D7.3

SECOND INTERMEDIATE PROJECT REPORT

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D7.3 Second intermediate project report

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Short abstract:	This deliverable provides a summary of the major results and achievements of the project during the second year of the project.
Keywords:	5G-SMART, 5G trial sites, 5G optimization, 5G use cases, 5G deployment

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Disclaimer

This work has been performed in the framework of the H2020 project 5G-SMART co-funded by the EU. This information reflects the consortium's view, but the consortium is not liable for any use that may be made of any of the information contained therein.

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Executive summary

This second intermediate project report contains an overview of the results attained in 5G-SMART during the second year of the project. The main achievements of the project are highlighted, and references are provided to relevant deliverables and documents.

During the second year of the project, 5G-SMART has continued its work on a wide range of challenges within the smart manufacturing sector, including business models, the evaluation of deployment options, use case development and the investigations on new 5G features targeting the manufacturing sector. The work builds upon the broad analysis of smart manufacturing use cases, Key Performance Indicators (KPIs) and requirements made during the first year of the project, as well as preparations for realizing the use cases. While the Covid-19 pandemic with travel restrictions and limited access to labs etc. has had a severe impact on the project, there has still been major progress for all working streams in 5G-SMART. Delays have occurred for the trials activities, however the concept work of the project is well on track.

The 5G networks are now installed at all trial sites and ready to support the execution of the use cases. The use case development is ongoing at all three trial sites, with several demos and proofpoints achieved in the second year of the project. While use case execution has been possible to some extent at the Aachen trial site, for the Kista and Reutlingen trial sites, due to Covid-19 restrictions, the use cases have so far only been developed and demoed off-site. For the trials activities, the project is therefore experiencing a delay of approximately 4-6 months.

A major milestone of the project has been the execution and evaluation of the Electromagnetic Compatibility (EMC) tests and the channel measurement campaign at the Reutlingen trial site.

Building on the thorough gap analysis between the state of the art and the smart manufacturing use cases specified during the first year of the project, 5G-SMART has started the evaluation of important 5G features, such as integration of 5G with Time-Sensitive Networking (TSN), 5G end-to-end time synchronization and 5G positioning. Furthermore, the project is also progressing on its investigations and assessment of 5G network architectures, and a framework solution for network management functions.

The project's work on business value creation enabled by 5G and operator business models has resulted in the development of two deliverables and an MS Excel demo tool. A framework and methodology for business value creation has been elaborated and applied to a 5G-SMART use case. Furthermore, the project has investigated business models focusing on the value proposition a Mobile Network Operator (MNO) can bring to the new ecosystem. In the second year of the project, 5G-SMART has analyzed and discussed new market actors, new business relationships, and new business models emerging with 5G for industries.

Finally, the project has shown to have a successful dissemination and communication strategy, creating impact with publications, keynotes, standard contributions and demos. A highlight has been the endorsement of all three trial site testbeds by 5G-ACIA. To compensate for lacking exhibition and dissemination possibilities due to Covid-19, the project has with its strategy to reach out to a wide audience via a series of webinars, attracted a lot of interest. Moreover, the project has developed three videos explaining the work at the trial sites to the general public.

Contents

1 Introduction

5G-SMART is a European Union funded project, that started 1st of June 2019 and is running for 30 months. The total project budget is a bit more than 10 M€ and there are around 27 full time person equivalents working during the project execution. 5G-SMART is one of 5G-PPP's phase III projects[1].

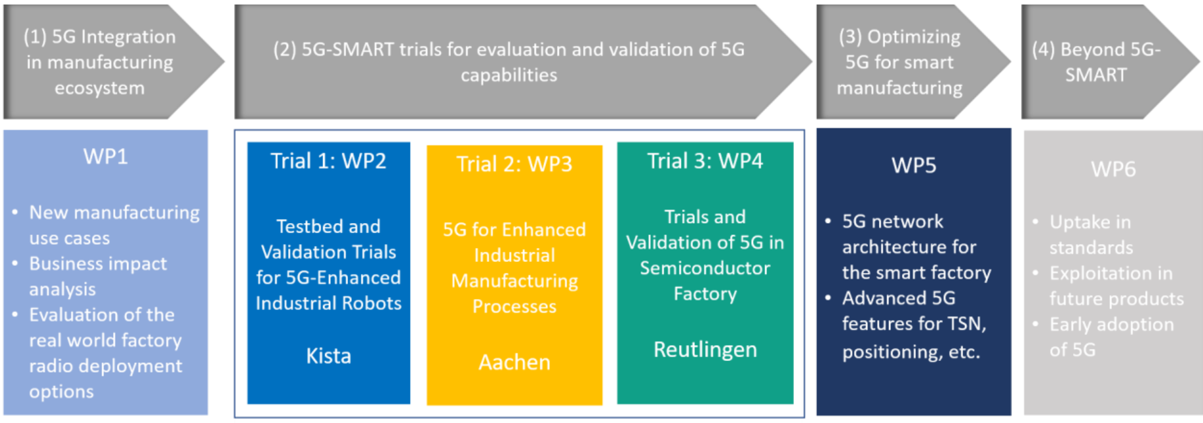

Figure 1: 5G-SMART project structure

Figure 1 shows the structure of the project with its four focus areas, and the work packages (WPs) addressing these. The focus areas are:

(1) 5G integration into the manufacturing ecosystem
(2) Trials for evaluation and validation of 5G capabilities
(3) Optimizing 5G for smart manufacturing
(4) Beyond 5G-SMART

For the evaluation and validation of 5G capabilities, three trial sites are built up by the project. These are at an Ericsson factory in Kista (Sweden), at the machine hall of the Fraunhofer Institute of Production Technology (IPT) in Aachen (Germany), and at a Bosch semiconductor factory in Reutlingen (Germany).

This document is the second 5G-SMART intermediate project report, which gives an overview of the 5G-SMART achievements during its second year. In particular, this report highlights the main projects results and provides references to the deliverables and other output for interested readers who wish to learn more. All this information can as well be found on the project website, https://5gsmart.eu.

1.1 Objective of the document

This document summarizes the progress made in 5G-SMART during the second year of the project. For all the ongoing activities, a brief outlook is given over next steps and future plans. Moreover, this deliverable collects references to all other documents already produced within 5G-SMART. With this

[1] 5G PPP Phase 3 Projects ‹ 5G-PPP (5g-ppp.eu)

document being an intermediate project report, its objective is very much aligned with the objectives of 5G-SMART. These objectives are:

(1) To demonstrate and evaluate 5G technologies and architecture capabilities for smart manufacturing use cases by validating related 5G KPIs defined in ITU/3GPP and 5G PPP as well as 5G support of concurrent usages of network resources by different vertical domains.
(2) To identify, assess and propose innovative advanced "industrial" 5G KPIs with more focus on industrial characteristics.
(3) To identify, assess and propose new 5G features targeting connected industries.
(4) To identify viable business models for 5G manufacturing use cases.
(5) To identify regulatory aspects with direct impact on the realization of 5G for smart manufacturing.
(6) To disseminate and exploit 5G-SMART outcomes and contribute to standards development organizations (3GPP/ITU-T/IETF/ETSI), regulatory forums, scientific and industrial domains.
(7) To contribute to the 5G Action plan for Europe, validating 5G capabilities ("phase 1" features) in real factory environments.

1.2 Structure of the document

This document is structured as follows. Section 1 gives an introduction to the deliverable. Section 2 provides insights into the achievements of 5G-SMART made in the areas of use cases, business models and network design (WP1). Section 3 focuses on the three different trial sites of 5G-SMART (WP2, WP3 and WP4). For each of the trial sites, the efforts and progress made during the second year of the project are described. Section 4 presents the achievements towards 5G optimization made by 5G-SMART (WP5). An overview of the dissemination and communication efforts of 5G-SMART (WP6) is provided in Section 5. For each section, the next steps to be taken in the project are briefly described. Section 6 concludes the document and gives an outlook about what to expect in the last year of the project.

2 Use cases, business models and network design

2.1.1 Achievements during the second year

In the second year of the project, 5G-SMART has built upon the results of the analysis of the use cases and their requirements performed in the first year of the project, which have been summarized in deliverable D1.1 [5GS20-D110]. The project has identified and discussed different radio network deployment options for smart manufacturing, aiming at providing an overview for any desired industrial 5G scenario or service. The input data needed to select the most feasible deployment options has been identified. For the different Non-Public Network (NPN) architecture options, the feasibility has been analyzed. Moreover, the impact of spectrum options available for the stakeholder deploying and operating a non-public network has been discussed. A number of system-level simulation studies have been performed that assess the technical performance of the identified deployment scenarios. The results from the discussions, analyses and performance evaluations related to the different radio network deployment options are summarized in deliverable D1.4 [5GS20-D140].

