results

For the measurement, the BM-SC server was configured to offer the 10 MB test file for download through cellular multicast. The test app in the UE had no automation or scripting available for file download and each download had to be manually triggered from the phone. Hence, for the initial measurements and analysis of the multicast performance, 21 distinct file downloads were performed in laboratory conditions. The average performance during the test runs is shown in Table 20.

Table 20: Average performance of the eMBMS-based cellular multicast for file download

<table>
<thead>
<tr>
<th>File download time</th>
<th>9.8 s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total downloaded data amount per file</td>
<td>11.8 MB</td>
</tr>
<tr>
<td>Achieved DL throughput</td>
<td>9.63 Mbps</td>
</tr>
</tbody>
</table>

Based on the results, eMBMS multicasting introduced an average overhead of 1.8 MB for each 10 MB file. The measured throughput is close to the target 10 Mbps set at the BM-SC server. The achieved average throughput of 9.63 Mbps must be considered as the upper bound for the multicast download performance in the utilised configuration as the UE was located close to the pico eNB with Reference Signal Received Power (RSRP) over -70 dBm, which enabled the use of high MCS 25. In worse channel conditions, it is expected that the packet loss would increase because MCS adaptation was not implemented. This would require lowering of MCS and correspondingly the achievable throughput.

Multicasting of OTA updates can improve the QoS by reducing the file download time as long as there is enough UEs requesting the same file. A key question from the perspective of performance vs scalability is how many UEs could download the same file at the same time using 5G NR unicast instead of LTE broadcast/multicast? A theoretical upper bound can be estimated by the maximum 5G NR DL throughput divided by the download file size and multiplied by the average multicast download time:

\[
\frac{690 \text{ Mbps}}{80 \text{ Mb}} \times 9.8 \text{ s} = 84 \text{ UEs}
\]

In the calculation, we have used the maximum DL throughput achieved for a single user in Phase 1 with 60 MHz bandwidth and 1/4 UL/DL time slot division (see [2] for more details). In practice, the number of UEs is significantly less because the network may also serve some other application traffic and not all UEs are in such a favourable position that transmission with the highest MCS and rank-4 is possible.

For network operators, the main motivation for using multicasting is the increased spectral efficiency when multiple users are receiving the same content. Based on the measurement results, the spectral efficiency of the LTE broadcast/multicast can be estimated as the number of served UEs \(x\) multiplied by the average throughput and divided by the effective bandwidth:

\[
x \times 9.63 \text{ Mbps} / (0.4 \times 10 \text{ MHz}) = 2.4x \text{ bit/s/Hz}
\]

Similarly, the upper bound on the 5G NR DL spectral efficiency is:

\[
690 \text{ Mbps} / (3/4 \times 60 \text{ MHz}) = 15.3 \text{ bit/s/Hz}
\]

Based on this initial example, as long as the number of users requiring the OTA update exceeds 6, eMBMS is able to provide better spectral efficiency. However, as the simple calculations presented here are only providing the expected upper bound for the performance, the added value of cellular multicast in the OTA updates use case scenario will be estimated from the service scalability perspective in more detail during the Phase 3 trials. During the Phase 3 trials, more tests with eMBMS-based cellular multicasting will be performed and the 5G NR DL performance will be estimated in more realistic manner by using multiple emulated users to receive the test traffic in a single cell.

9.4 Next step plans

During Phase 3, the scalability of the OTA updates service in 5G networks will be evaluated using the
hardware-based UE emulator to generate additional UEs and receive test traffic in the utilised 5G NR cell. The achieved 5G performance will be validated against the use case scenario specific KPIs and analysed against the performance achievable with the eMBMS-based multicasting.
10 T4S3: SMART TRAFFIC CORRIDORS

10.1 Description and motivation

This use case is motivated by the fact that vehicles can utilize selected routes in order to reduce pollution or congestion, especially in areas that suffer the most. This solution focuses on providing a routing/navigation service, which minimizes the impact of pollution for most of the Air Quality Management Areas (AQMAs) due to the vehicle’s emissions, while simultaneously minimizing the travel time and the respective travel costs for the driver. This scenario looks at how historical and real-time data gathered from air quality sensors and information related to vehicle-emissions can be intelligently utilized and combined to control the routes that a vehicle is recommended or mandated to take in any given journey. This can be achieved through monitoring of emissions and guiding individual, or groups of vehicles to be routed based on locally implemented emissions corridors. Vehicles such as lorries, trucks and buses, or older vehicles with high emissions may be guided through a high emissions corridor whilst low emissions or electric vehicles may be given more flexibility on routes to their destination. The possible gain resulting from implementing such a service is:

- Reduction of the pollution levels especially in urban areas which is becoming increasingly crucial.
- More effective routing for the drivers resulting in saving time and fuel costs.

