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AI4CSM

Automotive Intelligence for Connected Shared Mobility

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1 Executive/Publishable summary

This document is intended to give an overview of the Task 1.5 Requirements and specifications for Connectivity and Communications which is assigned to the Supply Chain 5 of the AI4CSM project. The task comprises the identification of technical and non-technical requirements and specification concerning the communication sub-systems in the project. This communication includes the communication within a vehicle, as well as the communication between the vehicle and the external systems in the infrastructure. In-vehicle communication should enable future automated driving applications and thus offer low latency and high-bandwidth.

Based on technological gaps in SOA technologies when it comes to a fully connected shared mobility ecosystem, the results are specific requirements of the components subsystems of the envisaged novel communication methods and their architectural requirements on in-car, edge and cloud level. Specific focus was be put requirements concerning low latency and scalability of the communication channels.

The communication between the vehicle and the external systems—or infrastructure—is required for cooperative functionality as well as in the output enabler supply chains of the project. It enables new active safety features and supports a conjoint approach to self-awareness and cross-vehicle exchange of sensor data. The presented requirements cover on-board, road-side wireless communication units, communication architecture, as well as functional requirements to implement the demonstrators in the supply chain.

The requirements identified in task T1.5 are essential to Supply Chain 5 (SC5) with respect to a proper sub-system design in T2.5 and the technical enhancement. These developments will result in two demonstrators in Supply Chain 5: **SCD 5.1: Proof-of-concept communication platform and SCD 5.2: Proof-of-concept demonstrator novel wireless data transmission (Edge/Cloud)**. The findings collected in the task represent the foundation to develop these show cases in SC5.

Within T1.5 we followed a bottom-up approach to collect and compile T1.5 results and findings of each individual task member:

- Partners concentrated on their individual work package tasks and contributed to the chapter of D1.5 describing their work executed for T1.5.
- The task leader provided a template for requirement definition. Partners used the template to collect their requirements and compiled them into a separate document.
- Inputs where reworked and consolidated. Furthermore, partners discussed cooperation and requirements alignment in the status meetings of SC5.
- The task leader compiled and aggregated the developed requirements into this document and described the approach and achievements in T1.5.

The following chapter of this deliverable D1.5 is describing the scope of the document and is giving an introduction and overview. The main chapter in which all SC5 partners describe their contribution in detail follows it. Finally, a conclusions chapter sets the work in context to related AI4CSM tasks and summarizes on the impact and contributions to the work packages and supply chains.

The annex of this deliverable includes a detailed list of developed technical and non-technical requirements for the two demonstrators together with corresponding SC5 demonstrator descriptions.

2 Non publishable information

All the information below is publishable.

3 Introduction & Scope

3.1 Purpose, vision and objectives

The **AI4CSM** project will **develop advanced electronic components and systems (ECS)** and architectures for future mass-market ECAS vehicles. This fuels the digital transformation in the automotive sector to support the mobility trends and accelerate the transition towards a sustainable ecosystem.

Supply chain 5 will provide the communication techniques that enable AI-enabled methods to access data from the edge (e.g. cars, infrastructure) and the cloud (e.g. city-model) and fulfil fast, reliable, low-latency data connection. SC1 as output enabler will showcase the results. In addition, SC5 will implement two different demonstrators focusing on communication and connectivity which will focus a) on in-car data communication i.e. fast data channels between sub-systems and sensors considering zonal architectures b) edge/cloud communication between car and infrastructure systems and cloud services for mobility solutions.

The **vision** of Connectivity and Cognitive Communication in AI4CSM is as follows. SC5 peruses an end-to-end approach that integrates independent hard- & software elements into a comprehensive platform that can improve functionality and decrease complexity, with focus on:

- Safe and secure **communication, high data rates and bandwidth** for edge perception and in-car computing power.
- **Novel functionality** for merging of edge perception results with cloud data sources w.r.t. high and secure data connectivity and low latency.
- Robust and low latency communication methods for **wireless connectivity based on 28 GHz mmW** beam forming.
- OEM identity manager for personalized cloud services enabling an improved end-to-end security for car sharing management.
- **Edge computing** with optimized provisioning and mapping from tasks to compute resources.

From this vision the **key challenge** identified by the partner in SC5 are as follows.

- R&D on secure external communication, with high data rates (5G) and bandwidth,
- the cloud fusion of edge perception results into the digital twin as well as
- fast and reliable wireless communication channels based on 28 GHz mmW technology.

Within T1.5 the major objective from the supply chain perspective is investigating and identifying connectivity and interoperability challenges between devices and systems and evaluate low latency end-to-end security solutions to overcome bottlenecks regarding seamless integration of the V2X communication platform and its constituent parts. This is related to the overall project objectives O2 and O6. The specified vision and identified key challenges of SC5 are linked to the objectives within SC5 and depicted in Figure 1.

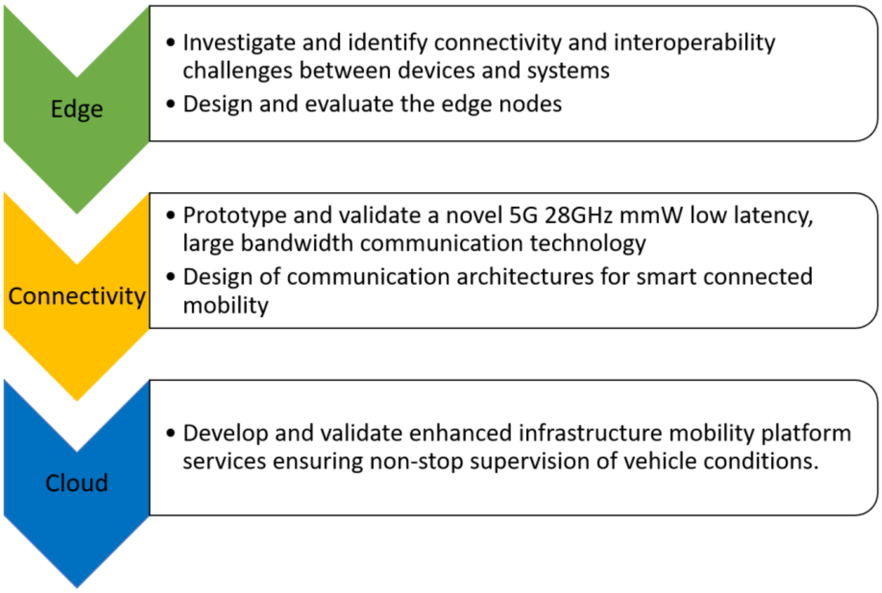

FIGURE 1: SC5 OBJECTIVES

The most important objectives of SC5 relevant for T1.5 can be categorized into edge-, communication- and cloud specific objectives. Results this task activities will be utilized during the design phase of the communication and connectivity sub-system in T2.5. Finally, the validation of the identified requirements is performed in the two demonstrators in the supply chain: **SCD 5.1: Proof-of-concept communication platform** and **SCD 5.2: Proof-of-concept demonstrator novel wireless data transmission (Edge/Cloud).**

3.2 Contributions of partners

Individual partner summarized their contributions in the following table and provided detailed contributions in the referenced chapters.

TABLE 1 OVERVIEW PARTNER CONTRIBUTIONS

Chapter	Partner	Contribution
1, 2, 3, 4.3, 0	TTTAUTO	Deliverable structure and draft outline, demonstrator SCD 5.1 description, requirements for demonstrator SCD 5.2, conclusion section
4.2	TTTAUTO,	Demonstrator SCD 5.1 description, requirements for demonstrator SCD5.1
4.2	IMA	IMA contribution and requirements description as part of SCD 5.1
4.2, 5, 7	NXP	NXP defines the requirements for cross-protocol in-vehicle communication architecture for latency, functional safety, and security, used in demonstrator SCD 5.1.
4.3	IFAG	Demonstrator SCD 5.2 description, requirements for demonstrator SCD 5.2
4.3	FHG(HHI)	Demonstrator SCD 5.2 description, requirements for demonstrator SCD 5.2
4.3	TUD	TUD defines the requirements for the edge platform. Communication with the edge shall follow industry standards. Computation on the edge, as requested by mobile clients, shall be implemented in standard deployment strategies. Constraints on timeliness and its reliability by clients shall be honoured by the edge.

4.2, 4.3	AIT	AIT contribution and requirements description as part of SCD 5.1 and SCD 5.2 w.r.t. the standards.
3, 4	TTTAUTO	Visualization of SC5 key figures, finalizing the document.

3.3 Relation to other activities in the project

As technology provider, supply chain 5 is related mainly to the output enabler in the project. In particular SC5 will provide SC1 with functionalities concerning communication architectures and approaches for vehicle -2-vehicle, and vehicle-2-infrastructure communication. These will be achieved by providing and integrating technologies as WP5 activity. Figure 2 also highlights the relation to SC8 where AIT is predominantly active in linking the supply chain activities to existing initiatives in Standardization to foster the exploitation in this area.

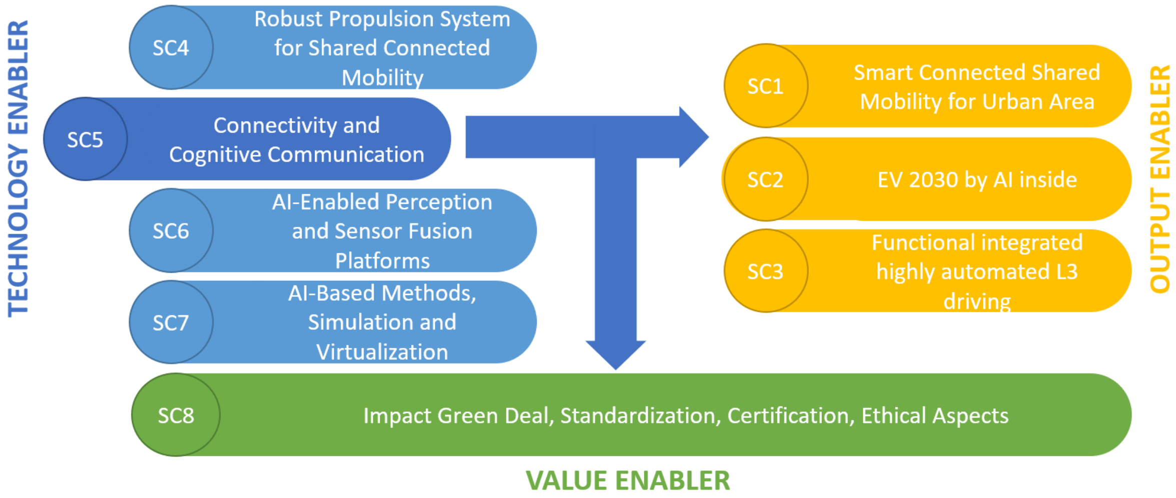

FIGURE 2: OVERVIEW SC5 INTERCONNECTIONS

Therefore, this supply chain will collaborate with the following supply chains in the following aspects:

- Showcasing of communication and connectivity functionalities into the demonstrator SC1 - **SCD 1.2** of supply chain "Smart Connected Shared Mobility for Urban Area".
- Alignment of interfaces for connectivity solutions with **SC2** and **SC3** during the sub-system design phase of AI4CSM.
- Close and bidirectional exchange with **SC8** concerning Standardization activities and inclusion of Green-Deal principles whenever possible into the development and design within SC5.

3.3.1 Input from WPs, SCs and tasks

Task 1.5 is dedicated to the collection of the functional and non-functional requirements for the communication sub-system in the project. This comprises building blocks towards a fully connected shared mobility ecosystem in-vehicle as well as on the edge-to-cloud side. The technical building blocks are developed in two demonstrators within SC5.

- **<u>Demonstrator SCD 5.1:</u> Proof-of-concept communication platform (lead: TTTAUTO, partners: NXP, IMA, AIT)**

- **<u>Demonstrator SCD 5.2:</u> Proof-of-concept demonstrator novel wireless data transmission (edge/cloud) (lead: IFAG, partners: TUD, FHG (HHI), TTTAUTO, AIT)**

The process of collecting the requirements for the demonstrators followed a mix between a top-down and bottom-up approach, where a list of high-level functional requirements was drafted for each supply-chain demonstrator. Since specific focus was put on low latency and scalability of the communication channels, those aspects are covered in the list of requirements as well. A synchronization meeting with the other technology enabler and output enabler supply chains was organized to make sure specific requests were covered for SC5. The final collection of SC5 requirements will be shared with the relevant other supply chains (see Figure 2 for most relevant links) to ensure that technical development addresses the right assumptions w.r.t. communication abilities of the sub-system out of SC5.

3.3.2 Output from these results

The results of task 1.5 are requirements of the components subsystems and specifications of the demonstrators SCD 5.1 and SCD 5.2, their functional safety and security aspects of the envisaged novel communication methods and their architectural requirements on in-vehicle, edge, and cloud level. The findings will feed into the development of a sub-system level design in WP2 (Task 2.5) and the algorithmic and functional development in WP4 (Task 4.4). The verification of requirements will take place in WP6 on "Validation and Testing", where SC5-relevant KPIs are verified. Since AI4CSM follows a V-Model approach for work packages, the links specific to SC5 are summarized below, and depicted in Figure 3.

<u>Supply chain links:</u>

- Interface alignment with technology enabler supply chains:
    - SC4: Robust Propulsion System for Shared Connected Mobility
    - SC6: AI-Enabled Perception and Sensor Fusion Platforms
    - SC7: AI-Based Methods, Simulation and Virtualization
- Integration of connectivity and communication functional blocks into demonstrator SCD 1.2.
- Bi-directional input of Standardization activities between SC5 and SC8 on connectivity and communication issues.
- Synchronization of SC5 activities with Green Deal principles developed and evaluated in SC8

<u>Work package links within SC5:</u>

- The list of requirements will shape the architectural concept, sub-system design and simulations for the connectivity function in **WP2 (T2.5),** as part of a smart mobility approach on different levels (e.g., in-vehicle embedded computing, connectivity platform on the edge, and cloud connectivity for automated and connected vehicles).
- Within **WP4 (T4.4)** the architecture of the communication system will be implemented and techniques and methods for reliable, robust, and flexible, data channels are required to be aligned with the requirements given in 6.
- The integration of the developed methods and functions concerning communication and connectivity (a) the secure in-vehicle communication backbone and (b) the 28GHz 5G Connectivity RF Frontend will be integrated in **WP5 (T5.5)**.