5G-SMART has the ambition to analyze the business value created due to the implementation of a 5G network. In the second year of the project, the assessment framework and methodology to evaluate the business value creation for the industrial actors, developed by the project, have been finalized. The framework and methodology go beyond conventional comparison of costs (e.g., for hardware, running costs, etc.) and the generated revenues, by also taking into account the value creation by 5G due to the introduction of new products and services, which could further enhance the daily business. The project has developed a 4-step evaluation model consisting of Process Identification (1), KPI Allocation (2), Data Acquisition (3), and Process Evaluation (4) [KS20]. A suitable 5G-SMART use case for the analysis has been chosen. For this use case, relevant processes being affected by implementing 5G have been identified and classified regarding their network requirements (e.g. latency, reliability). In order to evaluate the use case based on technical improvements, seven goals from a production point of view have been identified and operationalized with 24 respective KPIs. An Excel-based tool has been developed in which the user can get a first estimate of the potential of 5G based on the use case data, goals, and data available. A screenshot of the Excel tool can be found in Figure 2. The results of the business value creation activity of 5G-SMART are summarized in deliverable D1.2 [5GS21-D120]. The tool will be made available on 5G-SMART's website.

The service provisioning of 5G connectivity for industrial customers and use cases differs from providing public mobile network services to consumers. 5G-SMART has therefore a workstream on business models, in particular focusing investigation on the value proposition a Mobile Network Operator (MNO) can bring to the new ecosystem. In the second year of the project, 5G-SMART has analyzed and discussed new market actors, new business relationships, and new business models emerging with 5G for industries. Six business roles for NPNs have been identified, which are the NPN user, the NPN operator, the integrator, the spectrum owner, the NPN owner and the Edge cloud service provider. These business roles can be taken by stakeholders such as the industrial party, the MNO, or a third party. For a number of plausible 5G architecture options, business relationships and value proposition have been identified. For these options, the pro's and con's, as well as the costs, have been analyzed together with the Operational Technology (OT) partners in the project. To further understand the spectrum aspects of industrial deployments, a state-of-the-art analysis of the present regulatory framework has been performed. The results of this activity will be made available in July 2021 in deliverable D1.3.

5G-SMART's work on use cases, business models and network design during the second year of the project is considered to be on track.

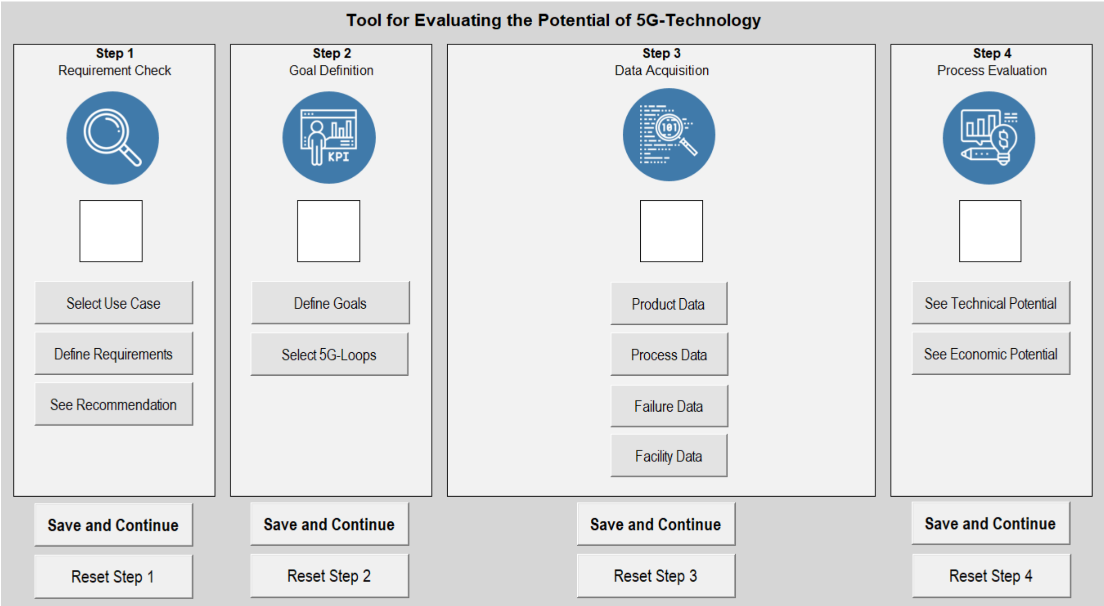

Figure 2: Screenshot of the Excel tool on determining the potential of 5G for a use case

2.1.2 Next steps

With the publication of deliverables D1.2 and D1.3, the business-centric activities of 5G-SMART will be concluded. The work on radio network deployment options does however continue, moving further in its phase on evaluating the different options. Here, the attention of the project is now on further system-level simulation studies to assess the technical performance of the identified deployment scenarios with more realistic service requirements. The tradeoff between decreasing latency, improving reliability, and reducing spectral efficiency will be analyzed to realize feasible spectrum options for different identified service cases. The results will be summarized in deliverable D1.5 due in November 2021.

3 5G trials across Europe

3.1 Kista trial site

At the Kista trial site, 5G-SMART will validate 5G-enabled industrial robotics in three distinct use cases. The setup consists of two stationary robots and a mobile robot that will collaboratively solve a task of transporting material between different robot workstations, with major parts of robot control functionality being moved into the edge cloud. Machine vision and video analysis will be added to support the robot collaboration. In another use case, the purpose is to explore possibilities of enhancing real-time human-robot interactions, e.g. while a technician performs contactless teaching of robot arm motion through demonstration. Finally, a use case of providing Augmented Reality (AR)-based visualization of production-related information to the personnel on the factory floor is developed. Feasibility of these different approaches will be validated via the 5G network. An overview of use case setup is illustrated in Figure 3.

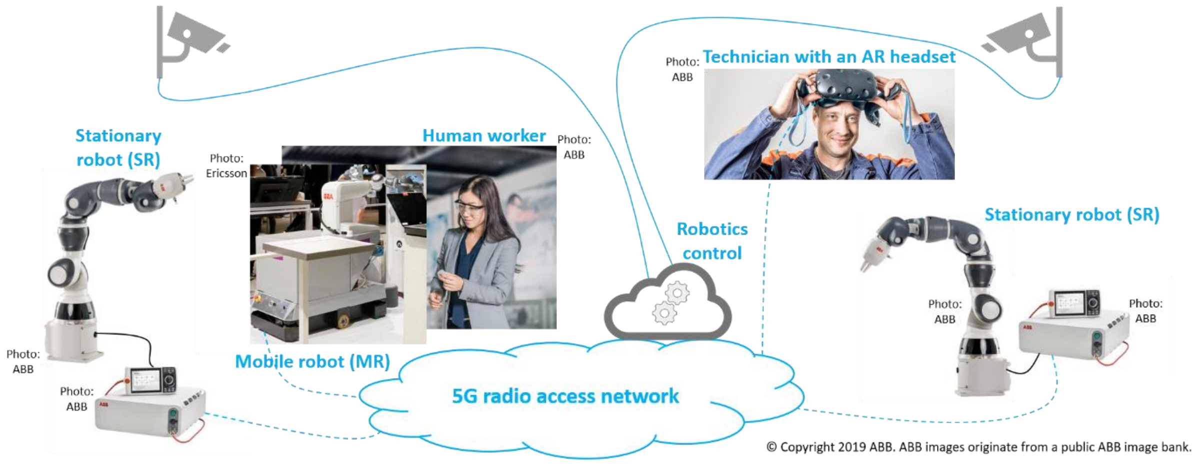

Figure 3: A use case setup at the Kista trial site

3.1.1 Achievements during the second year

In the second year of the project, the focus has been on further developing the 5G-based testbed, taking into account the work done in the first year of the project, where KPIs and requirements have been determined and summarized in deliverable D1.1 [5GS20-D110]. The work furthermore builds on the design of the 5G-based testbed for industrial robotics described in deliverable D2.1 [5GS20-D210]. Therein, besides other design aspects, architecture components have been identified from an application-level perspective and key functional roles have been described. The functional architecture for the testbed is shown in Figure 4.

