UNOFFICIAL MACHINE TRANSLATION

The use of 5G and other electronic communications networks for the digitalisation of of businesses, including the use of modern information systems

Prepared for the Ministry of Industry and Trade

May 2024

UNOFFICIAL MACHINE TRANSLATION

Grant Thornton

Contents

Definition of Terms

Defining key terms is an important starting point for the rest of the study and for practical implications. 5G technologies themselves are, in most cases, precise, as they are based on clear 3GPP specifications. However, the field of digitalisation and other areas within companies, such as innovation, product development and their application to specific use cases, are not a science, and even in specialist literature we may encounter a range of different interpretations of individual terms. This does not necessarily mean that one interpretation is correct and another incorrect. It depends on the context and purpose.[1]

Digitalisation vs. Digital Transformation.

Digitalisation and digital transformation are not synonyms, although they are sometimes used interchangeably. The difference between them is therefore explained below.

<u>Business digitisation:</u>

- Digitalisation usually focuses on specific processes or operations within a business.
- The aim of digitisation is to replace traditional, analogue and paper-based procedures with digital technologies in order to increase efficiency, reduce costs and improve operational management.
- Digitalisation may involve automation, a transition to digital systems and processes, the elimination of paperwork, and the optimisation of specific areas of the business.

<u>Digital transformation:</u>

- Digital transformation is a broader and more comprehensive concept that involves a complete overhaul of a company's strategy, culture and operations using digital technologies.
- It is a strategic approach that may involve restructuring business models, changes to business processes, the implementation of new technologies, and the transformation of corporate culture.
- Digital transformation need not be limited to specific operations; it can involve radical changes across the entire business ecosystem to better adapt the business to the digital environment and innovation trends.

The difference between MEC and Edge Computing

MEC is a subset of edge computing, specifically designed to optimise network architectures and improve application performance in mobile networks, including 5G. It focuses primarily on the mobile edge, extending services within mobile network environments. In contrast, edge computing is a broader concept applicable across various networks and sectors, including IoT, manufacturing, healthcare and others, regardless of whether they are mobile or fixed networks.

Integration with mobile networks: MEC is, by its very nature, designed to integrate closely with the operation of mobile networks, particularly 5G, facilitating services such as content caching, real-time processing and context-aware services. Edge computing, whilst capable of operating on mobile networks, is not inherently tied to these networks and can be implemented in any local environment. Both MEC and edge computing are key to the digitalisation of societies, particularly with the advent of 5G (see later in this document).

5G use case	A 5G use case is then a logical extension of the above definition: 'A task that a company needs to carry out in order to achieve a specific result. And for which it makes sense, from both a technical and spectives."

[1] Note: Czech vs. English terms. As in many specialist fields, there are a number of terms in the field of digitalisation and innovation for which no suitable Czech equivalent has been established. As a matter of principle, new terms will also be in English. Just like most specialist literature. It is therefore sometimes necessary to use the original English term, or to use both the English and Czech equivalents. Another reason for using English terms is to enable users to search for further information on the topic. This is straightforward when using the original English term; using an unestablished Czech equivalent could prove problematic.

Case Study	A specific implementation of a Use Case. Within the case study, a specific solution is used to fulfil the task defined in the Use Case. That is, a particular technology, products and services from a specific provider. Regardless of whether this implementation is already in commercial operation, or whether it is a demo implementation or a Proof of Concept.
Digital twin	A digital twin is a virtual model of a physical object, process, system or service. This digital replica mimics a real-world entity in a digital space and captures its behaviour, processes and performance. Digital twins are used for simulation, analysis and control, enabling real-time monitoring and decision-making. They integrate the Internet of Things, artificial intelligence, machine learning and software analytics to update and adapt as their physical counterparts evolve.
Digitalisation	• Digitalisation typically focuses on specific processes or operations within an organisation. • The aim of digitalisation is to replace traditional, analogue and paper-based procedures with digital technologies in order to increase efficiency, reduce costs and improve operational management. • Digitisation may involve automation, the transition to digital systems and processes, the elimination of paperwork, and the optimisation of specific areas of the business.
Business digitalisation	Digitalisation uses digital technologies to transform business processes and provides new opportunities for value creation. It involves converting existing analogue information into digital formats and certain processes that companies can perform more effectively using the latest technologies and tools. The aim of digitalisation is: • increase productivity, • to improve service quality and thereby creating a competitive advantage for the business by using information and communication technology (ICT) to streamline processes.
Digital transformation	• Digital transformation is a broader and more comprehensive concept that involves a complete overhaul of a company's strategy, culture and operations through the use of digital technologies. • It is a strategic approach that may involve restructuring business models, changes to business processes, the implementation of new technologies and the transformation of corporate culture. • Digital transformation need not be limited to specific operations; it can involve radical changes across the entire business ecosystem to better adapt the business to the digital environment and innovation trends.
Edge Computing	Edge computing refers to the practice of processing data near the edge of the network, where the data is generated, rather than in a centralised data processing facility. 'Edge' in this context can refer to any computing and networking resources along the path between data sources (such as IoT devices) and cloud data centres. Edge computing reduces the need to send data there and back to a central server, thereby reducing latency and bandwidth usage.
Innovation	As mentioned above, the digitalisation of a business using 5G technologies is, in principle, an innovation. And this is usually a business process innovation. Let us therefore examine what these terms mean. For a definition of innovation, we can refer to the 'Oslo Manual'. This is a manual prepared by the OECD in collaboration with Eurostat and a number of other global organisations, which serves directly as a guide for the collection, reporting and use of data on innovation. The definition used here therefore has broad practical application. Definition of innovation according to the Oslo Manual: "The term innovation can refer to both an activity and the result of an activity." "An innovation is a new or improved product or process (or a combination thereof) that differs significantly from previous products or processes and that has been made available to potential users (product) or put into use (process)." It is clear from the definition that the object of innovation is either a product or a process. Note: the term 'process' here refers to a business process for one of the company's functions. This is a certain simplification compared to older versions of the Oslo Manual, which included more types (objects) of innovation. Indeed, this can also be found elsewhere in the literature. For example, organisational innovation, marketing and sales innovation… however, all these types of innovation can be classified under the broader concept of a business process. For this reason, the Oslo Manual also provides definitions for these two types of innovation: "Product innovation is a new or improved good or service that differs significantly from the firm's previous goods or services and that has been brought to market." "Business process innovation is a new or improved business process for one or more business functions that differs significantly from the company's previous business processes and which the company has started to use." In simple terms, it can therefore be summarised that the digitalisation of a business using 5G represents an innovation in the form of implementing a new or improved process for one or more business functions and making it available for use.
MEC (Multi-access Edge Computing)	Multi-access Edge Computing (MEC) is a network architecture concept that enables cloud computing and IT service environments at the network edge. MEC brings computing resources closer to where data is generated and consumed, reduces latency, improves processing speed and enhances the user experience. It is often associated with mobile networks, particularly 5G, where it can process data in the vicinity of mobile base stations or other network access points. The difference between MEC and Edge Computing: MEC is a subset of edge computing, specifically designed to optimise network architectures and improve application performance in mobile networks, including 5G. It focuses primarily on the mobile edge, extending services within mobile network environments. In contrast, edge computing is a broader concept applicable across various networks and industries, including IoT, manufacturing, healthcare and others, regardless of whether they are mobile or fixed networks. Integration with mobile networks: MEC is, by its very nature, designed to integrate closely with the operation of mobile networks, particularly 5G, facilitating services such as content caching, real-time processing and context-aware services. Edge computing, whilst it can operate on mobile networks, is not inherently tied to these networks and can be implemented in any local environment. Both MEC and edge computing are key to the digitalisation of societies, particularly with the advent of 5G (see later in this document).
Processes	Digitalisation focuses primarily on processes. It is therefore important to define business processes. In a business context, a 'process' refers to a set of structured activities or tasks performed by people or systems in sequence to achieve a specific business outcome or objective. These activities

	transform inputs, such as raw materials, data or information, into outputs, which are goods or services provided to customers. The purpose of a process is to add value, increase efficiency and improve the organisation's performance. Types of business processes: 1. Core processes: These are critical processes that directly influence the organisation's value proposition and are essential for delivering primary products or services to customers. Examples include product development, manufacturing and sales. 2. Support processes: These processes support core processes and ensure the organisation runs efficiently. They do not directly add value to a product or service, but are essential for the smooth running of the business. Examples include human resources, accounting and IT support. 3. Management processes: These are the processes involved in the administration and strategic management of the organisation. They include activities such as planning, decision-making, performance management and corporate governance. 4. Operational processes: These processes are the day-to-day activities that contribute to the running of the business. They are, by their nature, repetitive and routine, such as order processing, customer service and inventory management.
Solutions incorporating 5G technology	Products and related services, particularly • technology delivery, • access to resources, • service operations. Which are designed to deliver value to the customer by addressing their needs for high-quality connectivity. Solutions incorporating 5G technology typically include the following components of the value chain: • spectrum, • infrastructure, • equipment, • services, • applications, • management.
Use case	A use case is a term that plays a key role in the application of 5G for business digitalisation. It is therefore worth paying close attention to its definition. The general definition of a use case is as follows: The term 'use case' refers to a specific situation or scenario in which a product or service can be used. In software and systems engineering, a use case is a list of steps that typically defines the interaction between a so-called role and a system. The role may be a person or an external system. This definition is well known to those working in the field, but it is not suitable for the area of digitalisation and innovation. From the perspective of digitalisation, which is essentially an innovation process, it is appropriate to use a definition based on JTBD, or Jobs Theory. A use case can then be defined as follows: "A task that a company needs to carry out in order to achieve a specific result." This definition is suitable because it highlights the fact that a use case serves to achieve a specific outcome, or a range of different desired outcomes (such as increasing work efficiency, minimising risks to employees, minimising waste, etc.). Furthermore, it is thus possible to apply other suitable JTBD procedures , such as breaking the task down into stages and sub-tasks, creating a task map, increasing or decreasing the level of abstraction of the task, etc.
Vertical	In a business context, the term 'verticals' is used to describe the categorisation of companies or industries according to their specialisation or focus on a specific market segment. Verticals are usually industries or sectors comprising businesses that specialise in a specific type of product, services or market segments.

Executive summary

The digitalisation of businesses using 5G technologies in the Czech Republic is progressing. The pace of this progress is comparable to that of other European countries, but it still lags behind both leading nations such as Germany and the expectations of the professional community associated with the 5G spectrum auction. This comparison is based primarily on projects involving private 5G networks, as the capabilities of public 5G networks—currently without support for so-called network slicing—are limited for supporting most use cases of business digitalisation.

The state of business digitalisation using 5G is characterised in the study from the perspective of (1) the regulatory environment, (2) the state of research and development, (3) the availability of support programmes, and also (4) projects implemented to date.

The regulatory environment in the Czech Republic allows for the establishment of private 5G networks. However, it is subject to restrictions (designated solely for Industry 4.0, machine-to-machine communication, and a non-reserved band for private networks only), which affect the low utilisation of the potentially available spectrum for private 5G networks and, indirectly, the high costs of private networks. The study therefore proposes ways to further improve the regulatory environment. These range from the necessary interpretation of the existing band, through the use of other possible bands, to the use of unlicensed bands for 5G technologies.

The Czech Republic has a significant research and development base in the field of Industry 4.0. This includes operational testbeds (CIIRC in Prague and CEITEC in Brno) with their own 5G networks, which are ready to collaborate with companies on their digitalisation projects, including the possibility of testing proposed technologies and solutions. It will certainly be desirable to further promote these opportunities in order to increase the number of companies that actually make use of them.

Companies in the Czech Republic can make use of support programmes both in the field of research and development of 5G technologies and in the implementation of specific use cases related to the use of 5G. We should see the results of these programmes by 2025 at the latest. It will certainly be desirable to maintain, or rather repeat, support programmes specifically aimed at promoting digitalisation with 5G. Czech companies can also make use of programmes at European level, specifically, for example, ‘5G for smart communities’. However, this is not yet happening. In this regard, further awareness-raising and support are needed to help companies utilise these resources.

Several corporate digitalisation projects utilising private 5G networks are already underway in the Czech Republic: Škoda Auto, Toyota, Continental, Kvados, BD Sensors, and LARS Chemie. *Use cases associated with the Continental and Kvados projects are described in more detail in the case studies attached to this report.*

Based on an analysis of specific solutions and in-depth interviews with stakeholders across the entire ecosystem, including manufacturers, suppliers, system integrators, service providers, operators and potential customers, we have identified the following barriers to faster corporate digitalisation using 5G: (1) regulatory conditions, (2) costs, (3) lack of know-how, and (4) a limited ecosystem.

The study proposes steps for each of these areas to remove or mitigate these barriers. It also suggests further steps to support 5G-enabled digitalisation in the areas of education, financial incentives and further improvements to the regulatory environment.

For businesses, as well as other stakeholders, who have plans and ambitions in the field of digitalisation and have use cases that require data connectivity, this study provides information to help them navigate the entire issue:

- A comprehensive overview not only of 5G technology but, in particular, of private 5G networks, including their types, a comparison with Wi-Fi, cost aspects, links to edge computing, and spectrum acquisition conditions.
- An overview of more than 40 use cases for digitalisation with 5G, which may serve as inspiration. The use cases are for verticals where the use of 5G for digitalisation is most common: industry, logistics and transport, healthcare, and agriculture. The use cases are further categorised for easier navigation.
- Guidance on how to formulate and implement a 5G digitalisation strategy. The OKR methodology is used to define objectives, key results and necessary activities. Digitalisation using 5G is, in principle, an innovation project. The study therefore includes guidance on how to proceed so that innovation is driven by user needs, not by technology.
- The study includes detailed case studies. Unlike general use cases, these contain specific solutions and technologies, and their value also lies in explaining the actual benefits of using 5G in each specific instance.

Management summary

The digitisation of businesses using 5G technologies in the Czech Republic is advancing. The pace of this progress is comparable to that of other European countries, but it still lags behind both leading countries such as Germany and the expectations of the professional community, which were linked to the auction of 5G frequencies. This comparison is based primarily on projects related to private 5G networks, as the capabilities of public 5G networks without support for network slicing are limited when it comes to supporting most use cases of enterprise digitalisation.

The study characterises the state of enterprise digitalisation using 5G in terms of (1) the regulatory environment, (2) the state of research and development, (3) the availability of support programmes, and (4) the projects implemented to date.

The regulatory environment in the Czech Republic permits the emergence of private 5G networks. However, it is subject to restrictions (intended solely for Industry 4.0, machine-to-machine communication, and a non-reserved band exclusively for private networks), which result in the underutilisation of potentially available spectrum for private 5G networks, and consequently in the high costs of private networks. Therefore, the study proposes ways to further improve the regulatory environment. These range from the necessary interpretation of the existing band, through the use of other possible bands, to the use of unlicensed bands for 5G technologies.

The Czech Republic has a significant base of research and development in the field of Industry 4.0. This includes functional testbeds (CIIRC in Prague and CEITEC in Brno) with their own 5G networks, which are ready to cooperate with companies on their digitalisation projects, including the possibility of testing the proposed technologies and solutions. It will certainly be desirable to further promote these options in order to increase the number of companies that actually use them.

Companies in the Czech Republic can benefit from support programmes both in the field of research and development of 5G technologies and the implementation of specific use cases associated with the use of 5G. We should see the results of these programmes by 2025 at the latest. It will certainly be desirable to maintain, or rather repeat, support programmes aimed specifically at supporting digitisation with 5G. Czech companies can also make use of programmes at the European level, specifically, for example, ‘5G for smart communities’. So far, however, this has not been the case. In this regard, further education and support are needed to help companies utilise these resources.

In the Czech Republic, several digitalisation projects by companies using private 5G networks have already been implemented: Škoda Auto, Toyota, Continental, Kvados, BD Sensors, LARS Chemie. *The use cases associated with the Continental and Kvados projects are described in more detail in the case studies in the appendix to this study.*

Based on an analysis of specific solutions and in-depth interviews with stakeholders across the ecosystem, including manufacturers, suppliers, system integrators, service providers, operators, and potential customers, we have identified the following barriers to accelerating business digitalisation with 5G: (1) regulatory conditions, (2) cost, (3) lack of know-how, and (4) a limited ecosystem.

The study proposes steps to remove or reduce these barriers in each of these areas. It also sets out a proposal for further steps to support digitisation with 5G in the fields of education, financial incentives and further improvement of the regulatory environment.

For companies and other stakeholders with plans and ambitions for digitalisation and use cases that require data connectivity, this study provides information to help them navigate the issue:

- A detailed description not only of 5G technology, but particularly of private 5G networks, including their types, a comparison with Wi-Fi, cost considerations, links to edge computing, and the conditions for obtaining spectrum.
- An overview of more than 40 use cases for digitalisation with 5G that can inspire them. The use cases cover the sectors where the use of 5G for digitalisation is most common: industry, logistics and transport, healthcare, and agriculture. Use cases are further categorised for easier reference.
- Guidance on how to formulate and implement a digitalisation strategy using 5G. The OKR methodology is used to set goals, key results and necessary activities. Digitalisation using 5G is essentially an innovation project. Therefore, the study provides guidance on how to proceed so that innovation is driven by user needs, not by technology.
- Detailed case studies form part of the study. Compared to general use cases, they contain specific solutions and technologies, and their value also lies in explaining the real benefits of using 5G in a given scenario.

1 Introduction

1.1 The significance of digital transformation using 5G

On the cusp of the Fourth Industrial Revolution, the digital transformation of businesses is proving to be not only a path to competitive advantage, but a key strategy for survival. This transformation, characterised by the integration of digital technologies into all areas of business, is fundamentally changing the way organisations operate and deliver value to customers. It is a comprehensive journey that encompasses everything from streamlining operations to innovating products and services, whilst emphasising agility and fostering a culture of change.

One of the pillars of this digital metamorphosis is the advent and integration of 5G technology. With its promise of unprecedented capacity, reliability and low latency, 5G is set to bring about radical change across a range of sectors by enabling new ways of connecting, communicating and managing operations. The impact of 5G is expected to be far-reaching, affecting various sectors from manufacturing to healthcare, from retail to smart cities, and enabling a vast array of use cases ranging from real-time data processing to remote surgical operations.

A key aspect of the 5G revolution for businesses is the emergence of private 5G networks. These networks offer businesses customised connectivity solutions that meet their specific requirements for security, capacity and speed. Unlike public networks (note: to a certain extent with the exception of network slicing, which is not yet available in the Czech Republic), private 5G networks can be tailored to a company's unique operational requirements, ensuring data privacy, dedicated resources and a scalable infrastructure that supports both current needs and future digitalisation projects.

However, the significance of this transformation lies not merely in technological improvement. It is about reshaping the business environment to enable companies to innovate, scale up and compete in a rapidly changing world. For the Czech Republic, harnessing the potential of 5G to support digital transformation is not merely a matter of economic competitiveness, but a strategic necessity. It has the potential to increase the operational efficiency of Czech businesses, strengthen their global competitiveness and thereby improve the country's standing in the field of digital innovation.

The path to widespread adoption of 5G in the implementation of digital transformation is, understandably, fraught with challenges. It requires a concerted effort by all stakeholders – government agencies, businesses, technology providers and educational institutions – to create an ecosystem that supports innovation, addresses regulatory and infrastructure barriers, and cultivates the necessary skills and knowledge.

This study, commissioned by the Ministry of Industry and Trade of the Czech Republic, aims to assist in navigating this demanding journey. It places emphasis on a realistic assessment of the current situation as a basis for identifying problems and formulating solutions.

1.2 Objectives of the study

The aim of the study is to support the actual progress of business digitalisation using 5G technology and to help ensure that these solutions become accessible to a wide range of businesses engaged in digitalisation, regardless of their size or sector. The study aims to achieve this by fulfilling the following tasks:

- **Facilitate the roll-out of 5G technologies**: The study will help the Ministry of Industry and Trade and other government bodies create favourable conditions for the roll-out of 5G technologies in the context of business digitalisation. This includes identifying barriers and ways to overcome them in the areas of regulation, knowledge, the ecosystem and costs, which currently hinder the wider use of 5G technologies for digitalisation purposes.
- **To assist companies with more effective digitalisation using 5G technology**: In particular, by presenting suitable use cases and case studies, including possible methods of implementation and how to set objectives and a strategy based on user needs rather than the technology itself. Furthermore, by clarifying the various ways of deploying 5G technologies, including an indicative cost structure for the relevant solution. This will enable companies to navigate the complexities of using 5G technologies and help them integrate them into their digital transformation strategy.
- **Informing and engaging stakeholders**: The study focuses on a broad spectrum of stakeholders, including government bodies, businesses seeking to digitise, educational institutions, providers of digitisation solutions, and current and potential suppliers of 5G solutions. It aims to increase their understanding of the current situation, and to provide information on the possibilities and conditions for using 5G technologies for digitalisation in the Czech Republic, compared with international benchmarks.

1.3 Scope and focus of the study

Business digitalisation is an almost all-encompassing concept that encompasses all corporate functions, processes and systems. This study therefore focuses specifically on the use of 5G technologies for business digitalisation, rather than on digitalisation in the general sense. A clear focus will enable this issue to be analysed in sufficient depth and quality to deliver real added value. The study therefore examines aspects of 5G technology essential for business digitalisation (whether technical, commercial or regulatory) on the one hand, and use cases for which it makes sense to utilise 5G technology on the other.

2 Digitalisation using 5G in the EU and the Czech Republic

2.1 EU initiatives to support 5G

There are a number of initiatives within the EU aimed at maximising the potential of 5G. These initiatives demonstrate the European Union's commitment to advancing the roll-out of 5G technology and its integration into various sectors for digital transformation. Some of these initiatives can be utilised by local entities to support their 5G-based projects. However, participation by entities from the Czech Republic is practically non-existent. This contrasts with many other European countries, including those in Central Europe. This indicates untapped potential. There are several reasons for this:

- One of them is a general lack of awareness of the existence of these opportunities.
- Another is the concern about the complexity of preparing, drafting and submitting a project proposal, which must, of course, be written in English.
- Finally, there may be concerns regarding the subsequent administration and reporting of the project.

Most of these obstacles can be overcome by improving awareness of both the existence of these initiatives and their conditions, as well as the conditions for subsequent administration. The key initiatives to support 5G are outlined below:

2.1.1 5G Action Plan (2016)[2]

The first major 5G initiative announced by the European Commission was the 5G Action Plan, which was announced in 2016. It established pioneering frequency bands and set out 5G targets. One of the targets was the commercial launch of 5G services in all EU countries by 2020. Most EU countries have achieved this target, and only a few are still working towards it.

The 5G Action Plan was part of a broader vision for connectivity, including achieving gigabit connectivity for key social and economic sectors and ensuring continuous 5G coverage in urban areas and along major transport routes by 2020.

2.1.2 Gigabit Society[3]

In 2016, the Commission launched the Gigabit Society initiative, which sets out a vision for connectivity in the EU over the next decade. Key objectives include 100 Mbps networks for all households and gigabit speeds for key businesses and institutions. 5G can help achieve these speeds through technologies such as fixed wireless access (FWA).

The initiative also sets specific targets for 5G, such as seamless 5G coverage in all urban areas and along major transport routes, and access to mobile data anywhere by 2025.

---

[2] *5G Action Plan*. (5 April 2024). Shaping Europe's Digital Future. https://digital-strategy.ec.europa.eu/en/policies/5g-action-plan

[3] *Connectivity for a European Gigabit Society - Brochure*. (23 September 2019). Shaping Europe's Digital Future. https://digital-

strategy.ec.europa.eu/en/library/connectivity-european-gigabit-society-brochure

2.1.3 EU Toolbox for 5G Security[4]

This set of measures was introduced in 2021 to secure 5G networks within the EU, raise security requirements, assess supplier risks and reduce dependence on individual suppliers. The initiative reflects the EU's focus on the security aspect of 5G deployment.

An EU-wide coordinated risk assessment for 5G network security identified nine main risks grouped into five risk scenarios.

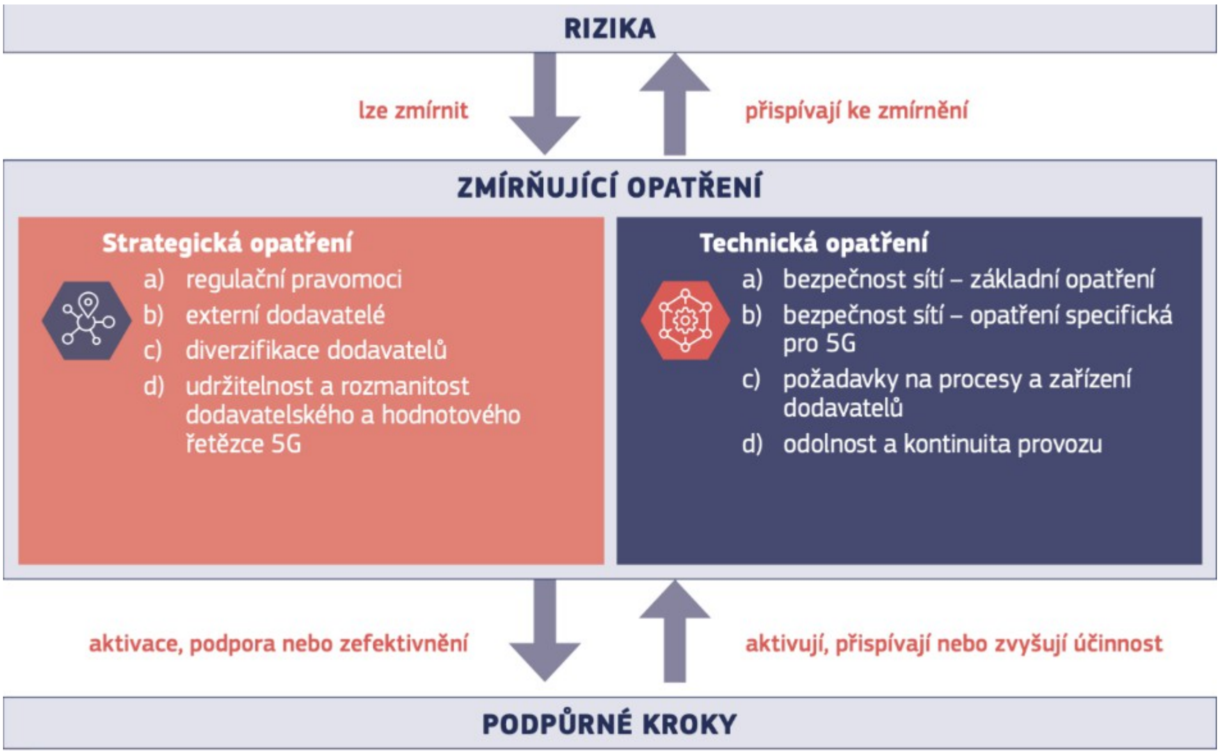
Figure 1: Risk diagram according to the EU Toolbox for 5G Security. Source: The EU Toolbox for 5G Security, 2020.