10.2 Proposed setup

This use-case scenario is being trialled on the 5GENESIS trial facility located in Surrey, UK.

10.2.1 Network architecture

The network architecture consists of:

- The 5G gateway node which receives the air-quality sensors information
- The 5G access and core network (5GENESIS)
- The Cloud

More details on the network architecture can be found from Section 12.2.1 of the deliverable D4.2 [2].

10.2.2 User application architecture

The user application architecture consists of:

- A UDP-server feeding the data from the air-quality sensors into the database system.
- The cloud infrastructure containing the software components listed in Section 10.2.4.
- The end-user application (Web dashboard).

More details on the user application architecture can be found from Section 12.2.2 of the deliverable D4.2 [2].

10.2.3 Hardware components

The following section presents information regarding the developed sensors (by WINGS). The devices installed form a low-cost multi-sensor station deployed over the area of “Agios Kosmas” in Attica region, calibrated to produce accurate measurements of the following quantities:

- Gases: Ozone (O3), Carbon monoxide (CO), Sulphur Dioxide (SO2), Nitrogen Monoxide (NO), Nitrogen Dioxide (NO2)
- Particulate Matter (PM): PM1, PM2.5, PM10
4.3: Evolved Solution and Verification of Transport Use Case Trials

- Other metrics: Noise, Temperature, Pressure and Humidity.

In terms of network and local connectivity, the supported technologies are ZigBee, LoRA, Narrowband Internet of Things (NB-IoT), Global System for Mobile Communications (GSM) and SigFox. The evaluation of the installed devices has been made by comparing the measurements with the Greek Ministry of Environment and Energy data.

10.2.4 Software components

In the current phase the software components are the ones mentioned in D4.2 as well as a dedicated web dashboard developed to serve the end-user visualization purposes:

- The UDP server feeding the sensor to the Database system.
- The software component (Java server) responsible for the Air Quality Index (AQI) calculation processing the supplied entities from the sensor side.
- The Relational Database Management System (RDBMS) maintaining the sensor data.
- The python server, where the Central Decision-Making system resides.
- A web-dashboard to visualize the proposed route

The developed dashboard consists of a map as showed in Figure 61 showing the user's current location and an address search field. The application is developed in Angular 10. The main map of the website is based on OpenStreetMap and Leaflet, an open-source JS library for mobile-friendly interactive maps. The address search field has an autocomplete feature, based on Geoapify Geocoder Autocomplete, a JavaScript (TypeScript) library that provides autocomplete functionality for the Geoapify Geocoding API.

Figure 61: Web dashboard to visualize the proposed route to the end-user.

10.3 Testing and verification

10.3.1 Methodology

The methodology to test the validity of the afore-mentioned scenario, as well as the network capabilities, will be based on the simulation of the user requests.

As a first step, the streaming latency of air quality data from the installed sensors to the cloud infrastructure, could be measured and evaluated after integrating them with the rest of the service components. In terms of application metrics, as described in the plans of D4.2 [2], the end-to-end latency
of a single request from the end user has been measured and evaluated (Section 10.3.3). Regarding the network metrics the measurement and testing tools are described in the following section.

### 10.3.2 List of key performance indicators

The key target KPI for Phase 2 trials is the E2E latency as shown in Table 21. The full target KPIs list for the use case scenario is presented in Section 12.3.2 of the deliverable D4.2 [2].

<table>
<thead>
<tr>
<th>Network requirements</th>
<th>Target values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latency requirements</td>
<td>Low (25 ms)</td>
</tr>
</tbody>
</table>

### 10.3.3 Measurement and testing tools

On the network side, the measurement and testing tools of the 5GENESIS trial facility will be exploited. In particular, the following components will be used:

- Infrastructure Monitoring, which focuses on the collection of data that synthesize the status of architectural components, e.g., end-user devices, radio access and networking systems, computing and storage distributed units.
- Performance Monitoring, which is devoted to the active measure of performance indicators.
- Storage and ML Analytics, which enables efficient management of large sets of heterogeneous data and drives the discovery of hidden values and correlation among them.
- InfluxDB (storage).
- Grafana (visualization).