During the second year of the project the testbed system has moved from planning to implementation phase. The testbed has been populated with two stationary YuMi[2] robots and a mobile robot platform that are now installed and operational at the ABB premises. Furthermore, a workstation has been setup, acting as an edge node, hosting the robot control software that will later be migrated to the Ericsson edge solution. Finally, a common external camera system with several video cameras has

[2] ABB's Collaborative Robot -YuMi - Collaborative Robots | ABB Robotics

been deployed, to provide machine vision features for executing both the pick-and-place operation by YuMi robots as well as the docking procedure for the mobile robot platform. Due to the restrictions related to the Covid-19 outbreak, the use case development has not been moved to the final trial site destination in Kista but continues at the ABB site in Västerås. This work is supported by a locally deployed 5G network, which has been installed to mitigate impact of Covid-19 induced restrictions regarding the Kista trial site.

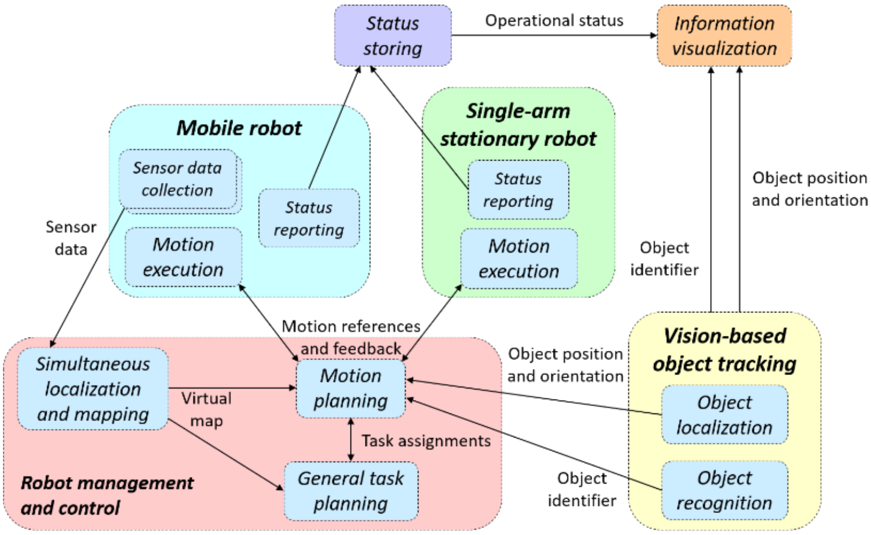

Figure 4: Functional architecture for the 5G-based testbed at the Kista trial site

5G-SMART is now in an intense phase of implementing and finalizing prototype software for the three use cases to be trialed at the Kista site. During the second year of the project several intermediate results have been achieved. These include, for instance, prototype of edge- and 5G-based motion planning, or navigation, for mobile robot platform, which exploits laser sensor readings and a virtual map of its surrounding physical environment, as well as prototype of vision-assisted execution of the pick-and-place operation by single-arm YuMi robots.

A method that facilitates programming of robot arm motion and exploits human-robot interaction has been implemented. Instead of writing software code which governs the motion, a so called lead-through programming software has been developed to allow motion teaching via demonstration. This enables the user to ”mimic” motion of the robot arm, which is equipped with a marker, by utilizing a 5G smartphone to estimate position and orientation of the marker (i.e., the arm). The position and orientation values are then sent to the motion planning software, which executes the movement in real-time. Figure 5 shows a scene from lead-through programming.

Figure 5: Lead-through programming of single-arm YuMi robot using 5G smartphone

Work has also started for the use case on the visualization of factory floor related information. This will enable a human worker to interact with, e.g., YuMi robots while receiving their status information displayed in the headset. Work on prototyping the AR visualization is ongoing and will include, for instance, realizing hand gestures to inspect robot time-in-operation.

The targeted 5G solution for the Kista trial site has been installed and commissioned. The 5G system is deployed based on the Non-Standalone (NSA) architecture. The testbed at the Kista trial site has become a 5G-ACIA[3] endorsed testbed and was presented at Hannover fair 2021. A video[4] has been produced to introduce the testbed to the general audience.

Due to Covid-19 related restrictions, the work for the Kista trial site is delayed by 4-6 months.

3.1.2 Next steps

Work on implementing and testing the last features of the 5G-based testbed, such as for mobile robot docking and general task planning, will continue and be finalized at the ABB site in Västerås. Once finalized, the testbed will be moved to the Ericsson smart factory in Kista for integration with the 5G system on site. In parallel, different validation scenarios are modelled focusing not only on 5G communication performance but also on identifying industrial KPIs which will be used for the trials. The testbed realization and final evaluations will be documented in deliverable D2.2 and D2.3, respectively due at the end of the project.

[3] 5G Alliance for Connected Industries and Automation endorses testbeds for evaluation of industrial 5G use cases - 5G-ACIA (5g-acia.org)

[4] 5G-Based Industrial Robotics - YouTube

3.2 Aachen trial site

At the Aachen trial site, on the shop floor of the Fraunhofer IPT, 5G-SMART works on realizing two important use cases: a multi-sensor platform (MSP) for monitoring of workpieces and machines, and a 5G-based wireless acoustic emission (AE) sensor system. Both use cases have been described in detail in deliverable D1.1 [5GS20-D110], and D3.2 [5GS20-D320]. The implementation of the use cases is described in D3.3 [5GS21-D330].

The MSP developed by 5G-SMART is a highly ruggedized and compact device, that allows for an easy connection of different subsystems, sensors or other data infrastructure. The platform contains some standard sensors (e.g. accelerometer, gyroscope, microphone, temperature sensor). The MSP introduces flexibility and versatility on the shop floor, as it is capable of addressing a large variety of possible sensors and applications.

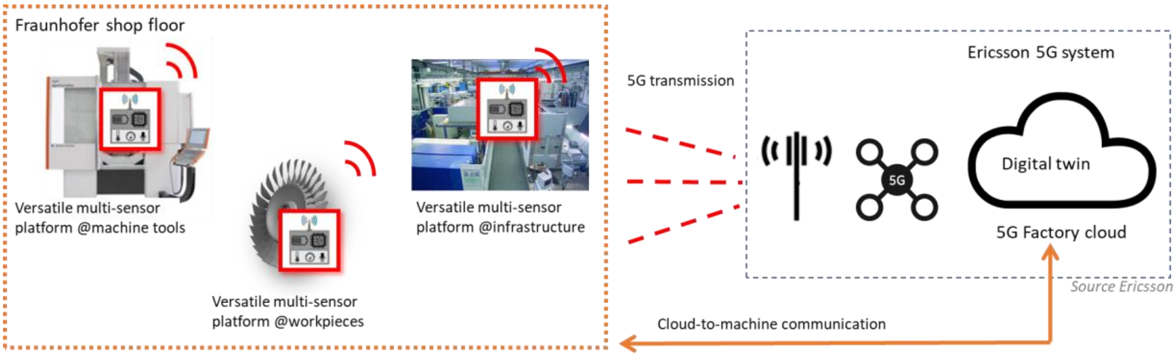

Figure 6: The MSP use case at the Aachen trial site

Figure 6 illustrates the first use case under development at the Aachen trial site. Here, a 5G-connected MSP is integrated into a milling machine and used to monitor the milling process of a jet engine component. Data generated by the MSP will help to detect critical process conditions, which can be used to compensate process deviations and safeguard the quality of the product. Furtermore, data from sensors and machines can be used for creating a digital twin of the components. The MSP will be integrated into multiple machines and attached to multiple workpieces. Furthermore, a cloud-to-machine communication pipeline will be developed and integrated.

With the AE sensor system illustrated in Figure 7 both wear or breakage of the tool and process errors can be detected at an early stage of production and intercepted by immediate process control. This ensures an adequate usage of the cutting tool and enormous cost savings due to interrupting the cutting process immeadiately and continuing it at the same position. In 5G-SMART, the system will be validated, for instance by the latency between a tool break and its detection.

