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Abstract	This deliverable describes the Phase-1 (baseline) trials of the various use case scenarios of the transport vertical. These Phase-1 trials contribute to the milestone MS2 of the project.
Keywords	5G, transport, trials

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EXECUTIVE SUMMARY

This deliverable describes the Phase 1 trials of the transport vertical use cases of the 5G-HEART project. These trials contribute to the milestone MS2 (i.e., "*Phase 1 trials of multiple verticals*") from the perspective of WP4 (i.e., "*Solutions for Delivery of Transport Vertical*").

As the first step of the 5G-HEART's three-phased approach for trials and validations, the described Phase 1 trials aim to validate the baseline performance (i.e., of fourth generation (4G)/long-term evolution (LTE) technologies) and initial 5G solutions developed for the transport vertical sector. Based on the observations made during these trials, insights have been gained into the limits of the existing solutions and the improvements that are brought by the developed solutions. These will augment and guide the subsequent more advanced (i.e., Phase 2) trials using optimised 5G networks. *(Note: due to COVID-19, access to the transport trial facilities has been significantly restricted or even completely blocked. Subsequently, for most use cases, less progress has been made in the initial tests and measurement campaigns compared to what was originally planned. This is being compensated and more results will be reported in the next deliverable (i.e., D4.3).)*

A set of four representative use cases have been considered for the transport vertical sector, each of which is further divided into one or more scenarios:

- T1 – "*Platooning*" that considers vehicles forming a tightly coordinated "train" with significantly reduced inter-vehicle distance, thus increasing road capacity and efficiency.
- T2 – "*Autonomous/assisted driving"* that involves semi-automated or fully-automated driving to achieve safer traveling, collision avoidance, and improved traffic efficiency.
- T3 – "*Support for remote driving"* that enables a remote human operator or cloud-based application to operate a remote vehicle.
- T4 – "*Vehicle data services*" that focuses on interconnecting various third-party data sources to connected and automated vehicles via the available 5G infrastructure.

The Phase 1 trials have been conducted per scenario, coordinated by the scenario leaders, and using the 5GENESIS (Surrey, UK), 5Groningen (Groningen, the Netherland) and 5GTN (Oulu, Finland) trial facilities. Different levels of progress have been achieved on the various use case scenarios depending on the availability of vehicles for trials. For most T2 scenarios (i.e., *T2S1&T2S2: Smart junctions and network assisted & cooperative collision avoidance (CoCa)* and *T2S4: Human tachograph*), the initial solutions have been developed and evaluated using specially equipped vehicles/ambulances. For the others (i.e., T1, T3 and T4 scenarios), the focus has been on designing, testing and validating different individual components (e.g., high-definition (HD) cameras, sensor nodes and software-defined radios (SDRs)) for integration into the research experimentation vehicles provided by the new member who recently joined the consortium (i.e., Technical University Chemnitz (TUC)). To ensure the by-design integrability of these components, extensive discussions and remote collaboration have been established with the team responsible for maintaining these vehicles, while the actual integration will be performed during a set of on-site workshops that will be held at the TUC premises as soon as the COVID-19 restrictions are lifted.

Based on the results, observations and insights acquired during Phase 1 trials, a planning of the next steps has been provided for each of the use case scenarios. Certain synergies have also been identified between transport scenarios (e.g., *T2S3: Quality of service (QoS) for advanced driving* and *T3S1: Tele-operated support (TeSo)*) and with other verticals (e.g., *T2S4: Human tachograph* with healthcare use cases), and these will be exploited in future combined trials.

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ABBREVIATIONS

3GPP	Third Generation Partnership Project
4G	fourth generation
5G	fifth generation
5G-PPP	5G Infrastructure Public Private Partnership
5GC	5G core
5GIC	5G Innovation Centre
5GTN	5G Test Network
5GTNF	5GTN Finland
10G	10 Gigabit
ADAS	advanced driver-assistance system
ADC	analog-to-digital converter
AI	artificial intelligence
AMF	access and mobility function
AP	access point
API	application programming interface
AQI	air quality index
AQMA	air quality management area
AR	augmented reality
ASE	area spectrum efficiency
AV	automated vehicle
bpm	beats per minute
bps	bits per second
BSI	British Standards Institution
BW	bandwidth
C-V2X	cellular V2X
CACC	cooperative adaptive cruise control
CAM	cooperative awareness message
CAN	controller area network
CN	core network
CNL	Converging Networks Laboratory
CO	carbon monoxide
CoCA	cooperative collision avoidance
COTS	commercial-of-the-shelf
CPE	customer premises equipment
CPM	collective perception message
CV	computer vision
DAC	digital-to-analog converter
DC	dual connectivity
DÉCOR	dedicated core network
DENM	decentralised environmental notification message
DL	downlink
E2E	end-to-end
EBG	Economic Board Groningen
EC	European Commission
ECG	electrocardiogram
ECU	engine control unit
ELCM	experiment life cycle manager
eMBB	enhanced mobile broadband
eMBMS	evolved multimedia broadcast multicast service
eNB	evolved NodeB
EPC	evolved packet core

ETSI	European Telecommunications Standards Institute
FDD	frequency division duplex
gNB	next generation NodeB
GNSS	global navigation satellite system
GPS	global positioning system
GPSDO	GPS-disciplined oscillator
GUI	graphical user interface
GW	gateway
HARQ	hybrid automatic repeat request
HD	high-definition
HIL	hardware-in-the-loop
HLS	HTTP live streaming
HMI	human-machine interface
HTTP	hypertext transfer protocol
HW	hardware
ICMP	internet control message protocol
IMU	inertial measurement unit
IoT	internet of things
IP	internet protocol
ISM	industrial, scientific and medical
ITS	intelligent transport system
ITS-S	ITS-station
KPI	key performance indicator
LAN	local area network
LDM	local dynamic map
LiDAR	light detection and ranging
LO	local oscillator
LoA	level of automation
LoRa	long range
LoRaWAN	LoRa wide area network
LoS	line-of-sight
LTE	long-term evolution
LUT	look up table
LWA	LTE-WLAN aggregation
M&A	monitoring & analytics
MAC	medium access control
MANO	management and network orchestration
Mbps	megabits per second
MCS	modulation and coding scheme
MEC	multi-access edge computing
ML	machine learning
MME	mobility management entity
mMTC	massive MTC
MQTT	message queuing telemetry transport
MRC	minimal risk condition
MS/s	mega-samples per second
MTC	machine type communication
MTU	maximum transmission unit
NB-IoT	narrowband IoT
NFV	network function virtualisation
NFVO	network function virtualization orchestrator
NI	National Instruments
NLoS	non-LoS
NO_2	nitrogen dioxide

NR	new radio
NS	network service
NSA	non-standalone
NUC	next unit of computing
O3	ozone
OAI	OpenAirInterface
OBD-II	on-board diagnostics – second generation
OBU	on-board unit
ODD	operational design domain
OLoS	obstructed LOS
OOH	out-of-home
OpenCV	open source computer vision
OS	operating system
OSM	open source management and network orchestration
OTA	over-the-air
PC	personal computer
PCF	policy charging function
PCRF	policy and charging rules function
PDCP	packet data convergence protocol
PDR	packet delivery ratio
PER	packet error rate
PGW	packet data network gateway
PGW-C	PGW control plane
PGW-U	PGW user plane
PHP	personal home page
PHY	physical
PM	particulate matter
PPC	pay-per-click
pps	packets per second
PRB	physical resource block
PSCCH	physical sidelink control channel
PSSCH	physical sidelink shared channel
PTP	precision time protocol
QoE	quality of experience
QoS	quality of service
RADAR	radio detection and ranging
RAN	radio access network
RAT	radio access technology
RB	resource block
RC	reselection counter
RDBMS	relational database management system
Rel	release
REM	radio environmental map
RF	radio frequency
RFSP	RAT/frequency selection priority
ROC	remote operations centre
RSU	road side unit
RTT	round-trip time
RX	reception
SA	standalone
SAE	Society of Automotive Engineers
SB-SPS	sensing-based semi-persistent scheduling
SC-FDMA	single carrier frequency division multiplexing access
SCI	sidelink control information

SCP	secure copy
SDK	software development kit
SDN	software-defined networking
SDR	software-defined radio
SFC	service function chaining
sFDR	spurious-free dynamic range
SGW	serving gateway
SGW-C	SGW control plane
SGW-U	SGW user plane
SINR	signal-to-interference-plus-noise-ratio
SLA	service level agreement
SMF	session management function
SO_2	sulfur dioxide
SoC	system on a chip
SotA	state-of-the-art
SPAT	signal phase and timing
SRM	signal request message
SSE	streaming single-instruction-multiple-data extensions
SSH	secure shell
SSM	signal state message
SUMO	simulation of urban mobility
SW	software
TAP	test automation platform
TB	transport block
TBD	to be determined
TCP	transmission control protocol
TDD	time division duplex
TeSo	tele-operated support
TLC	traffic light controller
Trr	time of refreshment rate
TTI	transmission time interval
TUC	Technical University Chemnitz
TX	transmission
UDM	unified data management
UDP	user datagram protocol
UE	user equipment
UL	uplink
UOS	University of Surrey
UPF	user plane function
URLLC	ultra-reliable low-latency communication
USRP	universal software radio peripheral
UTM	universal traverse mercator
V2I	vehicle-to-infrastructure
V2N	vehicle-to-network
V2P	vehicle-to-pedestrian
V2V	vehicle-to-vehicle
V2X	vehicle-to-everything
VIM	virtual infrastructure manager
VM	virtual machine
VNF	virtual network function
VRU	vulnerable road user
WiFi	wireless fidelity
WLAN	wireless local area network

1 INTRODUCTION

This deliverable describes the Phase 1 trials of the transport vertical use cases of the 5G-HEART project. These trials contribute to the milestone MS2 (i.e., "*Phase 1 trials of multiple verticals*") from the perspective of WP4 (i.e., "*Solutions for Delivery of Transport Vertical*").

As the first step of the 5G-HEART's three-phased approach for trials and validations, the described Phase 1 trials aim to validate the baseline performance (i.e., of fourth generation (4G)/long-term evolution (LTE) technologies) and initial 5G solutions developed for the transport vertical sector. A set of four representative use-cases have been considered, each of which is further divided into one or more scenarios, with a total of 13 scenarios. For each of these scenarios, insights have been gained into the limits of the existing solutions and the improvements that are brought by the developed solutions. This will augment and guide the subsequent more advanced (i.e., Phase 2) trials.

Due to COVID-19, access to the transport trial facilities has been significantly restricted or even completely blocked. Subsequently, for most use case scenarios, less progress has been made in the initial tests and measurement campaigns compared to what was originally planned. This is being compensated and more results will be reported in the next deliverable (i.e., D4.3).

1.1 Use cases and Phase 1 trials overview

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 Phase 1 trial facilities, locations and list of involved partners.

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

Use case scenario	Planned trial facility	Planned trial location	Scenario **owner** and partners (in alphabetical order)	Other collaboration
T1S1&T1S2: High bandwidth in-vehicle situational awareness and see-through for platooning	5GENESIS	Surrey, UK	EPI, TUC, **UOS**	-
T1S3: Dynamic channel management for traffic progression	5GENESIS	Surrey, UK	EPI, TUC[†], **UOS**	-
T2S1&T2S2: Smart junctions and network assisted & cooperative collision avoidance (CoCa)	5Groningen	Groningen, Netherlands	CEA, DYNNIQ, EPI, **TNO**, TUC, UOS	-
	5GENESIS (possibly)	Surrey, UK (possibly)		

[†] The use of TUC's research experimentation vehicles for trialling this use case scenario is to be further discussed.

T2S3: Quality of service (QoS) for advanced driving	5GENESIS	Surrey, UK	EPI, NTUA, TUC†, **UOS**	-
T2S4: Human tachograph	5GTN	Oulu, Finland	POLAR, **VTT**	Potential collaboration with healthcare trials
T3S1: Tele-operated support (TeSo)	5GENESIS	Surrey, UK	EPI, **NTUA**, TUC, UOS	Potential collaboration with healthcare trials
T4S1: Vehicle prognostics	5GTN	Oulu, Finland	EPI, UOS, **VTT**	-
T4S2: Over-the-air (OTA) updates	5GTN	Oulu, Finland	EPI, UOS, **VTT**	-
T4S3: Smart traffic corridors	5GENESIS	Surrey, UK	EPI, OCC, TUC, UOS, **WINGS**	-
T4S4: Location based advertising	5GENESIS	Surrey, UK	**EPI**, TUC†, UOS	-
T4S5: End-to-end (E2E) slicing	5GENESIS	Surrey, UK	EPI, NTUA, TUC†, **UOS**, VTT	Potential collaboration with healthcare trials
T4S6: Vehicle sourced high-definition (HD) mapping	5GENESIS	Surrey, UK	**EPI**, TUC, UOS	-
T4S7: Environmental services	5GENESIS	Surrey, UK	**EPI**, TUC†, UOS	-

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 4G evolved NodeB (eNB), fifth generation (5G) next generation NodeB (gNB) or in a stationary user equipment (UE) [1].
- **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 [2]:

  0 – No Automation,
  1 – Driver Assistance,
  2 – Partial Automation,
  3 – Conditional Automation,
  4 – High Automation,
  5 – Full 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

The remainder of this deliverable is organized as follows. Chapter 2 describes the latest capabilities and features of the trial facilities (i.e., provided by the 5GENESIS, 5Groningen and 5GTN projects) and research experimentation vehicles that will be used by the various use case scenarios of the transport vertical. The following chapters (i.e., 3-16) provide a detailed description of the Phase 1 trials of each of the considered scenarios, including the key motivation, proposed setup, testing and validation, and next-step plans:

- Chapter 3: T1S1&T1S2: High bandwidth in-vehicle situational awareness and see-through for platooning
- Chapter 4: T1S3: Dynamic channel management for traffic progression
- Chapter 5: T2S1&T2S2: Smart junctions and network assisted & cooperative collision avoidance (CoCA); trial track
- Chapter 6: T2S1&T2S2: Smart junctions and network assisted & cooperative collision avoidance (CoCA); simulation track
- Chapter 7: T2S3: Quality of service (QoS) for advanced driving
- Chapter 8: T2S4: Human tachograph
- Chapter 9: T3S1: Tele-operated support (TeSo)
- Chapter 10: T4S1: Vehicle prognostics
- Chapter 11: T4S2: Over-The-Air (OTA) updates
- Chapter 12: T4S3: Smart traffic corridors
- Chapter 13: T4S4: Location based advertising
- Chapter 14: T4S5: End-to-end (E2E) slicing
- Chapter 15: T4S6: Vehicle sourced high-definition (HD) mapping
- Chapter 16: T4S7: Environmental services

The conclusions are drawn in Chapter 17.

2 TRIAL FACILITIES AND RESEARCH VECHICLES

This section provides a description of the latest capabilities and features of the trial facilities (i.e., 5GENESIS, 5Groningen and 5GTN) and research experimentation vehicles that will be used by the various use case scenarios of the transport vertical.

2.1 Trial facilities

2.1.1 5GENESIS

The 5G Innovation Centre (5GIC) testbed on the University of Surrey (UOS) Campus in Guildford, UK is the test site hosting the “Surrey Platform” of the 5GENESIS project. The aim of the Surrey Platform is to demonstrate the support of massive Internet of Things (IoT) and multimedia communications in a multi-radio access technology (RAT) environment using Wireless Fidelity (WiFi), Long Range (LoRa), and Narrowband IoT (NB-IoT) access technologies. The different (e.g., software (SW) and hardware (HW)) components provided by the Platform partners will be integrated in the Surrey site.

More specifically, the Surrey Platform comprises a multitude of both 3GPP and non-3GPP RATs. Commercial-of-the-shelf (COTS) New Radio (NR) solutions, developed for 5G, are integrated as part of a larger flexible 5G network infrastructure. These solutions will allow support for a wide range of 5G use-cases, empowered by network slicing in the scope of 5GENESIS. Moreover, 3GPP Release (Rel)-15-compliant SW upgrade (from HUAWEI) to support NB-IoT is already available and deployed at the Surrey site (campus-wide).

The WiFi deployment is based on a series of access points (APs) interconnected to the Surrey Platform 5G Core (5GC) following the 3GPP Rel-16 statements. The LoRa devices integrated and used in the Surrey Platform serve as both sensor nodes that can be connected via (5G UEs acting as) gateways (GWs), as well as another set of non-3GPP access technologies exploiting unlicensed spectrum to support and facilitate operation and communication of non-mission critical IoT deployments. Using LoRa Wide Area Network (LoRaWAN) (i.e., a medium access control (MAC) protocol for wide area networks) will provide complementing coverage for Machine Type Communication (MTC) in dense urban area deployments. The Surrey Platform 5GC, developed in-house, fully supports the 3GPP Rel-15 for the core network (CN) functionality and Rel-16 context-aware network, to intelligently interwork with 5G NR, both in Standalone (SA) and Non-Standalone (NSA) modes.

2.1.1.1 Current status

During Phase 2 of the 5GENESIS project (i.e., June 2019 to March 2020), the Release A of the following Coordination Layer components have been integrated in the Surrey Platform:

- 5GENESIS Portal.
- Experiment Life Cycle Manager (ELCM).
- Monitoring & Analytics (M&A) Framework.
- Slice Manager.

Following the 5G Infrastructure Public Private Partnership (5G-PPP) Platform Cartography classification [3], the key capabilities and features of the Surrey node of the 5GENESIS project are summarised in Table 2.

Table 2: Cartography of the capabilities and features of 5GENESIS, Surrey node

Platform Capabilities	**Expected availability date**
Rel-15-5G NR in NSA mode	*Available since June 2019*

Rel-15-5G NR with Rel-15-5GC in SA mode	*Currently available.* *Not tested with commercial radio.* *5G Core tested with Landslide tool (Spirent)*
Rel-16-5G NR and 5GC (NSA or SA)	*After January 2021*
Network Slicing as a service.	*April 2020*
Customised network slice (e.g., service function chaining (SFC), security, enhanced Cloud access).	*December 2020*
Hosting of 3rd party virtual network functions (VNFs)	*After January 2020*
Interworking with other ICT-17 facilities	*After January 2020*
Integration of additional gNB to ICT-17 facility	*January 2020*
Edge Computing	*January 2020*
3.5 GHz 5G Radio	*January 2020*
Millimetre wave for Backhaul	*January 2020*
End User Testing	*January 2020*
Automatic testing framework	*January 2020*

For the specific purpose of experimentation, the timeline of expected functionalities is as follows:

- Open application programming interface (API) access and documentation (Release B scheduled for June 2021).
- Slicing-as-a-service (Release A of the 5GENESIS Slice Manager integrated, Release B scheduled for June 2021).
- Customised network slice (e.g., SFC, security, enhanced Cloud access) (December 2020).

2.1.1.2 Experimentation approach

The experimentation approach adopted in 5GENESIS is very flexible and is open to run a wide range of experiments always subject to agreement with the platforms' owners. The detailed descriptions of the experimentation approach can be found in Deliverable D5.3 of 5GENESIS, which will be available end of June 2020.

To evaluate the performance of a given network service (NS), the experimentation procedure is as follows:

- An initial consultancy phase is used to identify the required resources to onboard and instantiate, together with the parameters that need to be monitored to test the performance of the NS.
- The platforms integrate a monitoring framework that include a set of MONROE nodes [4] used as infrastructure monitoring probes to assess the end-to-end (E2E) performance. The interested readers are referred to Deliverable D4.11 of 5GENESIS [5] for more details about the configuration and usage of these probes. Given that service-specific measurements may be

needed by the experimenter, the platform owner will provide basic probes and instructions to equip the NS with extra customised probes. Once the required probes are in place, the NS is ready for the onboarding process.

The required artefacts are images, VNFs and NS packages. Each VNF has dependencies with the images onboarded in the Virtual Infrastructure Manager (VIM), while each NS has dependencies with the VNFs onboarded in the Network functions virtualization orchestrator (NFVO).

In the Release A of the 5GENESIS platforms, the verticals must provide the images and descriptors to the testbed operator who onboards them. In the Release B, 5GENESIS will offer an interface for the onboarding. Upon onboarding of each separate component, the experimenter receives a unique identifier that can be used for referencing the onboarded component during the definition of the experiment.

2.1.2 5GRONINGEN

The 5Groningen facility, described in Figure 1, is a platform for developing, testing and piloting applications for next generation networking. It is an E2E infrastructure including multiple wireless network access nodes and a Research Cloud platform, where it is possible to run workloads in various form factors (e.g., bare metal servers, virtual machines (VMs), standalone containers and Kubernetes bundles) at the same time, including VNFs. It features various HW and SW components such as programmable network interface cards, HW accelerated Software-Defined Networking (SDN) switches, virtual network elements (e.g., switches/routers/firewalls), a Virtual Infrastructure Management system (i.e., OpenStack) and a Network Function Orchestrator (i.e., Open Source Management and Network Orchestration (OSM)). The infrastructure spans across one central (i.e., The Hague) and two edge (i.e., Groningen and Helmond) sites, making it ready for edge computing scenarios.

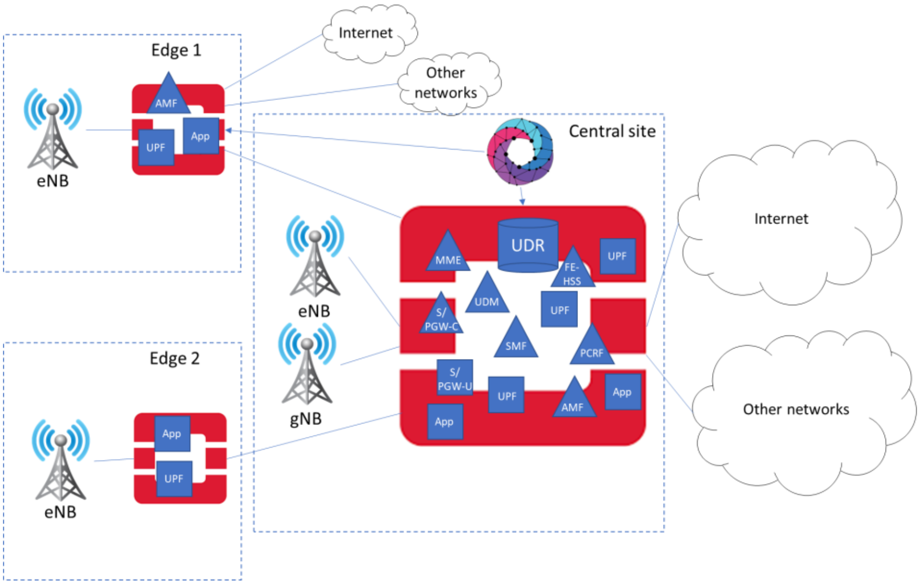


Figure 1. High-level overview of the 5Groningen facility.

In this environment, TNO's Hi5 platform is used in order to manage the connectivity of devices supporting 3GPP standards. It is an E2E mobile network consisting of multiple physical Radio Access Network (RAN) nodes (eNBs) and multiple virtual CN functions (e.g., Mobility Management Entity (MME), Serving/Packet Data Network Gateway-Control/User plane (S/PGW-C/U), Policy and Charging Rules Function (PCRF)) based on Fraunhofer's Open5GCore and 3GPP Rel-14, including trusted non-3GPP access and IoT features. It provides connectivity to subscribed devices with mobility and session management, as well as policy control. The process of upgrading the Hi5 to 3GPP Rel-15-compliant 5G system is under way, with the NSA option connected to the current core available since January 2020, and the SA option with new CN functions (e.g., Access and Mobility Function (AMF), Session Management Function (SMF), User Plane Function (UPF), Unified Data Management (UDM), Policy Charging Function (PCF)) and a third edge site planned to be completed in March 2020.

Network slicing is supported in the current infrastructure by using 3GPP's Dedicated Core Network (DÉCOR) feature for CN selection and RAT/Frequency Selection Priority (RFSP) indexes for enforcing sliced radio resource management. The network slices and hosted application functions are orchestrated by OSM and can be instantiated and removed via its northbound API. The ROBOT framework is used for acceptance testing of deployed slices and applications.

2.1.2.1 Current status

Following the 5G-PPP Platform Cartography classification [3], the capabilities and features of 5Groningen are listed in Table 3.

Table 3: Cartography of the capabilities and features of 5Groningen

Platform Capabilities	**Expected availability date**
Rel-15-5G NR in NSA mode	*March 2020*
Rel-15-5G NR with Rel-15-5GC in SA mode	*April 2020*
Rel-16-5G NR and 5GC (NSA or SA)	*2021*
Network Slicing as a service	*January 2020*
Customized network slice	*After July 2020*
Hosting of 3rd party VNFs	*To be determined (TBD)*
Interworking with other ICT-17 facilities	*TBD*
Integration of additional gNB to existing facility	*April 2020*
Edge Computing	*January 2020*
3.5 GHz 5G Radio	*January 2020*
End User Testing	*TBD*
Automatic testing framework	*January 2020*

2.1.2.2 Experimentation approach

The 5Groningen facility is managed by the Economic Board Groningen (EBG) in collaboration with industrial and research partners (Founding Fathers). New use cases emerge either from outreach by EBG/partners or contact with vertical sector partners. The steps of the on-boarding process are as follows:

1. Contact is established between the EBG and a vertical sector partner.
2. The vertical sector partner prepares a proposal for the 5G use case trial, including the main objective, requirements, scope, test facilities required, and timelines.
3. 5Groningen Founding Fathers review the proposal individually and signal their interest in the use case trial.
4. A meeting is organized between the vertical sector partners and interested 5Groningen Founding Fathers to discuss the use case further and confirm collaboration.

5. A formal project plan detailing the use case trial is developed by the vertical sector partner in collaboration with the involved 5Groningen Founding Fathers.
6. The use case trial is set up and conducted via collaboration between the vertical sector partner and involved 5Groningen Founding Fathers.
7. EBG and TNO organize an evaluation session with the partners involved in the use case trial to summarise the findings, experiences and learnings (including points for improvement).

2.1.3 5GTN

5G Test Network (5GTN) is a 5G technology and service development platform including a continuously evolving RAN and a cloud-based CN. The RAN part contains both 4G and 5G technologies for flexible utilisation in a variety of use-cases. The CN part is fully virtualised, supporting distribution of network functionalities both in control plane and user plane. The Multi-access Edge Computing (MEC) and evolved Multimedia Broadcast Multicast Service (eMBMS) functionalities are also available. The architecture has an integrated network monitoring, testing and management frameworks implemented, enabling new functionalities in these domains to be built either on top of the existing platform, or as parallel implementations complementing the existing functionality. The 5GTN architecture is connected to the Converging Networks Laboratory (CNL) infrastructure of the Technical Research Centre of Finland Ltd (VTT), which provides the service platforms and Internet connectivity for the 4G and 5G networks. 5GTN is also part of the Finnish 5G Test Network Finland (5GTNF) collaboration network, which contains several interconnected sites around Finland and opens additional possibilities for research cooperation.

2.1.3.1 Current status

The key assets of the 5GTN VTT Oulu test facility for the hosting of vertical industry use cases are the following:

- Combination of commercial carrier grade and open source network components
- Monitoring framework integrated into the infrastructure
- Open interfaces for inter-connectivity
- Multiple-frequency bands for cellular connectivity
    - 700 MHz for cellular IoT
    - 2.3 GHz and 2.6 GHz for 4G LTE metro and small cells
    - 3.5 GHz (w/ 60 MHz bandwidth (BW)) for 5G NR metro and small cells
- VTT acts as the network operator
- Continuously developed and maintained in national projects
- Utilised in national and international collaborations

The combined 5G test facility provided by the building blocks listed above forms the 5GTN VTT Oulu site utilised in the 5G-HEART trials. Following the 5G-PPP Platform Cartography classification [3], the availability of the key capabilities (currently installed or on the development roadmap) of the 5GTN VTT Oulu facility are listed in Table 4.

Table 4: Cartography of the capabilities and features of 5GTN

Platform Capabilities	**Expected availability date**
Rel-15-5G NR in NSA mode	*January 2020*
Rel-15-5G NR with Rel-15-5GC in SA mode	*After January 2020*

Rel-16-5G NR and 5GC (NSA or SA)	*After July 2020*
Network Slicing as a service.	*After July 2020*
Customised network slice (e.g., SFC, security, enhanced Cloud access)	*After July 2020*
Hosting of 3rd party VNFs	*TBD*
Interworking with other ICT-17 facilities	*After January 2020*
Integration of additional gNB to ICT-17 facility	*After July 2020*
Edge Computing	*January 2020*
Distributed Data fabric service for analytics	*January 2020*
3.5 GHz 5G Radio	*January 2020*
26 GHz 5G Radio	*After July 2020*
Millimetre wave for Backhaul	*TBD*
End User Testing	*January 2020*
Automatic testing framework	*TBD*

2.1.3.2 Experimentation approach

As the 5GTN VTT Oulu test facility is maintained and developed in the Finnish national collaboration projects participating in the 5GTNF ecosystem, the process of on-boarding vertical industry use cases always start with direct discussions with the test facility management team. Through the discussions, the projects providing and utilising the test facility synchronise their expectations and limitations related to the planned trials. The steps of the overall on-boarding process are currently as follows:

1. The vertical trials project contacts the test facility management team, e.g., through VTT personnel participating to the vertical trials project.
2. The key requirements of the planned vertical trials are discussed between the project teams and the scope, schedule, and resourcing for the trials are agreed upon (in the extent they can be supported in the test facility).
3. The vertical trials project provides a written detailed description of the trial case to the test facility development team.
4. The missing functionalities are developed and deployed (cooperatively) by the test facility development team and vertical trials project.
5. The trials are configured for execution by the test facility development team.
6. The trials are executed by the vertical trials project either on-site or remotely.
7. The trial execution logs are provided to the vertical trials project in raw text format and/or through a Grafana dashboard.

2.2 Research experimentation vehicles

2.2.1 General description

The research platforms at the chair for communication engineering at the Technical University Chemnitz (TUC) include three research experimentation vehicles (i.e., two Volkswagen Touran and one BMW i3) that have been gradually extended to allow a variety of research options related to autonomous driving. The three platforms (CARAI - Car AI) are equipped with a multitude of sensors to measure physical features that can be used to infer knowledge and understanding of the situation both inside (e.g., driver status, attention and tiredness) and outside of the car (e.g., traffic situation around the car, pedestrian or VRU detection, road surface, obstacle and vehicle neighbouring detection).

As part of the 5G-HEART project, two out of the three research experimentation vehicles (i.e., one Volkswagen Touran and one BMW i3 referred to as CARAI 1/C1 and CARAI 3/C3, respectively) will be used for trial execution at the UOS premises in Guildford, UK. TUC's vehicles can assist the autonomous driving research by providing precise global position of ego vehicle together with high definition video pertaining to the front and side view of the ego vehicle. It is also possible to have the high definition video relating to the face of the driver to study the physiological state experienced by the driver while driving. The ability to read/write controller area network (CAN) messages via the CAN bus of the vehicles provides access to the Odometry information and offers the possibility to control the actuators (only for C3).

At present, these vehicles can communicate with other vehicles or infrastructure using Intelligent Transport System (ITS)-G5 communication technology. During the course of the project, they will be updated with cellular (i.e., LTE/5G NR) V2X communication. The required HW is being acquired and installed in cooperation with UOS. The details specific to these research vehicles, shown in Figure 2 and Figure 3, are given in Table 5 and Table 6, respectively.

Table 5: TUC's CARAI 3 (C3) vehicle description

 Figure 2. TUC's CARAI 3 vehicle	**Model:** BMW i3 – Electric Vehicle **SAE automation level:** Level 4 **Autonomous Features:** Remote Driving **Sensors Installed:** • Global positioning system (GPS) • Camera • V2X (ITS G5, 5G-based V2X UE will be installed with the help of UOS) • Ability to access CAN data • Ability to control actuators • Inertial measurement unit (IMU) • Human-machine interface (HMI) screen

Table 6: TUC’s CARAI 1 (C1) vehicle description

 Figure 3. TUC’s CARAI 1 vehicle	**Model:** Volkswagen Touran **SAE automation level:** Level 3 **Sensors Installed:** - GPS - Camera - V2X (ITS G5, 5G-based V2X UE will be installed during the project with the help of UOS) - Ability to access CAN data - IMU - HMI screen

To support rapid prototyping and testing of advanced driver-assistance system (ADAS) algorithms, the various elements (e.g., sensors, SW algorithms, actuators, human-machine interface (HMI)) inside TUC’s vehicles are arranged in a flexible manner. Figure 4 depicts the high-level system architecture inside these vehicles. The sensors, HMI and actuators form the fundamental layer of the system architecture. A middleware acts as an interface layer between the HW and SW components i.e., it receives the sensor data, processes them into a common format and forwards them to the above layers. The middleware supports a publish/subscribe mechanism for data communication across various systems connected to a network. The sensors, present in the fundamental layer, communicate their data to the middleware via vendor specific HW interfaces. Similarly, the ADAS algorithms present in the top layer can subscribe to the sensor data of interest from the middleware. Whenever the middleware receives data from the sensors, it publishes the data to all the subscribers present in the local network. Section 2.2.2 provides more detailed information about the actual implementation of the Middleware at TUC’s vehicles.

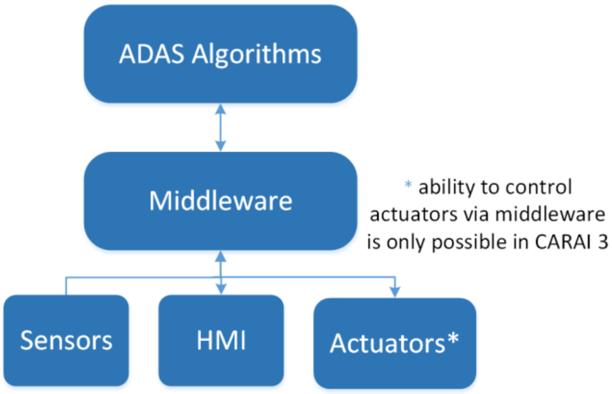


Figure 4. High-level system architecture of TUC’s vehicles

Apart from the above high-level architecture, the research experimentation vehicles also have an additional battery system installed to provide the electric power necessary to run all the HW components while driving on the road. A 4G LTE modem is connected to the local network inside the vehicles, thereby offering the possibility to access the Internet via a commercial cellular network.

The actuators (i.e., steering wheel, brake and accelerator pedal) in CARAI 3 can be controlled via SW. While controlling the actuators via SW, the security and safety of both the vehicle and passengers is extremely important. Therefore, CARAI 3 is equipped with a global stop switch inside it. While controlling the actuators via SW, there is a capability to stop the actuators by the driver by pressing the global stop switch. Also, when controlling CARAI 3 via SW, the driver can manually override and get back the control from the actuators. The testing of new SW functionalities integrated into the vehicles is restricted to happen in a closed road with open sky conditions, also controlled by a trained and experienced driver.

Table 7 lists the candidate use case scenarios for which TUC's vehicles may be used for conducting the trials on the 5GENESIS trial facility in Surrey, UK. To support these scenarios, various sensor data are necessary from the vehicles to execute the final trials. At present, CARAI 3 has one high-definition (HD) front camera to have the front view of the ego vehicle and one camera facing the driver. Additionally, three full HD cameras (i.e., side wise and back side) and 5G software-defined radios will be installed with the help of UOS. Therefore, during the course of the project, the existing architecture of CARAI vehicles will be updated wherever possible to have a smooth running of the end trials.

Table 7: 5G-HEART use cases to be trialled on 5GENESIS (Surrey, UK)

Use case	Scenarios
T1: Platooning	• T1S1&T1S2: High bandwidth in-vehicle situational awareness and see-through for platooning • T1S3†: Dynamic channel management for traffic progression
T2: Autonomous/ assisted driving	• T2S1&T2S2: Smart junctions and network assisted & cooperative collision avoidance (CoCa) • T2S3†: Quality of service (QoS) for advanced driving
T3: Support for remote driving	• T3S1: Tele-operated Support (TeSo)
T4: Vehicle data services	• T4S3: Smart traffic corridors • T4S4†: Location based advertising • T4S5†: End-to-end (E2E) slicing • T4S6: Vehicle sourced high-definition (HD) mapping • T4S7†: Environmental services

2.2.2 Integration methodology

To holistically test the performance of the considered use case scenarios, it may be necessary to integrate extra components into some of the involved elements. This section describes the methodology for integrating the HW/SW components into the research experimentation vehicles.

TUC's vehicles use link2 framework as a middleware to communicate across various systems connected to a network. It offers the possibility to:

- Access sensor data via a link2 node
- Convert vendor specific data format to a homogenous format
- Publish/subscribe sensor data
- Record the sensor data published on an offer to a file
- Replay the recorded data from a file

As shown in Figure 5, all the sensors installed in TUC's vehicles are connected to a central computer (TUC Personal Computer (PC)). This central computer, hosting the link2 middleware, will be connected to a local network via Ethernet. As part of the middleware, for each installed sensor, a node needs to be designed to access the sensor data and publish the accessed data to all subscribed nodes. In link2 framework, the collection of nodes communicating data via publish/subscribe mechanism is referred to as “Mesh”. The middleware abstracts data and data-access methods into a "Mesh" that exists transparently in a local Internet Protocol (IP) network. There is no dependency on specific hosts, operating systems (OSs) or programming languages, only "data" and tiny access layers. It also features "auto discovery", so zero configuration change is needed when changing environments, as long as IP connectivity is given.

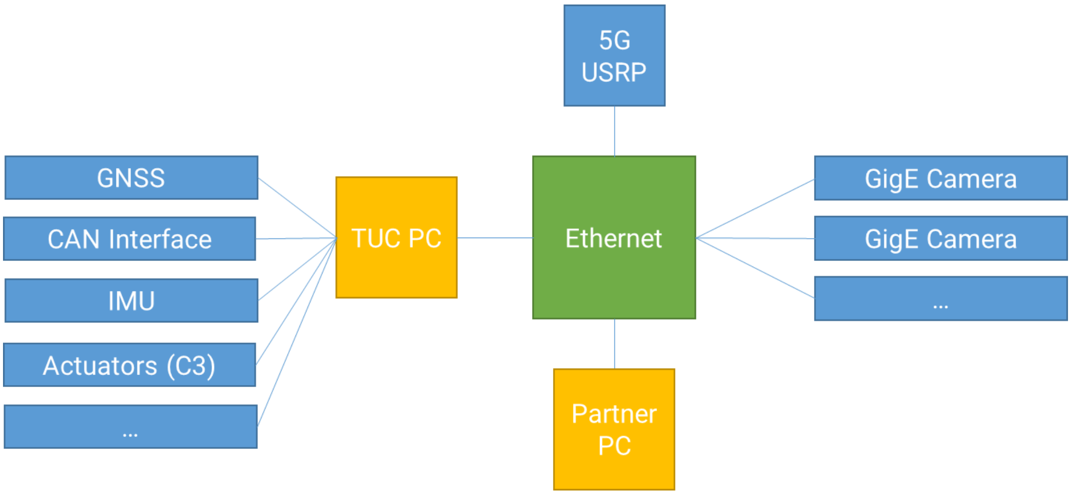


Figure 5. Integration approach at TUC’s vehicles

By the time of writing this deliverable, TUC has integrated the nodes that are necessary for accessing sensor data from the research experimentation vehicles using the link2 framework. Specifically, five link2 nodes have been integrated to access and publish data from the cameras and Global Navigation Satellite System (GNSS) receiver. A link2 mesh is also designed with these two link2 nodes to publish the data to link2 offers. During the course of the project, TUC will regularly develop new link2 nodes and update the mesh accordingly. By the time the final trials are started, each TUC’s vehicle, used as part of the 5G-HEART project, will have one link2 mesh designed in it. The necessary link2 sensor nodes, with the required configuration (e.g., frequency and message size), will be instantiated by TUC inside a link2 mesh.

TUC has also started assisting 5G-HEART partners in using the link2 framework. During the onboarding process, various partners have been provided with pieces of SW to co-create the required use case-specific nodes. During this process, these partners have been familiarizing themselves with the link2 functionality. Eventually, they will have access to the sensor data from TUC’s vehicles by bringing their own PCs and connecting it to the existing local network present in the vehicles. After integrating the link2 middleware into their computers, they will have the ability to not only subscribe to the sensor data published by the nodes present at the TUC PC, but also publish data to the nodes present inside the mesh, which in turn trigger the actuators (only for CARAI 3). The data published via link2 offers will be in a FlatBuffer format.

More generally, the implementation approach for integrating the HW/SW components designed by 5G-HEART partners is divided into four major steps as depicted in Figure 6.

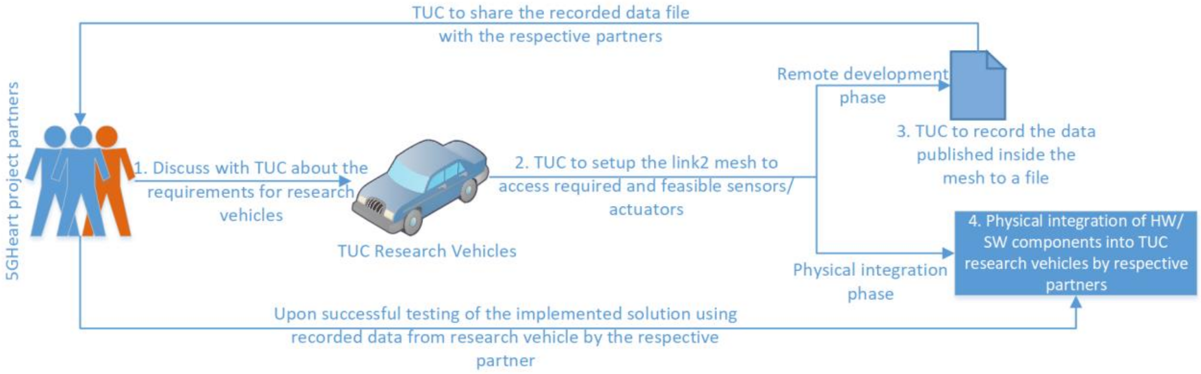


Figure 6. Implementation approach for integration at TUC's vehicles

During the first step, for each of the candidate use case trials, close discussions regarding the required sensor data/actuators have been maintained between the various contributing partners and TUC. During these discussions, the various partners have expressed their requirements and expectations from the research experimentation vehicles. TUC will check the feasibility of these requests and confirm if possible. This way, both TUC and the contributing partners can meet their expectations. During the second step, based on the accepted requests, TUC will start integrating the required nodes in link2 framework and create a link2 mesh with all the necessary nodes. From this step onwards, to make sure that the integration of components at TUC's vehicles happens in a hassle-free manner, the actual integration of these components into the vehicles is further divided into two separate stages i.e., Remote development stage and Physical integration stage (these correspond to the third and the fourth stages shown in Figure 6).

In the Remote development stage, TUC will run the updated link2 mesh setup for the 5G-HEART project along with the required configurations and go on a drive test in Chemnitz. During this drive test, the data published by the link2 nodes inside the mesh will be recorded to a file. Upon validating the recording file for data consistency and correct node configurations, TUC will share these recording files with the relevant partners. To access the data present in these recording files, these partners will first need to integrate link2 framework into their existing development environment. Second, the SW solutions developed for the various use cases should be configured to communicate with the link2 framework. Upon playing the link2 player with the recorded data file in the same development environment, the data pattern experienced by a SW solution developed for 5G-HEART would resemble that of the actual data pattern if this SW component was installed physically in the vehicles. This way, the partners can test the behaviour of their solutions without integrating them into the vehicles. While working with the data recording files, any encountered error can be corrected and worked upon until the desired performance is achieved. This marks the end of the first stage (i.e., Remote development).

During the second stage (i.e., Physical integration), partners should come to the TUC campus and integrate their verified solutions into TUC's vehicles. To support the physical integration of HW/SW components of 5G-HEART partners, TUC will organise a set of transport workshops at the TUC premises. The first workshop in this regard was planned to take place in the last week of September 2020. However, due to the COVID-19 pandemic, a workshop with physical presence was not feasible. Instead, a first virtual workshop was held on 05.11.2020, where all required SW and HW components were installed in the vehicle, while the partners operated their hardware with remote access.

It is worth pointing out that the Remote development and Physical integration phases do not necessarily happen in sequential manner but can rather run in parallel. Depending on the situation and maturity of the SW implemented for a given use case, there can be multiple cycles of the overall implementation approach described in Figure 6.

TUC's research experimentation vehicles are rapid prototyping platforms to assist research on ADAS algorithms for autonomous driving. They can only be utilised in research trials to create a near-to-reality situation for the evaluation of 5G performance. As such, it is recommended to exclude them from the Key Performance Indicator (KPI) evaluation (e.g. latency) chain in 5G-HEART. Having said that, to support KPI evaluation metrics for the rest of the components, TUC can provide information about the confidence values of the published sensor data along with the actual sensor data. It is also possible to append timestamp information (from a precise clock source e.g., GPS clock) to each message published by a link2 node at the time of publishing. This approach still needs to be further discussed with the other 5G-HEART partners and will be explained in the next deliverable (i.e., D4.3).

3 T1S1&T1S2: HIGH BANDWIDTH IN-VEHICLE SITUATIONAL AWARENESS AND SEE-THROUGH FOR PLATOONING

3.1 Description and motivation

Platooning allows vehicles to form a tightly coordinated "train" with significantly reduced inter-vehicle distance. The term was originally used, with a specific control algorithm, for truck platooning in the ADAS domain, with the aim to increase energy efficiency and to reduce fuel consumption. Recently, the term has also been used for passenger cars, focusing mostly on the issue of traffic congestion, and without much distinction from the aims and the control algorithms of other ADAS functions, such as Cooperative Adaptive Cruise Control (CACC) and Stop-&-Go. The vehicles in a platoon receive a continuous data stream from the lead vehicle for carrying out the platoon operations. This information allows the time headway between vehicles to become extremely small, even less than a second. The following vehicles in a platoon can drive (more or less) automatically, which may create economic, environmental and safety benefits, increase driving comfort by freeing up drivers to perform other tasks (for passenger cars), and reduce the need for professional drivers (for commercial vehicles).

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.

3.2 Proposed Setup

This use case scenario is being trialled on the 5GENESIS trial facility located in Surrey, UK. Given that the cellular V2X (C-V2X) functionality is currently not supported by the commercial nodes of 5GENESIS, a decision has been made to integrate a set of experimental setups based on OpenAirInterface (OAI) [6] and software-defined radios (SDRs). The considered OAI+SDR setups do support C-V2X and will be used to make progress on the various components and perform the required tests and verifications. Once the 4G/5G C-V2X support becomes available on the commercial nodes of 5GENESIS, the experimental setup will evolve to a mixed one, where both SDRs and commercial 4G/5G modems will be used with their performances compared.

3.2.1 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 reader is referred to Chapter 14 for more details about the associated experimentation methodology.

3.2.2 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. Figure 7 describes the associated colour-coded architecture, where the various colours represent the responsible partners.

The main effort needed is to upgrade the trial facility to support C-V2X communications and extend the research experimentation vehicles described in Section 2.2.1 to support the basic platooning operation.

