D3.1

REPORT ON INDUSTRIAL SHOP FLOOR WIRELESS INFRASTRUCTURE

The 5G-SMART project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement no 857008.

D3.1

Grant agreement number: Project title: Project acronym: Project website: Programme:	857008 5G Smart Manufacturing 5G-SMART www.5gsmart.eu H2020-ICT-2018-3
Deliverable type: Deliverable reference number: Contributing workpackages: Dissemination level: Due date: Actual submission date:	R: Document, report D9 WP3 Public 2019-11-30 2019-11-30
Responsible organization: Editor(s): Version number: Status:	ERI-DE Dhruvin Patel V1.0 Final
Short abstract:	This deliverable describes the wireless infrastructure to be deployed at the Fraunhofer IPT trial site.
Keywords:	5G, NSA, SA

Contributor(s):	Leefke Grosjean (ERI-SE) Krister Landernäs (ABB) Niels König (IPT) Jose F. Monserrat (UPV)

Disclaimer

Executive summary

This document describes the wireless communication infrastructure planned to be deployed in the trial site at the Fraunhofer Institute for Production Technology (IPT) in the context of the 5G-SMART project. Information is provided both about the trial facility of Fraunhofer IPT, a short introduction to the use cases that will be trialed, as well as the 5G infrastructure elements that will be installed there. Two different architectures of the 5G system are explained and the 5G solution in form of the Ericsson Radio Dot System is described. Furthermore, an overview of the validation tests is given that will be made once the final system is installed and running in stable mode.

Contents

1 Introduction

The Fraunhofer IPT trial site is one out of the three trial sites, where a 5G communication infrastructure will be deployed within the 5G-SMART project in order to test and validate 5G for advanced manufacturing applications. Two important use cases will be trialed at this site: 5G based wireless acoustic emission measurement and multi-sensor platform for monitoring of workpiece and machines.

The objective of this document is to describe the 5G system that will serve as the wireless infrastructure at the Fraunhofer IPT trial site. It needs however to be highlighted that the intended 5G system is not installed yet at the point of writing of this deliverable.

Once the wireless infrastructure is installed at the trial site, it will be validated and evaluated with a number of coverage and connectivity tests. An overview of the connectivity tests and relevant Key Performance Indicators (KPIs) are provided in this document.

1.1 Relation to other documents of 5G-SMART

While this document focuses on the wireless infrastructure at the Fraunhofer IPT trial site, it only gives a very brief overview of the trialed use cases. The realization of the use cases is ongoing and a detailed description of those will be given in the upcoming deliverable D1.1. The deployment of the indoor 5G New Radio (NR) is still in preparation; this document provides an overview of the 5G network deployment and the 5G standard components that will be installed in the trial setup. Once in place, different connectivity test of the 5G systems will be made and the trial use cases will be evaluated. Results of the test evaluations and use case validation will be provided in the later deliverable D3.2.

Apart from technical parameters, 5G-SMART will also report on non-technical parameters related to the setup and maintenance of the 5G system at the trial site, covering for instance everyday suitability on the premises of shop floors, plug-and-play capabilities, easy usability and intuitive operation. The conclusions related to this activity will be provided in D3.4.

Figure 1 illustrates the workflow of work package 3 (WP3) which handles all activities at the Fraunhofer IPT trial site related to 5G-SMART.