### 10.3.4 Intermediate results

Based on laboratory tests conducted by simulating user requests, in Figure 62, one can observe a histogram of E2E latencies of the provided service. The mean value of the E2E RTT latency is 1.023 s, with a standard deviation of 0.1162 s. This includes the processing time of the service and internal RTT latencies regarding requests to external APIs. As such for the time being this is not directly comparable to the Network latency requirement (25 ms). Further experiments will be carried out during Phase 3, to directly measure the network latency and compare it to the target value.
10.4 Next step plans

For Phase 3 the goal is to integrate the installed sensors for an End-To-End user experience. This E2E integration will enable to perform tests on user experience using dedicated use case KPIs as well as evaluate the defined performance metrics.
11 T4S4: LOCATION BASED ADVERTISING

11.1 Description and motivation

With vehicle and passenger information readily available, location-based servers can be implemented to stream content (upon request, if required) as well as local advertising or traffic guidance to vehicles and road users. This becomes especially useful in car-sharing models where vehicles are not owned, and the origin and destination of each journey may vary depending on the passengers.

As the adoption of AVs rises, millions of eyes will be off the road. This creates a world of opportunity where content like games, movies and news will be consumed in vehicles. If music streaming apps were successful at luring millions of radio listeners, self-driving cars and the accompanying new scores of passengers will not just listen to music, but they’ll also have the opportunity to binge watch video content, work collaboratively and play video games whilst on route to their destinations.

11.2 Proposed setup

This use-case scenario is being trialled on the 5GENESIS trial facility located in Surrey, UK. Due to the access restrictions at the facility during the Phase 2 work, most performance verification measurements for the extended trial implementation have been re-scheduled to the beginning of Phase 3.

11.2.1 Network architecture

The planned implementation envisages a GUI application running on the OBU, which displays the advertisement data streamed from the server. Menus will also be provided to indicate the user preferences and offer the ability to turn the service on/off. The application platform should have the required decoders to process the received contents. More details on the network architecture can be found from Section 13.2.1 of the deliverable D4.2 [2].

11.2.2 User application architecture

The OBU is based on Android Operating System (OS) and uses a standard automotive grade System on a Chip (SoC). The application is written portably in the Java language native to the platform. The server uses standard server HW based on Intel and runs Hypertext Transfer Protocol Live Streaming (HLS) Application. More details on the user application architecture can be found from Section 13.2.2 of the deliverable D4.2 [2].

11.2.3 Hardware components

The required HW components to conduct the Phase 2 trials are the following:

- OBU: This consists of an ARM based automotive board running Android.
- 4G Frontend: This is the Radio Frequency (RF) HW to access the 4G network.
- 5G CPE: Huawei LF 7880 CPE\(^{10}\). This is the HW to access the 5G network over WiFi and Ethernet interfaces.
- Server: These are standard datacentre servers running Linux or Windows.

11.2.4 Software components

The required SW components to conduct the Phase 2 trials are the following:

\(^{10}\) https://consumer.huawei.com/en/routers/5g-cpe-pro/
• Client App: This is a Java application to playback HLS streamed from the server.
• Streaming App: This is a Personal Home Page (PHP) application to serve HLS file segments.
• Network Middleware: Uses standard TCP/IP and Point-to-Point Protocol (PPP) SW available in the system.
• USB Driver: This is the device driver to interface the 4G Frontend to the system.
• Network Driver: These device drivers provide WiFi and Ethernet access to the application software in the case of 5G.

11.3 Testing and verification

11.3.1 Methodology

The Phase 2 trials are planned to be carried out by running the client/server applications and measuring the related KPIs by inserting logs into the code. An example of the planned approach is presented in Section 13.3.1 of the deliverable D4.2 [2].

11.3.2 List of key performance indicators

The Phase 2 trials aim to assess the performance of the 5G network in the use case setup and compare it to the baseline performance of the 4G and 5G networks measured during Phase 1. The key target KPIs for Phase 2 are listed in Table 22, which are a subset of the full target KPIs list presented in Section 13.3.2 of the deliverable D4.2 [2]. In addition to the KPIs presented in Table 22, the average payload size for the HD video is also measured.

