D4.1

REPORT ON DESIGN AND INSTALLATION OF THE 5G TRIAL SYSTEM IN REUTLINGEN

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Short abstract:	This deliverable describes the designed and installed 5G trial system in the semiconductor factory of Bosch in Reutlingen including all considered requirements and constraints, and the deployment model.
Keywords:	5G standalone (SA), semiconductor factory, 5G deployment

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Disclaimer

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This deliverable has been submitted to the EU commission, but it has not been reviewed and it has not been accepted by the EU commission yet.

Executive summary

This deliverable provides insights into the design and installation of the 5G trial system in the semiconductor factory of Bosch in Reutlingen. The characteristics of the trial site and in particular the cleanroom shopfloor area where the 5G deployment is undertaken are described, this includes for instance the regulations imposed on materials that are brought into the factory. The particular processes in the factory relevant for the 5G-SMART project are explained, providing a wider context for the use cases to be realized on the factory floor. All constraints coming from the trial site and use case perspective are taken into account for the 5G system deployment. Furthermore, the different steps of the design process of the 5G deployment as well as the final deployment design are detailed.

Contents

1 Introduction

Semiconductor chips are core technology enablers that power many of the cutting-edge digital devices we use today. With emerging technologies such as autonomous driving, artificial intelligence and the Internet of Things, global semiconductor industry is expected to continue to grow at a high pace in the next decade. Producing semiconductors is a highly complex and sensitive process requiring high-tech manufacturing plants. In the Bosch semiconductor factory in Reutlingen, 5G-SMART investigates the potential of 5G to improve productivity and automation of key activities in the factory, by validating 5G capabilities for manufacturing applications like control of mobile robots and industrial control communication. To this end, 5G-SMART has installed an independent on-prem standalone (SA) 5G system in the semiconductor factory of Bosch. Investigating the constraints and requirements for the 5G deployment has been a major effort in 5G-SMART and a key ingredient for the design of the 5G system that is the subject of this document.

Figure 1: Wafer cleaning at the Bosch plant in Reutlingen, Source: Bosch

1.1 Objective of the document

The objective of this document is to report on the design and installation of the 5G system in the semiconductor factory of Bosch in Reutlingen. Requirements and constraints both from the use cases and the trial site facility perspectives are described, and it is explained how the 5G deployment aims at fulfilling the requirements of the semiconductor factory at all levels, including radio propagation, application performance and IT-security levels. Furthermore, details on the 5G system installation are presented. Due to confidentiality reasons related to the factory itself and the processes involved, this document can only provide high-level descriptions.

1.2 Relation to other documents

This deliverable builds on the work presented in D1.1 [5GS20-D110], which provides a detailed description of the use cases to be trialed in the Bosch semiconductor factory, including both requirements and Key Performance Indicators (KPIs). While D1.1 has the focus on the use case realization, in this deliverable, the focus is on constraints and deployment requirements for the design and installation of the 5G system. Due to restrictions related to the Covid-19 pandemic, the channel measurement campaign of 5G-SMART in the factory, as well as the Electromagnetic Compatibility (EMC) tests conducted in a close by testing area, had to be delayed. The design and installation of the 5G system in the factory has therefore been conducted as an independent activity. Deliverable D4.2 (to be published in January 2021) reporting on the 5G radio deployment in the factory adds however further insights to the information presented in this document. In connection with the installation of the 5G trial system, initial acceptance tests have been conducted. The results of these tests as well as other performance and validation tests will be reported on in Deliverable D4.3, due in November 2021.

1.3 Structure of the document

This document is structured as follows. Section 1 introduces the document, including a description of the relation of this deliverable to other deliverables in the 5G-SMART project. In section 2, the trial site is described in detail and an overview of the use cases is provided. Here, the focus is on the requirements and constraints imposed by the trial site and the use cases on the design of the 5G deployment. Section 3 elaborates on the design of the 5G deployment. Section 4 summarizes and concludes the deliverable.

Note that in this document the terms, mobile robot and Automated Guided Vehicle (AGV) are used interchangeably.

2 Trial site and use case description

This section describes the trial site in detail, including a short background information on the Bosch group in general.