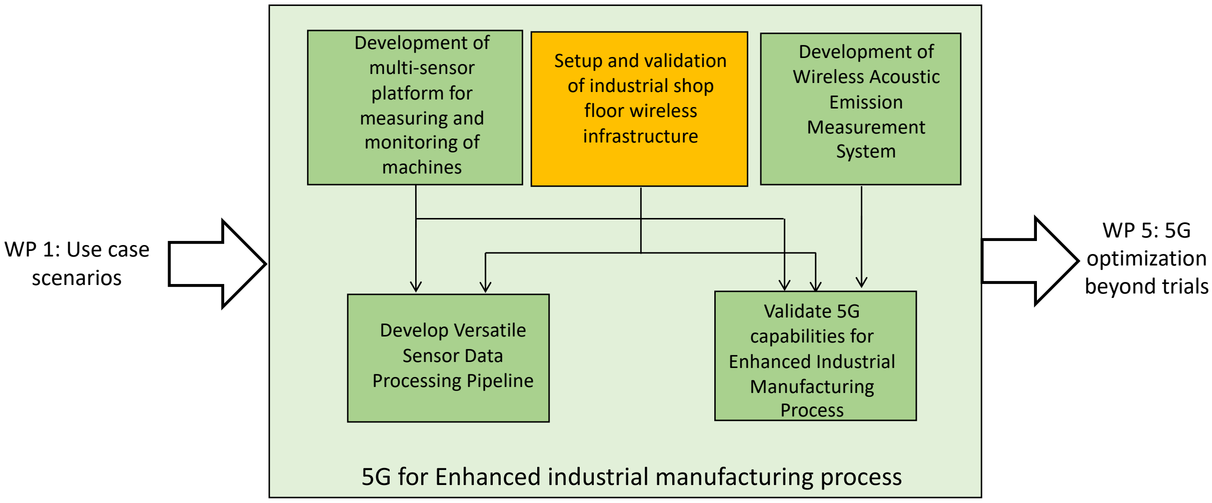

Figure 1: Workflow of workpackage 3

1.2 Structure of the document

This document is structured as follows, Section 1 provides the introduction to the deliverable including the objective of the document and its relation to other activities and documents produced within 5G-SMART. Section 2 focuses on the trial site description. Section 3 provides an overview of the trialed use cases and their requirements. Details on the wireless infrastructure in general terms are provided in Section 4 whereas section 5 describes the particular 5G system deployed at the trial site. Section 6 outlines the planned tests to be conducted once the 5G system is installed. Section 7 contains concluding remarks.

2 Trial site description

The Fraunhofer IPT trial site is located in Aachen, Germany. It consists of a machine hall equipped with various kinds of machine tools from different vendors, thus representing a realistic shop floor environment. At the time of writing this document, the following machines are installed in the shop floor:

- 5-axis and 3-axis milling machines (Georg Fischer Machining Solutions, Makino, Starrag, Heller, etc.).
- Combined milling and turning centers (DMG Mori).
- 5-axis water-jet cutting (Ridder).
- 5-axis and 3-axis laser structuring machines (Kern, Axis, Fraunhofer IPT, etc.).
- Injection molding machines with different sizes (Arburg).
- 400t-press for metal blanking (Schuler).
- Tool grinding machine (Walter).
- Multi-tool robot cell with laser structuring, tool spindle and 3D-sensor (ABB, Scanlab, Zeiss).
- EDM and ECM machines (Georg Fischer Machining Solutions, EMAG, Makino).
- Temperature-controlled measurement laboratory with high-precision coordinate measuring machine and 3D-fringe projection system (Zeiss, Steinbichler).

Several of the machines are either already equipped or will be equipped with machine monitoring systems during the project lifetime. For 5G-SMART, a 5-axis milling machine from Georg Fischer Machining Solutions (Mikron HPM 800) is of most relevance, as the Acoustic Emission (AE) sensor and the Multi-Sensor Platform (MSP) developed within the project will be trialed on this particular machine.

2.1 Shop floor characteristics

The IPT factory hall is subdivided into three shop floors with different characteristics. The area relevant for the 5G-SMART project has an inner size (wall to wall) of 91.5 x 28.9 m and a height of 10 m with two aisles and a gate at one end, large enough for trucks to drive in. Both aisles have separate rail-mounted hall cranes. Figure shows a picture of the interior of the shop floor.

Figure 2: Fraunhofer IPT shop floor

3 Planned use cases and requirements

There are two use cases to be trialed at the Fraunhofer IPT trial site:

1. 5G for wireless acoustic workpiece monitoring.
2. 5G versatile multi-sensor platform for digital twin.

In this section an overview of these use cases is given and their requirements on the wireless infrastructure are outlined. The full specification and requirements of the use cases will be given in full detail in the upcoming deliverable D1.1 of 5G-SMART.

3.1 5G for wireless acoustic workpiece monitoring

In order to safeguard manufacturing operations, different kind of monitoring technologies are available, which can be used to gain information about the condition of workpieces, machines and the manufacturing processes. Acoustic workpiece monitoring is one such monitoring technology that makes use of acoustic emission (AE) sensors for collecting relevant data for the monitoring system. AE sensors are widely applied for monitoring cutting processes, in particular for performing the following items in real-time:

- Monitoring of tool wear
- Detection of tool breakage
- Detection of collision of the machine spindle
- Detection of inhomogeneities of the workpiece material

A timely detection of any of the above disturbances is desirable as it allows an intervention into the process, to optimize the fabrication process, as well as to reduce the production costs due to decreased failure rates.