- Finally, the validation of reliable and robust V2X communication platform for smart connected mobility and its applications is performed in **WP6 (T6.5).** Here the technologies and methods will be validated against the requirements, specifications and KPIs defined in 6.

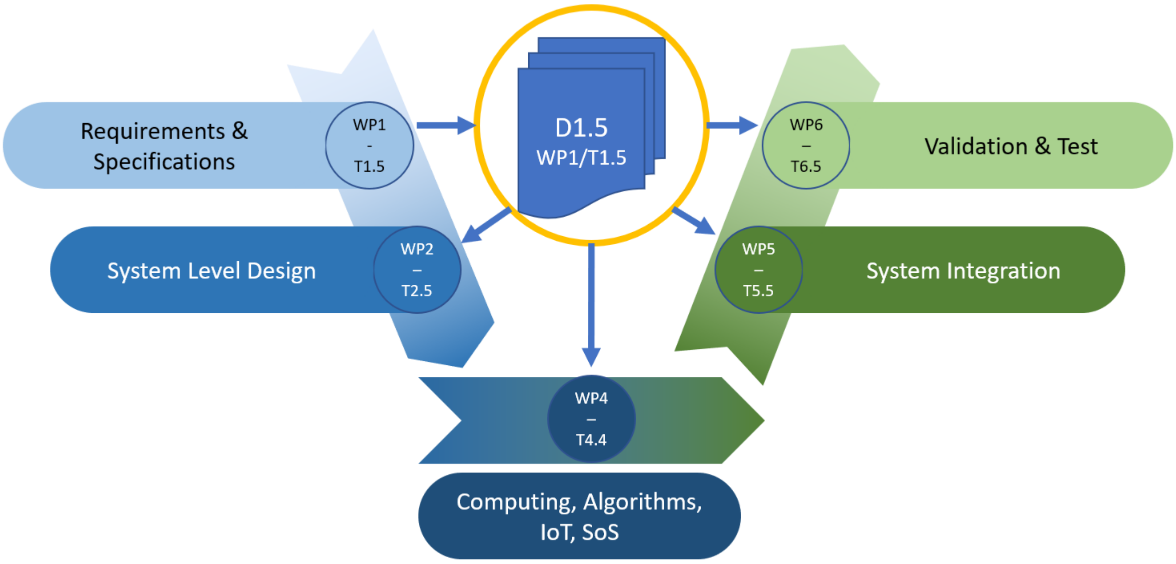

FIGURE 3: RELATION OF DELIVERABLE 1.5 WITH OTHER ACTIVITIES WITHIN AI4CSM.

4 Requirement collection process and methodology

The methodology followed in SC5 combines a top-down and a bottom-up approach. This means the two demonstrators within SC5 were defined first top-down with the outcome and their structure addressing the SC vision and objectives accordingly. To showcase the targeted SC5 objectives, all requirements are linked to a corresponding demonstrator and use case, including use case specific KPIs, which are used to validate the objectives. SC5 partners will evaluate the performance of the targeted **communication technologies to (a) access data from the edge (e.g., cars, infrastructure) and the cloud (e.g., city-model) and (b) to fulfil fast, reliable, low-latency data connectivity** (see Figure 4) in dedicated lab-based environments. Demonstrators SCD 5.1, SCD 5.2 and selected functionalities will be demonstrated in a SCD 1.2 real-world demonstrator vehicles in the output enabler supply chain.

The supply chain demonstrators (SCD 5.1 and SCD 5.2) will be used to set up scenarios for developing the technologies in a controlled lab-based environment. These developments integrate independent hard- & software elements into a comprehensive platform that can improve functionality and decrease the overall complexity of the sub-system. Due to the dependency of network infrastructure in both setups (a) wireless connectivity 28 GHz mmW beam forming and (b) secure, low-latency data links in-vehicle (edge) to cloud the relevant / industrial-oriented environment will be set up by the supply chain partners (e.g., 5G network infrastructure by TUD) and the planned demonstration in SC1 will provide a real-world setup in SCD 1.2.

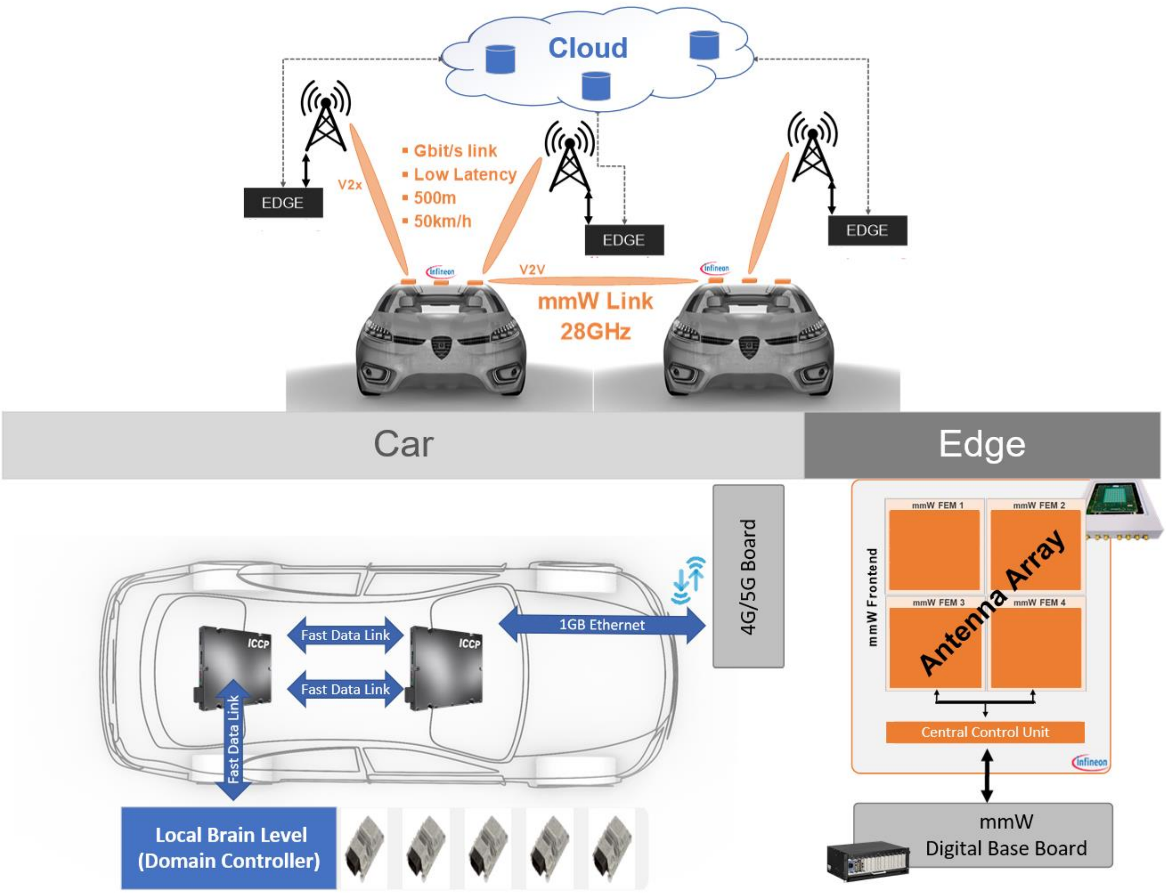

FIGURE 4: OVERVIEW SC5 DEVELOPMENT ACTIVITIES

4.1 Demonstrator specification

SC5 defines two specific demonstrators to address the targeted objectives and evaluate the selected KPIs:

- **Demonstrator SCD 5.1: Proof-of-concept communication platform (lead: TTTAUTO, partners: NXP, IMA, AIT)**

  Prototype reference setup with corresponding SW environment with HW/SW mechanisms to showcase next automotive communication technologies. The demonstration will incorporate HW from TTTAUTO and NXP to showcase fast data channels among different controllers and the in-vehicle decision making module. The performance of this connection will be evaluated and investigated based on the collected requirements in this document.

- **Demonstrator SCD 5.2: Proof-of-concept demonstrator novel wireless data transmission (edge/cloud) (lead: IFAG, partners: TUD, FHG (HHI), TTTAUTO, AIT)**

  The setup will showcase high bandwidth 5G mmW radio modules incorporating Infineon 28GHz RFICs. The provided hardware will demonstrate unique 360° azimuth angle coverage with optimized low latency beamforming function at small form factor.

4.2 SCD 5.1 - Proof-of-concept communication platform

4.2.1 Introduction

Tremendous progress has been made in the field of highly automated driving with increasing demand on data and computing power to derive the decision automatically and reliable in a well-specified time frame. The increased sensor content in vehicles and the infrastructure coupled with the enhanced automation of driving functions will necessitate the development of new standards for safe, secure, and low-latency communications technologies. Current state-of-the-art automotive computing platforms do not fulfill the high computing performance and memory requirements of future more complex ADAS applications and have to be enriched with new generation building blocks for this reason in an innovative way. State-of-the-art E/E vehicular architecture move from the traditional modular architecture where each function has his ECU to the centralization architecture, as we see in Figure 5.

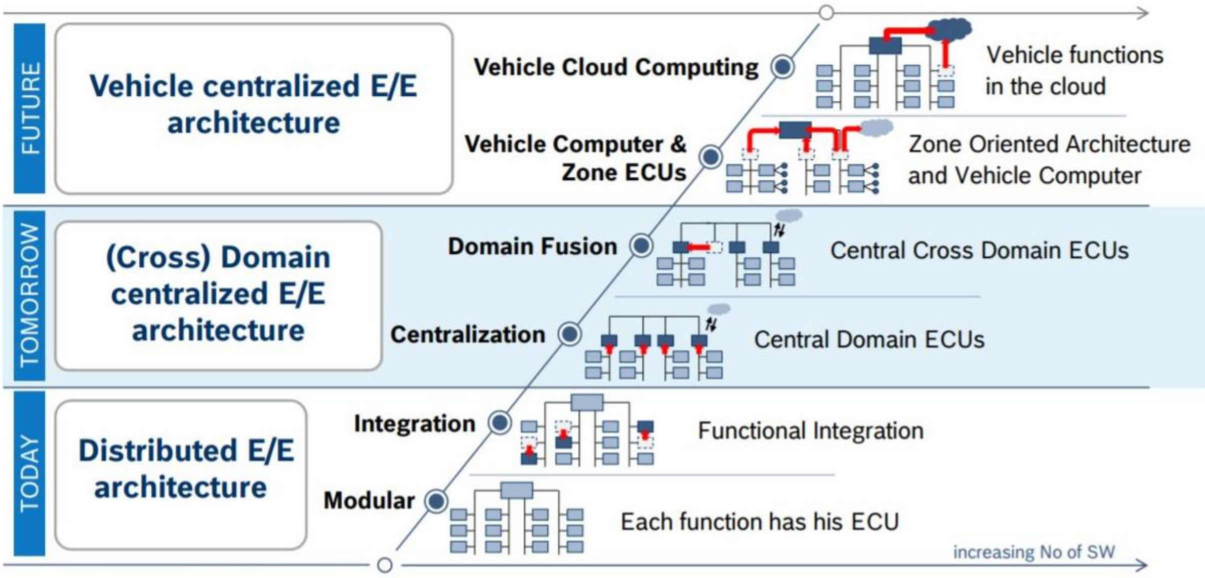

FIGURE 5: FUTURE E/E ARCHITECTURE[1]

The requirements on the in-vehicle communication architecture emerge from the trend towards a more centralized architecture, but also from the connectivity of the vehicles to the external networks. State-of-the-art in-vehicle networks include e.g., CAN bus, FlexRay, LIN and Ethernet. Most of these technologies will remain due to legacy systems, but also due to their cost effectiveness. However, standard network design is not able to fulfil the future requirements emerging from new applications such as autonomous driving, electrification and V2X connectivity. Future in-vehicle networks have to have high bandwidth (even in Gbit/s) but still guarantee hard real-time message exchange. In addition, these networks have to enable easier creation of redundant, or even fail-operational architectures, as well as enable easier creation of cybersecurity functionality. Within the demonstrator SCD 5.1, the partners TTTAUTO, NXP, IMA, and AIT will work on dedicated solutions for communication with the focus on in-vehicle connectivity considering future E/E architectures (see again Figure 5). Such a

[1] https://ipg-automotive.com/fileadmin/user_upload/content/Download/Media/Presentation/Apply_Innovate_2016_Bosch_Sardari.pdf

solution must be flexible enough to reliably enable different configurations for different applications in order to limit the integration and verification effort.

The planned activities and the developed methods showcased in this supply chain will contribute to the following project objectives:

- **O2** – Develop scalable embedded intelligence for edge and edge/cloud operation
- **O6** – Build ECAS vehicles for Green Deal for future connected shared mobility

In addition to that, our demonstrator supports the specific SC5 objectives **Edge**, **Connectivity**, and **Cloud** in the following way:

- **Edge:** Investigate and identify connectivity and interoperability challenges between devices and systems / Design and evaluate the edge nodes
- **Connectivity:** Design of communication architectures for smart connected mobility
- **Cloud:** Design of communication architectures for smart connected mobility

The following sections give an overview of the demonstrator platform, the key building blocks of the demonstrator, as well as the planned validation plan.