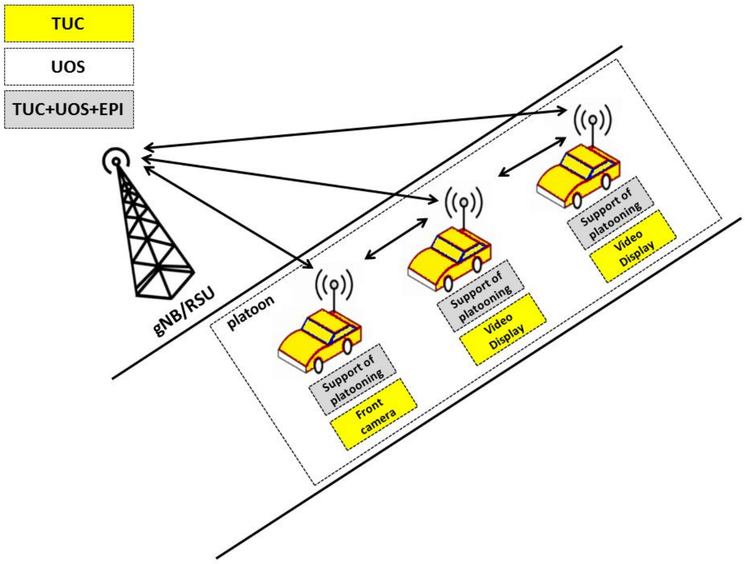


Figure 7. User application architecture for T1S1&T1S2.

On the trial facility side, an experimental (i.e., OAI+SDR) setup has been integrated to support 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.

In the following sub-sections, the setups used at each of these steps will be briefly described.

3.2.2.1 LTE experimental setup

An end-to-end LTE experimental setup for video streaming is built, where the various modules (i.e., UE, eNB, and evolved packet core (EPC)) are implemented based on the open-source OAI platform. The radio frequency (RF) ends associated with OAI UE and OAI eNB are configured using as SDR the Universal Software Radio Peripheral (USRP) 2954-R board provided by National Instruments (NI)/ETTUS [7]. As described in Figure 8, three desktop machines are used in this case to host the OAI UE, OAI eNB, and OAI EPC, while another one hosts a video server accessible through the Internet.

Figure 8. Experimental setup (LTE).

3.2.2.2 LWA experimental setup

To overcome the limitations of the LTE setup, another preliminary setup is built to exploit the LTE-Wireless Local Area Network (WLAN) Aggregation (LWA) functionality. LWA is a feature of 3GPP Rel-13 which allows a mobile device to be configured by the network so that it utilises its LTE and WiFi links simultaneously. It builds upon the Dual Connectivity (DC) split-bearer architecture of 3GPP Rel-12 with aggregation of data links at the Packet Data Convergence Protocol (PDCP) layer of the LTE protocol stack [8].

Figure 9 describes the considered LWA experimental setup. Compared to the previous (i.e., LTE) setup, both the UE and eNB are additionally equipped with WiFi dongles (see Appendix A for details). As such, this setup allows to aggregate the capacities offered by LTE and WiFi, and thus enables to achieve higher throughput.

Figure 9. Experimental setup (LWA).

3.2.2.3 5G experimental setup

The previous (i.e., LTE and LWA) preliminary setups have allowed to make some progress with the different components required to trial this scenario (i.e., T1S1&T1S2). The eventual objective is to build an experimental 5G setup that would able to fully support all the associated functionalities (i.e., situational awareness and see-through).

In this direction, two experimental 5G setups are currently under consideration:

- Experimental 5G setup #1: In this setup, a high-end laptop (i.e., Dell XPS 7590) hosts the OAI code for both OAI UE and OAI gNB. As illustrated in Figure 10, the gNB is connected to the CN of the 5GIC via a proper setting of the S1 interface. In this case, the selected SDR board is the USRP N320 board which fully supports 5G [9]. The usage of high-end laptops offers better portability for V2V or outdoor experiments.

Figure 10. Experimental 5G setup #1; OAI RAN and 5GIC CN

- Experimental 5G setup #2: In this setup, a COTS smartphone is used as UE. As illustrated in Figure 11, all the remaining components are the same as the previous setup.

Figure 11. Experimental 5G setup #2; COST UE, OAI gNB and 5GIC CN

The interested reader is referred to Appendix A for the full specifications of the individual components of the various experimental setups.

3.2.3 Hardware components

Table 8 lists the HW components that have been acquired to build each of the experimental setups.

Table 8: HW components of the experimental setups

4G and LWA experimental setups	5G experimental setup
5xUSRP-2954R	2x USRP N320
DELL OPTIPLEX 7050 (OAI UE)	2x Dell XPS 15 7590
DELL OPTIPLEX 7040 (OAI eNB)	10 Gigabit Ethernet Connectivity adapter
PCIe card and PCIe x4 cable	A set of Google Pixel smartphones
DELL OPTIPLEX 9020 for (OAI EPC)	
DELL OPTIPLEX 9020 (video server)	
GigaBlue WLAN 600 (WiFi dongle)	

The interested reader is referred to Appendix A for the full specifications of each of these components.

3.2.4 Software components

3.2.4.1 Introduction to OAI

OAI provides an open-source 3GPP-compliant SW implementation of the LTE protocol stack that is increasingly used for open experimentation and prototyping [5]. It was created by the Mobile Communications Department at EURECOM to enable innovation in the area of mobile/wireless networking and communications. It was originally developed for 4G LTE and is currently being extended for 5G NR.

The baseline 4G OAI provides a SW implementation of all key components (i.e., UE, eNB and EPC) of the LTE system architecture. OAI generally runs on general purpose computing platforms (x86) together with off-the-shelf SDR boards, such as ETTUS USRP, Lime SDR and ExpressMIMO2. It can be also used for indoor/outdoor field experimentation and controlled/scalable evaluations with highly realistic emulated wireless links.

3.2.4.2 OAI Features and Deployment Scenarios

After being first implemented based on 3GPP Rel-8, OAI has been extended to be fully compliant with 3GPP Rel-10 together with an increasing number of features from later releases. It offers various possible deployment scenarios depending on how the UE, eNB, and EPC are implemented. Some of the most common scenarios are the following:

- OAI UE <-> OAI eNB
- OAI UE <-> OAI eNB + OAI EPC
- OAI UE <-> OAI eNB + Commercial EPC
- OAI UE <-> Commercial eNB + OAI EPC
- OAI UE <-> Commercial eNB + Commercial EPC
- Commercial UE <-> OAI eNB + Commercial EPC
- Commercial UE <-> OAI eNB + OAI EPC
- Commercial UE <-> Commercial eNB + OAI EPC

3.2.4.3 System Requirements

For both the UE and eNB machines, OAI runs on standard Ubuntu Linux 14.04 LTS with low-latency kernel. From the HW perspective, OAI requires Intel processors that support the streaming single-instruction-multiple-data extensions 3/4 (SSE3/4). The host machines also need to have USB3 and PCIe interfaces to connect to SDR platforms (e.g., USRP). For the EPC machine, no low-latency kernel is required. The interested readers are referred to Appendix A for more details about the specifications of the various elements.

3.3 Testing and verification

3.3.1 Methodology

In Phase 1, the focus has been on building the see-through functionality to inform the passengers of the platoon members of what is happening ahead of the platoon leader. In this respect, an experimental OAI+USRP setup has been built, and its capability to support HD video streaming has been shown. The setup will be next installed inside two vehicles and used to stream video from one to another via their V2V link.

3.3.2 List of key performance indicators

The user requirements associated with this use case scenario have been analysed and converted into a set of network KPIs in Deliverable D2.2 [10]. Table 9 presents the resulting list of network requirements together with their target values.

Table 9: Target KPIs for T1S1&T1S2

Network requirements	Target values
User experienced downlink (DL) throughput	High (25-80 Megabits per second (Mbps))
User experienced uplink (UL) throughput	High (25-80 Mbps)
Broadband connectivity / peak data rate	DL: Medium (80 Mbps) UL: Medium (80 Mbps)
Latency requirements	Medium (5 ms)
Reliability	High (99.99999%)
Mobility	Medium (50-200 km/h)
Location accuracy	High (0.5 m)

Connection (device) density	4.3×10^3 platoon members/km^2 (peak)[‡] <50 platoon members/km^2 (typical)
Interactivity	Medium (100 transactions/sec)
Area traffic capacity	0.344 Mbps/m^2 (DL peak) 0.004 Mbps/m^2 (DL typical) 0.344 Mbps/m^2 (UL peak) 0.004 Mbps/m^2 (DL typical)
Security / privacy	Low (Public)

The Phase 1 trials aim to build an experimental (i.e., OAI+USRP) setup able to sustain HD video streaming. Hence, the target KPIs of Table 9 are not yet achievable. Instead, the Phase 1 trials are expected to reveal, as a starting point for the later trialling phases, the limits of current technologies (i.e., LTE and LWA) based on the perceived quality of experience (QoE) by the end-user.

3.3.3 Measurement and testing tools

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

On the network side, the 5GENESIS measurement and testing tools described in Section 14.3.3 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 the architectural components, e.g., end-user devices, radio access/networking systems, computing and storage distributed units.
- *Performance Monitoring*, which is devoted to the active measurements 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 briefly described in Section 2.2.2 will be further elaborated to capture the end-user perception and assess the contribution of the on-board components to the overall performance.

3.3.4 Initial results

To get insight into the capability of an experimental (i.e., OAI+USRP) setup to support HD video streaming, the LTE and LWA setups described in Section 3.2.2 have been considered.

[‡] Example estimate is for worst case US Freeway scenario that does not include arterial roads (i.e., onramps): 5 lanes in each direction or 10 lanes total per highway, for up to 3 highways intersecting = 3,100 to 4,300 cars per square kilometer [11].

[§] https://gitlab.eurecom.fr/oai/openairinterface5g/wikis/T

First, the experimental LTE setup described in Figure 8 is used, where LTE operates on licensed band 7 (2.6 GHz) with a BW of 5 MHz. An HD video is streamed from the video server to the OAI UE with a fixed data rate of 15 Mbps. Recall that, in this case, only the LTE interface is exploited to reach the UE.

Figure 12 make an analysis of the QoE perceived by the UE. To get an insight into the visual perception of the end user, two snapshots from the original (left) and received (right) videos are shown. It can be clearly seen that the perceived QoE is not acceptable. In fact, in the considered scenario, LTE does not have the capacity to sustain the required bitrate of the considered HD video stream.

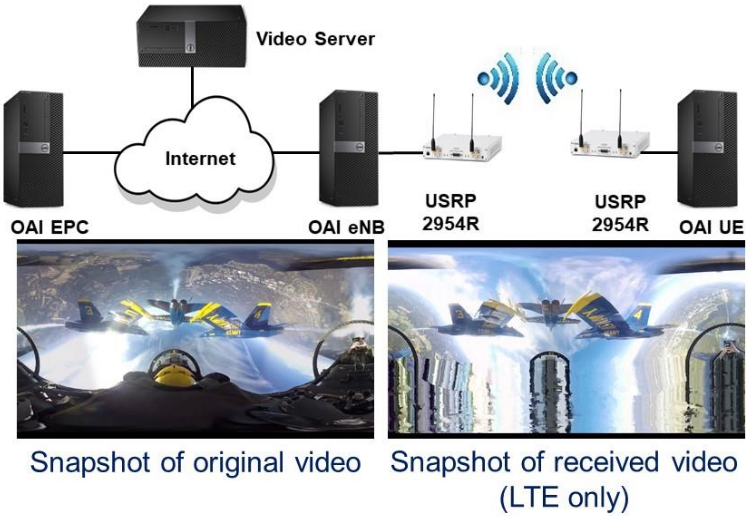


Figure 12. Performance of video streaming (LTE).

Next, the LWA setup described in Figure 9 is used, where LTE operates on licensed band 7 (2.6 GHz) with a BW of 5 MHz and WiFi operates at industrial, scientific and medical (ISM) 2.4 GHz frequency band with a BW of 20 MHz. The same HD video is streamed from the video server to the OAI UE. Recall that, compared to LTE, LWA simultaneously exploits the LTE and WiFi interfaces.

Figure 13 shows a snapshot of the received video stream side-by-side with its original counterpart. The observed results indicate that, compared to LTE, the perceived QoE is significantly improved. The aggregated LTE and WiFi capacities enable to sustain the required bitrate of the considered HD video stream, thus showing the capability of the experimental setup to support the see-though functionality.

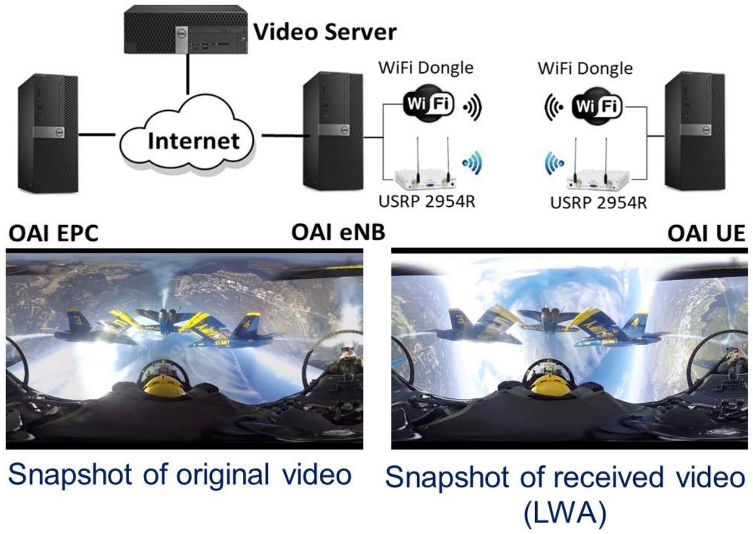


Figure 13. Performance of video streaming (LWA).

It is worth pointing out that aggregating LTE and WiFi (i.e., LWA) has been shown to sustain video streaming with a resolution (i.e., 15 Mbps) that may suffice for see-through in a controlled environment (i.e., lab). However, it may not sustain such resolution in less controlled environments, where the network may be highly loaded by other services and/or users. 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.

3.4 Next step plans

The 4G C-V2X functionality will be next tested based on the OAI+USRP setup described in Figure 8. The initial tests will involve an over-the-air (OTA) video streaming between two static USRPs placed in a controlled environment (i.e., lab). During a transport workshop that will be organised at the TUC premises as soon as the COVID-19 restrictions are lifted, the OAI+USRP will be placed inside the CARAI research experimentation vehicles, and the see-through functionality will be tested over the V2V link for different operating conditions (e.g., moving speed, inter-vehicle distance and network load). Once the 4G/5G C-V2X support becomes available on the commercial nodes of the5GENESIS 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.

4 T1S3: DYNAMIC CHANNEL MANAGEMENT FOR TRAFFIC PROGRESSION

4.1 Description and motivation

Platoons need a localised, low-latency, high-reliability communication channel to maintain their smooth operation. Due to their mobility, they cannot rely on the traditional broadcasting of messages over one fixed radio channel whose availability may vary from one location to another. Instead, the radio channels used by the V2I and V2V links of the various platoons should be dynamically assigned based on the speed, location and destination of the platoons together with spatial-temporal variability of the various channels.

4.2 Proposed Setup

This use case scenario will be trialled on the 5GENESIS trial facility located in Surrey, UK. Given the limited number of vehicles (i.e., two) available for trials, this scenario is currently being simulated with a high number of platoons to assess the effectiveness of the optimised channel management. To capture the constraints associated with the actual vehicles, the simulated scenario will evolve at a later stage to a hardware-in-the-loop (HIL) setup, where one of the simulated platoons will be substituted by a trialled platoon of actual vehicles.

The following sub-sections describe the network, user application architecture and HW components associated with the platoon to be trialled in the considered HIL setup. The simulated platoons will be separately described in a separate section on SW components.

4.2.1 Network architecture

On the network side, the platoon to be trialled will be supported by the slicing-as-a-service functionality of the 5GENESIS trial facility. The reader is referred to Chapter 14 for more details about the associated experimentation methodology.

4.2.2 User application architecture

Figure 14 describes the user application architecture associated with the platoon to be trialled in the considered HIL setup. The architecture is colour-coded, where the various colours represent the responsible partners. A centralised topology is initially considered, where the various platoon members report through the 5G network their speed, location and destination to their serving gNBs/RSUs via the European Telecommunications Standards Institute (ETSI) standardised Cooperative Awareness Message (CAM) messages [12]. A radio environmental map (REM) combining this geo-location information with the best radio channels is generated and continuously updated.

Please note that a distributed topology, where the best radio channels are determined based on a cooperative sensing (i.e., with other vehicles and/or RSUs), may also be explored in the future for some specific instances.

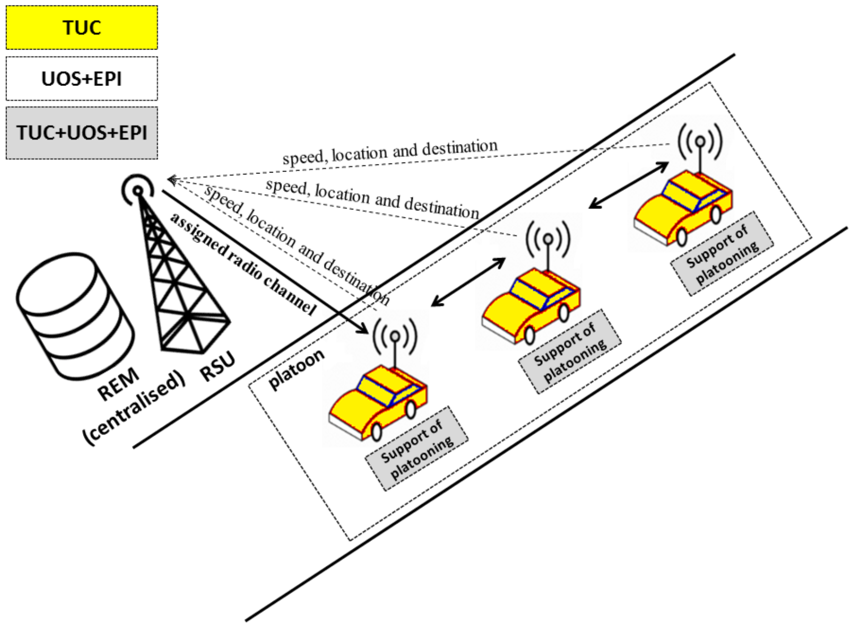


Figure 14. User application architecture for T1S3.

4.2.3 Hardware components

The HW components described in this section refer to the platoon that will be trialled in the considered HIL setup.

The platoon will be formed by the CARAI vehicles described in Section 2.2.1. Given that commercial gNBs are closed-source (i.e., do not provide access to customise the channel assignment logic), the open-source OAI+USRP setups described in Section 3.2 will be used. As such, the following HW components will be used:

- One USRP board will be installed inside each of the CARAI vehicles.
- Each of the USRP boards will be connected to an external antenna mounted on the vehicle roof.
- A laptop will be placed inside the vehicle to control the USRP board. It will be integrated into the in-vehicle Ethernet as explained in Section 2.2.2.

4.2.4 Software components

The basic platooning operation is currently being implemented using the open source NS3 simulator [13]. The implementation is initially based on the ETSI standardised CAM messages [12] sent over 4G C-V2X. The REM will combine CAM messages to optimize the assignment of radio channels to the various platoons for a given area. At a later phase, the setup will be upgraded to use 5G C-V2X once it is standardised.

4.3 Testing and verification

4.3.1 Methodology

Given that a proper assessment of the optimised channel management functionality would require a high number of platoons and only a limited number of vehicles (i.e., two) is available for trials, effort has been made to build an NS3 simulator that would scale up to a high number of platoons. The simulator will be initially based on 4G V2X and extended to support 5G V2X after its standardisation. To capture the constraints associated with actual vehicles, it will eventually evolve to a HIL setup, where one of the simulated platoons will be substituted by a trialled platoon of actual vehicles.

4.3.2 List of key performance indicators

The user requirements associated with this use case scenario have been analysed and converted into a set of network KPIs in Deliverable D2.2 [10]. Table 10 presents the resulting list of network requirements together with their target values.

Table 10: Target KPIs for T1S3

Network requirements	Target values
User experienced DL throughput	High (10-65 Mbps)
User experienced UL throughput	High (10-65 Mbps)
Broadband connectivity / peak data rate	DL: Low (65 Mbps) UL: Low (65 Mbps)
Latency requirements	Medium (5 ms)
Reliability	High (99.99999%)
Mobility	Medium (50-200 km/h)
Location accuracy	Medium (4 m)
Connection (device) density	4.3×10^3 platoon members/km^2 (peak)‡ <50 platoon members/km^2 (typical)
Interactivity	Medium (100 transactions/sec)
Area traffic capacity	0.2795 Mbps/m^2 (DL peak) <0.00325 Mbps/m^2 (DL typical) 0.2795 Mbps/m^2 (UL peak) <0.00325 Mbps/m^2 (UL typical)
Security / privacy	High (Confidential)

During Phase 1, some progress has been made to build a simulator that would scale up to a high number of platoons. The simulator would allow to achieve the target KPIs of Table 10 at scale. Additionally, the effectiveness of dynamic channel management will be evaluated based on the following indicators:

- The area spectrum efficiency (ASE) expressed in bits per second (bps)/Hz/unit of area. This metric can be used to benchmark the effectiveness of the proposed channel assignment scheme versus other approaches (e.g., traditional fixed assignment).
- The impact on the V2I and V2V links of the various platoons. Depending on the type of conveyed messages, it will be assessed based on a sub-set of the following metrics:
  - Throughput.
  - End-to-end latency.
  - Reliability.

4.3.3 Measurement and testing tools

For the platoon to be trialled, a set of measurement and testing tools will be exploited from both the infrastructure and vehicle sides. On the infrastructure side, the 5GENESIS tools described in Section 14.3.3 will be exploited with a particular focus on the components listed in Section 3.3.3. On the vehicle side, the methodology briefly described in Section 2.2.2 will be further elaborated to capture the end-user perception and assess the contribution of the on-board components to the overall performance.

Finally, for the simulated platoons, the measurements will be collected via NS3 (i.e., built-in and customised) probes and processed by various associated tools.

4.3.4 Initial results

N/A.

4.4 Next step plans

After finalising the REM implementation, the effectiveness of the proposed dynamic channel assignment will be evaluated and benchmarked against static assignment for an increasing number of platoons. At a later stage, the simulated scenario will evolve into a HIL setup, where one of the simulated platoons will be substituted by an actual platoon formed by the CARAI research experimentation vehicles. This would allow to scale up the scenario while capturing the constraints associated with actual vehicles.

5 T2S1&T2S2: SMART JUNCTIONS AND NETWORK ASSISTED & COOPERATIVE COLLISION AVOIDANCE (COCA); TRIAL TRACK

5.1 Description and motivation

As introduced in Deliverable D4.1 [14], this use case focuses on providing time critical safety information at intersections as well as improving the overall traffic efficiency amongst corridors. As described in the generic example of Figure 15, the safety information at the intersection may involve the exchange of precise traffic signal status information, vehicle information (e.g. location, speed and trajectory), as well as location information of VRUs.

Next to providing this safety information, these smart junctions could also help in improving the overall traffic flow in various situations e.g., when multiple of these smart junctions are adjacent to each other on the same corridor. That way they would be able to improve the traffic efficiency by creating a green wave or by giving priority to certain types of vehicles.

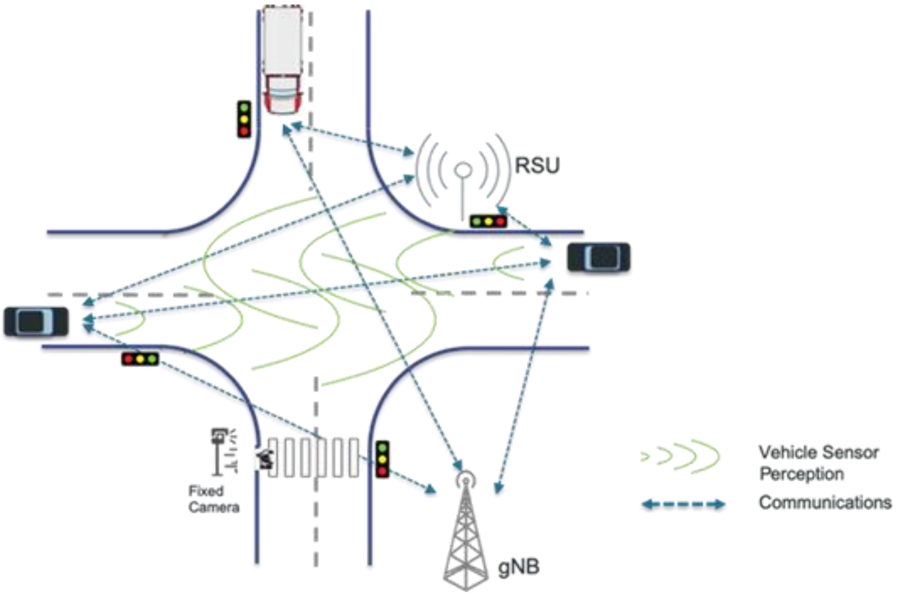


Figure 15. Generic example of a smart junction with traffic lights.

This scenario can be implemented in multiple ways. At the Dutch 5Groningen test facility for example, the earlier mentioned safety information is generally stored in a local dynamic map (LDM) running at the RSU. The intersection controller is hosted separately from the RSU and is, amongst others, responsible for controlling the traffic lights at an intersection.

LDM information will be sent to the vehicles periodically or on demand using ETSI collective perception messages (CPM) [15]. 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 can consist 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) [16] to request priority, which will be answered by the RSU with a Signal State Message (SSM) [17]. In order 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 1 trials at the Dutch 5Groningen test facility, an implementation with only CPM messages [15] has been used. The next sections will describe the Phase 1 architecture in more detail.

5.2 Proposed Setup

This use case scenario is being trialled on the 5Groningen trial facility located in Groningen, Netherlands.

5.2.1 Network architecture

This section presents the initial and evolved network architectures that have been used during Phase 1 and Phase 2 of the project, respectively.

5.2.1.1 Initial Phase 1 architecture

The Phase 1 trials aim to set the baseline of the current state-of-the-art (SotA) (3GPP Rel-14 LTE) performance with regards to the Smart Junctions use case. In the Netherlands, the Talking Traffic partnership (https://www.talking-traffic.com/nl/), is one of the SotA cloud implementations which provides parts of the concept of smart junctions as described earlier, traffic light status information. This Talking Traffic implementation is fully cloud based (e.g. no use of concepts like Edge Computing) and makes use of existing LTE telecom infrastructure in the Netherlands. Hence in order to do baseline performance measurements, the 5Groningen network situated in Helmond, was configured with a gNodeB in LTE mode, connected to an LTE EPC CN, as shown in Figure 16.

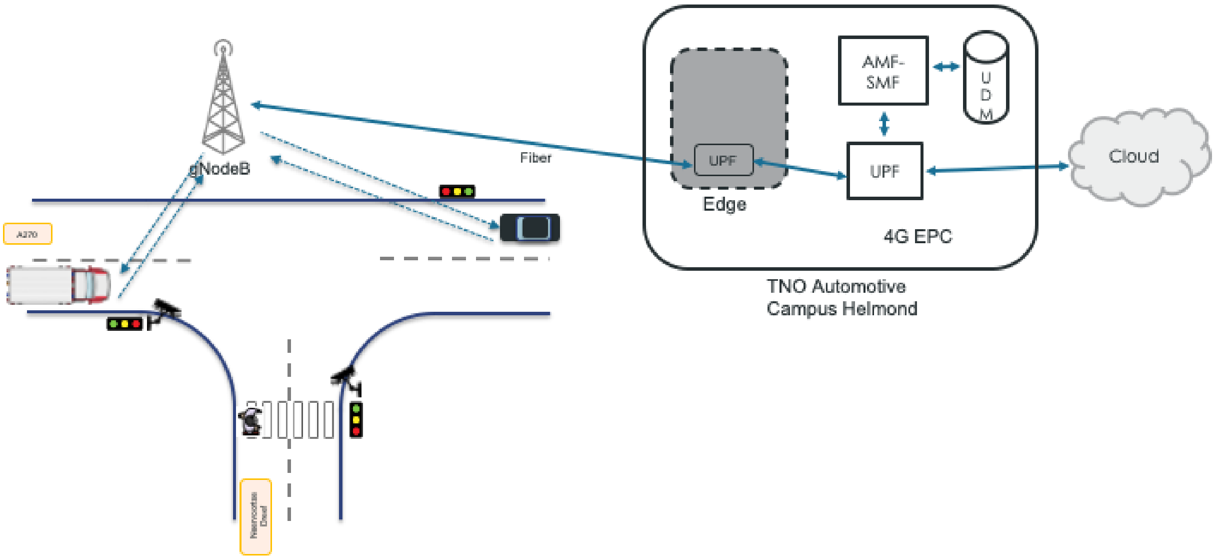


Figure 16. Initial network architecture of the 5Groningen – Helmond site (Phase 1).

5.2.1.1 Evolved Phase 2 architecture

During the course of Phase 2 of the project, the network architecture of the 5GRONINGEN test facility has been upgraded and reconfigured to support 5G SA on the 3.6 GHz frequency with a bandwidth of 100 MHz. Figure 17 depicts this updated architecture.

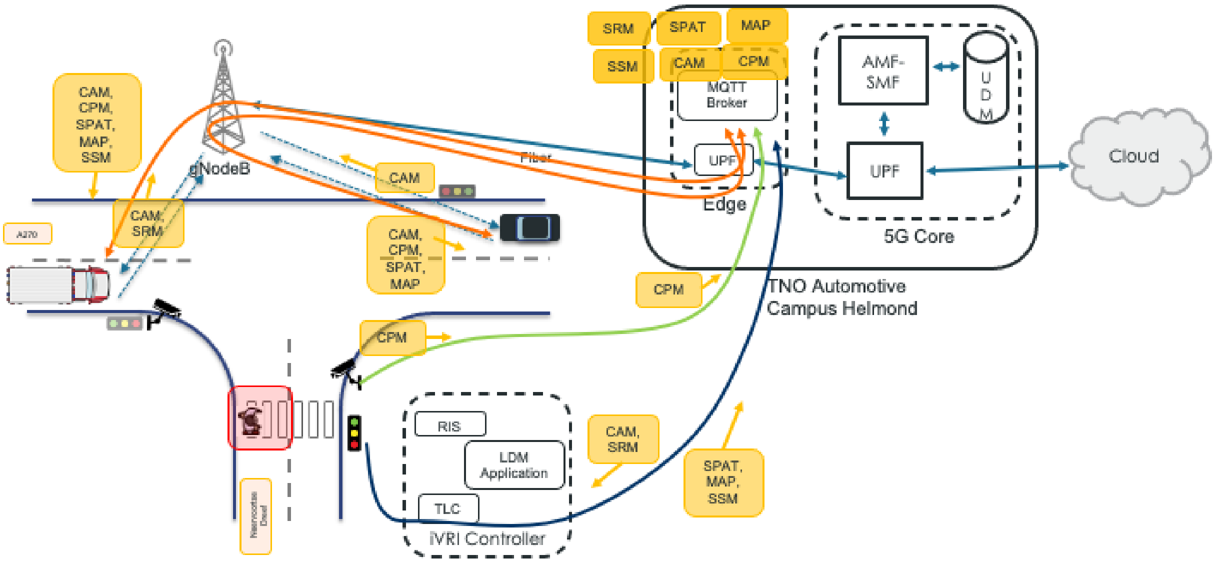


Figure 17. Evolved architecture of the Smart Junction on the 5GRONINGEN network (Phase 2).

In the Phase 2 architecture, the 4G eNB and EPC have been upgraded to 5G gNB and a 5GC, respectively, with the additional support for Slicing and Edge Computing. Additionally, on top of the Phase 1 network setup, a Traffic Light Controller (TLC) has been connected to the 5GRONINGEN network. Via the 5G network, the TLC can now provide Traffic Light data towards the vehicles that are approaching the intersection. These data include intersection topology and traffic light signal status information via ETSI SPAT messages and ETSI MAP messages, respectively as depicted by the *blue* line of Figure 17.

In what follows, the Phase 1 components will be described in more details together with the associated results. The Phase 2 components and results will be further elaborated in the next deliverable.

5.2.2 User application architecture

For the phase 1 trials at the Dutch 5Groningen test facility, an implementation with CPM messages [15] has been used. With this architecture described in Figure 16, the infrastructure is equipped with IP based camera’s capable of doing object detection & 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 cloud platform. The vehicles used for this project, connected to the network via OBU’s with 5G NR modules, can subscribe to the cloud platform 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.

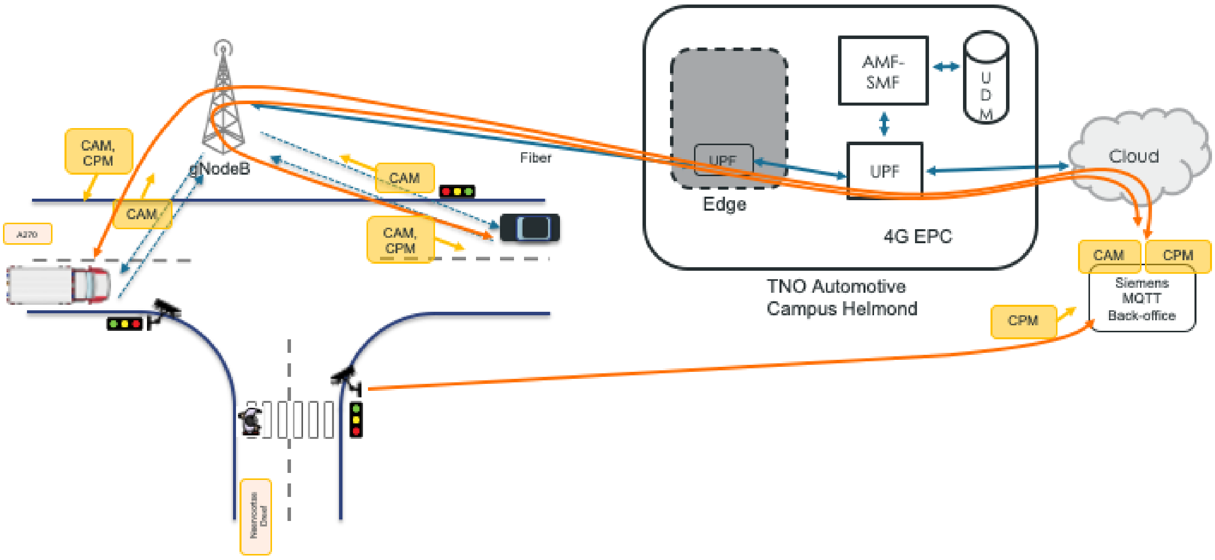


Figure 18. Helmond Data flow of CPM data through the 5Groningen network.

Figure 18 shows the information flow of CPM messages going through the network. The cloud-based MQTT back-office server 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.

The table below shows an example of the contents of an ETSI CPM message.

```
{
   "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":[
            {
               "confidence":0,
               "class":"vru",
               "subclassType":1
            }
         ]
      }
   ],
   "numberOfPerceivedObjects":1
}
```

5.2.3 Hardware components

The Phase 1 trial network architecture contains the following components:

- One OBU configured for both LTE-Uu and LTE-V2X
- LTE eNodeB:
  - Running LTE frequency division duplex (FDD) @ 1875 MHz with a BW of 5 MHz.
- LTE EPC CN

- IP based security cameras with object detection, e.g. vehicle and VRU tracking.
- Back-office cloud server running an MQTT broker, hosting the object detections

5.2.4 Software components

The Phase 1 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 and a back-office server platform.

On the vehicle side, the OBU is functioning as a UE connecting to the network via LTE-Uu. The OBU runs two applications, one application generating and publishing ETSI CAM messages to the network and another application consuming ETSI CPM messages from 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.

5.3 Testing and verification

5.3.1 Methodology

In Phase 1, the architecture presented in Figure 18 is tested. The focus of the trials will be on LTE reference measurements for both the general network latency and throughput of the LTE network, as well as the CPM application layer E2E latency. These two entities will be tested separately with the tools described in Section 5.3.3, from the same stationary OBU connected to the network via a gNodeB. 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 a cloud service, as shown in Figure 18.

5.3.2 List of key performance indicators

The *Intersection Safety Information System* is an application based on V2X communications to improve safety at intersections. The associated user requirements have been analysed and converted into a set of network KPIs in Deliverable D2.2 [10]. Table 11 presents the resulting list of network requirements together with their target values.

Table 11: Target KPIs for T2S1&T2S2, trial track

Network requirements	Target values
User experienced DL throughput	Medium (10 Mbps)
User experienced UL throughput	Medium (10 Mbps)
Broadband connectivity / peak data rate	DL: Low (20 Mbps) UL: Low (20 Mbps)
Latency requirements	Low (200 ms)
Reliability	Low (99%)
Mobility	Medium (max 160 km/h)
Location accuracy	High (0.5 m)
Connection (device) density	Low <4.3*10^3 devices/km^2 (peak) typical: N.A.
Interactivity	High (1000 transactions/sec)

Area traffic capacity	0.043 Mbps/m^2 (DL peak) 0.043 Mbps/m^2 (UL peak)
Security / privacy	Low (Public)

As the Phase 1 trials aim to set the baseline of the current SotA (3GPP Rel-14 LTE) performance with regards to this use case, the following key target KPIs will be measured:

- Throughput (DL and UL)
- Peak data rate / Message rate
- E2E latency

5.3.3 Measurement and testing tools

For the Phase 1 trials, both network and application layer performances 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

5.3.4 Initial results

In order to perform the necessary measurements to evaluate the network performance, two trial days have been scheduled. During the first trial day, the network layer performance has been measured and evaluated, e.g. only measurement at the network layer were conducted there was not yet an ITS application involved. During the second trial day, the focus was on evaluating the ITS application as described in Section 5.2.

Table 12 shows the averages of multiple runs of both the latency and throughput measurements at the network layer.

Table 12: Network layer performance results

Tool	From	To	Result
Ping	UE	Cloud	RTT: 36ms
iPerf	UE	Cloud	Upload: 8.49 Mbits/s
iPerf	Cloud	UE	Download: 10.5 Mbits/s

As described above, the network performance has also been evaluated by using the ETSI CPM-based application to determine the E2E latency. The latency shown in Table 13 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 13: CPM-based latency performance results

Log_stationid	Count	Min (ms)	Max (ms)	Avg (ms)	Stddev
123169	968	19	52	21.4969008264462810	2.9866976195472903

The results of these CPM-based measurements are plotted in Figure 19:

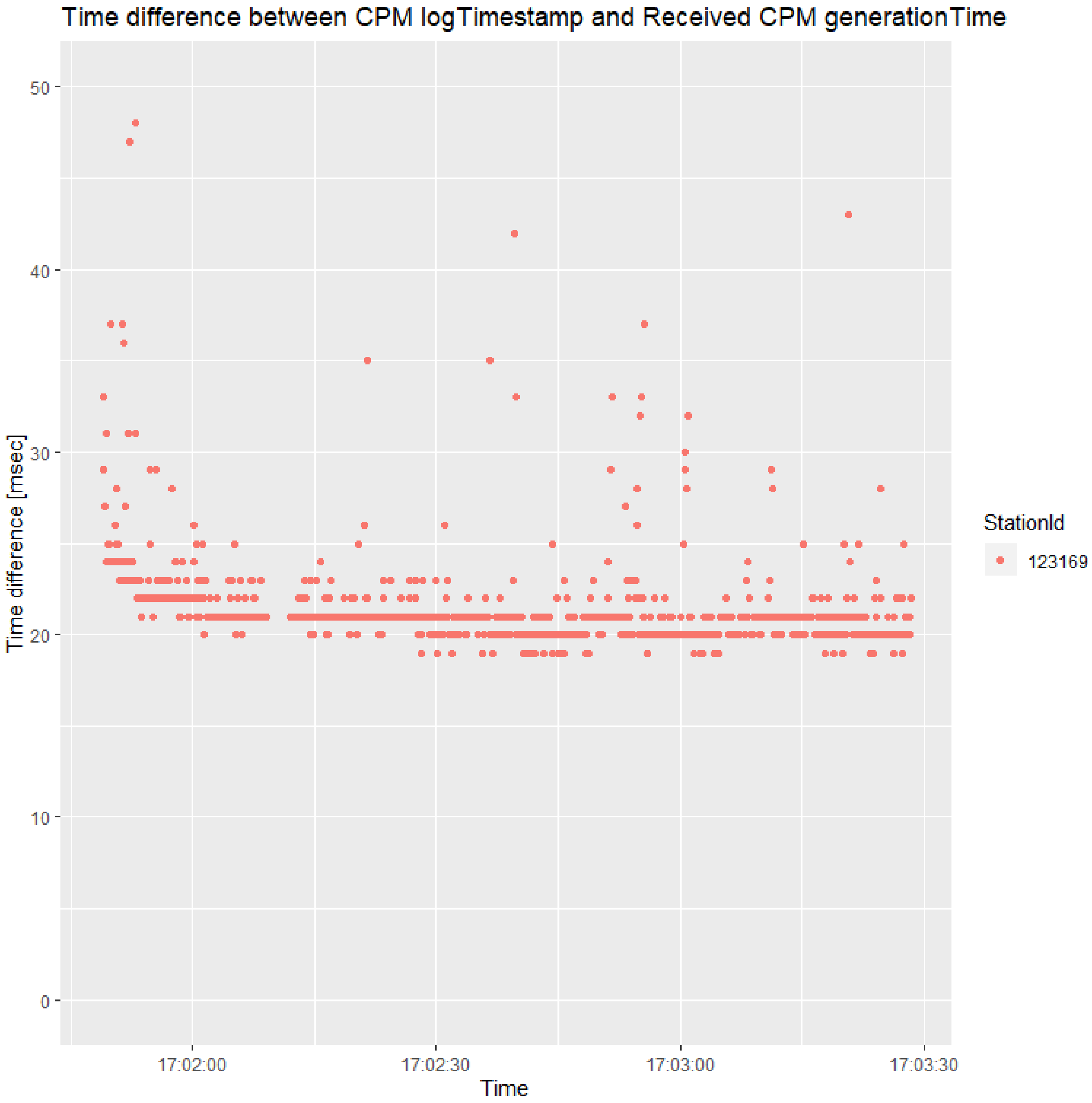


Figure 19. Results of the CPM-based E2E latency measurements.

5.4 Next step plans

1. Reconduct Phase 1 measurements on the 5G network and compare the network performance versus the earlier baseline (i.e., 4G) results.
2. Extend the Phase 1 measurements with the additionally connected TLC and its corresponding application.
3. 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 [16] to request priority, which will be answered by the RSU with an SSM [17]. 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.
4. The potential benefits of the Phase 2 Edge Computing and Slicing will be evaluated for the ETSI CPM-based application.

6 T2S1&T2S2: SMART JUNCTIONS AND NETWORK ASSISTED & COOPERATIVE COLLISION AVOIDANCE (COCA); SIMULATION TRACK

6.1 Description and motivation

The second scenario –related to the *Cooperative Collision Avoidance (CoCA) service*– consists in the exchange of Cooperative Occupancy Maps 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 and 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). To do so, the CoCA information is calculated (on-board the vehicle or at the RSU) following an LDM approach [18] to obtain precise digital maps of nearby surroundings (as the approach used in [19]) in order to predict trajectories and the probability of collisions. Then, this information is shared using a specific communication channel such as the 4G LTE) V2X (PC5 mode 4), the cellular LTE or the V2X 5G (side-link or not). In this work, two use cases are proposed to evaluate this track through simulations.

In the *first use case*, all concerned *UEs* on the road (e.g. vehicles, bus, trucks) are assumed to *have an LTE-V2X system embedded* and thus, they can broadcast LDM based information through the network. To do so, vehicles send periodic CAM [12] containing general information (e.g. GPS position, heading, speed). Then, the eNB/gNB or RSU collects/process these messages via the CoCA –LDM based– application in order to create a *global occupancy map*. This map uses the CAM information of each vehicle in order to calculate a vector indicating the possible trajectory of these vehicles and therefore, the probabilities of collision between them. If the RSU/eNB/gNB finds a high risk of collision, it sends immediately a warning in a decentralised environmental notification message (DENM) [20] that may contain new optimal trajectories or driving strategies to avoid the collision.

In the *second use case*, it is assumed that *not all the users can support a V2X communication or LDM application* such as old vehicles or vulnerable users. 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 non-V2X users in the global 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 vulnerable user with an associated probability. Then, the connected vehicles broadcast the local occupancy maps through dedicated messages for transmitting local maps in the network. Thus, the RSU/eNB/gNB can gather all available information from vehicles to build the global occupancy map and recreate the whole scene of the evaluated zone. At this stage, the RSU/eNB/gNB can either share the global map through dedicated messages or send a simple DENM to warn the vehicles in case of collision risk. Note that the local maps can also be used by other vehicles to increase the quality of the ego local map.

This work aims to complement the field trials described in Chapter 5 by evaluating large-scale simulations. In this first contribution, the focus is on the evaluation of the connectivity of a CoCA system based on 4G LTE-V2X network communication in the intersection scenario. To do so, the road traffic environment is simulated using the Simulation of Urban Mobility (SUMO) tool [21]. Then, the mobility traces from SUMO are used in the discrete-event NS3 simulator [13] to evaluate the performance of a cross-layer simulation between the physical and higher layers using a V2X communication. Thus, the performance of the network supporting CoCA is evaluated in terms of reliability, latency and scalability.

6.2 Proposed Setup

This use case scenario is being simulated with a possible subsequent trial on the 5GENESIS trial facility located in Surrey, UK.

6.2.1 Network architecture

Figure 20 shows the overall system architecture supporting a CoCA system based on V2X communications, as defined by the ETSI for the ITS architectures [22]. Both UEs and RSUs are considered as ITS-Stations (ITS-S) following an ITS protocol architecture:

- Facilities Layer to enable the CoCA, LDM, CAM and DENM related services.
- Access layer for the physical (PHY) and MAC based on V2X communication systems such as cellular 4G/5G, the LTE-V2X PC5 mode 3-4 or 5G sidelink.