In the use case trialed within 5G-SMART, an AE sensor will be developed and integrated into a 5-axis milling machine, in order to monitor the milling process of a jet engine component. Figure 3 depicts the setup. The AE sensor needs to be placed close to the area of contact between workpiece and tool, which cannot be reached with cables. The communication therefore needs to be wireless. The signal processing of the measurement data will be performed on an edge gateway and alternatively by cloud computing. AE sensors typically have sampling rates in the MHz-range and can generate data output rates of up to 100 Mbit/s. The trialed use case will be validated by investigating the latency between a tool break and its detection, which needs to be as low as possible. Hence overall, an ultra-low latency of the signal transmission is required as well as very high data throughput due to the high sampling rates. Existing wireless communication such as Wi-Fi or Zigbee lack performances in terms of latency and throughput. 5G aims at closing this gap. Therefore, in this use case, the performance of the AE monitoring system will be evaluated in connection with a 5G system.

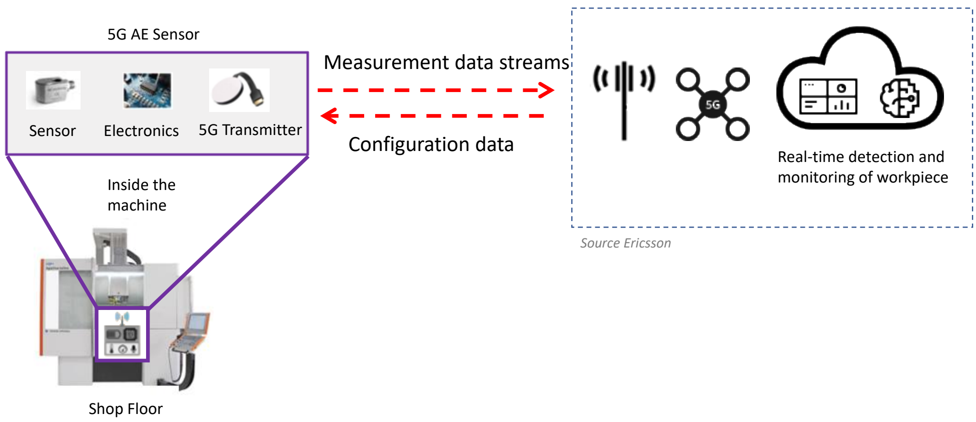

Figure 3: 5G for wireless acoustic workpiece monitoring

3.2 5G versatile multi-sensor platform for digital twin

The second use case trialed at the IPT Fraunhofer trial site targets non-time critical communication for a larger number of devices. While in today's production, one can find many different kinds of sensors, they are usually separated stand-alone systems not being aggregated in a platform format. Factory and process automation however can be optimized by collecting data from a multitude of sensors and thus monitoring a massive number of machines, work pieces and processes simultaneously. This is relevant input to the concept of a digital twin. A digital twin in manufacturing consists of a virtual representation of a physical entity or production system. Through connected smart devices, sensed data, mathematical models and real time data evaluation, the virtual representation is synchronized with the real system. The digital twin can then be used to forecast and optimize the behavior of the underlying physical system.

In the trial facility at the Fraunhofer IPT, a large number of sensors, implemented in the form of a multi-sensor platform (MSP), will be developed. The MSP will integrate different sensors such as accelerometer, gyroscope, microphone, temperature and humidity sensors into one compact device. Several identical copies of the MSP will be integrated into multiple machines and attached to multiple workpieces in the trial site. The measurement data collected from the MSPs will be processed over a new data processing pipeline. This pipeline will be hosted on the factory cloud enabling the real-time realization of a digital twin of the connected machines and workpieces. In order to enable real-time measurement acquisitions from multiple MSPs and synchronization between physical and virtual representation, hence this use case requires low latency, network slicing to isolate different sensors, and tight time synchronization. Figure 5 illustrates the setup.

