Part IV

Novel IoT Applications at the Cloud, Edge, and “Far-edge”

13

Enabling Remote-controlled Factory Robots via Smart IoT Application Programming Interface

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Abstract

This chapter explores the potential of the Internet of Things (IoT), a network capable of delivering real-time control, touch, and sensing/actuation information, to reshape industrial communication and transform operations in various industries. It covers the technological trends, from legacy industrial networks to emerging industrial wireless networks. It also examines the 5G networks' role in the key Tactile Internet applications developed for the iNGENIOUS project.

Keywords: Internet of Things (IoT), Tactile Internet, Industry 4.0, 5G.

13.1 Introduction

In the early days of mobile wireless communications, such as the second generation (2G) of mobile communications, and the first releases of

WI-FI, they were mainly employed for message exchange and data collection applications. More recently, it became an emerging technology in industrial applications and an indispensable component in today's life. It has not only connected a very large number of the world's population to the Internet, but also, in the last few years, provided connectivity between intelligent devices and machines creating the Internet of Things (IoT). IoT has gained a lot of interest and it has been introduced in different sectors including health, entertainment, and, in particular, in the industrial environment, where it determines the conditions for factories to evolve to the era of the fourth industrial revolution.

IoT applied in the industrial sector can be described as a network of sensors, machines, and monitoring devices connected to the internet and connected to each other. These different components collect data, analyze it, and interact together to continuously carry industrial processes and maintain a constant and efficient workflow. In the case of deviation, the IoT system issues an alert.

As wireless communication continues to be developed, unprecedented applications could be realized. Recently, the network became capable of communicating in real-time haptic information, e.g., touch, motion, and vibration, besides control and actuation commands in addition to the conventional audio–visual data traffic. This communication is ensured through highly reliable internet connectivity. Thus, the concept of the Tactile Internet appeared [1].

Tactile Internet is defined as a reliable network that allows real-time remote access, data exchange, and control of objects (real and virtual objects). It added an extra dimension to wireless communication by allowing real-time machine-to-machine and human-to-machine interactive systems while being highly available, reliable, and secure. In particular, Tactile Internet provides a promising opportunity to reshape industrial wireless communication and transform the operation of many existing industrial systems. It is also a promising technology to realize new use cases (UCs) such as in healthcare and industrial transportation.

Moreover, as 5G technology advances, it opens up new opportunities for smart manufacturing applications. One potential area of implementation is in UCs where wired solutions are impractical, such as mobile robots or automated guided vehicles (AGVs), which require high-performance and scalable wireless technology. Additionally, 5G can be used to improve flexibility and eliminate wear and tear on cables in situations where additional sensors are added to machinery.

This chapter explores the capabilities of IoT in the context of Industry 4.0 characterized by the integration of advanced technologies to improve efficiency and productivity. The iNGENIOUS project, a European Union-funded research project, serves as a prime example of how IoT can be utilized in such an industry. The Factory UC of the iNGENIOUS project specifically focuses on the implementation and demonstration of IoT in a real-world industrial setting. This chapter studies Tactile IoT in industrial environments. It focuses on the role of 5G wireless networks, which have the potential to revolutionize the way Tactile IoT is used in factories and warehouses. It explores how 5G networks can improve the speed, reliability, and scalability of Tactile IoT applications, enabling new and innovative use cases. This part focuses also on one of the key areas where IoT is being applied in the Factory UC of the iNGENIOUS project, which is in the use of automated guided vehicles (AGVs), within a warehouse or factory.

To conclude, this chapter delves into the capabilities of IoT in smart factories and warehouses, with a specific focus on the iNGENIOUS project's Factory UC. The utilization of AGVs and Tactile Internet in the Factory UC serves as an example of how IoT is capable of improving efficiency and productivity in industrial environments.

13.2 IoT Application for Supply chain

Supply chains are one of the most complex parts of business operations since they require synchronization and collaboration between different business segments and actors. In this context, IoT and data analytics applications can play a key role, since they are able to contribute to the optimization of operations, resolve issues, and identify potential bottlenecks across different segments like factories, warehouses, transportation, logistics, or maritime ports. The following presents several examples of IoT applications in supply chains.

13.2.1 IoT applications in smart factories and warehouses

Nowadays, many companies in the industrial manufacturing sector are carrying out smart factory initiatives where systems and devices are expected to become fully interconnected, and where the data among devices can provide valuable insights for improving production efficiency. In this context, next-generation IoT (NG-IoT) technologies will not only enable optimization of the industrial operations but also will affect product, development, storage, and delivery processes, thanks to the efficient use of the data.