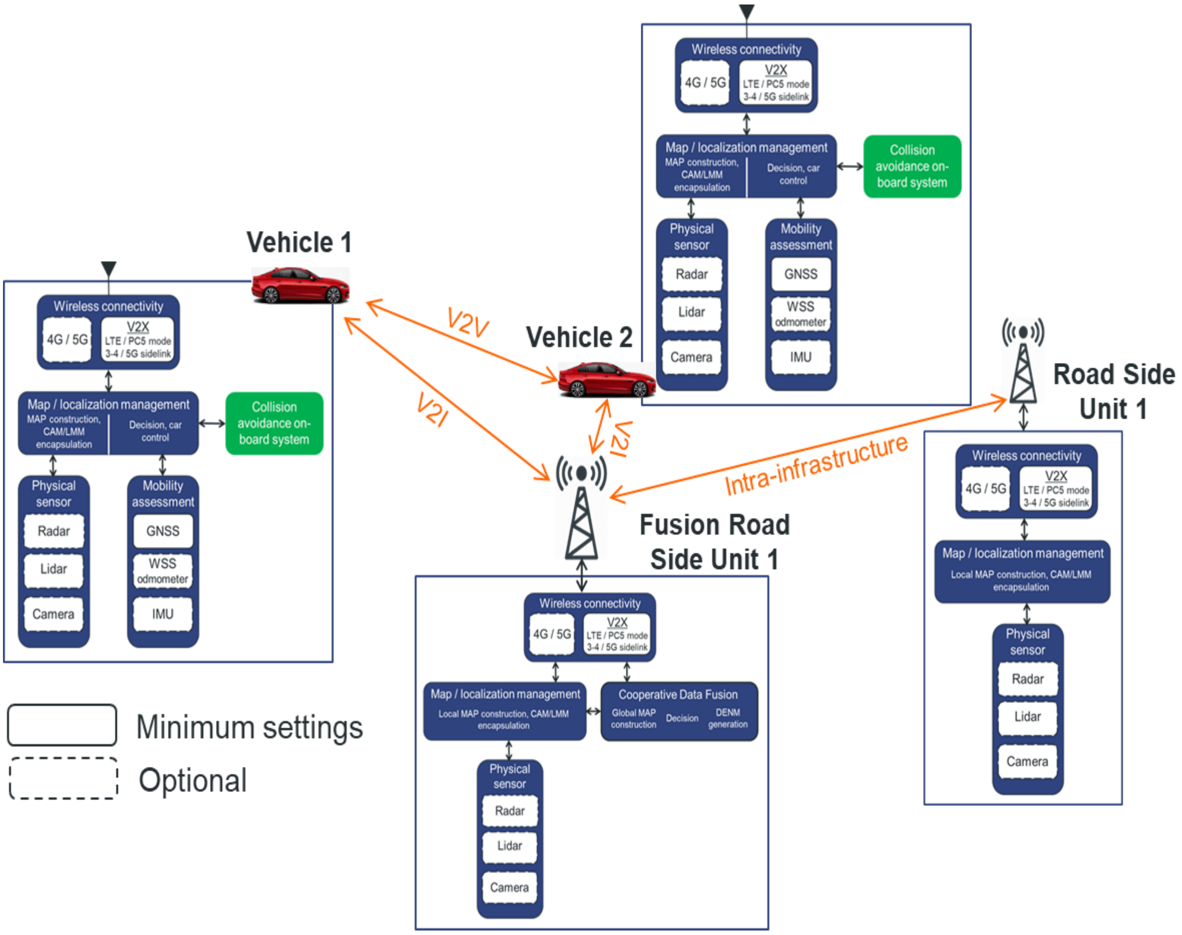


Figure 20. Overall architecture of the CoCA system based on V2X communications.

The architecture described in Figure 20 is common to use cases 1 and 2.

In both cases, information collected by vehicles is stored and processed by the on-board LDM system. In the first use case, only the navigation system is used to create periodic CAM messages, whereas in the second, physical sensors (e.g. RADAR, camera, LiDAR) and navigation system are used to build local occupancy maps. 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. 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 with the UEs. Note that UEs are assumed to have an on-board CoCA system to interpret the global occupancy map or the warning messages sent from the RSUs.

In this work, the following assumptions are made:

- The various UEs / RSUs must send a CAM or a MAP message every 100ms, depending on the scenario.
- Both UEs and RSUs are equipped with a V2X communication system based on the LTE-V2X PC5 mode 4 [23] [24]. For the physical layer, LTE-V2X operates using a waveform based on Single Carrier Frequency Division Multiplexing Access (SC-FDMA) over 10 or 20 MHz of BW. Channel occupation is defined by three main elements: sub-frames defining the Transmission Time Interval (TTI), subcarriers defining the Resource 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 an RB has a BW of 180 kHz (i.e. group of 12 sub-carriers of 15 kHz). When a user wants to communicate, it must send (in the same sub-frame) control information (e.g. modulation and RBs used) and data respectively in Sidelink Control Information (SCI) messages and in dedicated Transport Blocks (TBs). SCI (resp. TBs) transits over the Physical Sidelink Control Channel (PSCCH) (resp. Physical Sidelink Shared Channels (PSSCHs)). In order to send the TBs, LTE-V2X defines different Modulation and Coding Schemes (MCS), leading to a trade-off between throughput, range and capacity [25]. SCI are always transmitted with MCS 1, whereas TBs can be sent with any of the defined MCSs**.**
- A 10 MHz BW, divided in 50 RBs in the 5.9 GHz band, is considered. MCS-1, MCS-3 and MCS-7 / MCS-15 are used for the SCI, small packets of ~300 Bytes (such as CAM or DENM messages) and large packets of 700 Bytes or more (such as occupancy maps messages), respectively. 50 RBs (48 RBs for TB and 2 RBs for SCI) and 22 RBs (20 RBs for TB and 2 RBs for SCI) are considered for MCS-3 / MCS-7 and MCS-15, respectively.
- As to the MAC layer, LTE-V2X PC5 mode 4 lets UEs/RSUs select autonomously their radio resources following the Sensing-Based Semi-Persistent Scheduling (SB-SPS) [24]. In this scheme, UEs/RSUs can transmit packets every 100 sub-frames (i.e. 10 packets per second (pps)) or in multiples of 100 sub-frames (with a minimum of one packet per second). To do so, they reserve a group of sub-channels over several consecutive transmissions. A Reselection Counter (RC) is set randomly between 5 and 15 and decreased by one for each transmission. When the counter is equal to zero, the vehicle must select and reserve new sub-channels with a certain probability (i.e. 1-P, where P is set between 0 and 0.8). The selection of new resources is based on the observation of the previous 1000 sub-frames (i.e. selection window). Thus, vehicles can estimate which sub-channels are free and therefore, they can select one resource among the free sub-channels to reduce the risk of collisions.
- The selection probability is set to P=0, which means that vehicles will reselect resources every time RC reaches 0. At each new reselection, the RC is reset to a value between 5 and 15 with a reservation period of 100 ms (10 pps).

6.2.2 User application architecture

N/A

6.2.3 Hardware components

N/A

6.2.4 Software components

In order to evaluate the performance of a CoCA system, a simulator framework, dedicated to V2X communications, has been developed based on four SW layers (Figure 21).

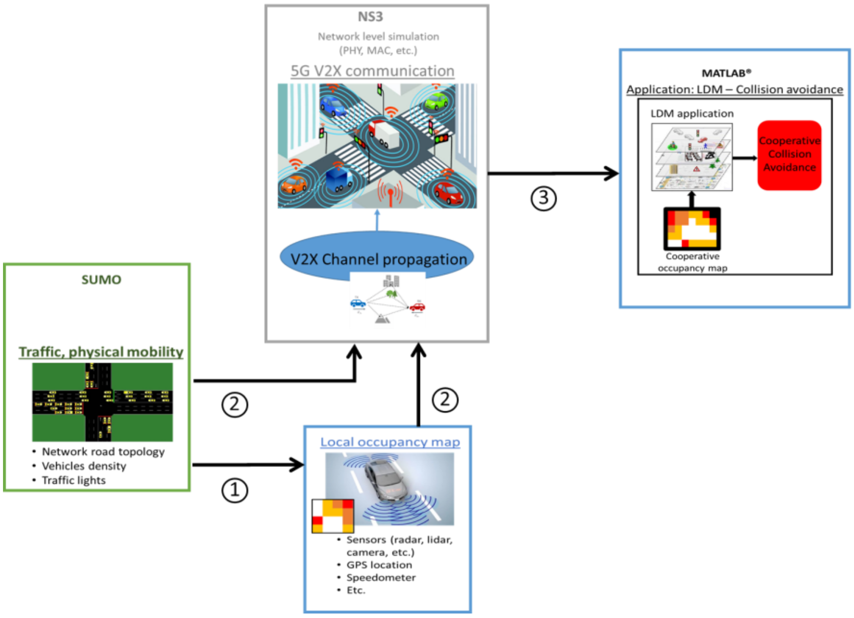


Figure 21. Simulation Framework to evaluate the performance of a CoCA system.

<u>Mobility simulation</u>

The road traffic was simulated using the SUMO simulator, introduced in [21]. With SUMO, it is possible to emulate different traffic scenarios (e.g. intersection or highway) under different conditions (e.g. vehicle density, speed limitation, topology, and existence of vulnerable users) and create a mobility model containing the positions of every vehicle at each timestamp. Then, this mobility model is entered into the network simulator to evaluate the connectivity and into the on-board LDM application to generate the local occupancy maps.

<u>Network simulation</u>

To evaluate the large-scale performance of V2X networks, several models have been implemented in the discrete-event NS3 simulator [13]. To do so, a cross-layer simulation approach has been considered (Cf. Figure 22) between the physical and higher layers to exploit the mobility traces from SUMO. At the application layer, the vehicles generate packets that vary in size e.g. 300 /700 Bytes for CAM and / or occupancy maps messages) and frequency (e.g. 10 pps). These packets are broadcast following the SB-SPS mechanism and using the MCS defined at the PHY layer. Then, each active UEs/RSU receiving the packet calculates the signal-to-interference-plus-noise-ratio (SINR) and Packet Error Rate (PER) depending on the link condition and path loss attenuation. Eventually, the time-average of the packet delivery ratio (PDR) and latency are obtained for each vehicle/RSU. Successfully received packets can be used by the CoCA fusion application to calculate the global occupancy map depending on the connectivity between vehicles and RSUs.

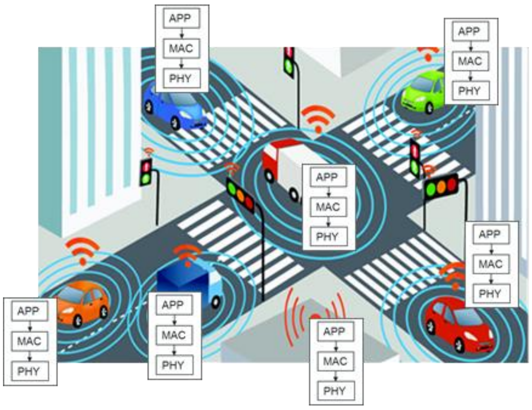


Figure 22. Simulation representation of CoCA in NS-3.

On-board LDM application

To calculate the local occupancy maps, an on-board LDM application, developed in MATLAB [26], is used. This application uses the SUMO mobility traces to calculate an occupancy map for each vehicle at each timestamp. These maps can be initially built from basic ego vehicle inputs (e.g. position, speed and heading) and can be completed with other sensor data (e.g. RADAR, LiDAR and camera) when available. Moreover, RSUs equipped with sensors may also use this application as source of information for the global occupancy maps or the prediction of trajectories to detect any possible collision.

LDM – CoCA fusion application

Finally, the CoCA fusion application will use the connectivity information coming from NS-3 to calculate the global occupancy map at each timestamp. Thus, the RSU having the fusion LDM application will use the local occupancy map only when connectivity is possible with the vehicles.

In this work, the focus is on the connectivity performance of the CoCA application. To do so, a mobility model is first generated with SUMO and then, used in NS-3 to evaluate the reliability of the LTE-V2X network. Note that the LDM application is under development and therefore, the evaluation of the on-board or fusion LDM application are not considered in this phase.

6.3 Testing and verification

6.3.1 Methodology

In this work, an intersection scenario, where a high density of vehicles and potential VRUs (e.g., cyclists and pedestrians) are located, is considered. As shown in Figure 23, the considered intersection is of two main streets (Quai du Commerce and Pont Robert Schuman) located in Lyon, France. Each street is four lanes wide, with two lanes in each direction. This intersection is located in the middle of an area of 400x400 m². The RSU is placed at the north-west of the intersection and the vehicles are generated randomly during the simulation in order to keep a constant density. In this deployment, vehicles can reach a maximum speed of 50 kph and obey the traffic lights instructions according to national regulations. Accordingly, the position of vehicles is calculated every 10 milliseconds. Thus, different mobility traces are generated over different simulations, varying the vehicle density between 0.0001 - 0.01 vehicles/m². Each simulation has a duration of 60 seconds.

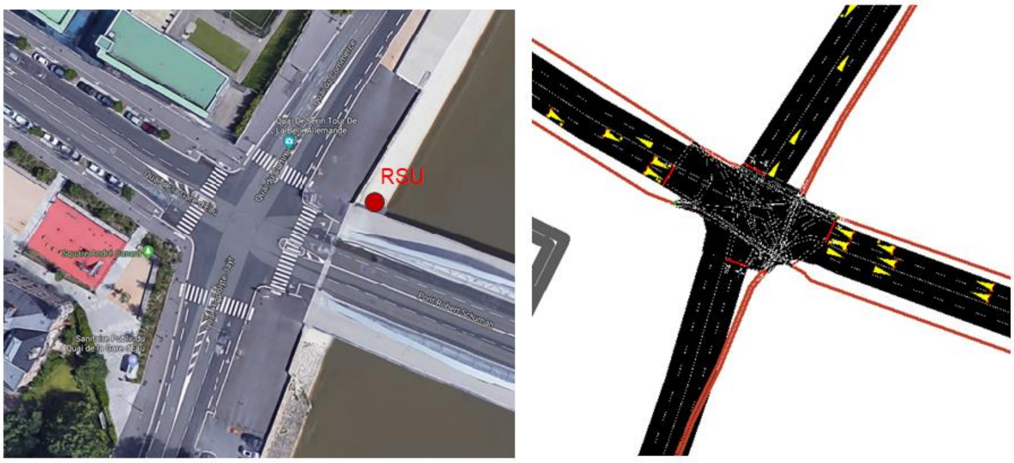


Figure 23. Representation of the intersection considered in this study with Google Maps (left) and SUMO (right)

Then, the link condition for all vehicles is calculated using the SUMO traces at each timestamp. 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, three types of link conditions are considered (as shown in Figure 24):

- Line-of-sight (LoS) to represent direct visibility between the RSU and vehicles;
- Non-LOS (NLoS) condition to represent the building effect between vehicles;
- Obstructed line-of-sight (OLoS) to represent the obstruction between vehicles.

Accordingly, the RSU and vehicles will always communicate in LoS. The vehicles navigating in perpendicular streets will encounter NLoS condition, whereas vehicles driving in the same street or in the intersection will experience either LoS or OLoS condition.

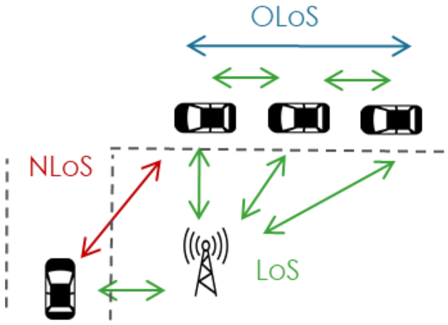


Figure 24. Representation of the three types of link conditions at intersections

For the channel model, the path loss model Winner B1 is considered as defined in [27], while the fast fading model based on the Extended Vehicular Model (EVA) is considered as defined in [28]. Note that the path loss is calculated depending on the link condition estimated previously, whereas the fast fading is simulated following the same methodology as [25]. For the path loss in OLoS condition, it is calculated as follows $PL_{OLOS} = \frac{2}{3}\ PL_{LOS} + \frac{1}{3}\ PL_{NLOS}$, where PL_{LOS} and PL_{NLOS} represent the path loss calculated in LoS and NLoS, respectively using the Winner B1 model.

At the reception, the received power (P_{Rx}) of the signal is calculated as $P_{Rx}(d) = \ P_{Tx} - PL\ (d)$, where the transmission power (P_{Tx}) is fixed to $P_{Tx} = 23$ dBm. Then, the SINR is calculated as a function of the received power, the noise (N) and the sum of interferences P_I as:

$$SINR = \frac{P_{RX}}{N + \sum P_I}$$

An interference scenario is considered, where another UE or RSU uses the same RB as the useful signal and therefore, P_I represents the reception power of the interference. Then, the noise of each received signal is obtained as follows:

$$N = NF \cdot kTB \cdot \frac{nRBs}{RBs(B)}$$

where NF is the noise factor fixed at 9dB, kTB represents the thermal noise (-174dBm/Hz) over the BW (10MHz) and $\frac{nRBs}{RBs(B)}$ represents the ratio between the useful RBs occupied by the signal (e.g. 20 RBs or 50 RBs depending on the MCS and packet size) and the total number of RBs in the BW (i.e. 50 RBs for 10MHz).

PER is obtained as a function of the SINR. A look up table (LUT) calculated for each MCS (based on the number of RBs and the packet size) is integrated in the NS-3 simulator. This LUT considers the performance results obtained by following the same methodology as in [25] under the EVA channel. Accordingly, it is assumed that an LTE-V2X packet is received when the SCI and the TB are correctly decoded using their respective MCS.

At the end of the simulation, the PDR and time of refreshment rate (Trr) are estimated depending on the network size. For the PDR, it is defined in “UL” as the capacity of the network to receive the CAM/MAP messages by the RSU, in “DL” as the capacity of the vehicles to receive the global map messages from the RSU, and in V2V as the capacity of the vehicles to share their information. The Trr defines the average time between two correctly received/decoded packets.

6.3.2 List of key performance indicators

The Intersection Safety Information System is an application based on V2X communications to improve safety at intersections. The associated user requirements have been analysed and converted into a set of network KPIs in Deliverable D2.2 [10]. Table 14 presents the resulting list of network requirements together with their target values.

Table 14: Target KPIs for T2S1&T2S2, simulation track

Network requirements	Target values
User experienced DL throughput	Medium (10 Mbps)
User experienced UL throughput	Medium (10 Mbps)
Broadband connectivity / peak data rate	DL: Low (20 Mbps) UL: Low (20 Mbps)
Latency requirements	Medium (5 ms)
Reliability	Medium (99.999%)
Mobility	Medium (max 160 km/h)
Location accuracy	High (0.5 m)
Connection (device) density	Low <4.3×10^3 devices/km^2 (peak)‡ typical: N.A.
Interactivity	High (1000 transactions/sec)
Area traffic capacity	0.043 Mbps/m^2 (DL peak) 0.043 Mbps/m^2 (UL peak)
Security / privacy	Low (Public)

During Phase 1, the focus has been on the evaluation of the connectivity of a CoCA system based on 4G LTE-V2X network communication in the intersection scenario. Hence, the target KPIs of Table 14 are not yet achievable.

6.3.3 Measurement and testing tools

In this work, the LTE-V2X communication is evaluated over three type of links to enable a CoCA system:

- The V2I connectivity in "UL" to evaluate the capacity of the RSU to collect the CAM messages or the local occupancy maps generated from the vehicles.
- The V2I connectivity in "DL" to evaluate the capacity of the RSU to transmit a DENM message or share the global occupancy map with all the vehicles in the intersection.
- The V2V connectivity to evaluate the capacity of vehicles to share their local information and perform a cooperative LDM with an on-board system (having fewer capacities than the RSU).

Accordingly, the PDR and Trr are calculated as follows:

- The PDR is calculated every 100 ms (i.e. application latency). Three different levels of performance evaluation are considered depending on the link:

$$PDR_{UL} = \frac{N_{Packets\ Rx-RSU}}{N_{Packets\ Tx-\ vehicles}}$$

$$PDR_{DL} = \frac{N_{Packets\ Rx-vehicles}}{N_{Packets\ Tx-RSU}}$$

$$PDR_{V2V}(d) = \frac{N_{Packets\ Tx-vehicles}}{N_{Packets\ Rx-vehicles}(d)}$$

  The PDR in UL is defined as the number of packets received by the RSU over the number of packets sent by the vehicles in the same selection window. The PDR in DL is the number of packets received by the vehicles over the number of active vehicles in the intersection when the RSU send its packets. Finally, the PDR for V2V ($PDR_{V2V}(d)$) is calculated over different distances (d): the first considering the whole intersection surface and the second considering a defined range (i.e. 150 m).

- The Trr is calculated for each type of link as follows:

$$T_{rr} = L + \sum_{i=1}^{K}(1 - PDR_j)^i \cdot PDR_j \cdot (i \cdot L)$$

  where PDR_j represents the PDR for a defined type of link j (i.e. DL, UL or V2V), L represents the application latency to recover the CAM/MAP messages from vehicles or the Global Maps messages from the RSU and $i \in [1, K]$ is a positive integer number defining the probability of receiving the message during the next K selection windows. A selection window lasts 100 ms and therefore, it represents the minimum latency L to retrieve the LDM information from UEs.

To do so, two different studies are considered (Figure 25):

- Evaluation of a single simulation to identify and understand the different limitations of V2X connectivity for the CoCA application in terms of number of collisions and PDR for each type of link.
- Evaluation of a larger number of simulations to evaluate the PDR and the refreshment rate (Trr) as a function of the number of vehicles in the intersection. Thus, each simulation changes its communication behaviour with different seed counter.

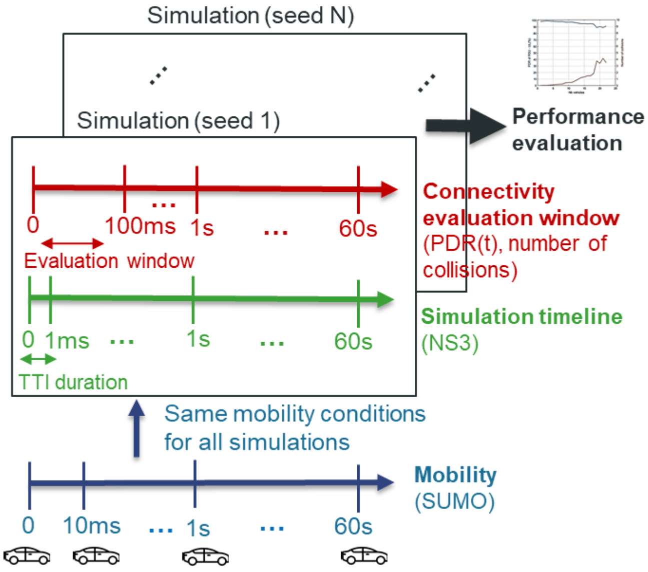


Figure 25. Simulation framework to evaluate LTE-V2X connectivity using NS-3 and SUMO

6.3.4 Initial results

PHY layer performances

In this section, the PHY performances of MCS-3, MCS-7, MCS-15 and MCS-20 are evaluated over the EVA channel [28] using the same methodology as [25]. Figure 26 shows the PER as a function of the SNR for each MCS configuration. MCS-3 and MCS-20 (resp. MCS-7 and MCS-15) are considered for packets of 300 Bytes (resp. 700 Bytes). Accordingly, MCS-3/MCS-7, MCS-15 and MCS-20 are using 48, 20 and 8 RBs for the TB.

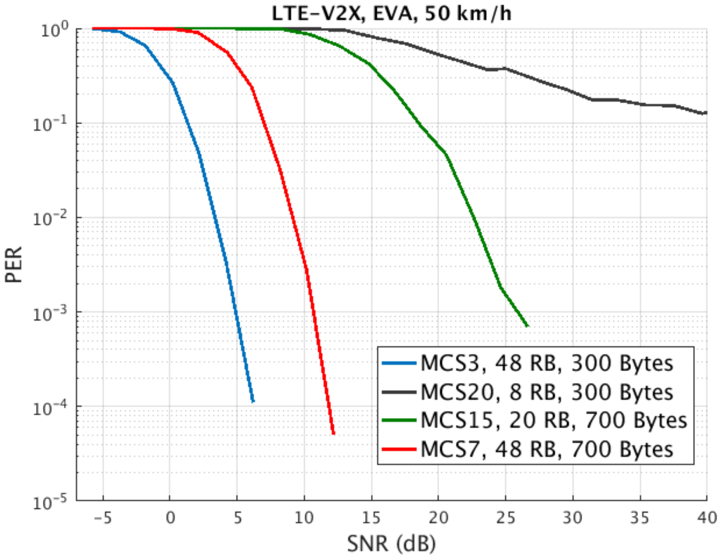


Figure 26. LTE-V2X physical layer performances over the EVA channel

These results show that a PER lower to 10^{-2} can be achieved with a SNR higher than 3dB, 9dB and 23dB with MCS-3, MCS-7 and MCS-15, respectively. However, MCS-20 (used in [29]) does not converge to a PER<10^{-2} with the EVA channel, this is why it will not be considered in our further simulations. From these simulations, it is concluded that MCS-3 and MCS-7 can achieve a higher range compared to MCS-15. However, MCS-15 may improve its link performance by increasing its capacity (22 RBs per packet) compared to MCS-3 and MCS-7 which use all the available BW (50 RBs per packet). As MCS15 operates only half of the band of 10 MHz, two users per TTI can be considered (compared to only one for MCS-3 and MCS-7). Therefore, the trade-off between the capacity and range will be evaluated for the CoCA system**.**

Evaluation of CoCA with LTE-V2X over time (single simulation)

In this section, the performance of a single simulation is evaluated to identify the different limitations of LTE-V2X connectivity for the CoCA application in terms of PDR and number of collisions for each type of link (V2I in UL / DL and V2V). It is assumed that a collision occurs when 2 or more UEs/RSU use the same TTI. During a collision, at most one transmission can be recovered depending on its SINR. In this first set of simulations, the first use case defined in Section 6.1 is considered, where all UEs are connected to the network with minimum capabilities to share LDM information, via CAM messages of 300 Bytes using the MCS-3 with 50RBs.

During this simulation, one RSU placed at the intersection (see Figure 23) is considered, with a maximum of either 10 or 100 UEs appearing gradually. Three main sub-cases can be identified (Figure 27):

- Initialization (0s-20s), where few UEs are generated (low network density). The distance between the UEs and RSU can be relatively high (>200m);
- Established (20s-40s), where most of UEs arrive to the intersection zone (high network density). The distance between the UEs and RSU is reduced (<200m); and
- Transitory (40s-60s), where some UEs disappear from the simulation. Most UEs are at the intersection zone (high network density) close to the RSU. Note that new vehicles can reappear during the simulation duration.

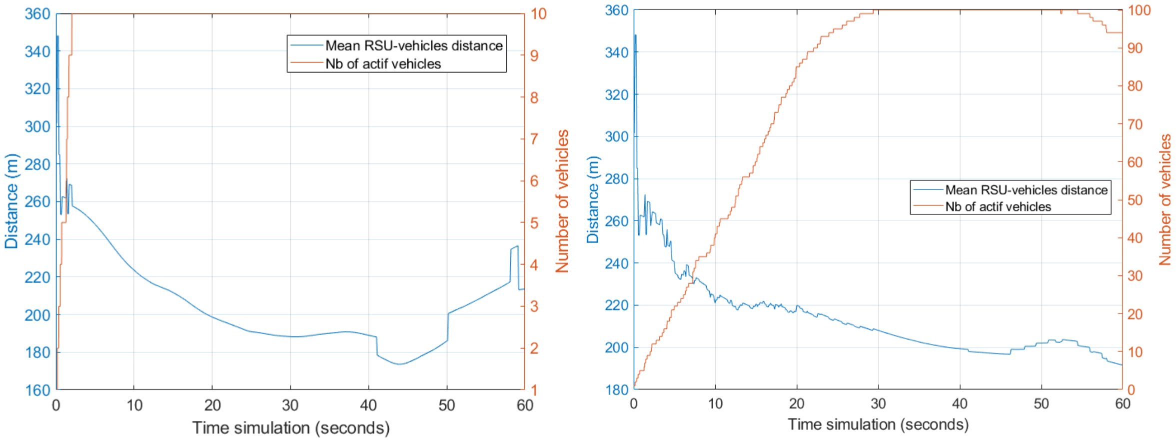


Figure 27. Evolution of the average RSU-UEs distance (blue) and number of UEs (red) during the simulation. In the left (resp. right) hand side figure, the maximum number of UEs is fixed to 10 (resp. 100).

Figure 28, Figure 29 and Figure 30 below show the evolution of the PDR for the different types of links respectively for V2I in UL, V2I in DL and V2V. It can be observed that, for all the links, the PDR decreases when the number of UEs increases.

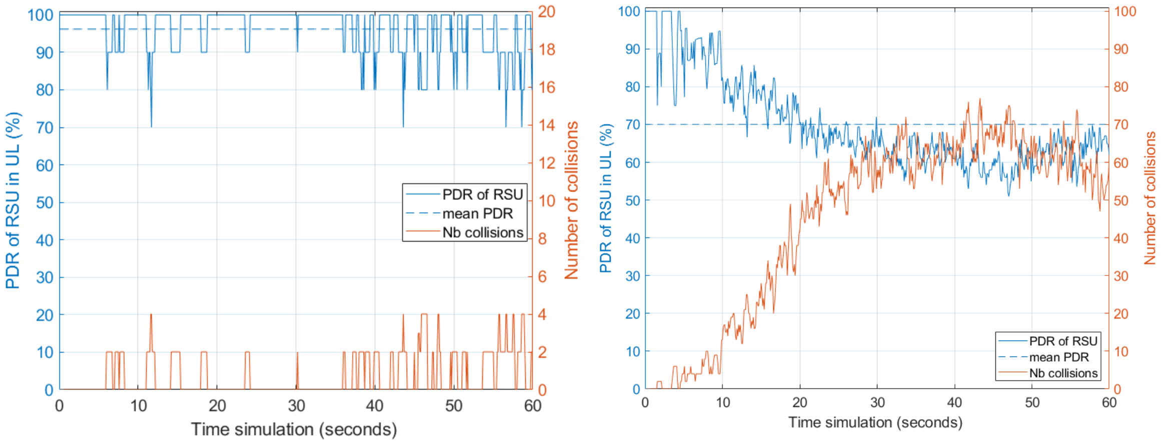


Figure 28. Nb. of collisions and PDR comparison of V2I in UL over one simulation of 60s using MCS-3 and 50RBs for packets of 300 Bytes. In the left (resp. right) hand side figure, the maximum number of UEs is fixed to 10 (resp. 100).

In the case of the PDR of V2I in UL (Figure 28), a global PDR of 69.8% (resp. 95.6%) for 100 UEs (resp. 10 UEs) is observed over the simulation. The loss of PDR has a high correlation with the number of packet collisions between the UEs. The impact of the path loss between RSU and UEs is low in the intersection scenario compared to the impact of the interference. During the initialization stage, the PDR of V2I in UL is high (>80%). The few collisions occurring in this case are due to the hidden terminal problem. For instance, two UEs that approach from different streets are in NLoS and therefore, it is possible that both select the same TTI provoking a packet collision at the RSU. Note that there are only 99 available TTIs for a UE to send its message. Indeed, the RSU will always choose one TTI to send its message. Therefore, any message sent in the same TTI used by the RSU is considered lost.

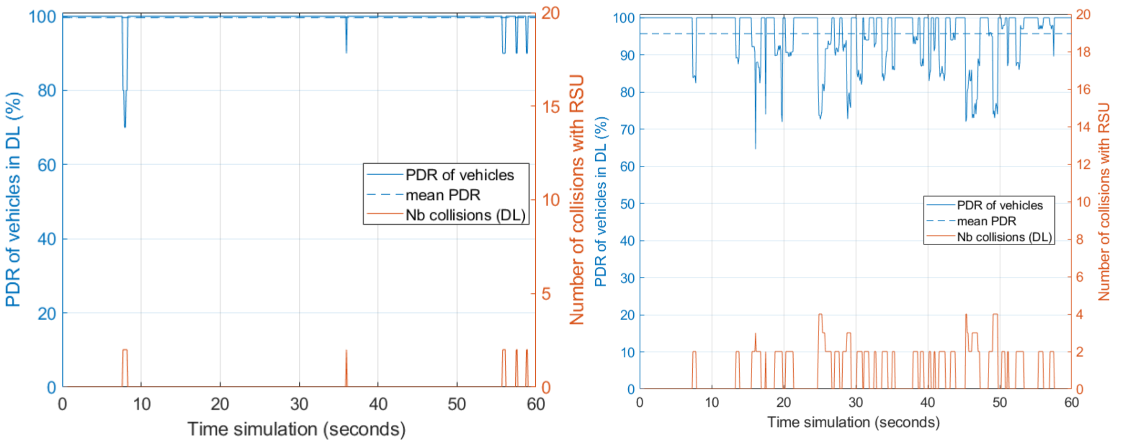


Figure 29. Nb. of collisions and PDR comparison of V2I in DL over one simulation of 60s using MCS-3 and 50RBs for packets of 300 Bytes. In the left (resp. right) hand side figure, the maximum number of UEs is fixed to 10 (resp. 100).

In the case of the PDR of V2I in DL (Figure 29), a global PDR of 95.6 % (resp. 98.7%) for 100 UEs (resp. 10 UEs) is observed over the simulation. The small loss of PDR is due to the low number of packet collisions between RSU and UEs. During the initialization stage, the PDR is most of the time at 100 %. However, a few packet collisions may happen because of the reselection process of the SB-SPS algorithm. For instance, when the RSU and a UE perform the TTI reselection process at the same time, they may have a similar knowledge of channel occupancy. Therefore, they can choose the same TTI for the next transmissions. If this happens, the UE will not be able to receive messages from the RSU. Note that the packet collisions between UEs and the RSU can also have an impact on other UEs. For instance, if a conflicting UE (A) is close to another UE (B), it is more likely that the UE (B) will receive the message from the UE (A) instead of the message from the RSU.

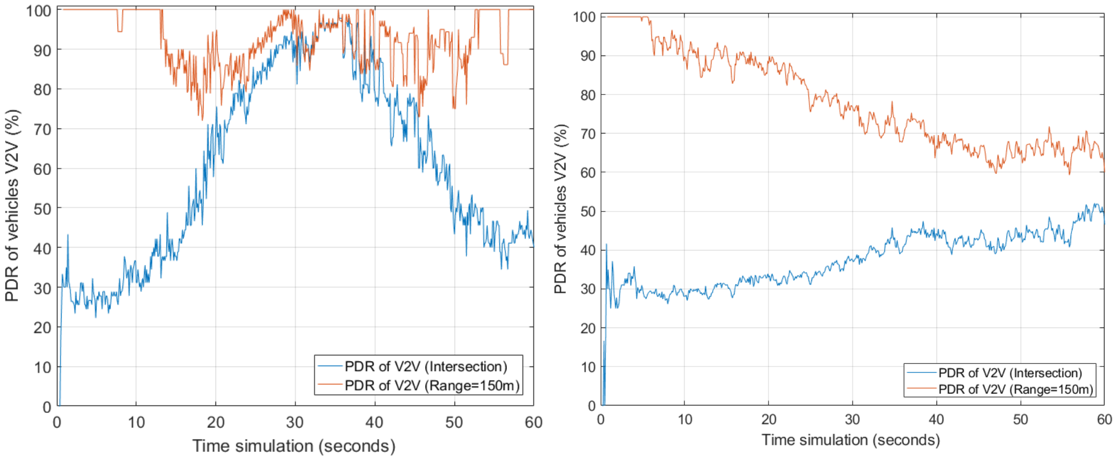


Figure 30. Nb. of packet collisions and PDR comparison of V2V over one simulation of 60s using MCS-3 and 50 RBs for packets of 300 Bytes. In the left (resp. right) hand side figure, the maximum number of UEs is fixed to 10 (resp. 100).

In the case of the PDR of V2V (Figure 30, right) with 100 UEs, a global PDR of 73.5% (resp. 37.5%) is observed when UEs try to cooperate with other UEs in a range of 150m (resp. in all the intersection). At the initialization stage, UEs can cooperate easier at a short range compared to the cooperation with all the UEs in the intersection. This is because the UEs are sparse in the scene and there are more NLoS condition between the UEs. However, when the number of active UEs increases and get close to the intersection, the number of packet collisions increases and the PDR of V2V decreases even at short range. Note that in the case of 10 UEs, the PDR of V2V increases to 90% when the UEs arrive at the intersection but decreases rapidly when they leave it.

From this study, it can be concluded that the CoCA system can be possibly under limited conditions when all the UEs are connected. Considering a network of 10 or 100 UEs, the RSU will be able to share important information to avoid road collisions to 95 % of UEs. However, this information may be limited because it will be calculated with information coming from a limited number of UEs (60 % in case of 100 connected UEs and 95% in case of 10 connected UEs). This can be dangerous if the missing UEs encounter a risk of collision and are not detected by the RSU. One solution would be to use the cooperation between UEs to send local information to the RSU but might be limited by the UEs local visibility. For instance, in the case of 100 connected UEs, it is observed that cooperation can only be possible with 60% of the UEs at a range of 150m, which represents 40% of the UEs in all the intersection.

Evaluation of CoCA with LTE-V2X as a function of the number of UEs (multiple simulations)

In this part, our analysis is extended with a larger number of simulations to evaluate the PDR and the time refreshment rate (Trr) as a function of the number of UEs in the intersection. This second set of simulations is relevant to the second use case of Section 6.1. Each simulation changes its communication behaviour depending on the enabled MCS and the UEs density (10-100 UEs). MCS-3 is used to evaluate the transmission of CAM/DENM messages (<300Bytes), while MCS-7 and MCS-15 are used to evaluate the transmission of occupancy maps (<700Bytes). Under these assumptions, the LTE-V2X connectivity over V2I in UL, V2V in DL and V2V are compared.

Figure 31 shows the PDR and the number of packet collisions for the V2I connectivity in UL and DL as a function of the number of UEs and of MCS configuration. It is observed that the PDR performance decreases for all MCSs when the UEs density increases. In the case of low density (<20 UEs), MCS-3 and MCS-7 show a better PDR (>90%) compared to MCS-15. This is because MCS-3 and MCS-7 have a better range performance compared to MCS-15 (Figure 26). Since UEs are on average farther from the RSU in low density simulations, MCS-15 cannot achieve a good PER. In the case of high density

(>80 UEs), the same behavior is observed for the three MCSs in DL. However, MCS-15 becomes more interesting for the V2I connectivity in UL when compared to MCSs-3 and 7. This is because MCS-15 has a higher capacity by using only 22RBs per UE transmission, hence allows twice as many resources to be shared between the same number of UEs, thus undergoes less packet collisions (see Figure 31 bottom curves).

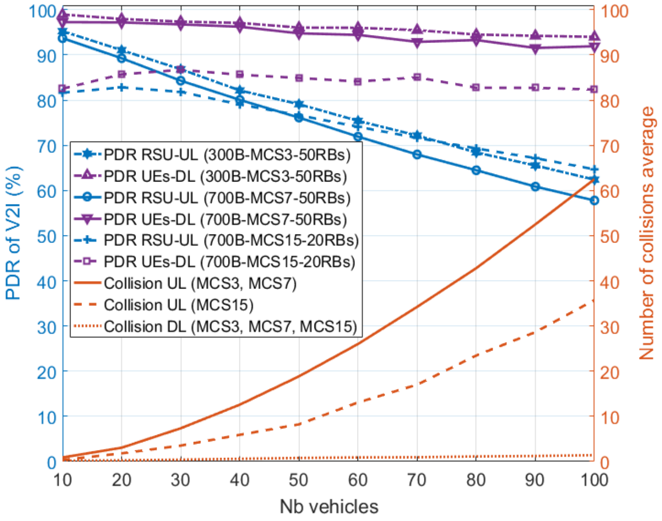


Figure 31. PDR of V2I in UL and DL as a function of the number of UEs in the intersection and of the MCS configuration (MCS-3, MCS-7 and MCS-15)

Figure 32 shows the TTI occupancy rate and average number of packet collisions over 100 milliseconds of selection window as a function of the number of UEs for all the MCS configurations. It can be observed that MCS-15 shows a lower number of packet collisions between UEs increasing its reliability and capacity. However, the observed number of packet collisions increases even when there are still free resources. This is because the SB-SPS has a random behaviour during the reselection process. Indeed, UEs have a similar knowledge of the channel occupancy and there is a risk that UEs select the same resource if they perform the reselection at the same time. This is an important point to consider for the 5G sidelink protocol.

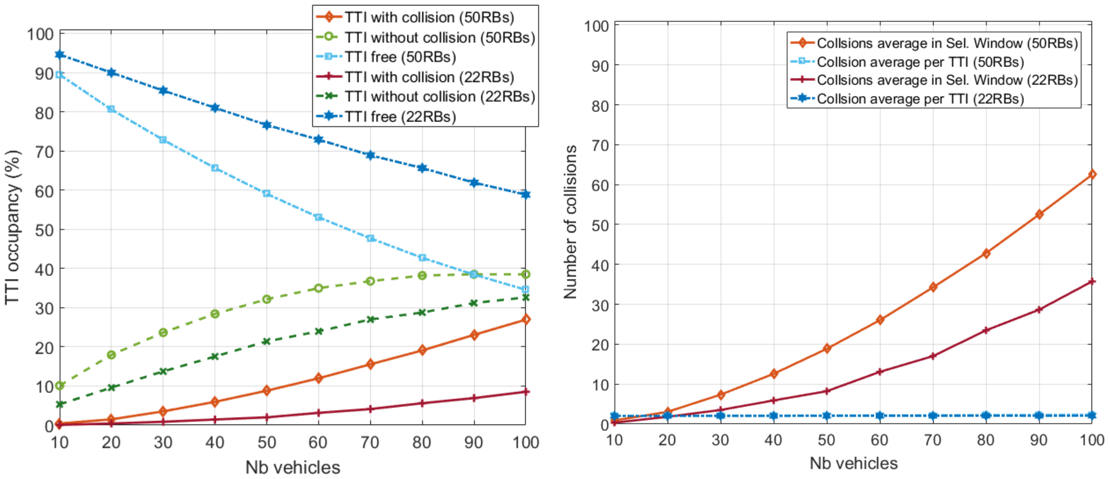


Figure 32. TTI occupancy (left) and packet collision average (right) over 100 ms (Selection Window) as a function of the number of UEs using 22 RBs (MCS-15) and 50 RBs (MCS-3 or MCS-7) per TTI.

Figure 33 shows the PDR of the V2V connectivity as a function of the number of UEs and of the MCS configuration. The observed PDR at short range (<150m) decreases when the UEs density increases.

Moreover, MCS-3 and MCS-7 show the best PDR to send packets of 300B and 700B respectively. Indeed, the path loss has a higher impact for V2V connectivity using MCS-15 because of the higher distance between UEs in the intersection, despite the reduced packet collision rate for MCS-15 (see bottom curves on Figure 33). For instance, in the case of a network with 100 UEs, UEs will be able to share CAM information (resp. local occupancy maps) with ~70% (~60%) of UEs at 150m of range. This represents ~40% (~35%) of the UEs at the intersection. Note that the PDR of V2V for the intersection remains constant in high density, but it shows a peak with 40 UEs in the network. This is because at low density, the PDR is highly impacted by the pathloss, while at high density, the PDR is impacted by the interference. However, when there are 40 UEs in the intersection, the sparsity and probability of packet collisions between UEs is reduced increasing the PDR.

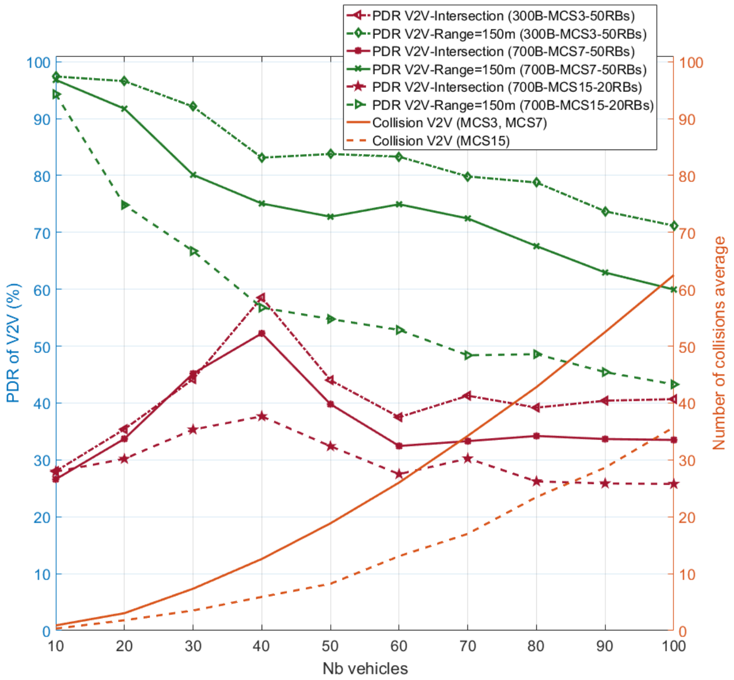


Figure 33. PDR of V2V as a function of the number of UEs in the intersection and the MCS configuration (MCS-3, MCS-7 and MCS-15)

To complete this comparison, Figure 34 shows the refreshment rate (Trr) defining the average duration between two successful LDM messages. In the case of the V2I in DL, it is observed that the latency to retrieve a DENM message or a global occupancy map from the RSU is relatively short with all the MCS (<120ms). In the case of the V2I in UL, the latency needed to retrieve a CAM message (MCS-3) from UEs is 106 ms (resp. 160 ms) for 10 (resp. 100) connected UEs. However, the latency to retrieve a local occupancy map in UL will take 108 ms (resp. 158 ms) for 10 (resp. 100) connected UEs using MCS-7 (resp. MCS-15). In the case of V2V, the observed latency to share CAM messages (resp. local maps) between UEs at a range of 150m is 103 ms (resp. 105 ms) with 10 UEs and 140 ms (resp. 164 ms) with 100 UEs. However, the latency to share LDM information between all the UEs (red curve) in the intersection would be higher than 210ms (expected around 40 vehicles).

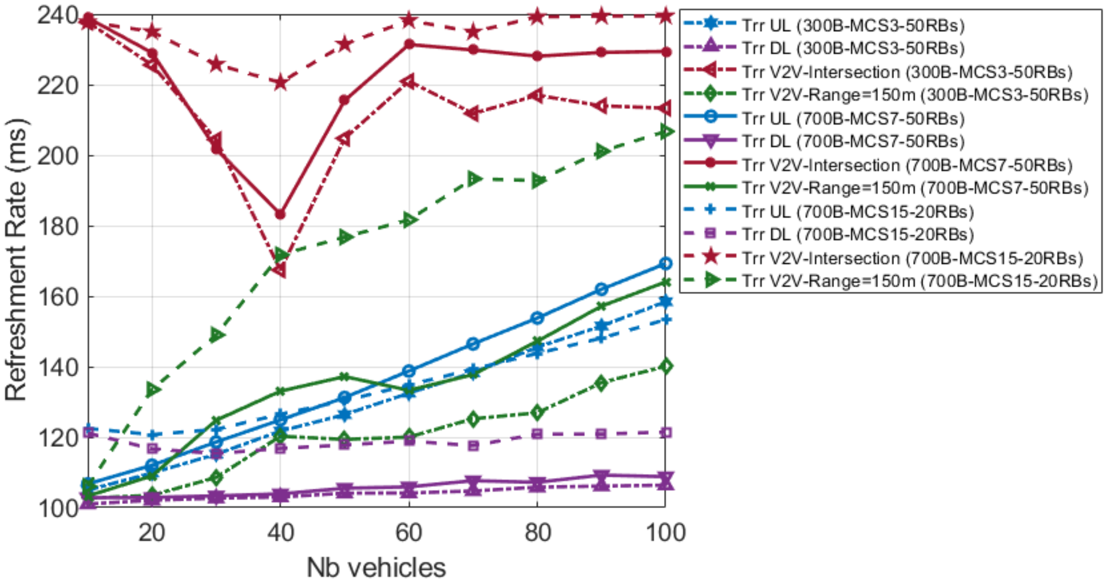


Figure 34. Refreshment rate (Trr) for all the links as a function of the number of UEs in the intersection and the MCS configuration (MCS-3, MCS-7 and MCS-15)

Conclusion

From this study, it can be concluded that it is better to send the local occupancy maps in UL using MCS-7 (resp. MCS-15) when the network presents a low UEs density (resp. high UEs density). However, it is preferable that the RSU sends the global occupancy map in DL using MCS-7 to reach all the UEs around the intersection. If the connection between UEs and RSU is limited, UEs can still cooperate by sharing their local occupancy maps using the MCS-7 to reach the maximum number of UEs.