2.1 The Bosch group

The Bosch group is a leading global supplier of technology and services. It employs roughly 398,000 associates worldwide (as of December 31, 2019). The company generated sales of 77.7 billion euros in 2019. Its operations are divided into four business sectors: Mobility Solutions, Industrial Technology, Consumer Goods, and Energy and Building Technology. As a leading Internet of Things (IoT) company, Bosch offers innovative solutions for smart homes, smart cities, connected mobility, and connected manufacturing. The Mobility Solutions business sector, one of the world's biggest automotive suppliers, accounts for 60 percent of Bosch's total sales. Its main areas of activity are injection technology and powertrain peripherals for internal-combustion engines, diverse solutions for powertrain electrification, steering systems, safety and driver assistance systems, technology for user-friendly infotainment as well as vehicle-to-vehicle and vehicle-to-infrastructure communication, repair-shop concepts, and technology and services for the automotive aftermarket. The sector combines the group's expertise in three mobility domains - automation, electrification, and connectivity. The Bosch semiconductor factory in Reutlingen is one of the main suppliers for these three domains.

Figure 2: Bosch plant in Reutlingen, Source: Bosch

2.2 The Bosch semiconductor factory

The Bosch semiconductor factory in Reutlingen (Figure 2) is the largest manufacturer of Micro-Electro-Mechanical systems (MEMS) technology, one of the biggest producers of semiconductors for mobility solutions and one of the driving forces behind the technology of Intellectual Property (IP) modules. As a semiconductor facility with frontend and backend production lines, Bosch owns a wide variety of databases required to store the relevant equipment and processing data. The collected data is mainly used for process control and monitoring of production processes in order to ensure the high level of quality required for automotive and consumer products. Several very specific software applications have to be developed, adapted and integrated to fulfill this purpose. As a result, data collection and analysis or many different applications are a key topic for Bosch. In 5G-SMART the potential of using 5G for the execution of these tasks is investigated. The particular tasks and activities performed in the semiconductor factory relevant for the 5G-SMART project are further explained in section 2.4.

2.3 Trial site constraints

The semiconductor factory is an operational factory with production running 24 by 7. The design and installation of the 5G trial system therefore had to be undertaken with the constraint of not interfering with the ongoing production.

The area in the semiconductor factory identified as having the highest benefits of introducing 5G is the cleanroom factory floor of around 8000 sqm. A glimpse of the shopfloor can be seen in the snapshots in Figure 1 and Figure 3. A cleanroom is designed to maintain extremely low levels of particulates, such as dust, airborne organisms, etc. Cleanrooms are typically classified by the number of particles per cubic meter at a predetermined molecule measure, with different International Organizational for Standardization (ISO) classes denoting different levels. The semiconductor factory in Reutlingen has an ISO class of 3 which corresponds to a maximum of 102 particles per cubic meter. Consequently, this statutory regulation must be ensured for all components brought into and tasks carried out in the production area. Other regulations for components brought inside the cleanroom are:

- EU declaration of conformity and the CE[1] certification: to make sure that the equipment under consideration conforms to the EU requirements and norms
- Approval through a Bosch officer, responsible for work safety: to make sure that all local requirements are fulfilled and there is no safety issue for the workers or the environment.
- High reliability: to make sure that the used equipment does not negatively affect the target productivity of the plant.
- No obstruction of escape routes: to further conform to the safety requirements.

With the 5G deployment components not being cleanroom certified by default, special cleaning procedures had to be undertaken to allow their installation on the factory floor. In particular, for the use case realization, CE certification and cleanroom conformity have imposed significant constraints and requirements on the development of the mobile robots, which are being addressed in a

[1] https://ec.europa.eu/growth/single-market/ce-marking/

continuous dialogue between project partners, involving different organizations within Bosch. While cleanroom tests can be conducted by Bosch, the feasibility of CE certification processes is still under discussion.

Figure 3: Inside the cleanroom of the semiconductor factory, Source: Bosch/Ericsson

2.4 Use case requirements and constraints

In the 5G-SMART project, advanced manufacturing use cases are under development to investigate the applicability of the 5G technologies on the manufacturing shopfloor. At the Reutlingen trial site, the following two use cases are considered: A cloud-based mobile robotics use case and a Time Sensitive Networking/ industrial LAN (TSN/I-LAN) -over-5G use case. Detailed descriptions of the use cases can be found in D1.1 [5GS20-D110]. In the following, the aspects of the use cases relevant for the 5G deployment design are highlighted.