I – Rizikové scénáře související s nedostatečnými bezpečnostními opatřeními	R1 – Nesprávně konfigurované sítě R2 – Nedostatečná kontrola přístupu
II – Rizikové scénáře související s dodavatelským řetězcem 5G	R3 – Nízká kvalita produktů R4 – Závislost na jediném dodavateli v rámci jedné sítě nebo nedostatečná vnitrostátní diverzita
III – Rizikové scénáře související se způsobem práce hlavních původců hrozeb	R5 – Zásahy státu prostřednictvím dodavatelského řetězce 5G R6 – Organizované zločinecké skupiny zneužívající sítě 5G nebo cílící na koncové uživatele
IV – Rizikové scénáře související se vzájemnou závislostí sítí 5G a dalších kritických systémů	R7 – Významné narušení kritické infrastruktury nebo služeb R8 – Vážné selhání sítí způsobené přerušením dodávky elektřiny nebo jinými podpůrnými systémy
V – Rizikové scénáře související se zařízeními koncových uživatelů	R9 – Zneužití internetu věcí, telefonů nebo chytrých zařízení

The set of measures is based on the EU-wide coordinated risk assessment for 5G network security and contains a range of security measures aimed at effectively mitigating risks and ensuring the deployment of secure 5G networks in Europe. It includes detailed plans for mitigating each of the identified risks and recommends a set of key strategic and technical measures to be adopted by Member States or the Commission.

[4] *The EU toolbox for 5G security*. (29 January 2020). Shaping Europe's Digital Future. https://digital-strategy.ec.europa.eu/en/library/eu-toolbox-5g-security

Figure 2 Mitigation measures. Source: The EU toolbox for 5G security, 2020.



Knowledge of the EU toolbox for 5G is also important because projects that may be supported under any of the EU programmes must demonstrate that they meet these security requirements.

2.1.4 EU Digital Decade[5]

This initiative, announced in March 2021, outlines a vision for Europe's digital transformation by 2030, focusing on ICT skills, business transformation, secure and sustainable digital infrastructure, and the digitisation of public services. 5G technology plays a crucial role in this transformation, with specific targets set for 5G coverage in all populated areas and along major transport routes by 2030.

The Digital Decade framework includes:

- **The Digital Decade targets** are measurable objectives for each of the four areas: connectivity, digital skills, digital business and digital public services. Member States' measures will be guided by the Digital Decade targets. The Commission will report on Member States' measures in an annual report.
- **The Digital Decade policy agenda** will enable the EU and Member States to work together to achieve the Digital Decade's objectives and targets. It sets out a mechanism for monitoring progress up to 2030. The Commission will publish an annual report assessing the progress made.
- **Multi-country projects** will enable Member States to pool investments and launch large-scale cross-border projects.
- **The rights and principles of the Digital Decade** reflect the EU's values, which must be respected in the digital world.

[5] *Europe's Digital Decade*. (11 April 2024). Shaping Europe's Digital Future. https://digital-strategy.ec.europa.eu/en/policies/europes-digital-decade

The Digital Decade's objectives

The Digital Decade programme sets out digital ambitions for the coming decade in the form of clear and concrete objectives. The main objectives can be summarised in four points:

- a digitally skilled population and highly qualified digital professionals;
- secure and sustainable digital infrastructure;
- the digital transformation of businesses;
- the digitisation of public services.

The digital transformation of businesses is explicitly defined as one of the four objectives of the Digital Decade. It is clear from this that the Digital Decade is highly relevant to the digitalisation of businesses. Knowledge of this framework can, once again, help ensure the success of selected projects and their funding.

Multi-country projects

These are large-scale projects that can contribute to achieving the Digital Decade's objectives. They will enable Member States to join forces and pool resources to build digital capacities that they would not be able to develop on their own. The Commission has identified an initial list of areas for multi-country projects and may update this list as necessary, based on annual progress monitoring.

Multi-country projects should pool investments from EU financial resources, including funds from the Recovery and Resilience Facility (RRF), as well as from Member States. Where necessary, other public and private entities may invest in the projects.

The Commission will assist Member States in identifying, launching and implementing multi-country projects. To establish a multi-country project where no other legal instrument exists, the policy framework envisages a new legal structure, the European Digital Infrastructure Consortium (EDIC), which will enable rapid and flexible implementation.

Projects may relate in particular to the following areas:

- Data infrastructure and services
- Blockchain
- Low-power processors
- **Pan-European 5G corridors**
- High-performance computing (HPC)
- Cybersecurity centres
- Digitalisation of public administration
- Digital innovation centres
- Partnerships for digital skills

2.1.5 The Recovery and Resilience Facility (RRF) under NextGenerationEU[6]

The Recovery and Resilience Facility (RRF) under NextGenerationEU: The RRF is a key component of the EU's recovery package, designed to mitigate the impact of the COVID-19 crisis. A significant portion of the budget, 20% or €130 billion, is earmarked for digital transformation, including 5G as a strategic area. This demonstrates that the EU recognises 5G as a vital tool for economic recovery and digital transformation.

The EU Recovery and Resilience Facility (RRF) is a central component of NextGenerationEU, designed to help EU countries emerge stronger and more resilient from the COVID-19 crisis. It plays a key role in funding the digital transformation in the EU, including the adoption and integration of 5G technologies.

The RRF provides over €670 billion in loans and grants to support reforms and investments across the EU. A significant portion of these investments is dedicated to the digital transformation of the economy and society, with at least 20% of the budget of each national plan earmarked for this area. This commitment includes the development and implementation of 5G technologies, which are essential to these efforts

[6] *Recovery and Resilience Facility*. (12 February 2021). European Commission. https://commission.europa.eu/business-economy-euro/economic-recovery/recovery-and-resilience-facility_en

digitalisation efforts. To finance these ambitious plans, the European Commission borrows on the markets at favourable rates and redistributes these funds among Member States. This strategy ensures that the EU can raise up to approximately €800 billion for NextGenerationEU.

Programmes and projects under the RRF related to digitalisation include updating educational curricula to improve digital skills, investing in workforce training, supporting digital innovation through Digital Innovation Hubs (DIHs), and upgrading digital equipment in schools and training institutions. These initiatives are vital for enabling the successful digital transformation of businesses and society at large, and support the development of advanced technologies such as artificial intelligence (AI), cybersecurity, and, not least, 5G.

Companies in the EU can participate in RRF projects and funding by aligning their activities with the digital transformation objectives set out in their country's national recovery and resilience plans. This may include participating in training and skills development initiatives, collaborating with educational and research institutions, and investing in digital infrastructure and capabilities that support the adoption of 5G and other advanced technologies.

The Recovery and Resilience Facility (RRF) works by allocating funds to EU Member States based on their national recovery and resilience plans. These plans outline a comprehensive package of reforms and public investment projects, including those relating to digital transformation and the adoption of 5G technologies. So, whilst the RRF provides an overarching financial framework and sets priorities, the actual funding of specific projects, including those proposed by companies, is managed at national level through these plans.

Companies wishing to benefit from RRF funding should therefore engage with their respective countries' national recovery and resilience plans. This involves understanding the specific priorities and criteria set out in these plans and how their projects can contribute to achieving national and pan-European digital transformation objectives.

2.1.6 Connecting Europe Facility (CEF) – CEF Digital

The Connecting Europe Facility is a key EU financial instrument for supporting growth, employment and competitiveness through investment in infrastructure at European level.

CEF – Digital[7]

From the perspective of this study, we are interested in the CEF Digital strand, which is managed by HaDEA (Health and Digital Executive Agency).

The Connecting Europe Facility Digital (CEF Digital) programme, with a budget of €1.6 billion for the period 2021–2027, is designed to support investment in digital connectivity infrastructure of common European interest. Its aim is to improve digital infrastructure across the EU and ensure high-quality, interconnected digital networks and services. Specifically for the roll-out of 5G, CEF Digital has allocated significant funding to strengthen 5G connectivity along major transport routes and for smart communities, with the aim of achieving comprehensive coverage and supporting the digital transformation of public services and businesses.

One of the key areas supported by CEF Digital in relation to 5G is the '5G for Smart Communities' programme, which has a budget of €142 million for the period 2021 to 2027. This initiative focuses on the early deployment of 5G and edge infrastructure, enabling innovative solutions for public administrations, healthcare centres, schools and other educational institutions. The aim is to make these entities smarter, more efficient and more adaptable to changing needs, thanks in part to the use of cutting-edge connectivity.

CEF Digital support for 5G also includes funding for 5G coverage along transport corridors, ensuring a pan-European network of 5G-enabled transport routes by 2027. This effort is key to enabling the roll-out of connected and automated mobility solutions across Europe.

Companies wishing to benefit from CEF Digital projects and funding for digitalisation via 5G can participate directly in the "5G for smart communities".

Participation in consortia: Companies, particularly mobile network operators – though this may also include providers of private 5G networks, so not necessarily just traditional mobile operators – and providers of services of general economic interest (SGI/SGEI), may form or join consortia and apply for funding under calls for proposals, such as those for "5G for

[7] *Connecting Europe Facility*. (27 March 2024). European Health and Digital Executive Agency (HaDEA). https://hadea.ec.europa.eu/programmes/connecting-europe-facility_en

'5G for smart communities'. These projects should utilise 5G infrastructure and combine it with cloud-to-edge middleware stacks that support data-intensive use cases.

Projects funded under CEF Digital are expected to serve as blueprints for digital innovation that can be replicated across Europe. Companies can use these blueprints to innovate within their local context or to expand their services into new areas using established 5G infrastructure.

By participating in or supporting the roll-out of 5G in smart communities, companies can gain access to new markets and opportunities for digital services tailored to the needs of public authorities, healthcare centres and educational institutions.

Given the competitive nature of CEF Digital calls and the detailed preparation required for successful applications, companies should stay informed about upcoming funding opportunities and requirements. Early engagement with national contact points and the use of CEF Digital's digital communication tools and social media guides can help companies navigate the application process more effectively.

In short, CEF Digital provides companies with a significant opportunity to engage in the EU's digital transformation, with a strong emphasis on the roll-out of 5G. By participating in relevant projects, companies can not only gain access to funding but also contribute to and benefit from broader digitalisation efforts across the continent.

However, participation by companies from the Czech Republic has so far been virtually non-existent, and this opportunity therefore remains entirely wasted from the perspective of Czech firms.[8] Annex 1 provides an overview of selected projects that were successful under the previous '5G for Smart Communities' calls and can thus serve as inspiration for Czech entities wishing to participate in the programme.

2.1.7 ESA Satellite 5G Initiative (S45G)

The European Space Agency (ESA) and the European space industry have joined forces in the field of satellite communications for 5G. Their aim is to develop and demonstrate the added value that satellite communications bring in the context of 5G. The premise is that satellite communications will bring added value by facilitating pan-European and global coverage, resilience, mobility and security for the provision of 5G services, and as a means of enabling innovative infrastructure and services. To this end, priority will be given to verticals in which satellite communications can play a significant role, such as transport, media and entertainment, and public safety (PPDR), without excluding other relevant verticals and use cases.

The ESA Satellite 5G initiative supports development activities falling under the following two types of activities:

1. Activity Type 1: Technology and product development and validation tests. These activities concern the development of an integrated satellite and terrestrial 5G system and/or its components.
2. Activity Type 2: Application development and vertical pilot projects. These activities concern the development and/or demonstration of applications and services based on 5G networks and space systems, where potential users are involved in the pilot projects.

Overall, it can be summarised that these initiatives represent a comprehensive EU approach to promoting the use of 5G technologies. They address various aspects ranging from connectivity and security to economic recovery and digital transformation across different sectors.

In some cases, businesses seeking to digitise using 5G can apply for funding for their projects directly under EU programmes (5G for Smart Communities). In other cases, support for their projects may be available through national programmes based on EU initiatives (National Recovery Plan under the RRF). Examples of projects implemented under 5G4SC are provided in Annex 1. These may serve as inspiration for interested parties in the Czech Republic who would like to participate in future rounds of this programme.

2.2 The state of business digitalisation using 5G in the EU

In 2024, the digitalisation of businesses using 5G and private 5G in the European Union shows progress, but compared to regions such as the US, South Korea, Japan or Israel, Europe lags behind in terms of both adoption rates and performance metrics.

[8] *5G for Smart Communities: second wave of projects co-funded under CEF Digital*. (26 January 2024). Shaping Europe's Digital Future. https://digital-strategy.ec.europa.eu/en/news/5g-smart-communities-second-wave-projects-co-funded-under-cef-digital

Europe's commitment to promoting 5G technology is clear, with significant public funding and initiatives aimed at closing the gap with global leaders. However, the region faces challenges in spectrum allocation, network upgrades and realising the full economic potential of 5G. Further investment in 5G infrastructure is essential to boost competitiveness.

5G adoption and performance

European countries have indeed launched commercial 5G networks, but their roll-out has been slower compared to their global counterparts. For example, by the fourth quarter of 2022, 5G connections in Europe accounted for 7.4% of total mobile connections, which is significantly lower than in the United States (43.1%), South Korea (42.4%) and other leading countries. Average 5G speeds in most European countries are below 200 Mbps, placing them in the '5G Improvers' category, whilst countries such as the United Arab Emirates and South Korea boast average download speeds of over 500 Mbps. 5G availability: The US leads with 56% 5G availability, which indicates the percentage of users of 5G-enabled devices who spend most of their time accessing 5G networks. In Europe, 5G availability exceeds 40% in Cyprus, Switzerland and Denmark.[9]

2.2.1 Private 5G networks in the EU

Private 5G networks are a good indicator of how the digitalisation of businesses using 5G technology is progressing. This is particularly because, for most use cases, private 5G is currently the most suitable option. A public 5G network will be suitable for certain use cases once network slicing becomes available. A public 5G network without network slicing is only suitable for business digitalisation to a limited extent. In practice, it does not actually guarantee service quality – it does not provide an SLA (or, if it does, only in the form of an 'insurance policy', not a technical guarantee). In practice, when connected to a public network, there is usually no distinction between 5G and 4G data connections from the user's perspective. The use of a public 5G network is therefore suitable for use cases that require connectivity outside a defined perimeter and do not require a strict SLA, such as long-distance transport.

The roll-out of private 5G networks in Europe has been gradually continuing since 2018. Germany is at the forefront of this development, utilising localised spectrum for industrial applications, thanks in part to industrial giants such as Siemens, Bosch and many others.

Appendix 2 contains a list of almost 100 private 5G networks in Europe[10] . Although this is not an exhaustive list (no reliably complete list exists; in this case, the list was compiled by the European 5G Observatory team from public sources, and naturally this team endeavoured to produce the most comprehensive list possible), it is clear from it that the highest number of private networks is in Germany, followed by France and Finland. In other countries, including the Czech Republic, the number stands at around five private 5G networks in the corporate sector.

Looking at the entities operating these networks, it is clear that some are used by industrial firms, others by local authorities, including towns and ports, and a further segment consists of university campuses.

European suppliers of technology for 5G and private 5G networks

The presence of European 5G technology manufacturers on both the European and global markets can be viewed positively. Traditional Tier-1 manufacturers are represented by Nokia and Ericsson. These companies also hold a high share of the private 5G networks already deployed. In addition to them, there are also smaller Tier-2 manufacturers, who usually focus on a specific part of the 5G ecosystem, such as just the core or just the RAN part of the network, orchestration, etc. These manufacturers include the Irish firm Druid, the former Italian company Athonet (now acquired by HP), and the French firm Amarisoft.

Other entities and projects also focus on the development of open-source 5G technologies. Among the most significant in Europe is the OpenAirInterface Software Alliance.

OpenAirInterface

OSA, founded in 2014, is a French non-profit organisation ("Fonds De Dotation") funded by corporate sponsors. OSA is home to OpenAirInterface, open-source software that brings together a community of developers from around the world who collaborate on building wireless cellular technologies for the Radio Access Network (RAN) and Core Network (CN).

[9] Kechiche, S. (22 February 2023). *European 5G Performance Trails its International Peers* | Ookla®. Ookla - Providing Network Intelligence to Enable Modern Connectivity. https://www.ookla.com/articles/european-5g-performance-q1-202

[10] *5G Private networks – 5G Observatory*. (n.d.). https://5gobservatory.eu/5g-private-networks/

The Alliance is responsible for:

- development planning,
- quality control,
- promoting OAI software packages deployed by our academic and industrial community for various use cases.

2.3 Germany leads the way in the use of private 5G networks

Germany is at the forefront of private 5G deployment thanks to its proactive regulatory approach and strategic focus on enabling highly localised private networks for industrial and other applications. The German Federal Network Agency (Bundesnetzagentur, BNetzA) has facilitated this progress by allocating 100 MHz of mid-band spectrum at 3.7 GHz specifically for industrial, agricultural or similar private networks. This spectrum allocation is aimed at supporting Industry 4.0 applications, which seek to develop innovative uses of digital technologies in industry.

In November 2019, Germany opened up 100 MHz in the 3.7–3.8 GHz band for local 5G spectrum licences. Applicants could apply for up to 100 MHz of spectrum in 10 MHz blocks using time-division duplex (TDD) for use within a defined coverage area. Applications had to include plans demonstrating that the requested spectrum would be used efficiently to ensure effective utilisation. Licences could be granted for up to 10 years, with the possibility of extension until December 2040 at the latest. Users must ensure interference-free operation, including coordination with other geographically proximate local users, and protect existing users in the band (e.g. FSS earth stations). The spectrum must be utilised within one year of allocation, and any transfers must be approved by the BNetzA.

BNetzA has sought to make local licences available to a wide range of interested parties and has set broad eligibility requirements and annual fees linked to usage criteria. Annual fees are payable for the use of the spectrum, calculated according to the bandwidth, the size and location of the required coverage area, and the duration of the spectrum licence.

Applications may be submitted at any time and are processed on a rolling basis according to current usage and the availability of the required spectrum. Under BNetzA's rules, information on local spectrum licences will be made available to parties with a legitimate need for access to licence details, for example for coordination purposes.

According to data from 2023, more than 200 applications to establish private 5G networks had already been submitted in

Germany.[11] Private 5G networks are used in Germany by leading industrial companies:

- Bosch was a pioneer in applying for local 5G licences to improve its manufacturing processes.
- Siemens and BMW are among other industrial giants using private 5G for smart manufacturing and automation.
- Lufthansa uses a private 5G network as part of its aircraft maintenance operations.

In terms of research and development activities, the Fraunhofer Institute for Integrated Circuits IIS is the most significant. This organisation deals with all aspects of 5G (and now also 6G) technology, with the aim of bridging the gap between 3GPP specifications and the technological solutions actually available.

Fraunhofer IIS operates its own 5G testbed in Nuremberg

The 5G Industry 4.0 test facility at Fraunhofer IIS is an open environment for testing specific use cases for customers in industry and logistics. It utilises the latest mobile technologies under real-world conditions within a dedicated 5G campus network. 5G can significantly boost the performance of wireless connections in industrial environments, thereby opening up new possibilities for the wireless implementation of more complex and safety-critical applications. Early testing of applications with 5G accelerates the transition to fully connected, flexibly adaptable manufacturing, assembly and logistics processes.

Companies, research institutions and universities can utilise Industry 4.0 test environments to explore how 5G can meet the various requirements of real-world industrial applications. Key users may include manufacturing companies, providers

---

[11] Hill, K. (22 November 2022). *Private network spectrum strategy, Part 3: Germany's BNetzA – RCR Wireless News*. RCR Wireless News. https://www.rcrwireless.com/20221122/spectrum/private-network-spectrum-strategy-part-3-germany

positioning systems, system integrators and telecommunications companies that require easy access to 5G test infrastructure in order to validate their solutions and prepare them for the market.

The time between the standardisation of new 5G features and their availability as commercial components can be used in a test environment to evaluate new applications and prototypes. Fraunhofer IIS helps companies make better decisions when investing in new developments and systems.

The German approach can inspire other countries in several ways:

1. Allocation of spectrum for local use: By setting aside part of the spectrum specifically for local and private use, Germany has enabled a diverse range of applications and services tailored to specific needs. According to BnetzA, Germany is keen to discuss harmonising the use of the 3.8–4.2 GHz band or other bands in Europe for private networks, as the possibility of using the same spectrum for private networks across multiple European countries "could provide a good market stimulus".
2. Support programmes, such as the PAiCE technology programme.
3. Research and development activities on a scale similar to that carried out by the Fraunhofer Institute.

To catch up, other countries may consider adopting similar regulatory strategies, including setting aside dedicated spectrum for private and local use, providing clear guidance and support for the deployment of private networks, and promoting the use of 5G technology for industrial and other specialised applications. Furthermore, fostering collaboration between the private sector, research institutions and regulatory bodies could further strengthen innovation and the adoption of 5G technologies.

2.4 Status of digitalisation using 5G in the Czech Republic

When assessing digitalisation using 5G networks in the Czech Republic, it is also appropriate, for the reasons outlined above, to examine the status of private network deployment. Network slicing of public networks is not yet available in the Czech Republic.

The digitalisation of businesses using 5G and private 5G networks in the Czech Republic is progressing, albeit apparently more slowly than was expected a few years ago. This progress is influenced by both regulatory conditions and support for innovative projects across various sectors.

2.4.1 Regulatory environment

At the end of 2020, the Czech Telecommunications Office (ČTÚ) held a major 5G auction in the 700 MHz and 3.4–3.6 GHz bands, which was concluded by five entities that acquired spectrum for a total of 5.6 billion Czech koruna (approx. 211 million euros). The aim of the auction was to facilitate the nationwide roll-out of 5G networks by existing operators O2, T-Mobile and Vodafone, alongside measures to support Industry 4.0 through the leasing of frequencies.[12]

As part of the auction, two frequency blocks were linked to a leasing commitment for the needs of private 5G networks and Industry 4.0. These are blocks of 60 and 80 MHz, which were won at auction by O2 and Incrate. They have thus become mandatory lessors. In addition to them, the C-band spectrum, suitable for both 5G and private 5G networks, was also acquired by Nordic Telecom, Poda, T-Mobile and Vodafone. However, without this commitment.

The obligation to lease radio frequencies is established in favour of any natural person engaged in business or legal entity that applies to lease radio frequencies for the purpose of operating a non-public electronic communications network for their own use or for the use of a business group of which they are a member, territorially limited to land they own, or, with the landowner's consent, to land over which they have a right of use, e.g. under a lease agreement. Such a person is referred to as
"eligible applicant for the lease of frequencies".

---

[12] Czech Telecommunications Office, Announcement of a tender procedure for the granting of rights to use radio frequencies for the provision of electronic communications networks in the 700 MHz and 3400–3600 MHz frequency bands

https://bit.ly/4beBkfn

The purpose of the undertaking is to create conditions that will enable eligible applicants for the lease of radio frequencies, who conclude a radio frequency lease agreement with the obligated lessor, access to radio frequencies for the purpose of using them to operate local non-public electronic communications networks within private industrial and similar premises under the conditions defined below in the announcement of the aforementioned auction.

In order to fulfil the radio frequency lease commitment, the mandatory lessor undertakes, upon request by an eligible party interested in leasing frequencies, to negotiate in good faith the conclusion of a radio frequency lease agreement in accordance with this radio frequency lease commitment, and, on the basis of the concluded agreement, to grant consent for the award of an (individual authorisation) by the Authority to the eligible party seeking to lease the frequencies.

The price for the lease of radio frequencies under this Radio Frequency Lease Commitment charged by the Obligated Lessor shall be determined as follows:

1. The one-off service set-up fee is CZK 50,000 excluding VAT;
2. The annual lease price will be calculated as follows:

$$Ron\ cena\ slu\ by\ (K) = m/12 \times 1000 \times V \times a$$

wher e:

- *m is the number of months of lease per calendar year,*
- *V is the leased bandwidth in MHz,*
- *and is the actual area of the plot in km².*

Eligible applicants must apply for a minimum channel width of 10 MHz; the maximum channel width is limited by the Mandatory Lessor’s total allocation in the 3400–3800 MHz band, and the requested channel width must be in multiples of 10 MHz.

‘Actual area’ refers to the size of the land in km², whereby, for the purposes of calculating the price, the area (size) of the entire plot of land as recorded in the Land Register is always considered to be the actual area (size) of the land to which the lease of frequencies relates.

Example:

A manufacturing company has a factory building measuring 20x100m on a plot of land measuring 50x200m. The plot therefore has an area of 10,000 m². That is 0.01 km². It applies to lease 60 MHz of spectrum. Annual service price: 12/12 x 1000 x 60 x 0.01 = CZK 600.

Even taking into account a one-off fee of CZK 50,000, the cost of leasing the spectrum is negligible.

For mandatory lessors, this price is not an incentive. On the other hand, lessors have already gained a significant economic advantage through the auction due to the lower price of these blocks.

The lease of radio frequencies under this radio frequency lease commitment must be territorially limited to land owned by the eligible applicant for the lease of frequencies (or to land which the eligible applicant has the right to use). The land in question must not be a public space.

An eligible applicant for the lease of frequencies is entitled to operate, on the leased frequencies in accordance with this radio frequency lease commitment, exclusively a non-public electronic communications network solely for their own needs or for the needs of members of the business group of which they are a member, for the purpose of providing electronic communications services ensuring machine-to-machine communication. The purpose of non-public networks as referred to in the preceding sentence is not the provision of interpersonal communication services or internet access services.

An eligible applicant for the lease of frequencies is obliged to ensure compliance with the legal and technical conditions laid down by law, as defined by the lessor in the contract (in particular the conditions for mutual network coordination and network synchronisation), the operational conditions relevant to the 3400–3800 MHz frequency band as set out in the terms of the aforementioned auction and in the relevant PVRS (Radio Spectrum Utilisation Plan).

On the basis of the concluded frequency lease agreement with the mandatory lessor, the eligible applicant for the lease of frequencies shall apply to the Office for the issue of an IO for the operation of their local non-public electronic communications network. They shall attach to the application all the supporting documents necessary for the issue of the IO. However, further market consolidation took place following this auction. The band originally acquired by Incrate has now been acquired by T-Mobile. The PODA band has been acquired by Vodafone. The mandatory lessors under the auction terms are therefore now O2 and T-Mobile. With the exception (for the time being) of Nordic Telecom, the C-band spectrum suitable for 5G/private 5G networks is thus exclusively leased by mobile operators.

Assessment of the regulatory situation in the Czech Republic

The above situation regarding spectrum for private 5G networks gives rise to certain limitations:

1. Unlike in Germany, there is no dedicated spectrum for private networks in the Czech Republic. This means that private networks will be established within the spectrum used for public networks and electronic communications services. Whilst this may not be a problem in remote logistics or industrial sites, in areas located within urban and suburban agglomerations, situations will arise where private networks will interfere with public networks and vice versa. And it is clear that in some cases it will not be easy, or indeed possible, to resolve the situation satisfactorily for all parties involved.
2. The leasing of spectrum for private 5G networks is not limited solely to the private use of these 5G networks. Furthermore, there is a restriction regarding its purpose for Industry 4.0. Yet Industry 4.0 is by no means the only area in which private networks for the digitalisation of businesses are to be utilised in the economic interest of the Czech Republic. There are sectors and verticals such as healthcare/eHealth, energy, the aviation and hospitality industries, agriculture, education and other areas for which the use of private 5G networks offers significant benefits, and their relevance to Industry 4.0 is, at the very least, debatable.
3. According to the regulations, a private 5G network is intended to facilitate only machine-to-machine communication. Not interpersonal communication or internet access. This is a further restriction that runs counter to the practical use of private 5G networks. A whole range of use cases involving some form of interpersonal communication are implemented in private 5G networks. Among the most significant use cases is, for example, ‘assisted work’, which involves remote support for maintenance, repairs, training, etc., and which involves communication between two people and typically requires an internet connection, much like many other significant use cases in private 5G networks. Group communication among work teams and the necessary use of SaaS services requiring internet access are also important.