6.4 Next step plans

- Continue the development of the LDM application to build the local occupancy map from SUMO traces and then, the fusion algorithm to generate the global occupancy map.
- Finalize the integration of "SUMO+NS3" and LDM application Phase 2.
- Investigate the possibility of comparing our approach based on occupancy maps with that of other partners (TNO, Epitomical) through simulations.
- Evaluate different scenarios such as intersection with vulnerable user or the highway scenario.

7 T2S3: QUALITY OF SERVICE (QOS) FOR ADVANCED DRIVING

7.1 Description and motivation

This scenario involves the dynamic selection of the appropriate driving mode based on the context at-hand. According to [30], 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, described in Figure 35, 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 quality of service (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).

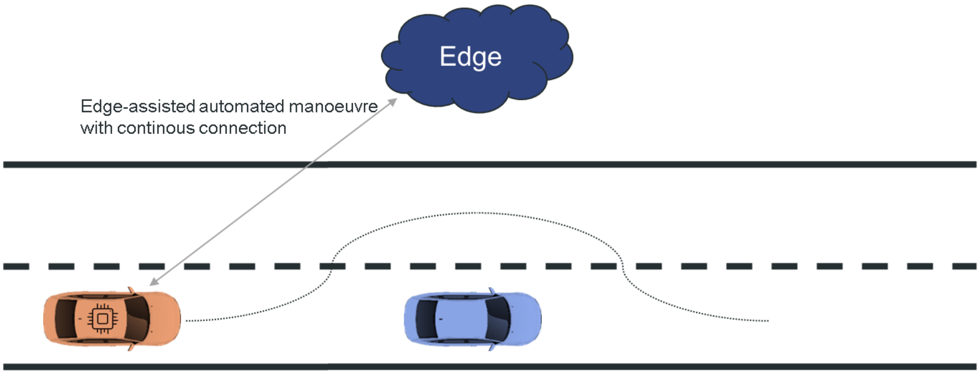


Figure 35. Edge-assisted automated manoeuvre.

7.2 Proposed Setup

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

Figure 36 presents a colour-coded architecture of the proposed setup, where the various colours represent the responsible partners. On the network side, two additional functionalities are needed, the first allows to negotiate the connectivity and QoS levels provided by the network, while the second authenticates V2X users and authorizes only trustworthy accesses. On the user application side, the decision-making entity controlling the driving mode is materialised by a V2X application that may be hosted in the vehicle, Edge or Cloud, depending on the capabilities of the vehicle, features of the network and constraints imposed by the vehicle manufacturer. In the preliminary considered scenario, the considered V2X application is a trajectory planning application hosted by the network Edge.

In what follows, the progress made on each of these components will be reported.

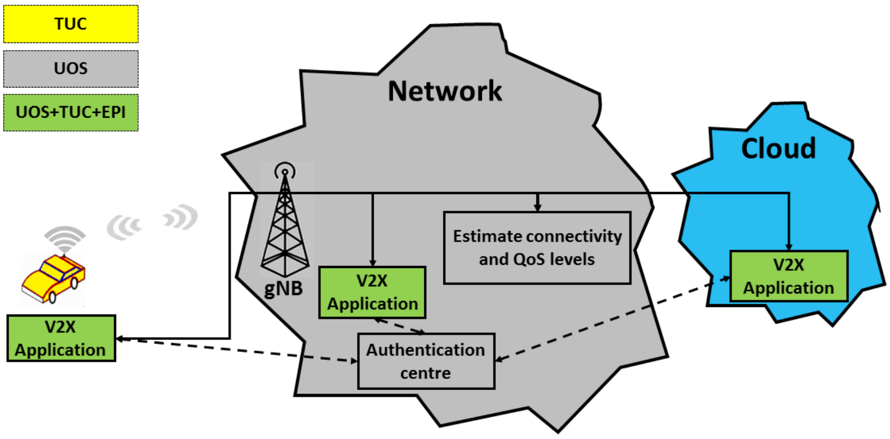


Figure 36. High level architecture for T2S3.

7.2.1 Network architecture

On the network side, the 5GENESIS trial facility is being extended to support the required functionalities described in Figure 36 (e.g., authenticator of V2X applications and estimator of connectivity and QoS levels). These functionalities will be exploited by the slicing-as-a-service functionality of 5GENESIS to support this scenario. The reader is referred to Chapter 14 for more details about the associated experimentation methodology.

7.2.2 User application architecture

The user application architecture of the T2S3 scenario is described in Figure 37. A trajectory planning, running at the Edge, interacts via the 5G network with the vehicle through a client/server architecture.

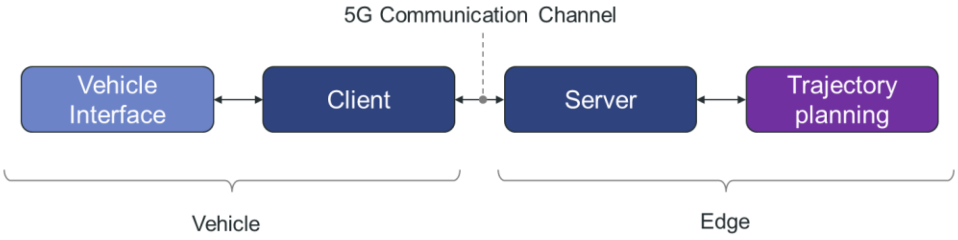


Figure 37. Use application architecture for T2S3.

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

7.2.3 Hardware components

The HW components of this use case scenario include the Edge facilities and 5G network entities situated at the UOS campus together with one of TUC's CARAI vehicles equipped with 5G communication capabilities.

7.2.4 Software components

7.2.4.1 Client agent (vehicle)

The flow chart of the client agent running on the vehicle side is presented in Figure 38.

The vehicle client initially receives routing information and current position from the vehicle interface. It requests manoeuvre assistance from the Edge. If the request is accepted, the client agent forwards the received manoeuvre instruction (e.g., trajectory) to the vehicle and keeps monitoring the execution of the manoeuvre and the performance of the communication channel.

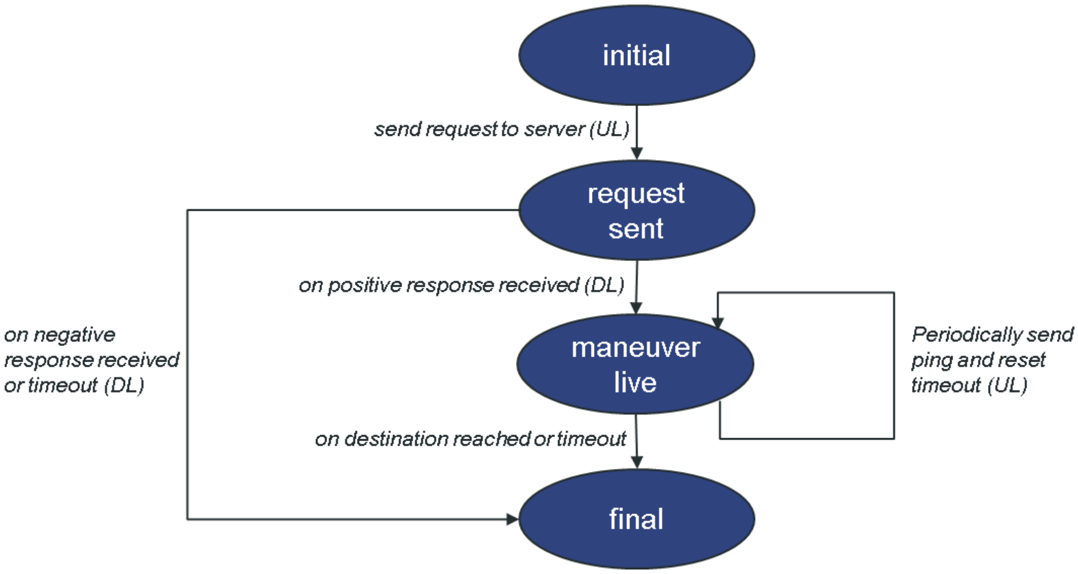


Figure 38. Client flowchart (vehicle side).

7.2.4.2 Server agent (Edge)

The flow chart of the server agent running on the Edge is presented in Figure 39.

The Edge server receives requests (i.e., position and destination) from the vehicles. It runs a trajectory planning application to determine a safe trajectory and interacts with the network to estimate whether the required QoS level can be guaranteed along the target path or not. Based on that, it accepts (i.e., OK) or rejects (i.e., NOK) the vehicle's request. If the request is accepted, the server agent provides the associated trajectory (if any) and starts monitoring the manoeuvre execution and the performance of the 5G communication channel.

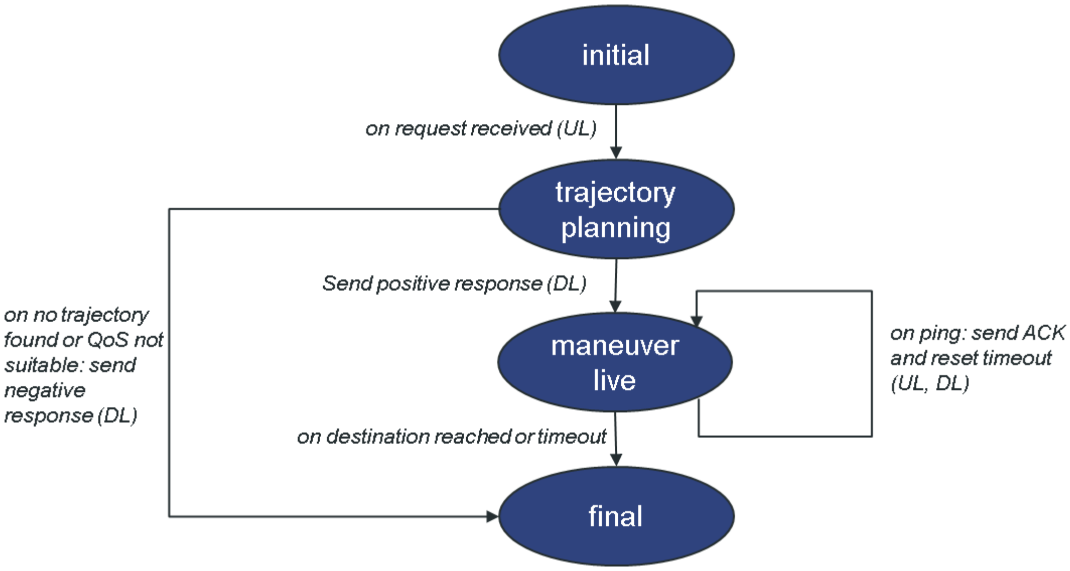


Figure 39. Server flowchart (Edge side).

To better understand the interaction between the flowcharts of Figure 38 and Figure 39, Figure 40 illustrates the exchanged messages between the vehicle and Edge sides.

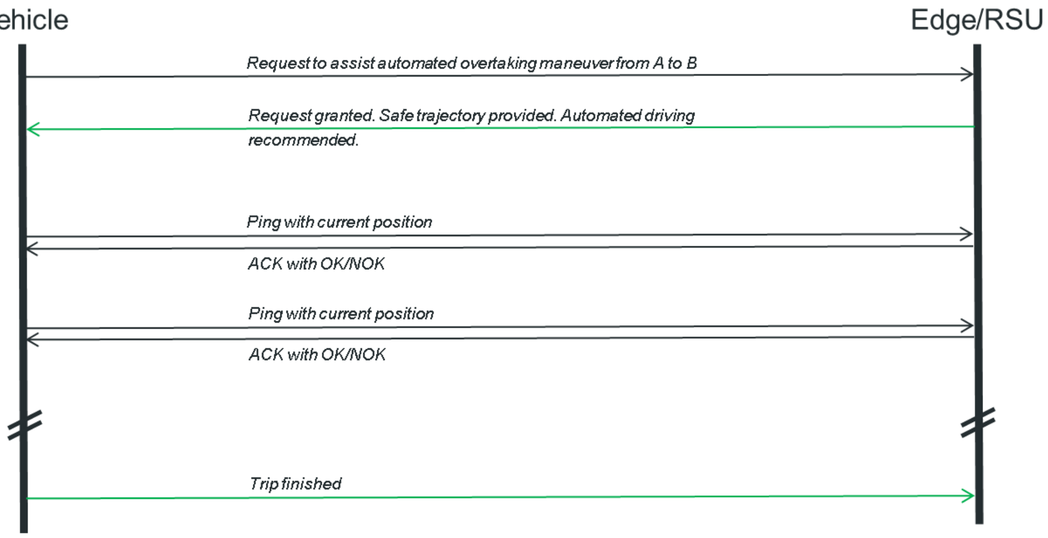


Figure 40. Message flow between the vehicle and Edge (T2S3).

7.2.4.3 Trajectory planning application

The trajectory planning application, hosted by the Edge, determines for a given manoeuvre (i.e., position, destination, heading and velocity), an optimal and collision-free trajectory on a given map subject to the existence of some obstacles. The map is modelled by a centre line (Spline, UTM) and road width to the left and right, while the obstacles are modelled by their position and trajectory (i.e., position/time).

Based to the algorithm proposed in [31], the developed application performs the following tasks:

- Calculate the Frenet coordinate of the given current position, namely the longitudinal (i.e., *s(0)*) and lateral (i.e., *d(0)*) offsets from the centre spline.
- Estimate a set of Frenet trajectories (i.e., a pair of lateral and longitudinal splines) by sampling over time, the target velocity and road geometry
    - Lateral spline: distance from the centreline over time. At planning time *t*, sample the whole road and generate multiple hypotheses for each *d(t)*.
    - Longitudinal spline: distance along centreline over time. Calculate a target offset *s(t)* at planning time *t* by sampling over the target velocity *v*.
- Eliminate any trajectory that collides with obstacles (squared distance).
- Calculate the cost for each trajectory and choose the most optimal. The relevant factors are the distance to the road centre, acceleration, and deviation from the target speed.
- Plan short Frenet trajectories in slices of 10s and repeat until destination is reached or an error occurs.

7.2.4.4 Vehicle-Edge communication

The communication between the vehicle and Edge is implemented based on ZeroMQ “Radio-Dish” sockets[**] 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[††].

[**] https://rfc.zeromq.org/spec/48/

[††] https://google.github.io/flatbuffers/

7.3 Testing and verification

7.3.1 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.

7.3.2 List of key performance indicators

The user requirements associated with this use case scenario have been analysed and converted into a set of network KPIs in Deliverable D2.2 [10]. Table 15 presents the resulting list of network requirements together with their target values.

Table 15: Target KPIs for T2S3

Network requirements	**Target values**
User experienced DL throughput	High (10-50 Mbps)
User experienced UL throughput	High (0.25-10 Mbps)
Broadband connectivity / peak data rate	DL: Low (50 Mbps) UL: Low (10 Mbps)
Latency requirements	Low SAE automation levels: Low (100 ms) High SAE automation levels: Medium (5 ms)
Reliability	High (99.99999%)
Mobility	Medium (50-200 km/h)
Location accuracy	Low SAE automation levels: Medium (4 m). High SAE automation levels: High (0.5 m)
Connection (device) density	4.3×10^3 vehicles/km^2 (peak)‡ 100 vehicles/km^2 (typical)
Interactivity	Medium (100 transactions/sec)
Area traffic capacity	0.215 Mbps/m^2 (DL peak) 0.005 Mbps/m^2 (DL typical) 0.043 Mbps/m^2 (UL peak) 0.001 Mbps/m^2 (UL typical)
Security / privacy	High (Confidential)

7.3.3 Measurement and testing tools

The T2S3 scenario (i.e., QoS for advanced driving) will be trialled on the 5GENESIS trial facility. As such, the measurement and testing tools described in Section 14.3.3 will be exploited with a particular focus on the components listed in Section 3.3.3.

Additionally, on the vehicle side, the methodology briefly described in Section 2.2.2 will be further elaborated to capture the end-user perception and assess the contribution of the on-board components to the overall performance.

7.3.4 Initial results

A limited functional testing has been performed based on an initial implementation of the Edge service and the first prototype of the client-server API.

The Edge service utilises the trajectory planning algorithm to calculate a safe and optimal trajectory for a vehicle on a geo-referenced map. Figure 41 shows the output obtained from a test scenario that was configured for the "Frauenhoferstraße" road in Chemnitz, Germany. The ported map (black) consists of the road network in question and a pre-configured ideal track (grey). The vehicle position (blue) has been extracted from the vehicle request and marked on the map. Further, an obstacle (red) has been placed on the way to simulate the need for Edge assistance. The Edge relies on the trajectory planning algorithm to calculate a safe and optimal trajectory for the ego vehicle (blue). Since the algorithm was able to identify a safe trajectory with a sufficient and guaranteed QoS level, a positive response is sent back to the automated vehicle which continues its journey at a high automation level.

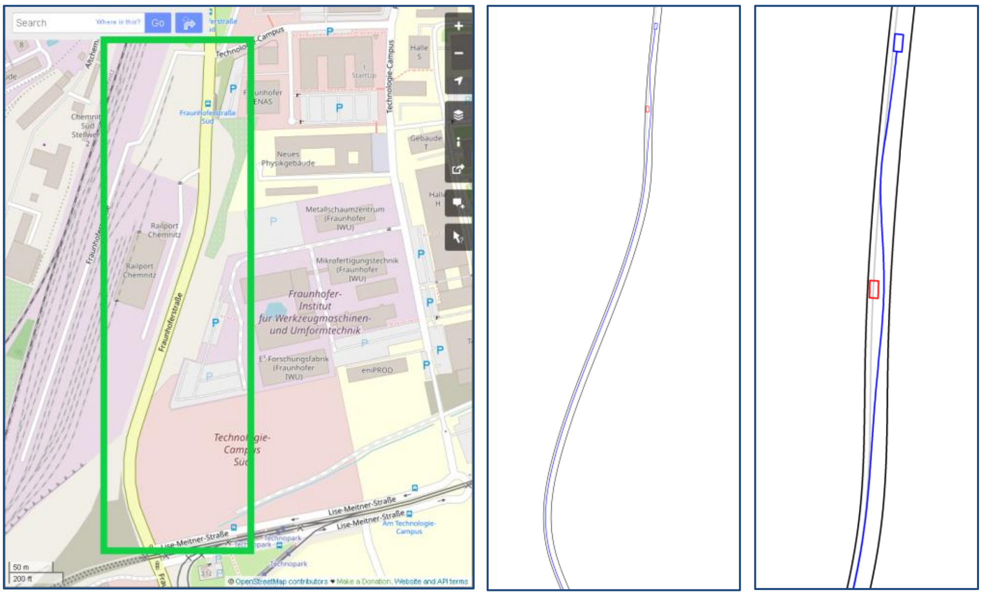


Figure 41. T2S3 test scenario with Used map from OpenStreetMap (left), Extracted map (middle) and Magnified excerpt (right). Different colours are used to distinguish "Frauenhoferstraße" [black], ideal track [grey], the automated vehicle position [blue rectangle], an obstacle [red rectangle] and the resulting ideal trajectory [blue].

7.4 Next step plans

Once all components are integrated, the initial tests will be conducted with the trajectory planning application running at the Edge of the network and interacting with an emulated vehicle via the first working prototype of the client/server API that has been developed. These tests will integrate a simplified and static form of QoS level estimation, possibly based on utility functions. As soon as the COVID-19 restrictions are lifted, a set of trials will be conducted using one of TUC's CARAI vehicles either at the TUC or UOS premises. During the course of the project, the setup will be extended to include a more advanced trajectory planning application relying on predictive QoS mechanisms based on the latest 3GPP progress. During 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.

8 T2S4: HUMAN TACHOGRAPH

8.1 Description and motivation

This scenario focuses on a wearable-based human tachograph service, which provides a direct measurement/assessment method and technology to assess the physiological status of professional drivers. Wearable sensor devices are typically worn continuously, thus also providing important information from time spent outside the vehicle. The driver's alertness and fitness-to-drive can be determined from sleep history, recovery status, stress levels and physical activity or lack thereof during the day. In addition, wearable sensors can provide real-time status information about the driver in the car while driving. The combination of historical data and real-time information of the drivers' status could also provide valuable input information for the fleet management of trucks and busses.

Wearable-based driver condition monitoring can provide useful data for the active safety systems utilised in cars and other vehicles, such as trucks and engines. However, this information will be especially useful for future connected autonomous vehicles where collision prevention can be aided by sharing information in the form of triggered warning messages between vehicles and other systems. If the monitoring data, typically restricted to the current state of the driver, is extended to include the potential risk factors identified from the driver's historical data (e.g. sleep deprivation and high stress), more proactive measures can be taken to improve the safety of driver, passengers and other road users. Wearables, when coupled with high-performance connectivity and service platforms, can furthermore provide driver condition monitoring capabilities to vehicles, which do not have an on-board system installed, or function as part of network-assisted warning and safety systems.

8.2 Proposed Setup

This use case scenario is being trialled on the 5GTN trial facility located in Oulu, Finland.

8.2.1 Network architecture

Figure 42 presents the simplified network architecture for T2S4 Phase 1 trials. The sensor device worn by the driver communicates with a 5G smartphone via short-range Bluetooth communication link. The 5G smartphone acts as a GW device and streams the sensor measurement data to the network through a 4G eNB / 5G gNB. The sensor data is then transferred through the CN to a remote service cloud. The required CN services in the Phase 1 architecture are emulated for both 4G EPC and 5GC.

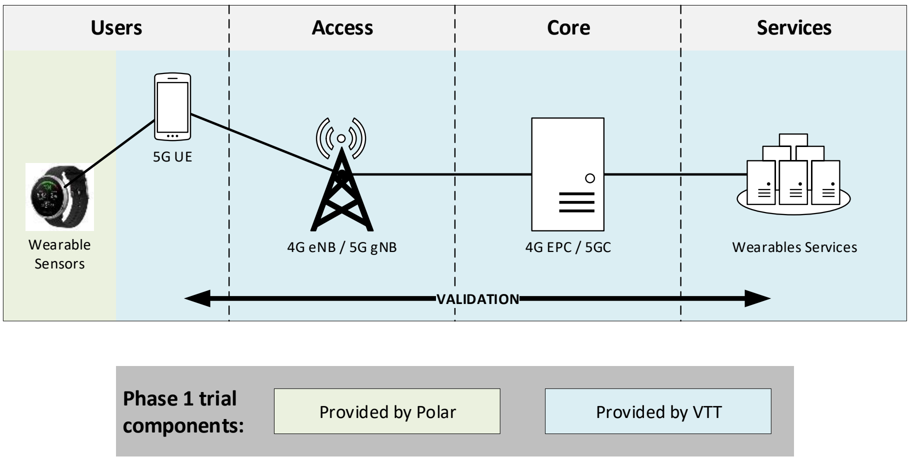


Figure 42. Network architecture for T2S4 Phase 1 trials.

The components in the Phase 1 network architecture are used as is in their default configuration. The optimisation of the network configuration for the exact needs of the Human Tachograph use case will be tested during Phase 2 trials. The wearable sensor devices are provided by Polar and the service cloud server implementation is provided by VTT. The 4G and 5G network equipment are part of the 5GTN VTT Oulu test facility and provided for the trials by VTT.

8.2.2 User application architecture

Figure 43 presents the user application architecture for T2S4 Phase 1 trials. The development and configuration of the trial setup is initially divided in two separate branches, i.e., sensor data streaming and historical data analysis. In the sensor data streaming branch, the service components include the wearable sensor device with SW, 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 forwarded to the network. In the historical data analysis branch, the server side algorithms as well as the API utilised to access the analysed historical data are developed. In Phase 1 trials, the two branches are progressing separately. The sensor data streaming trials are started on top of the 5GTN VTT Oulu test facility with reference measurements. The reference measurements are done in both the LTE and 5G NR networks to get better understanding of what the level of KPIs is in practice, using the default configuration. The historical data analysis functionality is added to the sensor data streaming trials in Phase 2 in order to enable data fusion at the smartphone or at the network edge.

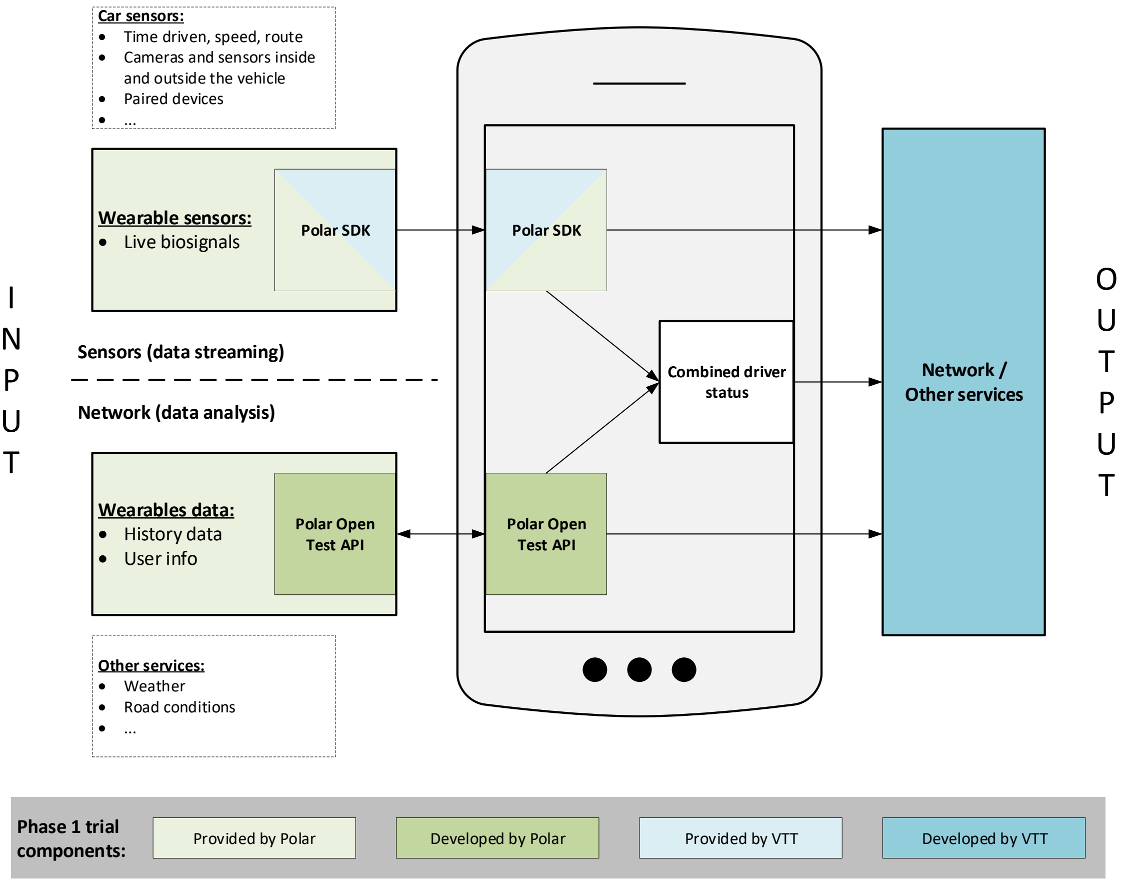


Figure 43. User application architecture for T2S4 Phase 1 trials.

8.2.3 Hardware components

The Phase 1 trial network architecture contains the following HW components:

- Wearable sensor devices:
    - Polar M600 sports watch
- 5G UE:
    - OnePlus 7 Pro 5G for receiving application traffic from Polar M600 and streaming it to the network (used for the initial results presented in subsection 8.3.4.1)
    - Samsung Galaxy S10 5G for throughput reference measurements using Nemo Handy (used for the initial results presented in subsection 8.3.4.2)
    - Nokia Fastmile 5G GW device for accurate delay reference measurements using Qosium [32] (used for the initial results presented in subsection 8.3.4.3)
    - Huawei 5G customer premises equipment (CPE) Pro GW device for refined delay and reliability measurements
- 4G eNB:
    - LTE 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)
- 5G gNB:
    - 5G NR time division duplex (TDD) Rel-15 NSA @ 3.5 GHz, BW = 60 MHz
        - outdoor macro gNB
        - indoor pico gNB (for accurate delay measurements)
        - The only supported numerology is 30 kHz subcarrier spacing, which corresponds to 0.5 ms slot duration
        - The UL/DL frame configurations that were compatible with the UEs were 1/4 and 3/7, i.e. the fraction of time slots for UL are approx. 20 % and 30 %, respectively.
- 4G EPC and 5GC:
    - Emulated CN services
- Wearables services:
    - VM server receiving the streaming sensor data in local cloud

8.2.4 Software components

The Phase 1 trial application architecture contains the following SW components:

- Polar Mobile software development kit (SDK) enables to read live data (streamed through Bluetooth) directly from Polar sensors, including electrocardiogram (ECG) data, acceleration data and heart rate broadcast.
- Polar Open Test API provides a direct information sharing link between the Polar ecosystem and smartphone/GW for historical data.
- VM server and database in the local cloud environment.
- Measurement and testing framework in the 5GTN VTT Oulu test facility.

8.3 Testing and verification

8.3.1 Methodology

In Phase 1, the focus of the trials will be on the streaming of the live sensor data at the client side and the update of the history/long-term data API at the server side. In Phase 1, these two components will be tested separately. The developed and tested features for Phase 1 trials are as follows:

- Phase 1: Initial trial implementation with long-term data service

  - Service: Analysis of driver's physiological parameters related to fatigue, such as sleep metrics, recovery status and physical activity.
  - Connectivity: Streaming of sensor data from slow moving (<50 km/h) sensor devices with short-range data transfer and 5G NR link through a dedicated smartphone or GW device. Unicast from user to application service and back.

8.3.2 List of key performance indicators

The user requirements associated with this use case scenario have been analysed and converted into a set of network KPIs in Deliverable D2.2 [10]. Table 16 presents the resulting list of network requirements together with their target values.

Table 16: Target KPIs for T2S4

Network requirements	**Target values**
User experienced DL throughput	Low to Medium (<10 Mbps)
User experienced UL throughput	Low to Medium (<10 Mbps)
Broadband connectivity / peak data rate	DL: Medium (>100 Mbps) UL: Low (<100 Mbps)
Latency requirements	Medium (5 ms)
Reliability	Low (99.99%)
Mobility	Medium (50-200 km/h)
Location accuracy	High (0.5 m)
Connection (device) density	4.3×10^3 devices/km^2 (peak)[‡] 0.43×10^3 devices/km^2 (typical)
Interactivity	High (1000 transactions/sec)
Area traffic capacity	<0.043 Mbps/m^2 (DL peak) <0.043 Mbps/m^2 (UL peak) <0.0043 Mbps/m^2 (DL typical) <0.0043 Mbps/m^2 (UL typical)
Security / privacy	High (Confidential)

The Phase 1 trials aim to verify the suitability and baseline performance of Rel-15 5G in the tested use case scenario. Hence, the target KPIs of Table 16 are not yet achievable. Instead, the Phase 1 trials are expected to reveal, as a starting point for the later trialling phases, the level of achievable service quality with the first generation 5G equipment.

The key 5G KPIs used for performance evaluation during Phase 1 are:

- Throughput for DL and UL
- E2E latency
- Reliability defined as the percentage of application packets that are successfully received within the pre-defined timeframe

8.3.3 Measurement and testing tools

The measurement and testing tools utilised in the Phase 1 trials:

- Qosium for E2E passive QoS/QoE measurements and monitoring [32].
- Keysight Nemo Handy [33] and Nemo Outdoor Playback [34] for throughput measurements and general connectivity debugging.
- Internal eNB/gNB performance counters for RAN measurements and monitoring.
- InfluxDB and Grafana for measurement data storage and visualisation.

Qosium is particularly used for measuring one-way E2E latency and reliability. Qosium is able to measure QoS parameters, such as latency, between two probes based on packet capturing. In order to get accurate latency results, it is essential that the timestamps, which the probes get from the corresponding system clocks, are accurately synchronized. For delay measurements, Qosium probes are installed at a Linux laptop and an edge server, which are accurately synchronized using precision time protocol (PTP). The delay measurement setup is shown in Figure 44. It is essential that both ends of the measured path are connected to the same PTP source with a low-jitter connection such as Ethernet.

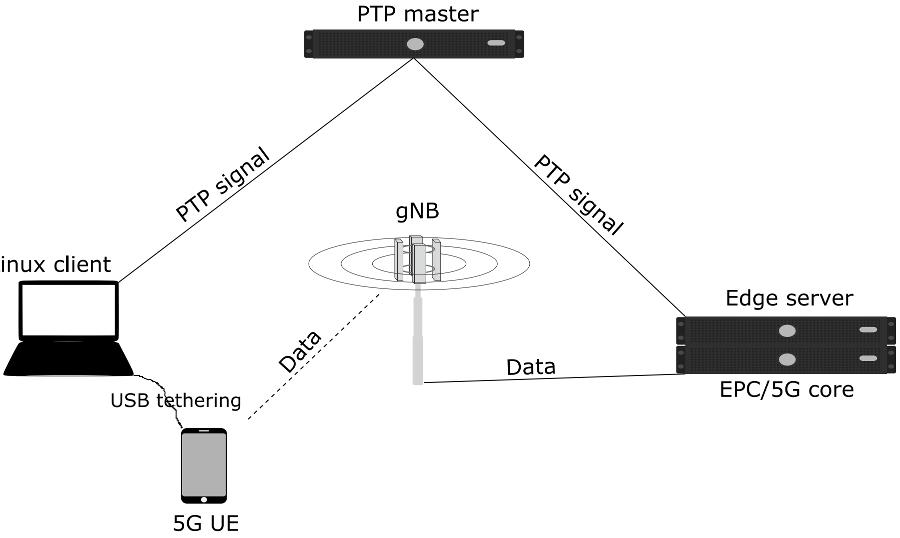


Figure 44. Delay measurement setup.

8.3.4 Initial results

The relevant KPIs, i.e. throughput, delay, and reliability, were measured in the live 5GTN VTT Oulu network for both 4G LTE and 5G NR. For the throughput measurements, the traffic generator iPerf3 was used to generate full buffer data to evaluate the maximum throughput at the given channel conditions. During the throughput measurements, there was no other activity in the same cell, i.e. the UE under consideration was scheduled with all the physical resource blocks (PRBs). For delay measurements, sensor data streaming SW compatible with a Polar watch was used in addition to conventional ping measurements.

8.3.4.1 Data and traffic model

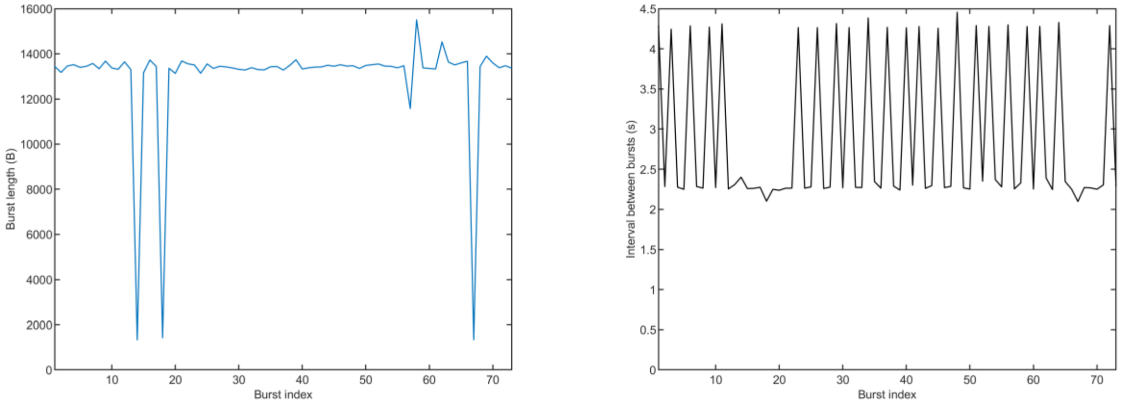
BeyondZen measurement data

During Phase 1, no new application SW for streaming and uploading the driver's physiological data was developed. Instead, an Android app developed in an earlier BeyondZen project in cooperation with VTT and Polar was utilised. The BeyondZen project was a small Finnish national SW development project focusing on the measurement and analysis of stress levels and recovery by combining information from different kinds of sensors. The app utilised in the Phase 1 measurements reads the measurement data that is transmitted from a Polar M600 watch and forwards it to an application server. While the streaming functionality of the existing SW is not optimized for low-latency alert-type services, it can be used for the reference measurements of the cellular network performed in Phase 1. A streamlined implementation for sensor data streaming will be developed for the Phase 2 and 3 trials in parallel with the sensor fusion functionality with the analysed historical data.

The current BeyondZen application version reports three different physiological measurements: Interval between two heart beats (in s), heart rate (in beats per minute (bpm)), and 3D accelerometer values of the M600 watch. The reporting frequency of the accelerometer is 50 or 100 samples/s where the higher sampling rate is used during frequent hand movement. During normal driving a heart beat interval is reported approx. every 800 ms while the heart rate reporting interval is longer, approx. 5 s. Each physiological measurement sample also includes an accurate time stamp and the location from the M600 watch GPS receiver.

BeyondZen traffic model

The M600 measurement data is transmitted from the Android phone to the server using open source remote procedure call (gRPC) protocol that is using hypertext transfer protocol (HTTP)/2. From the traffic analysis point of view, the application traffic is seen as a transmission control protocol (TCP) flow. When the TCP packet flow is analysed using the Qosium tool, it can be seen that there are long (~13500 B) and short (~1300 B) traffic bursts that are transmitted either with a long (~4.3 s) or short interval (~2.3 s). The typical burst size and the interval between successive bursts are shown in Figure 45 a) and b), respectively. The probabilities of a short burst length and a short burst interval are approx. 0.1 and 0.8, respectively. The average application data rate is ~36 kbps when measured over a several-hour session.



a) b)

Figure 45. Typical burst a) length and b) interval for the Phase 1 application traffic.

8.3.4.2 Achievable data rates in the network

The achievable data rates are measured in the outdoor drive tests next to the VTT premises in Oulu. Due to the HW-limited gNB transmission power and low antenna height with respect to the neighbouring buildings, the coverage of the outdoor 5G cell is quite limited. For this reason, the drive tests are performed around the closest road block with the maximum link distance of approx. 300 m. The same driving route is repeated in all the cases.

4G LTE, macro-eNB (reference)

The maximum achievable DL application throughput along the drive route is shown in Figure 46. The throughput variation during the drive test is shown in Figure 47 together with the other cases. The maximum throughput is ~84 Mbps, which is reasonable for a BW of 15 MHz. It can be seen that the reachable throughput varies quite a lot depending on the location. It is mainly caused by the varying channel rank that steers how many spatial multiplexing layers can be used.

Figure 46. Drive test results of the 4G LTE macro-eNB DL throughput.

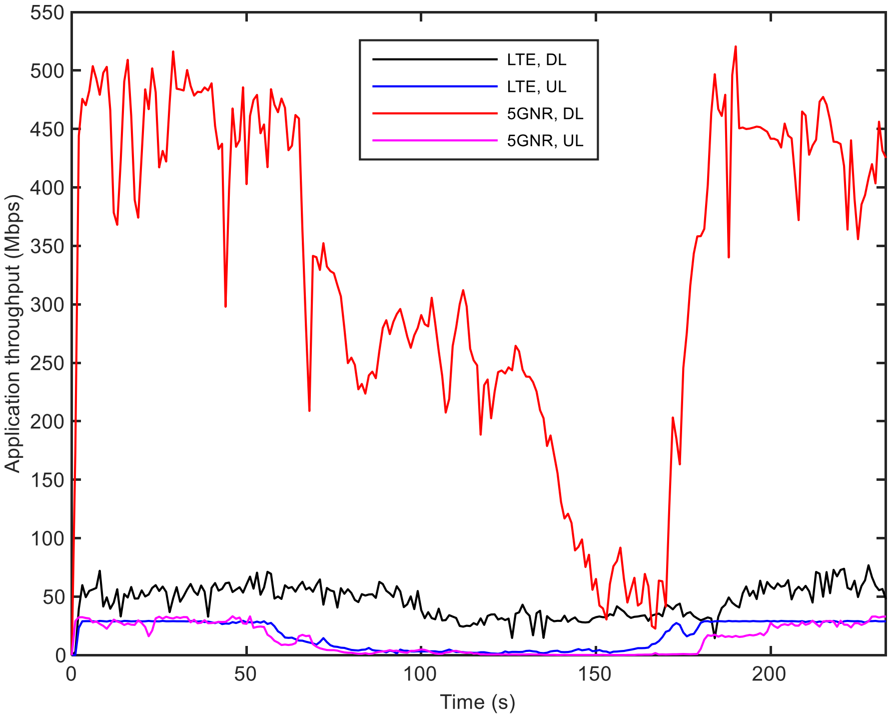


Figure 47. Drive test throughput variation for all considered cases.

Similar results from the same drive test route for UL are shown in Figure 47 and Figure 48. The maximum throughput is ~30 Mbps. The UL carrier aggregation is not used, and the UE connects only to the cell with 10 MHz BW.

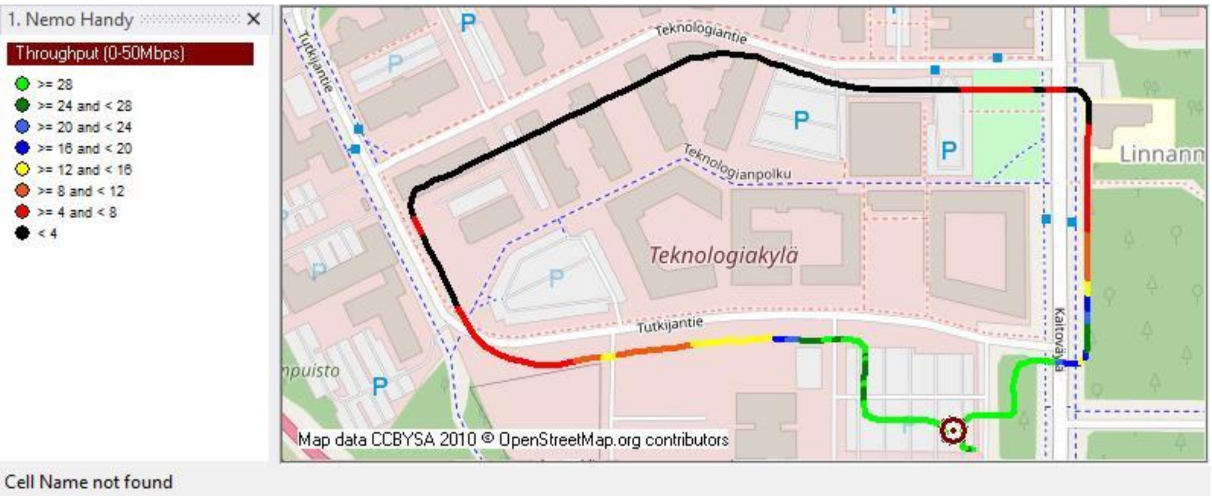


Figure 48. Drive test results of the 4G LTE macro-eNB UL throughput.

5G NR outdoor macro-gNB

The DL throughput from the same drive test route as in the 4G LTE case is shown in Figure 47 and Figure 49. It can be seen that the DL throughput varies between 20 and 520 Mbps and that the 5G NR cell has poor coverage in the northwest corner of the route. Based on the analysis of Nemo Handy logs, the peaks in throughput occur when both 256QAM modulation and rank-4 transmission are simultaneously used. However, this is very rare as can be seen from Figure 47. It is expected that the DL throughput could be even further improved by configuring a higher fraction of time slots for DL. The gNB transmission power is set to 35 dBm and 6 horizontal beams are used. It would be interesting to see the effect of configuring some other set of beams to throughput and coverage.

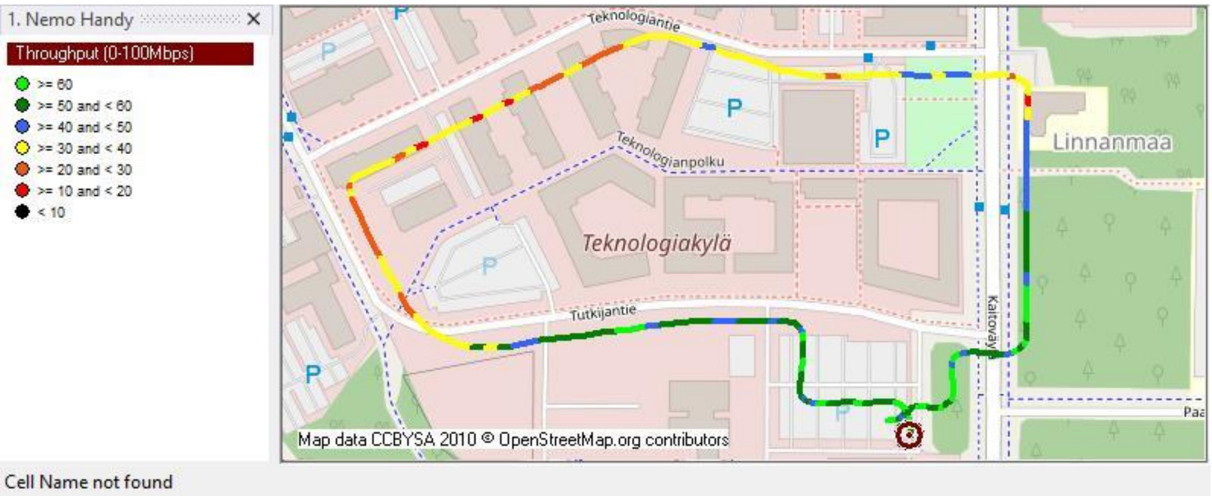


Figure 49. Drive test results of the macro-gNB DL throughput.

Similar results for the UL drive test are shown in Figure 47 and Figure 50. The throughput variation is between 0 and 33 Mbps, which is similar to the LTE UL case, and the coverage in the UL case seems to be even poorer than in the DL case. The main reasons for significantly lower throughput in UL are the lower fraction of time slots for UL (typically only 17.5 %), no spatial multiplexing is used, and 64QAM modulation at maximum. It is expected that the UL throughput can be improved by different gNB configuration, i.e. by allocating more UL resources and enabling UL spatial multiplexing.

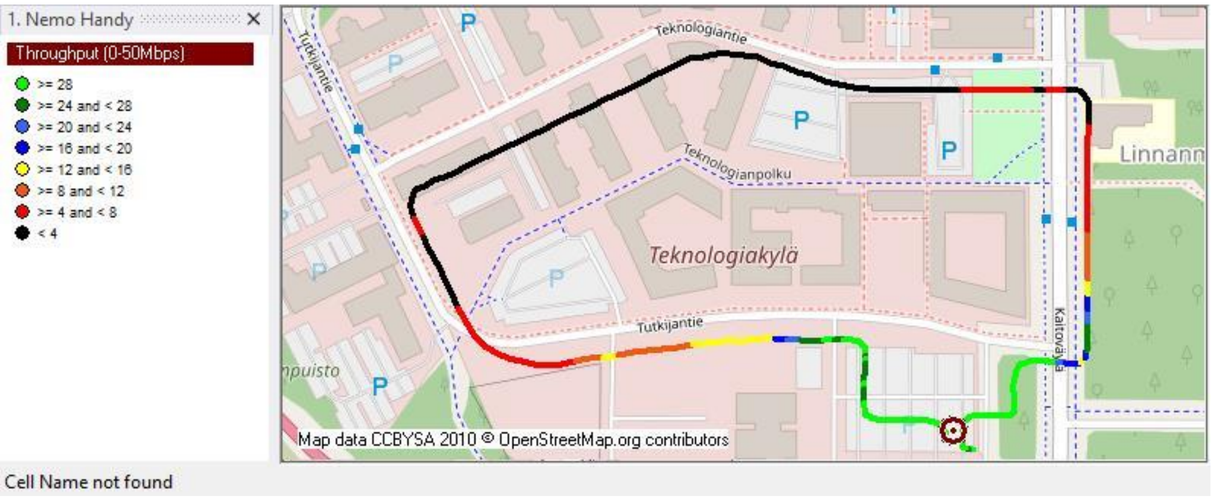


Figure 50. Drive test results of the macro-gNB UL throughput.