The first use case focuses on leveraging the 5G factory cloud – an on-premises cloud computing deployment that is able to operate without connections to central data centers – to offload AGV computation and decouple closed-loop control of robots from their embedded systems. Control is placed into the cloud environment for scalability, reliability and ease of maintenance, while at the same time satisfying the KPIs, like sufficiently low execution latency and adequate fault-tolerance. Figure 4 illustrates the conceptual 5G deployment for the use case.

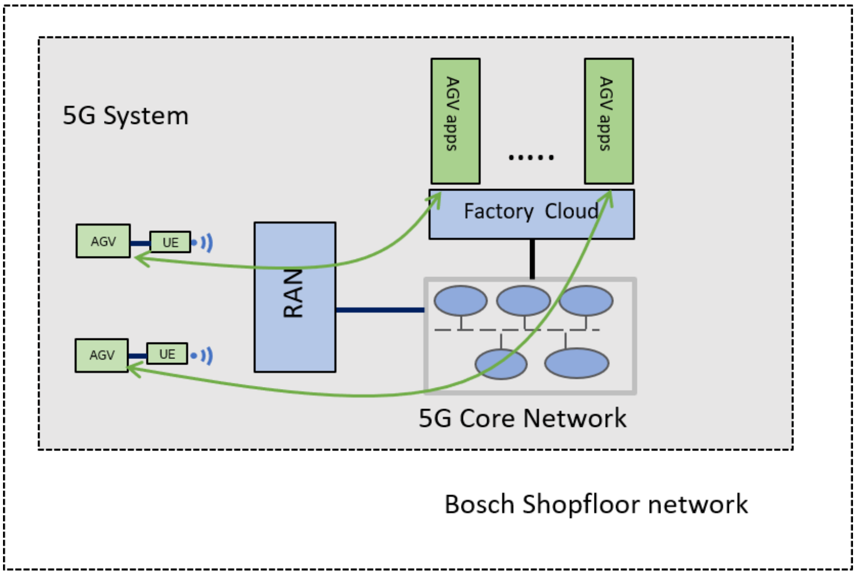


Figure 4: Mobile cloud robotics use case

Here, AGV applications such as AGV closed loop control, fleet control and safety functions are implemented in the factory cloud. Specifically, the following scenarios have been considered as relevant for the validation and evaluation of this use case:

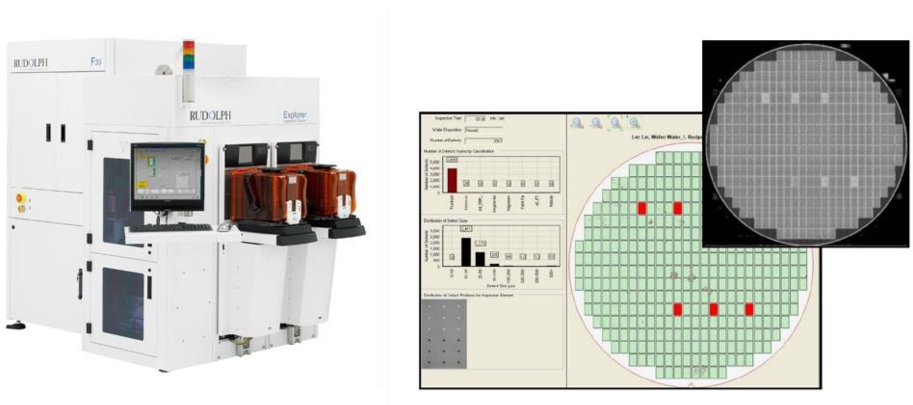
- **Scenario 1: Continuous operation**
  This scenario investigates the 24/7 operation of the AGVs between different stations, operation in a mixed human-machine environment, avoidance and bypass of obstacles and alarm notification in case of the loss of connectivity. Safety functions realized in the factory cloud, including hard stop on obstacles, detection and avoidance of the obstacles in the AGV path.
- **Scenario 2: Operation with common map**
  This scenario investigates the operation of the AGVs according to scenario 1 while creating and using a common map in the factory cloud, e.g. for AGV path control or fleet control.
- **Scenario 3: Obstacles in the common map**
  This scenario investigates the operation of the AGVs according to scenario 1 when forcing new routes for the AGVs by introducing obstacles.
- **Scenario 4: Handover between 5G radio cells**
  This scenario investigates the operation of the AGVs according to scenario 1 with seamless mobility between two 5G radio cells.