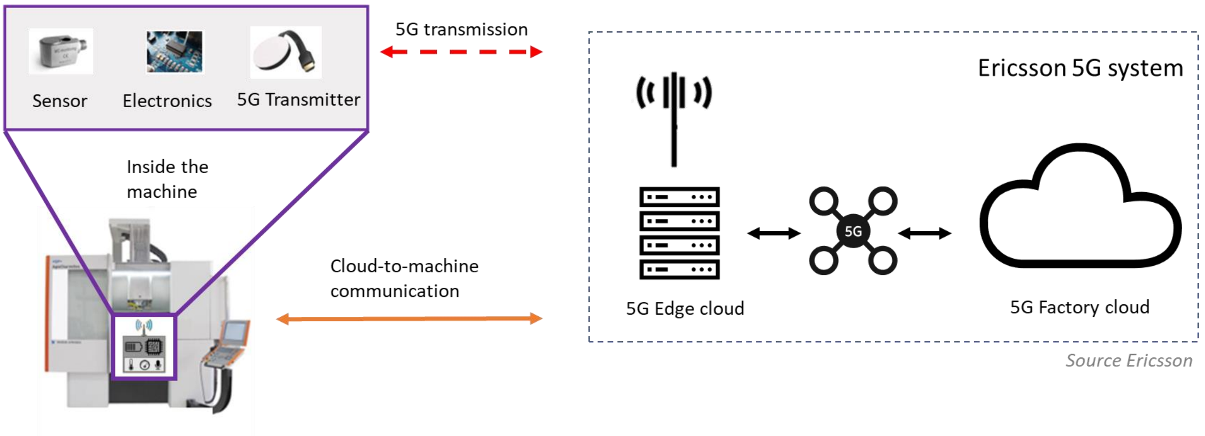

Figure 7: The AE sensor use case at the Aachen trial site

3.2.1 Achievements during the second year

5G Deployment

The 5G network deployment supporting the use cases at the Aachen trial site has been designed and installed in the beginning of the project. The network is a dedicated on-premise 5G NSA network operated as a non-public network. For the 5G NR system, the deployment is on frequency band n78 (3.7-3.8 GHz). For the 4G LTE part, the frequency band B40 (2.3-2.32 GHz) is utilized. The 5G system has been described in deliverable D3.1 [5GS19-D310]. During the second year of the project, the deployment has been extended with an outdoor deployment, allowing now also for the coexistence studies planned by the project. These studies have started and will evaluate and validate coexistence between indoor-outdoor 5G networks sharing the same spectrum frequencies. In parallel to the existing 5G NSA system, also a 5G Standalone (SA) system has been built up at the Fraunhofer IPT. Since January 2021 a parallel integration of the use cases with both the 5G NSA and SA systems is ongoing.

MSP use case

For the MSP use case, the project is continuing its work on a first prototype. In deliverable D3.2 [5GS20-D320] a detailed description of the sensor systems as well as the edge cloud infrastructure has been provided, discussing possible solutions to enable the tradeoff required to ensure flexibility and good performance of the prototype. In the second year of the project, the electrical circuit design of the MSP main board has been finished. Furthermore, the final design of the electrical Printed Circuit Board (PCB) and the sensor drivers has been specified. Figure 8 shows a picture of the current version, which includes onboard accelerometer, temperature sensor and gyroscope.

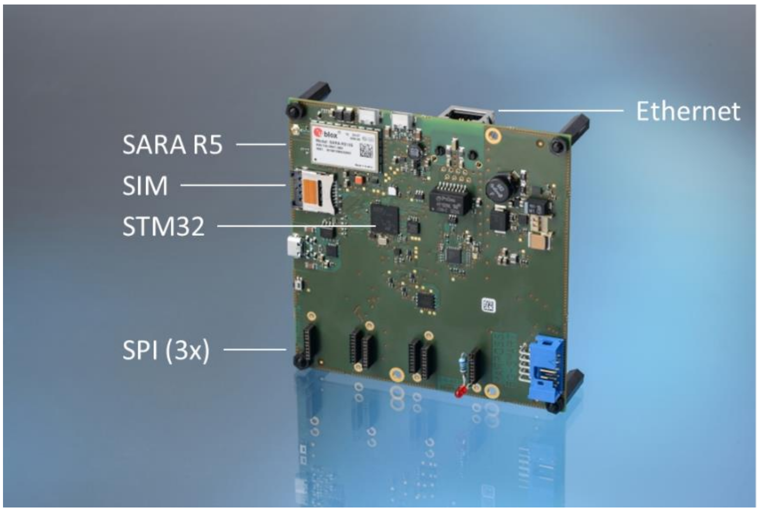

Figure 8: MSP prototype

AE use case

For the AE measurement system, the project has developed a first prototype which has successfully been connected to the 5G network via an industrial 5G router from WNC. The solution consists of a conventional AE probe, a custom design PCB for the signal sampling and pre-conditioning, and a Field-Programmable Gate Array (FPGA) platform with software developed in VHDL for the signal processing and UDP packet generation, see Figure 9: AE measurement system solutionFigure 9.

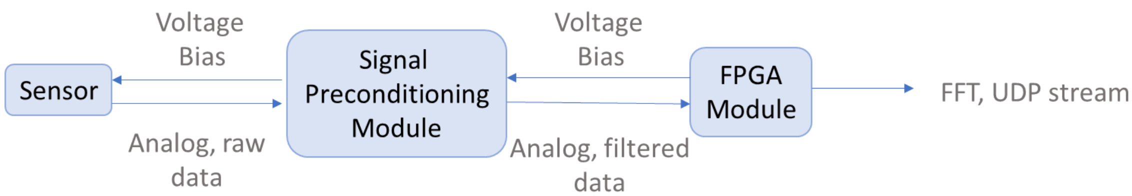

Figure 9: AE measurement system solution

Furthermore, the AE sensor system has been integrated into a drilling machine for demonstrations, while the sensor system triggers a power cycle of the machine upon detection of a certain threshold of the measurement signals amplitude. Figure 10 shows the AE measurement system including its integration into the drilling machine.

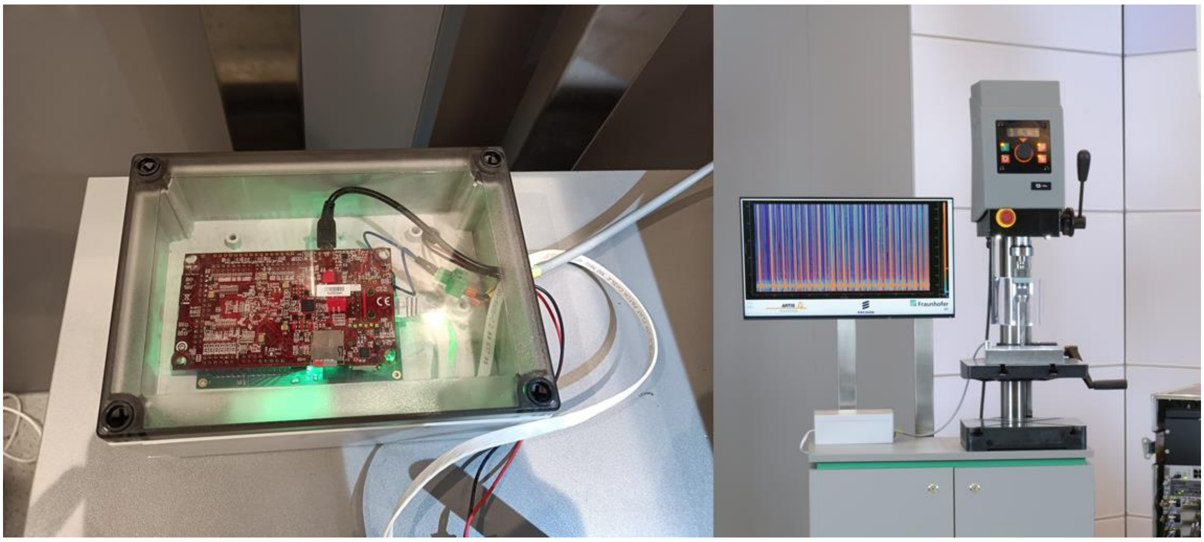

Figure 10: Left: AE sensor electronics consisting of a PCB for signal samping and pre-conditioning, and FPGA-platform on top, contained in an IP68 grad housing. Right: drilling machine with workpiece, the AE sensing probe is directly attached to the workpiece and connected with the sensor electronics. The measurement signal is visualized as waterfall diagram plotted by an industrial PC receiving the sensor data.