4.2.2 Demonstrator platform

This section depicts the composition of SC5 building blocks and technologies that will be used in the SCD 5.1 demonstrator, to showcase the performance of the developed and implemented methods. For development and testing purposes, different hardware platforms (e.g., computing units, ECU's, sensor platforms) are planned to continuously be able to check the functionalities and methods developed by SC5 partners.

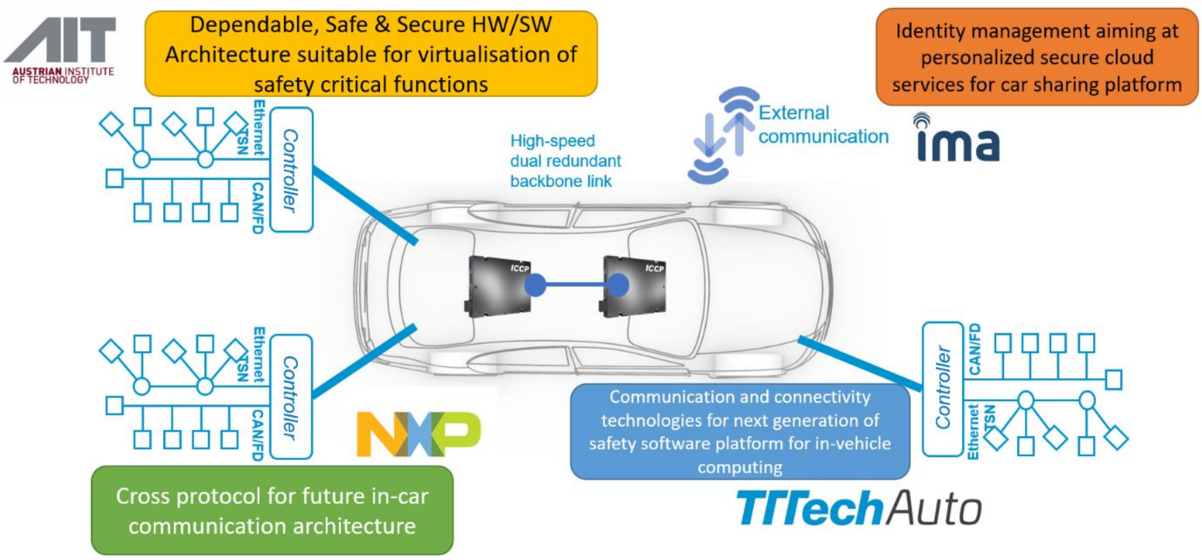

FIGURE 6: OVERVIEW OF THE KEY BUILDING BLOCKS AND PARTNER CONTRIBUTIONS WITHIN SCD 5.1 DEMONSTRATOR.

Figure 6 depicts the key building blocks of the SCD 5.1 proof-of-concept communication platform, mentioning the different partner contributions and connections of the building blocks. The blocks show the different parts of the communication and connectivity solutions. Part of the building blocks are developed separately and integrated during the progress of this supply chain, in close alignment between all partners. Since various partners have dedicated hardware and development boards available on their premise (see Section 4.2.2), dedicated integration and evaluation events are planned in year two and three of the AI4CSM project.

TTTAUTO will contribute with a prototypical reference setup for in-vehicle central computing platform (HW) and the corresponding software environment to showcase the communication and connectivity services in SCD 5.1. The demonstration environment consists of the following components:

- Hardware platform (CPU's / hardware board)
- Platform software (board support package, operation system, networking stack, middleware and run-time environment)

NXP will contribute with a functional-safety architecture and a safe and secure communication system. A heterogeneous end-to-end communication platform will be created, so that the safety and security features described in the requirements of Chapter 6 can be applied and integrated into the overall in-vehicle network. The in-vehicle communication infrastructure will be composed of the communication links and devices, as well as the controllers.

AIT's will bring in requirements coming from safety & security standards and from the SC1 and SC8 requirements phase. In the first phase, AIT provided, according to its task to support development of a dependable, safe and secure architecture and safety-critical functions, requirements on security modeling, security analysis, safety and security argumentation. AIT will conduct a security engineering based on ISO/SAE 21434, interfaced with safety based on ISO 26262, to define safety and security goals, considering novel threats proposed by UN R155 cybersecurity regulation, developing an example process application of the mentioned standards and regulations. This is linked to AIT standardization activities (SC8) in automotive standards (functional safety, cybersecurity, automated driving systems), which were ongoing and intensified during the first project period. Since ISO/SAE 21434 foresees work on an item level (e.g., system or combination of systems which offer a function at vehicle level) AIT will assume the usage of the components developed in SC5 in an extended vehicle (ISO 20077/20078) application. An extended vehicle is defined by ISO 20077 (Methodology) as "an entity, still in accordance with the specifications of the vehicle manufacturer, that extends beyond the physical boundaries of the road vehicle and consists of the road vehicle, off[1]board systems, external interfaces and the data communication between the road vehicle and the off-board systems", e.g., a combination of systems that are able to provide safe and secure third-party access to real-time vehicle data, which is a potential application of the envisioned set of systems designed in SC5. AIT will, based on approximated components used by the SC5 partners define an extended vehicle scenario and apply security engineering based on the relevant standards to this.

IMA's contribution within the demonstrator will be focusing on V2I SW and HW modules intended for car access control with respect to trusted access rights distribution, user verification and unauthorized usage detection. The individual building blocks will be based on high-level architecture with focus on security, reliability, transferability, and upgradeability. Multiple security layers will be employed in order to eliminate threats such as the data transfer eavesdropping (e.g., man in the middle attack), to validate the data credibility or to reliably validate the communicating party's identity. The relevant SW modules will be developed with a HW independent abstraction in order to ensure robust and reliable multiplatform functionality and compatibility. The crucial components for the V2I IMA use case scenario will be represented as a communication gateway, ID reader module and a V2I communication interface module. Possibilities of AI based approach for anti-tamper and unauthorized usage detection will be examined as an optional module for the system.

4.2.3 Key building blocks

A major component for the implementation of SC5 technological advances is an in-vehicle computing platform that meets the requirements and specifications that have been captured and derived for a suitable embedded intelligent platform. These comprise hardware as well as software related specifications and functionalities for the demonstrator in the project. Figure 7 depicts the demonstration platform by TTTAUTO, highly automated driving platform designed for application development and evaluation of advanced driver assistance systems (ADAS). Together with the dedicated software framework it will be used to set up the necessary test environment to benchmark the communication channels in the demonstrator.

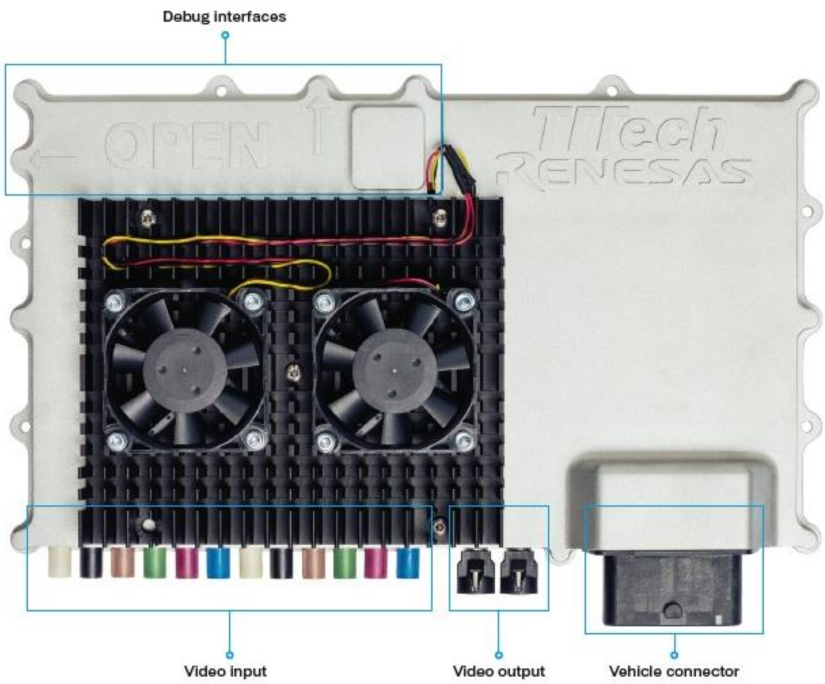

FIGURE 7: DEMONSTRATION PLATFORM BY TTTAUTO

The platform developed by TTTAUTO meets the highest safety requirements and therefore has a complex structure. Concerning communication and connectivity within the system the middleware must manage various levels of data/communication layers:

- High optimized middleware for data management:
    - Intra-Host communication (FFI-D*)
    - Inter-Host communication (FFI-D*)
        - Best Effort Ethernet
        - Deterministic Ethernet (FFI-C*)
        - PCIe
    - Vehicle communication
        - CAN,
        - FlexRay
        - Ethernet (UDP)

Apart from that, various communication services are affected by the requirements specified in Task T1.5. Those are the data synchronization layer (memory management), the middleware itself has to reflect the system architectural aspect on the software level, and the backbone communication. The backbone used in the project is based on deterministic Ethernet. Concerning data protection end-to-end communication methods will be tested on different protocol layers. Figure 8 illustrates the basic architectural concept with various applications on top and towards the DE Ethernet backbone different software layers handling data management and communication services on safety and performance partitions of the system.

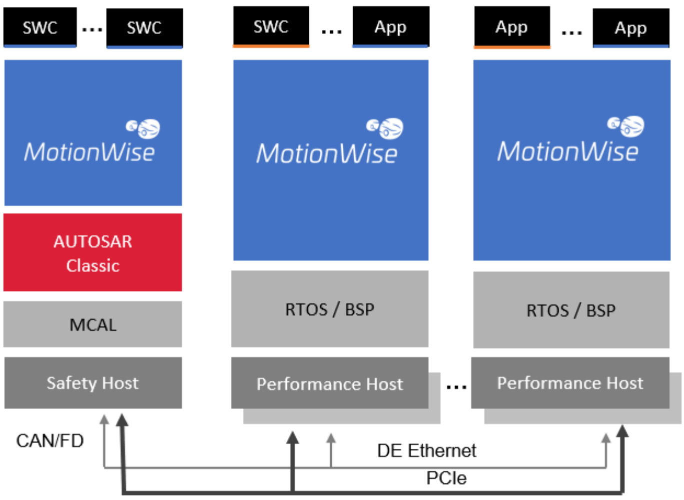

FIGURE 8: BASIC ARCHITECTURAL CONCEPT USED IN THE IN-CAR COMPUTING PLATFORM.

Other than the processing platform, the rest of the in-vehicle communication architecture is formed by the controllers, the CAN transceivers, and the Ethernet switches. NXP has a scalable portfolio of automotive processor solutions, the S32 family, suitable for different kind of automotive systems. In the SCD 5.1 demonstrator, S32G-based boards will be used for the initial tests. The device choice will then be adapted once deeper insights on the specific requirements and technological choices to be made in SCD 5.1 are obtained. As an example, Figure 9 shows the Reference Design Board 2 for the S32G Vehicle Network Processor, which provides connectivity as well as multi-core processing functionality. It can be used for a variety of automotive applications, including a controller in the communication architecture.

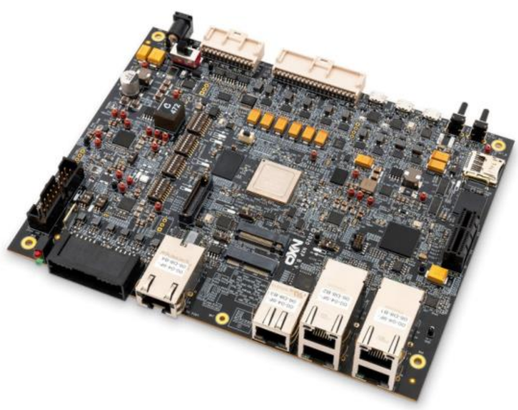

FIGURE 9: S32G REFERENCE DESIGN BOARD 2 (S32G-VNP-RDB2) BY NXP

In terms of Ethernet backbone, NXP provides a range of in-vehicle network communication solutions, for example the SJA1110 Ethernet switch. It can be used in Ethernet backbone networks. It is for example mounted on Reference Design Boards and Evaluation Boards, as shown in Figure 10. This device has features to improve the functional safety and security of ECUs.

FIGURE 10: SJA1110 - EVM EVALUATION BOARD BY NXP

In terms of legacy networks, NXP provides, among others, security-enhanced CAN transceivers, the TJA1152/TJA1153, which can detect and contain flooding of the bus by local nodes, transmission or reception of incompatible identifiers, and tampered messages. Figure 11 shows an example Development Board that integrates one of these secure CAN transceivers. This board can be used as a controller device, as well as an end-node.

FIGURE 11: S32K3X4-Q257 FULL-FEATURED GENERAL PURPOSE DEVELOPMENT BOARD BY NXP

4.2.4 Validation concept and Evaluation metrics

The validation concept utilized in SCD 5.1 is summarized in Figure 12. It extends the classical V-model for developing adding multiple phases of integration and testing as shown on the right-hand side. Since fully simulated communication and connectivity without dedicated hardware is not used in this demonstrator, participants will validate their technologies and methods in a lab environment at the first place. Later on, the individual components and devices will be integrated on supply chain level SC5 which is referred as SC5 integrated in Figure 12. To depict the extension to the output enabler in the project a third dimension of validation and testing is added to reflect the efforts towards a system level integration and validation where these efforts are planned. This is necessary to validate those components and their derived requirements, where the functionalities of the overall system are necessary. However, the proof-of-concept demonstrator of SCD 5.1 is self-contained and will be primarily evaluated in SC5. The cross supply-chain activities are nevertheless depicted for completeness and clarification.