The second use case focuses on investigating and validating the applicability of 5G for transporting the traffic of TSN/I-LAN applications. The use case focuses on the evaluation of the feasibility of partially replacing fixed interconnections between TSN/I-LAN nodes with 5G mobile communications. This reduces the capital and operational cost of the cables and connectors wear and tear, resulting in a minimization of the maintenance cost. Two subcases are planned to be investigated. In the first subcase, the wired connection between two Bosch industrial controllers (industrial control units) is replaced and realized with 5G connectivity. The industrial control units in the use case implementation (either IndraControl XM21/22 [XM21-22] or CntrlX [CtrlX]) are shown in Figure 5.

(a) (b)

Figure 5: Industrial control units (a) CtrlX (b) IndraControl XM21/XM22, Source: Bosch Rexroth.

The second subcase includes enabling wireless communication between an operational industry machine in the factory and the backend server via the 5G system. The machine involved in the use case is an industrial machine called Rudolph F30, depicted in Figure 66-a, which is a semiconductor production equipment for optical inspection of wafers in different steps of the production process.



(a) (b)

Figure 6: (a) Rudolph F30, (b) Output of the visual inspection, Source: Bosch

The result of the inspection are wafer coordinates of anomalies and abnormalities (defects) including a review and photos of this review (Figure 6-b). These results are transferred over the 5G network to the backend system which further analyzes the information and takes necessary actions to optimize the production process. The detailed steps of the process of wafer inspection are illustrated in Figure 7 and further explained in the following text.

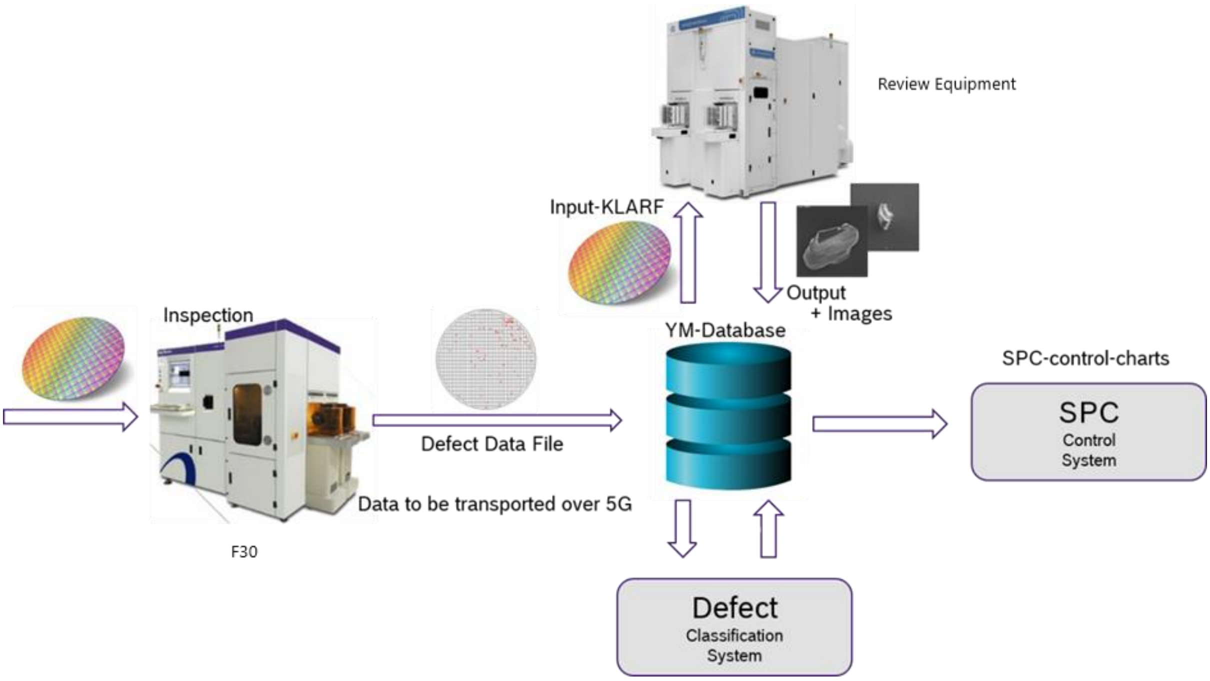


Figure 7: The process and steps involved in visual inspection of wavers, Source: Bosch.