Many of the scenarios and use cases mentioned above are borderline even within the current regulatory framework, and it might be possible to defend them in a legal dispute. However, given the potential for legal disputes over the legitimacy of spectrum use, entities—in this case, businesses—may prefer to avoid this option from the outset and not engage with private 5G networks. Or they may operate outside the regulatory framework and exclusively through mobile operators. This, however, may result in the potential solution being cost-prohibitive and economically unviable for them. The fact is that, at present, there are no commercial private 5G networks in the Czech Republic operating in accordance with the aforementioned regulations. For the future development of private 5G networks, it is therefore important to define a suitable spectrum within which the above-mentioned restrictions will be eliminated, thereby enabling greater liberalisation of the private 5G network environment to support the digitalisation of businesses in the Czech Republic. This primarily concerns the 3.8–4.2 GHz and 6 GHz spectrum bands.

2.4.2 Support programmes for the digitalisation of businesses using 5G

From the perspective of businesses, support programmes can be divided into two basic categories:

1. Support for research and development (R&D&I – Research, Development and Innovation)
2. Support for the implementation and operation of existing solutions

Support for research and development

Certainly, by no means all businesses seeking to streamline their operations through digitalisation using 5G technologies are pursuing their own research and development in this field. Support in this case is therefore focused (and limited) to businesses wishing to develop their own solutions in this area. What is important here is the genuine novelty of the entire solution. Only then does the company stand a chance of securing support. Support is provided primarily through the TREND programme under the Technology Agency of the Czech Republic (TAČR).

TAČR has already held two public calls for proposals specifically focused on development in the field of 5G technologies (the 7th and 8th).[13]

The subject of the public tender is the selection of proposals for industrial research and experimental development projects supported by public funds for the purpose of fulfilling the objectives of the TREND Programme. The public tender is aimed at supporting projects dealing with the development of 5G and higher technologies (hereinafter “5G”) and is funded from the National Recovery Plan under Component 1.3 entitled “Digital High-Capacity Networks and Related Investments: Scientific Research Activities Related to the Development of 5G Networks and Services”.

Ten projects were supported under the seventh public call for proposals and 14 projects under the eighth public call for proposals. A list of these projects is provided in Annex 3. The projects listed here have been underway since 2023 and are expected to be completed within 36 or 31 months, respectively. By the end of 2025 at the latest, we should therefore see 24 development projects in the field of 5G. As is evident from the focus

---

[13] *TREND Programme – Technology Agency of the Czech Republic*. (30 November 2023). Technology Agency of the Czech Republic. https://www.tacr.cz/program/program-trend/

of the individual projects, the output of many of them are solutions that can play a positive role in digitalisation across various sectors, such as healthcare, logistics, agriculture or transport.

Support for the implementation of existing solutions

The second type of support consists of programmes that contribute to the implementation of already functional solutions utilising 5G technology. This type of programme aims to accelerate digitalisation using 5G by supporting the implementation of projects that are then intended to serve as inspiration for other businesses. These projects demonstrate various use cases and thus serve as case studies. In the European context, this type of programme includes the aforementioned '5G for smart communities'. In the Czech context, these are projects to be implemented under the National Recovery Plan, specifically Demonstration projects for the development of applications for industrial areas using 5G networks.[14]

2.4.3 Research and development in the field of 5G

In the Czech Republic, research and development into 5G technologies and their use for digitalisation is carried out, on the one hand, by commercial firms, as is evident from the list of participants in the TREND programme, and on the other hand, by organisations and institutions dedicated directly to research and development, i.e. research organisations.

In the field of digitalisation using 5G technologies, the most significant research organisations include:

the Czech Institute of Informatics, Robotics and Cybernetics (CIIRC)

is a modern scientific and research institute of the Czech Technical University (CIIRC CTU), which brings together excellent research teams, young talent and unique know-how with the aim of pushing technological boundaries and building on the best traditions of Czech technical education. The focus of CIIRC CTU's research work centres on four key pillars: industry, energy, smart cities and a healthy society, in both basic and applied research.

CIIRC CTU was founded in 2013 by Professor Mařík and currently has more than 260 staff members, 29 of whom are professors involved in the education of 80 students in doctoral programmes. CIIRC CTU is a dynamically developing and growing institution which, by 2022, will employ more than 300 staff, primarily researchers.

From the perspective of this study, the Industry 4.0 Testbed is a particularly important project, forming the focal point of CIIRC's activities. In response to market demands, Industry 4.0 presents a vision of smart factories – a fully integrated, automated and continuously optimised environment based on the principle of connecting production equipment into so-called cyber-physical systems.

A research and experimental environment has been established for this purpose in the new CTU CIIRC building in Prague 6. Here, those interested in automated and digitised production according to the principles of Industry 4.0 can test innovative solutions for smart factories themselves, verify their compatibility, functionality and efficiency, and simulate and optimise production and related in-house processes.

The Testbed combines various technologies, such as additive manufacturing, machining, robotic handling, intelligent transport systems, human-robot collaboration, automated storage and more. Thanks to the flexible interconnection of universal production tools and a sophisticated control system, the same resources can be used to perform various operations, which are optimally planned as required.

A key aspect of the Testbed is the existence of a so-called digital twin, which can be understood as a virtual model of the product, the manufacturing process and the entire production facility, connected in real time via a network of sensors to the physical world in a cyber-physical space. With the help of advanced software, it is possible to carry out the digital design of new products, simulate and virtually commission the entire production line, and optimise the product and production process before the start of physical construction or refurbishment, thereby significantly reducing the time and costs involved in bringing the product to market.

The testbed is equipped with private 5G network technology, thanks to cooperation with T-Mobile. The company has equipped not only CIIRC in Prague but also VŠB-TU in Ostrava with a private 5G network and is currently implementing networking at VUT in Brno, the Technical University of Liberec and the Czech University of Life Sciences in Prague.

---

[14] *Call for Investment No. 6: Demonstration projects for the development of applications for industrial sectors using 5G networks, component 1.4 NPO | MPO.* (n.d.). https://www.mpo.cz/cz/podnikani/narodni-plan-obnovy/vyzvy/investice-c--8-demonstrativni-projekty-rozvoje-aplikaci-pro-prumyslove-oblasti-za-pouziti-siti-5g--275331/

CEITEC – Central European Institute of Technology

CEITEC was established in 2011 as a consortium of six leading Brno-based universities and research institutions, including Brno University of Technology and Masaryk University. CEITEC is multidisciplinary in nature. It integrates the fields of life sciences, advanced materials, nanotechnologies and cybernetics. In this respect, it is the first research centre of its kind in the Czech Republic.

From the perspective of this study, the key research area is technical cybernetics, instrumentation and system integration. This focuses on the research and development of automation, robotic, sensor and measurement technologies and their integration into industrial applications. In terms of applications, it covers in particular the fields of manufacturing technologies, transport (autonomous and electric vehicles), healthcare and others.

Research areas in cybernetics and robotics:

- Smart sensors and signal processing, sensor design using new materials
- Advanced control technologies, control of electric drives
- Mobile robotic systems, exploratory robotics, telepresence
- Embedded systems and communication technologies

The **RICAIP Testbed Brno** industrial laboratory operates at CEITEC.

RICAIP (Research and Innovation Centre on Advanced Industrial Production) is a European project aimed at creating a network of testbeds across Europe that will participate in so-called distributed manufacturing.

This project seeks to connect research institutions with domestic manufacturing firms, ensuring that businesses are aware of innovations and new technologies – and, crucially, that they make use of them. Companies can collaborate with researchers to jointly develop suitable solutions for improving production processes. At the RICAIP Testbed Brno industrial laboratory, interested parties can try out, for example, production automation testing. The aim is to enable companies to test new technologies before investing in them. The Brno Testbed focuses on testing and experimentation in the fields of digitalisation, automation and artificial intelligence.

Specialists at the Brno Testbed cover a wide range of areas, from additive manufacturing (3D printing) and CNC machining to sensor technologies such as vibration diagnostics and noise analysis, or advanced robotics. They also operate 5G networks for industrial communication and can assist with the use of artificial intelligence, including computing resources for its training. These areas are among the main ones that most frequently meet clients' needs. However, thanks to links with other expert teams within BUT, they are also able to offer services utilising expertise in other fields.

Thanks to partners within the consortium, they offer consultancy services in addition to experiments. In some cases, both types of services are combined. The output of the services provided, such as testing, consists of handover reports containing research reports with proposed solutions. Clients receive a comprehensive overview of market options and what the technology in question enables, thereby minimising the risk associated with selecting unsuitable technology and making economically disadvantageous decisions.

Support for small and medium-sized enterprises also includes the organisation of a variety of workshops at the RICAIP Testbed Brno industrial laboratory. One example is the Digital Transformation Academy, which is always fully booked, where participants, under the guidance of experienced coaches, create their own optimisation project ready for implementation. Outside the academy, courses also focus on 3D precision measurement, 3D printing, 5G networks and a range of other aspects of industrial digitalisation.

CEITEC's partner is **EDIH – DIGIMAT**. It provides companies with consultancy services, training services, assistance with the use of testbeds, etc. All this with the aim of helping with the digitalisation of production, or more generally with the application of innovative solutions from the broad field of digital technologies.

EDIH-DIGIMAT supports small and medium-sized enterprises. Companies with up to 499 employees can receive up to 100% funding from EU funds, and companies with up to 3,000 employees can receive up to 50% funding from EU funds.

VŠB – Technical University of Ostrava

Several projects directly related to digitalisation using 5G technologies are being carried out at VŠB – Technical University of Ostrava. The most significant of these are described below.

Smartfactory and Automotive Lab.[15]
As part of the activities of these two laboratories, various systems are being developed and tested in accordance with the principles of the Industry 4.0 concept and

[15]http://smartfactory.vsb.cz/

using 5G communication technology. Smart Factory is a comprehensive laboratory for teaching, demonstration, testing and research into technologies used in the digitalisation of industry. The Automotive Lab is developing a whole range of interesting systems in the field of autonomous driving and driver assistance services, for example in collaboration with Škoda Auto.

C-ITS test track.[16]

As part of the REFRESH project, a C-ITS (Cooperative Intelligent Transport Systems) test bed will be built next year and the 5G campus network will be expanded to ensure its coverage. The essence of C-ITS is communication between vehicles and the relevant wireless infrastructure – in this case, 5G operating in the millimetre wave band. As part of the project's research activities, advanced applications and systems will be developed, tested and implemented that utilise both communication between vehicles and communication with the 5G infrastructure in real time. The project's outputs will then be used to gain practical experience and data for the future planning and deployment of C-ITS and 5G technologies, not only in public transport.

Robotics Centre.[17]

The Robotics Centre at the Faculty of Mechanical Engineering, VŠB-TU Ostrava, carries out research and development activities in the field of collaborative and industrial robotics. As part of the use of 5G, the research team is engaged in the development of various types of mobile robotic systems where high reliability and data throughput of wireless connections are required.

Quantum5 Project.[18]

The aim of the project was to create an integrated solution that would enable the benefits of both technologies – 5G and QKD (Quantum Key Distribution) – to be utilised to improve the security of 5G infrastructure. As part of the testbed, a real-world integration of QKD technology into the campus 5G network infrastructure was carried out to demonstrate a quantum-secure 5G network.

New applications utilising the 5G campus network with mmWave support and CESNET infrastructure

As part of various activities related to the use of the 5G campus network at VŠB-TUO, a working group was established to develop and test multimedia applications that have the potential for use in 5G. These activities primarily involve the measurement, analysis and optimisation of multimedia traffic in a 5G network using QoS metrics, enabling us to subsequently define suitable transmission parameters, codecs and any QoS settings, as well as the radio layer itself in 5G, for a specific type of multimedia traffic. The use of 5G for the transmission of high-quality video with up to 8K resolution or a high frame rate of up to 120 fps, followed by the analysis of latency and jitter, appears to be a promising area, particularly in conjunction with data transmission via the CESNET infrastructure.

National Centre for Industry 4.0

The "Centre" is a coordinating rather than a research institution. Nevertheless, it is an important platform in the field of business digitalisation.

The Centre is a technology-neutral and open academic-industrial platform that connects innovation leaders, manufacturing and technology firms, universities, research and sectoral organisations with the state and the media. It aims to be a specialist partner in the process of change (digital transformation) for start-ups, SMEs and large industrial enterprises. It provides services ranging from the sharing of experience and knowledge, through information on Czech industry, to testbed and project services. From the perspective of companies seeking to increase their efficiency through digitalisation using 5G, particularly in the field of Industry 4.0, it is therefore important to know that there are research and coordination organisations in the Czech Republic that are willing and able to assist them with this task.

At the start of a planned project, it may be advantageous to approach one of the aforementioned institutions (depending on the subject of the planned project) and consult the entire project with them. In this way, a mutually beneficial collaboration can be established, enabling companies to choose a suitable digitalisation strategy and invest in appropriate technologies.

2.4.4 Implemented projects in the field of business digitalisation using 5G

The first initiatives in the form of projects involving private 5G networks are emerging in the Czech Republic. In addition to the aforementioned campus networks, which are used primarily for research activities, there are already several private 5G networks in the business sector:

[16] https://www.smaragdova.cz/

[17] https://www.fs.vsb.cz/354/cs/centrum-robotiky/kolaborativni-robotika/

[18] https://www.quantum5.eu/

Škoda Auto

It has a private 5G network implemented by Vodafone using Nokia technology. This is the first initiative of its kind in the Czech Republic, namely a private 5G SA network built in 2022. In terms of usage, it is still very much a Proof of Concept. Another private 5G network is currently being prepared for Škoda Auto's press shop. This is to be supplied by T-Mobile using Ericsson technology and will be used, among other things, to track pressing tools.

Toyota

Based on specific models for deploying 5G networks in industrial environments and in collaboration with its technology partners, T-Mobile built a private 5G network for Toyota in standalone mode at the end of 2022, which relies entirely on the latest mobile network standards. After Belgium and Poland, the Czech Republic is only the third European country where Toyota is actively testing 5G.

The new test environment at the Toyota plant in Kolín will initially serve to verify the feasibility of practical deployment of specific applications that utilise the advantages of private 5G networks:

1. In collaboration with ServisControl, autonomous trolleys controlled via the 5G network will be tested. In this case, 5G private network technology will ensure not only signal availability regardless of the trolleys' current position, but also highly accurate device positioning and very low data communication latency. The autonomous trolleys will be used to transport car components to the assembly line and to move parts within warehouses.
2. A key area of testing involves verifying the potential to improve performance in production monitoring using sensor networks connected to the car manufacturer's private 5G network. To this end, T-Mobile is providing the car manufacturer with integration between the 5G network and Internet of Things (IoT) devices.
3. Toyota will also test augmented reality glasses to streamline the training of new employees and to facilitate the ongoing development of skills and mentoring of production staff. T-Mobile has developed an application using Microsoft's augmented reality glasses, connected to the corporate network via a Pegatron 5G SA modem, to project instructions directly in front of production workers' eyes.

The test environment at Toyota's Kolín plant consists of a combination of radio elements, core elements and end devices. The private 5G network infrastructure is built on Ericsson's standalone 5G technologies and end devices from Advantech. The specific applications being tested were developed by T-Mobile in collaboration with ServisControl, Microsoft and Pegatron.

Continental

In August 2023, technology company Continental launched its first private 5G network between its European production plants at its display solutions plant in Brandýs nad Labem. The 5G network, specially configured to meet Continental's high-tech manufacturing requirements, is expected to further advance the digitalisation of production by accelerating communication between employees, equipment and machines, such as sensors, manufacturing robots and autonomous transport vehicles. In addition, it improves connectivity between Continental's plants within its global production network thanks to a unified and secure environment with reduced latency. In total, Continental plans to integrate more than 1,000 devices and sensors into the network at its Brandýs plant. Eight network access points covering an area of 5,000 square metres provide the signal for the private 5G network. The network was supplied by T-Mobile using Ericsson technology. Further information on this project can be found in the Ayes case study in this document.

Kvados

As part of the OPPIK Application IX grant call, KVADOS, in collaboration with VŠB – Technical University of Ostrava and Brno University of Technology, submitted and successfully completed a project proposal aimed at developing its own platform for controlling autonomous robots and other advanced technologies using a 5G network. For this purpose, a private 5G network was built on the premises of the Paskov logistics warehouse for commercial use in conjunction with Industry 4.0 elements. The company implemented a private 5G SA mobile network in its logistics ShowRoom for the control and processing of data from logistics robots. The 5G SA network was supplied by T-Mobile Czech Republic a.s. using Ericsson technology. Further information on this project can be found in the Kvados case study in this document.

BD Sensors

The network is built on technology from Ericsson, with whom O2, or rather CETIN, also collaborates on the construction of the wireless part of the standard 5G network. In the case of the Buchlovice private network, the 5G core is not located on the customer's premises. This is a 5G NSA network. It is therefore not a fully-fledged private 5G network. On the other hand, from the customer's perspective, it is crucial that O2 guarantees latency consistently below 20 milliseconds, though it typically hovers around 12 milliseconds. Similarly, speeds typically reach around 600 Mbps.

The primary purpose of this network is to replace the existing WiFi connection, with which the customer had long-standing issues. ZEBRA end devices (tablets) thus connect to the 5G network.

LARS Chemie

LARS Chemie is implementing a modern production management project using the Cerebrica Optimizer solution. For production management, data is collected via an infrastructure comprising a private 5G network supplied by T-Mobile using Ericsson technology. LARS Chemie uses the private 5G network to replace cabling, control conveyors wirelessly, collect data from forklifts, and also to track employees' time spent at individual workstations.

2.4.5 Assessment of the state of enterprise digitalisation using 5G in the Czech Republic

More than three years after the auction of suitable spectrum for 5G networks, a review of corporate private 5G network projects – which, in the absence of network slicing and guaranteed SLAs on public 5G networks, a good indicator of the progress of business digitalisation using 5G technologies, it appears that the progress of advanced digitalisation using 5G technologies lags behind leading markets in both a global and European context (particularly in comparison with Germany) and is closer to the European average.

It is therefore necessary to further investigate the causes of this development, identify the barriers to faster business digitalisation using 5G, and define ways to overcome them. The Czech Republic has a relatively strong research base in the field of business digitalisation, particularly Industry 4.0, including the use of 5G technologies. This research does not primarily focus on 5G technology itself, but on its application. Within testbeds, 5G technology is approached as a 'black box' provided by the supplier, which significantly limits the scope for research and experimentation with the technology itself.

Another question is to what extent this research base is being used effectively to advance business practice, how many businesses have gone through the testbeds, and whether the tested technologies have subsequently been commercially implemented. In the Czech Republic, and indeed at EU level, there are a number of programmes supporting research, development and the implementation of existing solutions using 5G technologies. Participation by Czech companies in these programmes is low, and here too it is therefore necessary to identify the causes and ways to improve the situation.

Barriers to faster business digitalisation using 5G in the Czech Republic can be identified in the areas of regulation, solution costs, lack of know-how, lack of information and a limited ecosystem. These barriers and their solutions are addressed in the following sections of this document.

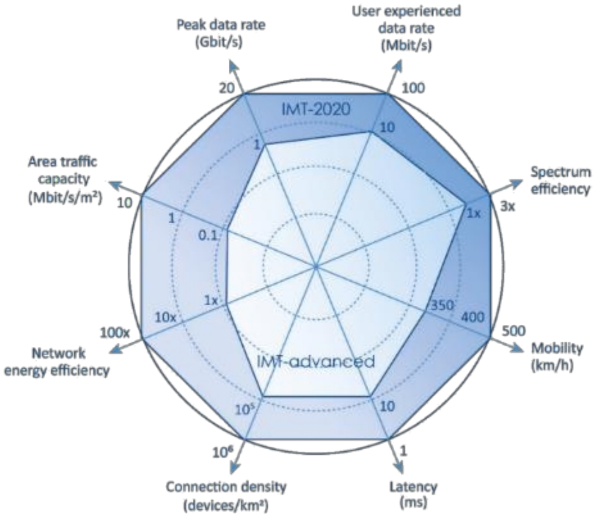
3 5G technology from the perspective of business digitalisation

3.1 Basic characteristics and functions of 5G and their availability

For the purposes of this study, we will further discuss the key aspects of 5G networks (5G technologies) in terms of what is of significant importance for their use in business digitalisation. In this section, we will summarise the known basic characteristics of 5G technologies. However, not all the features of 5G that are commonly presented are actually (yet) available in practice, and we will therefore examine their availability.

5G (or fifth-generation wireless networks) is a mobile network telecommunications standard that is a technical successor to the 4G LTE standard. The main benefit of the new technology is a significant, approximately tenfold increase in transmission speed and a substantial reduction in response time compared to the 4G standard, which, in addition to supporting more devices and customers, also enables the use of new technologies (online remote control of various devices, high-quality multimedia, high-speed access, low latency, high availability and reliability, QoS, etc.). The basic requirements for the 5G system were defined in IMT-2020, and for 4G LTE-A it was IMT-Advanced, as shown in the figure below, which summarises the requirements for user experience data rate, spectrum efficiency, mobility, latency, connection/device density, network energy efficiency, area traffic capacity and peak data rate.

Figure 3: Comparison of key characteristics of IMT Advanced (4G LTE-A) and IMT-2000 (5G NR). Source: International Telecommunication Union, 2018.

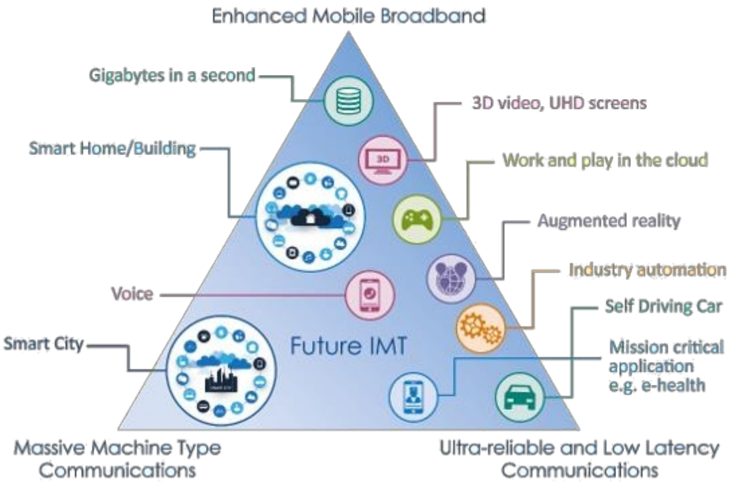


As can be seen from the comparison with the 4G LTE Advanced (IMT-Advanced) network, some parameters change by an order of magnitude and some even by two orders of magnitude. As with previous networks, it is clear that not all requirements and parameters will be met at the outset, but they will gradually improve as further 5G network specifications (Releases) are released.

New 5G network services are defined by 3GPP and ITU as:

- eMBB – Enhanced Mobile Broadband
- mMTC – Massive Machine-type Communications
- uRLLC – Ultra-Reliable Low Latency Service

Figure 4: 5G network services according to 3GPP and ITU. Source: ITU-T, Three major application scenarios for 5G, 2018.



The architecture of 5G networks is designed to be flexible and capable of adapting to various situations and requirements. The main elements of the 5G architecture include the following:

1. **NG-RAN (New Generation Radio Access Network)** – the part of the network consisting of antennas, transmitters and other equipment responsible for transmitting data between mobile devices and the rest of the network.
2. **5G Core Network (5GC)** – the core of the network, which processes and routes data traffic between different devices and networks. It consists of SDN (Software-Defined Networking), NFV (Network Function Virtualisation), containers and other technologies.
3. **MEC/Edge Computing** – a new element of 5G architecture that enables rapid data processing and the placement of computing resources closer to where they are needed.
4. **Virtualisation (NFV – Network Function Virtualisation)** – are further new elements that enable network functionality to be separated from the physical infrastructure, which greatly facilitates easy network management and maintenance, including the use of commodity hardware and virtualised infrastructure, ideally in the form of scalable containers.
5. **Network Slicing** – a technology that allows the network to be divided into different segments (so-called 'slices') in order to provide different levels of Quality of Service (QoS) for different customers, applications and services.

There are two basic architectures for 5G networks – NSA (Non-Standalone) and SA (Standalone):

1. **NSA (Non-Standalone) architecture:** This architecture is based on existing 4G LTE networks and utilises 4G infrastructure for network control and signalling, whilst 5G is used for data transmission. This means that end devices must be capable of supporting both 4G and 5G technologies. This architecture enables faster deployment of 5G networks, as there is no need to build new infrastructure and all network functions can be integrated into existing networks. However, this comes at the cost of lower performance compared to a fully standalone architecture.
2. **SA (Standalone) architecture**: This architecture is fully standalone and independent of existing 4G LTE networks. In this architecture, all elements of the 5G network are built from scratch, and 5G networks are controlled and signalled via a separate 5G network core. This enables higher performance, faster data transmission and lower latency compared to the NSA architecture.

RedCap

Reduced Capability (RedCap) 5G, also known as 5G Light, significantly enhances 5G's ability to support Internet of Things (IoT) solutions that rely on advanced 5G features other than just high speed. RedCap is ideal for applications requiring high reliability and speeds typically between ultra eMBB and LPWA, thereby enabling the deployment of billions of new IoT devices and services. RedCap devices have limited bandwidth compared to standard 5G services.

The RedCap specification has:

- only 20 MHz in the FR1 band and 100 MHz in FR2
- one transmit antenna and one receive antenna
- half-duplex only in FDD (no antenna duplexer required)
- 64 QAM modulation only
- lower transmit power

RedCap's ability to accommodate such a wide range of applications within a single network means more cost-effective IoT deployment across many sectors, such as industrial IoT, smart energy, and remote monitoring and control.

Availability of 5G features

As mentioned earlier, not all commonly presented features of 5G technology are currently available to end customers. Their availability is not only dependent on the finalisation of specifications in the relevant 3GPP releases, but even after specification within 3GPP, it can take several years before a given 5G feature or functionality becomes available at the level of commercial network elements and end devices. The 3GPP organisation defines standards for 5G networks through a series of releases. These releases provide specifications for technologies used in 5G networks, including radio access, core network architecture and service capabilities. Here is an overview of key 3GPP 5G releases:

Release 15

- Status: Completed
- Release date: December 2017 / June 2018
- Key features: This was the first release to include 5G specifications, representing Phase 1 of the 5G standard. It focused on Non-Standalone (NSA) 5G architecture, where the 5G network relies on existing 4G LTE infrastructure for certain functions.

Release 16

- Status: Completed
- Release date: July 2020
- Key features: Known as '5G Phase 2', it expanded on the capabilities introduced in Release 15. It included Standalone (SA) 5G architecture, improved network efficiency, Ultra-Reliable Low-Latency Communication (URLLC), enhanced Vehicle-to-Everything (V2X) communication, and the integration of satellite networks.

Release 17

- Status: Completed
- Release date: December 2021
- Key features: Focused on further enhancing 5G capabilities, including features such as improved support for the Industrial Internet of Things (IIoT/RedCap), enhanced V2X communication, integration of non-terrestrial networks (NTN), and advances in broadcasting services. Further development of network slicing capabilities.