TTTAUTO and NXP will validate the capabilities of the demonstrator platform by the benchmarking of the communication data channels by utilizing selected HW jointly with safety-critical and secure components. For example, this includes their real-time execution and freedom of interference between non-safety and safety-critical functions.

AIT plans to validate the security and safety by:

- Following the processes for security engineering defined by ISO/SAE 21434
- Evaluating the followed processes by an independent AIT expert (expert who was previously not involved in the SC5 activities) based on ISO PAS 5112 Road vehicles — Guidelines for auditing cybersecurity engineering
- Evaluating the security concept by a parallel security engineering process with a novel and domain-specific automotive security engineering toolset and a manual process and cross-evaluation

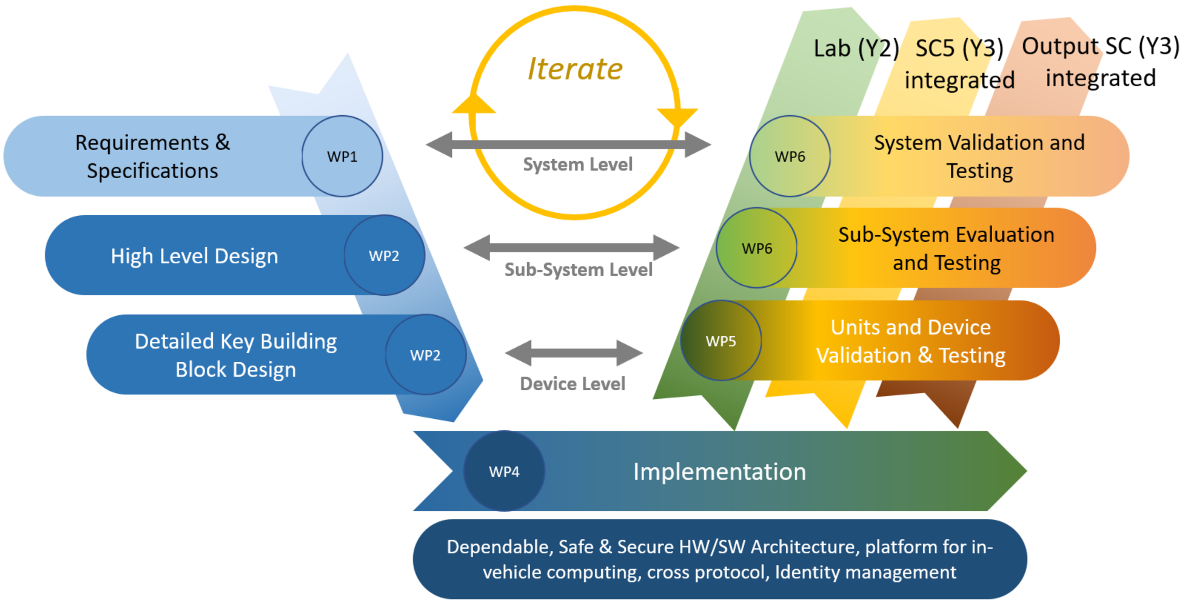

Figure 12: Validation concept in SC5 extending the V-Model approach of AI4CSM

4.2.5 Test plan for evaluation

In the following paragraphs summarizes an overview of the demonstrations planned in the duration of the AI4CSM project in the context of SC5.

Results and Evaluation Y1:
The results achieved for Y1 concerning WP1 are the collection of requirements and specifications for the demonstrator SCD 5.1. This deliverable describes the efforts and outcomes of this collection process and individual requirements are listed in Chapter 6 Annex 01.c.

Results and Evaluation Y2:

After year two of the project the requirements on sub-component level will have been validated. This will be achieved by evaluating the KPIs assigned to the requirements using lab-based setups and testing, including hardware-in-the-loop approaches and the prototypes and development boards mentioned in Section 4.2.3.

Results and Evaluation Y3:
During the final project year, the validated sub-components will be integrated into the demonstrator SCD 5.1. Having each key building block available, the activities in WP5 (T5.5) and specifically WP6 (T6.5) will demonstrate the improvements achieved in the AI4CSM project with respect to communication and connectivity. Participating partners in demonstrator SCD 5.1 will showcase the integrated functionalities. As depicted in Figure 12 the integration will be extended into the output enabler supply chains where those activities are planned.

4.3 SCD 5.2 – Proof-of-concept demonstrator novel wireless data transmission (edge/cloud)

4.3.1 Introduction

SCD 5.2 will evaluate and provide solutions to develop a novel intelligent and efficient V2X communication modular system incorporating a novel wireless 5G 28GHz mmW and 5G 3.7GHz radio link communication channels to the edge network. Concepts and methods for virtualized functions will be developed and integrated with the in-vehicle computing, cognition, control, connectivity platforms, to ensure safe, secure and reliable connectivity and interoperability for autonomous vehicle applications. IFAG will provide high bandwidth 5G mmW radio modules incorporating Infineon 28GHz RFICs. The provided hardware will demonstrate unique 360° azimuth angle coverage with optimized low latency beamforming function at small form factor. The mmW radios will be controlled by a digital baseband carrying a software stack by HHI which in consequence enables high data rate, low latency 5G communication channels. 5G mmW radios are complemented with a 5G 3.7GHz link by HHI to allow for extended range operation. Both modems, the mmW and the 3.7GHz ones, will connect to an in-car main domain controlling unit of TTTAUTO through a Gbit Ethernet interface. The low latency end-to-end communication concepts will be validated and benchmarked against existing solutions on the market. The demonstration will showcase low-latency, high performance and robust data channels at the network edge and smart infrastructure automation by providing low latency data communication from in-vehicle, edge and cloud data-sources. The TUD will handle the 5G core and the User Plane Functions (UPFs). UPFs supply the connectivity to WAN/Internet, the distribution of tasks, including the offloading of computation to dedicated edge nodes equipped with AI accelerators. An interface will be made available that allows tagging of workloads for low-latency inference. The interface exposes estimates and uncertainty measures of calculation time and connectivity characteristics.

Within the demonstrator SCD 5.2, the partners IFAG, TUD, FHG (HHI), TTTAUTO, and AIT will work on a prototype and validate a novel 5G 28GHz mmW low latency, large bandwidth communication technology for wireless vehicle to edge network data transfer as part of a combined connectivity system solution.

The planned activities and the developed methods showcased in the supply will contribute to the following project objectives:

- **O2** – Develop scalable embedded intelligence for edge and edge/cloud operation

- **O6** – Build ECAS vehicles for Green Deal for future connected shared mobility

In addition to that, our demonstrator supports the specific SC5 objectives **Edge**, **Connectivity**, and **Cloud** in the following way:

- **Edge:** Investigate and identify connectivity and interoperability challenges between devices and systems
- **Connectivity:** Prototype and validate a novel 5G 28GHz mmW low latency, large bandwidth communication technology
- **Cloud:** Develop and validate enhanced infrastructure mobility platform services ensuring non-stop supervision of vehicle condition

The following sections give an overview on the key building blocks of the demonstrator, an exemplary scenario description, associated key performance indicators (KPI) and an overview of the demonstrator platform as well as the planned validation plan.

4.3.2 Demonstrator platform

Figure 12 depicts the key building blocks of the SCD 5.2, mentioning the different partner contributions and connections of the building blocks. The blocks show the different parts of the communication and connectivity solutions.

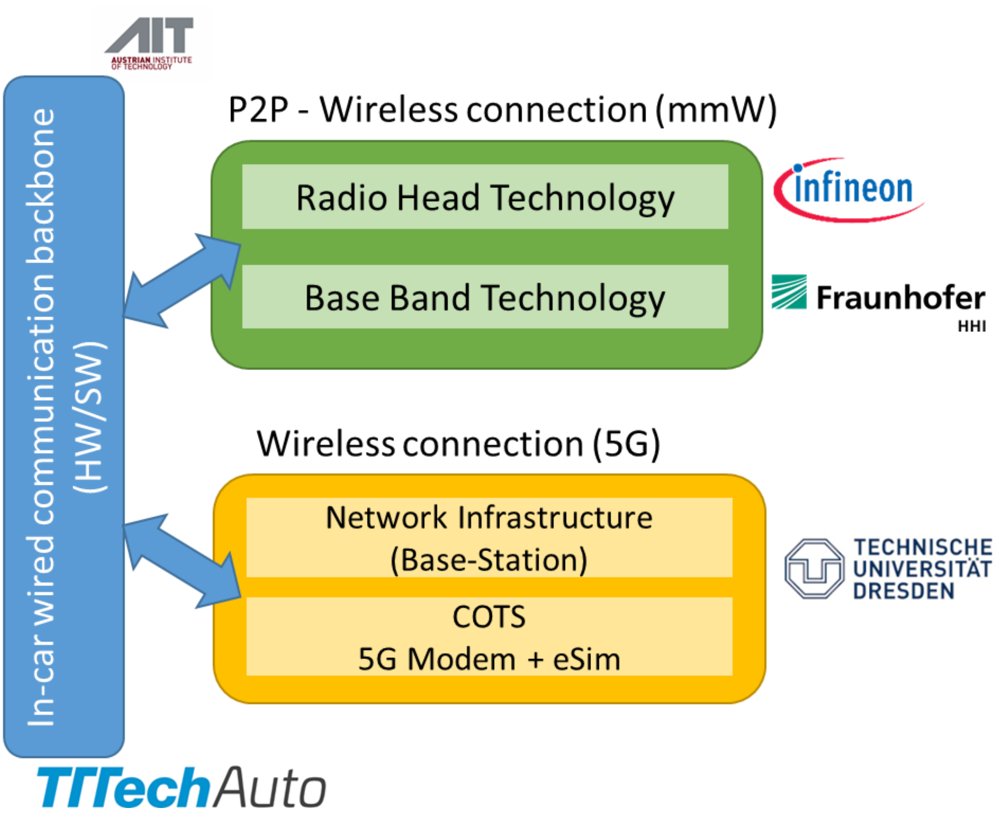

FIGURE 12: OVERVIEW OF THE KEY BUILDING BLOCKS AND PARTNER CONTRIBUTIONS WITHIN SCD 5.2 DEMONSTRATOR

The specification and purpose of this demonstrator was defined already in the introduction (Section 4.3.1) of this section and more details are mentioned in the Section 4.3.5. Main target is to create a demonstrator prototype and validate a novel 5G sub 6 GHz and 28GHz mmW low latency, large bandwidth communication technology.

4.3.3 Key building blocks

IFAG will develop a RF Radio Head for 28GHz mmW communication purpose. The Radio Head is using time domain duplexing (TDD) to enable receive (RX) and transmit (TX) on the same part. The intermediate frequency (IF) of the internal interface provides the interface to the base band modem directly.

The Radio head consists of the antenna Array, the up/down converter, the splitter circuit, the phase shifter part and a control unit. This internal control provides the external link to the modem and allows register-based control. The large antenna array is the wireless interface to the air and gives sufficient antenna gain for long distance point-to-point (P2P) links.

Multiple antennas form the array, where each individual antenna connects to a single digital controllable phase shifter and digital adjustable gain controller. The antenna array channels are combined to one resulting channel and converted down to a lower IF frequency. Nearly all the features are bundled by IFAG monolithic integrated mmW beam former integrated circuit (IC). A housing built out of aluminium cast shall simplify mounting the Radio Head on a pole or a vehicle. For validation purpose, the system consisting of the Radio Head and the Base Band Modem shall be mountable portable.

Fraunhofer HHI supports the development of a 5G Frontend for a low latency connectivity platform operating at 28GHz in the millimeter wave band. Therefore, Fraunhofer HHI will develop and integrate an SDR-based millimeter-wave (mmW) side link including beamforming, which will serve as a direct high-speed data link between cars. The Implementation of the side link is based on the PC5 interface from 3GPP Rel14, including potential enhancements towards 5G NR support (Rel 15 and Rel 16). It utilizes a 28 GHz antenna array from IFAG. The mm-wave side link connection is terminated within an embedded onboard processing unit, which provides a digital interface (e.g., Ethernet) to external parties.

AIT will work towards predicting the link quality of wireless side links based on the PC5 interface from 3GPP Rel14, IEEE 802.11p, and potentially 5G NR in urban areas for vehicular-to-everything (V§X) scenarios. Therefore, AIT will model V2X scenario using a geometry-based stochastic channel and use its channel emulator with actual standard compliant hardware for V2X communication in the loop. This will provide realistic wireless channel data and a realistic performance evaluation of the aforementioned wireless side links. Furthermore, AIT will develop a deep neural network allowing to predict the channel link quality, in terms of frame error rate, for selected standards, i.e., IEEE 802.11p or PC5 side link.

TTTAUTO will connect the wireless communication via 5G module with the point-2-point communication technologies provided by IFAG and FHG (HHI) to help validating the capabilities of the connectivity solution by supporting with data channels linking both technology bricks.

TUD works on the core network of the cellular communication system. Functionality in the fully virtualized core network is exposed via interfaces to relevant services. A UPF will be added as a high-performance layer around existing UPFs in order to quantify uncertainty for the given UPFs' performances. This allows for increased reliability, once traces of UPF performance have been recorded. One specific UPF offers to execute offloaded task execution (calculation-as-a-service).

4.3.4 Validation concept and Evaluation metrics

The validation concept utilized in SCD 5.2 follows the same principles as described in Section 4.2.4. As depicted in Figure 12 the first versions in year one and two will be verified in a lab environment. The final demonstrator (Y3) is meant to be an integrated showcase with all partner contributions integrated. Each demonstrator will be verified by its own. SCD5.1 and SCD5.2 will not be verified in one scenario since the infrastructure for wireless communication is hosted by FHG (HHI) and the demonstrators are designed to show their functionality on its own. In Section 4.3.5 the scenarios description is visualized and described together with the planned demonstrator layout.