8.3.4.3 End-to-end latency

4G LTE Internet control message protocol (ICMP) (ping) traffic

The normalized histogram of ping RTT for 4G LTE is show in Figure 51. Most of the values are between 20 and 30 ms that is well in line with the LTE RTTs reported in the literature for good channel conditions and non-congested networks [35]. Occasional longer RTT times are due to retransmissions at hybrid automatic repeat request (HARQ) level. Due to the nature of the scheduling request procedure in LTE, the UL delay is higher than the DL delay. This is clearly visible in Figure 52 a) and b) where the normalized histograms of UL and DL delays for ping packets are shown, respectively.

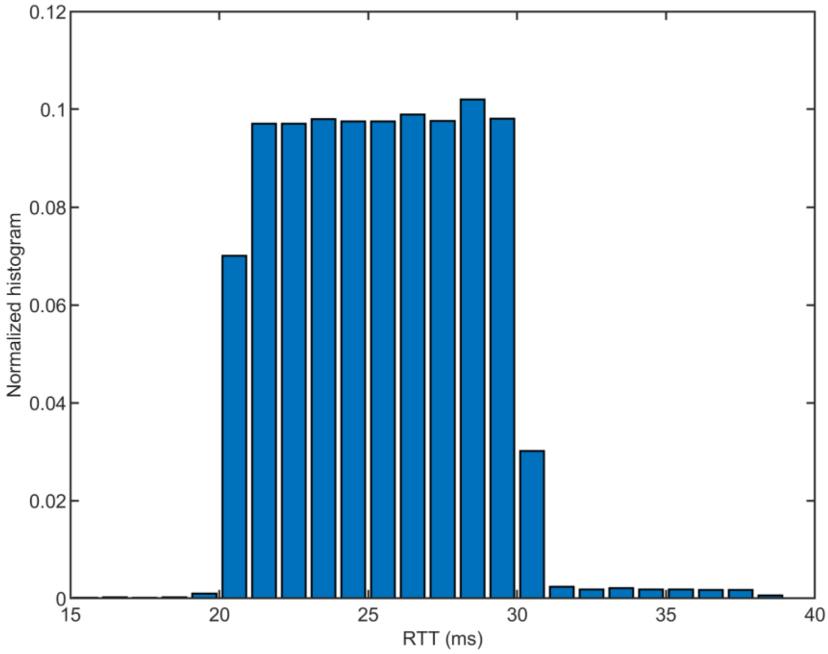
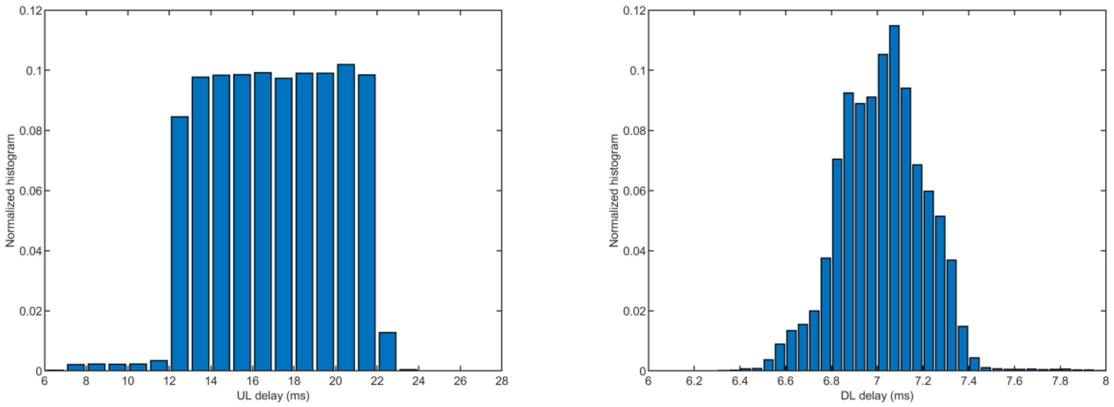


Figure 51. Normalized histogram of the overall 4G LTE RTT.



a) b)

Figure 52. Analysis of the 4G LTE RTT in a) UL and b) DL.

5G NR ICMP (ping) traffic

The best UL delay in 5G NR has been achieved using an optimized configuration according to the supported frame numerology. Using the 3/7 UL/DL frame configuration resulted in slightly shorter delays than with the 1/4 UL/DL configuration. The normalized histograms for the RTT, UL delay, and DL delay are shown in Figure 53 and Figure 54, respectively. Now the average RTT is less than 10 ms, which is clearly better than with LTE.

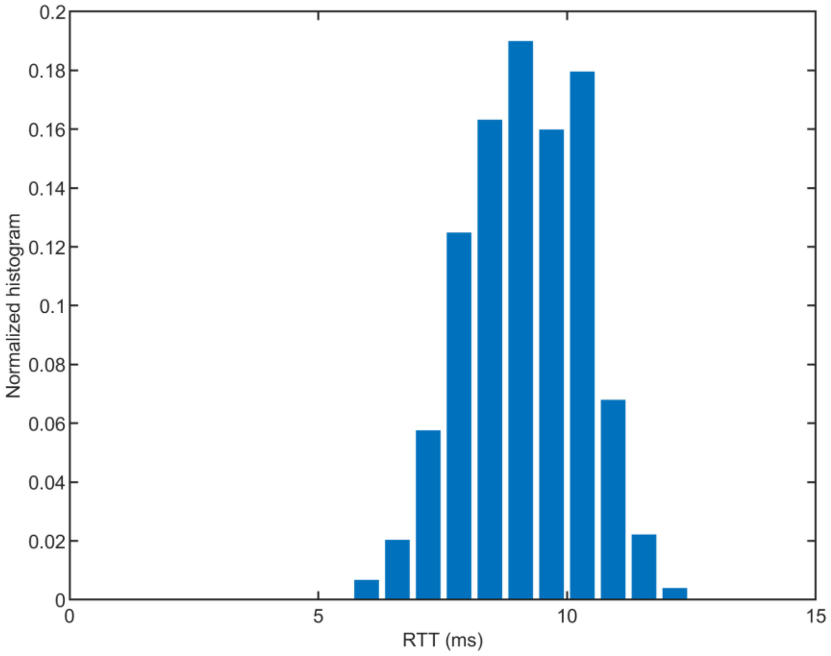
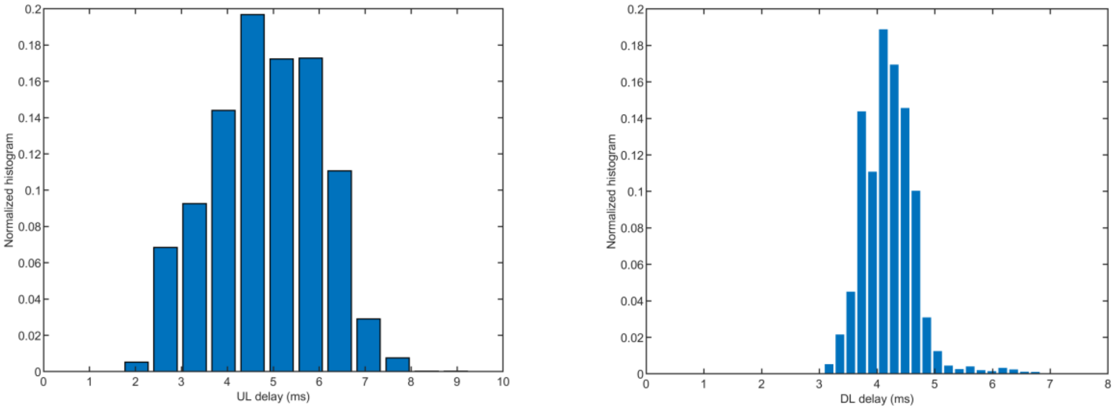


Figure 53: Normalized histogram of 5G NR ping RTT with Rel-15 optimized parameters.



a) b)

Figure 54: Normalized histogram of 5G NR a) UL and b) DL delay of ping echo request/reply with Rel-15 optimized parameters.

4G LTE BeyondZen traffic

The delay between the phone reporting BeyondZen measurements and the edge server receiving them is measured using Qosium. The normalized histogram is shown in Figure 55. The variation in the UL delay is larger than with simple ping traffic shown in Figure 52 a). This is due to the bursty nature of BeyondZen traffic, which causes some additional queuing delays for the last packets in the burst.

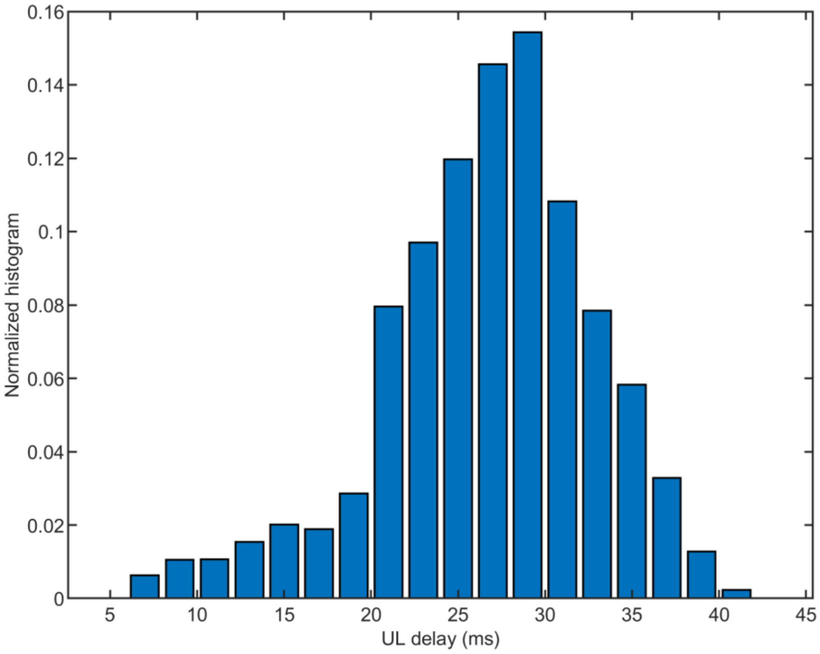


Figure 55. Normalized histogram of the 4G LTE UL delay for BeyondZen traffic.

5G NR BeyondZen traffic

The similar delay measurement for the BeyondZen application traffic was repeated when the phone was connected to the indoor 5G NR pico-gNB. The configuration changes that reduced the 5G NR ping RTTs significantly also reduced the delays for BeyondZen traffic to significantly lower levels. This is illustrated in Figure 56 where the normalized diagram for the UL delay is shown. The average of the delay is now less than 10 ms, which is clearly better than with LTE.

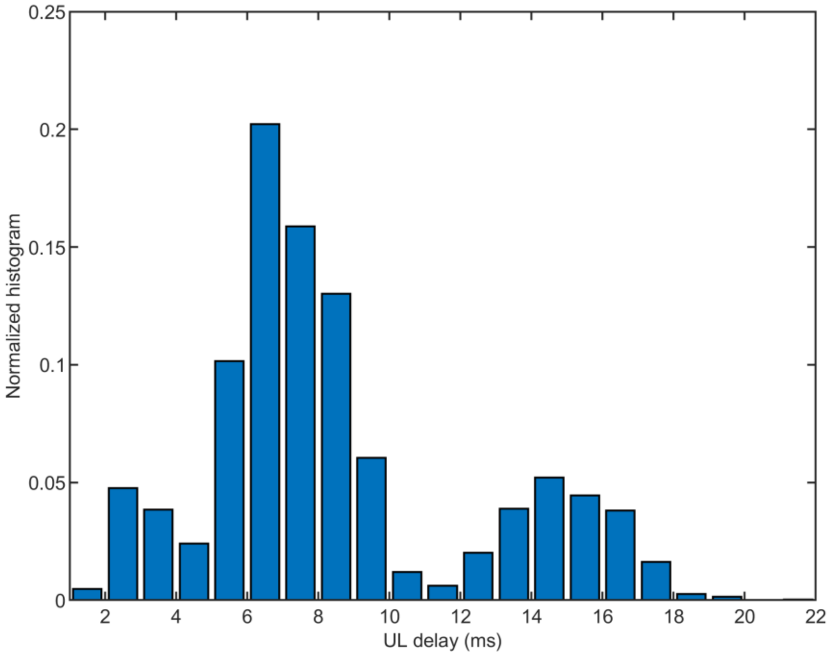


Figure 56: Normalized histogram of UL delay of BeyondZen traffic in 5G NR with Rel-15 optimized configuration parameters.

8.3.4.4 Reliability

The reliability in communication systems is defined as the number of sent data units for the given layer successfully delivered to the destination within the time constraint required by the targeted service, divided by the total number of sent data units [36]. This means that the delay results from the previous section can be used to present the reliability as a function of the time constraint.

To our surprise, all the Qosium measurements during H2/2020 had unacceptable IP-level packet loss values (up to 0.4 %). This high packet loss was visible for both LTE and 5G NR, and it was caused by ~30 s error bursts, during which all the packets were lost. However, when this phenomenon was carefully studied, it was found out that there was no visible degradation in the BeyondZen service. In addition, the air interface logging tool (Nemo), didn't report excessive number of ARQ or HARQ re-transmissions, which could have caused the packet loss at the air interface. Based on these findings, we can conclude that the packet loss was most likely due to Qosium having difficulties to correctly recognize the IP packets with almost identical payload after the GTP tunnelling in the core network. The reliability as a function of time constraint for BeyondZen traffic with optimized gNB parameters is shown in Figure 57. It can be seen that 5G NR provides clearly improved reliability when compared to LTE.

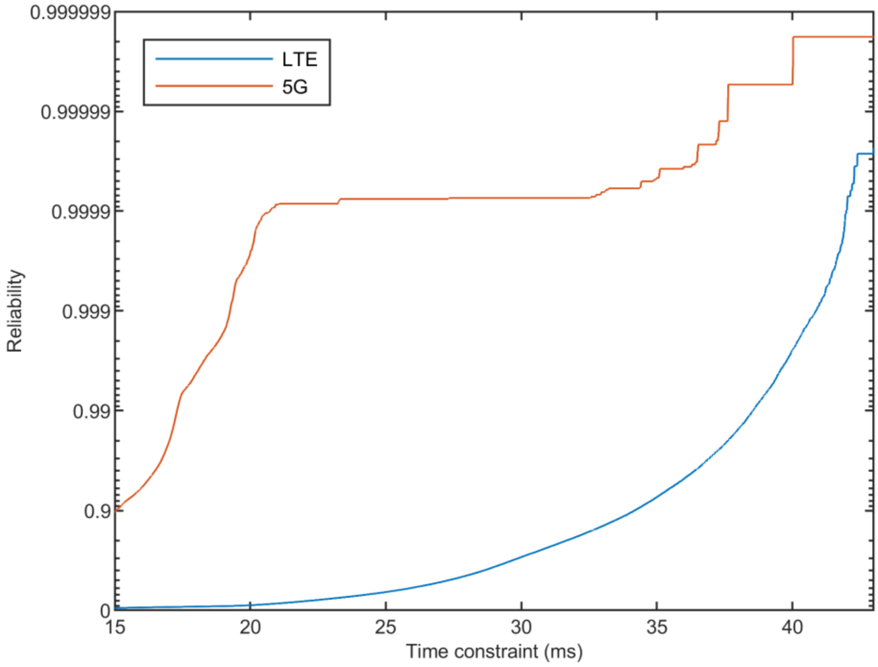


Figure 57: Reliability as a function of time constraint for BeyondZen traffic with Rel-15 optimized configuration parameters.

8.4 Next step plans

When moving from Phase 1 to Phase 2, the first step in the continuation of the sensor data streaming trials is to investigate further the different network configuration options supported by the current test facility setup and extend the tests to other service architecture options by introducing MEC functionality into the use case scenario. The current network configuration is optimised for enhanced mobile broadband (eMBB) use cases where DL performance is in a dominating role. In the streaming part of T2S4, the UL performance is in key role, so some re-configuration at least for the 5G NR link will be required. As the COVID-19 restriction slowed down the progress of the trial configuration and execution during the last months of Phase 1, measurements with different gNB configurations, especially to increase the gNB UL throughput and decrease the overall delay will be continued in the beginning of Phase 2. In addition, the application SW to support alert-type traffic with lower latency streaming of the live sensor data will be developed for the Phase 2 trials. As an additional feature, the inclusion of the analysed historical data to the trials setup through the updated API will be deployed. Finally, all reference measurements performed with Rel-15 5G gNB SW will be repeated with Rel-16 SW when it becomes available on the 5GTN VTT Oulu test facility.

9 T3S1: TELE-OPERATED SUPPORT (TESO)

9.1 Description and motivation

Remote driving is a concept in which a vehicle is controlled remotely by either a human operator or a Cloud computing SW. While autonomous driving needs a lot of sensors and sophisticated algorithms like object identification, path planning and vehicle control, remote driving with human operators can be realised using less of them, provided that ambient information is properly transferred and visualised to the remote vehicle operator. In the refined version of the tele-operated support (TeSo) scenario examined specifically in the framework of 5G-HEART, a vehicle is traveling in a public street, bearing HD video cameras (front, and potentially right-left side and rear views) and several sensors providing instrumentation data on the driving condition of the vehicle. With the aid of vehicle's instrumentation data and real-time video streaming, a remote human operator can monitor the vehicle and perform manoeuvres if required, i.e., control the direction and speed of the vehicle. In principle, tele-operation may be considered throughout the vehicle journey, or on-demand after the request of the driver for remote assistance. In the considered scenario, tele-operation will take place on-demand.

All instrumentation data and video streams are communicated to the remote location of the human operator, denoted as the remote operations centre (ROC), which can be either accessed through the core or located at the edge of the network. In the considered scenario the ROC will be at the edge of the 5G network. The instrumentation data and video feed represent sufficient ambient information that will allow the accurate creation of situation awareness and prompt reaction to emerging hazards (e.g., collision avoidance, eco-driving). In that sense, there is no need for sophisticated/expensive artificial intelligence (AI) computing infrastructure inside the vehicle. Furthermore, such TeSo capability, enables a single human operator to remotely monitor potentially multiple vehicles and control one of them on-demand for a short period of time, when the need arises. Subsequently, additional levels of protection and scales of economy are provided, e.g., allowing an operator to monitor the driving of three vehicles and prevent hazardous situations.

The benefit of realizing the TeSo scenario will be multi-fold for several involved stakeholders. These include the automotive industries and the AV technology suppliers at the lower technological level, certified human remote operators and companies offering TeSo-as-a-Service at the next level, network operators/providers that will enable such scenarios, and public administration bodies involved in the regulation domain at the top level. Of course, drivers of legacy vehicles and potential passengers are also considered as stakeholders, at the highest level as well. Allowing tele-operated driving support (of several semi-automated driving), can be a first cost-feasible step for the realisation of the broader vision for purely automated driving. This will mean a feasible solution for realizing lower-cost professional transportations and public support vehicles, e.g., tele-operated public vehicles such as gritters, by having human operators remotely controlling them. An advanced security layer will be, also, provided, since societies currently trust more the human-supervised tele-command than complete automated driving. Finally, the realization of the TeSo service will bring the public safety one step closer to the envisioned desired scenario of humans remotely operating vehicles in case of critical/emergency conditions. For example, a remote human operator could undertake the driving of the vehicle, in case of driving SW failure (vehicle-based or remotely based), human driver emergency sickness, or extreme weather conditions, in locations not accessible to public, while ensuring the necessary safety conditions for the rest of the required trip segments. Regarding the latter, the outcomes of this scenario, can be ideally combined with the Human Tachograph scenario, as presented in T2S4, and demonstrate this potential for situation awareness and protection. Furthermore, as already explained in Chapter 7, scenario T3S1 will be combined with T2S3 (i.e., QoS for advanced driving), since in terms of trials, they rely on the exact same infrastructure. Both T2S3 and T3S1 will be tested using the same equipment, while considering the different KPIs to be measured for each scenario.

9.2 Proposed Setup

This section describes the proposed setup and on-going developments in terms of the first trialling phase of this use-case scenario which will be trialled on the 5GENESIS trial facility located in Surrey, UK. The initial work described includes the development and testing of multiple SW components that are to be further extended and complemented with additional functionalities, enabling large-scale trialling execution. The evaluation and testing of the developed SW components have been performed in laboratory environment setup during the first trialling phase. Subsequent large-scale trials will take place in the 5GENESIS premises, utilizing the corresponding 5G testbed, as presented in Section 2.1.1.

9.2.1 Network architecture

The overall system architecture for the provision of a teleoperated support service is illustrated in Figure 58 below. The main parts that constitute the architecture are a remotely operated-enabled vehicle, the 5G access and CN infrastructure and a remote-control centre located at the cloud or at the edge of the CN – initially at the edge. The access and/or CN infrastructure secures the communication between the vehicle and the remote-control centre and thus, is crucial for the viability of the service, charged to meet the stringent requirements of data transmission from the vehicle to the ROC and vice versa. More precisely, the vehicle is equipped with the appropriate sensors/instruments and actuators to measure and control vehicle's speed, acceleration, steering angle, brake position, as well as cameras to allow video feed. An OBU that interfaces with the sensors/ instruments and the cameras is responsible to capture such useful data and enable their usability by other HW components integrated to the vehicle, as for instance the ROC gateway (ROC-GW) depicted in Figure 58. The ROC-GW is comprised by an Intel next unit of computing (NUC) mini PC and its purpose is the processing and aggregation of data extracted by the OBU and their final transmission over 5G to the ROC. Considering the DL communication scenario, the control commands, transmitted over 5G from the ROC to the vehicle, are received by ROC-GW and forwarded to the OBU, where their conversion into control commands for the vehicle's actuators takes place. Eventually, the OBU provides an interface with the vehicle's sensors\instruments and actuators, while the ROC-GW serves as an intermediate point for the communication between the vehicle and the ROC.

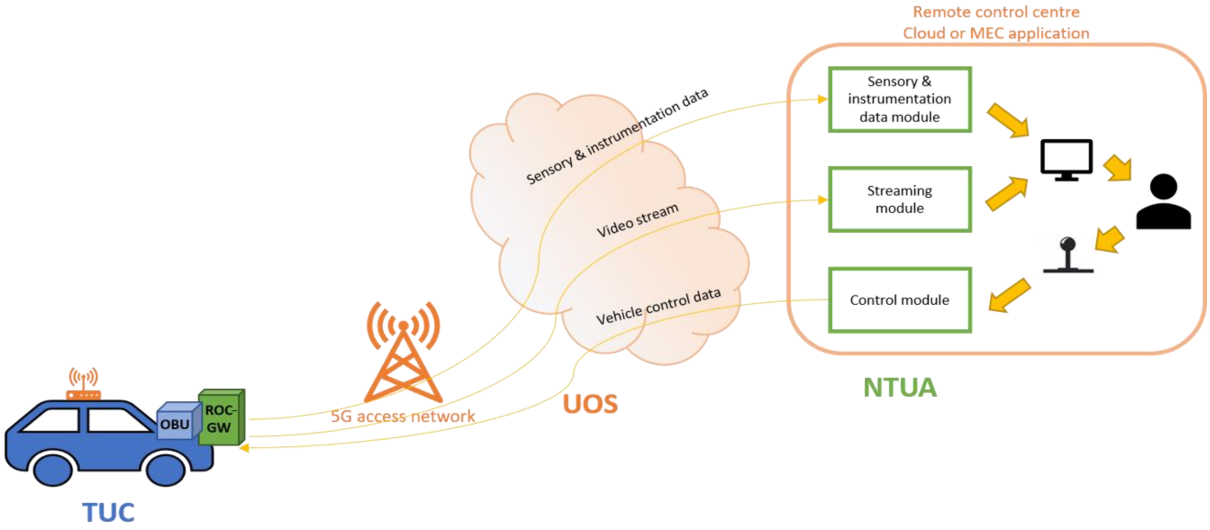


Figure 58. Overall architecture of T3S1.

On the other side of the network, a human operator handles the remote control of the vehicle, empowered by the visualization of the transmitted data, with respect to the functionalities that the deployed SW application provides them. In particular, the remote-control application consists of several sub-components, namely the sensory & instrumentation data module, the streaming module and the control module. Each of these three sub-components interfaces with an appropriate indicator/controller. The first two interface with a visualization indicator enabling the human operator to monitor the driving conditions and state of the vehicle, while the control module interfaces with an input device (e.g., keyboard and joystick) to allow the issuing of commands to the vehicle.

As depicted in Figure 58, in the context of TeSo use-case scenario, the 5G access and CN infrastructure of the 5GENESIS site (Section 2.1.1), as well as the research experimentation vehicles of TUC (Section 2.2), are utilized. The vehicles bear all appropriate HW that enables connectivity and communication with the 5G access network infrastructure, as analytically described in Section 2.2.2. In the following, the methodology for the deployment of the SW components/applications running at the vehicle and ROC sides is described, and the initial simulation results are presented to validate the operation of the proposed solution.

It should be noted that Figure 58 provides a colour-coded architecture of the proposed setup, where the various colours represent the responsible partners for each module, i.e., TUC for the vehicle, UOS for the 5G access/core and NTUA for the ROC application. The physical topology will be implemented over the UOS campus for the final trials, investigating the case of MEC scenario as explained above. An additional scenario with the ROC application installed at a physical machine at NTUA campus in Athens, Greece could be performed as well. In this scenario, the ROC application residing at NTUA will serve the purpose of a cloud-based ROC application and allow quantifying the metrics of interest under a more stringent environment. Furthermore, it could reveal the extent of the anticipated gap in achievable KPIs and pave the way for a roadmap that will allow convergence and future research.

9.2.2 User application architecture

The architecture of the user (i.e., remote operator) application is shown in detail in Figure 59. Further description of the functionality that each module bears, as well as their final deployment, is provided in the sections below.

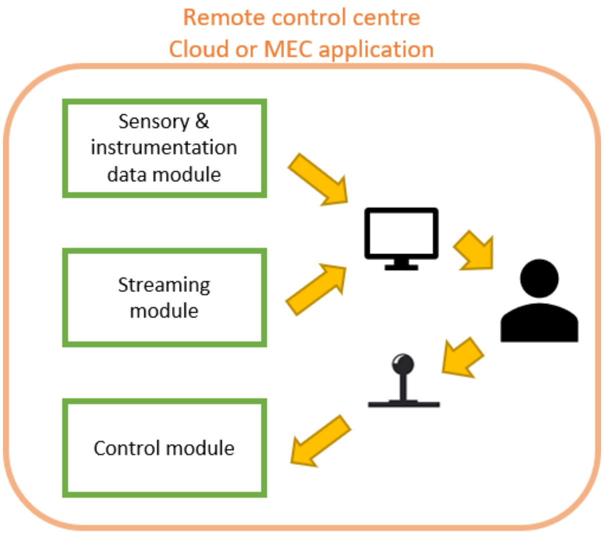
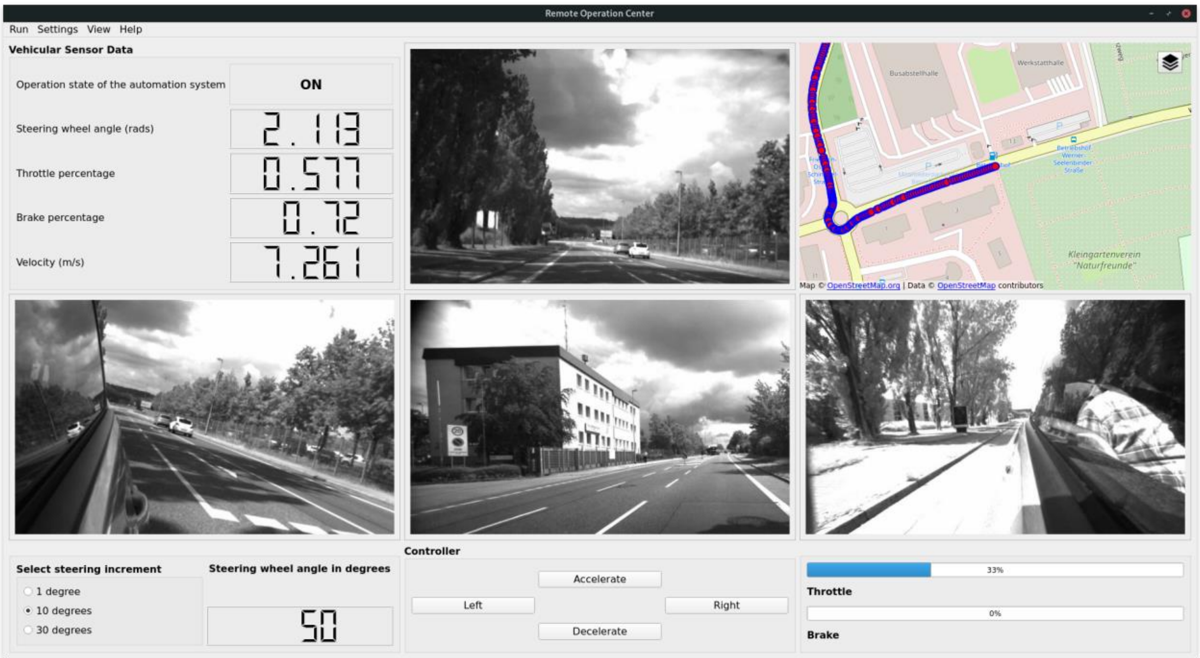


Figure 59. User application architecture of T3S1.

A screenshot of the ROC graphical user interface (GUI) application with sample output can be seen in Figure 60, obtained as part of the individual component testing activities. A map depicting the vehicle's trace, constructed based on the received GPS coordinates, is located in the upper right corner. Telemetry information regarding the automation state (e.g., steering wheel angle, throttle, and brake percentage) and the vehicle state (e.g., velocity) is presented in the left upper corner. The window's central components display the four video streams from the vehicle-mounted cameras (from left to right and top-down: back, left, front, and right cameras). Finally, the control-related components are located at the bottom row of the window. In the middle, there are four push buttons mapped to acceleration, deceleration, left and right turns. To the right, two bars visualize the percentage of throttle and brake given as input by the user and calculated based on how long the respective buttons are held pressed. To the left, the selected radio button declares the used angle increment that is added (or subtracted) each time the left (or right) button is pressed, while the steering wheel angle that will be sent to the vehicle is (re)calculated after every user input and displayed in degrees, with positive angles expressing steering to the left. The user input can be alternatively provided from the keyboard via the respective arrow keys, without pushing the graphical buttons. The shown steering wheel angle and throttle/brake percentage correspond to the input that the user is currently entering and serve as a way of setting the desired value, whereas the telemetry information displayed at the upper left corner describes the current state of the vehicle that was lastly reported by the onboard sensors and instruments.



Vehicular Sensor Data

Operation state of the automation system: ON
Steering wheel angle (rads): 2.113
Throttle percentage: 0.577
Brake percentage: 0.72
Velocity (m/s): 7.261

Controller

Select steering increment
○ 1 degree
● 10 degrees
○ 30 degrees

Steering wheel angle in degrees: 50

Throttle: 33%
Brake: 0%

Figure 60. ROC GUI Application.

9.2.3 Hardware components

The Phase 1 trial network architecture contains the following components:

- OBU: This is the OBU of TUC's research experimentation vehicles
- TUC's CARAI 3 (C3) vehicle and incorporated sensors (see Section 2.2)
- ROC-GW: Intel NUC mini PC (one of the following two configurations; TBD depending on the trials' requirements)
  - Intel Barebone NUC NUC8i3BEH 8109U
  - Corsair Desktop RAM Vengeance LPX 16GB Kit 3200MHz DDR4
  - Samsung SSD 860 EVO 500GB

  or

  - Intel Barebone NUC NUC8i7BEH 8559U
  - Corsair Desktop RAM Vengeance LPX 32GB Kit 2400MHz DDR4
  - WD SSD Blue 3D 1TB
- SDRs: USRP N320, 2 transmission (TX)/reception (RX) channels @ 3MHz-6GHz, BW=200 MHz
- eNB: OAI eNB
- 5GC: 5GIC core

9.2.4 Software components

The Phase 1 trial application consists of three SW components, each residing either at the vehicle or ROC side of the overall considered architecture, as depicted in Figure 58. Specifically, considering the vehicle side, two applications running at the OBU and ROC-GW have been developed. The third application running at the ROC side, hereafter referred to as ROC GUI, complements the SW development during the first trialling phase.

In the remainder of the current section, a detailed analysis of the SW development of the standalone ROC-GW and ROC GUI applications is presented, which further illustrates their seamless operation. The description of the corresponding application executed by the OBU can be found in Section 2.2.2.

9.2.4.1 ROC-GW Application

The ROC-GW application consists of the following modules, each of them corresponding to a different functionality:

- **Camera module:** By interacting with the OBU application, the camera module receives the video streams and transmits them through the network to the ROC to be further processed by the Streaming module of the ROC GUI application.
- **Sensor and instrumentation module:** By interacting with the OBU application, this module receives the sensor and instrumentation data (e.g., vehicle velocity, wheel angle, throttle percentage value, brake percentage value and GNSS position data) and transmits them through the network to the ROC to be further processed by its counterpart at the ROC GUI application.
- **Control module:** The purpose of the control module is to receive the remote-control commands issued by its counterpart at the ROC GUI application, before transferring them to the OBU and ultimately to the vehicle actuators.

The ROC-GW node was constructed using the DRAIVE Link framework[‡‡]. In Link, the communication between nodes that are part of the same mesh network is done via *messages*. Messages carry different data as payload and are being sent between the nodes using network transport protocols. In order to transport a message from a sender (publisher) to the receiver (subscriber), a publish-subscribe communication pattern is used. A publisher announces the types of data that are available for subscription. This comprises the publisher’s *offer*. A subscriber can subscribe to this offer either partially or to its entirety according to his *demand*. *Output pins* assemble the desired data into messages and send them to other nodes. *Input pins* receive these messages and decompose them into data objects for further processing. The advantage of this subscription model is the subscriber centric communication pattern. Data is transmitted only when there is a subscriber interested in it. This saves bandwidth in the mesh and reduces dependencies between publishers and subscribers. A subscription is defined by *mapping* data fields of the publishers’ offers to corresponding data fields of the demand of each input pin. The subscriptions and corresponding mappings are described in the *instance.json* file of the subscriber node. Offers and demands (i.e., data types) have a FlatBuffers[§§] table format. Data objects hold the actual data and they are an *instance* of the corresponding data type. The output pins of the publishers push these FlatBuffers objects to the mesh. Data are received and pulled from input pins by registering callback functions. More precisely, a thread is spawned that polls for messages, providing notifications about incoming messages via the respective callback function.

The design of the ROC-GW is presented in Figure 61. The implemented node acts both as a subscriber and a publisher, having seven input pins and three output pins.

[‡‡] https://draive.com/

[§§] https://google.github.io/flatbuffers/

According to the configured subscriptions, the input pins receive the respective FlatBuffers table data objects accompanied with the respective timestamps. These objects include:

- The JPEG encoded frames of the video streams from the front, back, right, and left camera,
- The vehicle velocity in meters per second,
- The automation state including the currently set steering wheel angle in radians, throttle percentage value and brake percentage value,
- The GNSS position data.

To forward these objects to the ROC over the 5G network, ZeroMQ[***], a high-performance asynchronous messaging library that runs without a dedicated message broker, is employed, and the FlatBuffers tables are packed inside ZeroMQ messages and are sent to the ROC via ZeroMQ sockets following the publish-subscribe messaging pattern (the ROC-GW is the publishing endpoint and the ROC the subscribing endpoint). Regarding the camera input pins, the received data objects (i.e., video frames) are further processed (downscaled and compressed using an adjustable predetermined level from 0 to 100) before being forwarded.

The output pins push the FlatBuffers table data objects that they receive from ROC (i.e., the desired throttle percentage value, brake percentage value, and wheel angle in radians) to the 5gh-carai3 mesh, where the OBU (i.e., TUC PC in Figure 5) has subscribed to them. Once again, the ZeroMQ publish-subscribe messaging pattern is employed for the transmission of these remote-control commands from ROC to ROC-GW (this time, ROC is the publishing endpoint and ROC-GW the subscribing endpoint).

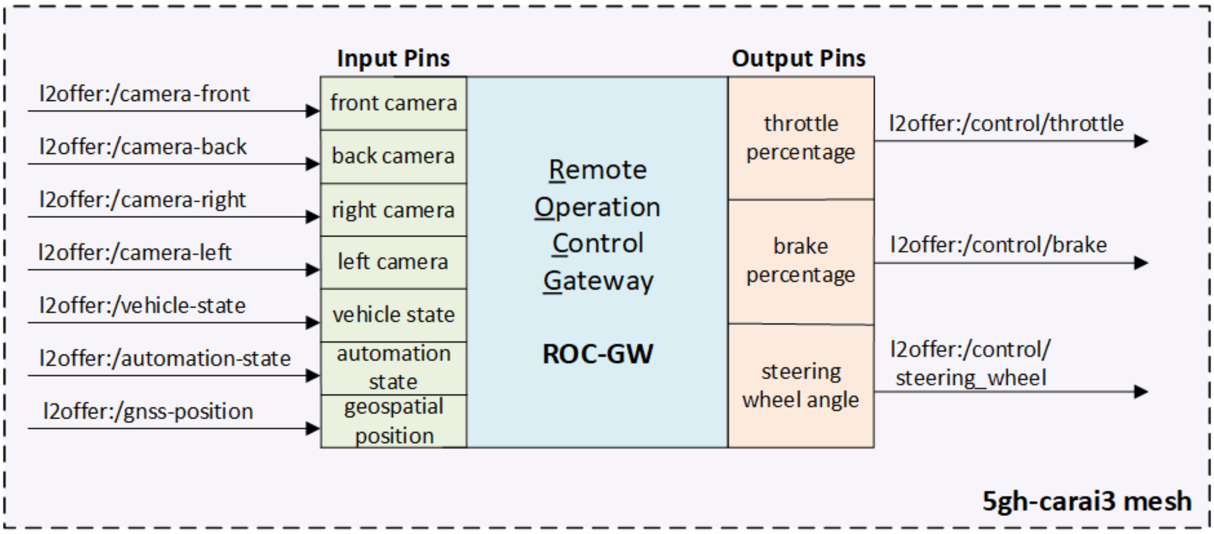


Figure 61. ROC-GW.

9.2.4.2 ROC GUI Application

The ROC GUI application consists of three distinct modules that are combined into one transparent application for the human operator. It can be installed at the cloud or MEC enabling the implementation of trials and comparisons of results.

- **Streaming module:** This part of the architecture resides at the cloud or MEC and is in charge of receiving the video streams through the network and displaying them appropriately to the human operator.

[***] https://zeromq.org/

- **Sensor and instrumentation module:** This part of the architecture resides at the cloud or MEC and is in charge of receiving the sensor and instrumentation data and displaying them appropriately to the human operator.
- **Remote control module:** This module is in charge of providing an interface to the human-operator in order to control the vehicle. It is responsible for transmitting the actual remote-control commands to the vehicle side control module.

The ROC GUI application (Figure 60) has been implemented using the Qt5[†††] framework and following a multithreaded design. The main (or GUI) thread is responsible for the construction of the main window with all the included widgets (described in Section 9.2.2) and for obtaining the user input and sending the remote-control commands to the ROC-GW. It should be noted that the 2D map displayed at the upper right corner visualizes the received GPS data by drawing a marker at the corresponding coordinates, and has been written in QML leveraging the Open Street Map Plugin[‡‡‡] that supports the following map types:

- Street map view in daylight mode,
- Cycle map view in daylight mode,
- Public transit map view in daylight mode,
- Public transit map view in night mode,
- Terrain map view,
- Hiking map view.

The *signals and slots mechanism* of Qt is used for displaying the vehicle's data sent from ROC-GW. In particular, separate threads are used for the reception of each data type through ZeroMQ (i.e., four video streams, vehicle state, automation state, and GNSS position), and, after the necessary processing and data type conversions, suitable signals connected to the appropriate display slots of the main window's widgets are emitted.

9.3 Testing and verification

9.3.1 Methodology

End-to-end topology

TUC's research experimentation vehicles, as presented in Section 2.2, use the DRAIVE Link framework as a middleware to provide access to sensor data. Link is based on a decentralized and consumer driven publish-subscribe architecture in order to provide low-latency data connectivity, extreme reliability and scalability. In order to integrate our solution to the vehicular platform, a NUC small factor PC, with the specifications described in Section 9.2.3, has been provided, henceforth denoted ROC-GW, which will be mounted to the vehicle and will serve a twofold purpose, as illustrated in Figure 62. On the one side, it will be connected to the vehicle's Ethernet switch and will leverage the automatic discovery functionality of Link to form a mesh network over the local network, together with the provided pub/sub communication model over TCP to access (subscribe to) the sensory/instrumentation data and the camera streaming feeds, as well as to transmit (publish) the remote control commands to the vehicle's actuators. On the other side, the ROC-GW will transmit over the 5G network the sensor data and video streams to the ROC that can be located at the cloud or MEC and will receive the remote-control commands in the opposite direction. Trials and performance evaluation will take place at the campus of the UOS and will employ the corresponding 5GENESIS infrastructure presented in Section 2.1.1.

[†††] https://www.qt.io/

[‡‡‡] https://www.openstreetmap.org/about

In order to extend the 5GENESIS trial facility with C-V2X support, the OAI UE[§§§] SW will be appropriately configured and installed either on the ROC-GW itself, or on another dedicated device (e.g., laptop) in the vehicle's local area network (LAN), and a USRP N320 will be utilized for the radio transmissions. Figure 62 illustrates the overall envisioned end-to-end topology. Note that the ROC-GW, installed inside the vehicle, is depicted separately for clarity of the data flow.

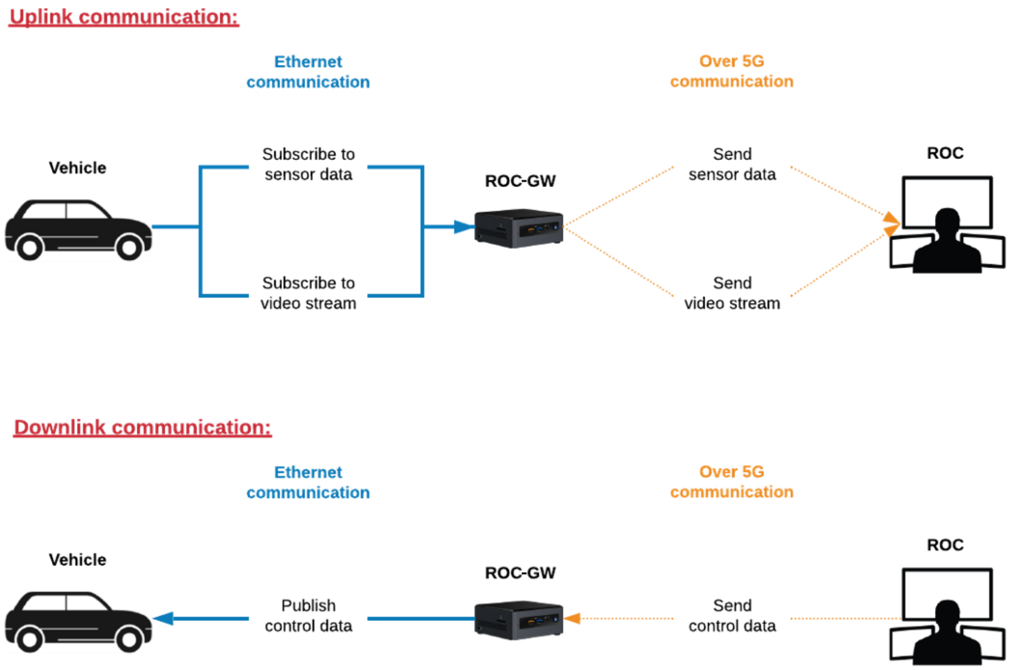


Figure 62. End-to-end data and video transmission overview.

9.3.2 List of key performance indicators

The user requirements associated with the TeSo use case scenario have been analysed and converted into a set of network KPIs in Deliverable D2.2 [10]. Table 17 presents the derived list of network KPIs together with their target (range of) values, which account for a wide variety of potential wireless environments (i.e., urban, sub-urban, highways), different connection densities, and thus, diverse wireless links conditions.

Table 17: Target KPIs for T3S1

Network requirements	Target values
User experienced DL throughput	Low to Medium (1-5 Mbps)
User experienced UL throughput	High (16-20 Mbps)
Broadband connectivity / peak data rate	DL: Low (5 Mbps) UL: Low (20 Mbps)

[§§§] https:// gitlab.eurecom.fr/oai/openairinterface5g

Latency requirements****	Medium (5-20 ms)
Reliability	Medium (99.999%)
Mobility	Urban environments: Low (0-50 km/h). Sub-urban environments: Low to Medium (0-100 km/h). Highways: Low to High (0-250 km/h).
Location accuracy	Urban environments: High (0.5 m). Sub-urban environments and highways: Medium (4 m).
Connection (device) density	4.3×10^3 vehicles/km^2 (peak)‡ 0.86×10^3 vehicles/km^2 (typical)
Interactivity	Medium (50 transactions/sec) High (200 transactions/sec)
Area traffic capacity	0.0215 Mbps/m^2 (DL peak) 0.0043 Mbps/m^2 (DL typical) 0.086 Mbps/m^2 (UL peak) 0.0172 Mbps/m^2 (UL typical)
Security / privacy	High (Confidential)

Phase 1 trials aim to develop the functionalities that establish a communication between the ROC-GW and the ROC, ensuring their smooth operation by performing simulation analysis. Hence, the target KPIs, listed in Table 17, cannot be yet pursued. The later trialling phases will push the capabilities on top of the 5G infrastructure if the required technology enablers can be made available in the utilised test facilities.

9.3.3 Measurement and testing tools

A thorough delay analysis throughout the closed control loop of the TeSo system has been performed to pinpoint the appropriate points, where the measurement and monitoring probes will be placed during the trials. For the purposes of the delay analysis, Figure 63 provides a graphical representation of the TeSo closed control loop, depicting the processing and transmission delays that occur between the different SW and HW subcomponents of the overall TeSo implementation.