Versatile sensor data processing pipeline

The implemented new sensors generate different measurands with different data rates, which are evaluated by the compute pipeline. Depending on the data, the results are either used for documenting the machining process in a digital twin, or for live feedback to the machining equipment for closed-loop manufacturing control. The solution by 5G-SMART therefore incorporates and satisfies requirement specifications for a sensor-to-cloud-to-machining communication pipeline with special focus on latency, and implements a self-controlled monitoring application using state-of-the-art cloud computing approaches, like on-premises edge cloud capabilities. In the second year of the project, a factory cloud system (ONCITE by German Edge Cloud) was set up at Fraunhofer IPT based on the latest version of OpenStack (Starling-X). The integration of the system into the Fraunhofer IPT intranet has been finished. Templates for Virtual Machines (VMs) have been developed for easy plug-and-play initialization of VMs. Each template has been designed to consider different security requirements depending on the application. As an alternative solution, access to another Factory Cloud system (Virtual Fort Knox by Fraunhofer) based on VMWare has been established. A high-level architecture for the data flow from the different sensor solutions via 5G base station, factory cloud, integration of VMs for data and signal processing, and Machine-to-Machine communication for feedback control of the manufacturing equipment has been designed.

The testbed at the Aachen trial site has become a 5G-ACIA endorsed testbed[5] and a live demo has been given at Hannover fair 2021. An introductory video for the trial has been developed[6].

[5] 5G Alliance for Connected Industries and Automation endorses testbeds for evaluation of industrial 5G use cases - 5G-ACIA (5g-acia.org)
[6] https://www.youtube.com/watch?v=PXQ-o4eZLPU&t=2s

Due to Covid-19 restrictions, 5G-SMART is experiencing a 2-3 month delay in progress at the Aachen trial site.

3.2.2 Next steps

In the coming months, the prototype of the MSP will be further developed and tested. This includes firmware programming but also the mechanical design of the housing. The AE sensor system will be enhanced to enable measurement of the latency between the application end-points, i.e., the physical signal and the machine control. Furthermore, the factory cloud system will be deployed at the Aachen trial site and connectivity for feedback-control to the machine control via Ethernet will be established. First virtual machines will be set up for data and signal processing and databases for digital twin approaches. In the remaining time of the project, the 5G capabilities for industrial manufacturing scenarios will be evaluated, by validating the developed sensor solutions in machining processes for turbine components. The prototype devices of the MSP will be integrated into multiple machine tools at the Aachen trial site, and multiple process- and condition-related data sources will be monitored and data transmitted to the cloud solution for analysis. The results will be documented in deliverable D3.4 at the end of the project.

3.3 Reutlingen trial site

At the Reutlingen trial site, 5G will be validated in a Bosch semiconductor factory environment from two different perspectives. First, the work focuses on 5G radio propagation in the production environment to ensure that 5G can provide the required stable connectivity and coverage throughout the factory floor, and that it provides the electromagnetic compatibility (EMC) levels as required in the semiconductor factory. Second, 5G will be validated on the application-level, by realizing two use cases on the factory shop floor: a cloud-based mobile robotics use case and a Time-Sensitive Networking (TSN)/Industrial Local Area Network (LAN) over 5G use case.

3.3.1 Achievements during the second year

5G deployment

In the second year of the project, the 5G Standalone (SA) system developed for the Reutlingen trial site has been further refined and tested before finally being successfully installed on site. The 5G system was designed to fulfill the specific requirements of the semiconductor factory in Reutlingen. This includes specification of network components and their configurations, and the integration of the 5G testbed into the existing manufacturing IT infrastructure at the factory. The system operates at 3.7 GHz. Details of the design and installation of the 5G trial system in Reutlingen are documented in deliverable D4.1 [5GS21-D410].

Channel measurements

The semiconductor factory floor is a challenging environment in terms of radio propagation, not only due to its layout consisting of narrow corridors and high walls, but also due to the large amount of reflective material/equipment. Therefore, attention needs to be given to how to provide a reliable coverage throughout the factory. Factory floors are usually environments characterised as rich scattering with various tools and machines, which contribute to shadowing effects and are in different ways interacting with the radio signals. In addition to that, moving people and robots introduce dynamic changes in the environment. 5G-SMART has designed channel measurement campaigns to study the effects of these aspects, measuring signal properties, such as signal strength, impulse response, delay spread, etc. During the second year of the project, the measurement campaigns have been executed on the factory floor. Figure 11 illustrates the channel measurement campaigns. Different scenarios and locations have been determined to obtain a comprehensive picture of the radio propagation characteristics in the factory. Two 5G frequency bands, both a mid-band frequency centred around 3.71 GHz and also a higher frequency centred around 27 GHz, have been considered. The results show that providing coverage at mid-band frequency looks promising, while at higher frequencies this is more challenging. Deliverable D4.2 [5GS21-D420] describes the performed tests and analysis in detail.

Figure 11: Pictures from the channel measurement campaigns

Electromagnetic compatibility tests

A major requirement in order to install 5G in industrial environments is that 5G is electromagnetically compliant with the industrial equipment on site. It is therefore crucial to make sure that 5G signals do not have any negative impact on the production processes. To address this issue, 5G-SMART has analyzed and evaluated the impact of 5G signals on semiconductor production using a test setup developed by the project. The setup makes use of a vector signal generator generating uplink or downlink 5G NR signals at 3.7 GHz with 20 MHz and 100 MHz bandwidths, which are amplified and transmitted via a Horn antenna. The impact of the electromagnetic fields created due to the 5G signals is then investigated for different devices under test (DUT). Figure 12 shows the EMC test setup. Different areas of the semiconductor factory have been considered.

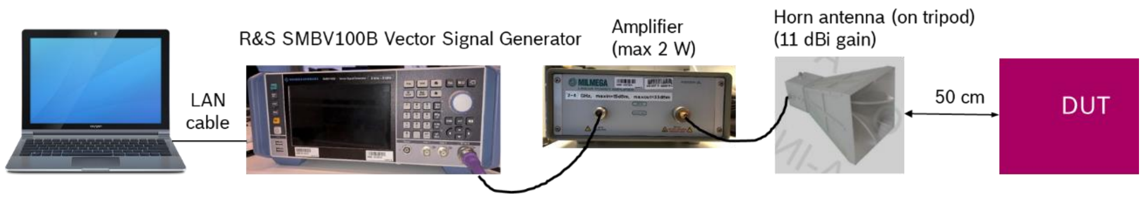

Figure 12: EMC test setup

In the second year of the project, the EMC tests were run inside the semiconductor factory in a controlled environment. A large set of data was collected and analyzed after the tests. The results are documented in deliverable D4.2 [5GS21-D420] and look positive for a large number of devices but, depending on the requirements of the specific production, compatibility may not be guaranteed for all and further investigations are needed.

Cloud-based mobile robotics use case

During the second year of the project, 5G-SMART has continued and intensified its work on the development of the use cases. For the mobile robotics use case, the focus has been on re-architecting the Automated Guided Vehicles (AGVs) and moving functionality into the cloud. Figure 13 shows the architecture of a typical commercial AGV together with the architectures of the 5G-enhanced commercial AGV and the 5G-enhanced research AGV that the project is aiming to achieve. It can be seen that for the certified commercial AGV platform, the project has succeeded in moving the common map, trajectory planning, trajectory control and Simultaneous Localization and Mapping (SLAM) to the cloud. For the 5G-enhanced research AGV, which is entirely built in the project, furthermore, servo control and sensor control have been moved to the cloud. Even the safety functionality is mirrored in the cloud. This means that in principle the entire intelligence of the research AGV is removed from the platform itself, reimplemented and extended in a cloud-native manner to the edge cloud. The certified commercial AGV platform and the research AGV are planned to be connected over 5G and used to show the benefit of collaborative knowledge collected in the factory cloud (e.g., using the common map of the research and commercial AGVs for trajectory planning). A demo[7] of the mobile robotics use case demonstrating the collaborative behavior has been developed and shown in the Ericsson facilities in Hungary. Due to the Covid-19 restrictions, so far, no tests have been executed at the trial site in Reutlingen. Deliverable D4.3 [5GS21-D430] summarizes

[7] 5G-SMART Cloud based mobile robotics in factories - YouTube

the current status of the development of the use case, which takes into consideration the use case requirements and KPIs determined in D1.1 [5GS20-D110].