The mmW sidelink and the cellular network developments will be evaluated in regard to correct beam acquisition and max throughput between two nodes. The validation of functional requirements is performed by:

- Automated measurements using RF equipment
- Functional tests and performance measurements against defined baselines
- Static analysis and design analysis for developed software modules
- Inspection and Verification of RF network analyser data samples

4.3.5 Test plan for evaluation

Demonstration Y1:
In the Y1 of the project, IFAG is focused on the requirements definition evaluation of building blocks. Building blocks simulations are performed to find a superior antenna geometry for broadband frequency usage. Antenna simulation together with the integrated beam former circuit (IC) is done for best system performance. Antenna Performance together with the beamformer integrated circuit is demonstrated. Key performance is max output power by using the novel antenna structure.
Within the first project year, Fraunhofer HHI implemented a V2X System Simulator that emulates vehicular communications under realistic operating conditions. The V2X System Simulator evaluates the performance of realistic V2V systems and compares different quality parameters when sub-6 GHz or millimeter-wave (mmW) links are used. In particular, the usage of beamforming antennas for the latter band and its enormous potential to enhance channel quality and unleash advanced connectivity use cases is studied. Simulations report that beamforming capabilities increase the received power. Regarding the mmW side link, additional losses compared to traditional sub-6GHz must be compensated and sharp beams generated with multi-element arrays make them feasible. Additionally, not only desired signal is enhanced, but also interference from neighbours can be mitigated thanks to the directional nature of the links.

Demonstration Y2:
IFAG will provide the first generation of mmW RF Radio Head prototypes to Fraunhofer HHI to form a simple communication system. These Radio Heads should work together with the HHI Controller to demonstrate and validate a wireless link. Static wireless links by using a 5G signal analyser shall be part of the demonstration together with the Fraunhofer HHI. Figure 13 depicts the layout of the demonstrator scenario in detail.

Within the second project year, Fraunhofer HHI will develop an instrument-based measurement setup, which aims for beam acquisition realization. The setup will comprise of a signal generator (R&S SMW200A), a signal analyser (R&S FSW43), two mmW radio frontends (IFAG IFX FEM) and two control units (HHI FEM Controller, Measurement Laptop). On the transmitter (TX) side, the signal generator provides a 5G NR waveform at an intermediate frequency (IF) of 5.8 GHz to the RF frontend. The frontend internally up converts the IF signal to the carrier frequency (CF) of 26 GHz. A beam-switch-marker-signal, which is also provided by the signal generator, is processed within a control unit that steers the frontend’s beams. On the receiver side (RX), the second RF frontend down converts the received 5g NR waveform to the mentioned IF and provides it for the signal analyser. The signal analyser samples the IF signal and provides the processed data to a measurement laptop, which controls the setup.

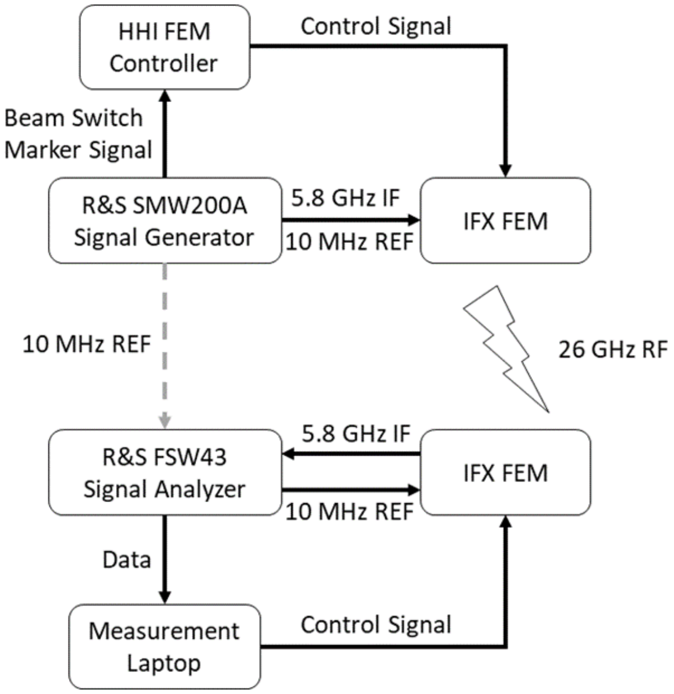

FIGURE 13: SCD 5.2 DEMONSTRATOR LAYOUT YEAR 2

Demonstration Y3:

Within the third project year, Fraunhofer HHI together with IFAG will develop a software-defined-radio (SDR) setup, that realizes a true LTE/5G mmW sidelink. Figure 14 illustrates the demonstrator scenario between FHG(HHI) and IFAG. The setup comprises of two SDRs (Ettus USRP), two local oscillators (LO) (R&S SFT100A), two RF frontends (IFAG IFX FEM), two control units for the RF frontends (HHI FEM Controller) and two LTE/5G mobile network interfaces. The SDRs will provide an IF signal that is up/down converted within the RF frontends. Besides the IF signal, the SDRs provide a TX/RX switch signal, that is processed by the control units to change the frontend’s operation mode. The LOs provide a common 10 MHz reference for the SDR and frontend, to guarantee synchronicity. The mobile network interfaces will simulate an eNodeB/gNodeB and a user equipment (UE) to provide the mmW sidelink. It is aimed to implement a high data rate communication.

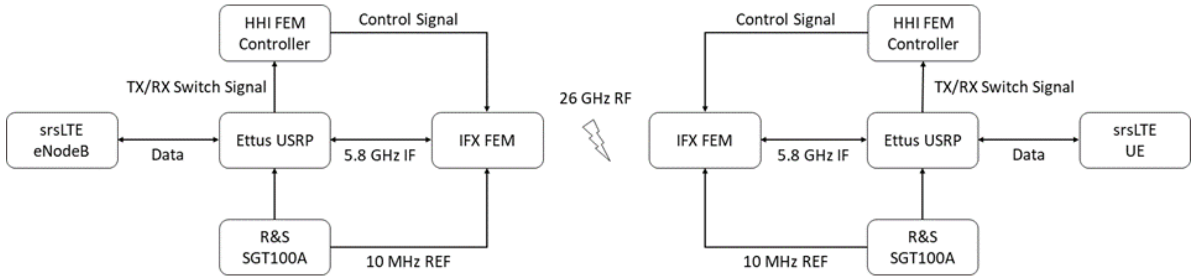

FIGURE 14: SCD 5.2 DEMONSTRATOR LAYOUT FINAL PROJECT YEAR

5 Conclusion

5.1 Contribution to overall picture

This deliverable provides requirements and specifications relevant for the design, integration, and verification of the communication and connectivity platform and methods to access data from the edge (e.g., cars, infrastructure) and the cloud (e.g., city-model) and fulfill fast, reliable, low-latency data connections in future shared mobility technologies.

The Task T1.5 partners delivered 43 requirements for all specified demonstrators SCD 5.1 (18), and SCD 5.2 (25). These requirements can be categorized into the following main topics:

Demonstrator SCD 5.1 - Proof-of-concept communication platform

- 8 requirements have been provided on the topic of security and safe communication channels,
- 4 requirements are linked to deterministic communication channels and timing,
- 3 requirements can be linked to monitoring and diagnostics,

and the reminder of requirements cover specific technical aspects of the demonstrator.

Demonstrator SCD 5.2 - Proof-of-concept demonstrator novel wireless data transmission (edge/cloud)

- 11 requirements have been provided on the topic of the RF frontend,
- 10 requirements are related to the baseband technology development for the 28GHz wireless communication,

and the remaining four requirements linked to SCD 5.2 are covering specifics for the mobile edge infrastructure.

All specified requirements are linked to function blocks within the demonstrators to be able to track them efficiently during the development process and to avoid misunderstandings over which partner is the specific owner of the requirements. All partner contributions are linked to one of the two supply chain demonstrators. The developed software building bricks are continuously evaluated with KPIs in the field of safety, efficiency, and compliance with the Green-Deal. All defined KPIs are evaluated against a specified baseline outlined in the requirement descriptions.

All specified requirements for the targeted SC5 technology bricks are synchronized with other technology enabler via this document, where the performance is evaluated on component and subsystem level before the integration on entire system level into the real-world demonstrators planned in SC1. To ensure consistent integration of the components, especially within the output enabler supply chain SC1 all interfaces to the other technology enabler SCs are clearly defined and synchronized during the requirements collection process.

5.2 Impacts to other WPs, Tasks and SCs

Table 2 briefly lists in which WP's, tasks, and SC's the outcome of task 1.5 will be used later in the project. The table is organized per partner or per topic.

TABLE 2: OVERVIEW OF WP, TASK AND SC INTERCONNECTIONS

Partner/Topic	Description
IFAG	Within WP2 (T2.5) IFAG will design the architecture and model the 28GHz RF Frontend. WP3 (T3.3) will comprise the development of optimized RFICs based on the design and requirements specified. These will be integrated and tested in WP5 and WP6 respectively.
AIT	Requirements provided by AIT are strongly correlated with SC1 and S8 and concern mainly the cybersecurity and safety frameworks in the automotive field of interest (including highly automated and connected driving, with respect also to UNECE regulations and standards, and the new paradigms of AI and functional safety, where AIT is particularly active in ISO TC22 SC32, SC31 and ISO/IEC TR 5469 connecting AI and safety. In addition, the requirements and processes described here will be be utilized in WP2 (T2.5) regarding the system-level design. The concept of a common usage of SCD5.1 in an extended vehicle item based on ISO 20077 and ISO 20078 will also connect the work done here to SC8, the overall topic of standardization and to the topic of shared mobility ecosystem in-car as well as on the edge to cloud side.
IMA	IMA activities presented here will influence the following work represented in WP2 T2.5 where the system design will be finalized, and critical implementation decisions will be made. This will further influence the realization of T3.5 where IMA intends to develop necessary electronic modules and basic building blocks for the system designed in WP2. Tasks 4.5 and 5.5 are then devoted to SW and FW development, algorithm and functional blocks development and integration with the HW and as such we consider these 2 activities as very closely connected. All the necessary tests and validation procedures are planned for T6.5.
FHG (HHI)	D1.5 introduces the concepts and requirements for the future work within the project of FHG (HHI). The requirements are related to work within WP2 (T2.5) - system level design, WP5 (T5.5) - integration of systems for connectivity and communications, and WP6 (T6.5) - validation and test of connectivity and communications.
NXP	The requirements described in this deliverable will be considered in WP2 (T2.5) for system-level design, WP3 (T3.3) for embedded HW/SW for connectivity and communication, in WP4 (T4.4) for cross-protocol in-car communication architecture., in WP5 (T5.5) for system integration, and in WP6 (T6.5) for validation and testing.
TUD	The requirements described in D1.5 will guide WP2 (T2.5) for system-level design and WP4 (T4.4) for provisioning the communication and computation architecture in a novel, predictive way. Subsequently, in WP5 (T5.5), the system will be integrated, after which it will be validated and tested in WP6 (T6.5).
TTTAUTO	The results of WP1 Task 1.5 build the basis for the upcoming tasks within WP2 dealing with the system level design and WP4 responsible for the implementation of the proposed methods and concepts. The results are later integrated and verified within WP5 Task 5.1 and are verified within WP6 Task 6.1.

Requirements, scenarios, KPIs, demonstrators and evaluation plans.	Links to the other technology enabler SCs (SC4, SC6, SC7) are established to ensure consistent interfaces that are of particular interest during the integration of the developed components and subsystems. A dedicated link is established into SC1, which focus on the integration of SC5 modules into one of the SC1 demonstrators later in the project (WP5, WP6).

5.3 Relation to the state-of-the-art and progress beyond it

Partner/Topic	Description
Communication and connectivity concept	AI4CSM will develop and standardize a set of hardware and software redundancy concepts for vehicular E/E architectures to minimize the probability of malfunctions in the autonomous driving functions to below 10E-9/hour. This standard architecture will provide a common minimum definition of safety and efficiency and serve as a blueprint for the modalities of their realization across components and sub-systems in the vehicle's E/E architecture. The communication architecture developed in SC5 will provide an important building block of the connected shared mobility platform in the project.
AIT	SCD 5.1: State of the Art research focusses on the integration of security and extended vehicle concept with the existing safety and vehicle engineering domain. The integration of vehicle in a wider eco-system and the continuous connection and integration challenges security and safety. With the new requirements on security for type approval all future vehicle system need to achieve a sufficient level of security. AIT will investigate how to approach these topics in an efficient way. [1] ISO 26262:2018 Road vehicles – functional safety [2] UNECE UN R-155 - Cyber security and cyber security management system, 2021 [3] ISO/SAE 21434 Road vehicles – cybersecurity engineering [4] ISO/PAS 5112 Road vehicles — Guidelines for auditing cybersecurity engineering [5] ISO 20077-1 Road Vehicles — Extended vehicle (ExVe) methodology — Part 1: General information
NXP	**SCD 5.1:** State-of-the-art research focusses on safety and security of the vehicle E/E architecture separately. In the AI4CSM project, these two aspects shall instead be jointly considered during the development of the vehicle system. Some safety requirements are similar to security requirement. For example, the actions to protect against "babbling idiots" are also useful against denial-of-service attacks. Other requirements differ, for example, safety focusses on the safety-critical elements of the system, while the security threats come mostly from external communication (e.g., through telematics modules). With the focus on end-to-end safe and secure communication, the demonstrator incorporates the requirements in a realistic automotive system, exhibiting future E/E architecture characteristics. See the references below for further reading on state-of-the-art safe and secure automotive systems. [1] ISO 26262:2018 Road vehicles – functional safety [2] IEEE 802.1CB-2017 - Frame Replication and Elimination for Reliability

	[3] Frigerio, et al., Automotive architecture topologies: analysis for safety-critical autonomous vehicle applications, 2021 [4] Schnellenbach, Fail-operational automotive systems, 2018 [5] UNECE UN R-155 - Cyber security and cyber security management system, 2021 [6] ISO/SAE 21434:2021 Road vehicles – cybersecurity engineering [7] AUTOSAR Specification of secure onboard communication (SecOC), 2017 [8] AUTOSAR E2E Protocol specification, 2017 [9] IEEE 802.1Q-2018 (Qci) Per-Stream Filtering and Policing [10] SECREDAS – European project https://secredas-project.eu/ 2018-2021

5.4 Contribution to demonstration

Table 3 briefly describes the relation between task 1.5 and the planned demonstrators. The table is organized per partner.