Release 18

- Status: In progress
- Expected completion date: 2024
- Key features: This version, dubbed '5G Advanced', is expected to include enhancements in areas such as artificial intelligence (AI) integration, further improvements to URLLC, energy efficiency, and more comprehensive support for the Internet of Things.

Release 19

- Status: Planned
- Expected timeline: Planning phase, completion expected around 2024–2025
- Key features: Details are still under discussion, but progress in 5G technology is expected to continue, focusing on areas such as further integration of AI and machine learning, next-generation V2X communications, and even more efficient and reliable network performance.

In practical terms, the situation is such that most 5G technologies available in Q1 2024 support Release 16 and part of Release 17. However, this does not mean that all the desired services specified in these releases are actually available for commercial use.

This applies in particular to:

- **RedCap** – defined in Release 17, but very few technologies and devices are currently available.
- **LMS** – in practice, the availability of end-to-end native location service solutions in 5G networks is limited, and their accuracy also remains a challenge.
- **QoS** – many 5G RAN components, particularly the more affordable ones, do not support QoS.
- **URLLC** – in practice, only a handful of 5G networks have been implemented with URLLC capability.

It is clear from the above list that many of the important services that 5G networks will bring are still in their infancy or exist only on paper, and we will see them in the coming years. This will certainly contribute to the further development of (private) 5G networks.

On the other hand, even the currently available 5G technologies enable the implementation of a significant proportion of the use cases that businesses need to implement. In particular, those requiring high capacity, security, stability and relatively low latency (albeit not yet, as a rule, in the order of milliseconds).

And what can we look forward to with 6G networks? Not all the planned functionalities of 5G networks have been implemented by a long shot, yet there is already intense talk of 6G technology. Standardisation will likely begin in 2026 with 3GPP Release 20 and beyond.

The following table shows, for interest's sake, a comparison of the theoretical parameters of 5G and 6G.

Table 1: Comparison of theoretical parameters for 5G and 6G

KPI	5G	6G
Peak data rate	20 Gbit/s	1 Tbit/s
User data speed	100 Mbit/s	1 Gbit/s
Maximum spectral efficiency	30 bit/s/Hz	60 bit/s/Hz
Typical spectral efficiency	0.3 bit/s/Hz	3 bit/s/Hz
Maximum bandwidth	1 GHz	100 GHz
Area capacity	10 Mbit/s/m²	1 Gbit/s/m²
Connection density	10^6devices/km²	10^7 devices/km²
Energy efficiency	Not specified	1 Tbit/J
Latency	1 ms	100 µs
Reliability	10^{-5}	10^{-9}
Jitter	Not specified	1 µs
Mobility	500 km/h	1000 km/h

3.2 Private 5G networks

3.2.1 The importance and types of private 5G networks

Private networks are a key area of 5G technology from the perspective of business digitalisation. In the future, network slicing will also be of great importance for business digitalisation, particularly for use cases outside a defined perimeter. However, network slicing is not yet available in practice, so let's take a closer look at private 5G networks.

Private 5G networks are dedicated networks tailored to the specific needs of an organisation, providing controlled connectivity, enhanced security and bespoke services compared to public 5G networks.

Definition: a private 5G network is a localised mobile network that uses 5G technology to create a dedicated wireless ecosystem for a specific company or entity. Unlike public 5G networks, which are operated by electronic communications service providers and are shared by all users, private 5G networks are used exclusively by a single organisation, providing greater control over data management, network traffic and security.

A specific category is also formed by so-called **hybrid networks**. A hybrid public-private 5G network utilises the infrastructure of both public 5G networks, which are operated by mobile network operators (MNOs) and are accessible to all users, and private 5G networks, which are dedicated networks built for specific business needs. A hybrid approach typically involves a setup where the core of the public network is utilised, whilst the radio access network, or part of it, is dedicated to a private company. Some solutions also allow the use of a single SIM card to access both public and hybrid/private networks.

The main benefits of private 5G networks for businesses are as follows:

- Higher level of security: They offer more robust security features, enabling organisations to manage their own security policies and protect sensitive data. Sensitive data does not have to leave the company premises.
- Customisable QoS: Businesses can tailor network settings to prioritise critical services, manage bandwidth and optimise performance according to their specific needs.
- Reduced latency: By operating an on-premises network infrastructure, organisations can achieve lower latency, which is essential for applications requiring real-time data processing.
- Increased reliability: They provide a more reliable connection with consistent quality of service, which is essential for critical applications such as manufacturing automation, healthcare monitoring and emergency services. The level of reliability can be tailored to the needs of the organisation and its applications, including HA solutions.

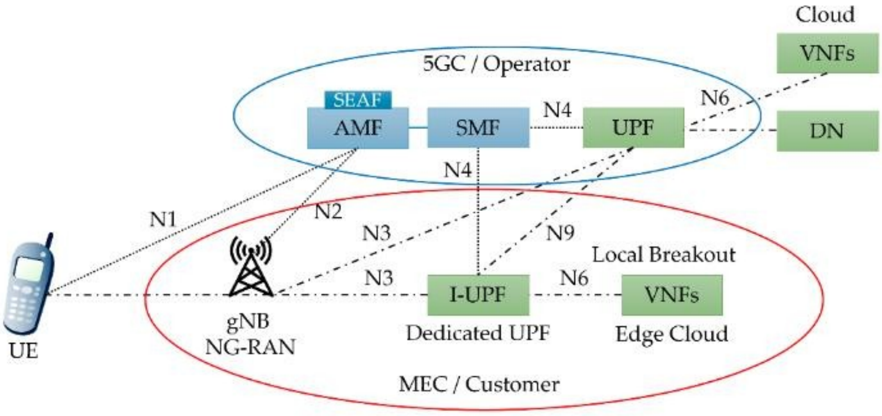
Types of private 5G networks

As mentioned above, from an architectural perspective, there are two basic types of 5G networks: NSA (non-standalone) and SA (standalone). However, only SA networks are full-fledged 5G networks (NSA networks effectively use a 4G core), and for the purposes of further categorising private 5G networks, we will therefore consider only the SA type of private 5G network.

From a deployment perspective, the following three types of private 5G SA networks can be defined:

1. **A network comprising** both **the core network and the radio access network (RAN) on the customer's premises** – Sometimes referred to as an island network. Typically the most expensive solution, but one that offers the greatest flexibility in terms of meeting specific requirements, including reliability, low latency and security.
2. **Network core in the cloud (control plane), user data (user plane) and RAN on-premises at the customer's site** – This option enables low latency; user data can be processed at the edge on the customer's site, even though the network core (control plane) is remote. This option is illustrated in the figure below.
3. **Network core in the cloud (or at the operator's site), RAN on-premises at the customer's site – This** option is typically the least expensive. However, it provides less control over the data and is inferior to the first two types in terms of latency (data first goes to the cloud and then back).

Figure 5: Local user data (user plane), remote core (control plane) [19]



The above-mentioned types of private 5G networks differ primarily in their architecture and the deployment of the network core.

The radio part of the network also has a number of deployment variants. In the case of private networks, there are mainly two types:

1. ORAN distributed architecture
2. All-in-one gNodeB

Open RAN (ORAN – Open Radio Access Network)

This is a new concept for mobile network architecture that aims to eliminate the dependence of mobile operators (or service providers in general, as ORAN can also be used in private 5G networks) on a single supplier for the radio access network (RAN). Open RAN allows the use of hardware and software from different suppliers, enabling mobile operators to choose from a wider portfolio of equipment and technologies and reducing their dependence on a single supplier.

Open RAN can also reduce network deployment and operating costs and increase the flexibility and speed with which the network can be adapted to new requirements. In Open RAN, the hardware and software layers are separated, which facilitates easier updates and replacement of network components. The RAN is divided into the CU (central unit), DU (distributed unit) and RU (radio unit). Each component may come from a different supplier.

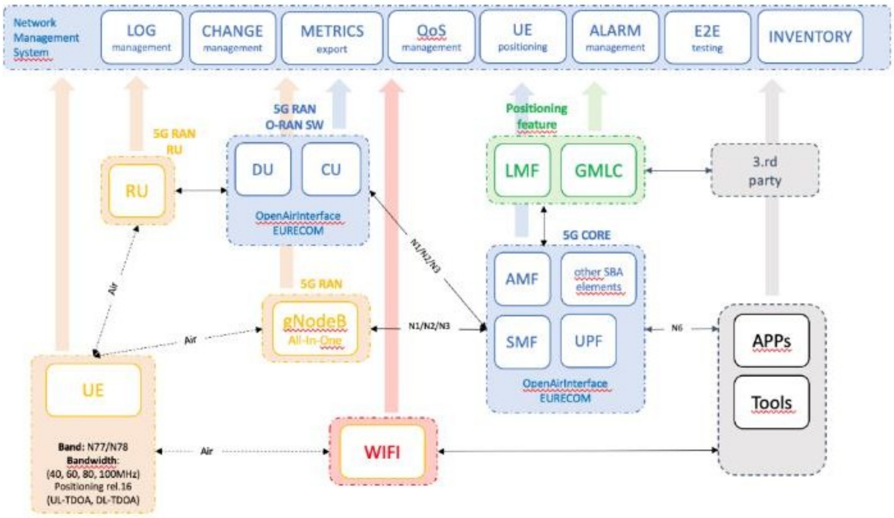
In recent years, Open RAN has become a major topic in the field of 5G networks. There are also organisations such as the Open RAN Alliance, the Telecom Infra Project (TIP) and the O-RAN Alliance, which are working to promote and develop Open RAN as a new standard for mobile networks.

gNodeB

This is an all-in-one solution where a single network element (HW) incorporates all the necessary RAN functions. It is a solution that is simpler to deploy and manage. The prevailing view in the industry is that for smaller-scale private 5G networks, it is more efficient to use the all-in-one gNodeB variant, whilst Open RAN is a more suitable solution for public networks and large-scale private networks.

[19] Source: Ing. Michal Poupa, 2024.

Figure 6: Private network with both variants – ORAN and gNodeB.[20]



3.2.2 Private 5G networks from a frequency perspective

As mentioned in the chapter describing the regulatory situation in the Czech Republic, it is possible, under certain circumstances and subject to certain restrictions, to establish private networks in the 3.4–3.8 GHz band. Specifically, interested businesses may utilise the 3400–3480 MHz or 3640–3700 MHz bands.

Technologies in these bands use time-division duplex (TDD), where the same frequency band is used in each direction of communication (downlink, uplink). The division of communication into downlink and uplink takes place within a time slot according to a given frame. Communication is then full-duplex and can be used to advantage where there is asymmetry in the volume of data transmitted (e.g. greater data capacity on the downlink than on the uplink).

According to the CTU document entitled "Part of the Radio Spectrum Utilisation Plan No. PV-P/7/02.2022-3 for the 2700–4200 MHz frequency band", all network operators in this band must use uniform time synchronisation and the same (or compatible) radio frame (pattern). This measure is important to minimise interference between individual networks in this band.

However, this is not the only potentially usable spectrum for private 5G networks. In the future, there is a possibility of further bands being released under the regulations, particularly 3.8–4.2 GHz.

Furthermore, there is the option of utilising so-called unlicensed bands. Frequencies for wireless and mobile networks can be divided into licensed and unlicensed bands. In licensed bands, the use of a particular frequency is restricted to a specific entity (one that holds an individual licence for that frequency). Conversely, unlicensed bands are not allocated to a single operator in terms of licensing, but may be used freely provided the conditions set out in the relevant General Authorisation are met.

Unlicensed bands for wireless network (WLAN) operation

Pursuant to General Authorisation No. VO-R/12/11.2021-11 of 12 November 2021, we may use frequencies in the Czech Republic subject to the following restrictions:

Table 2: Overview of frequencies with restrictions

Band	Bandwidth	Note
2.4 GHz	2401–2483 MHz apping channels of 20 MHz each)	max. 100 mW e.i.r.p. indoors
5 GHz	5150–5250 MHz 5 non-overlapping 20 MHz channels	max. 200 mW e.i.r.p.

[20] Source: Josef Miléř, 2024

	5250–5350 MHz 5 non-overlapping 20 MHz channels 5470–5725 MHz 12 non-overlapping 20 MHz channels 5725–5850 MHz 6 non-overlapping 20 MHz channels	max. 200 mW e.i.r.p., for indoor use only 1 W mean e.i.r.p. 1 W mean e.i.r.p. except in protected zones
6 GHz L6 band	5945–6425 MHz	max. 200 mW e.i.r.p., (indoor) max. 25 mW e.i.r.p., (anywhere)

The 6 GHz (L6) band is currently used by Wi-Fi 6E wireless systems and is also envisaged for use in NR-U in future. As part of the standardisation of 5G bands, this frequency band is being considered and has been designated as n102 or n96.

5G NR-U technology

The primary challenge of operating in NR-U is operating in the heavily utilised 5 GHz bands whilst ensuring harmonious coexistence with other mobile technologies, such as Wi-Fi. To this end, the (RAN) has also been introduced for the NR-U bands, meaning that whilst NR-U utilises the 5G NR physical layer (PHY) to take advantage of the evolutionary benefits of 5G, the medium access control (MAC) layer protocols for processes such as channel access have been adapted to be compatible with Wi-Fi. This means that the impact of NR-U on existing Wi-Fi networks is equivalent to adding another Wi-Fi access point. NR-U follows the same LBT (listen-before-talk) protocol used in 802.11, ensuring equal access to available channels. This is referred to as NR-U's asynchronous operation and limits some of the benefits of 5G NR, such as the ability to support ultra-reliable low-latency communication (URLLC).

Even more opportunities for improved spectral efficiency have opened up as new, less congested frequency bands have become available for NR-U. In the US, the EU and South Korea, the 5.925 GHz to 7.125 GHz (or 6 GHz) frequency range is now being opened up for unlicensed devices. In the US, the Federal Communications Commission (FCC) permits unlicensed use of the 6 GHz band for low-power (30 dBm) indoor applications and outdoor operation at the same power levels as 5 GHz systems (36 dBm) with the mandatory use of an automated frequency control (AFC) system, similar to the spectrum access system (SAS) used in the Civil Broadband Radio Service (CBRS). This is intended to prevent interference with existing earth-to-space satellites and point-to-point microwave links, which also operate at these wavelengths.

Although the 6 GHz band is used by some technologies, including the new Wi-Fi 6E, it is considered a greenfield spectrum because sufficient spectrum is available and the signal is naturally isolated due to the physical properties of the frequency, meaning that interference will be negligible. As a result, NR-U operating in the 6 GHz band or higher is not necessarily subject to the strict LBT protocols adopted for harmonious coexistence in the 5 GHz bands. This enables rapid access to transmission channels to support low-latency automation and Internet of Things applications.

26 GHz band (high band, K-band)

The 26 GHz band (so-called millimetre waves) will enable the use of very wide channels (a 1 GHz bandwidth is expected to be made available). Their main advantage over lower frequencies is an order of magnitude higher data throughput due to the greater channel width, allowing data to be transmitted at speeds of up to 10 Gbit/s. The disadvantage, on the other hand, is short range and difficulty in passing through obstacles (network range limited to Line-of-Sight (LoS) conditions or reflection from nearby obstacles – buildings). It is anticipated that cells will typically have a coverage range of 50–200 metres and will thus be used, for example, to provide coverage in city centres, sports stadiums and other locations where large numbers of people gather.

In mid-2020, the Czech Telecommunications Office (ČTÚ) launched a public consultation on a draft section of the radio spectrum utilisation plan for the 24.25–27.5 GHz frequency band and, at the same time, made this band available for experimental operation of IMT/5G networks. In addition to the 26 GHz band (NR band n258), the 28 GHz band (NR band n261, Ka-band) and the 39 GHz band (NR band n260, Ka-band) are also in use worldwide.

3.2.3 Private 5G networks and WiFi

Digitalisation without data connectivity is not possible. In many cases, digitalisation is neither possible nor effective without wireless data connectivity. This is an obvious fact for businesses. However, which wireless connectivity to use is, and will remain, a complex question for many companies.

The decision to use a private 5G network, a WiFi network, or both networks for various use cases within a company's digitalisation strategy will be a strategic decision for many firms, one that will shape their future direction for many years to come. It is therefore important to have a clear understanding of the characteristics of WiFi and 5G networks and their implications.

The data connectivity provided by private 5G networks is technically superior compared to other options. In particular when compared to Wi-Fi networks. But what is the real difference? And is this true in all circumstances? It is worth examining this in a detailed comparison.

Another aspect is the coexistence of WiFi networks and 5G. There are a number of reasons why private 5G networks and WiFi networks are better suited as complementary solutions rather than as replacements. Whilst private 5G networks offer the advantages described above in terms of security, stability, QoS, etc., and are certainly suitable for business-critical use cases, the benefits of using Wi-Fi include relatively easy and affordable implementation, as well as the availability of a vast number of end devices. Some of these end devices are more expensive on 5G (such as scanners in logistics), whilst others are not available at all. WiFi is therefore a suitable solution for non-critical use cases, even in the long term. Private 5G and WiFi networks can not only coexist, but can even function as an integrated solution.

Comparison of private 5G and WiFi

Wireless WiFi networks have been with us for over 20 years. During this time, there has been significant development of standards in the field of WiFi networks. Currently (Q1 2024), the latest standard is WiFi 7. In reality, however, due to the prevalence and availability of devices, networks are most commonly built using WiFi 6/6E today.

Table 3: Parameters of modern WiFi technologies

Technology	WiFi 6E	WiFi 7
Standard	802.11ax	802.11be
Max. theoretical transfer rate	~9.6 Gbps	~46.1 Gbps
frequency band	2.4 GHz, 5 GHz, 6 GHz (Wi-Fi 6E)	2.4 GHz, 5 GHz, 6 GHz
Channel bandwidth	up to 160 MHz	up to 320 MHz
Highest modulation order	1024 QAM	4096 QAM
Max. number of spatial streams	8x8 UL/DL MU-MIMO	16x16 UL/DL MU-MIMO
Security	WPA3	WPA3

WiFi 6E/7 networks add the option of using the 6 GHz band to the existing 2.4 GHz and 5 GHz bands. At the same time, they aim to address the shortcomings of older implementations, such as issues with connecting a large number of devices or interference from nearby access points.

Other key benefits of WiFi 7 networks compared to WiFi 6:

- Multi-RU – assigning a user to multiple RU units simultaneously
- Puncturing – carving out a portion of ‘occupied’ but unused channels – improves spectrum utilisation
- Multi-Link Operation – using multiple bands simultaneously

The mechanisms listed above contribute to higher throughput and lower network latency.

Table 4: Comparison of technical parameters of WiFi 6 and 5G

	WiFi 6/6E	5G
Network capacity	theoretical up to 9.6 Gbit/s	up to 6 Gbit/s
Spectral efficiency in a simulated environment[21]	150 Mb/s/ 80 MHz (at max. delay 4 ms 4x4 MIMO)	360 Mb/s/ 80 MHz (at max. delay 4 ms 4x4 MIMO)
number of connected devices per cell	less than 50	more than 250
air latency	2–4 ms	1 ms (URLLC)
frequency	unlicensed	licensed
output power	100 or 200 mW (indoor) 1 and 4 W (outdoor)	tens of W (outdoor)
mobility	with restrictions	high
reliability	99.9%	up to 99.999% (URLLC)
safety	low to medium	high
Localisation	approx. 5 m	1–3 m
backward compatibility	possible	possible (to 4G level)

[21] Policy Impact Partners Ltd, ANALYSIS OF WI-FI 6E AND 5G SPECTRUM EFFICIENCY AT 6 GHZ

The capacity of both types of networks is very high and depends on the available bandwidth. Whilst bandwidth availability can be guaranteed in the licensed 5G band, with Wi-Fi networks the band is only available to you if it is not already occupied by someone or something else and is not subject to interference. Therefore, although the theoretical values are high in both cases, only 5G can guarantee high capacity. When comparing the number of end devices per cell/base station, 5G technology offers significantly greater potential, with more than five times the network capacity.

Spectral efficiency – the data rate relative to bandwidth – is, in a model case in an ideal, interference-free environment, at approximately the same level for both technologies, namely theoretically 20 bits/s/Hz per stream; with MIMO, it is higher. Why is it the same for both technologies? Because both Wi-Fi 6 and 5G use the same maximum modulation scheme, 1024-QAM.

However, one of the reasons why 5G networks can be faster and have higher throughput relates to another aspect, and this brings us back to interference. In the case of 5G networks, we operate in the licensed spectrum, and in the licensed band there is no interference from other sources. Here, we have a higher signal-to-noise ratio (SNR), which is important for determining the resulting spectral efficiency – see the Shannon–Hartley theorem. With Wi-Fi networks, there is greater interference from other sources. Here, we are operating in an unlicensed band, which is used by other technologies or devices, including other Wi-Fi networks. In the case of Wi-Fi 4, interference can also occur from Bluetooth technology. Under real-world conditions, the SNR value is therefore much lower compared to 5G networks. Thanks to the higher signal-to-noise ratio (SNR) in 5G networks, 5G networks can achieve approximately 2–4 times higher spectral efficiency in real-world deployments compared to Wi-Fi 6, depending on the actual SNR.[22] Another aspect that improves spectral efficiency in 5G networks is transmitted power. Higher transmitted power enables a higher signal-to-noise ratio, whereas in Wi-Fi networks, the maximum transmitter power is regulated – see output power below.

Air latency (delay in the transmission medium). 5G networks were designed for specific use cases involving real-time applications, where low latency and high availability are crucial. URLLC (Ultra-reliable Low-Latency Communication) defines very high network availability (at 99.999%) and radio latency of 1 ms. The latency reported for WiFi networks is not in a different order of magnitude, but it depends greatly on how congested the network is, how many devices are currently connected, and how many of them are active and transmitting data. Because a WiFi network is a collision-prone medium, collisions can occur on the shared medium (the space between the transmitter and receiver), and the transmission must be repeated or the data must wait to be sent, which leads to packet delays; consequently, the resulting latency is unpredictable and can fluctuate significantly in a busier network. 5G networks in the Sub-6GHz band use time division duplex (TDD), where it is precisely determined when data will be transmitted and when it will be received, and therefore no collisions occur. Transmission can thus be scheduled by a scheduler, and we can set the quality of service (QoS) for individual services.

Frequencies are one of the most important differentiators between the two technologies. Wi-Fi networks use unlicensed (shared) frequencies, which anyone can use provided certain conditions are met. This sounds advantageous, but let's not forget that it naturally also implies that surrounding networks may interfere with you. A good example of interfered-with Wi-Fi networks are locations where a large number of access points are used, either due to coverage requirements or network capacity (a large number of devices). The use of licensed bands in the case of Private 5G is therefore one of the most important benefits. Simply put, no one can interfere with you, and where there is no interference, there is also high network reliability.

Transmit power is a particularly important aspect for network design and deployment. For Wi-Fi networks, the maximum transmit power is determined by national regulations and the regulatory authority. And because Wi-Fi networks operate in an unlicensed band and we want to prevent networks from interfering with one another, it follows that the maximum power will be low. This then affects the network architecture itself, where we must use more radio units.

A private 5G network typically requires fewer base stations (compared to Wi-Fi) due to the larger cell size. 5G networks require four to six times fewer indoor and outdoor access points than Wi-Fi. 5G base stations can transmit at higher output power than Wi-Fi because they use licensed spectrum. This results in a higher signal-to-noise ratio (SNR) at the end device and higher throughput for 5G.

Mobility in 5G networks, which are by definition mobile networks, poses no problem for the mobility of connected devices, and for many use cases, mobility is literally key – e.g. use cases for AGVs (automated guided vehicles), logistics in general, semi-autonomous devices in ports and transhipment terminals, etc. Individual gNodeBs (base stations) take over client UEs in real time, which cooperate on the handover of the data stream. End devices monitor the surrounding available transmitters and, based on reception conditions, decide whether to perform a handover to a given base station.

In contrast, in Wi-Fi, handover when an end device moves is not a native feature of the technology. The UE remains connected to the original access point as long as it can hear it and exchange data with it, regardless of the fact that it has since entered an area with a stronger signal from a new access point. Only when it loses communication with the original access point does it establish a connection with the stronger – new – one. In managed WiFi networks (networks controlled by a controller), this shortcoming is addressed by a mechanism whereby the managed network itself is aware of the reception conditions of the end stations and is able to disconnect the end device from the weaker access point. The end device then immediately establishes a connection with the stronger access point. Whilst this solution is functional, it falls far short of the fluidity of 5G.

---

[22] Policy Impact Partners Ltd, ANALYSIS OF WI-FI 6E AND 5G SPECTRUM EFFICIENCY AT 6 GHZ

The reliability of both solutions depends primarily on the reliability of the transmission and is very strongly linked to the potential for interference and access to the medium. In 5G networks, reliability is very high, mainly due to the use of a licensed band (where there is no interference) and the TDD access method, in which a precisely allocated time slot is used for data transmission.

For **security**, the SIM card is the cornerstone of mobile networks – without it, a device cannot connect to the network. The SIM card contains important keys for identifying and authenticating clients on the network, and without a SIM card (or e-SIM), access to the 5G network is not possible. An alternative exists in the form of SIM-less authentication, where device authentication is performed using either a virtual identifier or a digital certificate instead of a traditional SIM card. This is advantageous for IoT or IIoT devices that do not contain a SIM module. In any case, network access security is at the highest level.

For Wi-Fi networks, access is secured either at the key level, which is either predefined as common for the entire network or defined separately for each client. Security can be enhanced through authentication via a RADIUS server and a certificate. In the case of security-critical applications, further security measures should be considered, as vulnerabilities and flaws in the WEP, WPA and WPA2 protocols have already been demonstrated. Other potential vulnerabilities in Wi-Fi networks are based on 'rogue access points' or 'phishing access points'.

Wi-Fi networks can be configured to be relatively secure, just as they can be configured to be potentially vulnerable. This is in contrast to 5G, where security is a native feature.

Device **localisation** indoors, where no GPS signal is available, is carried out using triangulation, whereby we know the exact location of at least three base stations and estimate the position of the UE moving within the range of these base stations. Because 5G networks are synchronised with precise time from GPS, the determined position is more accurate. LBS (location-based services) are part of 3GPP Release 16 and will be a native service in 5G networks.

Backward compatibility with the WiFi 6E standard can also be supported by earlier standards (WiFi 4, WiFi 5), albeit at the cost of lower security (WPA2). Private networks can be designed to support connections from both older 4G devices and newer 5G devices, but this is not the expected scenario. Private 5G networks are being built precisely because of the unique features of the 5G standard.

Summary of the comparison between private 5G networks and WiFi

Although at first glance many of the technical parameters of both technologies appear almost comparable, in reality there is a significant difference between them, particularly in terms of guaranteed capacity, stability, security and mobility. This is due both to the fundamental functioning of the technology (particularly in the case of mobility and security) and to the use of licensed/unlicensed spectrum.