Table 22: Target KPIs for T4S4

<table>
<thead>
<tr>
<th>Network requirements</th>
<th>Target values</th>
</tr>
</thead>
<tbody>
<tr>
<td>User experienced DL throughput</td>
<td>High (100 Mbps)</td>
</tr>
<tr>
<td>Latency requirements</td>
<td>Medium (5 ms)</td>
</tr>
<tr>
<td>Interactivity</td>
<td>Medium &gt; 1, ≤ 100 transactions/sec</td>
</tr>
</tbody>
</table>

11.3.3 Measurement and testing tools

No third-party testing tools are used. The measurements are to be taken by inserting logs into the code.

11.3.4 Intermediate results

The initial baseline results for the use case scenario have been presented in Section 13.3.4 of the deliverable D4.2 [2]. Further tests with an optimised 5G network configuration have been scheduled to the beginning of Phase 3.

11.4 Next step plans

The previous baseline tests were done over the 4G and 5G networks but not always under the best conditions. As such, the next tests are planned to be performed using an optimized 5G network. Video streaming with much higher resolution is also planned, by which more bandwidth will be consumed. Tests will also be done inside moving vehicles, travelling in areas with varying network coverage. The next immediate steps also include scalability testing for the use case scenario.
12 T4S5: END-TO-END (E2E) SLICING

12.1 Description and motivation

The multiplicity of use case scenarios that may run simultaneously inside the same vehicle calls for a form of customisation to simultaneously support the diverse and often conflicting requirements of each of them. With the recent introduction of softwarisation enablers into mobile networks, network slicing has emerged as an efficient tool to create customised logical network instances on the same physical infrastructure.

In this respect, different E2E slices can be used to simultaneously support the various V2X applications running inside the same vehicle. For instance, passengers can watch a HD movie, while a collision awareness application detects a road hazard and triggers an emergency message for the cars behind to slow down or stop to prevent a collision. In such scenarios, a minimum level of isolation is needed to ensure that the operation of one slice does not affect the others e.g., the QoS of safety-related V2X applications is not impacted by other applications running on the same network.

12.2 Proposed setup

This use-case scenario is being trialled on the 5GENESIS trial facility located in Surrey, UK. In particular, the slicing-as-a-service functionality of 5GENESIS is being exploited to support the various use cases of the transport vertical. Due to the access restrictions at the facility during the Phase 2 work, most performance verification measurements and tests for the extended slicing support for transport use cases have been re-scheduled to the beginning of Phase 3.

12.2.1 Network architecture

The detailed description of the utilised 5GENESIS architecture can be found from Section 14.2.1 of the deliverable D4.2 [2].

12.2.2 User application architecture

N/A

12.2.3 Hardware components

The 5GENESIS test facility offers access to a range of 3GPP and non-3GPP Radio Access Technologies (RATs) available on the UOS campus. Full list of the 5GENESIS RAT options can be found from Section 14.2.3 of the deliverable D4.2 [2].

12.2.4 Software components

Description of the most relevant SW entities of the 5GENESIS architecture from the experimenter perspective, i.e., the Slice Manager, Open API and Portal, can be found from Section 14.2.4 of the deliverable D4.2 [2].

12.3 Testing and verification

12.3.1 Methodology

Detailed description of the 5GENESIS testing methodology can be found from Section 14.3.1 of the deliverable D4.2 [2].
12.3.2 List of key performance indicators

For a given slice, the degree of fulfilment of the associated requirements will be evaluated during a set of E2E measurement campaigns. Specifically, the relevant KPIs are evaluated against their associated target values agreed-upon in the Service Level Agreement (SLA) between the V2X application and slice provider. The concurrent slicing of a mixture of use case scenarios, associated with heterogeneous requirements, on the same infrastructure will be trialled and assessed based on the isolation level between the various slices. This metric will check if each slice is able to meet its SLA when established in conjunction with other slices on the same infrastructure.

12.3.3 Measurement and testing tools

On the 5GENESIS trial facility side, the monitoring and analytics framework includes monitoring tools and advanced ML-oriented analytics, devoted to the collection and analysis of the heterogeneous data produced during the usage of the 5GENESIS platform. The measurement and testing tools of the 5GENESIS trial facility will be exploited during 5G-HEART trials. In particular, the following components will be used:

- Infrastructure Monitoring, which focuses on the collection of data that synthesize the status of architectural components, e.g., end-user devices, radio access and networking systems, computing and storage distributed units.
- Performance Monitoring, which is devoted to the active measure of performance indicators.
- Storage and ML Analytics, which enables efficient management of large sets of heterogeneous data and drives the discovery of hidden values and correlation among them.
- InfluxDB (storage).
- Grafana (visualization).