TABLE 3: OVERVIEW OF CONTRIBUTIONS TO DEMONSTRATORS

Partner/Topic	Description
IFAG	IFAG will focus on implementation of algorithms for secure external communication, with high data rates (5G) and bandwidth. The cloud fusion will be designed with fast and reliable wireless communication channels based on 28 GHz mmW technology.
AIT	Research on safe and secure especially with a focus on runtime threat management, extending the work done in WP2. This work aims to harden the SC5-developed energy efficient, virtualised and connected in-car computing platform against cyberattacks or component/software failures. Work will be done based on an assumed usage of the components in a “extended vehicle” item and demonstrate security engineering and argumentation based on this usage.
IMA	IMA Car access system V2I communication module and platform independent SW based services will be developed. The necessary interfaces will be provided to relevant stakeholders.
FHG (HHI)	Interface specification of the developed onboard processing and baseband unit towards the 28GHz beamforming antenna from IFAG as well as the interface to the main domain controller (Brain). The onboard processing and baseband unit implements the 5G V2X connectivity in the mm-wave and sub-6 GHz bands (26/28 GHz and 3.7 GHz)
NXP	NXP will demonstrate qualitative and quantitative results of safe and secure in-vehicle networking. In addition, traffic captures will be obtained to document realistic in-vehicle traffic behaviour.
TUD	Demonstrate the availability and performance of a proactive and on-demand provisioning system for edge compute and other functionality. Traces of the behaviour of deployments and scaling will be recorded, together with the respective ingress (traffic and computational workload). The foundation for mapping of (specific) tasks to accelerators are laid herein.

TTTAUTO	Technologies for software platform which enables safety execution of cognitive functions to ensure that uncertainty in such functions does not lead to failures in automated driving functions at the vehicle level.

5.5 Other conclusions and lessons learned

Table 4 briefly describes other conclusions and learnings derived during the execution of task 1.5 described in this deliverable.

TABLE 4: CONCLUSIONS AND LESSONS LEARNED

Partner/Topic	Description
Consistent interfaces	An essential aspect of ensuring consistent interfaces between the technology enabler and output enabler SCs is the fact that all key partners are represented in the requirements specification process in WP1 and task 1.5 respectively. Represented means that they take part in all related tasks even if their entire project contribution focuses on a specific SC.
AIT	The demonstrators receive, on the one hand, essential input from the existing and evolving standards, which are also referenced in context of the UNECE regulations, e.g., on cybersecurity engineering, safety and software update. On the other hand, they are expected to influence the evolving standards with respect to new computing paradigms (highly automated systems, AI, connected vehicles/Extended vehicle standards). This is an overarching issue concerning the other supply chains as well.
NXP	The requirements defined in this document will be further analyzed and refined in WP2. Some of the requirements will need additional specification based on the use cases used in the demonstrator platform.

6 Appendices

The Appendix contains the consolidated requirements and the demonstrator descriptions. Content is publishable.

1. Demonstrator descriptions:
    a) AI4CSM SC5_1 Demonstrator
    b) AI4CSM SC5_2 Demonstrator
2. Key building block requirements:
    a) AI4CSM SC5 Requirements

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Appendix 1a – AI4CSM SC5.1 Demonstrator

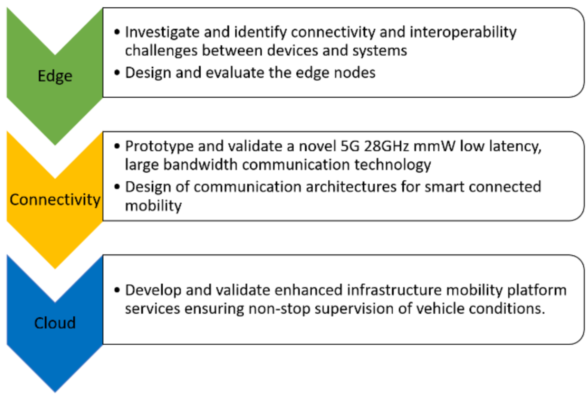
Demonstrator SCD 5.1: Proof-of-concept communication platform

Description

Short general description (main target of the demonstrator)

- Design of communication architectures for smart connected mobility demonstrating significant higher performance than state of the art.
- Validation of a prototypical reference board with corresponding SW environment, including a diagnostics interface with information for subsequent external monitoring.
- Develop and validate enhanced infrastructure mobility platform services ensuring non-stop supervision of vehicle conditions

Link to SC5 objectives:



Beyond state of the art:

- Future in-car communication architecture (zonal, central).
- Fast, reliable, low-latency in-care data channels across zones, domains.
- Improvement of identity management between edge and cloud services.

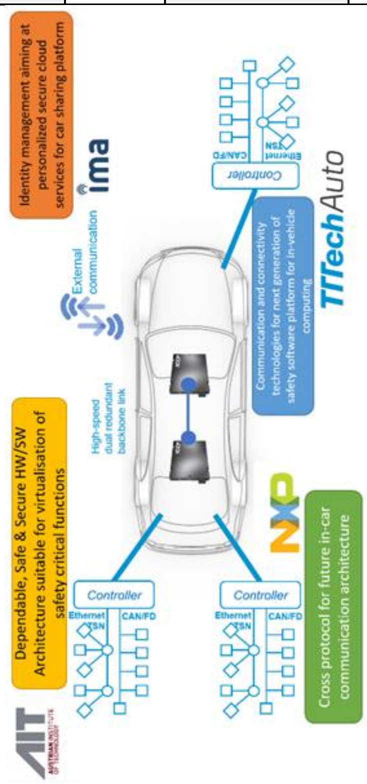
Lead

TTTAUTO

Link to entire project objectives

	O1 – Develop robust and reliable mobile platforms
x	**O2** – Develop scalable embedded intelligence for edge and edge/cloud operation
	O3 – Design silicon for deterministic low latency and build AI-accelerators for decision and learning
	O4 – Solve complexity be trustable AI, in functional integrated systems
	O5 – Design functional integrated systems
X	**O6** – Build ECAS vehicles for Green Deal for future connected shared mobility

Start TRL	3	**End TRL**	5



Partners	
NXP-DE, NXP-NL, IMA, AIT	

Scenario description	
Prototype reference setup with corresponding SW environment with HW/SW mechanisms to showcase next automotive communication technologies. The demonstration will incorporate HW from TTTAUTO and NXP-NL to showcase fast data channels among different domain controller and the in-vehicle decision making module. The performance of this connection will be evaluated and investigated based on the collected requirements in this document. NXP will contribute to the overall functional safety architecture by creating a proposal for the safety contribution by the vehicle communication system. Each communication protocol needs to have its own consideration what will be a separate "chapter" in the concept proposal. An end-to-end ethernet reference backbone system will be provided by TTTAUTO and part of reference system will be SW device drivers so that features for safety can be applied and integrated into the overall vehicle network management.	
Evaluation KPIs	**Baseline**
• Detailed KPIs and validation metrics are listed for each requirements in Annex 1.c.	• Current solutions used in series production and on the market technologies e.g., ECU in automotive industry

Demonstrator platform
Results and Evaluation Y1: The results achieved for Y1 concerning WP1 can be summarized as collection of requirements and specifications for the demonstrator SCD 5.1. This deliverable describes the efforts and outcomes of the process and individual requirements are listed in Annex 1.c of the deliverable document D1.5. **Results and Evaluation Y2:** After year two of the project the requirements on sub-component level will be validated. These will be achieved by demonstrating the technical improvement mostly via lab-based demonstration and testing using hardware in the loop approaches and the prototypes and development boards. **Results and Evaluation Y3:** During the final project year, the verified sub-components will be integrated into the demonstrator of SCD 5.1. Having each key building block available, the activities in WP5 (T5.1) and specifically WP6 (T6.5) will demonstrate the improvements achieved in AI4CSM with respect to communication and connectivity. Participation partners in the SCD 5.1 will showcase the integrated functionalities and the integration will be extended into the output enabler supply chains where those activities where planned.

Appendix 1b – AI4CSM SC5.2 Demonstrator

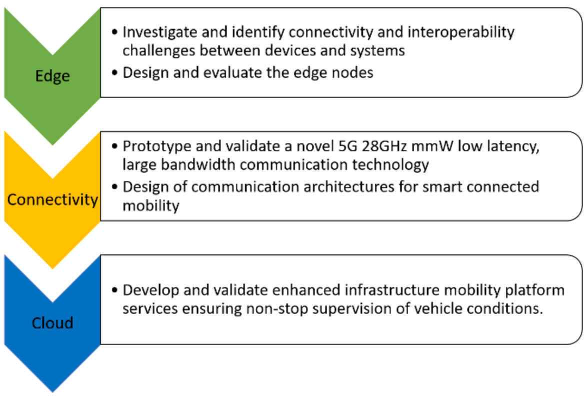
Demonstrator SCD 5.2: Proof-of-concept demonstrator novel wireless data transmission (edge/cloud)

Description

Short general description (main target of the demonstrator)

- Prototype and validate a novel 5G 28GHz mmW low latency, large bandwidth communication technology
- Investigate and identify connectivity and interoperability challenges between devices and systems to overcome bottlenecks regarding seamless integration of the V2X communication platform and its constituent parts
- Design and evaluate the edge nodes receiving computational tasks, including the distribution of work to physical resources

Link to SC1 objectives:



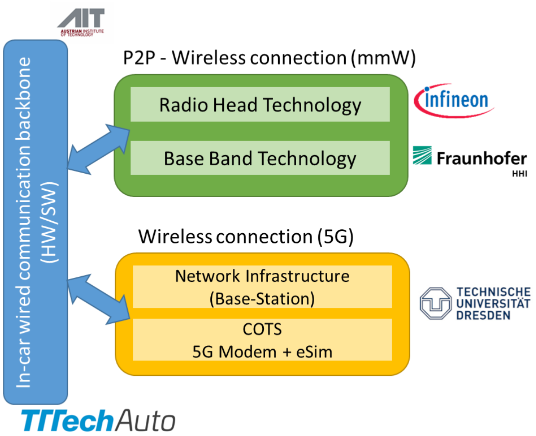
Beyond state of the art:

- unique 360° azimuth angle coverage with optimized low latency beamforming function at small form factor
- low latency end-to-end communication concepts for V2V & V2I.
- safe & secure function virtualization

Link to entire project objectives

	O1 – Develop robust and reliable mobile platforms
X	**O2** – Develop scalable embedded intelligence for edge and edge/cloud operation
	O3 – Design silicon for deterministic low latency and build AI-accelerators for decision and learning
	O4 – Solve complexity be trustable AI, in functional integrated systems
	O5 – Design functional integrated systems
X	**O6** – Build ECAS vehicles for Green Deal for future connected shared mobility

Start TRL	3	**End TRL**	5



Lead

IFAG

Partners

TUD, FHG (HHI), TTTAUTO, AIT

Scenario description

IFAG will provide high bandwidth 5G mmW radio modules incorporating Infineon 28GHz RFICs. The provided hardware will demonstrate unique 360° azimuth angle coverage with optimized low latency beamforming function at small form factor. The mmW radios will be controlled by a digital baseband carrying a software stack by HHI which in consequence enables high data rate, low latency 5G communication channels. 5G mmW radios are complemented with a 5G 3.7GHz link by HHI to allow for extended range operation. Both modems, the mmW and the 3.7GHz ones, will connect to an in-car main domain controlling unit of TTTAUTO through a Gbit Ethernet interface. The low latency end-to-end communication concepts will be validated and benchmarked against existing solutions on the market. The demonstration will showcase low-latency, high performance and robust data channels at the network edge and smart infrastructure automation by providing low latency data communication from in-vehicle, edge and cloud data-sources. The TUD will handle the 5G core, the distribution of tasks, and the user plane functions that offload computation to dedicated edge nodes equipped with AI accelerators.	
Evaluation KPIs	**Baseline**
• Detailed KPIs and validation metrics are listed for each requirements in Annex 1.c.	• conventional sub-6GHz 4G/5G data streams
Demonstrator platform	
Demonstration Y1: Year one demonstration will focus on building block simulation to find a superior antenna geometry for broadband frequency usage. The antenna performance Antenna Performance together with the beamformer integrated circuit is demonstrated. Key performance is max output power by using the novel antenna structure. Fraunhofer HHI implemented a V2X System Simulator that emulates vehicular communications under realistic operating conditions. The V2X System Simulator evaluates the performance of realistic V2V systems and compares different quality parameters. **Demonstration Y2:** Year two demonstration will showcase the first generation of mmW RF Radio Head prototypes to Fraunhofer HHI to form a simple communication system. These Radio Heads should work together with the HHI Controller to demonstrate and validate a wireless link. Static wireless links by using a 5G signal analyser shall be part of the demonstration together with the Fraunhofer HHI. **Demonstration Y3:** Within the final year of the project the SCD 5.2 partner will demonstrate the integrated demonstrator as described in the above. Fraunhofer HHI together with IFAG will develop a software-defined-radio (SDR) setup, that realizes a true LTE/5G mmW sidelink. The setup comprises of two SDRs (Ettus USRP), two local oscillators (LO) (R&S SFT100A), two RF frontends (IFAG IFX FEM), two control units for the RF frontends (HHI FEM Controller) and two LTE/5G mobile network interfaces. TTTAUTO will demonstrate the data link between both communication modules and TUD will showcase the designated 5G core functionalities.	