Integration of private 5G and Wi-Fi networks

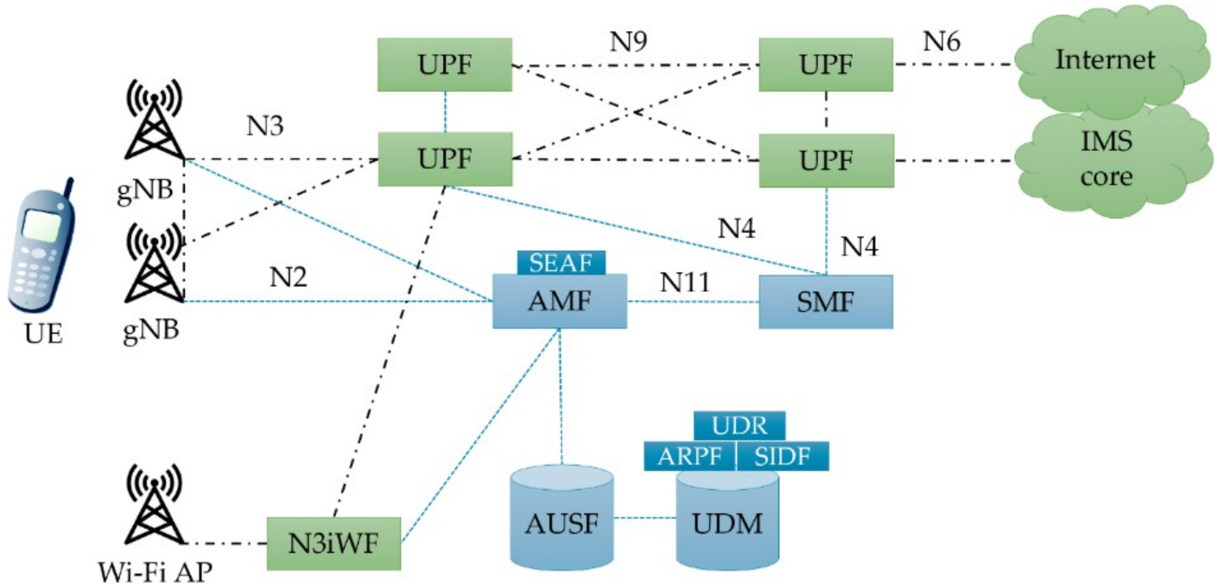
Private 5G and WiFi networks need not merely coexist side by side for use in business-critical and non-critical applications. It is possible to go a step or several steps further and build the entire solution as an integrated system, thereby achieving potential synergies.

The integration of P5G and WiFi is possible at several levels:

- Network monitoring and orchestration.
  Using a single environment for monitoring, quality control and, where applicable, resource management will undoubtedly increase management efficiency.
- Infrastructure synergies.
  The ability to utilise shared computing resources for both the 5G network core and the WiFi controller.
- Edge computing.
  Using the same approach to process data from both networks at the network edge.
- Authentication.
  The possibility of using a shared authentication mechanism, which will significantly increase security, particularly on the WiFi network side.

The diagram below illustrates the integration at the authentication level, where 5G network elements are also used for authenticating WiFi users. Different types of integration can, of course, be combined.

Figure 7: 5G and WiFi integration



Source: Ing. Michal Poupa, 2024.

3.2.4 Voice services on private 5G networks

Many businesses, particularly in the manufacturing and logistics sectors, are addressing the issue of effective voice and data communication for their staff. One cause is often the lack of public network signal coverage within buildings, which frequently have metal structures. Another is the unsuitability of standard telephone communication for team collaboration. It is a logical expectation of companies that, when building their own private 5G network, the solution will also include improvements to voice communication. In the case of private 5G networks, there are several ways to address this issue.

From a technical perspective, there are essentially two approaches:

- **Native communication on 5G networks (Voice over NR) –** Voice support in 5G is called VoNR (Voice over NR) and utilises a new family of EVS (Enhanced Voice Services) voice codecs, as well as the IMS (IP Multimedia Subsystem). Enhanced Voice Services (EVS) is a wideband standard for speech audio coding developed for VoLTE. It offers an audio bandwidth of up to 20 kHz and exhibits high robustness against delay, jitter and packet loss thanks to its coding scheme and greater resilience to packet loss. It was defined within the 3GPP and is described in 3GPP TS 26.441. The areas of application for the EVS codec include enhanced telephony and teleconferencing, audiovisual conferencing services and audio streaming.
- **OTT (over-the-top) –** Generally speaking, an OTT application is any application that uses a device's data connection (computer, laptop, tablet, smartphone, etc.) to offer a service provided by a third party; that is, someone other than the mobile operator itself. Common examples of OTT voice applications include Skype, WhatsApp and Viber. In the case of private 5G networks, however, it would be a logical choice to use a professional application. There are a number of applications that enable professional group communication. These applications allow not only voice communication, but also video and data transmission. In addition to OTT mode, some suppliers also allow the integration of these applications, particularly from a QoS perspective, into the network core, thereby making the OTT application a solution suitable for critical communication as well.

From the perspective of voice service usage, they can also be categorised according to whether:

- they are used for internal company communication
- they are used for communication with the outside world.

In some cases, companies may prefer communication that is truly internal, such as communication between work teams. If external communication is required, it is necessary to connect the private 5G network to the public telephone network (VTS). This solution seems natural if the private 5G network is implemented by a mobile operator. However, connecting to the public telephone network can also be achieved if the private network provider is, for example, a systems integrator.

One option is to use the private 5G network as wireless access to the company's private branch exchange (PBX), from which calls are then handled in the standard way. Another option is to use an existing ISP service that includes a SIP client for mobile phones, with the entire connection to the PSTN already included in that service.

3.2.5 Open-source technology in private 5G networks

Open-source 5G technology refers to 5G network infrastructure and solutions where the source code is freely available to anyone who can view, modify and improve it. This contrasts with proprietary 5G solutions, where the source code is owned by a specific organisation and is not publicly accessible.

The purpose of open-source 5G

The purpose of open-source 5G technology is to foster innovation, reduce costs and accelerate the roll-out of 5G networks by enabling a community of developers, companies and other stakeholders to collaborate on this technology. Open-source 5G aims to provide a more flexible, scalable and adaptable network infrastructure capable of meeting the diverse needs of modern digital applications.

Advantages and disadvantages of open-source 5G

Pros:

- Cost-effectiveness: Reduces costs associated with licensing fees and vendor lock-in, as organisations can use and adapt the technology without major investment.
- Innovation: Facilitates a collaborative environment where developers and companies can contribute to the technology, leading to rapid innovation and improvements.
- Flexibility and customisation: Enables organisations to tailor their 5G network to their specific needs and requirements, thereby enhancing network performance and efficiency.
- Community support: Benefits from a large community of developers and users who can offer support, share knowledge and develop best practices.

Disadvantages:

- Complexity of implementation: Requires significant technical expertise for implementation and management, as open-source solutions can be complex and require customisation.
- Support and maintenance: There is no formal support structure, unlike with proprietary solutions, which can pose a problem for organisations without in-house expertise.
- Security risks: The open-source nature means it may be more exposed to security vulnerabilities if not properly managed and secured.
- Interoperability issues: With many contributors and variations, ensuring interoperability between different open-source components can be challenging.

Network cores – 5G Core

In the 5G core domain, there are several open-source projects, the most significant of which include:

- **OpenAirInterface (OAI)**: The OSA is home to OpenAirInterface, an open-source initiative that brings together a community of developers from around the world working collaboratively on technologies for wireless cellular radio access networks (RAN) and core networks (CN). One of these projects is the development of an open 5G Core.
- **Free5GC**: is an open-source implementation of a 5G Core network, consisting of several modules for network control, identity management and other functions.
- **NextEPC**: is an open-source implementation of a 5G Core network, comprising several modules for network control, identity management and other functions.
- **Open5GS**: in our opinion, this is one of the most ambitious and widely supported projects for implementing a 5G NR / LTE Core network. It currently supports 3GPP Release-17 features.
- **Aether SD-Core**: is an open-source 5G Core stack that focuses on providing a simple interface for developers to create applications for 5G networks.
- **Open5GCore**: the Fraunhofer FOKUS Open5GCore toolkit is the world's first practical implementation of the 3GPP 5G core network. It provides a prototype of the 3GPP Release 15 and 16 core network functions in a form suitable for research and development activities.

Radio Access Network – RAN

Open-source projects in the RAN domain make extensive use of SDR. Among the most significant RAN open-source projects are:

- **OpenAirInterface (OAI)**: OSA is home to OpenAirInterface, an open-source project that brings together a community of developers from around the world who are working together on technologies for wireless cellular radio access networks (RAN) and core networks (CN). One of the projects is the development of an open 5G RAN.
- **Intel FlexRAN**: FlexRAN is an open-source project focused on the flexible implementation and management of RAN functions. The project is part of the Open Networking Foundation (ONF) and provides a platform for research and development in the field of software-defined RAN (SD-RAN).
- **Aether**: SD-RAN project
- **srsRAN**: an open-source project by Software Radio Systems, which focuses on developing high-performance 4G and 5G RAN solutions based on software-defined radios. Their product is a fully "ORAN-native full stack built on a CU/DU topology"

3.2.6 Commercial and cost aspects of private 5G networks

Even the best technology may be doomed to failure if the solution built on this technology is not considered by the customer to be the most effective option available to them for fulfilling their task. A 5G network customer will logically compare the costs of P5G with the benefits of P5G. In practice, this often involves comparing the additional costs of P5G versus Wi-Fi on the one hand, and the additional benefits of P5G versus Wi-Fi on the other.

Benefits of a private 5G network

In general terms, much has been written about the advantages of 5G networks. A comparison with Wi-Fi shows (see above) that these are not technologies that differ dramatically in their parameters at first glance. Nevertheless, differences that are not immediately apparent (such as the reliability of mobile connectivity) can have a significant impact on the efficiency of the customer's operations. Quantifying these impacts, however, will not be straightforward and will require a thorough understanding of both the specific use case and its economics, as well as a thorough understanding of the connectivity solution and its capabilities.

Example: In a case study, Huawei based the benefits of P5G on the fact that it enables the speed of AGV operations to be increased from 0.6 m/s (when operating on WiFi) to 1.2 m/s. This leads to a reduced number of AGVs being required and, consequently, a 30% reduction in AGV operating costs.

Costs of a private 5G network

The actual costs of a private 5G network can vary significantly depending on a number of factors. It is therefore understandably impossible to quantify a specific cost, but it is possible to identify the main factors that influence costs. By way of illustration, it can be said that a private 5G network will almost always be more expensive than a WiFi network of a comparable standard. This is despite the fact that a 5G network will often use fewer radio elements due to the potentially higher transmission power available on the licensed band.

Any business undertaking digitalisation using a private 5G network should, first and foremost, carefully define its requirements. It should then have a P5G solution designed that meets these requirements. It is therefore important for the business to know what requirements need to be defined and within what range their values may fall.

From the P5G user's perspective, the main requirements are as follows:

- Service Level Indicators (SLI)
- Types of planned services
- Security
- Coverage
- Technology
- Network support and monitoring methods

Depending on these requirements, the P5G network provider will address the following areas in particular when designing the network:

- P5G deployment method – island network, local user data, local radio-only network (see P5G specifications above).
- RAN architecture – for example, use of ORAN, all-in-one gNodeB.
- HA (high availability) design and DR (disaster recovery) process
- URLLC design
- Traffic patterns
- Use of IMS, LMS and other network functions
- Additional cybersecurity layers
- Supplier selection – tier-1 suppliers, other suppliers, open-source.

The list above illustrates just how broad the concept of a private 5G network is, how much its architecture can vary, and consequently, how much costs can differ. Nevertheless, it is possible to identify a general cost structure. This will enable businesses to structure their commercial requirements appropriately, for example when preparing an RFP. They can choose different approaches for individual parts of the delivery and thus achieve the optimal result.

The following table shows the general cost structure of a private 5G network.

Figure 8: General cost structure of a private 5G network

	One-off cost	Monthly/annual cost
5G CORE		
5G RAN		
Infrastructure		
Server		
Switch		
Virtualisation		
Cabling		
GPS		
Other infrastructure		
Equipment (UE/CPE/SIM)		
Frequency leasing		
Professional services		
Design		
Installation		
Managed services		
O&M		
L1-L3 support		

For some cost items, the cost may be one-off or recurring, depending on the supplier's approach or the customer's requirements. For example, the CAPEX vs. OPEX model for technologies.

Other cost items may involve a combination of one-off and recurring costs. Typically, for 5G RAN/5G CORE technologies, this may involve a one-off payment followed by recurring payments for licences and fees for technology maintenance/upgrades.

The network can be acquired as a capital expenditure and managed in-house, or alternatively, everything can be requested as a service, for example for a defined fixed monthly payment. Alternatively, a combination of both approaches. In this case, it is a matter of customer preference. Regardless of the preferred operating model, however, it is important to understand the structure of P5G so that alternative offers can be compared effectively and the optimal option selected.

3.2.7 MEC/Edge computing

This is one of the key features of 5G and, particularly in the context of private 5G networks, can bring a number of benefits to businesses. This is evident from the case studies (see appendices), which illustrate use cases requiring not only private 5G itself, but also edge computing.

MEC/Edge Computing is a new element of 5G architecture that enables rapid data processing and the placement of computing resources closer to the sources of this data. In this respect, edge computing differs from cloud or on-premises architectures, in which 'workloads' (in this context, computational tasks) are processed in centralised data centres, subsequently accessed via the network, and remain relatively distant from users.

In an edge computing architecture, workloads are typically hosted at localised aggregation points that are physically closer to users, devices, sensors, production tools or other operational equipment, rather than in larger central data centres of public clouds or local infrastructure.

In the case of conventional, non-distributed computing architectures, on which most businesses have relied for at least the last decade, businesses host their applications and data in centralised data centres, and users access these resources via the internet. The internet usually becomes the weakest link in workload performance. Slow network connections between remote locations and the central data centre result in slower application response times and delays in data retrieval. In the event of a remote connection failure, the workload becomes completely inaccessible.

For businesses, edge computing offers the following key benefits:

- Lower latency, high availability, fast data processing
- Reduced network costs
- Reduced service outages
- Greater control over data
- Faster services
- Consistent user experience

Thanks to its advantages, edge computing is ideal for use in the following types of services and applications, for example:

- Real-time data and video analytics using AI/ML (including applications in Industry 4.0)
- IoT
- Augmented reality/virtual reality
- Autonomous vehicles
- CDN
- Location tracking services

From a real-world operational perspective, it is desirable for edge computing to utilise a centralised platform and a standardised stack so that the edge cloud can be operated effectively. The edge stack should therefore be derived from the cloud environment used by the organisation in question.

A private 5G network is, in principle, one of the use cases for edge computing. Conversely, the architecture of a private 5G network (MEC) enables the implementation of a range of scenarios that leverage all the benefits of edge computing.

4 Use cases

4.1 Significance and categorisation of use cases

As stated in the introductory definition of terms, a 5G use case (hereinafter also 'UC') is 'a task that a company needs to carry out in order to achieve a specific result, and for which it makes sense, from both a technical and commercial perspective, to utilise 5G technology.'

In contrast, a case study is a concrete implementation of a use case. Within a case study, a specific solution is used to fulfil the task defined in the Use Case. That is, a particular technology, products and services from a specific provider. Regardless of whether this implementation is already in commercial operation, or whether it is a demo implementation or a Proof of Concept.

Use Cases are a very important part of the whole issue of business digitalisation using 5G technologies. Listing and defining use cases related to the use of 5G for business digitalisation can significantly help these companies in their digitalisation efforts in several ways:

- By identifying specific use cases, companies can understand how 5G technology can be applied to their operations. This clarity helps them visualise the practical aspects of integrating 5G into their business processes and infrastructure.
- Specific real-world examples of these use cases (i.e. case studies) provide examples of successful 5G implementations, enabling companies to benchmark their efforts and adopt industry best practices.
- With a clear set of use cases, companies can better strategically plan their digital transformation journeys.

In practice, it will be difficult to justify the purchase of relatively expensive 5G technology (private 5G) based on a single use case. Typically, a whole range of use cases will need to be utilised to ensure a return on investment. It is therefore important to have a comprehensive understanding of which use cases can be realised, even though implementation will usually take place gradually over time.

Categorisation and types of use cases

There is potentially a very large number of 5G use cases. To navigate them effectively, they need to be categorised. This can be done from various perspectives, depending on the purpose of the categorisation.

Categorisation by vertical

For business needs, categorisation by vertical will be the first logical step. This will allow each business to focus on use cases specific to its vertical.

Use cases, by addressing specific tasks within business processes, can bear a considerable resemblance to one another. For example, a 'connected worker' may receive training or instructions from an expert in manufacturing, logistics or aircraft maintenance. Despite this partial similarity, it is advisable to implement categorisation by vertical, as this will enable the specifics of a given industry to be captured.

Categorisation by common purpose

In many cases, several different use cases serve a common purpose and aim to achieve a common result. It therefore makes sense to group them into a common category.

An example of use cases aimed at a common outcome is:

- Creating a smart factory or a smart warehouse.
- Connecting a worker so that they can receive remote support for training, assistance with their work and other tasks.
- Secure and reliable connectivity within a healthcare facility.

Categorisation by perimeter

From the perspective of implementing a solution for a given use case, it is very important whether the use case is limited to a specific, clearly defined area – i.e. a perimeter – or not. If the use case is confined to a specific perimeter, the use of a private 5G network can be considered, and in many cases this will be the best solution. Conversely, if the use case is not limited to a perimeter, then a private

A 5G network is practically out of the question, so a public network must be considered, ideally one that utilises network slicing or another form of QoS provision.

Example:

- AGV operations in a warehouse – limited to a specific perimeter.
- Connected ambulance – not restricted to the perimeter.

Categorisation by application type

Within a given use case, specific application solutions are always employed. This means that a specific technology (beyond 5G) is utilised to provide a specific service. These application solutions then largely determine the connectivity requirements in terms of downlink/uplink data transfer speeds, the number of concurrent connections, latency, etc.

Example:

- High-resolution camera technology with AI data processing used for anomaly detection (can be utilised in a range of different use cases across various verticals).
- Data transmission from sensors to an IoT platform.
- Augmented reality (for various use cases involving connected workers).
- Group communication applications.

Categorisation according to specific 5G requirements

Categorisation according to 5G requirements goes hand in hand with categorisation by application type. In principle, applications determine the requirements for specific 5G features.

The basic specific features of 5G are:

- eMBB – suitable for mobile broadband connectivity. Typical applications requiring eMBB: HD video (cameras), gaming services.
- mMTC – suitable for massive IoT-type communication. Typical applications requiring mMTC: smart city – monitoring, predictive maintenance, digital twin.
- URLLC – suitable for highly reliable communication requiring low latency. Typical applications requiring URLLC: traffic management, telemedicine.

In the case of network slicing, specific 5G features are also defined for V2X (Vehicle to X) and HPMT (High-Performance Machine-Type Communications).

4.2 Overview of use cases in selected verticals

Below is an overview of use cases in verticals where the use of 5G for digitalisation offers significant advantages and there is therefore a high likelihood of their practical implementation. The overview of use cases takes into account the above-mentioned categorisation types.

4.2.1 Healthcare sector

4.2.1.1 Category: telemedicine

Telemedicine is the remote transmission of medical information from patient to doctor via telecommunications and information technologies. It is therefore a clear candidate for utilising the advantages of 5G technology. Typically, this will involve public (macro) 5G networks. However, in addition to the remote end with 5G, there is also the other side – healthcare facilities – and here it will be highly advantageous to have private 5G for connectivity and the 'receipt' of information. High-quality connectivity combined with flexibility of movement is a critical requirement in this case.

UC Name	Description	Perimeter	5G features
Remote diagnosis and consultation between doctor and patient	Two-way HD video is used between the patient and a primary/secondary care specialist to conduct initial screening examinations, routine check-ups (which do not require physical procedures), therapeutic/rehabilitation sessions and, increasingly, visual diagnoses (e.g. conditions and symptoms). By conducting these meetings remotely, patients do not need to travel to healthcare professionals and vice versa, which reduces the burden on the patient and lowers the cost of each appointment.	No	eMBB
Patient monitoring using wearables and other devices	Remote patient monitoring is considered a key factor in the more efficient and proactive delivery of healthcare services and the management of chronic conditions. Using sensors, wearable devices and e-health devices, patient data can be collected and analysed without patients having to travel to a primary care facility for a face-to-face appointment with a doctor.	No	mMTC
Connected ambulance	A connected ambulance and its crew act as a means of collecting and transmitting patient information—whether via wearable devices, sensors or HD video/body camera streaming—back to the hospital A&E department, whilst the patient is being transported. This allows hospital staff to better understand the patient's condition before their arrival. Network slicing is the ideal solution for this use case.	Not	eMBB, URLLC
Remote consultation between doctors, including AR, e.g. during remote surgery.	In the context of 5G, a frequently mentioned use case for healthcare is 'telesurgery', where a specialist can perform an operation from a remote location. A more realistic short-term opportunity is the use of 5G-enabled AR/VR headsets, which enable a specialist to observe an operation taking place in real time, guide the surgeon on site and comment on what they see based on their own experience.	Not	eMBB, URLLC

4.2.1.2 Category: services within a healthcare facility

A group of UCs that improve the quality of healthcare and are implemented within the limited perimeter of a healthcare facility. A common feature of all is that they require the high reliability of a private 5G network. Often combined with high capacity, flexibility of mobility and, ideally, the use of location services.

UC Name	Description	Perimeter	5G features
Training medical students using AR	The use of AR/VR headsets, whether in a hospital or a classroom, could enable medical students and trainees to perform practical procedures in a virtual environment (on virtual/non-real patients) and even	Yes	eMBB, URLLC

	collaborate on these virtual procedures in real time. In few areas is this as meaningful as it is in the training of medical students.		
Monitoring patient behaviour in facilities using video analytics.	In hospitals, care homes, psychiatric centres, etc., video analytics can be used in corridors to identify patients who are behaving abnormally, have had an incident such as a fall, or are becoming a danger to themselves or others. Hosting analytics on-premises using smart cameras can lead to disproportionately expensive hardware, and therefore analytics should take place in the cloud (or ideally using edge computing to maintain localisation and data security).	Yes	eMBB
Broadcast and processing of diagnostic and other data	In healthcare, there are many high-resolution images and files that may require high-performance computing for diagnosis and treatment planning. With 5G, for example, once an MRI or CT scan has been received, the images can be sent in real time to where they need to be analysed in order to make a diagnosis. Furthermore, connecting devices to 5G can also be used to track their location within the hospital.	Yes	eMBB
Monitoring patients' vital signs in bed, using bed pads.	Multifunctional pads, naturally with connectivity, not only transmit information on patients' vital signs but also monitor positioning to prevent pressure sores. Hospitals often face issues with heavily congested Wi-Fi networks. Therefore, such critical communication definitely belongs on a private 5G network. This also maintains the necessary mobility for moving beds.	Yes	URLLC
Group communication among healthcare staff	Medical staff need to communicate frequently and effectively with one another. Modern group communication, including video transmission, can significantly increase work efficiency. To make full use of all the possibilities and functionalities of modern applications, fast data transmission with minimal latency and high reliability, which only 5G technology can guarantee.	Yes	eMBB, URLLC

4.2.2 Industry and manufacturing

4.2.2.1 Category: smart factory

The term 'smart factory' encompasses a range of use cases that help streamline production through digitalisation in terms of automation, robotisation, quality, and worker safety. Given the limited perimeter of the factory and the requirements for high reliability, often also high capacity associated with video data transmission and low latency associated with AR technology, private 5G is a suitable connectivity solution for these use cases.

UC Name	Description	Perimeter	5G features
Quality control of production outputs	This use case utilises 5G-enabled cameras and machine vision systems for real-time inspection and fault detection in manufacturing processes. The high bandwidth and low latency of 5G enable rapid processing visual data and the identification of defects or discrepancies on the production line. The solution typically utilises AI-powered image analysis.	Yes	eMBB, URLLC
Predictive maintenance	Automated monitoring of asset (machine) condition enables manufacturers to optimise maintenance and ensure that downtime due to insufficient maintenance does not occur. It also reduces the consumption of spare parts and minimises unnecessary routine work for employees. Unplanned downtime is one of the biggest obstacles for manufacturers in achieving maximum productivity. Studies have shown that unplanned downtime costs industrial manufacturers approximately USD 50 billion annually, with 42% of these downtimes being caused by equipment failures.	Yes	mMTC
Asset and Operations Monitoring (SOP)	Standard Operating Procedures execution checking – this essentially involves monitoring production assets and operations within the factory. One specific application is FAT (Factory Acceptance Testing), carried out remotely by the customer without the need for physical presence, thanks to video transmission from HD cameras. Another application is the use of this information for effective production management.	Yes	eMBB
Operation of AMR (autonomous mobile robots)/AGV	5G facilitates the operation of AMRs (Autonomous Mobile Robots) in manufacturing facilities. These robots can transport materials efficiently and safely and adapt to changing layouts and operational requirements. The use of (private) 5G connectivity is particularly beneficial for data transmission from AMR cameras for processing via edge computing. It is also useful AMR teleoperation is required.	Yes	URLLC, eMBB
Site and worker safety in manufacturing	Safety improvements are often achieved by using a high-resolution camera system combined with AI analytics, which detects undesirable occurrences (missing protective equipment, presence in restricted zones, etc.). Another option is to enhance safety through solutions that prevent collisions between employees and robots, using sensors, etc.	Yes	eMBB

Improving production efficiency through synchronisation and dynamic planning	The use of 5G in this scenario enables the synchronisation of production processes and dynamic task planning. This use case focuses on optimising workflows by ensuring that the various parts of the production process are perfectly coordinated and can be adapt adapt changes. The use of wireless technology also speeds up and reduces the cost of reconfiguring production lines.	Yes	
Collaborative robots (cobots)	Collaborative robots, or cobots, work alongside operators to perform manufacturing tasks such as operational work, drilling or assembly, as well as automatic quality checks on products still on the production line. In this way, it is possible to automatically check all parts, not just samples. Thanks to cobots, factories can inspect every part without extending the time required to do so, which improves overall quality and customer satisfaction.	Yes	eMBB, URLLC
Digital twins in manufacturing	The effective use of digital twins requires the processing and management of vast amounts of data. This applies to both the creation and operation of the digital twin. Sensors built into machines transmit performance data to the digital twin in real time. This is used for modelling efficient production processes, configuring production lines, etc., but also for maintenance schedules and reduced maintenance costs.	Yes	mMTC
Transfer of data files to machines or products in production	As part of the manufacturing process, data files need to be transferred – with high reliability and at high speed. These may be files containing production programmes for individual machines, or firmware to be loaded onto products on the production line – for example, vehicles in the automotive sector.	Yes	

4.2.2.2 Category: connected worker

A category of use cases that enable workers to work more efficiently thanks to their connectivity (ideally via 5G) and the use of technologies such as AR (smart glasses), or tablets/mobile phones and suitable application solutions. A high-quality and reliable connection for the worker helps with a whole range of tasks they have to perform, thanks to the possibility of remote assistance.