Starting from the vehicle side, an internal processing delay (i.e., associated with the communication between the OBU and ROC-GW) occurs, so as for the ROC-GW to obtain the video streams and the sensor and instrumentation data. Possible transmission delays arising during the 4G/5G wireless transmission of the video streams and the sensor and instrumentation data lead, subsequently, to the delayed data transmission and reception by the “Sensory and Streaming module of the ROC-GUI application. At this point, a further processing delay may occur for the proper visualization of the vehicle’s state in the human operator’s monitoring device. Next, the human operator’s delayed response is also taken into consideration, constituting the highest factor within the TeSo closed control loop. Finally, the transmission delays over the 4G/5G wireless network of the response control commands complements the presented delay analysis. Considering that the processing delays occurring in between the different SW and HW subcomponents are, on the one hand, hard to measure, while on the other hand cannot be evaluated under a predefined set of KPIs, they will be separately taken into account in the

---

[****] The latency requirement corresponds exclusively to the one-direction wireless transmission (i.e., UL or DL) from the ROC-GW to the ROC, or vice versa.

context of the 5G-HEART trials (and possibly excluded from the end-to-end delay considerations, as in an actual system implemented fully on a single board, they will have negligible impact). On the contrary, the impact of the transmission delays arising due to the 4G/5G wireless network connectivity to the TeSo use case scenario is of utmost importance. As such, the determined points, where the measurement and monitoring probes will be placed, are located prior and after the wireless video and data transmission, as illustrated in Figure 63.

To measure the occurring delays at the considered monitoring points, a proper synchronization of the respective SW components/modules is required. A possible solution to this synchronization problem, that is currently examined, is the use of GPS timestamps before and after the (e.g., video, data or control commands) transmission by each SW component/module. Eventually, the end-to-end latency from one endpoint to another (i.e., ROC-GW to ROC and vice versa) will be acquired.

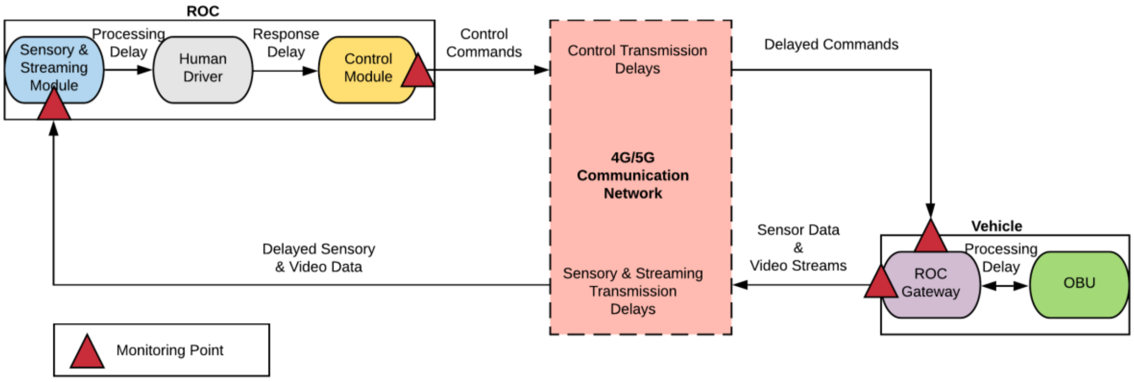


Figure 63 TeSo closed control loop delay analysis and monitoring points.

As far as the measurement of the achieved 4G/5G throughput is concerned, the use of different measurement and monitoring tools is scrutinized, such as iperf or Qosium, among others. Finally, regarding the evaluation of the achieved reliability, 3GPP guidelines and nomenclature will be employed, identifying the most suitable and representative parameters for monitoring from each layer of the protocol stack.

In terms of Phase 1 trials, the following components have been used in different capacities:

- NUC device (representing the ROC-GW to be eventually installed at the vehicle).
- Ordinary consumer devices (e.g., laptops and desktop PCs) for testing locally the implemented functionality during development. These modules, serving only the purpose of preliminary testing, will not be used in the next Phases.
- Azure VM playing the NUC role when testing remote operation over the Internet. This component, also serving only the purpose of preliminary testing, will not be used in the following Phases.
- The ROC GW Application SW module, installed in the NUC device.
- The ROC GUI Application SW module, installed in a dedicated physical machine.

The obtained results have been displayed on the running device’s screen (representing the screen that is used by the remote human operator) and the resulting video or map image has been qualitatively evaluated by the end user (remote operator).

9.3.4 Initial Results

During the Phase 1 trials, the prototypes of all individual modules/functionalities described in Section 9.2.4 have been fully developed and tested, both individually and combined within the “ROC-GW” or the “ROC GUI” applications, respectively. The seamless operation of these applications has been additionally verified and tested. As trials progress, these components will be further refined as needed.

Due to limitations in accessing the actual research experimentation vehicles, recorded sensor and instrumentation data files, pertaining to the operation of the actual research experimentation vehicles, were used to ease the SW development and simulation process. In particular, the two link mesh recording architectures, described in Figure 64 and Figure 65, have been considered. The first (Figure 64) is an initial architecture that consists of two nodes (one sensor and one camera node), whereas the second (Figure 65) is an evolved architecture that has been developed along the course of the project to incorporate more types of sensor data. Each node in the "5gh-carai3" mesh of these architectures publishes its data via a link offer as follows:

- Data from the four cameras are published via "l2offer:/camera-front", "l2offer:/camera-left", "l2offer:/camera-right", and "l2offer:/camera-back" respectively.
- Data regarding the vehicle state via "l2offer:/vehicle-state".
- Data regarding the automation state via "l2offer:/automation-state".
- The geospatial coordinates from node GNSS via "l2offer:/gnss-position".

Information about the employed data formats that are published across the respective offers in the mesh are given in Table 18, Table 19, Table 20 and Table 21. These objects correspond to the data received at the input pins of ROC-GW, as shown in Figure 61. Furthermore, Table 22, Table 23 and Table 24 present the formats of the data objects that are pushed at the output pins of ROC-GW. The recording files include the four video streams and the GPS positions captured during a predetermined route with the actual vehicle, and they have been replayed during simulations using the provided link2-player. The remaining offers for the vehicle and the automation state have been populated with dummy data.

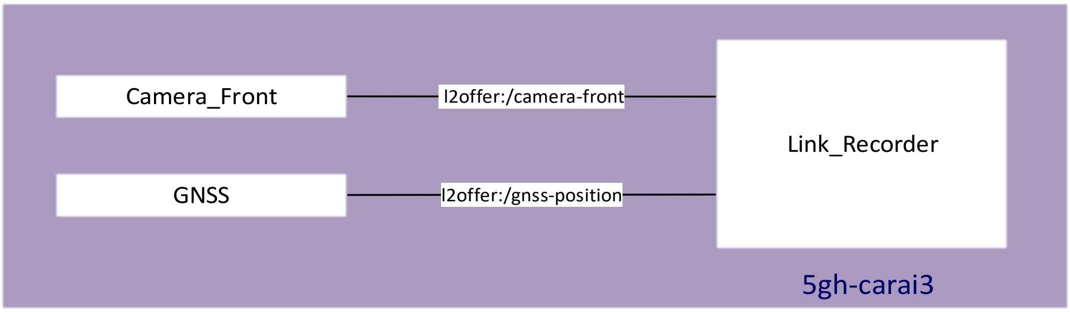


Figure 64. Initial link mesh recording architecture.

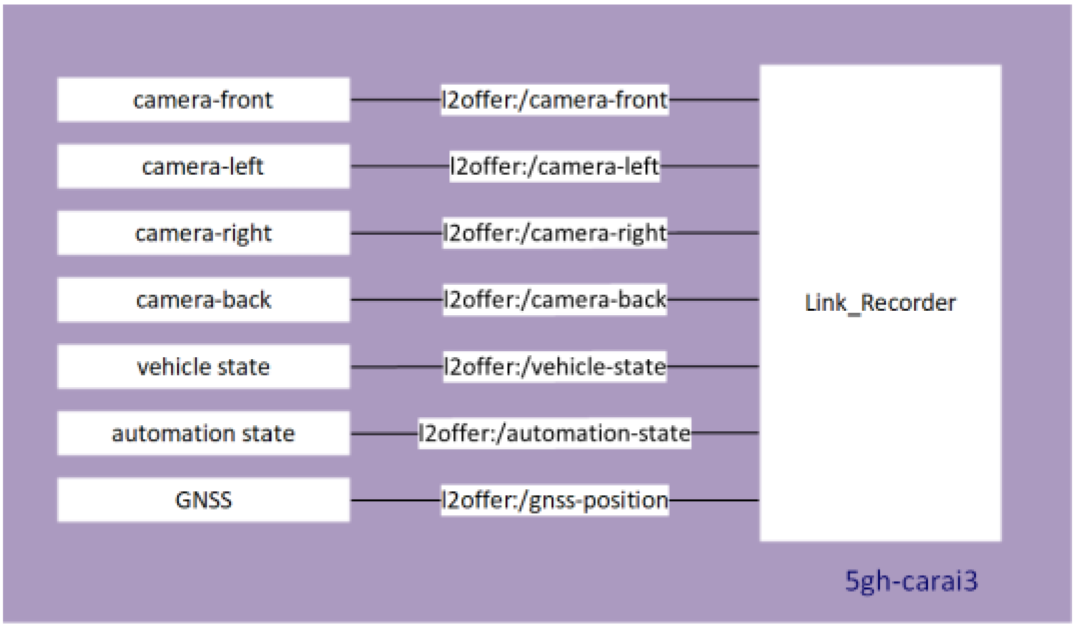


Figure 65. Extended link mesh recording architecture.

Table 18: Cameras Nodes offer.

Configuration			
Output data frequency: 25 Hz, Image height: 780, Image width: 1280			
Output data			
Field name	**Description**	**Data type**	**Value**
/image/format	encoding format of the output data	enum	NotSpecified, GRAY_U8, RGB_U8, BGR_U8, DEPTH_U16, DEPTH_F32, COMPRESSED_JPEG
/image/data	actual video without compression	---	
/image/ CompressedData	actual video in compressed format	uint8	
/timestamp	number of seconds since the Unix epoch in nano seconds	int64	

Table 19: GNSS Position Node offer.

Configuration			
Output data frequency: 4 Hz			
Output data			
Field name	**Description**	**Data type**	**Value**
timestamp	number of seconds since the Unix epoch in nano seconds	int64	
latitude	latitude position in degrees	double	south<0, north>0
longitude	longitude position in degrees	double	west<0, east>0
altitude	height information in meters	double	
gpsQuality	GPS quality according to the NMEA standard	uint8	

Table 20: Vehicle State Node offer.

Output data			
Field name	**Description**	**Data type**	**Value**
timestamp	number of seconds since the Unix epoch in nano seconds	int64	
velocity	vehicle velocity in meters per second	single	10.1

Table 21: Automation State Node offer.

Output data			
Field name	**Description**	**Data type**	**Value**
timestamp	number of seconds since the Unix epoch in nano seconds	int64	

state	operation state of the automation system	enum	"off" or "on"
steering_wheel_ angle	currently set steering when angle in radians	single	zero means "straight" and "steer to left" is expressed by positive angles
throttle_ percentage	currently set throttle value in percent	single	0.0 means "none", 1.0 means "full", value range: 0<=value<=1
brake_ percentage	currently set brake value in percent	single	0.0 means "none", 1.0 means "full", value range: 0<=value<=1

Table 22: Steering Control Node offer.

Output data			
Field name	**Description**	**Data type**	**Value**
steering_wheel_ angle	desired wheel angle in radians	single	zero means "straight" and "steer to left" is expressed by positive angles

Table 23: Throttle Control Node offer.

Output data			
Field name	**Description**	**Data type**	**Value**
percentage	desired throttle value in percent	single	0.0 means "none", 1.0 means "full", value range: 0<=value<=1

Table 24: Brake Control Node offer.

Output data			
Field name	**Description**	**Data type**	**Value**
percentage	desired brake value in percent	single	0.0 means "none", 1.0 means "full", value range: 0<=value<=1

The integration of all components into the CARAI 3 (C3) vehicle located at Leibnitz, Germany, has been effectively completed. A NUC device has been configured as ROC-GW and has been mounted on the vehicle, verifying the interoperability with its sensors and actuators via the OBU. The full communication chain (i.e., vehicle ↔ OBU ↔ ROC-GW ↔ ROC) has been tested in a wired configuration, either with all components operating locally in the same LAN or with ROC running remotely at NTUA premises, in Athens, Greece. Both of the DL and UL directions, demonstrated in Figure 62, have been successfully validated. The local execution of the developed components at the same device or inside a LAN performs well and presents real-time data without any issue. However, some delay is observable to the viewer when the ROC-GW is executed remotely (i.e., either at an Azure VM located somewhere in West Europe or at the actual vehicle in Germany) and communicates over the internet with the ROC GUI application (i.e., running at a laptop at NTUA, in Athens, Greece).

9.4 Next step plans

Having developed all SW components that establish the two-direction data flow between the ROC-GW and ROC and integrated the overall solution into the TUC’s research experimentation vehicles, appropriate measurement of the target KPIs will be pursued. First, a set of preliminary baseline measurements will be performed using wired/ethernet connections. Then, a second set of measurements will be made, where 4G connectivity will be used for the communication between the ROC-GW and the ROC. Finally, the completely integrated solution will be evaluated on the 5GENESIS trial facility at the UOS’s campus using 5G connectivity.

10 T4S1: VEHICLE PROGNOSTICS

10.1 Description and motivation

An RSU application, having the capability to access the Internet, will enable any passing vehicle to report its current functional state to a local/remote diagnosis service and receive a “Just in time repair notification”. A vehicle service application linked to local repair centres needs to obtain and analyse data from the vehicle periodically.

An RSU application can provide this data by collecting in from the passing cars on the road. Based on the analysis outcome, the repair centre will notify the vehicle owner with any identified issues.

10.2 Proposed Setup

This use-case scenario is being trialled on the 5GTN trial facility located in Oulu, Finland.

10.2.1 Network architecture

Figure 66 presents the simplified network architecture for T4S1 Phase 1 trials. The 5G UE represents a vehicle with 5G connectivity capability. The 5G UE transmits the vehicle status data through the 5G gNB and 5GC to the service cloud for analysis.

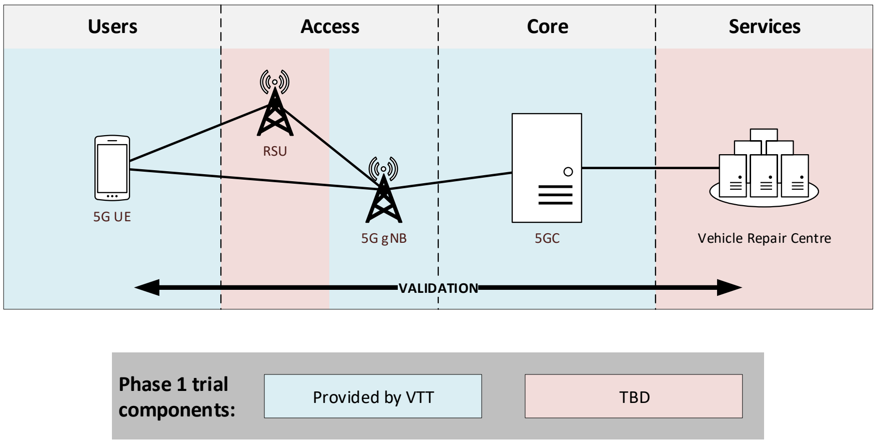


Figure 66. Network architecture for T4S1 Phase 1 trials.

10.2.2 User application architecture

Service components are not yet part of the Phase 1 trials as the focus is on the baseline 5G NR UL performance for generic data transfer.

10.2.3 Hardware components

The Phase 1 trial network architecture contains the following HW components:

- 5G UE:
    - Samsung Galaxy S10 5G for UL throughput measurements using Nemo Handy
    - Huawei 5G CPE Pro GW device for UL throughput and latency measurements
- RSU:
    - Not included in the Phase 1 setup
- 4G eNB:
    - LTE FDD @ 2600 MHz (band 7), BW = 5+10 MHz (anchor for macro 5G gNB)

- 5G gNB:
  - 5G NR TDD Rel-15 NSA @ 3.5 GHz, BW = 60 MHz
- 5GC:
  - Emulated CN services
- Vehicle repair centre:
  - VM server receiving the streaming sensor data in local cloud

10.2.4 Software components

Service components are not yet part of the Phase 1 trials. The different possibilities for the inclusion of the RSU and server side applications shown in Figure 66 will be investigated during the preparation of Phase 2 trials.

10.3 Testing and verification

10.3.1 Methodology

In Phase 1, the focus of the trials will be on the baseline performance of the 5G NR UL for generic data transfer. The developed and tested features for Phase 1 trials are as follows:

- Phase 1: Configuration and testing of the architecture for collecting the vehicle data. Focus will be on basic connectivity and performance of the 5G UL.

10.3.2 List of key performance indicators

The user requirements associated with this use case scenario have been analysed and converted into a set of network KPIs in Deliverable D2.2 [10]. Table 25 presents the resulting list of network requirements together with their target values.

Table 25: Target KPIs for T4S1

Network requirements	**Target values**
User experienced DL throughput	Medium (1-10 Mbps)
User experienced UL throughput	Medium (1-10 Mbps)
Broadband connectivity / peak data rate	DL: Low (peak 100 Mbps) UL: Low (peak 100 Mbps)
Latency requirements	Low (> 100 ms)
Reliability	Medium (99.999%)
Mobility	Medium (50-200 km/h)
Location accuracy	Medium (4 m)
Connection (device) density	4.3×10^3 devices/km^2 (peak)‡ 0.5×10^3 devices/km^2 (typical)
Interactivity	Medium (<100 transactions/sec)
Area traffic capacity	0.043 Mbps/m^2 (DL peak) 0.005 Mbps/m^2 (DL typical) 0.043 Mbps/m^2 (UL peak) 0.005 Mbps/m^2 (UL typical)
Security / privacy	Medium (Restricted)

The Phase 1 trials aim to verify the suitability and baseline performance of Rel-15 5G in the tested use case scenario. Hence, the target KPIs of Table 25 are not yet achievable. Instead, the Phase 1 trials are expected to reveal, as a starting point for the later trialling phases, the level of achievable performance and service quality with the first generation 5G equipment.

The key 5G KPIs used for performance evaluation during Phase 1 are:

- Throughput for UL
- E2E latency for UL

10.3.3 Measurement and testing tools

The measurement and testing tools utilised in the Phase 1 trials:

- Qosium for E2E passive QoS/QoE measurements and monitoring [32].
- Keysight Nemo Handy [33] and Nemo Outdoor Playback [34] for general connectivity debugging.
- Internal eNB/gNB performance counters for RAN measurements and monitoring.
- InfluxDB and Grafana for measurement data storage and visualisation.

All Phase 1 trials in this use case scenario are performed in laboratory conditions. The main KPI assessment tool utilised during the measurements is Qosium, which is used to measure both the UL throughput and UL latency during the trial runs. The same basic measurement setup, shown in Figure 67, is used for the tests as in the T2S4 – Human Tachograph use case scenario presented in subsection 8.3.3. For the throughput measurements, a message queuing telemetry transport (MQTT) broker is running at the edge/local cloud server in the 5GTN VTT Oulu test facility. MQTT was chosen for the initial tests as it uses a publish/subscribe messaging pattern that is suitable for this scenario and has been already adopted by a variety of use cases in the transport vertical. For the one-way latency measurements, both ends of the measured path are connected to the same PTP source with a low-jitter connection, in this case, Ethernet.

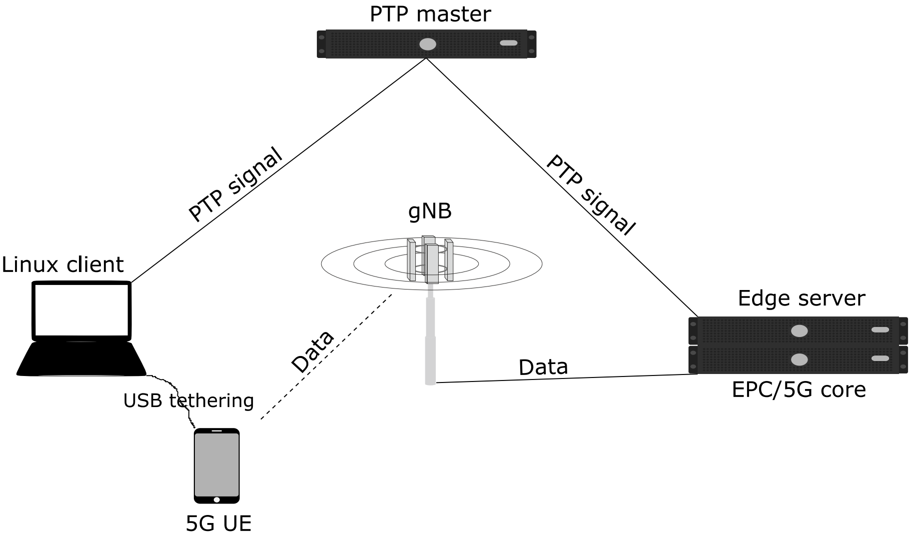


Figure 67. T4S1 measurement setup.

10.3.4 Initial results

The relevant KPIs, i.e. UL throughput and UL delay, were measured in the live 5GTN VTT Oulu network for both 4G LTE and 5G NR. For the planning of Phase 2 and 3 trials, the main interest in the baseline measurement was on the 5G NR performance, whereas the 4G LTE was used as a performance reference. During the measurements, there was no other activity in the same cell, i.e. the UE under consideration was scheduled with all the PRBs.

10.3.4.1 Data and traffic model

Three different TCP packet payload sizes were used for the measurements. The smaller payload sizes correspond with typical on-board diagnostics – second generation (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. All test traffic was transferred between the UE (client) and edge/local cloud server (broker) using the MQTT protocol.

10.3.4.2 Achievable data rates in the uplink

Table 26 presents the measured UL throughput and goodput performance for a single MQTT client, i.e., one vehicle reporting its functional state. For a single client, the achieved throughputs over the 4G LTE link are quite modest ranging from 40 kbps to 112 kbps with the OBD-II compliant payload sizes, and just over 450 kbps with MTU sized packets. Without any optimisation, e.g., in the form of header compression, while encapsulating the payloads with different protocol headers, the achieved goodputs are significantly lower with the smaller OBD-II compliant payload sizes. The transfer of a single 12 B and 255 B and payload over the wireless link results into 85% and 21% overhead, respectively. For the MTU sized packets, the overhead is less than 5%. For 5G NR, the measured single client throughputs are 230 kbps for the 12 B payload and 376 kbps for the 255 B payload. The corresponding goodputs of 34 kbps and 294 kbps again result into 85% and 22% overheads for the smaller OBD-II compliant payload sizes. For the MTU sized packets, the achieved single client throughput is 1.7 Mbps. With a corresponding goodput of 1.62 Mbps, the overhead is again less than 5%.

Table 26: Average UL throughput and goodput performance per client for T4S1

Payload size [B]:	**12**	**255**	**1400**
4G LTE			
Throughput [kbps]	40	112	451
Goodput [kbps]	6	88	430
Maximum throughput for full buffer traffic [kbps]			28,000
5G NR			
Throughput [kbps]	230	376	1703
Goodput [kbps]	34	294	1620
Maximum throughput for full buffer traffic [kbps]			62,000

The achieved maximum UL throughputs for the 4G LTE and 5G NR using full buffer traffic are 28 Mbps and 62 Mbps, respectively. When compared to the 5G NR UL throughput value of 520 Mbps reported for a smaller packet size in the same test facility setup in subsection 8.3.4.2, the UL performance measured for the 5G NR in T4S1 is significantly lower. The main reason for the big difference in the measured maximum UL throughputs between T4S1 and T2S4 is the single client measurement approach used in T4S1. Even with the large MTU sized packets, the data amount from a single client entity is not enough to fill up the 5G NR transport blocks at the MAC layer before they are scheduled for transmission at the PHY layer.

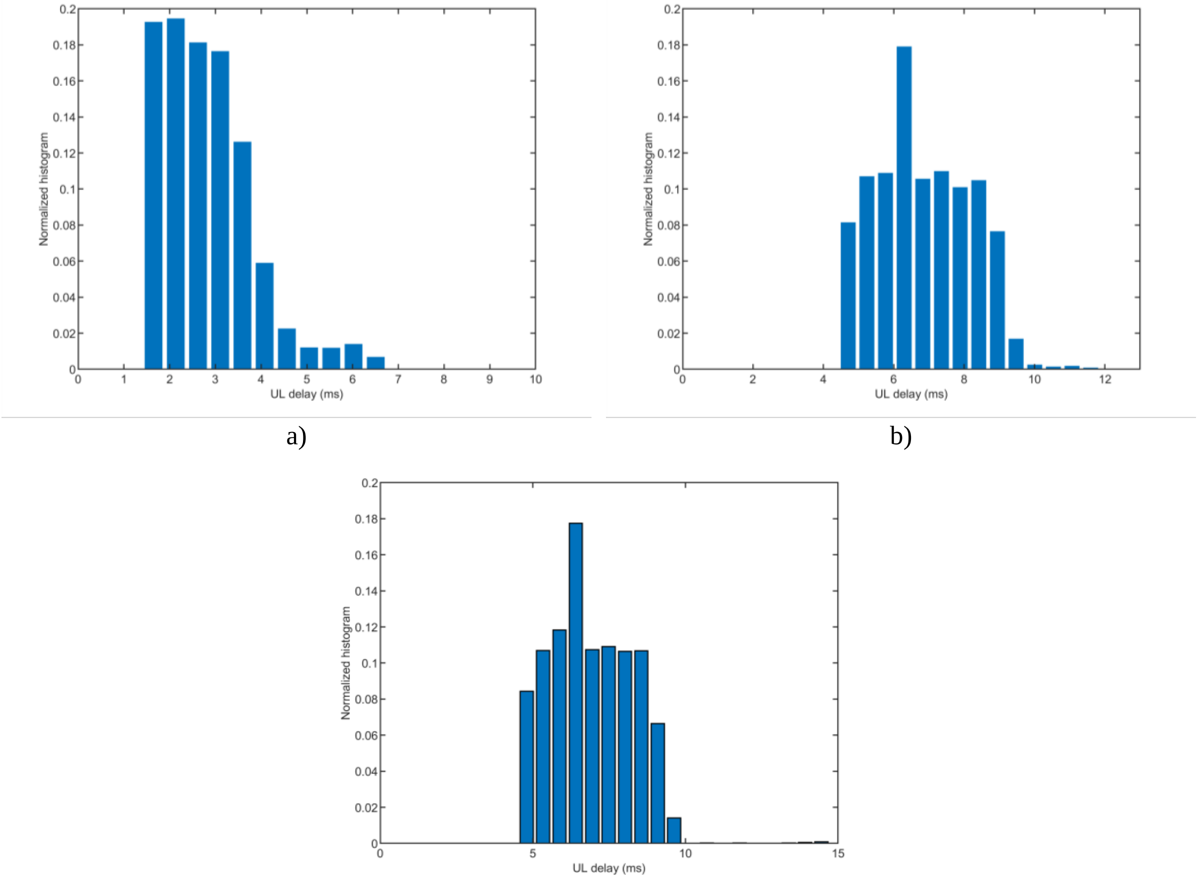
10.3.4.3 End-to-end latency in the uplink

Table 27 presents the measured average UL latencies for a single MQTT client. For 4G LTE, the measured one-way latencies are 16.3 ms and 23.3 ms for the smaller 12 B and 255 B OBD-II compliant payloads, respectively. For the MTU sized packets, the measured one-way latency is 26.1 ms on average. For 5G NR, the average one-way latencies for the 12 B and 255 B payloads representing typical OBD-II message lengths are 2.8 ms and 6.9 ms, respectively. For the MTU sized packets, the average latency is the same as with the 255 B payload at 6.9 ms.

Table 27: Average UL latency performance per client for T4S1

Payload size [B]:	**12**	**255**	**1400**
4G LTE			
Delay [ms]	16.3	23.3	26.1
5G NR			
Delay [ms]	2.8	6.9	6.9

For most of the packets with 12 B payload, the measured latency in 5G NR UL varies between 1.5 ms and 6.5 ms as shown in Figure 68 a), whereas for most of the packets with 255 B and 1400 B payloads, the latency varies between 4.5ms and 10 ms as shown in Figure 68 b) and c). These results are in line with the results presented for ping traffic (with 56 B payload size) in subsection 8.3.4.3. The larger latencies for larger packets are expected as the transmission and reception of larger amount of data takes more time.



a)

b)

c)

Figure 68. The normalised histogram of the measured 5G NR UL latencies for a) 12 B, b) 255 B and c) 1400 B payload size.

10.4 Next step plans

The baseline measurements performed at the 5GTN VTT Oulu test facility during Phase 1 trials confirm that, from the perspective of a single end user, both 4G LTE and 5G NR are capable to fulfil the basic KPI requirements of the T4S1 use case scenario. However, when it comes to the scalability of the services relying heavily on the UL performance, the large overheads recorded during the single client trials are making a direct analysis based on the first results difficult. If the actual service components for the large-scale trials are not available in the project's time frame, the scalability assessment of this scenario will be continued in conjunction with the T2S4 – Human Tachograph trials. The combination of these two use case scenarios provide a good overall test case for UL oriented trials in the 5GTN VTT Oulu test facility during Phases 2 and 3 of the project.

11 T4S2: OVER-THE-AIR (OTA) UPDATES

11.1 Description and motivation

Engine Control Unit (ECU) is a generic term for a HW module with corresponding SW in a car that controls some electronic functions within the vehicle system. It controls anything from the steering wheel to the brakes and with automated driving. The ECU is a key part of the vehicle and will possibly need regular SW updates.

OTA updates will provide significant cost-savings, as the vehicles will not need to be recalled by a manufacturer or service centre. Note that such an update mechanism requires significant security protection measures.

11.2 Proposed Setup

This use-case scenario is being trialled on the 5GTN trial facility located in Oulu, Finland.

11.2.1 Network architecture

Figure 69 presents the simplified network architecture for T4S2 Phase 1 trials. The 4G/5G UE represents a vehicle with cellular connectivity capabilities. The 4G/5G UE receives the OTA updates and/or related information from the service cloud either as broadcast/multicast through the 4G EPC and 4G eNB, or as unicast through the 5GC and 5G gNB.

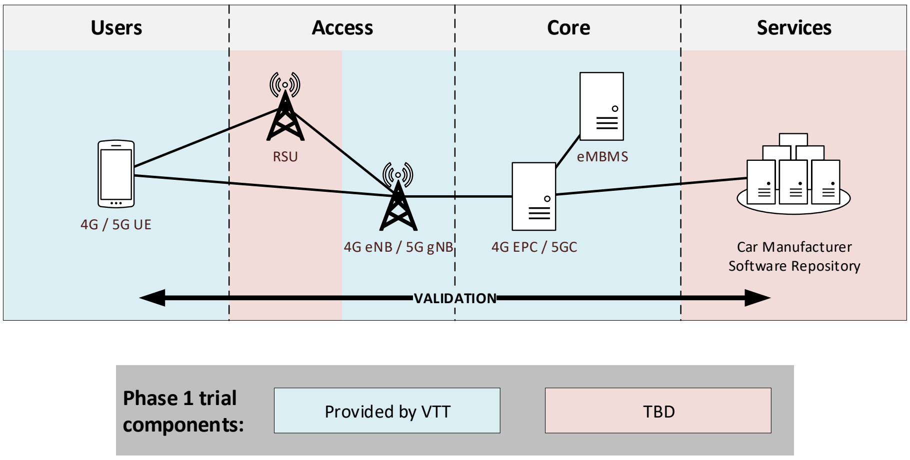


Figure 69. Network architecture for T4S2 Phase 1 trials.

11.2.2 User application architecture

Figure 70 presents the user application architecture for T4S2 Phase 1 trials. The use case scenario specific SW consists of the eMBMS middleware and client application required in the 4G UE to receive the multicast/broadcast traffic from the eMBMS server. The utilised SW is developed by Enensys and is configured and provided for the Phase 1 trials by the 5GTN VTT Oulu test facility and VTT.

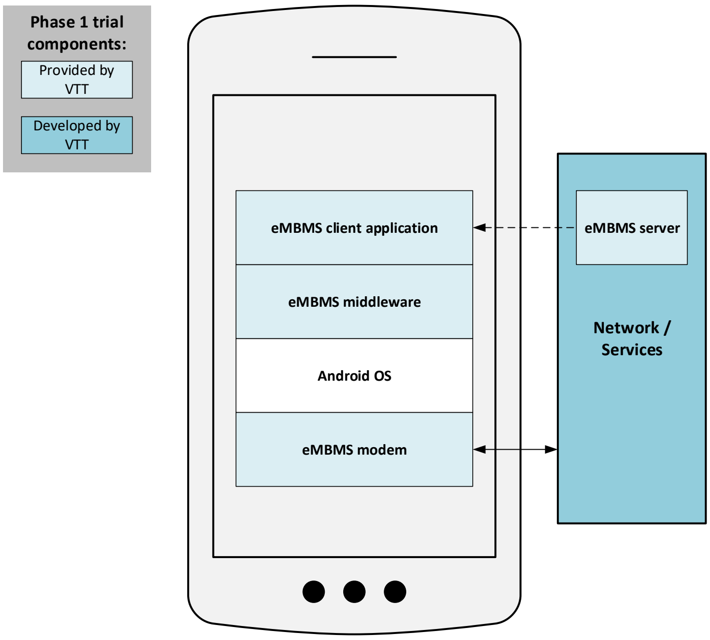


Figure 70. User application architecture for T4S2 Phase 1 trials.

11.2.3 Hardware components

The Phase 1 trial network architecture contains the following HW components:

- 4G UE:
    - Samsung Galaxy S9 for initial multicast/broadcast tests
- 5G UE:
    - Huawei 5G CPE Pro GW device for DL throughput and latency measurements
- RSU:
    - Not included in the Phase 1 setup
- 4G eNB:
    - 4G LTE FDD @ 2600 MHz (band 7), BW = 5+10 MHz (anchor for macro 5G gNB)
- 5G gNB:
    - 5G NR TDD Rel-15 NSA @ 3.5 GHz, BW = 60 MHz
- 4G EPC and 5GC:
    - Emulated CN services
- eMBMS:
    - Enensys Expway eMBMS server
- Car manufacturer SW repository:
    - VM server receiving the streaming sensor data in local cloud

11.2.4 Software components

The Phase 1 trial application architecture contains the following SW components:

- eMBMS middleware and client application in the 4G UE.
- eMBMS server in the local cloud environment.
- Measurement and testing framework in the 5GTN VTT Oulu test facility.

11.3 Testing and verification

11.3.1 Methodology

In Phase 1, the focus of the trials will be on the baseline performance of the 5G NR DL for generic data transfer and the application of 4G eMBMS functionality for the broadcasting of the vehicle SW updates. In Phase 1, these two components will be tested separately. The developed and tested features for Phase 1 trials are as follows:

- Phase 1: Configuration and testing of the architecture for collecting the vehicle data and distributing the required updates. Focus will be on basic connectivity and performance of the 5G NR DL.

11.3.2 List of key performance indicators

The user requirements associated with this use case scenario have been analysed and converted into a set of network KPIs in Deliverable D2.2 [10]. Table 28 presents the resulting list of network requirements together with their target values.

Table 28: Target KPIs for T4S2

Network requirements	**Target values**
User experienced DL throughput	High (10-100 Mbps)
User experienced UL throughput	Medium (1-10 Mbps)
Broadband connectivity / peak data rate	DL: Medium (peak 1000 Mbps) UL: Low (peak 100 Mbps)
Latency requirements	Low (> 100 ms)
Reliability	Medium (99.999%)
Mobility	Medium (50-200 km/h)
Location accuracy	Medium (4 m)
Connection (device) density	4.3×10^3 devices/km^2 (peak)‡ 0.5×10^3 devices/km^2 (typical)
Interactivity	Medium (<100 transactions/sec)
Area traffic capacity	0.43 Mbps/m^2 (DL peak) 0.05 Mbps/m^2 (DL typical) 0.043 Mbps/m^2 (UL peak) 0.005 Mbps/m^2 (UL typical)
Security / privacy	High (Confidential)

The Phase 1 trials aim to verify the suitability and baseline performance of Rel-15 5G and 4G eMBMS in the tested use case scenario. Hence, the target KPIs of Table 28 are not yet achievable. Instead, the Phase 1 trials are used to verify the baseline performance of the current state-of-the-art. The later trialling phases will push the broadcasting capabilities on top of the 5G infrastructure, if the required technology enablers can be made available in the utilised test facilities.

The key 5G KPIs used for performance evaluation during Phase 1 are:

- Throughput for DL
- E2E latency for DL

11.3.3 Measurement and testing tools

The measurement and testing tools utilised in the Phase 1 trials:

- Qosium for E2E passive QoS/QoE measurements and monitoring [32].
- Keysight Nemo Handy [33] and Nemo Outdoor Playback [34] for general connectivity debugging.
- Internal eNB/gNB performance counters for RAN measurements and monitoring.
- InfluxDB and Grafana for measurement data storage and visualisation.

All Phase 1 trials in this use case scenario are performed in laboratory conditions. The main KPI assessment tool utilised during the measurements is Qosium, which is used to measure both the DL throughput and DL latency during the trial runs. The same basic measurement setup, shown in Figure 71, is used for the tests as in the T2S4 – Human Tachograph use case scenario presented in subsection 8.3.3. Linux secure copy (SCP) command is used for DL throughput measurements. SCP was chosen for the initial tests for its simplicity and wide availability in the Linux operating systems as well as for its secure file transfer approach based on the secure shell (SSH) protocol. For the one-way latency measurements, both ends of the measured path are connected to the same PTP source with a low-jitter connection, in this case, Ethernet.

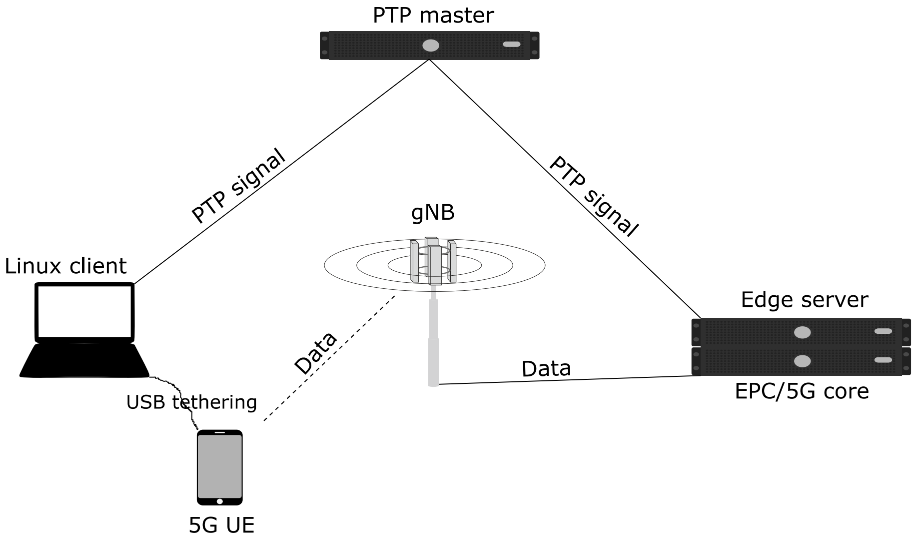


Figure 71. T4S2 measurement setup.

11.3.4 Initial results

The relevant KPIs, i.e. DL throughput and DL delay, were measured in the live 5GTN VTT Oulu network for both 4G LTE and 5G NR. For the planning of Phase 2 and 3 trials, the main interest in these baseline measurements was on the 5G NR performance, whereas the 4G LTE was used as a performance reference. During the measurements, there was no other activity in the same cell, i.e. the UE under consideration was scheduled with all the PRBs.

11.3.4.1 Data and traffic model

Three different update package sizes were used for the measurements. The smallest package size of 1 MB represents a case where differential or delta updates are used and only the changes are delivered in each update package. The 10 MB package size represents a case where more complete updates packages are provided, e.g., for an ECU. The largest 100 MB package size represents a case where a complete update, e.g., for a vehicle infotainment system is provided. All test packages were downloaded from the edge/local cloud server to the UE using SCP over TCP.

11.3.4.2 Achievable data rates in the downlink

Table 29 presents the average single client DL throughput for different download package sizes measured from the active file transfer session only, i.e., the handshake procedures when setting up and tearing down the session are excluded from the results. For a single client over 4G LTE DL, the measured average throughput during a 1 MB, 10 MB and 100 MB file download are 23 Mbps, 79 Mbps and 117 Mbps, respectively. This results into download times of 0.61 s, 1.43 s and 7.3 s for the same respective package sizes recorded by the SCP program (including the session setup and tear down). For 5G NR, the measured download throughputs for 1 MB, 10 MB and 100 MB package sizes are 45 Mbps, 128 Mbps and 294 Mbps, respectively. The corresponding download times recorded by the SCP program are 0.36 s, 0.87 s and 3.4 s. Based on the average results in the current test facility setups, the 5G NR DL is able to provide 1.6 to 2.5 times higher data rates for file download than 4G LTE.

Table 29: Average DL throughput performance per client for T4S2

Package size [MB]:	**1**	**10**	**100**
4G LTE			
Throughput [Mbps]	23	79	117
Maximum throughput for full buffer traffic [Mbps]			155
5G NR			
Throughput [Mbps]	45	128	294
Maximum throughput for full buffer traffic [Mbps]			693

The achieved maximum DL throughputs for the 4G LTE and 5G NR using full buffer traffic are 155 Mbps and 693 Mbps, respectively. These values are in line with the theoretical maximum values for the test facility configuration. For the smaller package sizes of 1 MB and 10 MB, the achieved 5G NR DL throughput is impacted by the partially filled transport blocks in the same way as in the measurements reported for T4S1 – Vehicle Prognostics use case scenario in subsection 10.3.4.2. For the largest 100 MB package size, the main performance bottleneck in laboratory conditions is the utilisation of TCP with suboptimal flow and congestion control configuration parameters for file transfer over wireless links constricting the maximum data transmission rate. With UDP traffic, it is possible to fill the transmission buffer for the wireless link and the maximum throughput for the utilised DL configuration is achieved.

11.3.4.3 End-to-end latency in the downlink

Table 30 presents the measured average DL latencies during file download. For 4G LTE, the latencies range from 7.8 ms for the smallest 1 MB package size to 12.6 ms recorded for both 10 MB and 100 MB packages. For 5G NR, the measured latencies are 4.8 ms for the 1 MB package size, 6.6 ms for the 10 MB package size, and finally, 10.7 ms for the 100 MB package size. Even though the recorded E2E latency performance with the largest package size is not as consistent as during the download of the smaller packages, 5G NR is able to provide lower latencies in all test scenarios.

Table 30: Average DL latency performance per client for T4S2

Package size [MB]:	**1**	**10**	**100**
4G LTE			
Delay [ms]	7.8	12.6	12.6
5G NR			
Delay [ms]	4.8	6.6	10.7

11.3.4.4 Cellular multicast/broadcast performance

During the implementation and execution of Phase 1 trials, the multicast/broadcast functionality through 4G eMBMS has been updated and configured for the 5GTN VTT Oulu test facility. All architectural components on the user and network sides have been installed and their functionality has been verified. However, due to the slow progress of the update process during the summer and autumn 2020, the installation of the required measurement probes for the end-to-end multicast/broadcast data path is still an ongoing task. Numerical values for the KPIs can be measured only after the probe installations are finished and, hence, the initial results for the multicast/broadcast performance in T4S2 - OTA updates scenario will be reported in the Phase 2 trials documentation.

11.4 Next step plans

The baseline measurements performed at the 5GTN VTT Oulu test facility during Phase 1 trials confirm that, from the perspective of a single end user, both 4G LTE and 5G NR are capable to fulfil the basic KPI requirements of the T4S2 use case scenario when small update packages are used. The larger the package size becomes, the more prominent is the performance difference between the two technologies. In case of multiple simultaneous downloads inside a single cell, the difference becomes even larger and, at some point, switch from unicast to multicast/broadcast should happen in order to reserve resources, if most of the clients are downloading the same update content.

The multicast/broadcast trials are executed in close collaboration with 5G-HEART's Healthcare vertical subcase H1A – Educational Surgery, where the eMBMS framework provided by the 5GTN VTT Oulu test facility is utilised to deliver same video content to a large number of end users. Due to the slowed down trial architecture update and configuration process during the COVID-19 restrictions, the installation of the KPI measurement probes into the updated trial architecture was not fully finished during Phase 1. As a result, the initial results for the multicast/broadcast performance in T4S2 – OTA updates scenario and a comparison between the key requirements for multicast/broadcast communications in Healthcare and Transport domains will be performed during the Phase 2 trials. The results of this comparison between the two verticals will be exploited in the 5G-HEART WP7 for the business development studies.

In addition to the measurements, the planning for the inclusion of the required service application components continues, in order to take the trials from the 4G and 5G feasibility and performance studies more towards real use case tests. If not available in the project's time frame, the multicast/broadcast tests in the 5GTN VTT Oulu test facility will be continued in conjunction with the T2S4 – Human Tachograph trials. The combination of these two use case scenarios provide a good overall test case for utilisation of multicast/broadcast in the Transport vertical during Phases 2 and 3 of the project.

12 T4S3: SMART TRAFFIC CORRIDORS

12.1 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 for areas that suffer the most. The solution focuses on providing a routing/navigation service, which minimizes the pollution impact for the most 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. The 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 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 the routes they take 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.

12.2 Proposed Setup

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

12.2.1 Network architecture

The considered network architecture is described in Figure 72. It consists of:

- The 5G GW node which receives the air-quality sensors information
- The 5G access and CN (5GENESIS)
- The Cloud

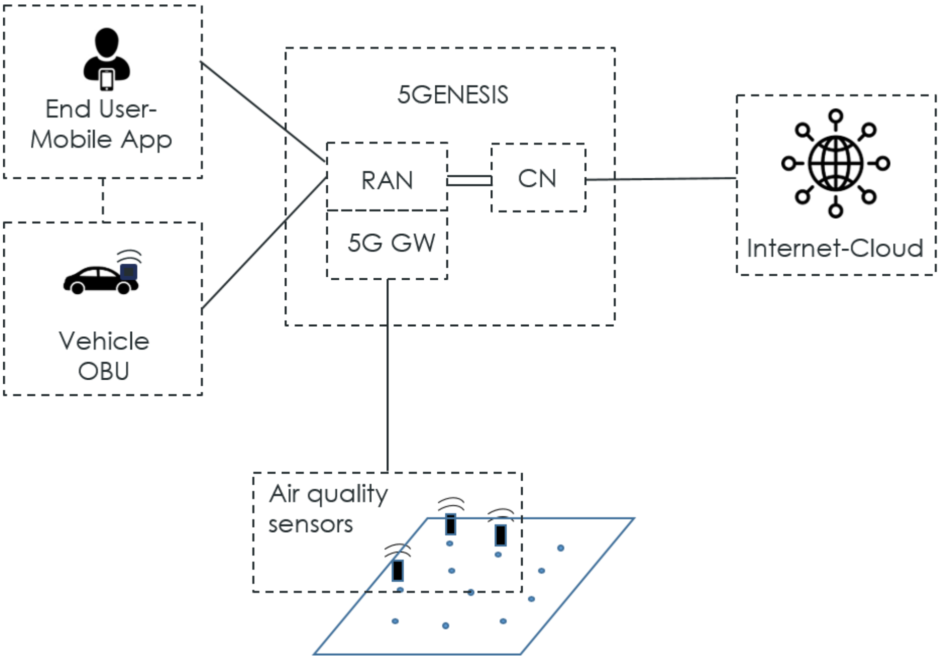


Figure 72. Network architecture of T4S3.