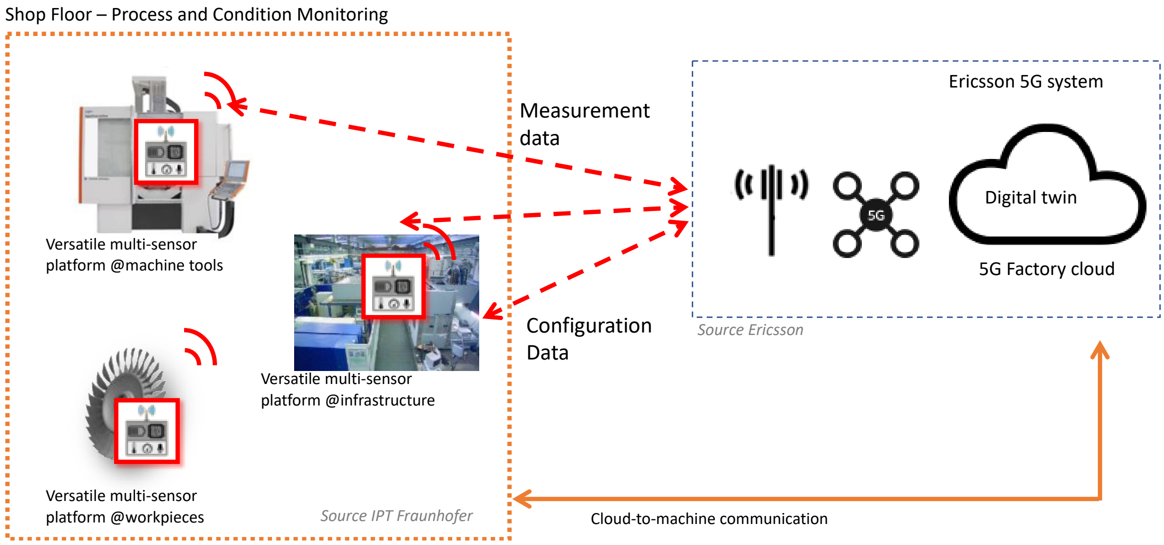

Figure 4: 5G versatile multi-sensor platform for digital twin

3.3 Monitoring system

The monitoring system used together with the machines is a Genior Modular (GEM) monitoring system developed by Marposs Monitoring Solutions. The GEM will be integrated into the Profinet fieldbus of the Mikron HPM 800 milling machine. It is able to communicate with the controller of the milling machine in both directions, thus enabling an extraction of machine data and matching with data acquired by the sensors developed within 5G-SMART. Furthermore, it allows for feedback to the machine based on processed sensor data.

4 Wireless infrastructure – the 5G system

In this section, an introduction to the 5G infrastructure planned for the Fraunhofer IPT trial site is given, where relevant terms are explained, and an overview of the Ericsson Radio Dot System is provided. The setup specifically used at the trial site is detailed in Section 5.

Cellular networks like 5G cellular network consist of two main components: A core network, that manages routing, mobility, authentication and other related functions and the Radio Access Network (RAN), primarily responsible for sharing radio resources and all other radio related functionality, implementing a Radio Access Technology (RAT). 5G NR and 4G LTE are two RATs relevant for the Fraunhofer IPT trial site.

In previous mobile communication network generations, such as 4G LTE, the RAT and core network had to be of the same generation, meaning that a 4G LTE network can only be connected to a 4G core network. For 5G systems this is different [GSMAR-2018]. Here, two different architectures are possible: The Non-standalone Architecture (NSA) and the Standalone Architecture (SA). These options are further clarified in the following.

4.1 Non-standalone Architecture (NSA)

In the 5G Non-standalone Architecture (NSA) both 4G LTE and 5G NR are used. Figure 5 illustrates the setup. A user is connected to both 4G LTE and 5G NR. Depending on the traffic to be transmitted either the 4G or 5G connection is used. For all control traffic such as initial access, paging, and mobility 4G LTE is used. Data traffic on the other hand is primarily handled using 5G NR. The core network utilized in NSA is a 4G core network, the so-called Evolved Packet Core (EPC). For simplicity, in the illustration, eNB and gNB can be thought of as base stations for 4G LTE and 5G NR respectively. In NSA gNB and eNB are connected via an interface.

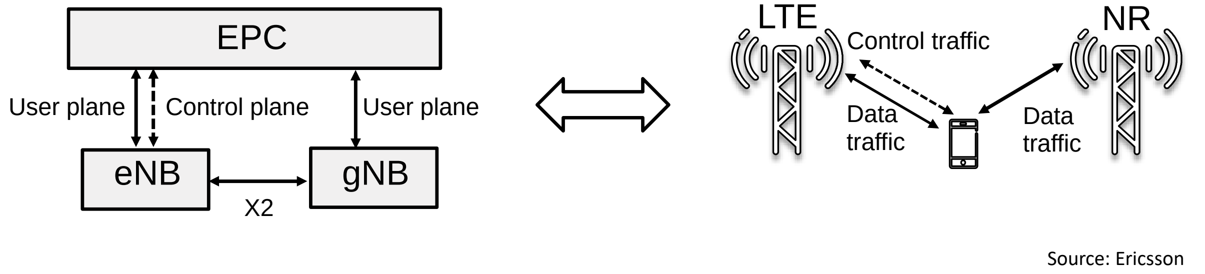

Figure 5: 5G Non-Standalone architecture

4.2 Standalone Architecture (SA)

In the Standalone Architecture (SA), 5G NR acts as dedicated radio access technology for both control and data traffic and no anchor needs to be established to a 4G network. The core network utilized in SA is a 5G core network (5GC). Figure 6 illustrates the setup. As before, in the context of this document, gNB can be thought of as a base station for 5G NR.