UC Name	Description	Perimeter	5G features
Lonely worker protection	Protection of workers in the event of loss of consciousness, a fall, etc. It utilises end-device sensors and location tracking. This is often a use case associated with control centre-managed group communication.	Yes	eMBB
Maintenance using AR	Thanks to the use of AR, maintenance can be carried out without the physical presence of the supplier's experts; a worker without special qualifications is sufficient. This is cost-effective and also offers advantages when carrying out maintenance in challenging environments.	Yes	eMBB, URLLC
Connected tools	Not only workers, but their hand tools themselves can be connected to increase work efficiency. In addition to diagnostics, this can also be used to track the location of tools.	Yes	eMBB, URLLC
Training using AR	Training new employees using AR, for example production line operators in the automotive industry, is already a practical use case in use today. As with other AR use cases, the use of 5G is not essential, but it will improve the user experience.	Yes	eMBB, URLLC
Group communication	Group and dispatch-controlled voice and video communication is a necessity in many areas and the most effective means of communication. A range of OTT applications can be used for this use case, and it is also possible to integrate them with the network core to achieve a higher level of QoS.	Yes	eMBB, URLLC
Sharing of instructions and documentation	Staff always have the necessary documentation available in the field thanks to sharing, for example using AR glasses or other end devices such as tablets.	Yes	eMBB

4.2.3 Logistics and transport sector

4.2.3.1 Category: smart warehouse

The UC group, which enhances storage efficiency, includes automation, robotisation, inventory management and quality improvement.

UC name	Description	Perimeter	5G Features

Product packaging with computer vision	The use of computer vision for packaging quality control in logistics. Computer vision is a field of artificial intelligence that trains computers to interpret and understand the visual world. Using digital images from cameras and videos, along with deep learning models, computer vision systems can accurately identify and classify objects and then respond to what they 'see'.	Yes	eMBB
AGV and AMR operations in logistics	The use of AGVs and AMRs in warehouses is growing. Their connectivity using 5G increases the efficiency of their operation. This is particularly true in cases requiring teleoperation, data transmission from cameras and processing at the edge, for example for collision scenarios. In these cases, truly minimal latency is required.	Yes	URLLC
Inventory management	Tracking and managing stock. Ideally in real time. For example, in the form of a so-called smart shelf. And/or using RFID and barcode readers. In any case, all information must be in digital form and the data transmitted to a central unit, which may be located at the edge. Everything is then managed using Warehouse Management System software.	Yes	

4.2.3.2 Category: assisted work in logistics

The UC group, which increases storage efficiency, includes automation, robotisation, inventory management and quality improvement.

UC name	Description	Scope	5G features
Remote visual inspection (Virtual table inspection)	Remote inspection (Virtual table inspection), for example of aircraft engines, using high-resolution image transmission. A tablet or AR glasses can be used as the end device. A similar use case can also be applied in healthcare/care homes (saving doctors' time).	Yes	eMBB
Picking using AR (Vision picking)	The use of smart AR glasses for order picking in logistics is another application of AR technology, ideally in conjunction with a private 5G network for greater service reliability and a better user experience. This use case is already in practice, for example by AYES (see the case study for more details).	Yes	eMBB, URLLC
Scanning of goods and other assets	The ability to maintain a perfect overview in the field by obtaining information about goods and other assets through scanning with an end device. Scanning is certainly possible without 5G technology using Wi-Fi, but practical experience confirms that disrupted and unreliable Wi-Fi connectivity in warehouses also affects scanning.	Yes	eMBB

4.2.3.3 Category: smart logistics hub

Logistics hubs that go beyond the level of warehouses, such as ports and rail terminals, require a range of UCs utilising the potential of 5G for their efficient operation.

UC name	Description	Perimeter	5G features
Digital twin of a logistics organisation	A digital twin of a complex system such as a logistics centre – in many cases a port, in our context for example a rail terminal – enables the efficiency of the entire hub to be improved through the modelling of 'what if' scenarios and the analysis of vast amounts of data collected by sensors and cameras from the real environment and fed into the digital twin.	Yes	mMTC, eMBB
Transport of materials using autonomous vehicles.	The vehicles are used to transport materials between individual warehouses, within industrial sites, etc., i.e. operations extend beyond a single warehouse and the environment is often challenging. The use of (private) 5G connectivity offers significant benefits in the case of teleoperation (remote control) of vehicles and in the transmission and processing of data from cameras, for example when evaluating collision scenarios.	Yes	URLLC, eMBB
Smart railway terminal	A railway terminal – a transhipment point – is a location where there is considerable scope for robotisation and automation, and thus for the use of a private 5G network. A large number of cameras are installed within the automated terminal, enabling teleoperation.	Yes	eMBB, URLLC, mMTC

4.2.3.4 Category: supply chain management

Managing the entire supply chain typically requires a combination of UC and various technologies; public 5G networks can be supplemented by hybrid or private networks, or other IoT technologies

UC Name	Description	Perimeter	5G Features
Fleet management	Fleet management is not a new use case, but 5G (in this case public, ideally with slicing) brings a new level of data connection quality and thereby expands its potential. 5G connectivity will enable transport and logistics companies to utilise real-time diagnostic data via digital dashboards that provide insights into driver behaviour, as well as route and fuel consumption. By utilising smart sensors and on-board computers that monitor and transmit location, speed, fuel consumption, vehicle wear and tear, and component failures, organisations can improve operational efficiency across all areas.	No	mMTC, eMBB
V2X Communication	Communication between vehicles and other infrastructure elements, or between vehicles themselves, provides the necessary element of safety and reliability for autonomous operation. It can be used, for example, for platooning, i.e. the operation of a convoy of vehicles, which saves fuel and costs.	No	URLLC
Asset tracking	Tracking items during transport is an important part of managing the entire supply chain and a prerequisite for its efficiency. Nationwide technology is required, specifically from the LP-WAN category. In the case of 5G, this could therefore be RedCap.	No	mMTC

4.2.4 Agriculture and food industry

4.2.4.1 Category: smart farm – precision farming

Smart farming, also known as precision farming, refers to the integration of advanced technologies into agricultural practices to increase efficiency, productivity and sustainability. This approach utilises various information and communication technologies to monitor, analyse and manage agricultural operations.

UC Name	Description	Perimeter	5G features
Autonomous tractors and agricultural machinery	Autonomous tractors and other agricultural machinery use 5G to receive and transmit data in real time, enabling them to perform tasks such as planting, weeding and harvesting with minimal human intervention. As with other autonomous vehicles, 5G enables efficient teleoperation when required and the transmission of data from cameras on the machines for immediate evaluation.	Yes	URLLC, eMBB
Automated harvesting systems	Automated harvesting systems use robotic machines to harvest crops autonomously. These systems typically consist of self-driving vehicles equipped with sensors, cameras and robotic arms that can identify ripe crops, cut or pick them precisely, and collect the produce. The effectiveness of these systems depends on their ability to process vast amounts of data in real time, make rapid decisions and operate with high precision across large areas of agricultural land.	Yes	eMBB, URLLC
Smart irrigation systems	Smart irrigation systems utilise a network of sensors distributed across the entire agricultural field. These sensors measure various environmental and soil parameters, such as moisture levels, temperature, and even the nutrient status of the soil. The sensors send data to a central system for analysis. This may be an edge server. Based on the analysis, commands are sent to the irrigation system to adjust the irrigation schedule as required. This may involve switching sprinklers on or off, adjusting flow rates, or changing the timing . The system can target specific zones within the field to ensure that each area receives the exact amount of water required.	Yes	mMTC
Livestock Monitoring	Monitoring focuses on tracking the location and health status of animals. Wearable IoT devices collect data on the location, health and behaviour of livestock. 5G ensures the continuous transmission of this data, which can be used for real-time health monitoring, disease prediction and optimisation of breeding cycles.	Yes	mMTC
Monitoring the condition of crops and soil	Crop monitoring systems utilise various sensors distributed across the field. These include soil moisture sensors, nutrient level sensors and climate sensors that measure parameters such as temperature, humidity and CO2 levels. Drones provide additional data that is essential for assessing crop health on a larger scale. These images can detect variations in colour, size and crop development, which indicate health and nutritional status. Data collected from ground-based sensors and aerial imagery is integrated and transmitted to a central unit, where advanced analysis . The system provides useful information that can be utilised immediately. For example, if a potential pest infestation is detected, the system can recommend specific areas for pesticide application.	Yes	mMTC, eMBB

4.2.4.2 Category: agricultural supply chain tracking

This UC category aims to track the supply of agricultural products from source to retail chains. This is done both to record the origin of products and to ensure and monitor appropriate transport conditions.

UC Name	Description	Scope	5G Features
Tracking products from farm to point of sale	This UC addresses a key aspect of the agricultural supply chain: ensuring transparency, traceability and efficiency from point of origin to the consumer. Products are tagged at farm level using barcodes, RFID tags or smart sensors capable of capturing and recording various data including harvest time, origin, treatments and quality ratings. Stakeholders can track the status and progress of goods as they move through the supply chain. This monitoring helps with logistics management, route optimisation, responding to delays and ensuring compliance with safety and quality standards.	No	mMTC
Monitoring of conditions during the transport of agricultural products	UC focuses on maintaining the integrity and quality of agricultural goods during transport from farms to markets or processors. Sensors are integrated into transport vehicles or individual product packages. During transport, these sensors monitor various environmental parameters such as temperature, humidity, vibration and atmospheric pressure – factors that are crucial for maintaining product quality . The data is transmitted to a central unit, evaluated and subsequently used to generate relevant reports.	No	mMTC

5 Corporate strategies for digitalisation using 5G

5.1 Strategy and OKRs

In general terms, a strategy is usually defined as a plan for achieving long-term goals. In the context of business digitalisation, strategy refers to a comprehensive plan designed to achieve specific company objectives by integrating digital technologies into its management and operations. This strategy defines how a company can use technology to create new – or adapt existing – business processes, products and services to meet changing market demands.

The strategy therefore has two basic components: (1) objectives and (2) the means of achieving them.

Digitalisation **goals** must logically align with the company's objectives and thus contribute to their fulfilment. The OKR (Objectives and Key Results) framework[23] is suitable for defining these goals. This framework helps set goals for the entire company and its sub-units. These may also include individual product lines or functional areas. Its advantage is that it is suitable for use by everyone from small businesses to global corporations. A good example is Google (Alphabet), which began using OKR when it had just 40 employees and continues to use it to this day.

OKR introduces the following system for setting goals:

- **Objective** – the ultimate goal. It must be aligned with the company's goals, clear and, above all, inspiring. It should be time-bound, though it need not be directly measurable. This is made possible by the fact that measurable metrics have results that lead to this ultimate goal.
- **Key Results** – measurable results that lead us to the ultimate goal. We can and want to influence them, but we do not have direct control over them. They are therefore 'outcomes', the expected results.
- **Initiatives** – activities that we carry out and therefore have under our control. For example, individual tasks or projects. They should help achieve the results.

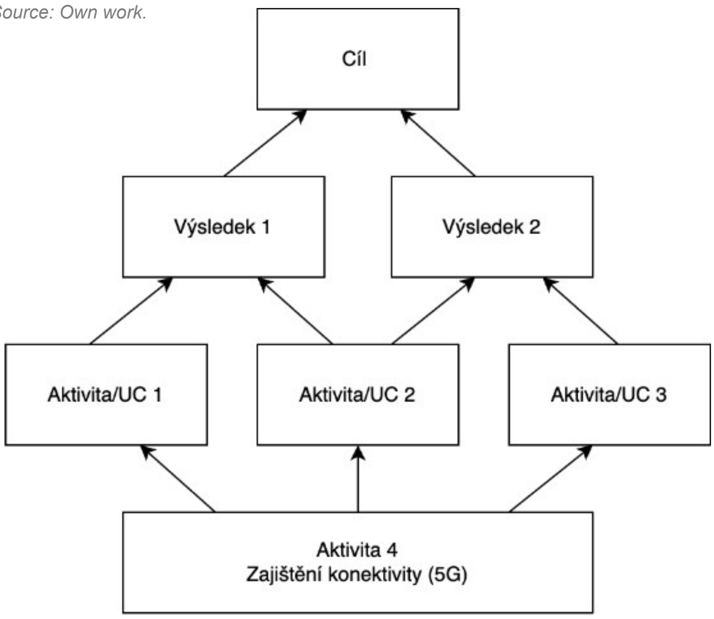
In the case of business digitalisation, a key activity will typically be the implementation of an innovation project focused on business process innovation (see below). OKR also enables an agile approach without chaotically changing goals: whilst our goal and planned results remain, it is possible to flexibly change the initiatives intended to lead to their achievement.

---

[23] Doerr, J. (24 April 2018). *Measure What Matters*. Penguin.

Figure 9: OKRs for digitalisation with 5G: how individual activities help achieve results that lead to the defined objective. It also illustrates how the activity of ensuring the necessary connectivity supports other activities in the form of use cases (UC).

Source: Own work.



Notes on activities:

- Individual activities aim to deliver defined results within the OKR framework.
- Some activities are, in fact, use cases (UC) – see the definition of UC – tasks that the organisation needs to complete to achieve the desired outcome (Key Results).
- Activities are often also innovation projects.
- The implementation of 5G is a possible component of one of the activities: the initiative should not be about implementing 5G/P5G, but about defining requirements and subsequently selecting and implementing the best connectivity option for the defined use cases.
- Typically, several activities/UCs justify the implementation of P5G.

5.2 Examples of objectives and key results in the field of digitalisation using 5G

5.2.1 Example of using OKRs for the Smart Factory sector

Objective:

To transform our production facility into a fully functional smart factory within two years.

Key Results:

- Key Result 1: Reduce production downtime by 40% through predictive maintenance and automation.
- Key Result 2: Improve production efficiency by 30%, measured by output per hour.

Initiatives:

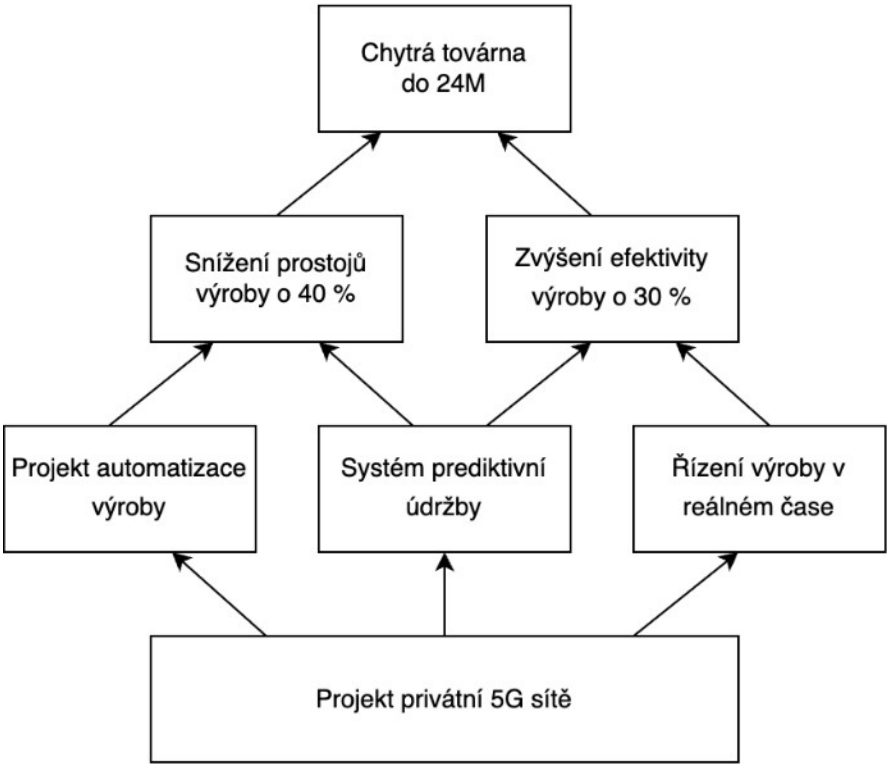
- Initiative 1: Production automation project – The aim of this initiative is to identify and implement a suitable production automation solution, including the necessary retrofitting of machines with sensors, robotisation, etc.
- Activity 2: Predictive Maintenance System Project – The aim of the project is to design and implement a suitable predictive maintenance system.

  The initiative may include
  - Development of algorithms/use of AI for real-time analysis of data from Internet of Things sensors and prediction of equipment failures and maintenance requirements.
  - Training of technical teams for the effective implementation and management of the predictive maintenance system.

- Activity 3: Real-time production monitoring project – The aim of the project is to implement a centralised control panel that displays analyses of production metrics, machine status and other important data in real time.
- Activity 4: Connectivity Provision Project – The aim of the project is to define the connectivity requirements for individual use cases, and to select and implement connectivity with the required parameters.

The OKR setup is shown in the diagram below. It is clear from this that a private 5G network alone will not deliver any of the required outcomes. It serves to support use cases/projects that contribute to achieving key results and objectives. There is no point in implementing a private 5G network until the company's objectives in this area and the activities leading to them are clearly defined.

Figure 10: Sample OKR setup for a Smart Factory. Source: Own work.



5.2.2 Example of OKR use for the Smart Warehouse sector

Objective:

To have the smart warehouse fully operational by the end of the second quarter of 2025, incorporating advanced technological solutions for inventory management and quality control.

Key Results:

- Key Result 1: Achieve a 30% reduction in stock handling time through the deployment of automated guided vehicles (AGVs) and autonomous mobile robots (AMRs).
- Key Result 2: Improve product packaging quality assurance by implementing computer vision systems, reducing error rates by 50%.
- Key Result 3: Improve inventory accuracy to 99% and reduce inventory processing time by 40% using advanced management systems.

Activities (Initiatives):

- Activity 1: Deployment of AGVs/AMRs

The AGV/AMR deployment project will include the selection of AGV/AMR suppliers that integrate seamlessly with existing warehouse management systems.

Design and reorganisation of the warehouse layout to optimise AGV/AMR routing and efficiency.

- Activity 2: Deployment of computer vision for quality control

The project will include:

  - Deployment of high-resolution cameras and associated hardware around key quality control points.
  - Integration of software capable of analysing defects and discrepancies in real time using AI algorithms.
- Activity 3: Advanced inventory management systems

The project will involve upgrading the existing inventory management system to a more robust solution capable of seamless integration with IoT devices and providing real-time analytics.

- Activity 4: Connectivity Provision Project

The aim of the project is to define the connectivity requirements for individual use cases, and to select and implement connectivity with the required parameters.

5.2.3 Example of OKR use for Smart Farm – precision farming

Objective:

To establish a fully functional smart farm by the end of 2025, thereby increasing the farm's overall productivity and sustainability through the use of precision farming technologies.

Key Results:

- Key Result 1:
  Increase crop yields by 25% through automated harvesting and precision farming techniques.
- Key Result 2:
  Reduce water consumption by 30% whilst maintaining or improving crop health through the use of smart irrigation systems.
- Key Result 3:
  Achieve a 20% reduction in operating costs through the implementation of autonomous agricultural vehicles and automated systems.
- Key result 4:
  Improving livestock health and productivity by 15% through enhanced monitoring systems.

Activities (Initiatives):

- Activity 1: Use of autonomous agricultural vehicles.

Deployment of autonomous tractors and drones that can be used for planting, spraying and monitoring.

Installation of a software platform for route planning and vehicle management to ensure optimal field coverage and operational efficiency.

- Activity 2: Automated harvesting systems.

Selection and installation of automated harvesting machines tailored to the specific types of crops grown on the farm. Training of technical staff

in the maintenance and operation of automated harvesting equipment.

- Activity 3: Deployment of smart irrigation systems.

Installation of soil moisture sensors and an IoT-enabled weather station.

Implementation of an automated irrigation control system that adjusts water supply based on sensor data and real-time weather forecasts.

- Activity 4: Setting up livestock monitoring systems.

Equipping livestock with wearable health monitoring devices that track vital signs and activity levels.

Creation of a centralised monitoring platform that alerts staff to any anomalies or health issues in real time.

- Activity 5: Crop and soil monitoring.

Implementing a comprehensive network of sensors for continuous monitoring of soil conditions and crop health.

Using drone and satellite imagery to assess crop vitality and identify potential problems, such as nutrient deficiencies or disease.

- Activity 6: Connectivity provision project.

The aim of the project is to define the connectivity requirements for individual use cases and to select and implement connectivity solutions with the required parameters.

5.3 Business digitalisation with 5G as an innovation project

The individual activities that lead to the necessary results within the framework of a company's digitalisation are, in fact, use cases – that is, tasks that must be carried out to achieve the desired outcome. These activities/use cases usually take the form of an innovation project.

They meet the definition of innovation:

> *"Innovation is a new or improved product or process (or a combination thereof) that differs significantly from previous products or processes and that has been made available to potential users (product) or put into use (process)."* [24]

At the same time, it is usually an activity that requires a project-based approach, due to its complexity, cost and the need for involvement across various corporate functions. For an innovation project to be successful, it must be implemented in accordance with principles and best practices. These are similar for all innovations regardless of their subject matter, whether it involves the development of new products, services or processes.

"Discovery-driven" vs. "technology-first".

When it comes to 5G technologies and their use in digitalisation, a great deal of attention is often paid to highlighting their features. Low latency, high reliability, high transmission speeds… Yes, these features may be 5G's selling points. But no company invests millions of Czech crowns in a technology simply because it has a particular feature. Practice clearly shows that companies are still struggling to understand why they should adopt 5G technology. And this is reflected in the low level of adoption to date. The "technology first" approach is one of the reasons.

A "discovery-driven" approach to innovation essentially means that we must first identify a suitable problem, or need, and only then design an appropriate solution to that need.

On closer inspection, the Discovery process looks like this:

1. Defining the area we will focus on

In our case, this area can be defined within the framework of OKRs (see above). For example, as part of building a Smart Farm, we want to address the activity/use case 'Monitoring of crops and soil'.

2. Identifying and characterising customer segments

We must define who our customer is and who the potential user of our solution is.

---

[24] OECD/Eurostat (2018), *Oslo Manual 2018: Guidelines for Collecting, Reporting and Using Data on Innovation, 4th Edition*, The Measurement of Scientific, Technological and Innovation Activities, OECD Publishing, Paris/Eurostat, Luxembourg.

Note: Customer vs. user vs. sponsor – It is important to understand the difference between a customer (or buyer), a user and a sponsor. This distinction is defined, for example, in the ITIL framework. The customer is the one who defines the product requirements and sets the parameters on which the purchase decision is based. The user is the one who actually uses the product. The sponsor is the one who finances the purchase of the product and decides on the allocation of the budget.

It is advisable to characterise the customer and user, for example by using a customer persona. Because only by identifying our customer/user can we identify their problems and subsequently find solutions to them.

3. Identifying the right need

Identifying the right need within our target segment that our solution will satisfy is a key point in the innovation process. All too often, companies come up with an amazing solution, with a well-thought-out design based on advanced technology – and then desperately search for reasons why there is no demand for it. In other words, they are desperately looking for a problem that their solution would fit. A suitable need, however, is one that is significant to the customer and, at the same time, is not sufficiently well met by existing solutions.

To identify the problem, or rather the suitable need, the JTBD (Jobs To Be Done) framework can be used successfully. With this methodology, we can map out the tasks our target user needs to carry out, break them down into individual steps and divide them into smaller micro-tasks. We then determine how they need to carry out these tasks. This helps us identify tasks for which there is currently no good solution, or where we are able to provide a better one.[25]

4. Solution Design

Designing a new solution is, to a large extent, a creative process, precisely because of the novelty involved. One of the proven approaches to designing new solutions is to use Design Thinking. Design Thinking is a user-centred methodology for solving complex problems and driving innovation, which combines empathy for the context of the problem, creativity in generating ideas, and rationality in their implementation.

In the case of business digitalisation, the aim is not typically to develop entirely new products or software. On the other hand, every business has its own processes, which are to some extent unique. When digitalising them, it will therefore be useful to utilise existing applications/software solutions; however, it will most likely be necessary to adapt them for specific processes, including finding a suitable combination of software and hardware components.

5. Solution validation

The proven agile approach to development, as widely applied in product and software development, can also be utilised in the digitalisation of businesses. The essence of the agile approach lies not only in customer focus but also in iterative development. Instead of attempting to develop the final product all at once, the MVP (minimum viable product) approach is applied, with functionalities developed incrementally. This makes it possible to incorporate user feedback during solution validation.

In the case of business digitalisation, the logical approach is to use a 'proof of concept' to validate the solution, i.e. a limited-scope and time-bound trial of our solution (within the scope of an MVP) under real-world conditions. Validation is the final step of the Discovery process. If it yields a positive result, it means we have 'discovered' a suitable solution to the right need. And we can move on to the implementation phase. Otherwise, we must return to the start of the process and look for another solution, or even choose a different task or need.

The Delivery process then involves the following steps:

6. Development of the final solution

So far, we have developed and validated the solution at the MVP level. The MVP may be built on significantly different technologies and infrastructure than the final solution. In other cases, it is more a matter of adding the necessary additional functionalities.

7. Deployment and Release Management

The developed solution must be transferred to the production environment in an appropriate manner (deployment) and made available to users (release management).

8. Go-To-Market

The final step in the innovation process is bringing the solution to market. In the case of business digitalisation, this will mostly involve internal processes and therefore internal customers. However, the launch may also affect external partners. In any case, it is necessary in this instance as well

[25] Kalbach, J. (7 April 2020). *The Jobs To Be Done Playbook*. Rosenfeld Media.

carry out the necessary activities related to communication, staff training and user support. A well-organised user onboarding process can significantly influence how successfully the new solution is adopted.

The above-mentioned innovation process, comprising the Discovery and Delivery phases, is suitable for implementing individual activities/use cases.

Data connectivity for digitalisation projects.

Within the framework of innovation projects related to the digitisation of a company, ensuring connectivity will always play a crucial role. It is not possible to define a priori the specific values of the connectivity parameters required by individual use cases. This can vary significantly depending on specific conditions, criticality requirements and the technology used. An example of a specific requirement is provided in the AYES case study, although this already concerns a specific technological solution. It is, however, possible to determine which parameters a company undertaking digitisation requiring connectivity should define for individual use cases. Connectivity requirements for individual use cases that need to be defined:

<u>Service Level Indicators (SLI)</u>

- availability level (e.g. 99.99%)
- maximum latency
- stability (jitter)
- total capacity
- Downlink and uplink levels per user
- number of concurrent connections, etc.

<u>Types of planned services</u>

- data services and their types, video streaming, IoT
- Voice services and their types – connection to VTS, group communication, etc.
- location services – required accuracy
- Planned application solutions, QoS requirements for various applications

<u>Security</u>

- cybersecurity requirements
- Local data processing

<u>Coverage area</u>

- indoor
- outdoor

<u>Technology</u>

- Geopolitical requirements
- Open-source capability

<u>Method of network support and monitoring</u>

- Definition of time to fix for different incident levels
- Provision of management and monitoring as a service by the supplier
- Provision of defined activities in-house

Based on the definition of requirements for individual use cases, an analysis can be carried out to recommend the appropriate type of connectivity. Depending on the requirements of specific use cases, this may be a private 5G network, a public 5G network utilising network slicing, or a WiFi network.

6 Supporting digitalisation using 5G

6.1 Barriers to wider use of 5G in the digitalisation of businesses and ways to overcome them

As mentioned above and evidenced, among other things, by the number of private 5G networks already in place, digitalisation using 5G technology is progressing more slowly than would be desirable for the modernisation of industry towards Industry 4.0. The same applies to other sectors such as healthcare and agriculture.

Let us now take a closer look at the reasons for this situation in the form of barriers that are hindering faster digitalisation using 5G. And, at the same time, at the possibilities for removing these barriers. We base our analysis on both regulatory analysis and in-depth interviews with stakeholders across the entire ecosystem, including manufacturers, suppliers, system integrators and potential customers.