The semiconductor production is operated in lot sizes of maximum 25 wafers. These lots are inspected by a Rudolph F30 either completely or partially, depending to the specific production step. Based on the specific product and process step the F30-inspection will generate some hundred photos for each inspected wafer. A Rudolph F30 will inspect about one hundred wafers per hour and will generate a data volume of about 50 Mb/s data. Latest 1 minute after inspection of the last wafer the complete data of one lot has to be loaded into the related database in order to enable automatic classification of detected defects. For this purpose, the production equipment is currently connected to central Bosch databases as well as to automatic classification applications via high-speed loaders. Production data is sent from main inspection equipment as Defect Data File (called KLARF) to a central yield-manager database (YM-database) which collects all yield related data. This database is connected to other production equipment. The KLARF-data file is sent to the Review-Equipment which performs a defect review inspection. The result of this review inspection is a modified KLARF-file including additional pictures. These files and pictures are sent again to the YM-database. After this review, the data can be accessed by several analysis systems like SPC (Statistical Process Control) control system and the Defect Classification System.

A typical semiconductor production area usually contains tens of inspection equipment (e.g., Rudolph F30). As the location of Rudolph F30 is changing over time due to various boundary conditions of the semiconductor production, replacing the cables between the Rudolph F30 and server with wireless technology would improve the overall productivity of the semiconductor manufacturing. However, the existing wireless technologies such as Wi-Fi are not reliable and performant enough for this purpose.

Figure 8 shows the conceptual 5G deployment for both the controller-to-controller communication subcase and the backend communication subcase.

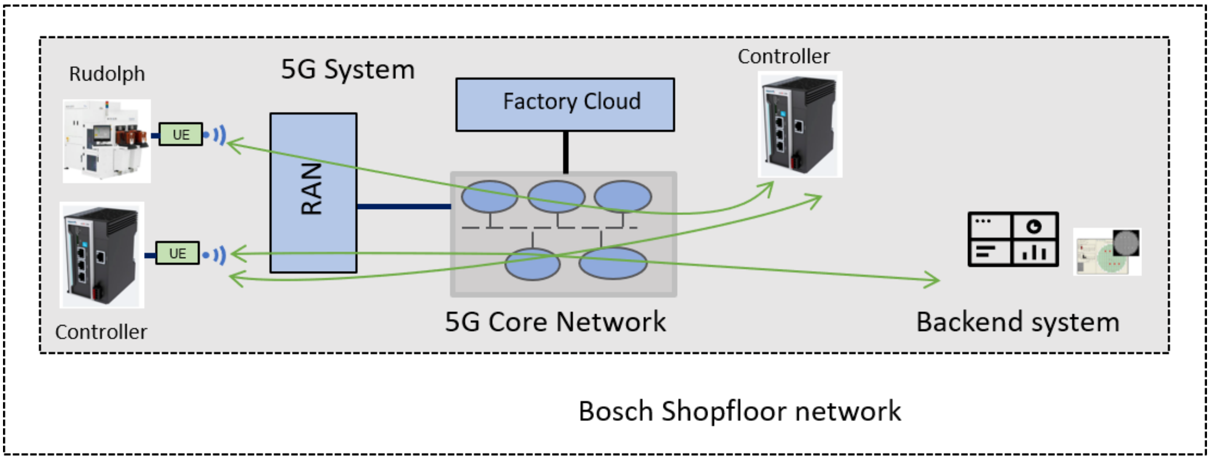


Figure 8: TSN/Industrial LAN use case

3 5G system deployed at the trial site

The constraints and requirements for the design and implementation of the 5G trial system, resulting from the scenarios to be investigated for the use cases, are summarized as follows. Coverage and high performance have to be guaranteed by the 5G deployment on the entire factory floor, comprising an area of around 8000 sqm. The deployment design has to take into account the challenging manufacturing environment and in particular the location of all potential AGV routes and industrial machines. At least 2 cells have to be deployed in order to allow for investigations regarding mobility-related handover.