The 5GC is responsible for authentication, QoS enabling and connectivity setup. The 5GC provides advanced network slicing and advanced QoS features.

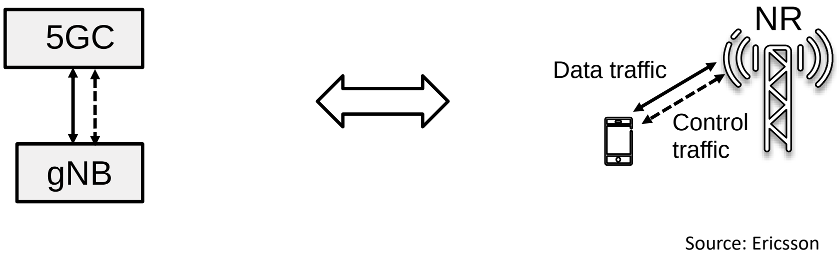

Figure 6: 5G Standalone architecture

4.3 Non-Public Network (NPN) deployment

Non-public networks (NPN), also often called private networks, provide 5G network services to a dedicated user organization or group of organizations [5G-ACIA-2019]. NPNs are deployed partially or fully on the organization's defined premises. They stand in contrast to public networks offering mobile network services to the general public.

In the context of industrial and Industrial Internet of Things (IIoT) scenarios, NPNs are typically divided into two categories: NPNs deployed as isolated, standalone networks, and NPNs deployed in conjunction with a public network. Further information and investigations on possible deployment options will be given in the deliverable D1.4 of 5G-SMART.

4.4 The Ericsson Radio Dot System

The Ericsson Radio Dot System (RDS) is specifically designed to provide a flexible, cost-effective architecture and superior network performance for indoor deployment. It can be easily installed at the ceiling. The RDS has three main components: The Indoor Radio Unit (IRU), the Radio Dots (RD) and the digital unit containing the baseband processing. The main components are further explained in the following part of this subsection. A block diagram of the RDS for one RD, one IRU and one digital unit is shown in Figure .

The **Radio Dot (RD)** is a radio front-end including the radio antennas and the radio frequency (RF) part. Figure 7 shows the physical form of RD. A block diagram of the RD is illustrated in in Figure 9. The RD generates and receives the radio waves enabling radio coverage. Each RD is connected to an IRU with a dedicated LAN cable. Several RDs can be connected to the same IRU in a star topology.

Figure 7: Ericsson 5G Radio Dot

The **Indoor Radio Unit (IRU)** acts as an aggregator of signals coming from Radio Dots and provides the digital interface towards the BBU. Moreover, it provides power to the RDs. As shown in Figure , the IRU includes radio processing functions and Analog-to-Digital conversion (ADC) and Digital-to-Analog conversion (DAC). The IRU is connected to the RD via a LAN cable. The IRU is connected to the digital unit over fiber using, e.g., the Common Public Radio Interface (CPRI).

The **Baseband Unit (BBU)** is responsible for the Baseband (BB) processing. Baseband processing of 4G radio access and NR access are realized in 4G and 5G BBUs. The BBU performs radio resource handling, encoding, decoding of uplink and downlink radio signals, radio control signal processing and radio network synchronization. The BBU has features that include for instance: combined cell, carrier aggregation, lean carrier enabling coordination for operating in small cells under large multi-antenna indoor environments.

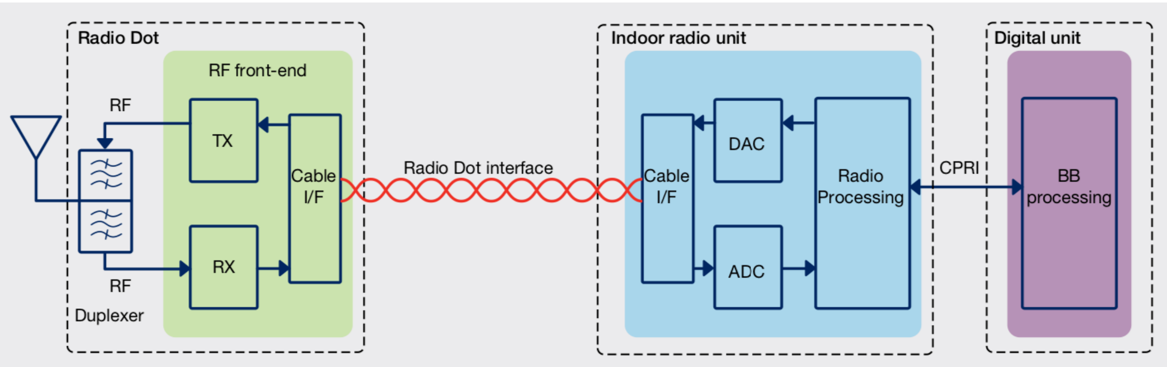

Figure 8: Radio Dot System block diagram [**CTD-2014**]