The use of NG-IoT applications to connect sensors and establish machine-to-machine (M2M) communication protocols will help factories and warehouses to get real-time data at every stage of the supply chain with communication services offering high levels of reliability and availability (up to 99.999% for control and up to 99.9% for sensing), low latencies (below 10ms), and accurate positioning ($\leq$0.5 m) [2]. Additionally, the combination of IoT applications with cloud-based management systems and artificial intelligence modules can improve machinery operation and asset management procedures [3], thus allowing companies to know the location and status of machinery and goods while predicting risky events like machinery failures or low-stock events.

Other innovations like automated guided vehicles (AGVs) will be able to calculate the shortest route for product delivery, reducing the amount of time needed to complete the operation together with fuel costs. At the same time, by connecting IoT platforms and enabling the exchange of data between supply chain players through distributed ledger technology (DLT) solutions, factories and warehouses will be able to track the different events that take place when products are manufactured and when orders are delivered out of the facilities.

Some examples of IoT applications in smart factory and warehouse scenarios are:

- MindSphere industrial IoT solution [4] developed by Siemens is an industrial IoT as a service solution that uses advanced analytics and AI to power IoT solutions from the edge to the cloud. Thanks to MindSphere, factories and warehouses can ingest and visualize immediate real-time data and analytic results in one centralized location with no development required. For that purpose, it includes different components such as an asset manager, fleet manager, usage transparency, or operator cockpit.
- Amazon Web IoT services for industrial [5] developed by Amazon is an industrial IoT solution that combines machines, cloud computing, and analytics to improve industrial processes' performance and productivity. Thanks to this AWS module, factories and warehouses can cover different use cases such as predictive quality and predictive maintenance or asset condition monitoring. A detailed set of the different components together with their role within the AWS industrial IoT (IIoT) architecture is shown in Figure 13.1.

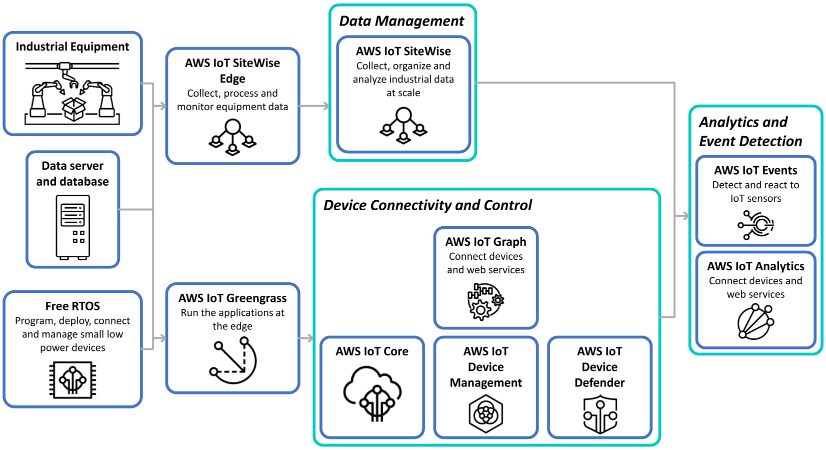


Figure 13.1 AWS IoT architecture. Figure adapted from AWS website: https://aws.amazon.com/de/iot/solutions/industrial-iot/

13.3 Tactile IoT Applications

Tactile Internet is an evolution of IoT characterized by extremely low latency in combination with high availability, reliability, and security. Tactile IoT applications are designed to perform certain tasks by monitoring input data and altering output data accordingly.

These applications involve remote interactions between objects, such as humans, physical machines, or virtual ones, while preserving similar perceptions as when the objects are directly connected. These interactions include remote accessing, perceiving, manipulating, or controlling real or virtual objects or processes and are distinguished by the requirements of ultra-reliable and low-latency communication (URLLC) within 5G networks to achieve perceived real-time response.

The main task is realized by means of one or more processes that define the relations between a set of inputs and a set of outputs. The outputs of some processes might be used as input to others. An exemplary procedure could be: if a bell rings, check the identity of the person and open the door if the person is found in a whitelist. In this case, the input data is the bell signal, and the process is to check the identity of the person, which can be accomplished by sending a command to a camera to take a picture. This leads to a second procedure where the input is now the image, the process is face detection, and the action is to open the door or decline entry.