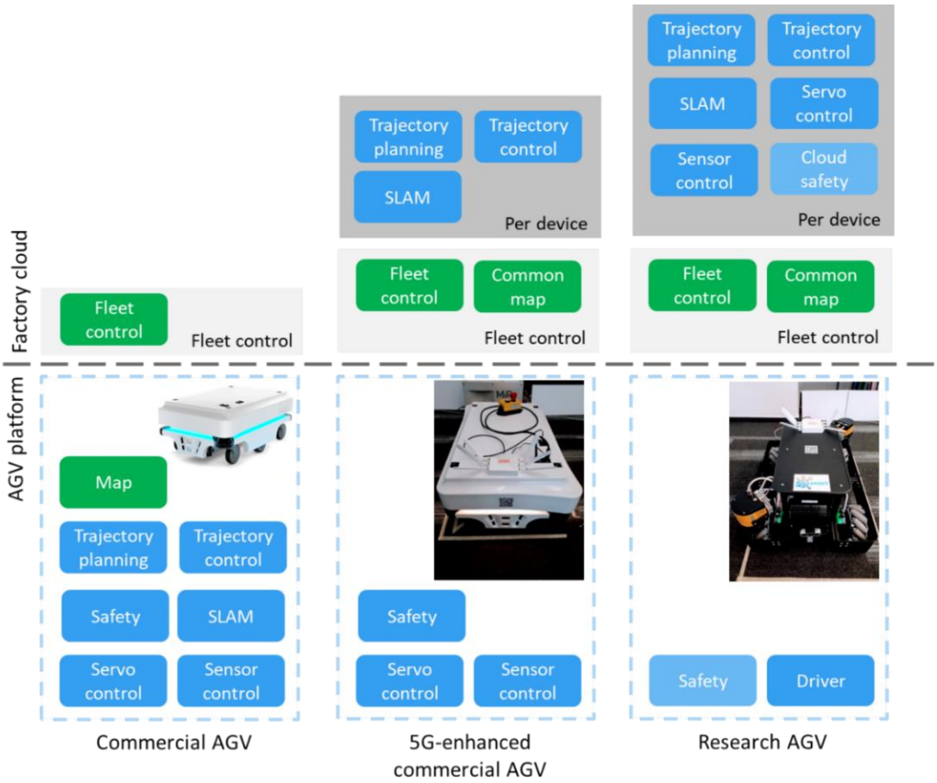

Figure 13: AGV architectures

TSN/Industrial LAN over 5G use case

For the TSN/Industrial LAN over 5G use case, the project has designed a real-factory scenario and started the implementation and testing on the factory floor. A number of validation scenarios have been identified. These involve, for instance, the validation of Controller to Controller (C2C) communication over 5G and evaluating the C2C communication when background traffic is present with different network configurations. Figure 14 shows the system architecture of the TSN/industrial LAN over 5G use case and the different communication streams considered in the project. The details of the current status of the use case are summarized in deliverable D4.3 [5GS21-D430]. A thorough use case description and requirements analysis can be found in D1.1 [5GS20-D110].

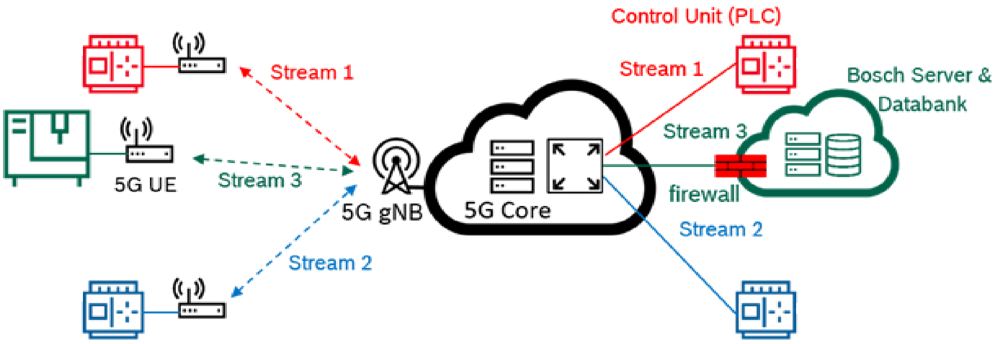

Figure 14: End-to-end system architecture for the TSN/Industrial LAN over 5G use case

With respect to the use case testing possibilities, the progress of the work within 5G-SMART at the Reutlingen trial site is delayed by 6 months due to the Covid-19 restrictions.

The testbed built around the TSN/industrial LAN and mobile robotics use cases has become a 5G-ACIA endorsed testbed[8] and was presented at Hannover fair 2021. Two videos have been produced for the Reutlingen trial site to provide a short introduction into the use cases[9] and measurement campaigns.

3.3.2 Next steps

While the EMC and channel measurement activities have been concluded, the use case development, evaluation and validation continue until the project's end. The next steps here involve the finalization of the use case implementation, and eventually the testing, integration and validation of the use cases on-site in Reutlingen. Both the cloud-based mobile robotics use case and the TSN/industrial LAN over 5G use case will be tested and demonstrated in realistic factory scenarios, validating that the 5G system does provide the required performance support. The results will be documented in deliverable D4.4 at the end of the project.

[8] 5G Alliance for Connected Industries and Automation endorses testbeds for evaluation of industrial 5G use cases - 5G-ACIA (5g-acia.org)
[9] Media – 5gsmart.eu

4 5G optimization and design for manufacturing

The vision of Industry 4.0 represents a new stage in the organization and control of the industrial value chain and 5G is expected to play a key role in the digital transformation of the manufacturing industry. While today's factory communication infrastructure is mainly based on wired technologies, factories of the future are expected to have a large part of their communication being wireless. Advanced use cases on the factory floor impose, however, very stringent communication requirements, for instance in terms of latency and reliability. The latest specifications for 5G have, therefore, specified ultra-reliable and low-latency communication (URLLC) and new architectural models.

5G-SMART dives deep into various technical aspects of the 5G systems beyond those that are already standardized or currently under standardization. The project focuses on aspects that have a strong business value for the manufacturing ecosystem, and investigates needed enhancements and their integration into the ecosystem. Three dimensions play a major role here:

1. Advanced technical features tailored to support functional and non-functional requirements of smart manufacturing applications, such as support for integration with existing industrial wired networks (e.g. Industrial LAN and TSN), support for time synchronization, and positioning
2. New 5G network architectures suitable for deployment in smart manufacturing ecosystem
3. An industrial-centric network management of 5G system

4.1.1 Achievements during the second year

During the first year of the project, a thorough state of the art analysis has been performed for several 5G features relevant to vertical industries. For all the identified technical features, a gap analysis has been performed between the state of the art and the requirements put forth by the 5G-SMART use cases. Moreover, technical features have been evaluated, and, first recommendations are proposed to standardization organizations. The work has been summarized in deliverable D5.1 [5GS20-D510]. In the second year of the project, 5G-SMART has further complemented this work with an evaluation methodology and early investigations on the evaluation of the technical features. These investigates are continued work in progress and final results will be presented in the upcoming deliverable D5.3.

The project's work on developing and optimizing 5G technical features that enable integration with existing Ethernet-based industrial networks, namely industrial LAN and TSN, has shown so far a need of improvement of certain areas in the 3GPP Release 16 specification. As an example the project has identified shortcomings of the virtual network grouping mechanism applied for the integration of 5G with Ethernet-based networks. Furthermore, the role of 5G-TSN in the manufacturing ecosystem is explored, and 5G-TSN integrated deployment models are proposed and analyzed considering the 5G-SMART use cases. The output of the analysis is documented in deliverable D5.2 [5GS20-D520] and is being provided as an input to ongoing work in SDOs and industry alliances (e.g. 5G-ACIA and NGMN). A scientific paper prepared by the project on 5G NPN support for Ethernet-based industrial networks is currently under review. Deliverable D5.2 also documents the investigations of different edge cloud architectures enabling low latency.

A qualitative analysis is currently underway to check the feasibility of several non-public operation models in the manufacturing ecosystem. The result of this analysis will be reflected in deliverable D5.4

on network architectures due in November 2021, which is a follow-up of deliverable D5.2 [5GS20-D520].

Significant progress has been made in the areas of time synchronization and network architectures. Here, several contributions have been made towards the research community and standard organizations: A highlight has been the project's magazine article on 5G-supported time synchronization for smart manufacturing, which has been published in IEEE Communications Standards Magazine [G20]. Four contributions on integration of 5G with TSN for industrial automation were made to the 5G-TSN work item of 5G-ACIA. These contributions are reflected in the recently published 5G-ACIA paper on integration of the 5G-TSN for industrial communication[10]. The project is currently working on identifying different time synchronization solutions supported by the 5G system. This also includes the identification of components in the end-to-end (E2E) chain that contribute to time uncertainty. For a given time synchronization solution, initial analysis on achievable time synchronization error is performed. The continuation of deliverable D5.1 [5GS20-D510] on the new technological features to be supported by 5G will be documented in deliverable D5.3 due in November 2021.