6.1.1 Barriers in the regulatory environment

As mentioned above in the chapter analysing and evaluating the regulatory environment in the Czech Republic, on the one hand there is potentially available spectrum for the implementation of private 5G networks; on the other hand, for interested businesses, this spectrum is subject to several rather unwelcome restrictions, namely:

- Limitation to Industry 4.0
- Communication between machines only
- The spectrum is not dedicated to private networks, so problems may arise, particularly in cities.

These restrictions are described in detail in the chapter mentioned above. In any case, they may be a deterrent to potential corporate clients. These may turn to other solutions or rely exclusively on mobile operators. This, however, leads to further restrictions due to the oligopolistic nature of the market, resulting in limited technological and cost options.

6.1.2 Possible solutions

Existing C-band spectrum 3400–3800 MHz:

It is not possible to retroactively change the terms and conditions for the use of this spectrum. Nevertheless, there is a way to support the use of the spectrum for private networks – namely by providing a clear interpretation of the conditions for spectrum use. Many conditions can be interpreted in different ways. For example, according to some studies, Industry 4.0 technologies are also used in other sectors, such as healthcare, agriculture, etc. Furthermore, it stands to reason that all non-public communications should be supported; it makes no sense to exclude certain use cases that undoubtedly belong to Industry 4.0, such as the ‘connected worker’.

If an interpretation of the conditions were available from a generally recognised authority supporting a liberal approach, it could contribute to faster and more effective business digitalisation using 5G.

New spectrum for private networks:

In future negotiations on the conditions for further frequency blocks, particularly 3.8–4.2 GHz, it will be appropriate to take into account the situation and constraints in the 3.4–3.8 GHz band and draw inspiration from the solution adopted in Germany. This means:

- allocating a 100 MHz band for use in the digitalisation of businesses,
- across all sectors, not just for Industry 4.0,
- enabling all use cases to be realised, rather than imposing inappropriate restrictions.

The 3.8–4.2 GHz band is suitable for private networks from a technological perspective, as it still offers a good combination of high capacity and acceptable penetration. At the same time, it is a spectrum for which a 5G ecosystem already exists, including European manufacturers of 5G technologies.

Another option is the 26 GHz band. Its advantage is its truly wide bandwidth, which should provide sufficient spectrum for local use. On the other hand, given its specific physical properties, this spectrum will always be suitable only for a certain subset of use cases and cannot therefore be considered a direct replacement for the C-band.

Unlicensed spectrum:

Unlicensed spectrum may be a good solution for certain types of use cases. If it were possible to utilise 5G technology without restrictive conditions such as ‘listen before talk’, for example in part of the 6 GHz spectrum, it would be possible to use 5G in the unlicensed band even for relatively critical applications.

6.1.3 Cost-related barriers

The chapter addressing the commercial and cost aspects of private 5G networks analysed the cost structure of private networks. It was noted that the definition of network parameter requirements has a significant influence. The costs of a private 5G network can therefore vary across a relatively wide range.

Can it therefore be argued that costs are among the barriers to faster business digitalisation using 5G?

Yes, this is possible based on a comparison with the cost of alternative solutions and discussions with potential customers. Although it may be misleading to quote a specific cost for a private 5G network, the 5-year TCO for a smaller logistics or manufacturing site will generally range between CZK 5 and 10 million. And that is a significant difference compared, for example, to a managed WiFi solution.

This difference would need to be balanced against the benefits on the use case side. This is not straightforward in a situation where many use cases can still function using Wi-Fi. An example might be AGV operations (see case study), or AR, where the availability of suitable AR glasses with native 5G support remains problematic (see case study).

Possible solutions

A diverse ecosystem of service providers

If the supply of (private) 5G solutions is effectively limited to an oligopoly of mobile operators, particularly in view of the regulatory constraints mentioned above, it is certain that costs will always be high. This is borne out not only by economic theory but also by long-standing practice. Only a competitive environment in which a range of different service providers can operate will bring a variety of solutions at different levels to the market, from which companies of all sizes seeking effective digitalisation will be able to choose. The regulatory environment is key in this regard.

Research and development of 5G technologies, particularly open-source software

Examples from abroad show that research organisations and businesses can effectively engage directly in the development of 5G technologies, particularly open-source ones. In France, examples include the work of Eurecom and the Open AirInterface Software Alliance, whilst in Germany it is the Fraunhofer Institute.

In the field of enterprise infrastructure, the open-source Kubernetes solution has become the benchmark, upon which the most complex services of global corporations are built. Open-source K8s is used, for example, by Google, Microsoft, Amazon and SAP. There is no reason why 5G technologies based on open-source solutions could not be utilised in the future for projects of various sizes.

6.1.4 Barriers relating to know-how

A lack of the necessary know-how is indeed a significant obstacle to the faster adoption of 5G technologies for business digitalisation. This obstacle manifests itself in several ways:

Understanding 5G capabilities: There is often a gap in understanding what 5G technology is capable of and how it can be used to improve business processes. Without in-depth knowledge of these capabilities, businesses may struggle to see the practical benefits of using 5G, leading to hesitation in its implementation.

Process innovation and application development: Developing new solutions using 5G technology requires specific expertise that many businesses may not possess in-house. This limits the potential for innovation and bespoke solutions that could significantly benefit from 5G's capabilities.

Possible solutions

- Education and training programmes.
- Government and industry partnerships (including trade associations and organisations).
- Demonstration projects: pilot projects that demonstrate the tangible benefits of 5G across various sectors. Success stories from these projects can serve as practical examples and learning opportunities for other businesses considering adopting 5G.
- Consultancy and advisory services.
- Support for participation in trade fairs and other professional events.

6.1.5 Barriers within the 5G ecosystem

As with the advent of previous generations, the ecosystem of technologies and devices for 5G is also emerging as a gradual process. The fact remains, however, that even today the ecosystem presents a barrier that affects the progress of digitalisation in two ways:

- availability of end-user devices
- availability of network technologies and their functions.

5G-enabled end devices are generally quite expensive compared to similar devices supporting Wi-Fi or previous generations of mobile services. Whilst the price difference may not play a decisive role in a company's decision-making when it comes to devices such as industrial routers, it is a significant issue for IoT devices.

There is a limited range of 5G-enabled end devices to choose from, or they may not be available at all. The problem of limited choice applies to devices such as cameras or industrial scanners. In the case of AR glasses, the situation can be even more complex, as there are none available with the required functionality combined with 5G support, making it necessary to find a workaround (see the AYES case study).

In the case of network technologies, the problem lies in the unavailability of certain functions that are important for the 5G solution ecosystem. Some of these functionalities have already undergone the standardisation process, yet their actual availability in the form of accessible technologies remains limited. This applies, for example, to location services or URLLC solutions. A significant problem for the development of IoT use cases is the limited availability of solutions based on RedCap technology. For other use cases, the current absence of network slicing functionality is a disadvantage.

Possible solutions

The 5G ecosystem is a global endeavour, and its development within the context of local activities is no simple task. However, certain possibilities do exist, for example:

- The development of specialised devices by local technology firms to meet the needs of specific use cases. An example is a highly robust 5G positioning probe being developed in collaboration between CIIRC and T-Mobile.
- The development of specialised devices according to the requirements of Czech companies in collaboration with foreign manufacturers – for this purpose, the TAČR DELTA2 programme and cooperation with, for example, Korean suppliers can be utilised.

6.2 Reasons for and ways to support digitalisation using 5G

There are several good reasons why it is appropriate to support the digitalisation of businesses using 5G technologies and thus help to ensure that progress in this area is faster than before.

These reasons include:

- **Competitiveness**: Businesses that utilise 5G technology can gain a significant competitive advantage. This is particularly due to increased operational efficiency: the features of 5G support the deployment of advanced applications, as evident from the overview of use cases above. This will assist companies in their digital transformation process.
- **Economic growth**: Supporting the roll-out of 5G helps not only businesses but, indirectly, the entire economy and its growth. This is because 5G can facilitate the creation of smart factories, smart cities or digital healthcare services – sectors that not only boost productivity but also create new jobs.
- **Sustainability:** 5G can support environmental sustainability through the increased efficiency of technologies such as smart grids and connected sensors for monitoring and reducing energy consumption.

Ways to support digitalisation using 5G:

1. Further improvements to the regulatory environment for private enterprise 5G networks

Current regulatory conditions allow for the establishment of private 5G networks, albeit with a number of restrictions (as described in detail above in the chapter analysing the regulatory environment in the Czech Republic). An appropriate means of support is therefore to include the spectrum requirements for private 5G networks without the current restrictions as a starting point for further discussions and analyses regarding the use of other parts of the spectrum, particularly the 3.8–4.2 GHz band.

Another certainly beneficial activity would be to commission a study that would clarify in detail the possibilities and conditions for the use of private 5G networks in unlicensed bands. This would provide clear guidance for potential corporate users as well as providers of these solutions. Last but not least, an interpretation of the current regulatory situation regarding the 3.4–3.8 GHz spectrum should be prepared, making it clear to all potential interested parties in which verticals and for which use cases they can operate within the given spectrum and regulatory conditions.

2. Financial incentives

There are currently programmes in place that enable grants to be obtained for research and development as well as the implementation of solutions involving 5G technologies (as described in the chapter on support programmes). It would be advisable to continue implementing programmes specifically focused on the research, development and implementation of 5G technologies and solutions incorporating 5G technologies. In the case of general programmes, it is very difficult to obtain a grant for research and development. For example, within the TAČR programmes, the success rate is a few per cent, which may be discouraging for many applicants.

Furthermore, it would be advisable to identify funding opportunities for:

- International cooperation. This is always highly inspiring and beneficial. (It is supported to a limited extent under TAČR programmes, but only with selected countries/partners).
- The development and implementation of open-source solutions. Due to their open nature, these solutions are always a source of innovation and are also highly suitable for use in education.

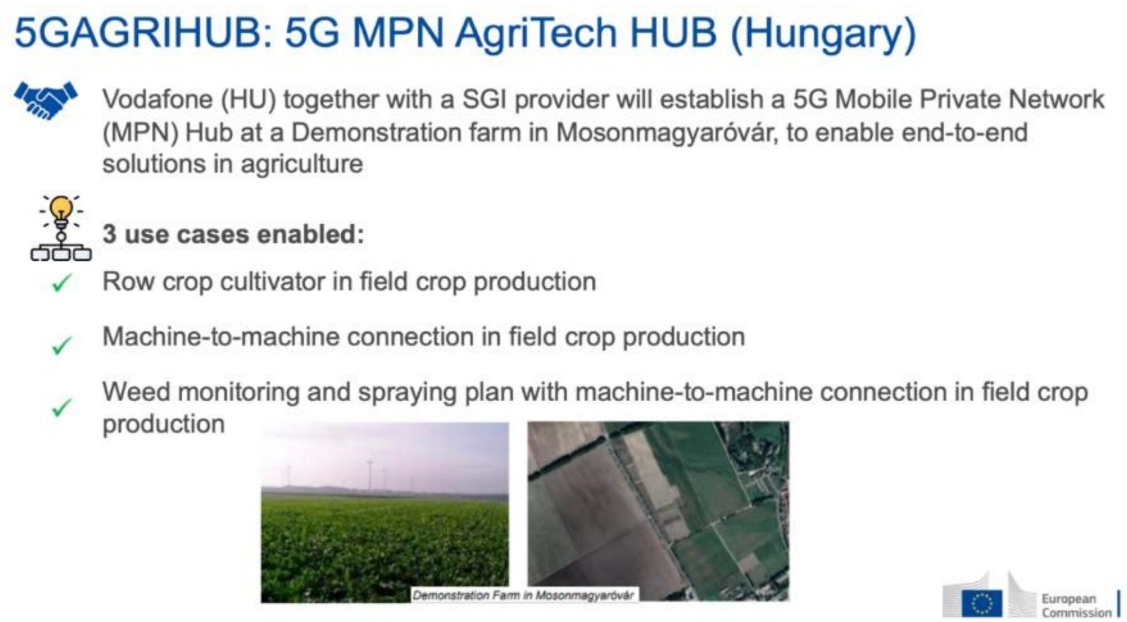
3. Education and training

A lack of know-how has been identified as one of the obstacles to faster progress in digitalisation using 5G. It would therefore be advisable to support the creation of targeted education programmes and training for businesses with the aim of increasing their know-how in the use of 5G technology. Educational programmes could include demonstrations within testbeds or projects that have already been implemented. Through activities in these areas, the Ministry of Industry and other stakeholders can significantly increase the speed and efficiency of 5G deployment for business digitalisation in the Czech Republic.

7 Annexes

Appendix 1 – Overview of selected “5G for Smart Communities” projects [26]

Figure 11: The 5GAGRIHUB project. Source: 5G for Smart Communities, 2022.



[26] *5G for Smart Communities: first wave of projects selected for co-funding of 5G connectivity infrastructure*. (20 December 2022). Shaping Europe’s Digital Future. https://digital-strategy.ec.europa.eu/en/news/5g-smart-communities-first-wave-projects-selected-co-funding-5g-connectivity-infrastructures

Figure 1 Project 5G4ASSAC Source 5G for Smart Communities, 2022

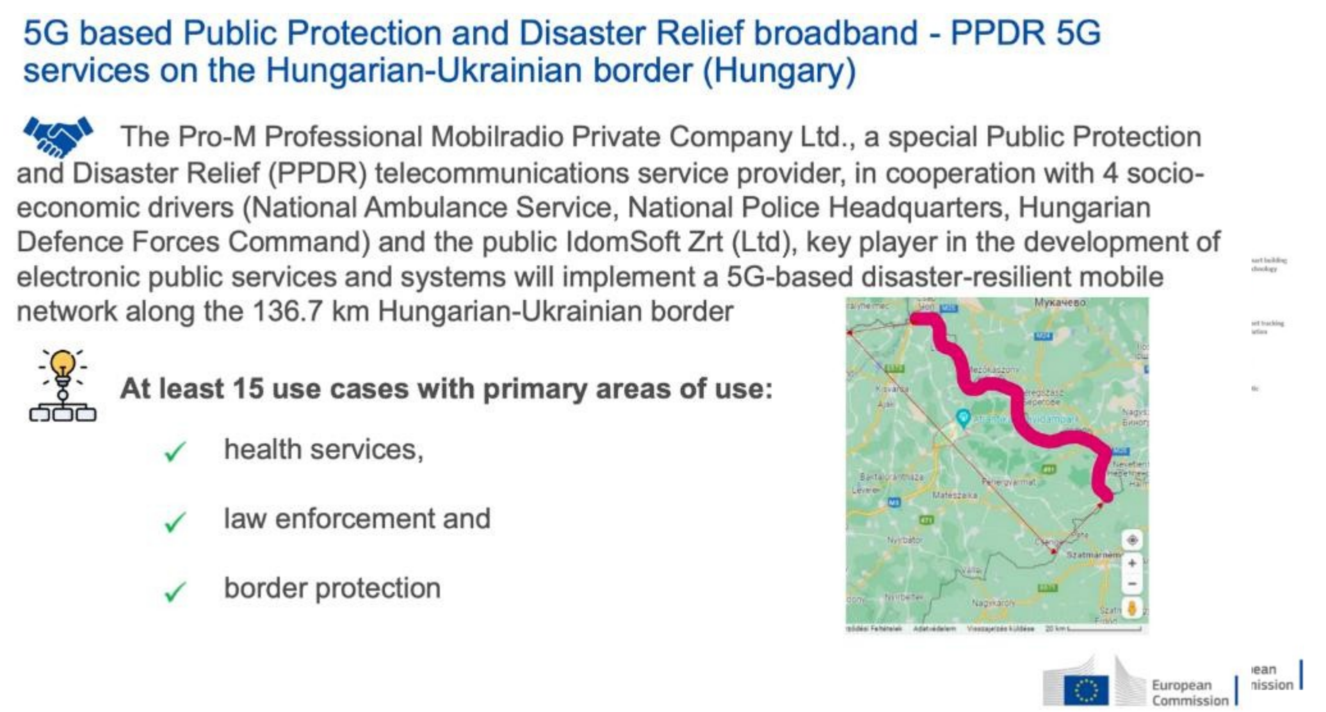
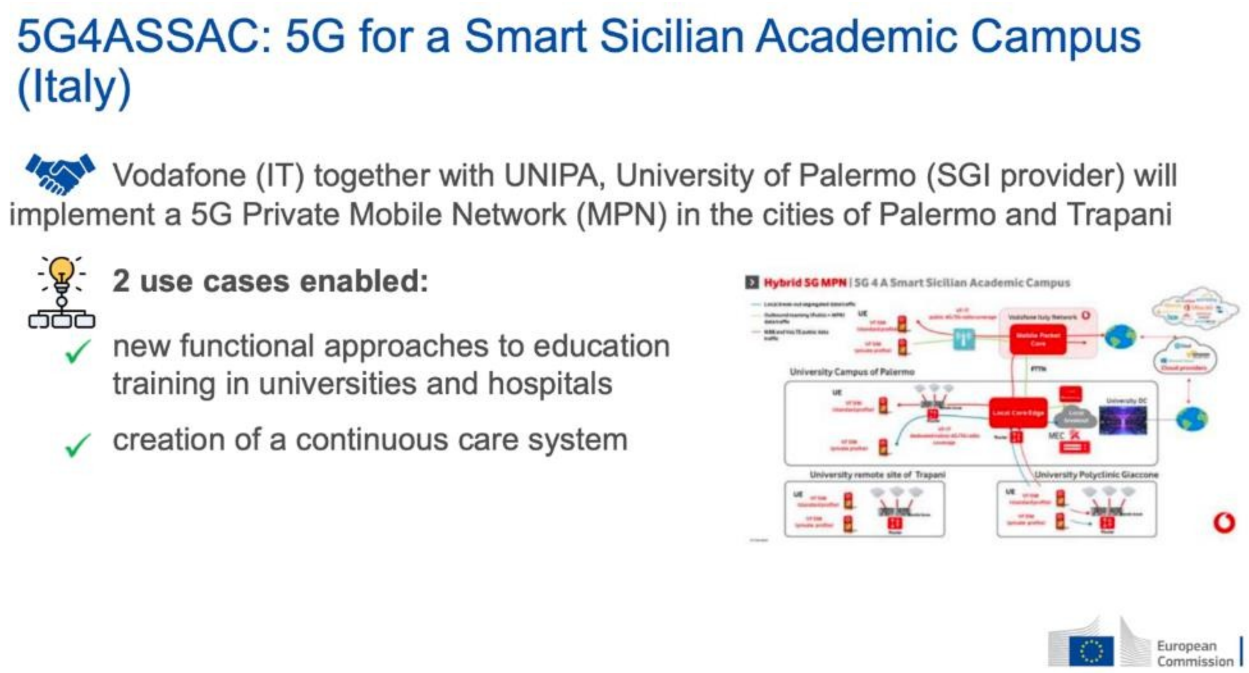


Figure 12: The 5G4ASSAC project. Source: 5G for Smart Communities, 2022



Annex 2 – Private 5G networks in the EU

The list of private 5G networks in the table below is based on a survey of publicly available information. It was compiled by the European 5G Observatory initiative. It is not an exhaustive list.[27]

Table 5: List of private 5G networks

Year	Country	Company/Entity	Operator	5G technology supplier
2018	Germany	Port of Hamburg	Deutsche Telekom	Nokia
2018	Netherlands	Port of Rotterdam – Shell, ABB and ExRobotics	KPN	Huawei
2019	France	TransDev (mobility)		Ericsson
2019	Germany	German electric microcar company e.GO Mobile AG (Aachen complex)	Vodafone	Ericsson
2019	Germany	Siemens		Qualcomm (5G test network)
2019	Spain	FC Barcelona Stadium	Telefónica	Huawei
2020	Austria	Automotive manufacturer Magna Steyr	A1 Austria	Nokia
2020	Austria	5G playground Carinthia	A1 Austria	Nokia
2020	Austria	Vienna Airport	A1 Austria	Nokia
2020	Austria	Siemens Renewable Energy Microgrid	A1 Austria	Nokia
2020	Belgium	Port of Antwerp	Proximus	
2020	Belgium	Port of Zeebrugge		Nokia and Citymesh
2020	Belgium	Brussels Airport		Nokia and Citymesh
2020	Finland	Fortum Power and Heat (State-owned energy company)		EDZCOM
2020	Finland	Qualcomm, UROS	Elisa	
2020	Finland	Sandvik Mining		Nokia
2020	France	Schneider Electric	Orange	
2020	France	Lacroix	Orange	Ericsson
2020	France	ADP Group (Hub One) Air France		Ericsson
2020	France	EDF		Thales and Ericsson
2020	Germany	BMW Group Leipzig plant.	T-Mobile	Ericsson
2020	Germany	Bosch		Ericsson
2020	Germany	Centre for Connected Industry (CCI)	Deutsche Telekom	Ericsson
2020	Germany	Lufthansa, the airline's aircraft hangar at Hamburg Airport	Vodafone	Nokia
2020	Germany	Mercedes-Benz, Sindelfingen plant	Telefonica	Ericsson
2020	Germany	Rohde & Schwarz		Nokia
2020	Germany	Volkswagen		
2020	Poland	PGE Systems		Nokia
2020	Slovakia	CEIT (R&D centre)130	Slovak Telecom	Ericsson
2020	Slovenia	5G-connected factory – Iskratel production plant in Kranj	Telekom Slovenia	Iskratel
2020	Spain	BASF	Masmovil	Cellnex, Nokia, Lenovo
2020	Sweden	Atlas Copco	Telenor	Ericsson, Fujitsu
2020	Sweden	Saab		Nokia, Vinnergi
2021	Czech Republic	5G Campus network, University of Ostrava	T-Mobile	Ericsson
2021	Czech Republic	5G network Czech Institute of Informatics, Robotics and Cybernetics (CIIRC CVUT)	T-Mobile	Ericsson
2021	Denmark	Grundfos (pump manufacturer).	TDC NET	Ericsson
2021	Denmark	Maersk Port of Aarhus	Three	
2021	Estonia	Thinnect OÜ		Nokia
2021	Finland	KymiRing motor		Nokia, EDZCOM (Cellnex
2021	Finland	Konecranes		Nokia and Edzcom
2021	Finland	Steveco shipping terminals in Kotka		Edzcom and Athonet
2021	Finland	Agnico Eagle Finland Oy Kittilä mine		Nokia, Digita
2021	France	Private 5G connectivity to enterprise networks in the PB5 La Défense building in Paris		Colt Technology Services, Icade, ADVA, Ai
2021	Germany	Deutsche Messe	Deutsche Telekom	Siemens

[27] *5G Private networks – 5G Observatory*. (n.d.). https://5gobservatory.eu/5g-private-networks/

2021	Germany	Porsche		Ericsson
2021	Greece	Calpak (solar thermal manufacturer)	COSMOTE	Ericsson
2021	Hungary	Foxconn Komarom factory	Vodafone	Ericsson
2021	Hungary	East-West Gate Intermodal Terminal (EWG)	Vodafone	Huawei
2021	Ireland	Irish Manufacturing Research	Vodafone	Ericsson
2021	Italy	Exor International	TIM	Athonet
2021	Poland	Orange Polska Campus	Orange Polska	Ericsson
2021	Poland	Nokia factory in Bydgoszcz	Orange Poland	Nokia
2021	Sweden	Skogforsk	Telia	Ericsson, Volvo, SCA and Biometria
2022	Croatia	5G private network solutions	Croatian Telecom	FER
2022	Croatia	AD Plastik		Nokia and OIV Digital Signals and Networks
2022	Czech Republic	5G Standalone network at the Škoda factory	Vodafone	Nokia
2022	Finland	City of Tampere (Smart City)		Edzcom and Signify
2022	France	5G trials at Marseille's Stade Vélodrome	Orange	
2022	France	5G trial at a port in France		Blu Wireless
2022	France	Paris Metro / Société du Grand Paris (SGP)		Nokia
2022	Germany	Frankfurt Airport (FRAPORT)		NTT
2022	Germany	Umlaut test network		Aispan Network and Druid Software
2022	Germany	Segula Technologies		Cellenex Telecom
2022	Latvia	Latvian Ministry of Defence	LMT	Ericsson / Nokia
2022	Poland	Industry 4.0 network in Krakow	Deutsche Telekom	IS-Wireless
2022	Sweden	X Shore	Tele2	
2023	Belgium	Port of Antwerp		Citymesh
2023	Belgium	Nationwide Emergency drone network	Citymesh	Nokia
2023	Belgium	CONNECTNOW (City of Wavre)	Citymesh	
2023	Croatia	Klimaoprema (air conditioning equipment manufacturer)	OiV	
2023	Croatia	Zagreb Faculty of Mechanical Engineering and Shipbuilding (FSB)	Hrvatski Telekom	
2023	Czech Republic	5G Standalone network at the Toyota factory	T-Mobile	ServisControl
2023	Czech Republic	Continental (automotive supplier)	T-Mobile	
2023	Estonia	Ericsson Supply Site	Telia	Ericsson
2023	France	Europe's largest private industrial 5G network at its Alcatel Submarine Networks	Illiad	Nokia
2023	France	ArcelorMittal France		Ericsson
2023	France	Toulouse Métropole		Nokia
2023	France	Orange (Arcueil facility)	Orange	Ericsson, Nokia and Oracle
2023	Germany	Bayer	Vodafone	
2023	Germany	Arburg (machine manufacturer)	Deutsche Telekom	
2023	Germany	EUROGATE	Deutsche Telekom	Nokia
2023	Germany	CampusDynA (Industry consortium)		IS - Wireless
2023	Germany	Rheinisch-Westfälische Technische Hochschule (RWTH) Aachen University	NTT	Cisco
2023	Greece	Onex (shipbuilder)		Cisco
2023	Ireland	ESB Networks (Utility)	ESB Networks / Sigma Wireless	
2023	Italy	University of Palermo	Vodafone	
2023	Italy	Porsche	Vodafone Business	
2023	Italy	Solvay	Vodafone	Nokia
2023	Portugal	NOS 5G Hub	NOS	
2023	Spain	Adif Alta Velocidad (Adif AV)		Cellnex, Nokia
2023	Spain	Aena - San Sebastian Airport	Aena	Cellnex, Nokia
2023	Spain	Port of Barcelona	Orange	Ericsson, Nokia and Oracle
2023	Spain	Spanish Ministry of Defence	Telefónica	
2023	Sweden	Fiskarheden Sawmill		Radtonics, Airspan

Annex 3 – Projects supported under the TREND programme in the field of 5G technologies