IoT is commonly associated with the massive deployment of light devices such as sensors and switches with relaxed timing requirements. Tactile internet IoT includes a wide range of applications that are technically distinguished by stringent end-to-end latency requirements.

13.3.1 Tactile Internet applications encountered in supply chain stages

IoT has the potential to revolutionize the way supply chains operate. There are a variety of IoT applications that are currently available for use in supply chain management such as real-time response, predictive maintenance, and smart inventory management. The integration of IoT technology into supply chain operations can bring significant cost savings, improved delivery times, and early identification of issues.

The exact definition of real-time response depends on the application. Accordingly, two main scenarios are encountered:

- Human-in-loop: Here, humans should be able to remotely interact with real or virtual objects and perceive different auditory, visual, and haptic feedback with the same experience when directly dealing with the physical objects. This requires a hyperspectral imaging (HSI) device such as haptic gloves, virtual reality (VR) headset, to translate the human actions to machine-type commands, and the machine feedback to human perceived signals. This category of applications is specifically driven by the challenges of remotely conveying the sensing of haptic touch and kinesthetic muscular movement for humans, in addition to the timing requirements of closed-loop control systems.
- Machine-in-loop: This corresponds to the connection of machines, such as sensors, actuators, robots, and control processes to a computer-based simulation model. In this case, the different interactions should lead to a realistic environment and performance as when the different identities are directly or closely connected.

Tactile applications have practical use in supply chain operations. For example, teleoperation and automation can improve working conditions and increase productivity in logistics. In addition, it enables autonomous applications, e.g., in transportation and warehouse management. These applications are outlined in more detail below.

13.3.1.1 Teleoperation

This application allows a human user to operate a device or machine located in a remote area. Teleoperation enables performing a task in hazardous or inaccessible environments to ensure workers' safety, and it can also be employed to provide comfortable working conditions. Additionally, it allows one operator to control multiple objects (e.g., one driver for more than one AGV). In contrast to conventional remote control, the tactile version of it, depicted in Figure 13.2, offers a realistic experience as the user feels like they are operating a physical device. It is important to note that the application involves one or more robots and one acts as the master and the rest as slaves. The master robot is responsible for receiving commands from the operator and relaying them to the slave robots. A key aspect of this architecture is that not all robots need to be connected to the central server executing the orders, reducing the load in the network, especially if they connect to the master using any type of connectivity for short distances, such as device-to-device (D2D) communications. However, one bottleneck of this architecture is that all communication goes through the master robot, and if it fails, the whole system has problems. For that, the master operator and the slave teleoperator device exchange haptic signals, such as forces, position, velocity, vibration, and torques, in addition to video and audio signals by means of an HSI. The HSI encodes the human actions to commands understood by the teleoperator and translates the feedback from the teleoperator to signals perceived by the human.

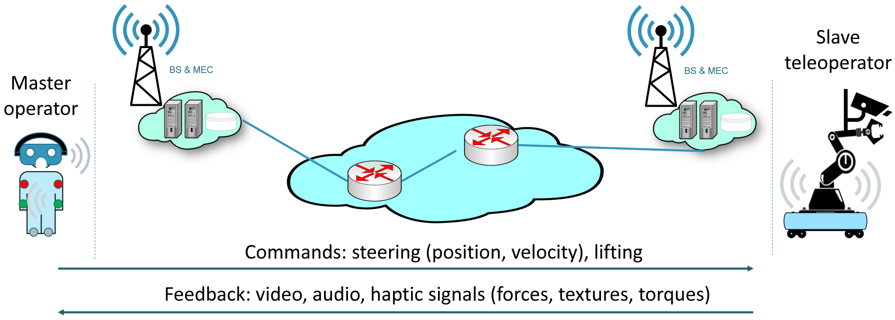


Figure 13.2 Tactile remote operation.