Several contributions to standards have been made in the area of deployment architectures [5GS-SCS]. An investigation of different architectural models considering the distribution of the network functions from deployment and operation point of view has been completed [5GS20-D520]. In addition, 5G technical enablers such as edge computing and networking slicing have been considered in the investigation. Furthermore, a systematic deployment validation analysis of such technical enablers when applied to possible NPN deployment models has been performed [5GS20-D520]. The work on 5G network architecture options and assessments will be documented in deliverable D5.4 due in November 2021.

For the development of an industrial-centric conceptual network management framework, the requirements and analysis of existing network management approaches for industrial wired networks have been produced in the second year of the project. The functional blocks and interfaces of such a network management solution are currently being identified. In a private 5G network, the management of the required reliability and specific network resources for the industrial applications

[10] https://5g-acia.org/whitepapers/integration-of-5g-with-time-sensitive-networking-for-industrial-communications/

will be made by a network slice manager (NSM). An early prototype of a network slice manager has been developed. A screenshot of the tool can be found in Figure 15.

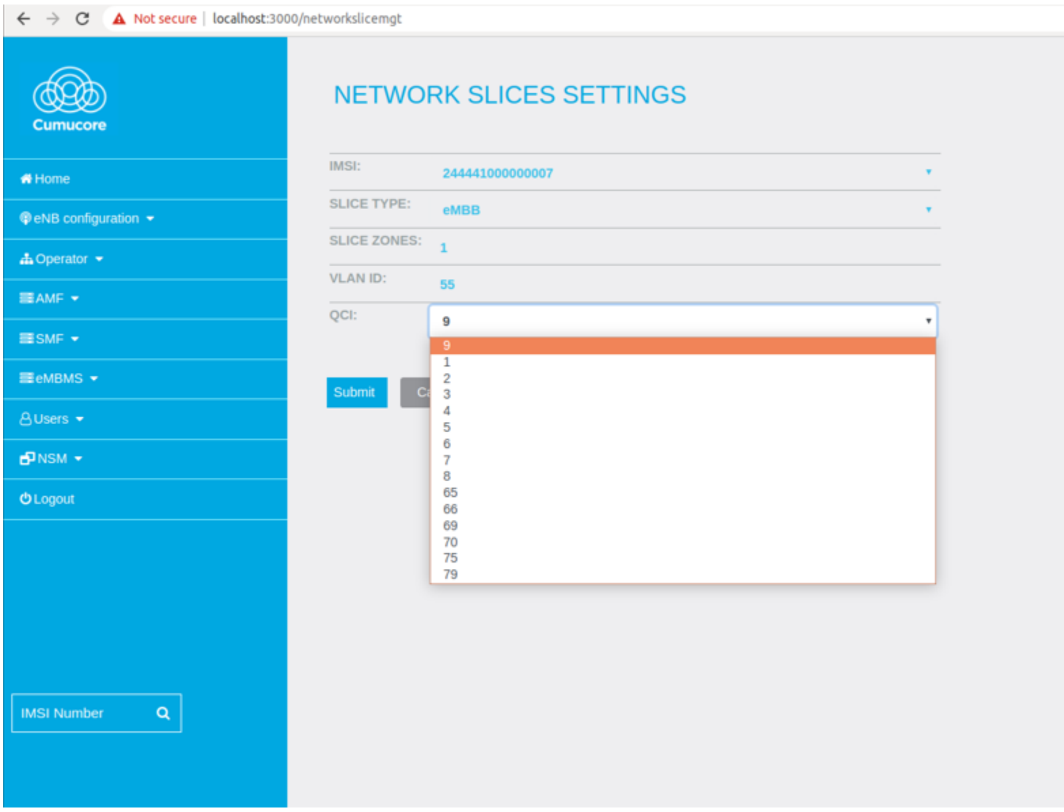

Figure 15: Screenshot of the Network Slice Manager prototype

The tool is 3GPP standard complaint. The NSM is currently being enhanced to support additional functionality, e.g. to align with 3GPP standards TS 28.531 (use cases and functionality) and TS 28.541 (slice metadata). The work on network management will be documented in upcoming deliverable D5.5, which is due in November 2021.

All of 5G-SMART's workstreams on 5G optimization and design for manufacturing are considered to be on track.

4.1.2 Next steps

The next steps in the work stream on 5G optimization and design for manufacturing involve the evaluation of the developed new 5G features, e.g. of time synchronization, 5G-TSN integration and positioning. For 5G-TSN evaluation, the Industrial LAN use case described for the Reutlingen trial site is considered. Regarding the network architecture options, the project will in the following year focus on completing the operation model qualitative analysis. Furthermore, a study on the integration of edge cloud for different NPN models is planned. Reliability mechanisms for different NPN deployment options are also planned to be investigated. The work on network management and configuration continues with analyzing the network management requirements and enhancing the NSM tool.

5 Dissemination and impact

5G-SMART implements a coordinated dissemination and communication plan that foresees presentation and publication of project results at scientific conferences, in journals, workshops, consumer expos, industry groups and forums, magazines and cross-project consortia, etc. Deliverable D6.1 [5GS19-D610] provided the project's impact and dissemination plan early on in the project. Deliverable D6.2 [5GS20-D620] provides a broad overview of the communication, dissemination and exploitation activities implemented within the 5G-SMART project in the first 18 months of its execution, together with information about the dissemination and exploitation activities planned for the rest of the project.

The communication activities aim at interacting with both technical and non-technical audiences, with the overall goal of spreading awareness of 5G technology in Industry 4.0. Dissemination activities include showcasing the use of 5G for smart manufacturing in a number of demonstrations and validation events, as well as contributions to international conferences, workshops, training and teaching activities. The dissemination and impact plan of 5G-SMART includes the following major activities:

(1) International conferences, workshops, journals, magazines, and books.
(2) Workshop organizations.
(3) Participation in and contribution to European cluster and standardization meetings.
(4) Interaction with worldwide consortia, fora, and institutes.
(5) Participation in public industry events and exhibitions.
(6) Academic dissemination.

5.1.1 Achievements

As it can be expected, the lockdown caused by the Covid-19 pandemic that spread worldwide from February 2020 strongly impacted the dissemination activities planned by the project, making it impossible to participate in physical events. Several events, where 5G-SMART was supposed to be present, have been cancelled or heavily downscaled, including e.g. the Mobile World Congress 2020, EuCNC 2020, etc. Table 1 contains the dissemination and communication activities linked to the project since the beginning of the project, from June 2019 to May 2021. As it can be seen, 5G-SMART's dissemination activities still show good progress, apart from the participation in major conferences, for obvious reasons related to the Covid-19 outbreak. 5G-SMART dissemination targets are kept unchanged, despite the pandemic situation, but events are moved, whenever possible, to online mode.

Dissemination activities	Target (M30)	Current status
Journal papers, white papers and international conference papers	20	15
Contributions to standards and regulatory bodies	30	18
Keynotes and panels in major conferences	10	3
Participation in 5G for industry events and forums in Europe and worldwide	10	10
Workshops in major conferences	5	3
Training activities	5	2
5G demos and validations events	3	8

Table 1: Number of 5G-SMART dissemination and communication activities since the project's start

In order to compensate for the lack of physical events, the project has pushed its online presence, preparing content that can be shared online via the social media channels established at the project's start. The project's website https://5gsmart.eu, the LinkedIn account [5GS-LIN], as well as Twitter [5GS-TWI] posts register a large number of visitors. These channels are used to publish the results produced by the project, the project's presence at various events, upcoming events, as well as other news about the project. The project's YouTube channel [5GS-YOU] is used to publish demos and presentations that have been recorded.

A particular activity to mention are the 5G-SMART webinars, that have been organized to ensure the project's reach-out even during the pandemic. The webinars are listed below, together with the number of attendees and online views counted until May 2021:

- "5G for smart manufacturing – Industry and 3GPP latest status", 91 attendees and 532 views online[11]
- "5G process monitoring in manufacturing", 96 attendees and 162 views online[12]
- "5G TSN deployment model and time synchronization aspects", 164 attendees and 524 views online[13]

In addition to the webinars organized by 5G-SMART, the project has also participated in a webinar together with other 5G-PPP projects on 5G experimentation facilities and vertical trials[14].