Appendix 1c – AI4CSM SC5 Requirements

	#1 Functional Requirements / FR
ID	AI4CSM_SC5_D1-1
FR Naming	Bounded (communication) device configuration time.
Definition of FR	The secure communication shall be configured within τ after the activation of the system
Description of FR	Devices for secure communication need to be configured for operation within a limited time after power up
What is measured:	Time needed for device configuration as needed for secure communication
KPI	[s] time for the device to be operational for secure communication
Method of collection and measurement	Time needed for register configuration of device (including secure boot, if the device has an integrated microcontroller)
Target Value	$\tau<50$ms
Verification and validation method	Measurement of time needed to configure registers over host interface for secure communication

	#2 Functional Requirements / FR
ID	AI4CSM_SC5_D1-2
FR Naming	Bounded secure communication link setup time
Definition of FR	The secure communication links must be available within τ after the reset of the system or parts of the system (partial networking)
Description of FR	Communication links need to be up and running within a limited amount of time after reset
What is measured:	Time before first data exchange after power on or wake-up
KPI	[s] time before first data exchange
Method of collection and measurement	A timestamp taken at the activation of the system must be compared with a timestamp taken at the time of the first data exchange on the sender side
Target Value	$\tau<100$ms
Verification and validation method	Time before first data exchange at startup measured on demonstrator platform

	#3 Functional Requirements / FR
ID	AI4CSM_SC5_D1-3
FR Naming	Sender authentication
Definition of FR	Messages shall be authenticated
Description of FR	Secure communication shall use sender authentication
What is measured:	-
KPI	Yes / No

Method of collection and measurement	Static analysis of the platform
Target Value	Yes
Verification and validation method	Sender authentication shall be configured on secure communication links

	#4 Functional Requirements / FR
ID	AI4CSM_SC5_D1-4
FR Naming	Intruder detection
Definition of FR	The secure communication network shall detect malicious traffic
Description of FR	An intrusion detection system shall detect malicious traffic that is being transmitted on the secure communication links. The malicious traffic is generated with specific test attack vectors to simulate possible cyber security attacks on the demonstrator platform. The intrusion detection system shall detect spoofing, man in the middle, and denial of service attacks. The logging information about the detected malicious traffic shall be recorded
What is measured:	Detected malicious traffic
KPI	Yes / No
Method of collection and measurement	Test the intruder detection system by executing specific attack vectors on the network and logging the identification of malicious traffic
Target Value	Yes
Verification and validation method	Validate the intruder detection system by comparing the detected and logged malicious traffic with the injected malicious traffic. Verify that the system detects the test attacks vectors

	#5 Functional Requirements / FR
ID	AI4CSM_SC5_D1-5
FR Naming	Redundant communication
Definition of FR	The platform shall provide redundant communication links
Description of FR	For safe communication, the demonstrator shall have redundant communication links. No single-point of failure shall be present in the communication links
What is measured:	-
KPI	Yes / No
Method of collection and measurement	Static analysis of the platform
Target Value	Yes
Verification and validation method	Verify that the demonstrator platform provides redundant communication links

	#6 Functional Requirements / FR

ID	AI4CSM_SC5_D1-6
FR Naming	End-to-end data protection
Definition of FR	Secure communication shall make use of E2E data protection
Description of FR	Data integrity on secure communication links shall be provided with E2E data protection from application to application
What is measured:	-
KPI	Yes / No
Method of collection and measurement	Static analysis of the platform
Target Value	Yes
Verification and validation method	E2E data protection shall be configured on secure communication links

	#7 Functional Requirements / FR
ID	AI4CSM_SC5_D1-7
FR Naming	Network diagnosis
Definition of FR	The communication network shall provide diagnostics services
Description of FR	The state of health of the communication links shall be monitored. The diagnostics data shall provide details of points of failure and detected malicious traffic
What is measured:	Availability of diagnostics services
KPI	Yes / No
Method of collection and measurement	Static analysis of the platform
Target Value	Yes
Verification and validation method	The diagnostic services are present on the board and provide the correct data in case of failures or detection of malicious traffic

	#8 Functional Requirements / FR
ID	AI4CSM_SC5_D1-8
FR Naming	Communication protection
Definition of FR	Communication shall be protected against denial of service by "babbling idiots", nodes with incoming link failures, misconfigured nodes
Description of FR	Lower communication layers can prevent (in some cases) illegal bus access/babbling idiots.
What is measured:	Communication correctness in presence of faulty links or other communication nodes
KPI	Yes / No
Method of collection and measurement	Force faulty communication in the network and collect communication data from the nodes under test

Target Value	Yes
Verification and validation method	The correctness of the communication shall be verified in presence of faulty elements

	#9 Functional Requirements / FR
ID	AI4CSM_SC5_D1-9
FR Naming	Real-time requirement
Definition of FR	Real-time data communication platform including HW / SW and configuration tools for testing and verification
Description of FR	The communication platform and ECUs shall support defined timings for exchanging data packages across the network. The specific boundaries have to be set by the business logic or application and aligned with the capabilities of the underlying platform.
What is measured:	Functionality to configure
KPI	Yes/No
Method of collection and measurement	Analysis of the platform and tools
Target Value	Yes
Verification and validation method	Analysis of the HW and software configuration methods. Assurance of configuration tools suitable for the test/verification scenario.

	#10 Functional Requirements / FR
ID	AI4CSM_SC5_D1-10
FR Naming	Defined timing for communication channels
Definition of FR	Communication channels in the network shall provide deterministic data transfer based on pre-defined schedule.
Description of FR	The network shall ensure that there is no temporal impact of any message on messages of highest criticality. There is a highest criticality message class for hard real-time control and fail-operational systems. Using Time-Triggered Ethernet it can be guaranteed that the time-triggered messages (or a pre-defined subset of them) will not be subject of temporal impact from any other message. The network may transport other messages which are of lowest criticality without bounds of temporal impact from other messages. Medium-criticality messages should have a known bound in the temporal impact on them
What is measured:	Latency between messages, schedule of messages according to a predefined test protocol.
KPI	Schedule of messages is valid (Yes/No)
Method of collection and measurement	Simulated setup of multiple data channels between sensors and applications or bi-directional communication between applications across the network stack.
Target Value	Schedule of messages is valid – Yes

Verification and validation method	Timing and measurement of deterministic schedule, post-analysis of timing protocol.

	#11 Functional Requirements / FR
ID	AI4CSM_SC5_D1-11
FR Naming	Mixed Criticality Functionality
Definition of FR	Safety relevant functions and performance applications shall not interfere with each other on a single ECU.
Description of FR	Separation, i.e. freedom from interferences, among applications with different criticality levels (as defined in ISO 26262) shall be ensured in one and the same ECU.
What is measured:	Correct functionality under different network and application loads
KPI	A predefined safety function is not affected by other performance applications.
Method of collection and measurement	Simulating faulty behavior of an application and verification of the correct functionality of the safety function under investigation.
Target Value	Freedom from interference observed
Verification and validation method	Scenario based simulated test case and automated analysis of correct function.

	#12 Non-Functional Requirements / FR
ID	AI4CSM_SC5_D1-12
FR Naming	Architectural support for Cloud to Edge communication
Definition of FR	Design and architecture for the system has to support the cloud to edge approach to ensure data exchange in future smart mobility solutions.
Description of FR	Architecture evaluation of the selected sub-system design and comparing alternative E/E architectures, including embedded network communications, to identify the most suitable one that meets a given set of requirements as well as supports scalability, flexibility, re-usability, and adaptability.
What is measured:	Design Concepts for Communication and Connectivity
KPI	Yes/No
Method of collection and measurement	Comparison and Analysis
Target Value	Yes
Verification and validation method	Design Analysis

	#13 Non-Functional Requirements / FR
ID	AI4CSM_SC5_D1-13
FR Naming	Safe message transfer

Definition of FR	Communication Software Platform shell ensure safe message transfer on all communication channels available within and outside of an ECU
Description of FR	In the context of reliable communication (safe message transfer) Communication Software Platform protects against and handles faults in exchange of data.
What is measured:	Faults
KPI	Type of faults (Repetition of information, Loss of information, Delay of information, Incorrect addressing, etc.)
Method of collection and measurement	Logging, network sniffing
Target Value	Yes
Verification and validation method	Demonstration of detection of faults

	#14 Non-Functional Requirements / FR
ID	AI4CSM_SC5_D1-14
FR Naming	Safe State
Definition of FR	In a case of a failure, it shall be ensured by the external system that unavailability of the communication software platform does not lead to a hazardous event.
Description of FR	The ECU running Software Communication Platform shall be silent towards all Safety-critical interaction with peripherals in case of fault occurrence. Silent means that all communication channels and external data transmission interfaces (e.g., to sensors and actuators) must be shut down. This behaviour is referred to as "fail-silent". Subsequent recovery actions after fault detection and the transition to the safe state might require a complete reset of the ECU.
What is measured:	Fault occurrence
KPI	Ensure that a transition to the ECU's safe state is triggered within a defined time interval.
Method of collection and measurement	The Fault handling time interval is determined by the scheduling order and execution times of the services which are part of the computation chain. The chain starts with the service which detects the fault and ends with the service which triggers the safety reaction (usually the error handler).
Target Value	Yes
Verification and validation method	Time measurement, logging

	#15 Non-Functional Requirements / FR
ID	AI4CSM_SC5_D1-15
FR Naming	Freedom from interference in communication and software execution
Definition of FR	Communication software platform shall provide freedom from interference between software components in memory, time, and communication domains.

Description of FR	If several different software components have been successfully integrated on the platform separate from each other, it shall be guaranteed that the behaviour of software is unchanged on a system with all c
What is measured:	Composability
KPI	Yes/No
Method of collection and measurement	Success of component integration, no interference
Target Value	No
Verification and validation method	Demonstration that functionality of components is not affected

	#16 Functional Requirements / FR
ID	AI4CSM_SC5_D2-16
FR Naming	Security Modeling
Definition of FR	Build up a approximated model of the system with external communication, with high data rates (5G) and bandwidth, focused on the security related parts
Description of FR	In order to conduct the security engineering process based on ISO/SAE 21434 and to combine the steps with ISO 26262, we will define an assumed item, based on extended vehicle. For this a model with the approximated components and systems from SC5, including all security related properties will be defined.
What is measured:	Security engineering approach
KPI	Efficiency gained
Method of collection and measurement	Comparison between manual and tool-based security engineering
Target Value	+20%
Verification and validation method	Reviews and expert judgment

	#17 Functional Requirements / FR
ID	AI4CSM_SC5_D1-17
FR Naming	Security Analysis
Definition of FR	Automatically analyse the model for potential risks based on UN R155 threat list (linked to process requirement)
Description of FR	In order to gain type approval for a new vehicle type in Europe after 2024, consideration of UN R155 and the included threat list has to be demonstrated. We will utilize an automated and model-based tool for identifying if any of the listed threats are relevant for the considered system.
What is measured:	Coverage of UN R155 threats in analysis
KPI	All threats are covered by automated analysis

Method of collection and measurement	Results from the tool will be reviewed and compared with the threat list.
Target Value	100%
Verification and validation method	Compare and evaluate automated analysis with manual analysis

	#18 Functional Requirements / FR
ID	AI4CSM_SC5_D1-18
FR Naming	Safety and security augmentation
Definition of FR	Build up a security and safety argumentation for at least one measure
Description of FR	Security needs to be argued, e.g., based on the considered threat intelligence, followed process and selected technical measures (in- and outside of the vehicle and during development) a convincing statement has to be given that a sufficient level of security can be assumed. We will develop such a argumentation for one security requirement and measure and connect this to safety.
What is measured:	Sufficiency of security requirement (yes / no)
KPI	Security argument
Method of collection and measurement	An independent AIT expert (expert who was previously not involved in SC5 work) will review and assess the security argument
Target Value	yes
Verification and validation method	An independent AIT expert (expert who was previously not involved in SC5 work) will review and assess the security argument

	#19 Functional Requirements / FR
ID	AI4CSM_SC5_D2-19
FR Naming	mmW Frontend Frequency Band
Definition of FR	The mmW RF Frontend equipment shall use the EU 5G mmW n258 (24.25GHz - 27.5GHz) band
Description of FR	The RX/TX Frontend is suitable for the EU frequency band and shall therefore operation in this band.
What is measured:	It is measured, whether the Frontend can be set into the EU Band
KPI	Yes/No
Method of collection and measurement	Automated measurement in the RF Lab
Target Value	Yes
Verification and validation method	Data inspection on the 5G Analyzer

	#20 Functional Requirements / FR
ID	AI4CSM_SC5_D2-20

FR Naming	mmW Frontend Channel Bandwidth
Definition of FR	The mmW RF frontend usable single channel bandwidth shall be minimum 400 MHz
Description of FR	The RX/TX Frontend bandwidth is critical for high speed wireless communication. A minimum bandwidth of 400 MHz in the RF Frontend is necessary to be future proof.
What is measured:	RF Frontend band width in RX and TX Mode from input to antenna output
KPI	Yes/No
Method of collection and measurement	Automated measurement in the RF Lab
Target Value	Yes
Verification and validation method	Visual inspection on RF network analyzer data

	#21 Functional Requirements / FR
ID	AI4CSM_SC5_D2-21
FR Naming	mmW Frontend RX/TX Duplexing
Definition of FR	The mmW RF frontend shall be implemented as a TDD (TimeDivisionDuplex) system
Description of FR	Due to RX/TX could not operate at the same time, RX/TX are switched alternating. No Duplexing Filter is necessary.
What is measured:	RX and TX switch on time and switch over time
KPI	Yes/No
Method of collection and measurement	Automated measurement in the RF Lab
Target Value	Yes
Verification and validation method	Data inspection on the 5G Analyzer