The end-user mobile application, with a direct connection to the OBU of the vehicle, has access to the service provided through the Internet-Cloud.

12.2.2 User application architecture

The user application architecture is described in Figure 73. It consists of:

- A UDP-server feeding the data from the air-quality sensors into the database system
- The cloud infrastructure containing the SW components listed in Section 12.2.4.
- The end-user application (Mobile app).

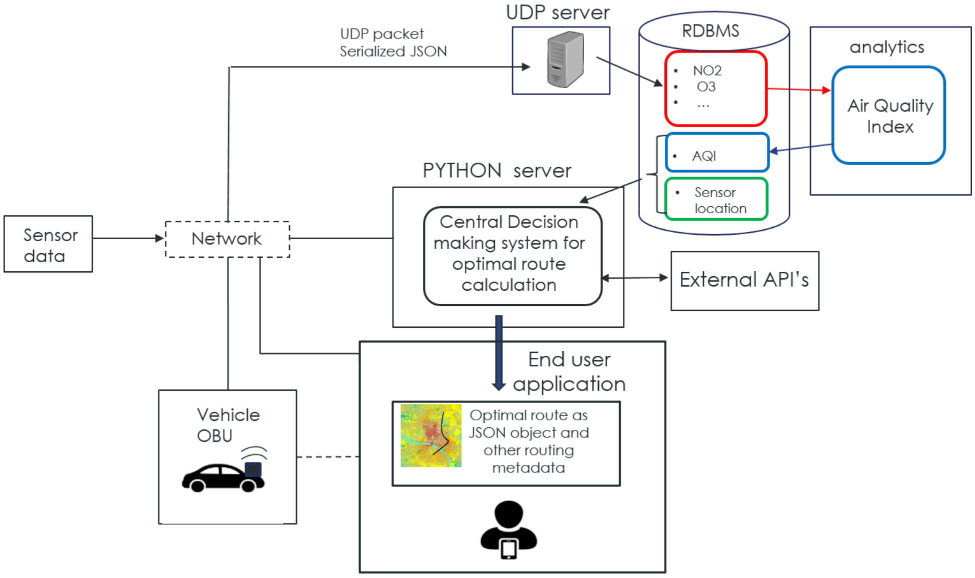


Figure 73. User application's architecture of T4S3

12.2.3 Hardware components

The HW components are:

- The air quality sensors. The sensors are used to measure the levels of specific entities that define the air-quality according to the European standards. Namely, these entities are nitrogen dioxide (NO_2), ozone (O_3), sulfur dioxide (SO_2), carbon monoxide (CO), particulate matter (PM)$_1$, $PM_{2.5}$ and PM_{10}. These levels are processed in the cloud infrastructure to derive the Air Quality Index (AQI), for the specific location.
- The OBU which gathers the appropriate information related to the condition and emissions of the vehicle.
- The Mobile Device of the End User which keeps track of the emission profile of the vehicle through the OBU as well as the starting point and destination and sends the request along with this information to the cloud for processing.

12.2.4 Software components

The SW components are:

- The UDP server feeding the sensor to the Database system.
- The SW component (Java server) responsible for the 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.

12.3 Testing and verification

12.3.1 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. On a second step, the end to end latency of a single request from the end user side will be measured and evaluated as well.

12.3.2 List of key performance indicators

The user requirements associated with this use case scenario have been analysed and converted into a set of network KPIs in Deliverable D2.2 [10]. Table 31 presents the resulting list of network requirements together with their target values.

Table 31: Target KPIs for T4S3

Network requirements	**Target values**
User experienced DL throughput	Medium (1-10 Mbps)
User experienced UL throughput	Low (≤1 Mbps)
Broadband connectivity / peak data rate	DL: Low (peak 10 Mbps) UL: Low (peak 10 Mbps)
Latency requirements	Low (25 ms)
Reliability	Medium (99.999%)
Mobility	Medium (50-200 km/h)
Location accuracy	Medium (4 m)
Connection (device) density	4.3×10^3 devices/km^2 (peak)[‡] 0.5×10^3 devices/km^2 (typical)
Interactivity	Medium (< 100 transactions/sec)
Area traffic capacity	0.043 Mbps/m^2 (DL peak) 0.005 Mbps/m^2 (DL typical) 0.0043 Mbps/m^2 (UL peak) 0.0005 Mbps/m^2 (UL typical)
Security / privacy	Low (Public)

During Phase 1, the focus has been on building the various HW/SW components needed to trial this use case scenario. Hence, the target KPIs of Table 31 are not yet achievable.

12.3.3 Measurement and testing tools

The measurement and testing tools of the 5GENESIS trial facility described in Section 14.3.3 will be exploited with a particular focus on the components listed in Section 3.3.3.

12.3.4 Initial results

Application side

For the initially carried out tests, air-quality related data from 2018 were used, which covered the Oxfordshire region in England. For the purposes of the testing scenario, the concentration of ozone (O_3) was used as an indicator of the air quality, as high concentration of ozone can be harmful to breathe. A screenshot from the resulting qualitative 'ozone - heatmap', using cubic interpolation on the scattered data, can be seen in Figure 74.

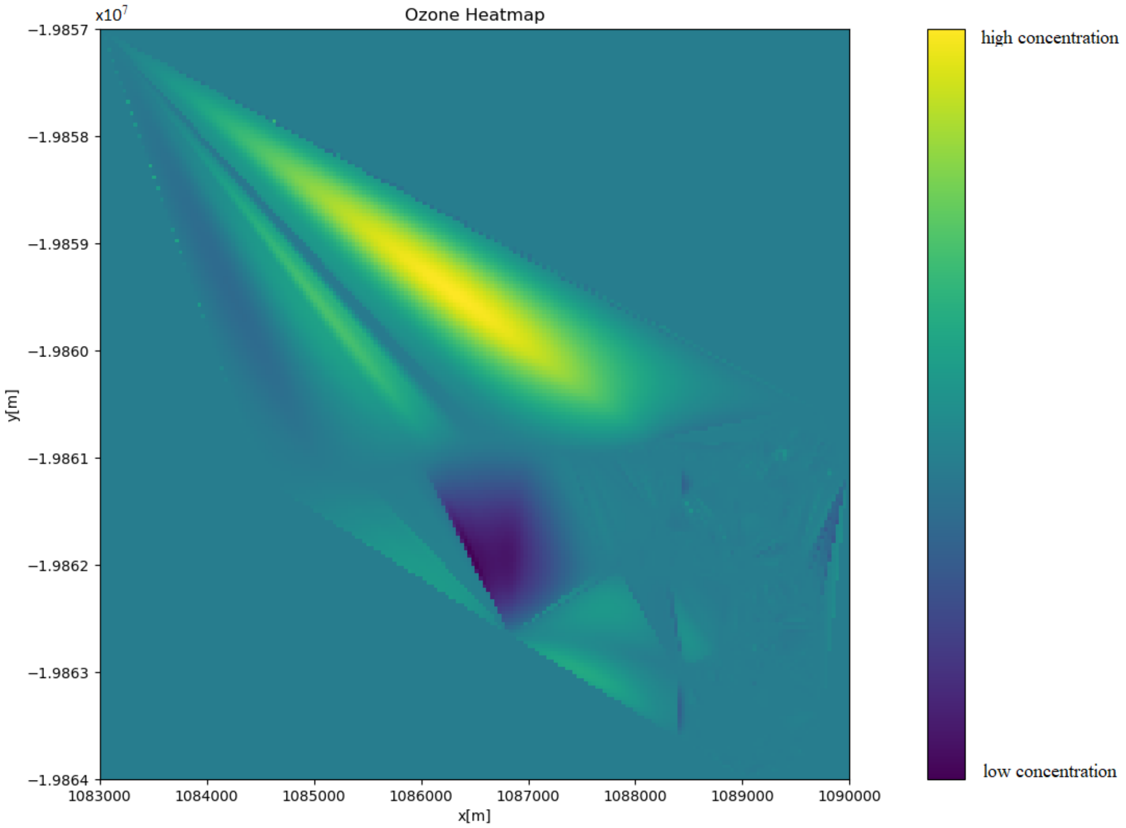


Figure 74. The 'ozone – heatmap' created for a region around Oxford based on air-quality data from 2018. The coordinates are in Universal Traverse Mercator (UTM) Zone 30.

The zone with high concentration in ozone that resides in the central-upper part of the image, projected on the map of the region, can be seen in Figure 75 below, indicated with red. Moreover, the regular route, as well as the one avoiding this zone, can be seen as well with blue and grey color respectively.

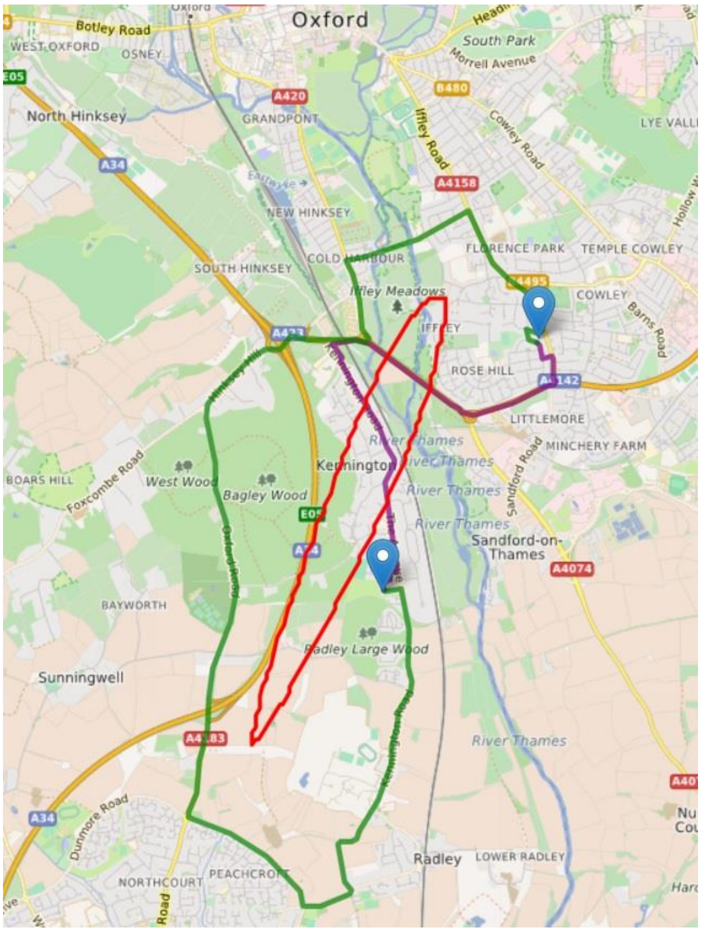


Figure 75. The regular (purple) and configured (green) routes. The configured route avoids the zone with high ozone concentration, indicated by the heatmap enclosed by the red line. For the routing requests, the Open Route Service was used.

12.4 Next step plans

In the next steps, a cost-benefit analysis will be conducted, where the gain in terms of trip time is assessed versus the associated cost. For a given pollution policy, the user will be able to adjust the weights of all relevant factors (e.g., time, distance and importance of the pollution zones) in a configurable way. This is going to be assessed from both the application and network perspectives. Finally, the size of the exchanged packets and service scalability will be tested within a simulated environment considering multiple users.

13 T4S4: LOCATION BASED ADVERTISING

13.1 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.

According to Forbes, cross-channel advertising opportunities in this fully immersive environment could combine the offline mediums, where commercial ads would sponsor your video content or streaming TV series. Of course, there would be digital banners and pay-per-click (PPC) targeting on your computer and mobile devices. While it may seem like it could be a further invasion to personal space, the in-vehicle experience will actually be more customised with personalised content based on past likes and online activities and histories. Imagine restaurant or activity recommendations made on the fly. The vehicle might even be programmed to take passengers directly to recommended destinations upon opt-in from the passenger. Eventually, the vehicle might even be able to be commanded to suggest a customised day, curated entirely by the AV. It's also easy to imagine a future in which our subscription car services have two tiers: ad-supported and ad-free. Riders looking to save money could choose to be exposed to video/audio ads during their travel. It is possible that brands will "takeover" select vehicles to create "experiences" for lucky few passengers, who in turn share on their social channels, promoting the brand organically.

The initial stages of automated and connected vehicles will be a boon for traditional out-of-home (OOH) — when drivers are still behind the wheel, but with more time to look around. This could be achieved using geolocation and geo-fencing targeting individuals but also groups of travellers in separate vehicles travelling to a common destination or event (e.g. picking up their children from school or attending a football game or concert). With opportunities abound the vehicle will become a new target for advertisers who can target and identify success of their advertising with detailed information of riders becoming available.

13.2 Proposed Setup

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

13.2.1 Network architecture

The considered network architecture is shown in Figure 76. 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.

Figure 76. Network architecture of T4S4.

13.2.2 User application architecture

The functional architecture on the user application side is described in Figure 77. The OBU is based on Android 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 HTTP Live Streaming (HLS) Application. In the initial phases, 4G USB dongles were used for initial testing, while in later stages, a 5G CPE was used to provide 5G connectivity.

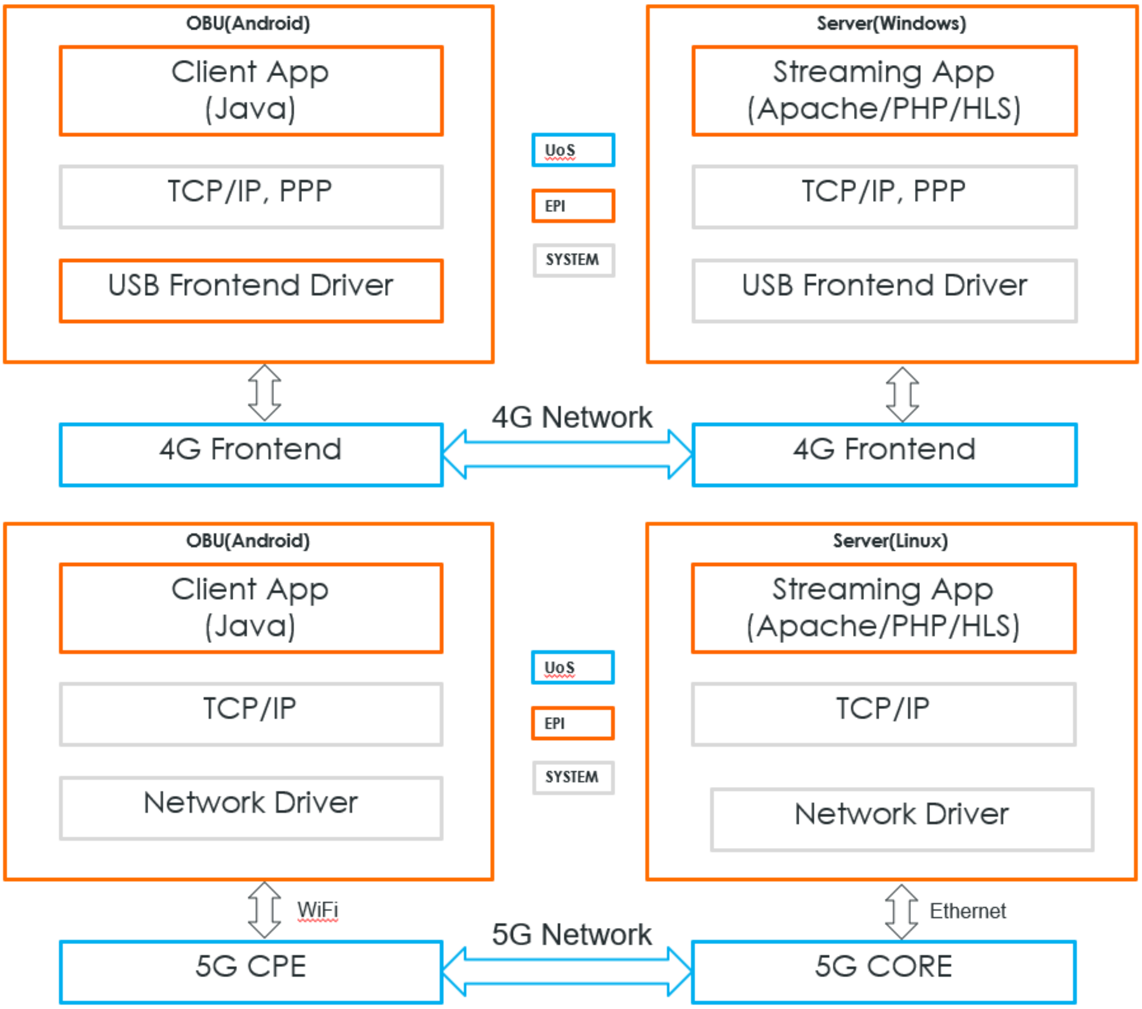


Figure 77. User application architecture with 4G and 5G connectivity, T4S4.

13.2.3 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[††††]. This is the HW to access the 5G network over WiFi and Ethernet interfaces.
- Server: These are standard datacentre servers running Linux or Windows.

[††††] https://consumer.huawei.com/en/routers/5g-cpe-pro/

13.2.4 Software components

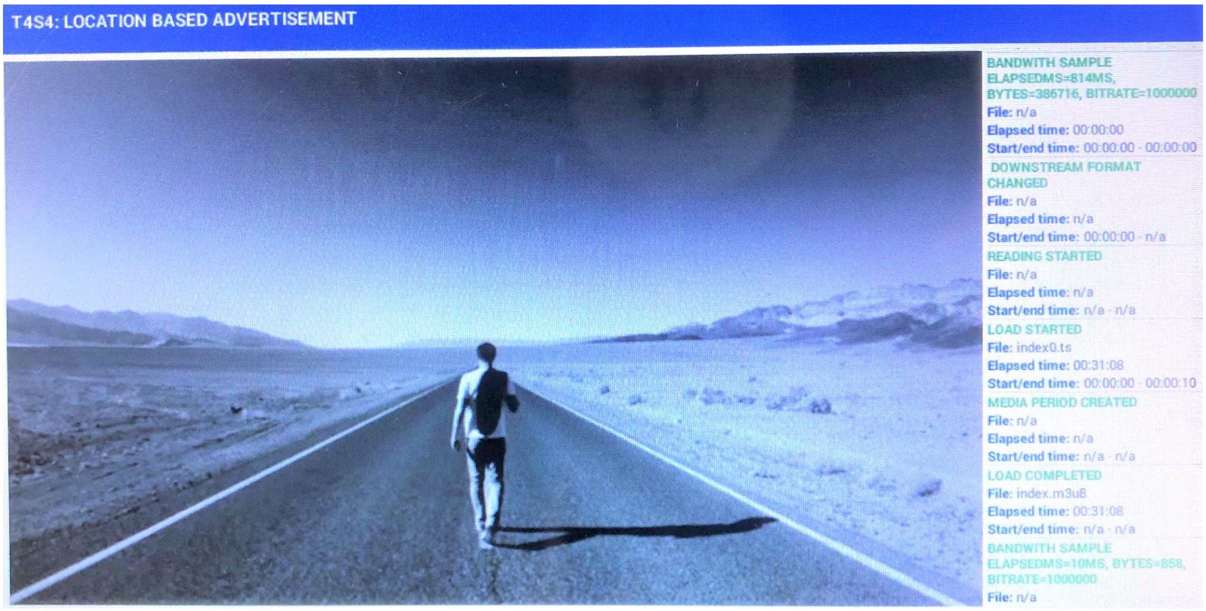
The required SW components to conduct the trials are the following:

- 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.

13.3 Testing and verification

13.3.1 Methodology

Testing was carried out by running the client/server applications and measuring KPIs by inserting logs into the code. A screenshot of the test application used for taking measurements is shown in Figure 78. Note that the measurement logs are shown alongside.



```
BANDWITH SAMPLE
ELAPSEDMS=814MS,
BYTES=386716, BITRATE=1000000
File: n/a
Elapsed time: 00:00:00
Start/end time: 00:00:00 - 00:00:00
 DOWNSTREAM FORMAT
CHANGED
File: n/a
Elapsed time: n/a
Start/end time: 00:00:00 - n/a
READING STARTED
File: n/a
Elapsed time: n/a
Start/end time: n/a - n/a
LOAD STARTED
File: index0.ts
Elapsed time: 00:31:08
Start/end time: 00:00:00 - 00:00:10
MEDIA PERIOD CREATED
File: n/a
Elapsed time: n/a
Start/end time: n/a - n/a
LOAD COMPLETED
File: index.m3u8
Elapsed time: 00:31:08
Start/end time: n/a - n/a
BANDWITH SAMPLE
ELAPSEDMS=10MS, BYTES=858,
BITRATE=1000000
File: n/a
```

Figure 78. Screenshot of the multimedia playback application for 4G and 5G.

13.3.2 List of key performance indicators

The user requirements associated with this use case scenario have been analysed and converted into a set of network KPIs in Deliverable D2.2 [10]. Table 32 presents the resulting list of network requirements together with their target values.

Table 32: Target KPIs for T4S4

Network requirements	Target values
User experienced DL throughput	High (100 Mbps)
User experienced UL throughput	Low (1 Mbps)

Broadband connectivity / peak data rate	DL: High >1000 Mbps, ≤ 20Gbps UL: Low ≤ 100 Mbps
Latency requirements	Medium (5 ms)
Reliability	Medium (99.999%)
Mobility	Low to Medium (0-200 km/h)
Location accuracy	High (0.5 m)
Connection (device) density	100 devices/km^2 (typical) 200 devices/km^2 (peak)
Interactivity	Medium > 1, ≤ 100 transactions/sec
Area traffic capacity	0.02 Mbps/m^2 (DL peak) 0.01 Mbps/m^2 (DL typical) 0.0002 Mbps/m^2 (UL peak) 0.0001 Mbps/m^2 (UL typical)
Security / privacy	Medium (Restricted)

The Phase 1 trials aim to check the baseline performance of the 4G network in the tested use case scenario and compare it to 5G. As such, the target KPIs of Table 32 are not yet achievable. Instead, the Phase 1 trials are expected to reveal the limits of 4G in sustaining an acceptable service quality.

The key target KPIs for Phase 1 are as identified below. Further KPIs are to be tested in later Phases.

- Payload
- Throughput
- Messaging Rate
- End-to-end latency

13.3.3 Measurement and testing tools

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

13.3.4 Initial results

The measurements were done by inserting logs into the code. The interactions between the client and server, shown in the sequence diagram of Figure 79, were traced and time, size measurements captured.

The main data exchange is occurring during HD video download and the average payload size and throughput was measured. The initial results, summarized in Table 33, show the limitations of 4G with respect to 5G in such use cases, where high-bandwidth multimedia streaming is involved.

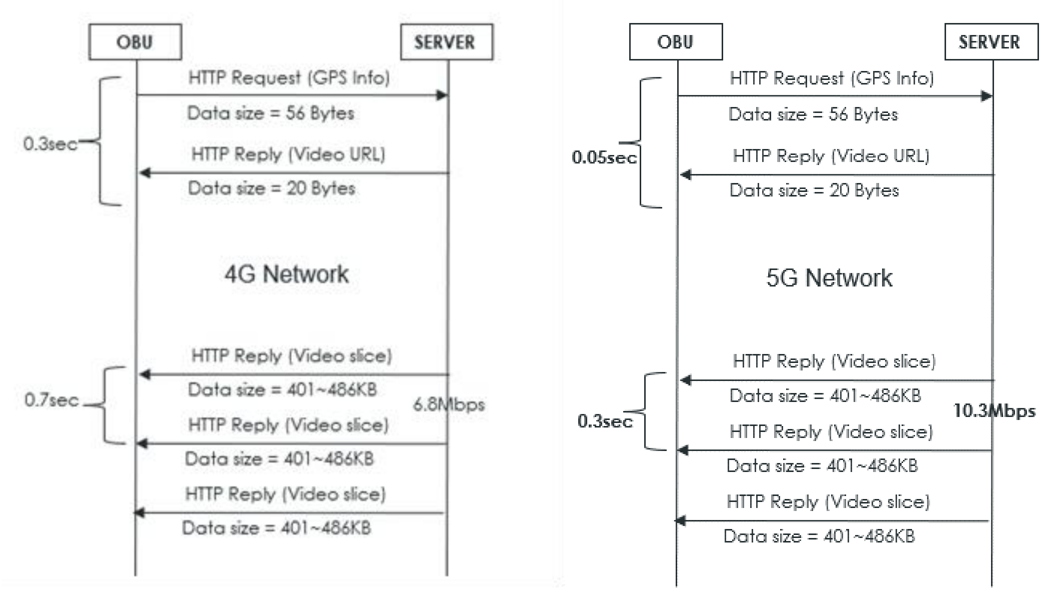


Figure 79. Interaction between OBU and backend for 4G and 5G connectivity, T4S4.

Table 33: Measurements taken in test environment (T4S4)

Parameter	Value (4G)	Value (5G)	Comment	Analysis/Interpretation
Payload	444KB (Average)	444KB (Average)	Size of video slice	As the application is same, the requested payload is same
Throughput	6.8Mbps (Average)	10.3Mbps (Average)	Average throughput for the transfer of one video slice	The throughput of 5G is better than 4G, but still reduced. The WiFi connectivity to the CPE could be the limiting factor.
Messaging Rate	0.7 sec (Average)	0.3 sec (Average)	Time between receiving video slices	As the 5G throughput is better, the associated application buffering is faster
Latency	0.3 sec	0.05 sec	Time for initial HTTP request-reply	Time reduced for 5G

Further KPIs will be tested in later phases which can bring out advantages of 5G analytically.

13.4 Next step plans

The current testing was done over the 4G and 5G networks but not always under the best conditions. As such, it is envisaged to next test 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 are the following:

- Scalability Testing
- Mobility Testing

14 T4S5: END-TO-END (E2E) SLICING

14.1 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 (e.g., network function virtualisation (NFV) and SDN) 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.

14.2 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. For each of these use cases, the V2X application will be acting as an experimenter interacting with the 5GENESIS trial facility through the modules described in the following sub-sections.

14.2.1 Network architecture

The 5GENESIS architecture, depicted in Figure 80 and described in detail in [37], is structured in three main blocks: Coordination (yellow), Management and Orchestration (green) and Infrastructure (blue).

Following a top-down explanation of the 5GENESIS architecture, the Coordination layer offers the northbound interfaces for the experimenter, the Portal and the Open APIs. It is in charge of the authentication, validation, the aggregation of the measurements and the control of the experiment lifecycle, which requires access to the components deployed at the infrastructure layer. The technology providers who are interested in integrating their products would need to develop the plugins that will allow their components to communicate with the key components of the 5GENESIS experimentation framework, i.e., the ELCM, the slice manager and the monitoring system. Details and examples of the development of such plugins are included in Deliverable D5.3 of 5GENESIS, which will be available end of June 2020. The first release that was delivered by the 5GENESIS consortium on June 2019 (i.e., Release A) includes the initial version of the Portal, the Open APIs and the ELCM. These components enable the definition and automated execution of the experiments.

In the Management and Orchestration layer, the slice manager is in charge of the configuration and deployment of the slices. This also implies access to the components available at the infrastructure layer. The 5GENESIS Release A includes the initial implementation of the slice manager and the plugins required to control and configure the components of the platforms.

The functionality provided by this scenario (i.e., E2E slicing) can be exploited to support any use case scenario of the transport vertical. As such, it is not associated with a specific user application architecture.

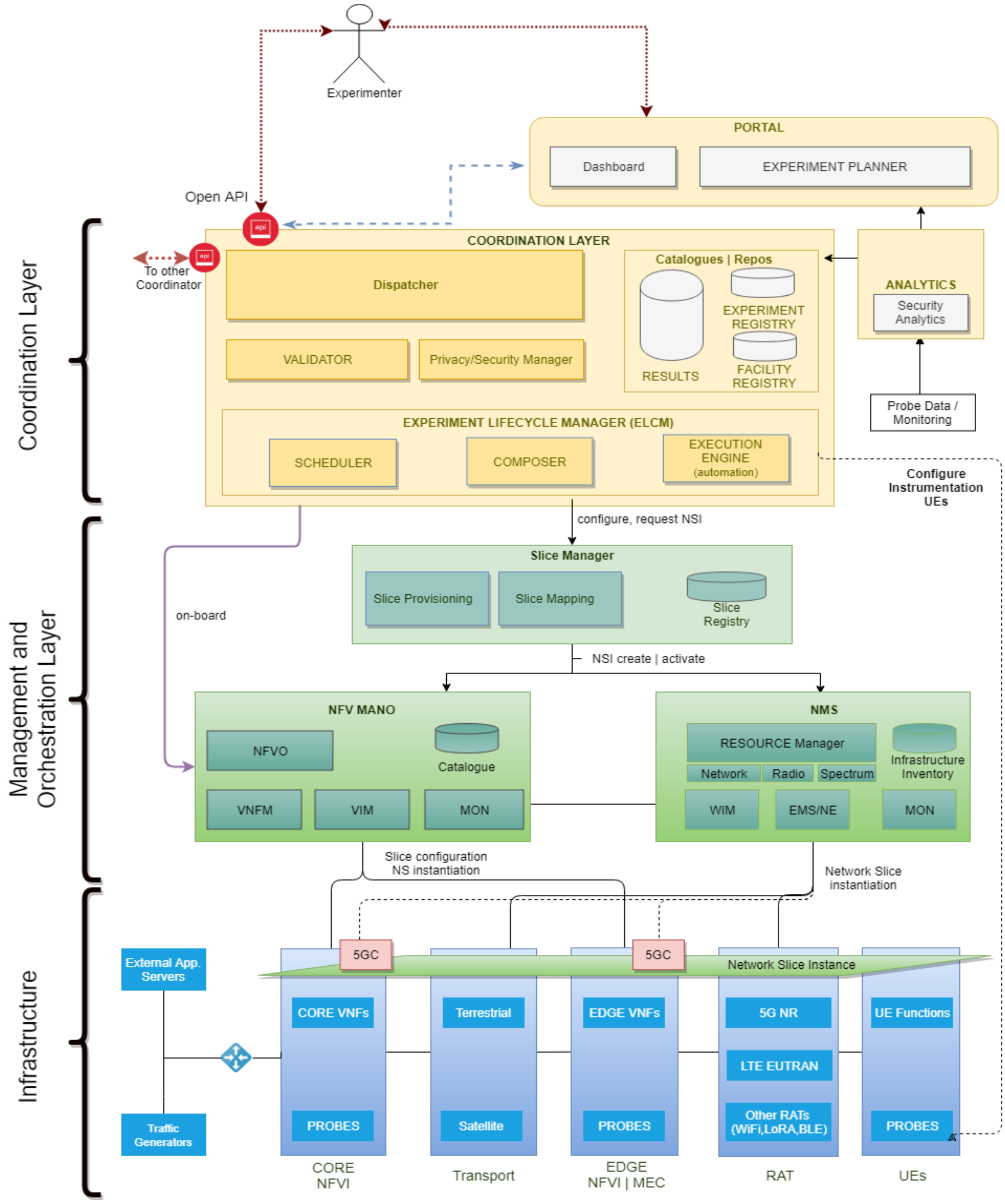


Figure 80. The 5GENESIS Architecture [37].

14.2.2 User application architecture

14.2.3 Hardware components

The 5GENESIS offers access to a range of 3GPP and non-3GPP RATs available on the UOS campus. The list of deployed nodes at the time of writing this deliverable can be found in Table 34 [5].

Table 34: Summary of deployed RATs at the Surrey Platform

Site Type	# Sites	# Cells	Access Type
Outdoor 2x Sector	36	58	LTE-A, 9 of which also support NB-IoT
Outdoor Omni	8	8	LTE-A
Indoor Lampsites	6	6	LTE-A
Outdoor 1x & 2x Sector	7	8	5G-eMBB
Outdoor 1 Sector	1	1	5G-URLLC
Outdoor Omni	1	1	700MHz – LTE-A
Indoor AP	6	6	Wi-Fi
Outdoor GW	3	3	LoRa GW

14.2.4 Software components

This section provides a brief description of the most relevant entities of the 5GENESIS architecture from the experimenter (i.e., 5G-HEART) perspective, namely the Slice Manager, Open API and Portal.

14.2.4.1 Slice Manager

The 5GENESIS is based on a highly modular architecture, built as a group of microservices, each running in a docker container. Figure 81 depicts an overview of the building blocks of the 5GENESIS Slice Manager. A detailed description of the 5GENESIS Slice Manager architecture, APIs, interfaces and functional use cases is provided in [38].

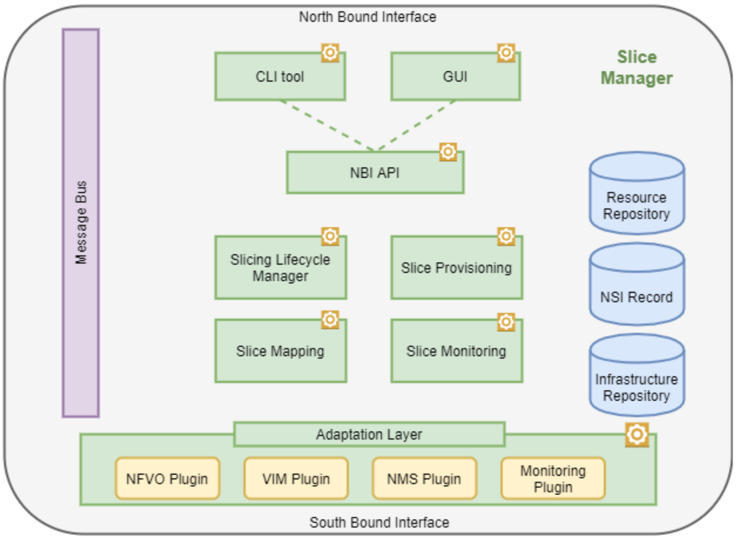


Figure 81. Slice Manager building blocks

14.2.4.2 Open API

The main function of the Open API architecture is to define the interface that can be easily consumed and accessed by the experimenter's client. It offers protocols and custom data format to facilitate the interaction with the 5GENESIS system.

During the design process, the requirements and needed exposed features to communicate with the different modules in the 5GENESIS facility were considered, specially the interfaces between the coordinator layer and the Management and Network Orchestration (MANO) layer. Beyond its functionality, the design of the API considers the exposed functionalities and the end-user experience.

Figure 82 depicts the architecture and interfaces between the components and modules involved in the creation of the experiment from the 5GENESIS portal.

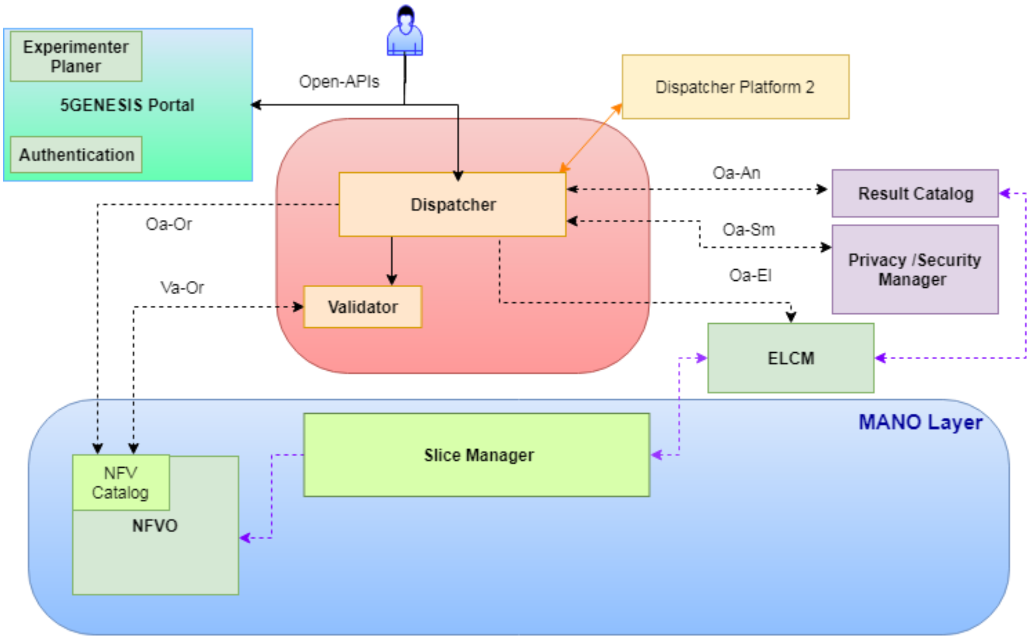


Figure 82. The Open API architecture.

A detailed description of the 5GENESIS Open API in terms of architecture, exposed features, and interfaces, as well as initial implementation resulting in Release A, is provided in [39].

14.2.4.3 Portal

Each platform will deploy its own instance of the 5GENESIS Portal. This allows external users to perform experiments in the 5GENESIS platforms, as well as to retrieve the results produced by the experiments. Prior to that, the first necessary steps to perform experimentation through the 5GENESIS Portal are the experimenter registration and login.

It is important to note that, during Release A, if an experiment needs the use of a NS, it must be available in the testbed or must be uploaded manually by the testbed operator. Additionally, any other functionality or necessity, not directly supported through the Portal, can be discussed with the testbed operator to study its feasibility. In Release B, the NS onboarding will be added in the Portal to allow experimenters upload the required NS artefacts by themselves.

When the user has logged in, the parameters for the experiment can be defined. The parameters that can be set are the name of the experiment, its type, the test cases to execute, the devices used for the experiment and the network slice.

The user's dashboard shows all the experiments previously created by the user. This dashboard allows the user to start the execution of an experiment or to view the history of both previous and current executions of a specific experiment. The visualization of the experiment results is based on Grafana.

14.3 Testing and verification

14.3.1 Methodology

5GENESIS is based on five complementary experimentation Platforms, which expose their underlying capabilities in a harmonised way, as described in the 5GENESIS common reference architecture [37]. This 5GENESIS reference architecture exposes the Open API described above with the goal of offering verticals an open and common method to interface for experimentation.

The 5GENESIS Open API is the interface offered by the coordination layer to experimenters for the definition and execution of the experiments. However, 5GENESIS also provides them with a Portal with a friendly Web Interface to facilitate their task even more. The Portal itself uses the 5GENESIS Open API to communicate with the coordination layer component.

Therefore, there are two ways in which the experimenters can interact with the 5GENESIS Facility, (1) via the Portal and/or (2) using the Open API directly in the case of more advanced users of the Platform or experienced verticals.

Figure 83 depicts, in more detail, the steps to run an experiment via the Portal, while Figure 84 shows the experimentation steps when using the Open API.

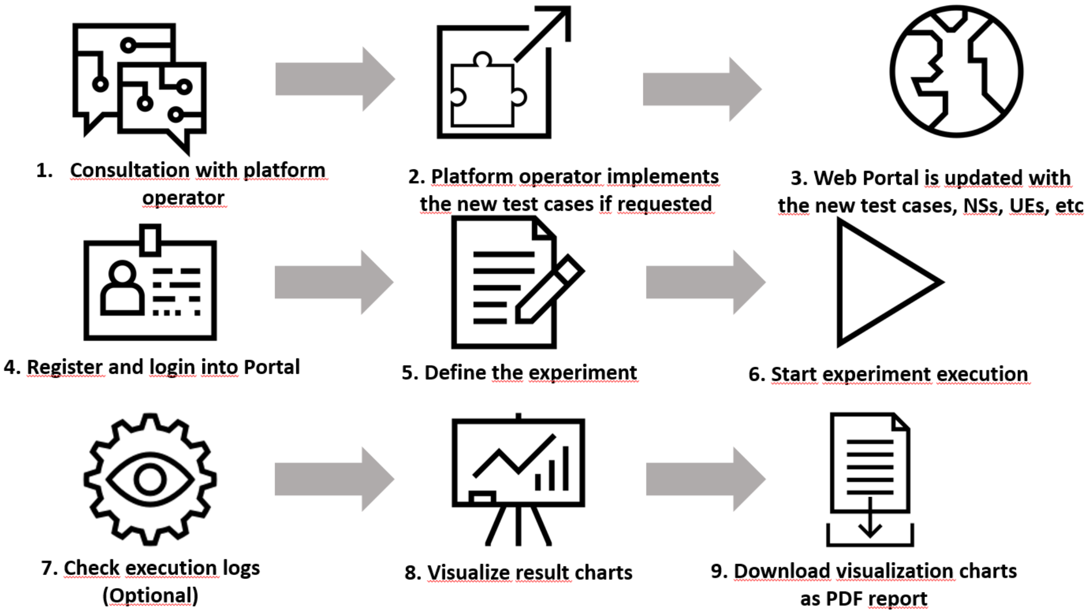


Figure 83. Experimentation via the Portal

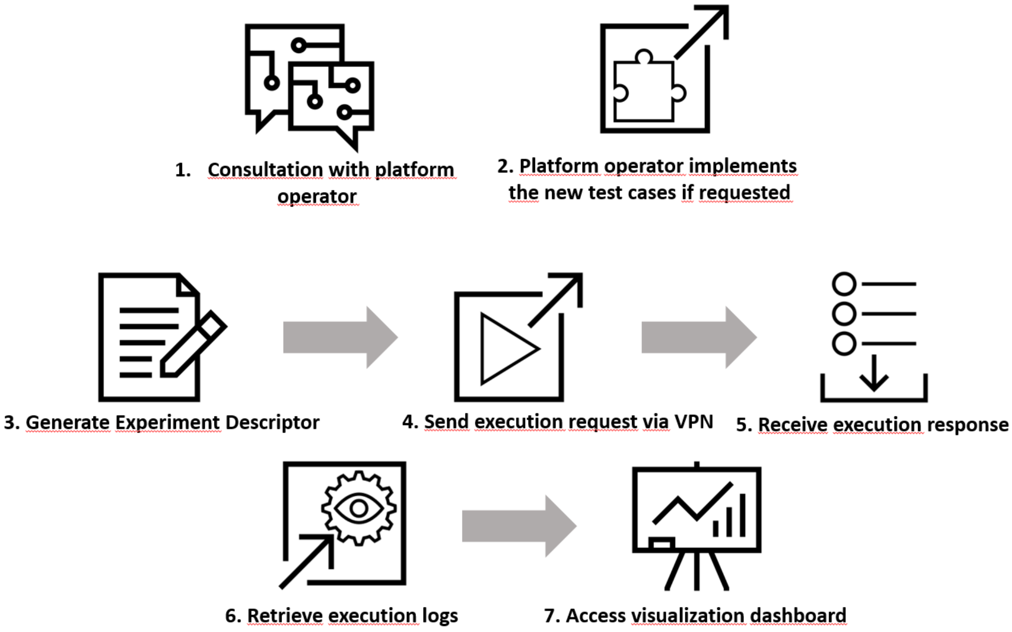


Figure 84. Experimentation via the OPEN API.

To provide insight into the 5GENESIS Experimenter Portal, a video tutorial[‡‡‡‡] has been recently published. The detailed descriptions of the experimentation via the Open API and Portal will be provided in Deliverable D5.3 of 5GENESIS, which will be available end of June 2020.

14.3.2 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.

Additionally, the concurrent slicing of a mixture of use case scenarios, associated with heterogeneous requirements (i.e., eMBB, URLLC and massive MTC (mMTC)), 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.

These metrics will be mainly collected on the ICT-17 5GENESIS trial facility and possibly the national 5Groningen (Netherland) and 5GTN (Finland) facilities.

14.3.3 Measurement and testing tools

On the 5GENESIS trial facility side, the M&A 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 ultimate goal, within the Project’s scope, is to verify the status of the infrastructure components during the execution of experiments for the validation of 5G KPIs.

In its Release A, the 5GENESIS M&A framework is designed and implemented in 3 main interoperable functional blocks:

[‡‡‡‡] https://www.youtube.com/watch?v=er0zE-17ULs

- *Infrastructure Monitoring*, which focuses on the collection of data that synthesize the status of architectural components, e.g., end-user devices, radio access/networking systems, computing and storage distributed units;
- *Performance Monitoring*, which is devoted to the active measurements of E2E QoS/QoE 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.

The parallel use of infrastructure and performance monitoring tools, along with ML Analytics, allows a full and reliable assessment of the KPIs, possibly pinpointing issues leading to performance losses, and ultimately triggering the use of improved network policies and configurations during the next experiment executions.

Both the framework design and implementation have been carried out considering the 5GENESIS common reference architecture, as well as both commonalities and peculiarities of the 5GENESIS platforms. The design and implementation of the 5GENESIS M&A framework is described in [40].

In the context of 5GENESIS, InfluxDB is used as common tool for the creation of platform-specific instances of a long-term storage utility. InfluxDB is the open-source storage engine provided within the InfluxData framework to handle time series data. Several motivations have triggered its use in the 5GENESIS M&A framework, including:

- InfluxDB provides a lightweight integration with both Prometheus and Zabbix, as well as with Grafana, which is used in the 5GENESIS Portal as a core SW for data visualization.
- InfluxDB is a key component of the overall InfluxData platform.

The visualization of the experiments' results is based on Grafana. The Grafana dashboard is accessible through the Portal. The corresponding dashboard is customized for each kind of test case. The experimenter can zoom in any of the included graphs in order to see a detailed view of certain periods of time.

Finally, on the vehicle side, the methodology briefly described in Section 2.2.2 will be further elaborated to capture the end-user perception and assess the contribution of the vehicle on-board components to the overall performance.

14.3.4 Initial results

This section provides the results of a set of baseline eMBB slicing experiments that were conducted in collaboration with the Surrey's team of the 5GENESIS project. These experiments perform two sets of test cases to assess the achievable end-to-end throughput and RTT on the 5GENESIS trial facility.

The considered network setup is depicted in Figure 85. It consists of the following components:

- **Core**: Rel.15 4G Core NSA,
- **Control Plane**: 4G RAN,
- **User Plane**: 5G RAN (Huawei Commercial),
- **UE**: 5G CPE.

The 5G CPE, connected to both the eNB and gNB according to an NSA deployment, hosts an iPerf client that is interacting with an Iperf server and controlled via Ethernet using the Test Automation Platform (TAP) from Keysight[§§§§]. The reader is referred to the Deliverables D6.1 [41] and D2.3 [42] of 5GENESIS for more details about the experimentation methodology and test case description, respectively.