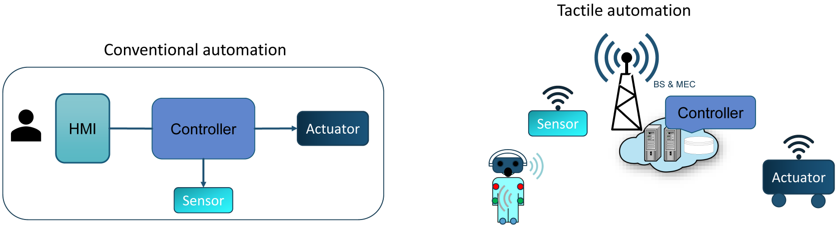
13.3.1.2 Autonomous driving

Mobility is essential for supply chains both for transporting goods and for handling raw materials and products in production lines. Autonomous driving enables smarter, more ecological, and safer movement of people and goods. Self-driving requires processing multiple types of information such as optical images, radar, etc., generated by sensors installed as part of the surrounding infrastructure or on vehicles. The sensed data are conveyed to a controller, which needs to compute and forward driving commands such as steering, braking, and acceleration within a latency constraint. Autonomous driving may also involve platooning, where it is required to control the speed of a line of vehicles traveling in the same direction.

As an example, AGVs are an attractive option for efficient material transportation within factory plants and warehouses. However, current technology hinders flexibility, as sensor and command data processing are carried out at the device, rather than a central command unit. To solve this issue, a common application programming interface (API) that allows communication among AGVs, controlling units, and sensors appears as an attractive way to implement such technology.

13.3.1.3 Industrial automation

Industrial closed-control loop has URLLC requirements similar to those of tactile internet. Thus, the first application is to replace the wired industrial network with a wireless one, as illustrated in Figure 13.3, which leads to greater flexibility and reduced cost of installation and maintenance, especially for connecting moving devices. This flexibility has inspired new industrial applications that connect people, objects, and systems. The conventional human–machine interface (HMI), which typically consists of a display, input terminal, and software for gathering data and altering control parameters, can be replaced by alternative augmented reality (AR) or virtual reality (VR)


Conventional automation

Tactile automation

Figure 13.3 From fixed conventional automation to flexible tactile automation.

interfaces. Mobile platforms such as AGVs and mobile robots can be programmed to perform various scenario-dependent tasks instead of fixed robot arms dedicated to certain tasks. This allows more efficient use of resources and forms the core of next-generation industrial applications.

13.4 Industrial and Tactile Application Programming Interface (API)

In the context of the emerging Industry 4.0 framework [6], the next-generation factories are expected to be efficient, flexible, dynamic, self-organized, and able to produce customized products rather than a massive number of products as in conventional factories. This requires flexible deployment and reconfiguration of production tools, in addition to a dynamic network to fulfill different requirements for connecting people and physical and virtual machines in real and virtual environments. Accordingly, the factory infrastructure, which includes different types of sensors, actuators, processing units, and network resources, will be considered as a ubiquitous computing platform that is ready to execute customized end-user applications. These applications are composed of multiple tactile and non-tactile processes. The tactile processes comprise available tactile applications as discussed in Section 13.3, such as remote operations, autonomous driving, and automation. The other processes involve non-time critical missions such as data collection for monitoring, surveillance, predictive maintenance, and reporting. Aligned with the concept of tactile internet, which focuses on providing a seamless experience when interacting with remote objects as dealing with a direct object, the tactile applications will provide similarity in programming remote distributed terminals as they are on a single computer (see Figure 13.4).

- The processing and storage capabilities act like multi-core processors and memories, which are used in the execution of specific tasks.
- The I/O domain consists of devices, which can be simple inputs (sensors), outputs (actuators), or a stand-alone device with local inputs and outputs, such as tactile HSI.
- The network provides the connection bus system to interconnect the I/O with the processors and memories.
- The network management and orchestration play the role of operating system and expose different APIs that abstract the hardware and provide the programming tools that are used by software developers like system calls as they program a single device, such as a smartphone.

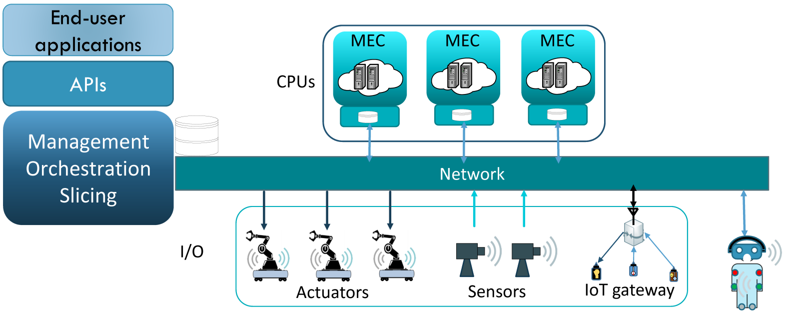


Figure 13.4 Network computer architecture.