	#22 Functional Requirements / FR
ID	AI4CSM_SC5_D2-22
FR Naming	mmW Frontend Phase adjustment range
Definition of FR	The mmW RF Frontend shall have minimum of 360° phase adjustment range for each individual RF channel
Description of FR	To take usage of antenna beam steering the phase could be adjusted individual for each Antenna.
What is measured:	input to output phase control range
KPI	Yes/No
Method of collection and measurement	Automated measurement in the RF Lab

Target Value	Yes
Verification and validation method	Visual inspection on RF network analyzer data

	#23 Functional Requirements / FR
ID	AI4CSM_SC5_D2-23
FR Naming	mmW Frontend Gain adjustment range
Definition of FR	The mmW RF Frontend shall have minimum of 20dB gain adjustment range for each individual RF channel
Description of FR	To take usage of antenna beam steering the gain adjustment range is used to control the antenna side slopes of the beam
What is measured:	input to output gain control range
KPI	Yes/No
Method of collection and measurement	Automated measurement in the RF Lab
Target Value	Yes
Verification and validation method	Visual inspection on RF network analyzer data

	#24 Functional Requirements / FR
ID	AI4CSM_SC5_D2-24
FR Naming	mmW Frontend Power Supply
Definition of FR	The mmW RF Frontend shall use max 3.3V for the main internal power supply to enable green and power saving architectures
Description of FR	The RF Frontend chips are operation on a standard supply voltage.
What is measured:	All chips functions shall be available at 3.3V
KPI	Yes/No
Method of collection and measurement	Automated measurement in the RF Lab
Target Value	No
Verification and validation method	Functional test

	#25 Functional Requirements / FR
ID	AI4CSM_SC5_D2-25
FR Naming	mmW Frontend Intermediate Frequency
Definition of FR	The mmW RF Frontend shall be suitable for intermediate frequency (IF) below 6 GHz (sub 6GHz)

Description of FR	The RF Frontend RX/TX frequency is converted to an IF frequency to be handled by the Modem
What is measured:	IF frequency and bandwidth at the IF frequency
KPI	Yes/No
Method of collection and measurement	Automated measurement in the RF Lab
Target Value	Yes
Verification and validation method	Visual inspection on RF network analyzer data

	#26 Functional Requirements / FR
ID	AI4CSM_SC5_D2-26
FR Naming	mmW Frontend Phased Array Antenna
Definition of FR	The mmW RF Frontend shall support multiple antennas in parallel to enable scalable phased array antenna architectures for reliable car to car communication
Description of FR	Multiple RX/TX channels on each integrated circuit helps to minimize the amount of interconnects and space.
What is measured:	How many channels are placed on the integrated circuit.
KPI	Yes/No
Method of collection and measurement	Automated measurement in the RF Lab
Target Value	No
Verification and validation method	visual inspection

	#27 Functional Requirements / FR
ID	AI4CSM_SC5_D2-27
FR Naming	mmW Frontend Channel Output Power
Definition of FR	The mmW RF Frontend shall feature state of the art RF output power for 5G modulated signals
Description of FR	The TX output power determines max wireless max link distance. A key indicator is the 1dB output power value.
What is measured:	Output power 1dB compression of each individual channel
KPI	Yes/No
Method of collection and measurement	Automated measurement in the RF Lab
Target Value	Yes
Verification and validation method	Visual inspection on RF network analyzer data

	#28 Functional Requirements / FR
ID	AI4CSM_SC5_D2-28
FR Naming	mmW Frontend Channel Input Sensitivity
Definition of FR	The mmW RF Frontend shall feature state of the art RF input sensitivity for 5G modulated signals
Description of FR	RX input sensitivity is determined by the RX noise figure. This Req is to ensure a proper sensitivity to weak signals, which correspond long distance wireless links.
What is measured:	Noise Figure on the RX interface to IF
KPI	Yes/No
Method of collection and measurement	Automated measurement in the RF Lab
Target Value	Yes
Verification and validation method	Visual inspection on RF network analyzer data

	#29 Functional Requirements / FR
ID	AI4CSM_SC5_D2-29
FR Naming	mmW Frontend Modem/Frontend Control
Definition of FR	The mmW Frontend shall be controlled by the mmW Modem via a control bus
Description of FR	A control bus is mandatory to control the RF Frontend from the Modem side. The control bus has to be simply and robust, to be operated on a vehicle mounted electronic unit.
What is measured:	Type and speed of the control bus.
KPI	Yes/No
Method of collection and measurement	Automated measurement in the RF Lab
Target Value	No
Verification and validation method	Visual data inspection

	#30 Functional Requirements / FR
ID	AI4CSM_SC5_D2-30
FR Naming	mmW modem communication protocol
Definition of FR	The modem shall make use of a communication protocol and broadband PHY aligned with a current wireless communication standard
Description of FR	The communication protocol defines the rules, syntax, semantics and synchronization needed for data transmission between two nodes. A standardized communication protocol is mandatory to ensure interoperability.
What is measured:	Communication protocol procedures
KPI	alignment to 3GPP (Unicast 5G Sidelink) standard

Method of collection and measurement	Automated measurement in the RF Lab
Target Value	No target value
Verification and validation method	Automated measurement in the RF Lab

	#31 Functional Requirements / FR
ID	AI4CSM_SC5_D2-31
FR Naming	mmW modem implementation
Definition of FR	The modem shall be implemented on a flexible computing platform for processing in real time
Description of FR	A flexible computing platform ensures adaptability and interconnection to other units
What is measured:	External accessibility
KPI	Runs on a CPU/GPU platform
Method of collection and measurement	Automated measurement in the RF Lab
Target Value	No target value
Verification and validation method	Automated measurement in the RF Lab

	#32 Functional Requirements / FR
ID	AI4CSM_SC5_D2-32
FR Naming	mmW modem duplex mode
Definition of FR	The modem shall support time division duplex (TDD)
Description of FR	The time division duplex (TDD) support of the modem enables a bidirectional communication link between the two nodes in the same frequency band.
What is measured:	Communication link between two mmW nodes
KPI	TDD functionality with bidirectional link
Method of collection and measurement	Automated measurement in the RF Lab
Target Value	
Verification and validation method	Automated measurement in the RF Lab

	#33 Functional Requirements / FR
ID	AI4CSM_SC5_D2-33
FR Naming	mmW modem IF interface

Definition of FR	The modem frontend shall provide an IF output/input with carrier frequency and power level adapted to the mmW frontend input/output
Description of FR	Hence, the IFAG mmW frontends have an internal up/down converter, the mmW modem shall provide an IF input/output. Power level adaption is mandatory for mobile scenarios to guarantee an appropriate SNR for short and high distances. Power level adaption is also useful for power consumption reduction.
What is measured:	Spectrum of Input/Output IF, course of power level adaption over time
KPI	Frequency and power level adaption values
Method of collection and measurement	Automated measurement in the RF Lab
Target Value	5.8 GHz IF, 50 Ohm, SMA connector
Verification and validation method	Automated measurement in the RF Lab

	#34 Functional Requirements / FR
ID	AI4CSM_SC5_D2-34
FR Naming	mmW modem / sub-6-GHz 5G modem control unit
Definition of FR	The mmWave link as well as the sub-6-GHz link shall be terminated at an integrated control unit with standard wired interfaces such as Ethernet
Description of FR	To integrate the modems into a network, a suitable digital data interface such as Ethernet is required.
What is measured:	Type of digital data interface
KPI	Standard digital data interface available and modem accessible via external periphery
Method of collection and measurement	Inspection of available interfaces of control unit
Target Value	Ethernet connection
Verification and validation method	Functionality test in the lab

	#35 Functional Requirements / FR
ID	AI4CSM_SC5_D2-35
FR Naming	sub-6-GHz 5G modem implementation
Definition of FR	The modem shall be based on dedicated COTS components
Description of FR	The modem shall make use of COTS components since tey enable a quick reproduction and save time/money on research and development
What is measured:	Degree of availability
KPI	Components available from known vendors

Method of collection and measurement	Market analysis, requests for quotation
Target Value	No target value
Verification and validation method	Purchase

	#36 Functional Requirements / FR
ID	AI4CSM_SC5_D2-36
FR Naming	sub-6-GHz 5G modem frequency band
Definition of FR	The modem shall enable a communication link to a 5G base station for a selected frequency band in Europe
Description of FR	A large number of frequency bands in the sub-6 GHz range are earmarked for 5G worldwide (n1-n95). The modem should support a band that has a high relevance in Europe.
What is measured:	Frequency band number
KPI	At least one selectable frequency band is of high relevance for Europe
Method of collection and measurement	Check of values that can be pre-selected the modem setup
Target Value	n78 frequency band
Verification and validation method	Measurement in the RF Lab

	#37 Functional Requirements / FR
ID	AI4CSM_SC5_D2-37
FR Naming	sub-6-GHz 5G modem communication range
Definition of FR	The modem shall support typical 5G communication ranges in the respective frequency band
Description of FR	A base station covers a specific area around its location, which means that a communication link can be established within this area with a suitable device/modem. The achievable range depends strongly on the frequency and the propagation environment. In the present case, typical ranges for the n78 frequency band in an urban environment shall be supported.
What is measured:	Data connection for a certain distance between modem and base station
KPI	Date connection is available up to the maximum target communication range
Method of collection and measurement	Measurement of data throughput via iperf up maximum target communication range
Target Value	Stable connection available (achievable data throughput) up to 500 m distance between modem and base station

Verification and validation method	Outdoor trial in urban environment

	#38 Functional Requirements / FR
ID	AI4CSM_SC5_D2-38
FR Naming	sub-6-GHz 5G modem channel bandwidth
Definition of FR	The modem shall support designated channel bandwidths associated with the chosen frequency band according to 3GPP
Description of FR	3GPP specifies frequency bands and channel bandwidths for the 5G NR standard. The channel bandwidths are defined on a grid of 5 or 10 MHz, e.g. in the range from 10 to 100 MHz. Depending on the data rate requirements and resource allocation, a suitable bandwidth can be selected by the system. The channel bandwidth is essential for the data rate between base station and
What is measured:	Channel bandwidth
KPI	Selected channel bandwidth meets the 3GPP specifications
Method of collection and measurement	Values that can be set in the modem setup
Target Value	10-100 MHz on a grid on 10 MHz (for n78 frequency band)
Verification and validation method	Measurement in the RF Lab

	#39 Functional Requirements / FR
ID	AI4CSM_SC5_D1-39
FR Naming	Cellular Network Communication Using Standard 3GPP
Definition of FR	The communication between clients (User Equipment, UEs) and the Edge and Cloud needs to follow 3GPP standards for 5G.
Description of FR	Cellular communication is well-standardized, and any deviation lowers the relevance of the results and tools by diverting effort towards implementing the respective access network.
What is measured:	Support of 5G communication standards
KPI	Yes / No
Method of collection and measurement	Static analysis of the platform and all clients
Target Value	Yes
Verification and validation method	Inspection of communication interfaces

	#40 Functional Requirements / FR
ID	AI4CSM_SC5_D2-40
FR Naming	Standard Containerization for Application Execution on Edge

Definition of FR	Applications that are requested by clients to be run on Edge resources need to be encapsulated in OCI-Containers.
Description of FR	Deployments in Kubernetes-like environments (cf. Functional Requirement 5, AI4CSM_SC5_D1-105) are based on containers in OCI format. This allows for easy deployment, versioning and eases (local) distribution. This is a strong requirement to allow for optimisation in later stages (WP4). The strong preference of Docker images is motivated by a single registry that is needed in this case. This saves effort at integration.
What is measured:	The format of applications to be run on the edge
KPI	Yes / No
Method of collection and measurement	Static Analysis of partners' contributions
Target Value	Yes
Verification and validation method	Inspection of images, validation with standard tools

	#41 Functional Requirements / FR
ID	AI4CSM_SC5_D2-41
FR Naming	Constraints for Edge and Cloud Tasks
Definition of FR	Communication and Application Execution requested by clients can optionally be tagged with constraints. Clients benefit by receiving confidence intervals on the response time.
Description of FR	Time critical communication tasks can be handled specially by the network ("Network slicing"). Vice-versa, if communication or computation becomes unusable after a deadline, this information helps the system as a whole, by proactively signaling the client the request cannot be satisfied. Stale information that arrives late only clogs pipelines
What is measured:	Implementation of interface
KPI	Yes / No
Method of collection and measurement	Analysis of application images, usage of interface
Target Value	-
Verification and validation method	Second-order analysis

	#42 Functional Requirements / FR
ID	AI4CSM_SC5_D2-42
FR Naming	Exposure of Computational Demands for Cloud Compute
Definition of FR	Scheduling and placing applications can be optimized if relevant information is exposed by the application (to be read by the scheduler). Clients benefit by receiving confidence intervals on the response time.

Description of FR	Analysis of an application's computational requirements (exemplary runtime, complexity, or even number of operations) can be done a priori. This information, when exposed to the edge scheduler, can allow for significant optimizations.
What is measured:	Implementation of interface
KPI	Yes / No
Method of collection and measurement	Analysis of application images, usage of interface
Target Value	Yes
Verification and validation method	Validate images which support exposure of demands, and test deployment decisions on example scenario

	#43 Functional Requirements / FR
ID	AI4CSM_SC5_D2-43
FR Naming	Availability of Standard Platform on Edge Locations
Definition of FR	The chosen edge location needs to support the developed tools and allow the methods to implement the relevant provisioning
Description of FR	The state-of-the-art industry standard will be used for development of the optimized provisioning and task-distribution. (Managed Kubernetes by cloud providers is acceptable)
What is measured:	-
KPI	Yes / No
Method of collection and measurement	Static analysis of the platform
Target Value	Yes
Verification and validation method	Verify that the node allows a Kubernetes-like cluster to be deployed

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