Detailed description of the 5GENESIS measurement and testing tools can be found from Section 14.3.3 of the deliverable D4.2 [2].

12.3.4 Intermediate results

The initial baseline results for the 5GENESIS architecture and slicing approach have been presented in Section 14.3.4 of the deliverable D4.2 [2]. Further tests extended functionality have been scheduled to the beginning of Phase 3.

12.4 Next step plans

The 5GENESIS slicing-as-as-service functionality will be exploited to trial selected 5G-HEART use case scenarios (see Table 1 for further details). The trials will be initially based on CN-slicing and eventually evolve to include also RAN slicing.
13 T4S6: VEHICLE SOURCED HIGH-DEFINITION (HD) MAPPING

13.1 Description and motivation

AVs do not only require on-board sensors to perceive the world around them, but also HD maps to aid their decision making. HD maps of roads and infrastructure will take years to capture and consolidate. There is the added issue of dynamic changes to these maps over time.

As such, an innovative means to collect and maintain up to date data would be to crowdsource this information through on-board cameras and sensors which would stream back to a regional or central service, firstly to establish baseline maps and subsequently to manage change detection.

Several mapping and self-driving companies have already started to produce and consume HD maps. However, it is still early days in terms of how these maps are being built, the richness of information they contain, and how accurate they are. Companies are iterating quickly on making these HD maps better and as such there is little standardisation between various providers and consumers, but this is being investigated in the UK by British Standards Institution (BSI) with Ordnance Survey. Therefore, the creation and management of HD maps forms a specialised function in the autonomy stack of AVs.

13.2 Proposed setup

This use-case scenario is being trialled on the 5GENESIS trial facility located in Surrey, UK. Due to the access restrictions at the facility during the Phase 2 work, most performance verification measurements for the extended trial implementation have been re-scheduled to the beginning of Phase 3.

13.2.1 Network architecture

In the planned network architecture, the HD mapping application should be running on both the OBU and cloud mapping server. More details on the network architecture can be found from Section 15.2.1 of the deliverable D4.2 [2].

13.2.2 User application architecture

The OBU is based on Ubuntu Linux/ Robot Operating System and uses a standard Intel SoC. Application is written portably in the C++ language native to the platform. The sensors like LiDAR, GPS and 5G CPE are interfaced, by which the sensors data is streamed to the backend. The server uses standard server HW based on Intel and runs an offline mapping Application. More details on the user application architecture can be found from Section 15.2.2 of the deliverable D4.2 [2].

13.2.3 Hardware components

The required HW components to conduct the Phase 2 trials are the following:

- OBU: This consists of an Intel-based board running Ubuntu Linux.
- LiDAR: SLAMTEC RPLIDAR A3 LiDAR\(^1\). This is a 2D LiDAR capable of gathering scans.
- GPS: A highly accurate GPS module is interfaced to the system.
- 5G CPE: Huawei LF 7880 CPE\(^2\). This is the HW to access the 5G network over WiFi and Ethernet interfaces.
- Server: These are standard datacentre servers running Linux.

\(^1\) https://www.slamtec.com/en/Lidar/A3
\(^2\) https://consumer.huawei.com/en/routers/5g-cpe-pro/
13.2.4 Software components

The required SW components to conduct the Phase 2 trials are the following:

- Client App: This is a C++ application to upload sensor data from LIDAR and other sensors and location info from GPS to the backend server.
- Upload and Mapping Apps: Cloud applications to store and analyse uploaded data.
- Network Middleware: Uses standard TCP/IP available in the system.
- Drivers: This is the device driver to interface LIDAR, GPS and 5G CPE to the system.

13.3 Testing and verification

13.3.1 Methodology

Testing is to be carried out by running the client/server applications and measuring KPIs by inserting logs into the code.

13.3.2 List of key performance indicators

The Phase 2 trials aim to assess the baseline performance of an optimised 5G network configuration and compare it to the performance of the non-optimised 5G configuration measured during Phase 1. The key target KPI for Phase 2 is the UL throughput as shown in Table 23. The full target KPIs list for this use case scenario is presented in Section 15.3.2 of the deliverable D4.2 [2].