In this section the 5G system deployed at the trial site as well as the methodology for determining a suitable deployment is described in detail. The methodology is illustrated in Figure 9 and summarized below.

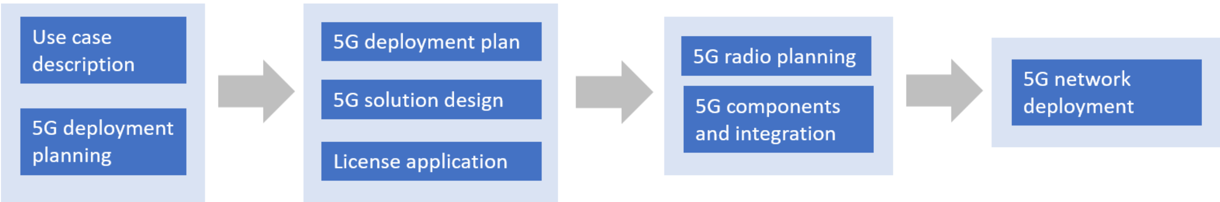


Figure 9: Methodology for determining a suitable deployment

The following steps have been undertaken to determine a suitable 5G network deployment. Starting with the use case description and trial site constraints, deployment constraints have been deduced including coverage, performance and other integration aspects. Taking these constraints into account, a 5G deployment plan along with a 5G network solution design was formulated and an application has been submitted for spectrum licenses. A radio planning activity was conducted which provided suitable location for placing radio antennas on the shopfloor to ensure full coverage and performance. Furthermore, investigations on the integration of the 5G components with the existing industrial IT infrastructure have been performed. Finally, the 5G network has been deployed and initial connectivity tests were performed.

3.1 Spectrum

In Germany the Federal Network Agency (Bundesnetzagentur, BNetzA) decided in 2019 to make spectrum in the 3.7-3.8 GHz band available for local 5G networks. The private spectrum is assigned to applicants on request and the fee is calculated taking into account the bandwidth, usage time duration, and the surface area covered by the assignment [BNE-2019]. 5G-SMART makes use of this spectrum, obtained through an application for test purposes. In particular, Bosch has received a license for 100 MHz bandwidth to be used for validation of the use cases trialed in 5G-SMART.

3.2 Deployment model

The network deployed at the Reutlingen trial site is a dedicated on-premise 5G network operated as an isolated non-public network (NPN). This means that all network functions required to operate the 5G system are located inside the premises of Bosch and the non-public network is completely separate from any public network. All control and user data traffic stay within the defined premises. No Mobile Network Operator (MNO) or other third party is involved in the 5G system operation. A high-level architecture of the deployment is depicted in Figure 10, showing the user equipment (UE) attached to industrial devices, the 5G core, and factory cloud.

The network at the Reutlingen trial site is chosen to be a 5G Standalone (SA) deployment. With the 5G SA deployment, both user plane traffic and control plane signaling are served over 5G New Radio (NR).