The 5G-ACIA endorsement of the testbeds of 5G-SMART has also boosted the visibility of the project. All three testbeds were presented at the 5G-ACIA booth in the virtual version of Hanover fair 2021. To make the content attractive for viewers, the project has, whenever possible, shown live demos.

The synergies with standardization and regulatory bodies have been identified as important for the project to accelerate its impact. The participation of 5G-SMART partners in standardization and regulatory bodies meetings, such as 3GPP and ETSI, industry alliances such as 5G-ACIA, and European Union project partnerships such as 5G-PPP ensures a good connection. Since its start, 5G-SMART has

[11] https://www.youtube.com/watch?v=5hatXCmMcPc&t=3s
[12] https://www.youtube.com/watch?v=puoFAayVpZk&t=142s
[13] https://www.youtube.com/watch?v=j-IHbjKL8wI&t=1219s
[14] 5G Trials in Europe – 5G Experimentation Facilities and Vertical Trials5G-PPP (5g-ppp.eu)

succeeded in making strong efforts in standardization and regulatory activities. The latter examples include 4 contributions to the 5G-TSN integration work item of 5G-ACIA and a number of contributions made to ITU [5GS-SCS].

5.1.2 Next steps

Until the project's end, 5G-SMART will continue its dissemination and communication activities. Special attention is given to intensifying the publication of academic articles as well as contributions to standardization. A continuation of the webinars organized by the project is planned until restrictions related to Covid-19 are eased and face-to-face meetings are possible again. Some upcoming events with a strong participation of 5G-SMART include:

- The co-organized workshop on "5G Non-Public Networks" at EuCNC 2021[15]
- The booth exhibition of the Reutlingen trial site use cases and measurements at EuCNC 2021[16]
- The booth exhibition of the Aachen trial site use cases at 5G++ Online Summit Dresden[17]
- The workshop on "5G enablers and trials for smart manufacturing" at PIMRC 2021[18]
- The special session on "Ultra-reliable Low-latency Communication and Industrial Networking" at ISWCS 2021[19]

[15] Workshops - EuCNC
[16] Exhibitions and Demos - EuCNC
[17] 2nd IEEE 5G++ Online Summit Dresden (5gsummit.org)
[18] Program - IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (ieee-pimrc.org)
[19] ISWCS 2020 - 17th International Symposium on Wireless Communication Systems (iswcs2021.org)

6 Conclusion and outlook

In this intermediate project report, the main achievements made by 5G-SMART during the second year of the project are highlighted. References to the deliverables of the project are provided. With a total of 12 published deliverables during the second year, the intermediate project report shows that 5G-SMART has continued to make a significant progress. The Covid-19 pandemic with travel restrictions and difficult access to labs etc., has had a severe impact on the project, resulting in an overall delay of up to six months for the activities related to the trials. Project activities which are not related to or dependent on the trials have, however, have been executed according to the work plan.

Major achieved milestones of the project are the finalization of the work on business models, as well as the execution and evaluation of the Electromagnetic Compatibility (EMC) tests and the channel measurement campaigns at the Reutlingen trial site.

For the trials activities, under the given constraints, the project has succeeded in finding intermediate solutions in order to continue the work and execute the use case development off-site as much as possible. During the remaining time of the project, and as soon as Covid-19 related restrictions are eased, the project will start demonstrating, validating and evaluating the 5G-SMART use cases at the final trial destinations. Furthermore, achieved results, issues encountered, and lessons learnd will be documented.

In the second year of the project, 5G-SMART started the evaluation of important 5G features, such as integration of 5G with Time-Sensitive Networking (TSN), 5G end-to-end time synchronization and 5G positioning. This work will continue while moving forward in the project. The findings will be documented, together with the results of the investigations and assessment of 5G network architectures and the framework solution for network management functions.

Another important work stream for the remaining time of the project is the evaluation of different RAN deployment options, which was started during the second year of the project.

Finally, the project has shown to have a successful dissemination and communication strategy, creating impact with publications, keynotes, standard contributions and demos. A highlight has been the endorsement of all three trial-site testbeds by 5G-ACIA, as well as the webinar series started by 5G-SMART, which demonstrate the relevance of the project. The development of three introductory videos for the trials helps in reaching out also to the general public. In the remaining project time, 5G-SMART will carry out the already planned dissemination activities, but also continue to search for more possibilities regarding workshops, keynotes, etc. If Covid-19 restrictions allow it, the project will realize a trial open day on site, otherwise a virtual event will be targeted.

Appendix

List of abbreviations

3GPP	3rd Generation Partnership Project https://www.3gpp.org/
AE	Acoustic Emission
AGV	Automated Guided Vehicle
AR	Augmented Reality
C2C	Controller to Controller
DUT	Device under Test
EMC	Electromagnetic Compatibility
ETSI	European Telecommunications Standards Institute https://www.etsi.org/
ITU	International Telecommunication Union https://www.itu.int/en/Pages/default.aspx
KPI	Key Performance Indicator
LAN	Local Area Network
LTE	Long Term Evolution
mmWave	Millimeter Wave
MNO	Mobile Network Operator
MSP	Multi-Sensor Platform
NPN	Non-Public Network
NR	New Radio
NSA	Non-Standalone
NSM	Network Slice Manager
PCB	Printed Circuit Board
RAN	Radio Access Network
SA	Standalone
SLAM	Simultaneous Localization and Mapping
TSN	Time-sensitive Networking
URLLC	Ultra-reliable and Low-latency Communication
VM	Virtual Machine
WP	Work Package

Table 2: List of abbreviations

References

5GS19-D310	5G-SMART, Deliverable 3.1, "Report on industrial shop floor wireless infrastructure", November 2019
5GS19-D610	5G-SMART, Deliverable 6.1, "Impact and dissemination plan for academic research, development of industry, standardisation and regulation synergies", August 2019
5GS20-D110	5G-SMART, Deliverable 1.1, "Forward looking smart manufacturing use cases, requirements and KPIs", June 2020
5GS20-D210	5G-SMART, Deliverable 2.1, "Design of 5G-Based Testbed for Industrial Robotics", May 2020
5GS20-D320	5G-SMART, Deliverable 3.2, "Report on System Design Options for Monitoring of Workpieces and Machines", May 2020
5GS20-D510	5G-SMART, Deliverable 5.1, "Report on new technological features to be supported by 5G standardization and their implementation impact", May 2020
5GS20-D720	5G-SMART, Deliverable D7.2, "First intermediate project report", May 2020
5GS20-D140	5G-SMART, Deliverable D1.4, "Radio network deployment options for smart manufacturing", November 2020
5GS20-D520	5G-SMART, Deliverable D5.2, "First report on 5G network architecture options and assessments", November 2020
5GS20-D620	5G-SMART, Deliverable D6.2, "Intermediate report on dissemination and exploitation activities", November 2020
5GS20-D410	5G-SMART, Deliverable D4.1 "Report on design and installation of 5G trial system in Reutlingen", Nov 2020
5GS21-D420	5G-SMART, Deliverable D4.2, "Report on 5G Radio Deployability in the Factory", January 2021
5GS21-D330	5G-SMART, Deliverable D3.3, "Report on implementation of options for monitoring of workpiece and machines", May 2021
5GS21-D120	5G-SMART, Deliverable D1.2, "Analysis of business value creation enabled by 5G for manufacturing industries", May 2021
5GS21-D430	5G-SMART, Deliverable D4.3, "Report on the development of the 5G use cases", May 2021
5GS-LIN	5G-SMART, LinkedIn page, https://www.linkedin.com/company/5gsmart/
5GS-SCS	https://5gsmart.eu/standard-contributions/
5GS-TWI	5G-SMART, Twitter account, https://twitter.com/5G_smart
5GS-YOU	5G-SMART, YouTube channel, https://www.youtube.com/channel/UCdhRYuUuSfT97tIivMGLRlg
KS20	R. Kiesel, R.H. Schmitt, "Requirements for Economic Analysis of 5G Technology Implementation in Smart Factories from End-User Perspective", 2020 31st IEEE Annual International Symposium on Personal, Indoor and Mobile Communications, *PIMRC* https://ieeexplore.ieee.org/document/9217281

G20	I. Godor *et al*., "A Look Inside 5G Standards to Support Time Synchronization for Smart Manufacturing," in *IEEE Communications Standards Magazine*, vol. 4, no. 3, pp. 14-21, September 2020, doi: 10.1109/MCOMSTD.001.2000010.