[§§§§] https://www.keysight.com/upload/cmc_upload/All/TapDeveloperGuide.pdf

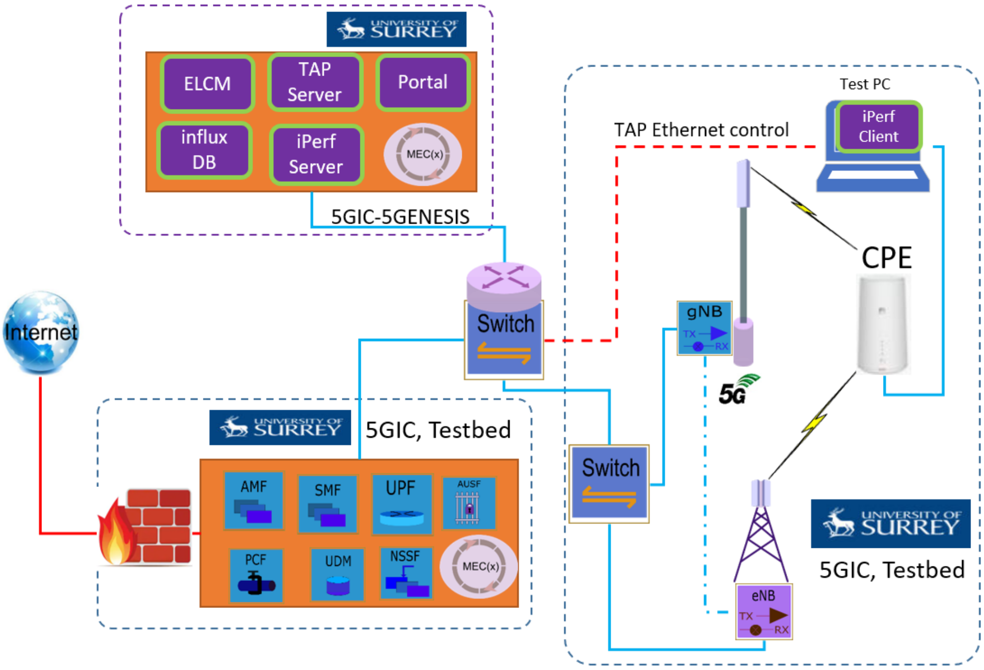


Figure 85. Architecture for the slicing baseline experiments on 5GENESIS

In what follows, the results of the conducted test cases are presented. The first assesses the end-to-end RTT, while the second measures the achievable throughput.

14.3.4.1 Round Trip Time

The purpose of this test case is to assess the end-to-end RTT from a 5G CPE client to a server over the 5G NR Rel-15 NSA deployment of the 5GENESIS trial facility. It is based on a ping message sent on the UL over ICMP type 8 (echo message) and the associated answer received on the DL over ICMP type 0 (echo message reply).

The results of the RTT test are shown in Figure 86. To visually display the RTT distribution through its quartiles, a box plot is shown for each of the considered iterations.

The 95th percentile RTT is 12.54 +/- 0.05 ms, which is quite short. This is because the 5G RAN components in the 5GENESIS trial facility are connected to the SDN switch in the core network via fast and reliable fibre links. Moreover, the 5GENESIS 4G network consists of powerful fast performing servers that are able of performing all required tasks in a computationally efficient manner, thus reducing the resulting latencies.

The detailed results of this test case (including 5th, 25th, and 75th percentile RTT) can be found on Table 49 of Appendix B.

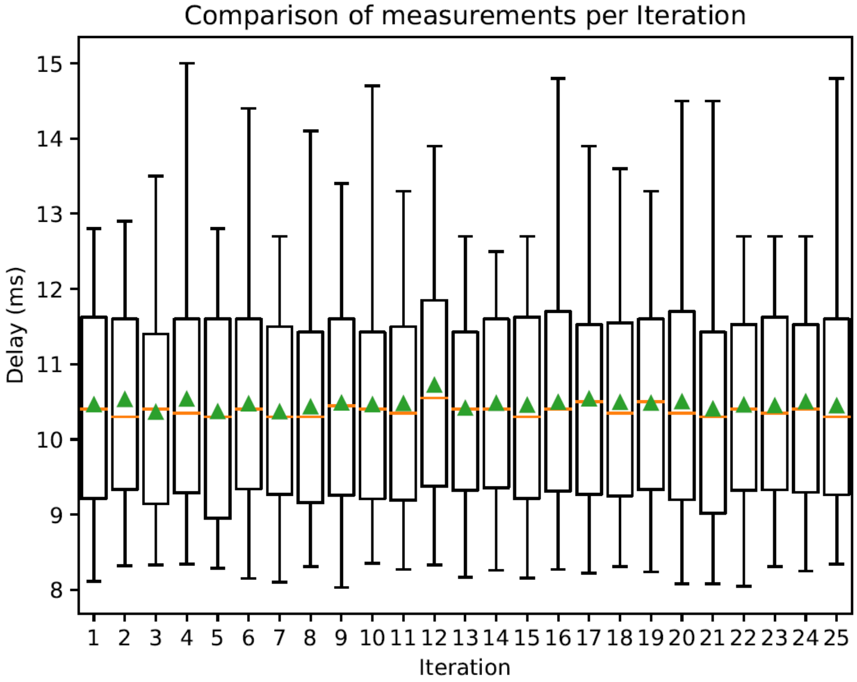


Figure 86. Round Trip Time test results

14.3.4.2 Throughput

This section presents and discusses the results of the throughput tests performed in the UL and DL directions of the 5G NR Rel-15 NSA deployment of the 5GENESIS trial facility.

The results of the UL and DL tests are shown in Figure 87 and Figure 88, respectively.

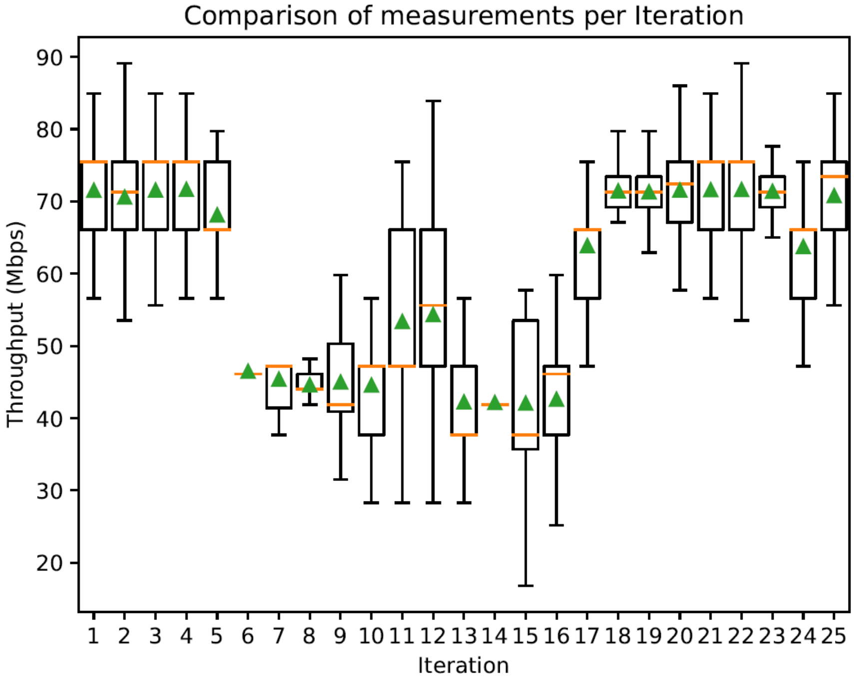


Figure 87. Throughput test results (UL, TCP)

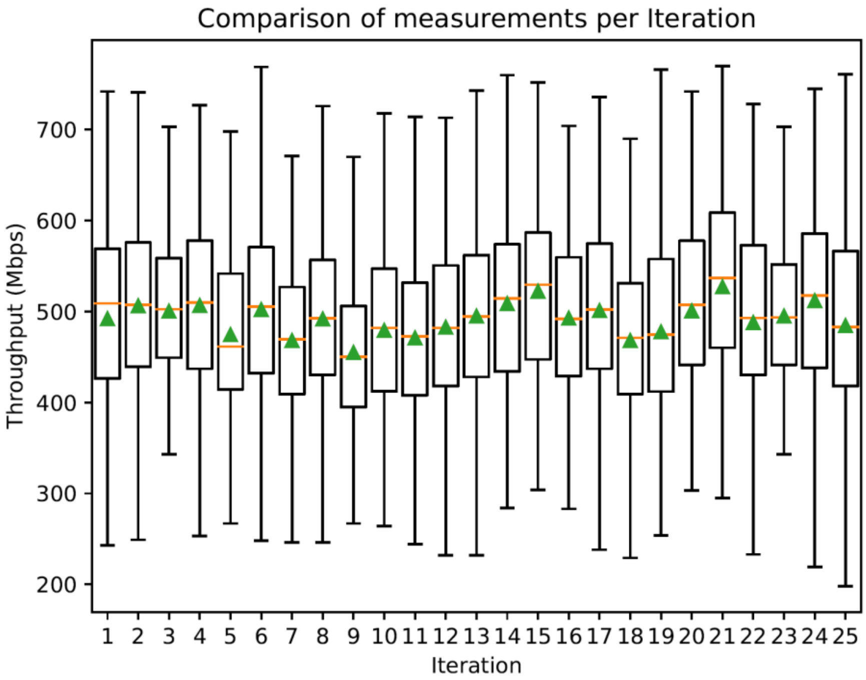


Figure 88. Throughput test results (DL. TCP)

In the UL direction, the 95th percentile throughput is 67.52 +/- 5.04 Mbps. The high variance of the results is mainly attributed to the environmental factors of the outdoor testbed at the time of testing. In the DL direction, the 95th percentile throughput is 651.83 +/- 10.30 Mbps, which is quite promising.

The detailed UL and DL results of this test case (including 5th, 25th, and 75th percentile throughput) can be found on Table 50 and Table 51 of Appendix B, respectively.

14.4 Next step plans

The conducted generic slicing experiments involved few manual adjustments to properly configure the used slices. These adjustments are being automated and extended to support the specific requirements of the transport vertical. The slicing-as-as-service functionality will be next exploited to trial a short list of use case scenarios, starting with TeSo (i.e., T3S1). The trials will be initially based on CN-slicing and eventually evolve to include a form of RAN slicing.

The original project plan of the 5GENESIS project is shown in Figure 89. However, due to COVID-19, a 6-month extension has been recently granted by the European Commission (EC). As such, the 5G-HEART project will maintain close interaction with the 5GENESIS platform owner to get synchronised with any revised timeline and decide if any specific extension and/or level of customisation is needed to support the transport use cases of 5G-HEART. Such interaction has been facilitated by a common core partner (i.e., UOS) as per the collaboration agreement between all ICT-17 facilities (i.e., in this case 5GENESIS) and ICT-19 trials (i.e., in this case 5G-HEART).

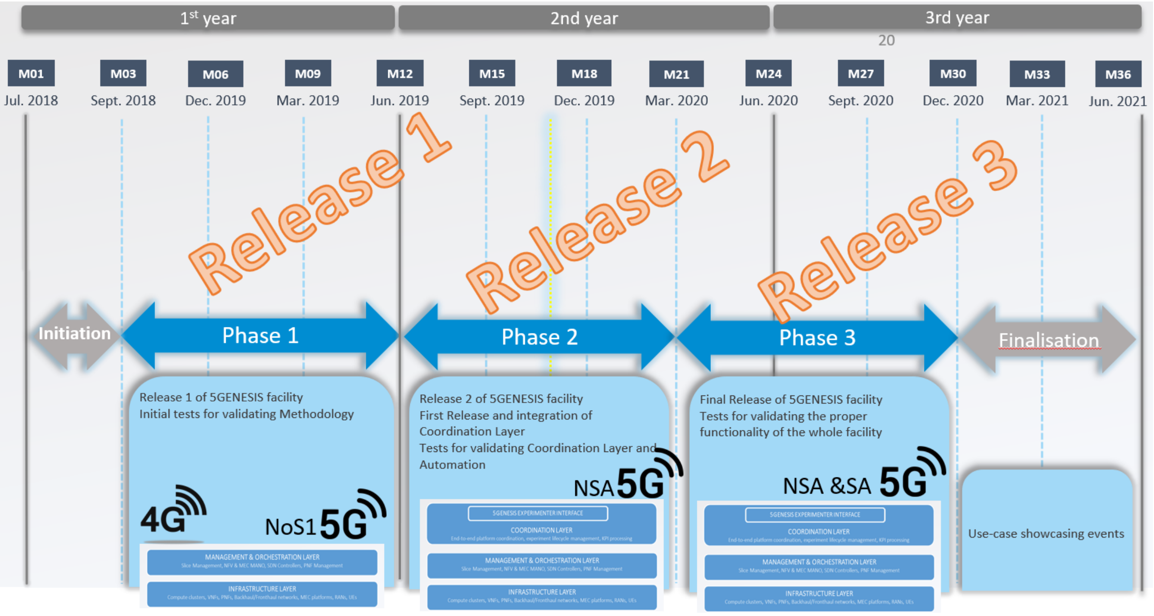


Figure 89. The 5GENESIS Project Plan.

15 T4S6: VEHICLE SOURCED HIGH-DEFINITION (HD) MAPPING

15.1 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.

As one of the most important of human inventions, man has been making maps for millennia. People have created and used maps to help them define, explain, and navigate their way through the world and beyond. These maps initially were in the form of two-dimensional drawings and eventually took the form of three-dimensional globes. Modern maps of the old and new worlds were developed during the age of discovery. The last century has ushered in the information age where the power of computing, connectivity and storage has allowed us to digitise maps and transmit real-time location information via satellite technology. These maps are commonly used in smartphones through the use of applications such as Google Maps and also in vehicles (e.g. TomTom and Garmin for road vehicles).

For Lyft, maps are a key component to building self-driving technology [43]. Unlike regular web map services which are in wide use today for turn by turn navigation, AVs require a new class of HD maps. Current maps and mass market location-based tracking using GNSS technology provides accuracy within a range of ten meters. HD maps for AVs need to represent the world at a centimetre level resolution, which is orders of magnitude greater than the resolution that map services offer today.

AVs demand such a high resolution because they need to routinely execute complex manoeuvres such as nudging into a bike lane to take a turn and safely passing cyclists. For example, marked bike lanes in Europe are typically 1.2 – 1.5 meters wide at a minimum, but are recommended to be between 1.5-2.5m in width. Other factors such as the type of road or junction, distance from the kerb, road signage as well as other considerations impact the design of these lanes. Centimetre level accurate maps are a must for an AV to be able to confidently reason about its position within a lane, assess distance from vehicles, cyclists, road infrastructure and potentially unique road features (e.g. potholes or other road conditions) to confidently take action.

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.

15.2 Proposed Setup

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

15.2.1 Network architecture

The considered network architecture during sensor upload is shown in Figure 90. The HD mapping application should be running on both the OBU and cloud mapping server.

Figure 90. Network architecture of T4S6.

15.2.2 User application architecture

The functional architecture on the user application side is shown in Figure 91. 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.

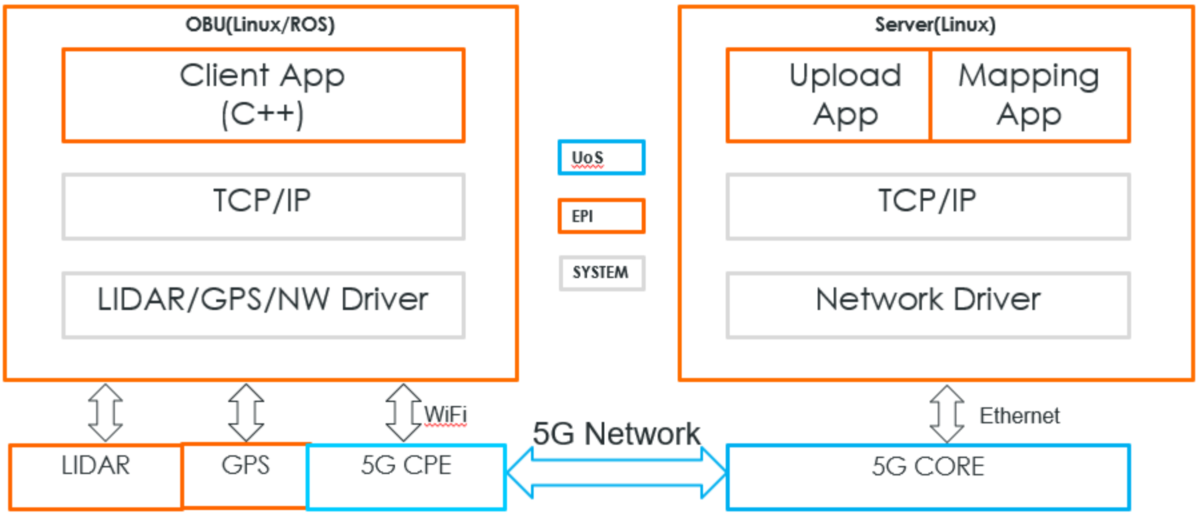


Figure 91. User application architecture with 4G and 5G connectivity, T4S6.

15.2.3 Hardware components

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

- OBU: This consists of an Intel-based board running Ubuntu Linux.
- LiDAR: SLAMTEC RPLIDAR A3 LiDAR[*****]. 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[†††††]. This is the HW to access the 5G network over WiFi and Ethernet interfaces.
- Server: These are standard datacentre servers running Linux.

[*****] https://www.slamtec.com/en/Lidar/A3

[†††††] https://consumer.huawei.com/en/routers/5g-cpe-pro/

15.2.4 Software components

The required SW components to conduct the 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.

15.3 Testing and verification

15.3.1 Methodology

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

15.3.2 List of key performance indicators

The user requirements associated with this use case scenario have been analysed and converted into a set of network KPIs in Deliverable D2.2 [10]. Table 35 presents the resulting list of network requirements together with their target values.

Table 35: Target KPIs for T4S6

Network requirements	Target values
User experienced DL throughput	Low ≤ 1 Mbps
User experienced UL throughput	High (100 Mbps)
Broadband connectivity / peak data rate	DL: Low ≤ 100 Mbps UL: High >1000 Mbps, ≤ 20Gbps
Latency requirements	Low (100 ms)
Reliability	Low (99.99%)
Mobility	Low to Medium (0-200 km/h)
Location accuracy	High (0.5 m)
Connection (device) density	100 devices/km^2 (typical) 200 devices/km^2 (peak)
Interactivity	Medium > 1, ≤ 100 transactions/sec
Area traffic capacity	0.0002 Mbps/m^2 (DL peak) 0.0001 Mbps/m^2 (DL typical) 0.02 Mbps/m^2 (UL peak) 0.01 Mbps/m^2 (UL typical)
Security / privacy	Low (Public)

The Phase 1 trials aim to check the baseline performance of a non-optimised 5G configuration in the tested use case scenario. As such, the target KPIs of Table 35 are not yet achievable. Instead, the Phase

1 trials are expected to reveal the limits of non-optimised 5G configurations in sustaining an acceptable service quality. This paves the way to future (i.e., Phases 2 and 3) trials based on optimised 5G configurations.

The key target KPIs for Phase 1 are:

- Payload
- Throughput
- Messaging Rate
- End-to-end latency

15.3.3 Measurement and testing tools

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

15.3.4 Initial results

Figure 92 shows the sequence diagram of the interaction between the OBU and backend.

The main data exchange is occurring during LiDAR/GPS data upload. The obtained results and their interpretation are summarized in Table 36.

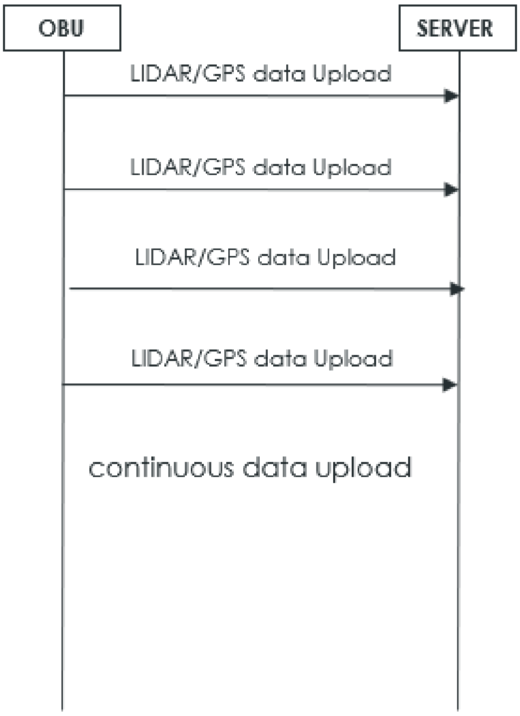


Figure 92. Interaction between OBU and backend, T4S6.

Table 36: Measurements taken in test environment (T4S6)

Parameter	Value (5G)	Comment	Analysis/Interpretation
Payload	Not Applicable	Using a TCP stream oriented reliable connection, data is uploaded continuously	

Throughput	301 Mbps	The rate at which data is uploaded.	The sensor data may be better curated to reduce the data throughput required for the application.
Messaging Rate	Not Applicable	Using a TCP stream oriented reliable connection, data is uploaded continuously	
Latency	Not Applicable	No reply messaging from server	

Further KPIs are to be tested in later phases which can bring out advantages of 5G analytically. Comparative performance with respect to 4G is also planned.

15.4 Next step plans

- Scalability and Performance testing
- Mobility Testing

16 T4S7: ENVIRONMENTAL SERVICES

16.1 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.

Vast amounts of environmental sensors exist both on board vehicles as well as in roadside infrastructure, but currently that data is not consolidated, integrated and used outside very specific and isolated applications for which each sensor is deployed. With the availability of 5G capabilities and infrastructure the opportunity for massive transfer and consolidation of on-board and roadside environmental sensor data and the utilisation of that data in different scenarios and applications becomes possible.

Key for the implementation for this use case would be a centralised hub or exchange that would consolidate, process, translate and make available the collected data and information. Some distributed processing and consolidation might be desirable for some applications, e.g. either at the vehicle OBU or RSU.

In vehicles, a wealth of environmental data can be accessed and collected using an OBU integrated or connected to the vehicle systems, including light sensors, wiper data and suspension sensors. Roadside infrastructure will include air quality sensors, non-ionizing radiation sensors, acoustic noise sensors which could be integrated into the same system for data collection and integration.

Weather and environmental sensor data can be used to create hyper local weather maps aiding drivers and AVs in day-to-day driving. Driver warnings and advisory speed limits would be an example of applications of such data from a vehicle point of view. External transportation systems would also use such data for proactive traffic management in real time.

Additionally, environmental information could be used in planning and management systems with data collected over time, for example for road maintenance by local authorities, weather forecasting by the Met Office, emergency services planning and response, asset inventory and management planning by authorities responsible for road conservation, pollen monitoring and mapping as well as water and sewage monitoring and maintenance.

16.2 Proposed Setup

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

16.2.1 Network architecture

The considered network architecture during sensor data upload to cloud is shown in Figure 93. 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.

Figure 93. Network architecture of T4S7.

16.2.2 User application architecture

The functional architecture on the user application side is shown in Figure 94. 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 IoT oriented server Application, using the MQTT protocol.

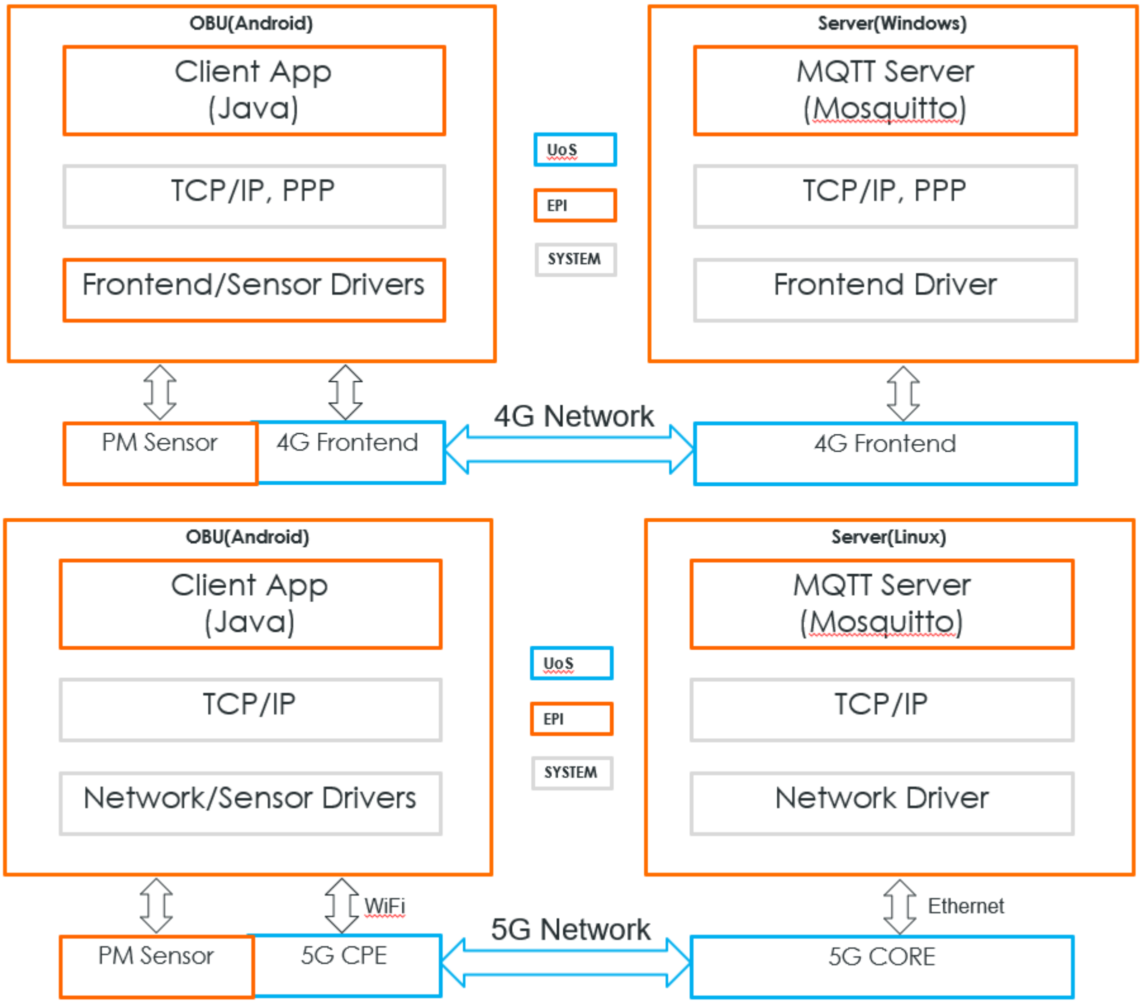


Figure 94. User application architecture with 4G and 5G connectivity, T4S7.

16.2.3 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[‡‡‡‡‡]. This is the HW to access the 5G network over WiFi and Ethernet interfaces.
- Server: These are standard datacentre servers running Linux or Windows.

16.2.4 Software components

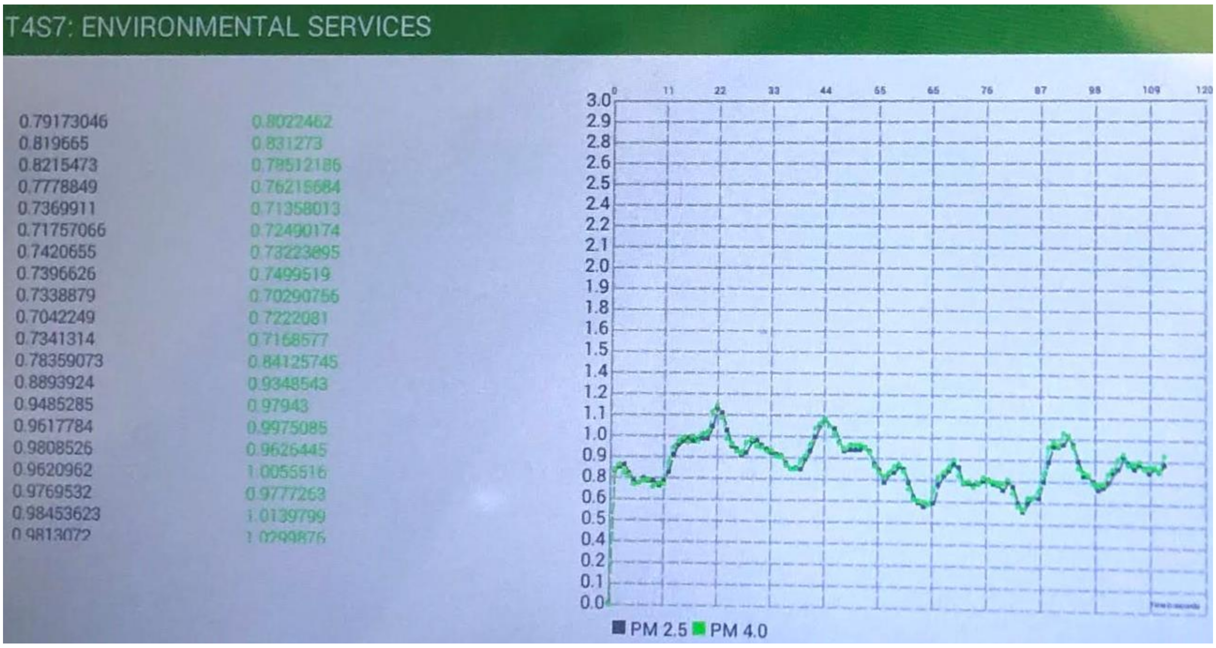
The required SW components to conduct the trials are the following:

- 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.

16.3 Testing and verification

16.3.1 Methodology

Testing was carried out by running the client/server applications and measuring KPIs by inserting logs into the code. A screenshot of the test application used for measurement is shown in Figure 95.



T4S7: ENVIRONMENTAL SERVICES

```
0.79173046    0.8022462
0.819665      0.831273
0.8215473     0.78512186
0.7778849     0.76215684
0.7369911     0.71358013
0.71757066    0.72490174
0.7420655     0.73223895
0.7396626     0.7499519
0.7338879     0.70290756
0.7042249     0.7222081
0.7341314     0.7168577
0.78359073    0.84125745
0.8893924     0.9348543
0.9485285     0.97943
0.9617784     0.9975085
0.9808526     0.9626445
0.9620962     1.0055516
0.9769532     0.9777263
0.98453623    1.0139799
0.9813072     1.0299876
```

Figure 95. Screenshot of sensor data capture application (4G and 5G setups).

[‡‡‡‡‡] https://consumer.huawei.com/en/routers/5g-cpe-pro/

16.3.2 List of key performance indicators

The user requirements associated with this use case scenario have been analysed and converted into a set of network KPIs in Deliverable D2.2 [10]. Table 37 presents the resulting list of network requirements together with their target values.

Table 37: Target KPIs for T4S7

Network requirements	Target values
User experienced DL throughput	Low ≤ 1 Mbps
User experienced UL throughput	Medium (10 Mbps)
Broadband connectivity / peak data rate	DL: Low ≤ 100 Mbps UL: Medium >100, ≤ 1000 Mbps
Latency requirements	Low (100 ms)
Reliability	Low (99.99%)
Mobility	Low to Medium (0-200 km/h)
Location accuracy	Medium (4 m)
Connection (device) density	100 devices/km^2 (typical) 200 devices/km^2 (peak)
Interactivity	Low (1 transaction/sec)
Area traffic capacity	0.0002 Mbps/m^2 (DL peak) 0.0001 Mbps/m^2 (DL typical) 0.002 Mbps/m^2 (UL peak) 0.001 Mbps/m^2 (UL typical)
Security / privacy	Low (Public)

The Phase 1 trials aim to check the baseline performance of the 4G network in the tested use case scenario and compare it to 5G. As such, the target KPIs of Table 37 are not yet achievable. Instead, the Phase 1 trials are expected to reveal the limits of 4G in sustaining an acceptable service quality.

The key target KPIs for Phase 1 are:

- Payload
- Throughput
- Messaging Rate
- End-to-end latency

16.3.3 Measurement and testing tools

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

16.3.4 Initial results

The measurements were done by inserting logs into the code. The interactions between the client and server, shown in the sequence diagram of Figure 96, were traced and time, size measurements captured and the average payload size and messaging rate measured.

The obtained results and their interpretation are summarized in Table 38.

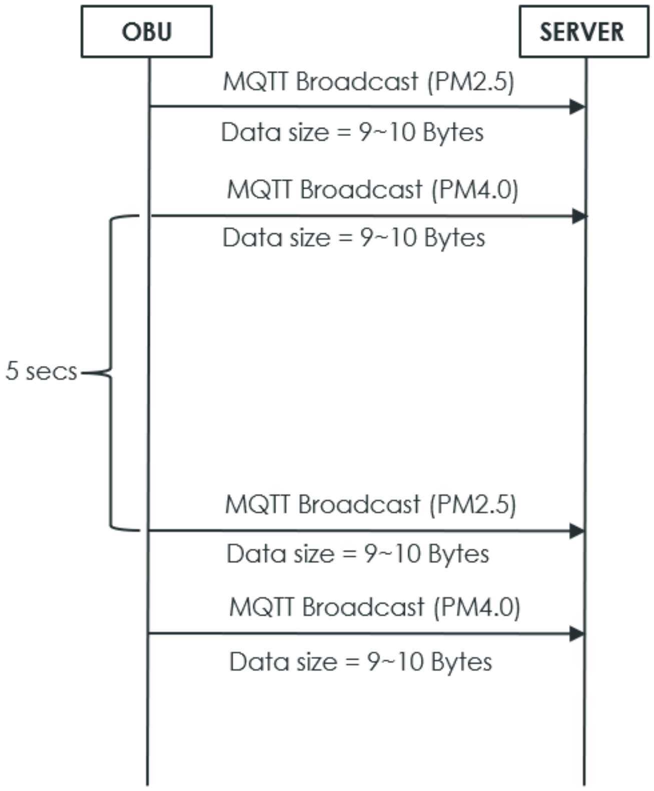


Figure 96. Interaction between OBU and backend with 4G and 5G connectivity, T4S7.

Table 38: Measurements taken in test environment (T4S7)

Parameter	Value (4G & 5G)	Comment	Analysis/Interpretation
Payload	9~10 Bytes	Protocol overhead of MQTT, TCP/IP not considered	The sensor data are of very small size
Throughput	Not Applicable	Required data rates are very low	As there are only few bytes of data, no observable difference between 4G and 5G
Messaging Rate	1 message each 5 seconds	Currently air quality samples are taken once in 5 seconds	The settling time for the device makes more frequent readings difficult
Latency	Not Applicable	No reply messaging from server	The data is only published, with no reply from server, reliability not critical

During the next phases, tests with higher device density are planned and the main target KPIs of Table 37 will be measured. These tests are expected to reveal the advantages of 5G in supporting this use case.

16.4 Next step plans

The current testing was done over the 4G and 5G networks. Further tests will be done inside moving vehicles under different operating conditions (e.g., radio conditions, network coverage and device density).

The next immediate steps are the following:

- Scalability Testing
- Mobility Testing

17 CONCLUSION

This deliverable reports the progress made on the Phase 1 trials of the 5G-HEART transport vertical use cases. These trials have been conducted per scenario, coordinated by the scenario leaders, and using the 5GENESIS (Surrey, UK), 5Groningen (Groningen, the Netherland) and 5GTN (Oulu, Finland) trial facilities.

Different levels of progress have been achieved for the various use cases depending on the availability of vehicles for trials. For most T2 scenarios (i.e., *T2S1&T2S2: Smart junctions and network assisted & cooperative collision avoidance (CoCa)* and *T2S4: Human tachograph*), the initial 5G solutions have been developed and evaluated using specially equipped vehicles/ambulances. These will augment and guide the subsequent more advanced (i.e., Phase 2) trials using optimised 5G networks. For the others (i.e., T1, T3 and T4 scenarios), the focus has been on designing, testing and validating different individual components (e.g., high-definition (HD) cameras, sensor nodes and software-defined radios (SDRs)) for integration into the research experimentation vehicles provided by the new member who recently joined the consortium (i.e., Technical University Chemnitz (TUC)). To ensure the by-design integrability of these components, extensive discussions and remote collaboration have been established with the team responsible for maintaining these vehicles, while the actual integration will be performed during a set of on-site workshops that will be held at the TUC premises as soon as the COVID-19 restrictions are lifted.

Based on the results, observations and insights acquired during Phase 1 trials, a planning of the next steps has been provided for each of the use case scenarios. Certain synergies have also been identified between transport scenarios (e.g., *T2S3: Quality of service (QoS) for advanced driving* and *T3S1: Tele-operated support (TeSo)*) and with other verticals (e.g., *T2S4: Human tachograph* with healthcare use cases), and these will be exploited in future combined trials.

APPENDIX A: SPECIFICATIONS OF EXPERIMENTAL USRP SETUPS

This appendix provides the specifications of the HW components of the experimental OAI+USRP setups described in Section 3.2.2

A.1 Experimental 4G and LWA Setups

A.1.1 Specifications of USRP-2954R

The USRP-2954R board contains a GPS-disciplined oscillator (GPSDO), which enables to lock the internal clocks to a GPS reference signal, synchronize using GPS timing information, and query GPS location information. The associated specifications of its transmitter and receiver modules are given in Table 39 and Table 40, respectively [7]:

Table 39: Specifications of the transmitter of USRP-2954R

Item	**Value**
Number of channels	2
Frequency range	10 MHz to 6 GHz
Frequency step	<1 kHz
Maximum output power (Pout)	50 mW to 100 mW (17 dBm to 20 dBm)
Gain range	0 dB to 31.5 dB
Gain step	0.5 dB
Maximum instantaneous real-time BW	160 MHz
Maximum I/Q sample rate	200 mega-samples per second (MS/s)
Digital-to-analog converter (DAC) Resolution	16 bit
Spurious-free dynamic range (sFDR)	80 dB

Table 40: Specifications of the receiver of USRP-2954R

Item	**Value**
Number of channels	2
Frequency range	10 MHz to 6 GHz
Frequency step	<1 kHz
Maximum output power (Pout)	50 mW to 100 mW (17 dBm to 20 dBm)
Gain range	0 dB to 37.5 dB
Gain step	0.5 dB
Maximum input power (Pin)	-15 dBm
Maximum instantaneous real-time BW	160 MHz

Noise figure	5 dB to 7 dB
Maximum I/Q sample rate	200 MS/s
Analog-to-digital converter (ADC) Resolution	14 bit
sFDR	88 dB

A.1.2 PC-USRP Connectivity

PCIe card and PCIe x4 cable are used to provide high-speed connectivity between a desktop PC (with an available PCI-Express x4 slot) and USRP-2954R. Figure 97 shows an example of the PCIe card and its associated cable.

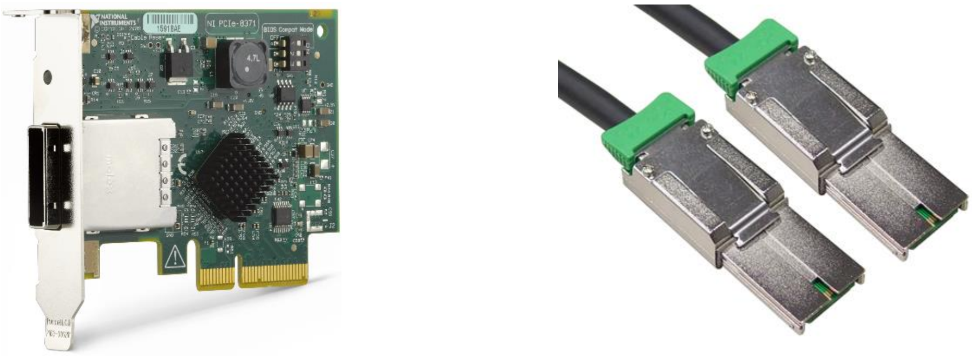


Figure 97. PCIe card and cable examples.

A.1.3 Specifications of the WiFi Dongle

The GigaBlue WLAN 600 Mbps dongle is used for WiFi connection. Its detailed specifications are given in Table 41.

Table 41: Specifications of the WiFi dongle

Item	**Value**
Standard	IEEE 802.11 b/g/n 2.4GHz/IEEE 802.11 a/n/ac 5.0GHz
WiFi Band	Dual Band 2.4 or 5GHz
WiFi Performance	AC 600Mbps (2.4G 150M/5.8 G 433M)
WiFi Range	Large Homes
Antenna	2dBi
HW version	version 1.0
Support	WIN XP/VISTA/WIN7/WIN8/MAC/LINUX
Working Temperature	- 0°C - 40°C
Storage Temperature	40°C - -70°C

Working Humidity	10% - 90% RH noncondensing
Storage Humidity	5% - 90% RH noncondensing

A.1.4 Specifications of the OAI UE machine

One DELL OPTIPLEX 7050 desktop is used for running OAI as UE. The detailed specifications of the OAI UE machine are given in Table 42.

Table 42: Specifications of the OAI UE machine

Element	Model
Processor	Intel Core i7-6700 @3.4GHz × 8
Memory	32 GB DDR4
Hard Drive	160 GB
Graphics	Intel HD
OS Type	Ubuntu 14.04 LTS

A.1.5 Specifications of the OAI eNB machine

One DELL OPTIPLEX 7040 desktop is used for running OAI as eNB. The detailed specifications of the OAI eNB machine are given in Table 43.

Table 43: Specifications of the OAI eNB machine

Element	Model
Processor	Intel Core i7-6700 @3.4GHz × 8
Memory	8 GB DDR4
Hard Drive	240 GB
Graphics	Intel HD
OS Type	Ubuntu 14.04 LTS

A.1.6 Specifications of the OAI EPC machine

One DELL OPTIPLEX 9020 desktop is used for running OAI as EPC. The detailed specifications of the OAI EPC machine are given in Table 44.

Table 44: Specifications of the OAI EPC machine

Element	Model
Processor	Intel Core i5-6700 @3.5GHz × 8
Memory	8 GB DDR4
Hard Drive	200 GB
Graphics	Intel Haswell Desktop
OS Type	Ubuntu 16.04 LTS

A.1.7 Specifications of the video server machine

The machine used as video server is one DELL OPTIPLEX 9020 desktop running MS Windows 10 with the same specifications as the OAI EPC machine.

A.2 Experimental 5G Setups

A.2.1 Specifications of USRP N320

The USRP N320 board is a networked SDR that provides reliability and fault-tolerance for deployment in large-scale and distributed wireless systems. The detailed specifications of its transmitter, receiver and RX noise figure are given in Table 45, Table 46 and Table 47, respectively [9]:

Table 45: Specifications of the transmitter of USRP N320

Specification	Typical	Unit
Number of Channels	2	–
Gain Range2	-30 – 25	dB
Gain Step	1	dB
Filter Banks	450 – 650 650 – 1000 1000 – 1350 1350 – 1900 1900 – 3000 3000 – 4100 4100 – 6000	MHz MHz MHz MHz MHz MHz MHz
External local oscillator (LO) Frequency Range	450 - 6000	MHz
Tuning Time	245	us
TX/RX Switching Time	750	us

Table 46: Specifications of the receiver of USRP N320

Specification	Typical	Unit
Number of Channels	2	–

Gain Range2	-16 – 34	dB
Gain Step	1	dB
Max Input Power	-15	dBm
Filter Banks	450 - 760 760 - 110 1100 – 1410 1410 – 2050 2050– 3000 3000 – 4500 4500 – 6000	MHz MHz MHz MHz MHz MHz MHz
External LO Frequency Range	450 - 6000	MHz
Tuning Time	245	us
TX/RX Switching Time	750	us

Table 47: Specifications of the RX noise figure of USRP N320

Frequency (MHz)	TX/RX port (dB)	RX2 port (dB)
< 800	11.0	10.0
800 – 1800	6.5	5.5
1800 – 2800	7.0	6.0
2800 – 3800	7.5	6.5
3800 – 5000	8.5	7.5
5000 – 6000	11.0	10.0

A.2.3 Specifications of Laptop Dell XPS 15 7590

The specifications of the used laptops (i.e., Dell XPS 15 7590) are given in Table 48.

Table 48: Specifications of Laptop Dell XPS 15 7590

Component	Specification
Processor	9th Generation Intel® i9-9980HK @2.40GHz
Memory	32 GB, DDR4
Hard Drive	2 TB Solid-State Drive
Video Card	NVIDIA® GeForce® GTX 1650 4GB GDDR5
Display	15.6 inches
OS type	Ubuntu 14.04 LTS

A.2.2 Laptop-USRP Connectivity

The 10 Gigabit (10G) Ethernet Connectivity adapter provides high-speed connectivity between a laptop and USRP N320. The associated module is presented in Figure 98.

Figure 98. 10G Ethernet module.

APPENDIX B: SLICING BASELINE EXPERIMENTS ON 5GENESIS

This appendix provides the detailed results of the baseline experiments conducted on the 5GENESIS trial facility.

B.1 Round Trip Time

The detailed RTT results are described in Table 49. They include a detailed statistical analysis in terms of mean, standard deviation, median, min, max and various (i.e., 5%, 25%, 75% and 95%) percentiles.

Table 49: Baseline slicing experiments – RTT

Test Case ID	TC_RTT_e2e
General description of the test	This test measures the mean and 95%, 5%, 25%, and 75% percentile RTT from a client (5G CPE) to a server over a 5GNR NSA Rel.15 mobile network.
Purpose	To assess the RTT.
Scenario	5GNR EMBB
Slicing configuration	eMBB slice
Components involved	Rel. 15 4G Core NSA, 4G RAN (control plane), 5G RAN (user plane), 5G CPE (UE), client and server laptops
Metric(s) under study	*Round-Trip-Time*
Additional tools involved	n/a
Statistical analysis	Mean: 10.47 +/- 0.03 ms Standard deviation: 1.46 +/- 0.04 ms Median: 10.38 +/- 0.03 ms Min: 8.23 +/- 0.04 ms Max: 15.60 +/- 0.78 ms 5% Percentile: 8.49 +/- 0.01 ms 25% Percentile: 9.25 +/- 0.04 ms 75% Percentile: 11.57 +/- 0.04 ms 95% Percentile: 12.54 +/- 0.05 ms

B.2 Throughput results

The detailed throughput results obtained on the DL and UL directions are described in Table 50 and Table 51, respectively. They include a detailed statistical analysis in terms of mean, standard deviation, median, min, max and various (i.e., 5%, 25%, 75% and 95%) percentiles.

Table 50: Baseline slicing experiments – TCP DL Throughput

Test Case ID	TC-THR-Tcp
General description of the test	The test measures the average maximum user data rate available.
Purpose	To assess the throughput in the DL direction.
Scenario	5GNR TCP
Slicing configuration	eMBB slice

Components involved	Rel. 15 4G Core NSA, 4G RAN (control plane), 5G RAN (user plane), 5G CPE (UE), client and server laptops
Metric(s) under study	Throughput
Additional tools involved	iperf
Statistical analysis	Mean: 492.08 +/- 7.24 Mbps Standard deviation: 101.80 +/- 4.80 Mbps Median: 494.16 +/- 8.67 Mbps Min: 125.63 +/- 20.84 Mbps Max: 738.08 +/- 8.52 Mbps 5% Percentile: 332.31 +/- 13.92 Mbps 25% Percentile: 427.87 +/- 6.40 Mbps 75% Percentile: 560.92 +/- 9.13 Mbps 95% Percentile: 651.83 +/- 10.30 Mbps

Table 51: Baseline slicing experiments – TCP UL Throughput

Test Case ID	TC-THR-Tcp
General description of the test	The test assesses the calculation of the average maximum user data rate available.
Purpose	To assess the throughput in the UL direction.
Scenario	5GNR iperf
Slicing configuration	eMBB slice
Components involved	Rel. 15 4G Core NSA, 4G RAN (control plane), 5G RAN (user plane), 5G CPE (UE), client and server laptops
Metric(s) under study	Throughput
Additional tools involved	iperf
Statistical analysis	Mean: 59.34 +/- 5.29 Mbps Standard deviation: 5.95 +/- 1.16 Mbps Median: 59.72 +/- 6.07 Mbps Min: 46.38 +/- 6.00 Mbps Max: 73.40 +/- 6.30 Mbps 5% Percentile: 51.55 +/- 5.12 Mbps 25% Percentile: 54.97 +/- 5.26 Mbps 75% Percentile: 63.63 +/- 5.35 Mbps 95% Percentile: 67.52 +/- 5.04 Mbps

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