- The end-user application runs on top of the network operating system.

As in any computer architecture, a compiler is required to translate the programming code to the hardware language and to ensure at least that some constraints are respected at the compile time. In the network scenario, the compiler is responsible for provisioning the required network and processing resources to fulfill different process requirements in terms of latency, reliability, and data rate, and to consider dynamic conditions such as mobility and changing environment. In addition, run-time error handling should be thoroughly considered to avoid any malfunctioning of the operating system. For instance, to check if a device is already in use by other applications, the communications key performance indicators (KPIs) are fulfilled, and proper release of unused resources is.

Connecting wireless terminals for computer systems is already implemented in everyday life, such as monitors, keyboards, mice, headsets, cameras, and remote controls. However, when considering stringent timing requirements in terms of latency and synchronization between many devices, existing operating systems and connectivity approaches are not sufficient.

5G wireless communication infrastructure is a key enabler for future industrial ecosystems and has become widely available in industrial sites. The sensors and actuators within factory plants can be regarded as available manufacturing resources that can be programmed to produce specific products according to particular specifications. After the production of a determined number of pieces or after the identification of possible product improvements, the resources should be easily rearranged to continue the production with the new specific requirements. In contrast, the current production lines are built to perform repetitive tasks without flexibility. For realizing such a flexible production technique, a software abstraction from the actual physical devices has to be designed. This conceptual abstraction is defined as an industrial and tactile application programming interface (API). In short words, the industrial and tactile API consists of a set of functions that enable the application developer to get data in and out of the system in a unified framework. Within this context, first, a set of common functionalities have been identified as an essential part of the API that enables user-defined applications to exchange data easily and securely.

The industrial and tactile API has to provide different levels of abstraction to effectively serve its purpose. Specifically, three levels can be identified:

1. End-user application development API: This level is crucial as it provides the end user with a simple and easily comprehensible graphical interface for instantiating new applications and presents data in a format that is understandable by the end user.
2. Mid-level function library: This level is important as it contains functions that do not need to be directly used by the end user, such as an object detection algorithm.
3. Low-level API: This level is crucial as it contains functions for data packet formatting and specification of parameters for the physical communication link based on the requirements given by the end user. These functions are fundamental in ensuring proper communication and data transfer between the devices.

For instance, AGVs are attractive options for automated material transportation within factories, as they can improve efficiency and reduce downtime. However, current technology limits the flexibility and dynamic control of multiple AGVs from a central command unit. To solve this, a common data exchange structure via an API is necessary, allowing AGVs, controlling units, and sensors to communicate and perform tasks. A smart IoT API also facilitates the recognition and initial configuration of devices for communication.

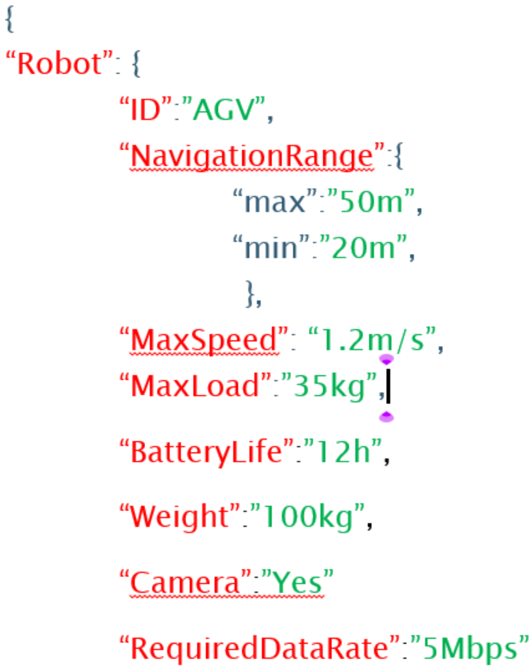
13.4.1 Proof-of-concept within the iNGENIOUS project

To demonstrate this concept within iNGENIOUS [7], the integration between a non-3GPP compliant radio access technology, and a management and orchestration (MANO) entity is carried out using JavaScript object notation

(JSON) format, which consists of an open standard file format for data exchange. A JSON file stores various data types in key-value pairs in a human-readable format, with the keys serving as names and the values containing the related data. An example is illustrated in Figure 13.5. It is commonly used for APIs because of its lightweight to exchange information due to its small file size and it is easy to read/write compared to other data formats, as it is written in an organized and clean way.