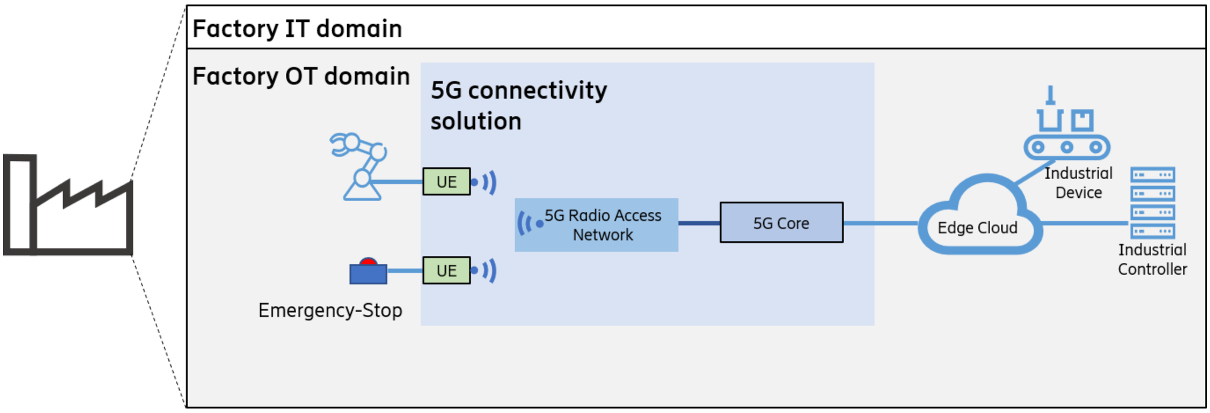


Figure 10: 5G deployment architecture

The Radio Access Network (RAN) is realized with the Ericsson Radio Dot System (RDS) [CTD-2014]. The RDS is specifically designed to provide a flexible, cost-effective architecture and superior network performance for indoor deployments. The RAN consists of three main components: Baseband Unit (BBU), Indoor Radio Unit (IRU) and Radio Dot (RD). 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. The RDs are installed in the ceiling and on walls in the production area according to the radio planning procedure explained in the following section. The IRU aggregates the radio dots' communication and provides power.

To ensure all use case requirements to be satisfied, two radio cells are deployed with in total 16 radio dots. Figure 11 illustrates the deployment.

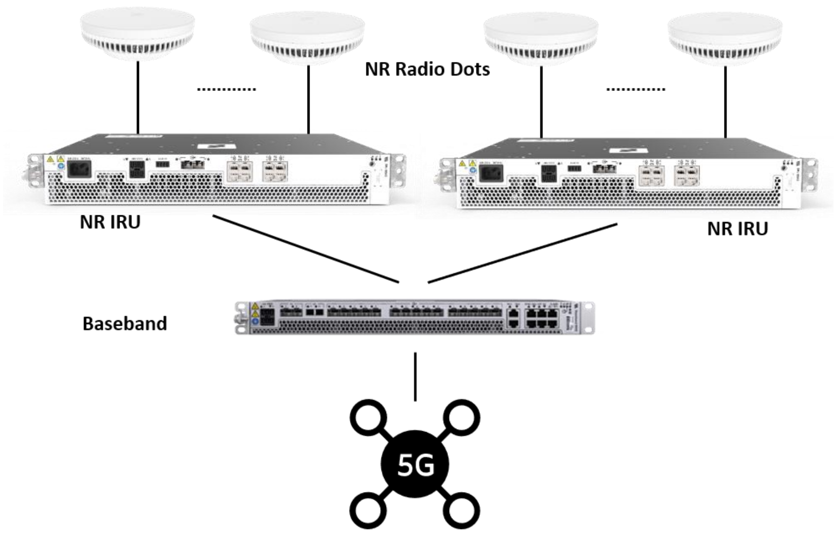


Figure 11: The 2-cell 5G standalone deployment at the Reutlingen trial site, Source: Ericsson.

3.2.1 Integration with the Bosch industrial communication network

The 5G trial system is integrated with the existing industrial communication network, in order to guarantee seamless interworking and a proper realization of the advanced use cases. To this end, industrial cybersecurity is a key topic. The ISA99/IEC 62443 standard is the main international reference framework for cybersecurity in industrial systems where availability and integrity are the most important factors for the adoption of protective measures against cyber threats, but also to reduce unintended technological incidents. In this context, the concepts of zone and conduit play an important role. A security zone according to IEC 62443 is defined as a logical grouping of physical, informational, and application assets that share the same security requirements. A conduit is a specific type of zone that groups the communications which enable information to be transmitted between different zones. It can be virtually or physically implemented via network services, direct physical access or combination of these. Conduits usually employ a firewall to validate any communication made via the conduits.

How zones/conduits are applied in practice on the shopfloor is up to the industrial operator. A common approach is to segment the industrial communication network into separate zones via virtual LANs (VLANs). The 5G deployment made in the semiconductor factory takes into consideration the above security zone concepts.

3.3 Radio planning

Based on the use case requirements and constraints outlined in Section 2.3, a radio network planning was performed using a simulation tool. The radio planning software for designing indoor wireless networks simulates the network in advanced 3D for both coverage and capacity based on floor plans. Due to confidentiality reasons, the floor plans of the semiconductor factory, the final locations of the radio dots and the radio planning simulation results cannot be disclosed in this public report.