Table 23: Target KPIs for T4S6

<table>
<thead>
<tr>
<th>Network requirements</th>
<th>Target values</th>
</tr>
</thead>
<tbody>
<tr>
<td>User experienced UL throughput</td>
<td>High (100 Mbps)</td>
</tr>
</tbody>
</table>

13.3.3 Measurement and testing tools

No third-party testing tools are used. The measurements are to be taken by inserting logs into the code.

13.3.4 Intermediate results

The initial baseline results for the use case scenario have been presented in Section 13.3.4 of the deliverable D4.2 [2]. Further tests with an optimised 5G network configuration have been scheduled to the beginning of Phase 3.

13.4 Next step plans

The next immediate steps include scalability testing with higher device density and higher video resolution as well as performance and mobility testing for the use case scenario using an optimised 5G network configuration. Comparative performance with respect to 4G is also planned.
14 T4S7: ENVIRONMENTAL SERVICES

14.1 Description and motivation

Local, regional, and national weather offices source their data through satellite earth observation maps and local weather stations. These are generally used for weather forecasts. Vehicles may provide a rich and real-time source of weather and environmental information through existing on-board sensors such as:

- Light sensors for external light conditions such as cloud cover and fog.
- Wiper data for intensity of rain.
- Suspension data for monitoring road conditions such as potholes.

These can be consolidated to create hyper-local weather maps aiding drivers and AVs in day-to-day driving but also to assist local authorities to improve road maintenance.

This scenario focuses on collection and consolidation of weather and environmental sensor data which can be used to create hyper-local weather maps aiding drivers and AVs in day-to-day driving but also to assist local authorities to improve road maintenance.

14.2 Proposed setup

This use-case scenario is being trialled on the 5GENESIS trial facility located in Surrey, UK. Due to the access restrictions at the facility during the Phase 2 work, most performance verification measurements for the extended trial implementation have been re-scheduled to the beginning of Phase 3.

14.2.1 Network architecture

In the planned network architecture, an OBU is installed in a vehicle with integration to the on-board environmental sensors. The collected data can be transferred using the 5G network to a centralised hub or exchange server application. A screen device (laptop or tablet) connected to the OBU can be used to simulate the distribution of data and information back to the vehicles. More details on the network architecture can be found from Section 16.2.1 of the deliverable D4.2 [2].

14.2.2 User application architecture

The OBU is based on Android OS and uses a standard automotive grade SoC. The Application is written portably in the Java language native to the platform. Air quality sensors measuring PM and 5G frontend HW are interfaced, by which the sensor data is uploaded to backend. The server uses standard server HW based on Intel and runs computer an Internet of Things (IoT) oriented server Application, using the MQTT protocol. More details on the user application architecture can be found from Section 16.2.2 of the deliverable D4.2 [2].

14.2.3 Hardware components

The required HW components to conduct the trials are the following:

- OBU: This consists of an ARM based automotive board running Android.
- 4G Frontend: This is the RF HW to access the 4G network.
- 5G CPE: Huawei LF 7880 CPE\(^\text{13}\). This is the HW to access the 5G network over WiFi and Ethernet interfaces.

\(^\text{13}\) [https://consumer.huawei.com/en/routers/5g-cpe-pro/](https://consumer.huawei.com/en/routers/5g-cpe-pro/)
### 14.2.4 Software components

The required SW components to conduct the trials are the following:

- **Client App**: This is a Java application to broadcast PM2.5 and PM4.0 readings over MQTT to the backend server.
- **MQTT Server**: Provides the data bus using MQTT via publish/subscribe methods.
- **Network Middleware**: Uses standard TCP/IP and PPP SW available in the system.
- **USB Drivers**: These device drivers interface the 4G Frontend and PM X.Y sensor to the system.
- **Network Drivers**: These device drivers provide WiFi and Ethernet access to the application software in the case of 5G.

### 14.3 Testing and verification

#### 14.3.1 Methodology

The Phase 2 tests are planned to be carried out by running the client/server applications and measuring KPIs by inserting logs into the code. An example of the planned approach is presented in Section 16.3.1 of the deliverable D4.2 [2].

#### 14.3.2 List of key performance indicators

The Phase 2 trials aim to assess the performance of the 5G network in the use case setup and compare it to the baseline performance of the 4G and 5G networks measured during Phase 1. The key target KPI for Phase 2 is the messaging rate/interactivity as shown in Table 24. In addition to the messaging rate, the average payload size for the sensor data is also measured.