The RDS has a centralized baseband-based architecture. This allows to add more digital units and IRUs in case of an increased demand without changing the cabling infrastructure [CTD-2014]. In order to realize NSA, BBU, IRU and RD need to support both 4G LTE and NR 5G. For SA only NR 5G needs to be supported.

5 5G system deployed at the trial site

While the previous section provided introductory information on the 5G system, in this section more information is given related to the particular 5G system components planned to be deployed at the Fraunhofer IPT trial site, containing more details on the core network, the user end device and the spectrum.

The network chosen to be deployed at the Fraunhofer IPT trial site is a dedicated on-premise 5G network operated as an isolated NPN. In practice, this means that all the network functions, including the EPC or 5GC, will be deployed on the shop floor. The isolated NPN includes the indoor radio network solution, the virtualized core network and the factory cloud solution. With first 5G standards developed by 3GPP supporting NSA, initially a 5G NSA is deployed. At a later stage of the project this will be changed to 5G SA. The radio system uses the previously introduced Radio Dots developed by

Ericsson, as they are particularly suitable for indoor coverage of the shop floor and can be installed at the factory ceiling. The radio deployment is based on the 3GPP NR specification of release 15.

Figure illustrates the setup for NSA: 4G and 5G RDs will be installed at the ceiling of the shop floor. The exact number of RDs will be chosen depending on the size of the area to be covered. The 4G and 5G RDs are connected to a 4G IRU and a 5G IRU, which are further connected to 4G and 5G BBUs. The connection towards the core network is realized via fiber.

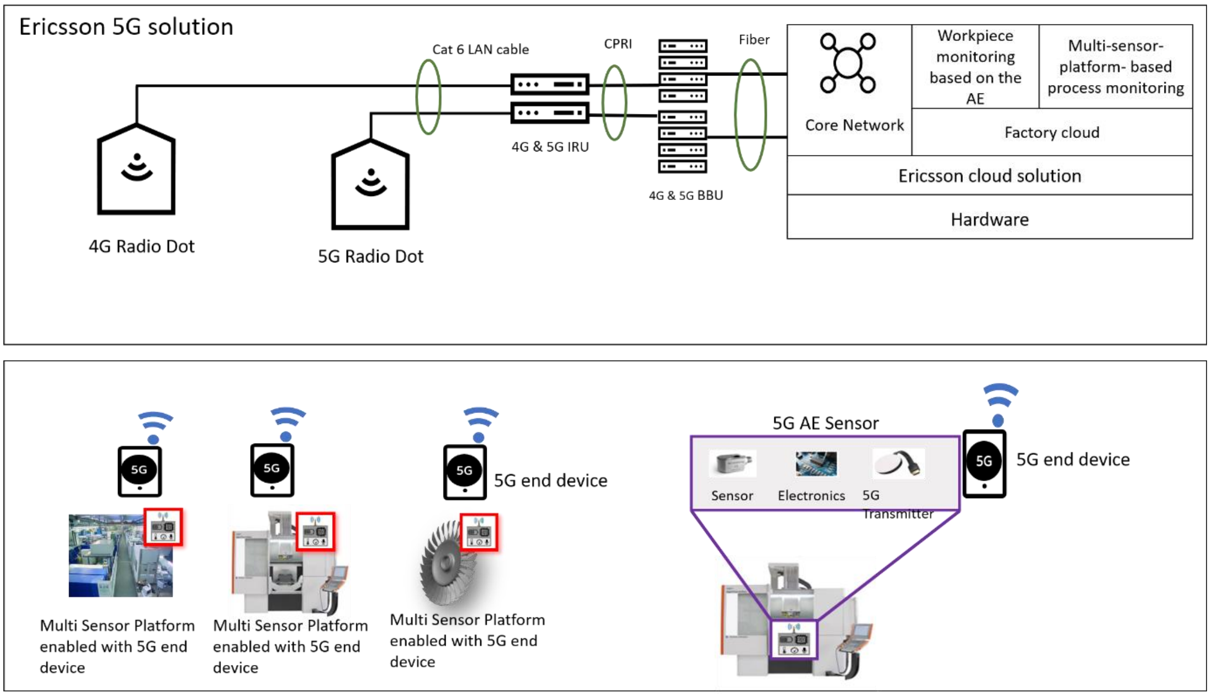

Figure 9: Wireless infrastructure at the Fraunhofer IPT shop floor (here NSA)

5.1 Core network

For the initial NSA deployment, a virtualized 5G EPC solution is planned to be installed based on the 3GPP Release 15 standard. Furthermore, a new factory cloud solution will be implemented on the same hardware platform, which will be utilized to run the applications for process and work piece monitoring developed within the project.