The following methodology of radio network planning has been applied for the radio network planning at the Bosch trial site

1. The first step comprises understanding the requirements of the factory owner as well as the requirements imposed by the use cases (see Section 2.3.).
2. In a second step the simulation environment has been built up, this means that a 3D model of the factory has been created. Essential for the simulation quality is the correct Radio Frequency (RF)-modeling of the environment, i.e. understanding the electro-magnetic characteristics of the building itself and its interior. To this end, Bosch provided the floorplan of the factory and additional information on the machinery and objects on the shop floor. Due to the restrictions imposed by the COVID-19 pandemic, a site survey was not possible to be conducted. Instead, an examination of the RF-characteristics of the building has been made based on photos of the manufacturing area.
3. In the environment created in the previous step, simulations were run to determine the optimum RD positions for optimal throughput and coverage. To minimize inter-cell-interferences, four RDs close to the cell border are equipped with external directional antennas. Directional antennas send and receive signals in one direction only. By thus limiting the cell overlap, directional antennas can enhance the coverage and increase the capacity.
   The following indicators have been used in the simulations:
   - Signal strength, SS-RSRP in dBm, SS-RSRP stands for synchronization signal reference signal received power. It is defined as the linear average over the power contributions of the resource elements that carry secondary synchronization signals. SS-RSRP is a measure for signal strength in 5G NR [TS38.215].
   - Signal quality, SNIR in dB, SS-SINR stands for synchronization signal signal-to-noise and interference ratio. It is defined as the linear average over the power contribution over the resource elements carrying secondary synchronization signals with the same frequency bandwidth. SS-SINR is a measure for signal quality in 5G NR [TS38.215].
   - Best server areas, describing to what radio dot a user would be connected depending on her/his location on the factory floor.
4. The determined RD positions were validated with Bosch, to understand the feasibility of their location. Based on this feedback, for some RD positions the locations had to be updated and new simulations had to be run.
5. With the final RD positions, simulations show that the entire cleanroom of the semiconductor factory can be covered with high performance. The results of performance tests will be reported on in Deliverable D4.3, due in November 2021. Due to confidentiality reasons, the simulations and final dot positions cannot be shown in this report.

With the final positions determined with the radio planning methodology described above, the RDs have been installed on site. Figure 12 shows some pictures from the installation.

Figure 12: Installation of the 5G trial system, Source: Ericsson/Bosch.

4 Summary and conclusion

In this deliverable the design and installation of the 5G trial system in the Bosch semiconductor factory are described. Different requirements and constraints to be taken into account for the design have been explained and the different steps of the network design process have been listed. In conclusion, it can be noted that in comparison with the other 5G-SMART trial sites, this fully operational production site required a significantly more advanced investigation and planning for the design and installation of the 5G trial system.

List of abbreviations

5GC	5G Core Network
AGV	Automated Guided Vehicle
BBU	Baseband Unit
CN	Core Network
E2E	End-to-end
IIoT	Industrial Internet of Things
IRU	Indoor Radio Unit
LAN	Local Area Network
MNO	Mobile Network Operator
NPN	Non-Public Network
NR	New Radio
QoS	Quality of Service
RAN	Radio Access Network
RD	Radio Dot
RDS	Radio Dot System
SA	Standalone
TSN	Time Sensitive Networking
UE	User Equipment

Table 1: List of abbreviations

References

BNE-2019	Press release, Bundesnetzagentur, October 2019, https://www.bundesnetzagentur.de/SharedDocs/Pressemitteilungen/EN/2019/
CTD-2014	The Ericsson radio dot system https://www.ericsson.com/en/portfolio/networks/ericsson-radio-system/radio/indoor/radio-dot-system
TS38.215	https://www.etsi.org/deliver/etsi_ts/138200_138299/138215/15.02.00_60/ts_138215v150200p.pdf
5GS20-D110	5G-SMART, Deliverable 1.1," Forward looking smart manufacturing use cases, requirements and KPIs", June 2020 https://5gsmart.eu/wp-content/uploads/5G-SMART-D1.1.pdf
XM21-22	Bosch Rexroth IndraControl, https://apps.boschrexroth.com/ .
CtrlX	Bosch Rexroth CtrlX, https://apps.boschrexroth.com/microsites/ctrlx-automation/en/ .
CE-MARK	https://ec.europa.eu/growth/single-market/ce-marking/