<table>
<thead>
<tr>
<th>Network requirements</th>
<th>Target values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interactivity</td>
<td>Low (1 transaction/sec)</td>
</tr>
</tbody>
</table>

#### 14.3.3 Measurement and testing tools

No third-party testing tools are used. Measurements are to be taken by inserting logs into the code.

#### 14.3.4 Intermediate results

The initial baseline results for the use case scenario have been presented in Section 16.3.4 of the deliverable D4.2 [2]. Further tests with an optimised 5G network configuration have been scheduled to the beginning of Phase 3.

### 14.4 Next step plans

Further tests will be done inside moving vehicles using an optimized 5G network configuration under different operating conditions (e.g., radio conditions, network coverage and device density). The next immediate steps also include scalability testing with higher device density.
15 CONCLUSION

This deliverable reported the progress made on the Phase 2 trials of the 5G-HEART transport vertical use cases. In Phase 2, the focus has been on the extended implementations of the use case service components, i.e. evolved solutions, as the work has continued from individual components trialled in Phase 1 towards integrated trial deployments. The performance of the extended Phase 2 implementations has been verified on top of the 5G test facilities. These trials have been conducted per scenario, coordinated by the scenario leaders and utilising the 5GENESIS (Surrey, UK), 5Groningen (Groningen, Netherlands) and 5GTN (Oulu, Finland) trial facilities, except for scenario T2S2, which during Phase 2 has been fully based on simulations, and for T2S3, which has been initially trialled in Chemnitz, Germany.

In order to better focus the work during Phase 2, the trial scenarios under the four main use cases in the transport vertical, i.e. “T1: Platooning”, T2: Automated/assisted driving”, “T3: Support for remote driving” and “T4: Vehicle data services”, were divided to core and supplementary scenarios. By focusing the large-scale implementation and in-depth trialling activities to the core scenarios, the key 5G functionalities and KPIs of the transport vertical use cases can be investigated and validated more deeply. The supplementary scenarios will provide additional insight into the 5G performance by providing validation results for specific technology enablers.

Moving towards Phase 3, the focus of the work will shift from testing and performance verification of the extended, but still partial, use case implementations towards the final trials and demonstrations, which will be performed using the full implementations of the use case scenarios. The work performed during Phase 3 will be reported in the subsequent deliverable D4.4 at the end of the project.
APPENDIX A: EXAMPLE OF ETSI CPM MESSAGE CONTENTS

{
    "type": "CPM",
    "protocolVersion": 1,
    "messageID": 14,
    "stationID": 1234,
    "generationDeltaTime": 32863,
    "generationTime": 1566400193751,
    "stationType": 15,
    "referencePositionLatitude": 48.091194,
    "referencePositionLongitude": 11.64769,
    "referencePositionSemiMajorConfidence": 0.05,
    "referencePositionSemiMinorConfidence": 0.05,
    "referencePositionSemiMajorOrientation": 0.0,
    "sensorInformationContainer": [
        {
            "id": 0,
            "type": 1,
            "details": "StationarySensorRadial",
            "range": 30.0,
            "stationaryHorizontalOpeningAngleStart": 250.0,
            "stationaryHorizontalOpeningAngleEnd": 280.0,
            "sensorPositionOffsetX": 231.0,
            "sensorPositionOffsetY": -239.34
        },
        {
            "id": 1,
            "type": 1,
            "details": "StationarySensorRadial",
            "range": 30.0,
            "stationaryHorizontalOpeningAngleStart": 248.2,
            "stationaryHorizontalOpeningAngleEnd": 278.2,
            "sensorPositionOffsetX": 180.6,
            "sensorPositionOffsetY": 12.64
        }
    ],
    "perceivedObjectContainer": [
        {
            "objectId": 1,
            "sensorId": 0,
            "timeOfMeasurement": 77,
        }
    ]
}
"objectConfidence":87,
"xDistance":212.33,
"xDistanceConfidence":0.11,
"yDistance":-234.85,
"yDistanceConfidence":1.0,
"xSpeed":0.91,
"ySpeed":0.4,
"yawAngleValue":66.2,
"yawAngleConfidence":0.0,
"planarObjectDimension1":0.5,
"planarObjectDimension2":0.5,
"objectRefPoint":0,
"classification":[
  
  
  
  
  ]
]
}

"numberOfPerceivedObjects":1
REFERENCES