In our case, the MANO sends a JSON file containing the resource allocation for each application, and the radio controller unit extracts this information and distributes the resources accordingly.

In AGVs UC for the iNGENIOUS project, an end-to-end (E2E) platform is developed for remotely controlling AGVs in the port area. The primary motivation for enabling remote operation is to improve the driver's safety by avoiding possible hazardous situations related to operating in industrial areas. This is achieved by designing a complete IoT system that enables the vehicle



```
{
“Robot”: {
        “ID”:”AGV”,
        “NavigationRange”:{
                “max”:”50m”,
                “min”:”20m”,
                 },
        “MaxSpeed”: “1.2m/s”,
        “MaxLoad”:”35kg”,

        “BatteryLife”:”12h”,

        “Weight”:”100kg”,

        “Camera”:”Yes”

        “RequiredDataRate”:”5Mbps”
```

Figure 13.5 Example of a JSON file containing information about an AGV device: this information is shared with the IoT application developer.

operator to have continuous situational awareness of the vehicle status and surrounding environment and enables real-time communication of necessary control signals to operate the AGV safely.

In the following, an exemplary set of functionalities is described for an industrial application of AGVs. Within the Factory UC, factory inspection is defined as an application where an AGV travels along a predefined track with a camera and sensors integrated. The video and environmental information collected by the AGV are sent to a remote user that monitors the factory site. The quality of the video can be specified at the beginning of the application by the user. The graphical user interface of such an application is illustrated in Figure 13.6. This example will be illustrated within the iNGENIOUS Factory UC.

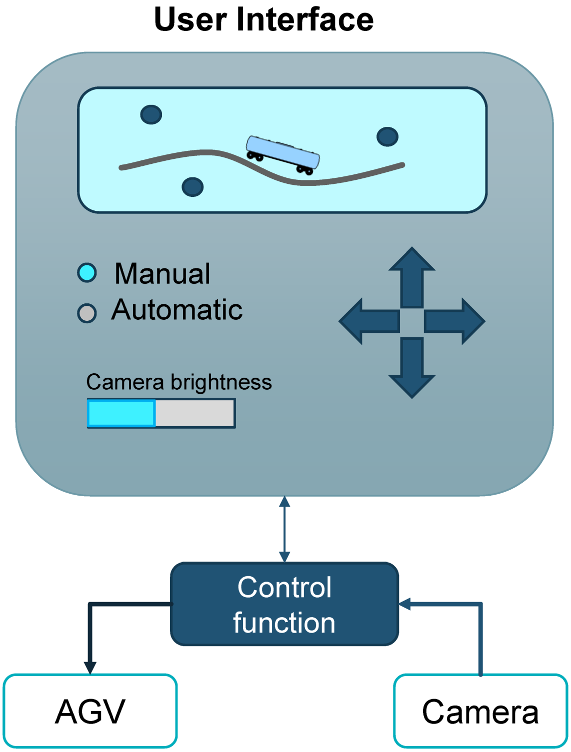


Figure 13.6 Exemplary end-user UI of factory inspection application.

The identified functionalities that have to be available from the industrial and tactile API are:

- Start, stop, and adjust the AGV's speed.
- Transfer the measurements from the AGV to the end user.
- Capture the current image frame and store it in the user's database.
- Transfer AGV's position to the end user.
- Translation of MANO resource allocation to PHY parameters.

The identified connection types of the devices are:

- AGV: UDP frames.
- Camera: UDP frames.

13.5 Conclusion

This chapter explores the potential of Tactile Internet in industrial communication, which aims to provide wireless real-time control and manipulation. It examines the role of Tactile Internet in current industrial systems, evaluating its potential in legacy, emerging, and future industrial networks, in particular within the iNGENIOUS project.

Within iNGENIOUS, it was shown that the operation of the Tactile Internet requires defining interfaces for communication between devices and access to the network. Therefore, the network techniques should be flexible to provide a similar experience for the application developer as programming on a computer by abstracting the hardware and network functionalities.

Moreover, this chapter suggests that the Tactile Internet, through high-performance wireless connectivity, would enable the transition toward wireless for industrial control, simplifying the design of legacy systems and enabling remote operation in various industries. It also notes that the emerging 5G wireless communication network is likely to be the winning technology for the Tactile Internet.

Acknowledgements

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