For the SA deployment, the 5GC will have capabilities to enable network slicing for each communication service [ERI-2018]. Logical network slices can be used to separate both use cases which are realized on the same physical network.

All core network functions are realized in the cloud execution environment. The factory cloud solution will also coexist with the core network functions.

5.2 5G end device

The 5G end device used in the Fraunhofer IPT trial site is an NR router with a 4G and 5G modem. The NR router is provided by Wistron NeWeb Corporation (WNC) and the modem is a Qualcomm® Snapdragon™ X50. The user equipment (UE) is connected with the router.

The technical features of the router are listed in Table .

Feature/Characteristic	Value/Details
NR modem	5G NR sub 6-GHz
Data Rate	Up to 2.2 Gbps
Antenna configuration	4x4 MIMO
Modulation scheme	256 QAM
External interface	USB 3.1 Generation 1 Type-C

Table 1: Test 5G end device characteristics

5.3 Spectrum

In order to operate the 5G system at the trial site, an application for spectrum has to be made. In Germany it is possible for industry to apply for local spectrum in the 3.7-3.8 GHz range. For the 5G NR system, the deployment is therefore planned for frequency band 78 (3.7-3.8 GHz). For the 4G LTE part the frequency band 40 (2.3-2.32 GHz GHz) is utilised. Depending on the possibility to apply for more spectrum and the availability of 5G network components, the wireless infrastructure can be upgraded to support high band (28 GHz) as well.

6 Planned tests

In order to fully investigate and evaluate the capabilities of the 5G solution for the use cases to be trialed at the Fraunhofer IPT trial site, tests and measurements need to be carried out to ensure good connectivity of the whole test area. This section provides an initial overview on the test setup architecture and the tests planned, in order to perform a connectivity evaluation of the wireless infrastructure, once it is installed at the trial site and running in stable mode. Further details as well as results of the connectivity test will be evaluated and reported in D3.2.

The following Key Performance Indicators (KPIs) have been identified as relevant for the 5G connectivity evaluation: uplink and downlink end-to-end (E2E) latency between the factory cloud and the UE, E2E latency variation, round-trip latency, and uplink throughput. These Key-Performance-Indicators (KPIs), testing methods and the test setup are described in the following subsections. The test setup architecture is illustrated in Figure . A test measurement device is installed, which connects to both the 5G end device and via a switch to the core network and the factory cloud. The test device contains a packet generator. Furthermore, it contains a measurement unit, which measures the parameters relevant for the connectivity tests. The test device represents both source and sink, thus avoiding problems with time synchronization, which could occur when using two devices. The measurement device to be used is a single board PC with AMD Quad Core 1 GHZ 64bit processor with an integrated LTE modem. The 5G modem will be connected via a standard interface such as USB interface. The measurement device hosts a Linux-based operating system. The network namespace feature of the Linux operating system will be configured such that internal routing of the data traffic within the measurement device is prevented. Namespaces are a feature of the Linux kernel that partitions kernel resources such that one set of processes sees one set of resources, while another set of processes sees a different set of resources. The network namespace feature virtualizes the network stack, meaning that each namespace can have its own private set of IP addresses and its own routing table, socket listing, connection tracking table and other network-related resources. For some tests the packet generator will be used to generate the packets, while for roundtrip latency tests, the AE or MSP will generate the packets.

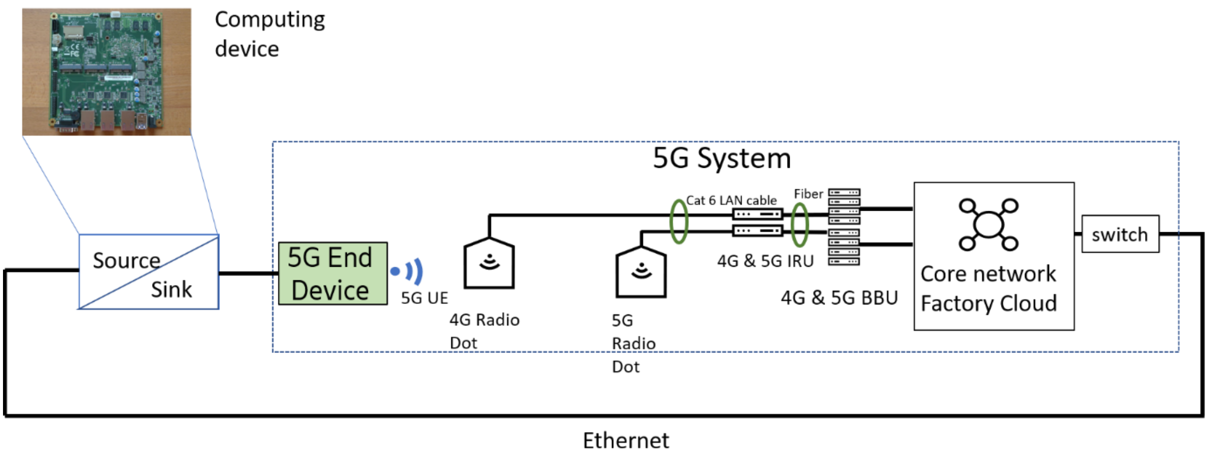

Figure 10: Test setup for 5G connectivity evaluation

6.1 Key Performance Indicators for 5G connectivity

The technical KPIs for 5G connectivity, together with the relevant testing method, are detailed in Table 2. The results of the test based on this KPI will be provided to basis for further activity as input to validate 5G performance for advanced manufacturing applications.

Key Performance Indicator	Definition	Testing method
E2E downlink latency	End-to-End (E2E) latency from factory cloud to a 5G UE	Measurement device with two network interfaces, one connected to the factory cloud and the other one to the LTE/NR modem
E2E uplink latency	End-to-End latency from a 5G UE to factory cloud	Measurement device with two network interfaces, one connected to the factory cloud and the other one to the LTE/NR modem
E2E latency variation	Variation in observed downlink and uplink latencies	Measurement device with two interfaces, one connected to the factory cloud and the other one to the LTE/NR modem

Round-trip latency	Depending upon the use cases (AE sensor or MSP) feedback control loop latency observed over 5G system	Measurement device with two network interfaces, one connected to the factory cloud and the other one with LTE/NR modem
Uplink throughput	Uplink throughput observed at the 5G UE connected to the AE sensor	Uplink throughput observed at the 5G UE, measured in Bit/s

Table 2: KPIs for connectivity

7 Conclusion

This document has provided an overview of the wireless communication infrastructure planned to be deployed in the trial site at the Fraunhofer Institute for Production Technology (IPT). A brief introduction of the use cases to be trialed was given. The realization of the use cases is ongoing work in 5G-SMART and more details and results of the trial will continuously be provided throughout the course of the project.

List of abbreviations and acronyms

3GPP	3rd Generation Partnership Project
AE	Acoustic Emission
BBU	Baseband Unit
CN	Core Network
EPC	Evolved Packet Core
RD	Radio Dot
RDS	Radio Dot System
MSP	Multi-Sensor Platform
NR	New Radio
NSA	Non-Standalone Network
UE	User Equipment
NPN	Non-Public Network
NG-RAN	Next Generation Radio Access Network
GEM	Genior Modular – tool and process monitoring system by Marposs
5GC	5G Core Network
LTE	Long Term Evolution
IIoT	Industrial Internet of Things
IRU	Indoor Radio Unit
CPRI	Common Public Radio Interface
LAN	Local Area Network
QAM	Quadrature Amplitude Modulation
MIMO	Multi-Input and Multiple-Output
E2E	End-to-end
QoS	Quality of Service

References

[CTD-2014] Connecting the dots: small cells shape for high-performance indoor radio, December 2014 https://www.ericsson.com/49617a/assets/local/publications/ericsson-technology-review/docs/2014/er-radio-dot.pdf

[5G-ACIA-2019] 5G-ACIA non-public networks for industrial scenarios, July 2019

https://www.5g-acia.org/fileadmin/5G-ACIA/Publikationen/5G-ACIA_White_Paper_5G_for_Non-Public_Networks_for_Industrial_Scenarios/WP_5G_NPN_2019_01.pdf

[ERI-2018] 5G deployment consideration https://www.ericsson.com/4a5daa/assets/local/networks/documents/5g-deployment-considerations.pdf

[GSMAR-2018] Road to 5G : Introduction and Migration, April 2018. https://www.gsma.com/futurenetworks/wp-content/uploads/2018/04/Road-to-5G-Introduction-and-Migration_FINAL.pdf