7. Public call [28]

Table 6: 7th public call

POŘADÍ	KÓD PROJEKTU	NÁZEV PROJEKTU	HLAVNÍ UCHAZEČ	DALŠÍ ÚČASTNÍCI
1	FW07010035	Multikanálové propojení fotonických čipů pro vysokorychlostní optické sítě 5G+	SQS Vláknová optika a.s.	České vysoké učení technické v Praze
2	FW07010026	Komunikační optický modul pro mikrovlnné systémy	RFspin s. r. o.	České vysoké učení technické v Praze
3	FW07010004	Využití předností sítí páté generace pro monitorování, optimalizaci a zefektivnění výrobního procesu v chytrých továrnách	EASYCON Solution s.r.o.	Vysoké učení technické v Brně
4	FW07010020	5G Platforma pro precizní zemědělství	ORBIT MERRET, spol. s r.o.	Česká zemědělská univerzita v Praze, JUMP-TECH s.r.o., T-Mobile Czech Republic a.s.
5	FW07010040	Univerzální teleoperační systém pro vzdálené řízení a dozor strojů pomocí 5G sítě.	Roboauto s.r.o.	T-Mobile Czech Republic a.s., Vysoké učení technické v Brně
6	FW07010048	Telematická jednotka elektro busu s integrovaným digitálním dvojčetem, predikcí poruch a životnosti vybraných mechanických komponent s využitím sítí 5G	TechSim Engineering s.r.o.	Západočeská univerzita v Plzni
7	FW07010019	Výzkum a vývoj sdílených služeb monitorování obráběcích strojů s využitím 5G sítí	4dot Mechatronic Systems s.r.o.	Vysoké učení technické v Brně
8	FW07010052	EMIR - Vestavěná inteligence s podporou 5G pro autonomii robotů a aplikace pro monitorování chytrých měst	COGNITECHNA s.r.o.	Vysoké učení technické v Brně
9	FW07010015	Monitorování kvality vnitřního prostředí budov pomocí senzorů pachu a umělé inteligence	UTILCELL, s.r.o.	Vysoké učení technické v Brně
10	FW07010027	Vývoj testovacího systému pro sítě 5G+ s podporou multi-gigabitových propustností a milimetrových vln	PROFiber Networking CZ s.r.o.	Česká zemědělská univerzita v Praze

[28] *Seventh public call for proposals – Technology Agency of the Czech Republic.* (18 January 2023). Technology Agency of the Czech Republic. https://www.tacr.cz/soutez/program-trend/sedma-verejna-soutez/

8. open call [29]

Table 7: 8th public tender

PROJECT RANKING	PROJECT NUMBER	PROJECT TITLE	MAIN BIDDER	OTHER PARTICIPANTS
1	FW08010063	Development of a measurement system for evaluating the quality of voice services provided by 5G+ networks	PROFiber Networking CZ s.r.o.	CETIN a.s.; Czech Technical University in Prague
2	FW08010050	Optoelectronic and communication system for robotic exploration	LTR s.r.o.	GK SERVIS, spol. s r. o.; T-Mobile Czech Republic a.s.; Brno University of Technology
3	FW08010065	Optimisation of a private 5G network for the robotisation and automation of logistics operations through research and development of localisation services and dynamic quality control.	Thein Digital s.r.o.	
4	FW08010048	Real-time visual communication and navigation for integrated emergency services using augmented reality and 5G connectivity	GINA Software s.r.o.	Brno University of Technology
5	FW08010017	RoSuM – Localisation of horizontal and vertical road markings, quality control and regular inventory with 5G support	COGNITECHNA Ltd.	Brno University of Technology
6	FW08010072	Railcar 5G Communication Unit	LEVEL, s.r.o.	
7	FW08010076	Robotic brick trolley	KM Robotics s.r.o.	Czech Technical University in Prague
8	FW08010039	The use of 5G in sensor-based transport networks for V2X	VDT Technology a.s.	Technische University Ingolstadt; Czech Technical University in Prague
9	FW08010025	Development of a telemedicine platform for the development of cognitive functions	MEDDI hub a.s.	University of Ostrava
10	FW08010022	DynaCount	INTENS Corporation s.r.o.	Brno University of Technology; O2 Czech Republic a.s.
11	FW08010042	Museum in XR using 5G	BeePartner a.s.	Ostrava University of Science and Technology; T-Mobile Czech Republic a.s.; RESTORE fx s.r.o.
12	FW08010029	Monitoring of bacteriophage therapy using nuclear medicine imaging techniques	FAGOFARMA s.r.o.	Palacký University in Olomouc
13	FW08010067	MCX 5G terminal for critical communications in emergency services and transport	TTC MARCONI s. r. o.	T-Mobile Czech Republic a.s.; Czech Technical University in Prague
14	FW08010018	RoQuIEm – Road quality monitoring based on embedded intelligence with 5G support	COGNITECHNA s.r.o.	CAMEA, spol. s r.o.; Brno University of Technology

[29] *Eighth public tender – Technology Agency of the Czech Republic*. (27 July 2023). Technology Agency of the Czech Republic. https://www.tacr.cz/soutez/program-trend/osma-verejna-soutez/

Appendix 4 – Case study: BringAuto autonomous robotic vehicle

Basic information about the solution provider

This case study describes a product by BringAuto s.r.o. in the form of an autonomous multi-purpose vehicle.

BringAuto is a Czech technology start-up based in Brno. It is therefore no surprise that their vehicle was also on display at the International Engineering Fair in Brno. BringAuto says of itself:

> *"We love it when things work automatically. Or perhaps, more precisely, robotically. Thanks to our vehicles, you'll soon be able to have parcels delivered right to your door without wasting a single minute. Fancy a stroll in the park or keeping an eye on the factory? No problem. Our vision is to leave repetitive tasks to robots and utilise human potential more effectively."*

BringAuto offers its autonomous vehicle in several variants:

- Delivery robot,
- last-mile delivery robot,
- mobile vending machine,
- sprayer,
- mobile security robot, or
- robotic platform.

In principle, they all share a similar autonomous vehicle base, which is fitted with various superstructures depending on the specific purpose.

The delivery robot is the ideal choice for industrial applications. Its robust and durable four-wheel chassis is designed for use in industrial sites. The delivery robot is primarily intended for transporting cargo.

The last-mile delivery robot can deliver a parcel to the end customer. After loading the parcels, it selects the optimal route for the fastest delivery and delivers all parcels to their respective addresses one by one. It informs recipients in good time of the exact delivery time. To collect an order, you need to enter a special PIN on the touchscreen located on the robot.

Figure 15: BringAuto, Source: BringAuto Archive, 2023.

The Sprayer autonomous robot variant was developed in response to the outbreak of the COVID-19 pandemic, and its primary use is therefore for disinfecting various spaces – from squares, parks and streets, through production halls and warehouses, to shopping centres and airport terminals. However, in addition to disinfection, it can also be used, for example, in municipal services for watering greenery or in agriculture for fertilising and harvesting crops.

Another undoubtedly interesting variant is the Security (Patrol) robot. It reliably monitors a production site or, for example, a shopping centre. Whether the robot is remotely controlled or fully autonomous, nothing untoward escapes its sensors.
The robot is equipped with various sensors, microphones and cameras. This combination of sensors captures everything happening within a 360° radius of the robot and immediately reports any unknown or suspicious activity to the control centre, to which it also continuously streams live footage from all cameras.

Customers and their needs

Different variants of the autonomous robotic vehicle can cater to different types of customers and their needs or challenges. The common denominator, however, is primarily the need to increase operational efficiency by replacing human labour and other less efficient modes of transport. A potential issue is the risks faced by staff who must operate in environments that are hazardous to health or otherwise dangerous.

Use Case:

In this case study, we will focus on the Use Case “Material transport using autonomous vehicles”. In this Use Case, autonomous vehicles are used to transport materials between individual logistics warehouses, within industrial sites, etc., i.e. operations extend beyond a single warehouse and the environment is often challenging. The Use Case is part of the “Smart logistics hub” category. These are use cases within logistics centres extending beyond the level of warehouses, such as ports and railway terminals.

The use of autonomous vehicles is currently restricted by legislation. Although they may already be technologically advanced, their operation is only permitted within private premises. They cannot yet be used, for example, for delivering parcels around the city.

From this perspective, the private premises of a logistics centre (including the logistics facilities of a manufacturing company) are the ideal location and way to utilise the advantages of an autonomous vehicle. It is also sufficiently robust and built for demanding outdoor conditions, unlike most AGV/AMR vehicles designed for indoor warehouse spaces with smooth floors.

Product/solution and its implementation

Delivery Robot Specifications

In this use case, the autonomous Delivery Robot vehicle is utilised. It can be equipped with various types of attachments: transport boxes, a robotic arm, a dispensing machine, etc.

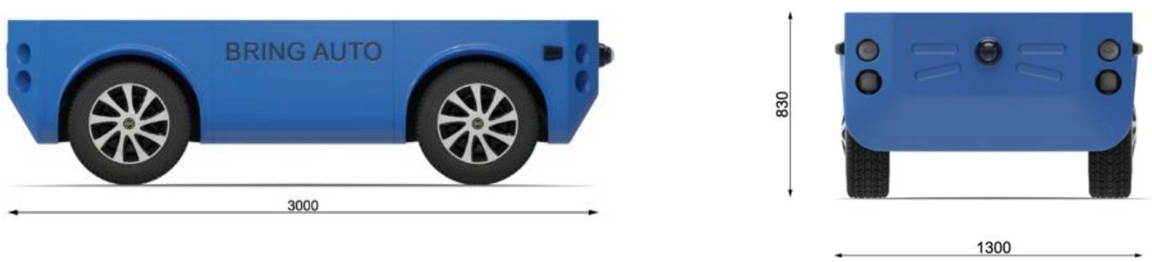
Figure 16: BringAuto 2. Source: BringAuto Archive, 2023.

The robot is controlled via autonomous operation, teleoperation (remote control), or manually (available in the event of any problem). For safety reasons, these control modes are defined hierarchically; this means that manual control always takes precedence over teleoperation, and teleoperation takes precedence over autonomous mode.

The delivery robot has an electrically powered rear axle (Benevelli motor); standard equipment includes a 48V lead-acid battery (330 Ah), which provides 10 hours of continuous operation on a single charge. The built-in 230V charger allows the battery to be recharged in 5
hours (from 10% to 90%). A lithium battery is also availa

The delivery robot can carry up to 1,000 kg of cargo. It can travel at speeds of up to 20 km/h. The delivery robot has a range of 100 km on a single charge. Its dimensions are 3 x 1.3 m:

Figure 17: BringAuto specifications. Source: Archi BringAuto, 2023.



Solution deployment process

Based on the specific type of use and in strict accordance with the customer's requirements, the robot is manufactured and prepared in the specified configuration with a superstructure tailored to the intended purpose. Depending on the selected control type, the necessary hardware is installed on the robot to ensure the safe and reliable operation of teleoperation (remote control) and/or autonomous mode. Subsequently, in collaboration with the supplier, the robot's individual routes are mapped and tested, the operations centre is set up, and the web application is launched.

Operation

The delivery robot transports goods along a pre-planned route, which can be modified via a web application. The robot's round-the-clock operation ensures the flexibility of the process – it does not only operate at regular intervals, but can also be summoned via the app when needed. The solution includes online tracking of the robot's location and status, as well as the route plan, and notifications with an exact arrival time. Last but not least, there is centralised fleet monitoring. The delivery robot can alter its route based on the situation and any obstacles. In the event of problems, it sends a notification to the control centre.

Reasons and forms of potential use of 5G or private 5G networks

For a solution such as a delivery robot, the use of 5G is not only suitable but essential. It increases the robot's efficiency and safety.

In the future, should legislative changes allow this type of robot to operate in public spaces, public 5G could also be a solution. That is, provided it can simultaneously guarantee Quality of Service through slicing, particularly in the form of low latency and high reliability (URLLC-type requirements), combined with sufficient capacity for HD video transmission.

At present, however, the deployment of a delivery robot is an ideal use case for a private 5G network. A private 5G network can cover a private site, including both outdoor and indoor areas.

In the case of the Delivery Robot, data connectivity is utilised for several purposes:

a. Teleoperation

That is, remote control using camera footage. The Delivery Robot is equipped with 4–6 cameras, which represents a massive source of data traffic. Typically, a public 4G/5G network and the public internet are used for transmission. A slight improvement to this setup is the use of two SIM cards. Furthermore, a safety mechanism is in place to ensure that if latency exceeds 150 ms, the robot automatically stops for safety reasons.

b. Collision avoidance – cloud processing

In some cases, data from the vehicle's cameras is sent to the cloud for processing. This is due to the high computational demands and the limited processing power of the computer located directly in the vehicle. This data processing also involves image analysis for collision avoidance, where response speed is critical. Currently, the public 4G/5G network and the public cloud are still commonly used for this task. The response time is therefore in the range of 100–500 ms.

c. Connectivity for processing orders

Orders placed directly with the delivery robot are sent for processing (depending on the type of delivery robot used).

The first two data transfer tasks in particular are precisely the cases where the deployment of a private 5G network is a key advantage. On a public network, it is not possible to ensure, let alone guarantee, the required level of service, particularly low latency and reliability (URLLC). The alternative of using Wi-Fi was not practically considered by BringAuto in this case, given its low security and obvious unsuitability in terms of performance in mobile scenarios.

Conversely, during testing with BringAuto's partners in Greece, a latency of 20 ms was achieved within the private network, which is entirely satisfactory for the purpose in question.

The second task, in particular, is a typical case for which MEC (multi-access edge computing) is suitable. It involves processing large amounts of data that must be done very quickly, requiring significant computing power that is not available directly at the CPE. At the same time, the processed data must be returned with minimal latency. A public cloud, where data is processed in a remote data centre, is therefore not suitable.

Note:

For example, in the case of AWS cloud services provided in the Czech Republic, these services are often located in Frankfurt am Main, Germany.

The ideal solution is therefore to use a local User Plane (user data) and process the data using computing power located within the logistics site.

Why this solution was chosen

The benefits of using a delivery robot for transporting materials within logistics sites are twofold:

a. Increased operational efficiency
   - Savings in human resources – thanks to its autonomy, the Delivery Robot reduces the need for human resources.
   - Increased speed – independence from operators makes the delivery robot a very fast transport option.
   - Replacement of less economical and efficient transport methods, such as transport by vans or forklifts.

b. Increased operational safety
   - The deployment of the Delivery Robot reduces the need for staff to move around in high-risk environments, such as those involving chemicals, fumes, etc.
   - The Delivery Robot is also a very safe mode of transport thanks to a range of collision protection features.

Project status

BringAuto's delivery robot is already a fully functional solution. The company has carried out several PoCs (Proof of Concept) and is preparing for commercial deployment.

Project evaluation and benefits

Given that the project is currently at the PoC stage, no quantifiable data on the deployment of the delivery robot is available at this time.

Potential uses and future applications

Solutions such as the Delivery Robot undoubtedly represent the future. In the case of enclosed premises, one could say the near future. This is because the solution is already fully functional and offers clearly defined benefits for both efficiency and worker safety. Furthermore, it is already possible to use this solution in combination with private networks, which will provide the necessary guarantee of service delivery.

For use in public spaces, we will still need to wait for regulatory conditions to be resolved. For use in public spaces, it will also be beneficial to have the option of utilising the guaranteed quality of service that network slicing promises to deliver in the future. The solution is suitable for any manufacturing company with logistics operations carried out within a closed site that require the transport of materials between individual locations within that site.

Appendix 5 – Case Study: AYES/Continental – AR and 3D models for industry

Basic information about the solution provider.

AYES specialises in the supply of smart glasses and the use of augmented reality in the digitalisation of industrial production. It not only provides a wide selection of hardware and software solutions, but above all acts as a partner to customers in the areas of service, consultancy and related services, such as the development of content for smart glasses or 3D data visualisation.

AYES' solutions are used primarily in the following areas of industry and logistics:

Figure 18: AYES solution. Source: AYES.

- Remote collaboration: Forms of remote collaboration include remote service interventions in cooperation with the supplier, repairs to critical equipment, operational problem-solving, training of new staff, installation of new equipment, sharing of know-how between plants, technology handover, audits and factory tours.
- Digital workflows: This involves projecting a 'step-by-step' workflow directly into the worker's field of view. Typical applications include routine maintenance tasks, assembly procedures, instructions, quality control, regular inspections, errands, training and induction. A graphical editor can be used to convert workflows into AR format without the need for programming.
- Vision picking: Vision picking assists with order picking and facilitates the process of locating stock items. Vision picking has the following applications and benefits in logistics: Suitable for warehouse logistics, picking, kitting, dispatch, etc. Increased process speed and productivity. Greater accuracy, reduced error rates. Easy training of new employees (speed, quality, etc.). Increased employee satisfaction thanks to improved ergonomics and visualisation. Improved data quality. High flexibility for process changes. Integration with external scenery. Possible integration with SAP or other ERP, WMS, etc.
- Visualisation of 3D models: AYES's XR solution enables work with 3D models created in CAD programmes within the context of a real-world environment. It facilitates the 3D visualisation of data in space. The purpose of this solution is to increase productivity in machine design and prototype manufacturing, check machine ergonomics and safety, immediately detect design errors, or display machines within the production environment (factory layout).

Customers, users and their needs

AYES has over 100 customers. These range from large industrial companies in the Czech Republic and Slovakia, through small and medium-sized enterprises, to international companies. AYES's solutions are used in over 30 countries worldwide.

The main customer needs that AYES's solutions help to meet:

- Improving working conditions, particularly for service and maintenance teams.
- Increasing the efficiency, speed and quality of processes, leading to cost savings

AYES's solution therefore focuses primarily on innovating processes and workflows.

Use Case:

In this case study, we will focus on a use case involving the use of advanced 3D model visualisation to streamline development processes. All the use cases described above are real and beneficial. The main reason for focusing on 3D models is that this use case is the most demanding in terms of data throughput and computing power. It is therefore the use case for which the use of private 5G network in combination with edge computing.

Figure 19: Examples of AYES solution applications. Source: AYES.

The use case involving 3D models essentially means that we create a 3D model and visualise it directly in a real-world environment. This approach enables us to streamline specific tasks, such as prototyping or checking the structural suitability and ergonomics of products.

The range of tasks and activities that 3D models can help us streamline is truly vast, as shown in the following figure:

Product/solution and its implementation

The solution for creating and utilising visualisations advanced 3D models consists of the following elem

- CAD software. The solution supports all standard formats – STEP, CATPART, FBX.
- Augmented reality headsets. HoloLens 2, Magic Leap 2 or Meta Quest headsets are typically used for 3D models.
- Infrastructure with sufficient computing power.
- Connectivity ensuring the stream is transmitted to the glasses.

In the case of 3D models, these are streamed directly to the XR glasses. This is due to the computational power, which is insufficient in the glasses themselves for this type of task. To illustrate, in the case of HoloLens glasses: they would only be sufficient for approximately 1.5 million polygons, which represents a model on the scale of a fridge. A production line, however, is orders of magnitude more complex.

5G/P5G + MEC – Reasons and forms of potential 5G/P5G usage

This use case is suitable in combination with a private 5G network for the following reasons:

- The data flow from the application to the glasses is large in volume.
- It requires low latency and high stability.

The specific requirements for data throughput are 20–50 Mbps, with latency up to 100 ms, though lower latency will provide a better user experience.

Furthermore, this is a mobile use case where the wearer of the glasses can move around the space. This is a situation in which fixed connectivity cannot be used, and the alternative of Wi-Fi suffers from a fundamental weakness during handover situations (when the end device switches between Wi-Fi access points).

A private network is the logical choice because the use case is typically implemented in a closed production hall. There is often a problem with signal penetration from public networks, which also lack the necessary low latency and SLA. It is a question of whether network slicing would be suitable for this use case in the future. It would likely be necessary to supplement it with internal coverage, resolving the UPF/local breakout of user data.

This use case is also suitable for MEC – edge computing. As mentioned above, it is not feasible to perform computational operations on the end device (in this case, glasses) due to the high demands on computing power. At the same time, to meet the need for low latency, it is not suitable to perform computational operations and transmit data from a remote data centre, or even a public cloud.

Forms of 5G usage

Smart glasses for AR are currently, in most cases, not equipped with a built-in 5G modem. To connect them via 5G, it is therefore necessary to opt for an indirect method, which can be described as a workaround:

Connection via a 5G modem in the form of a dongle plugged into a USB-C port. Given the high power consumption, this solution is often supplemented with a power bank. However, this, on the other hand, significantly increases the weight and reduces the comfort of the entire solution for the user.

Connection via Wi-Fi tethering. That is, via a hotspot created by a mobile 5G device (this could be, for example, a so-called MiFi, i.e. a mobile Wi-Fi router with a 5G modem, or a mobile phone with 5G). This solution is simple and functional.

The first types of AR glasses with a built-in 5G modem are also appearing, but they currently have other shortcomings. In the future, we can expect the range of options to expand, as the number of private 5G networks grows and, consequently, so does demand. Another aspect could be the expansion of the 5G variant of RedCap, which would be more economical in terms of battery consumption on the glasses.

Why this solution was chosen

The reason for choosing a solution involving the visualisation of 3D models using AR is generally to save time, increase efficiency and thereby reduce costs within the development process, particularly during prototyping.

As for the choice of AYES's solution, Continental, which uses AYES's solution at its plant in Brandýs nad Labem, states the following:

"The speed of preparing the trial operation and the willingness shown by AYES played a significant role in the selection of the supplier. At the same time, they assisted us in preparing the entire business case and helped us define all the areas where we can save money by purchasing smart glasses."

Project status

AYES has experience in deploying 3D model visualisation in several companies. These include Continental and Vitesco.

The project at Continental is unique in that one of the first and one of the few private 5G networks in the Czech Republic has been implemented at Continental since August 2023.

According to Continental, the private 5G network from T-Mobile will connect more than 1,000 devices and sensors at Continental's plant in Brandýs nad Labem. Smart connectivity provides the foundation for overcoming current and future challenges in display manufacturing. 5G optimises production processes, enables greater efficiency and reduces downtime. "By introducing a private 5G network at our site in Brandýs nad Labem in the Czech Republic, we have reached a significant milestone on the path to the digital factory," says Thomas Ebenhöch, Head of Operations in Continental's User Experience business unit.

AYES and Continental have been partners in the field of augmented reality since 2019, when they began testing the first applications of smart glasses in the production plant. This resulted in the successful implementation of RealWear glasses for remote support of maintenance staff by engineering colleagues, and subsequently the use of the same technology for remote production line audits (known as 'Remote Gemba').

Another use case implemented involves creating augmented reality guides designed to train operators at two workstations on the new production line. A solution was chosen that allows not only the display of text and images, but also more advanced animations and the use of 3D models of real components that the operator is required to assemble at the given workstation. The solution ultimately tested for the pilot operation was a combination of Microsoft HoloLens 2 smart glasses and TeamViewer Frontline Spatial software.

The creation of advanced 3D models using AR is currently in the pilot phase. Plans are also in place to migrate this to a private 5G network in the future.

Figure 20: Assisted maintenance of production equipment using augmented reality and 5G. Source: AYES Archive, 2023.

Project evaluation and benefits.

The project at Continental is still in its early stages, so there is currently no data available for its quantitative evaluation.

On a global scale, companies such as BMW utilise 3D models and their visualisation using AR glasses. The BMW Group uses a new augmented reality (AR) application in vehicle concept development and prototyping. According to BMW, this solution accelerates the process by up to twelve months, from individual vehicle components to complex production phases. AR glasses allow real-world geometries – such as a vehicle body – to be overlaid with life-size holographic 3D models, enabling a range of design variants and assembly processes for future production vehicles to be assessed flexibly and cost-effectively.

According to BMW's assessment, it can therefore be concluded that, in certain types of complex design processes, the use of AR 3D models can lead to truly significant time and cost savings.

Potential uses and future applications

The use of advanced 3D models and their visualisation using AR is undoubtedly a highly beneficial solution for process innovation, particularly for companies engaged in complex industrial development. Pioneers in this field are companies in the automotive sector. However, there is no reason why this solution should not be extended to other industrial sectors.

However, AR 3D modelling can find applications in product development across various sectors, particularly in prototyping, validating design solutions and their ergonomics.

Another issue is the need to utilise (private) 5G technology and MEC for 3D models with AR. As mentioned above, the demands on data throughput and computing power are considerable for complex models. It can therefore be assumed that for companies considering an investment in a private 5G network, this will be one of the additional use cases that can economically justify this investment.

Appendix 6 – Case study: DEXTRUM/KVADOS automated warehouse

Basic information about the solution provider

The solution provider for the DEXTRUM FULFILLMENT automated warehouse is KVADOS, a.s. KVADOS has long been developing, supplying and operating an application and control platform for the automatic handling and transport of goods in large logistics centres and warehouses on the WMS (Warehouse Management System) platform.

In addition to WMS, KVADOS also specialises in robotics and warehouse automation. It is an independent distributor and integrator of robots.

- KVADOS is an authorised business partner of leading global robot manufacturers
- It has its own R&D department for the design and delivery of solutions
- It is a founding member of the Association for Innovation in Logistics
- It operates a test showroom for automation and robotics in logistics
- It provides comprehensive services: solution design, implementation, inspection, maintenance and ROI calculation.

KVADOS’s customers include leading Czech e-commerce companies with particularly high demands on logistics solutions. These include CZC.CZ, Notino, Alza and Košík.

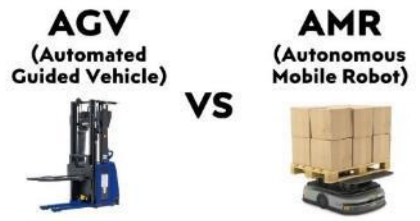
Use Case

The case study focuses on the use case: AGV/AMR operation in a warehouse. In this instance, AGVs are primarily used for handling pallets and crates. This use case falls under the ‘Smart warehouse’ category. This is a group of use cases that enhance storage efficiency, encompassing automation, robotisation, inventory management and improvements to warehouse logistics quality. In addition to AGV/AMR operations, this category includes, for example, the use of machine vision for packaging quality, or inventory management using smart racking, etc.

In principle, these are use cases defined by the warehouse perimeter; for their effective implementation, it therefore makes sense to consider the use of a private 5G network, which is always limited to that specific perimeter.

In AGV/AMR operations, companies aim to achieve high operational efficiency, which will enable them to speed up warehouse operations and reduce costs, whilst also ensuring a high level of safety. To gain an understanding of the ‘Smart warehouse’ sector, it is worth noting the difference between AGVs and AMRs.

Figure 21: AGV / AMR. Source: Warehouse Storage Solution, 2023.



AGVs (Automated Guided Vehicles) and AMRs (Autonomous Mobile Robots) are both types of autonomous robots used in industrial and logistics applications, but they differ in their navigation capabilities and flexibility.

AGV (Automated Guided Vehicles)

- Navigation: AGVs move along pre-determined paths. These paths are usually defined by physical guides, such as magnetic strips, underfloor guides or laser beacons. AGVs require these navigation elements to determine their position and direction.
- Flexibility: They are relatively less flexible, as changing their route requires physical modification of the navigation elements in the environment.
- Usage: Ideal for applications where materials need to be moved repeatedly between fixed points.

AMR (Autonomous Mobile Robots)

- Navigation: AMRs use advanced sensors and mapping algorithms for autonomous navigation. They can react dynamically to obstacles and change their route in real time without the need for any physical navigation guides.
- Flexibility: They are highly flexible and capable of easily adapting to changes in the environment or tasks. They can operate in more complex and variable environments.
- Applications: Suitable for more complex applications with variable routes and the need to navigate around obstacles, such as warehousing, packaging and transport within diverse environments.

Figure 22: KVADOS portfolio. Source: KVADOS

Whilst AGVs are well established for specific, repetitive tasks on fixed routes, AMRs offer greater flexibility and adaptability for dynamic environments and more complex tasks, thanks to their ability to navigate autonomously without the need for fixed guide elements. In practice, there is a vast array of different types of autonomous vehicles, devices and robots used in warehouses. The following figure illustrates KVADOS's portfolio:

Product/solution and its implementation

As part of the OPPIK Application IX grant call, KVADOS, in collaboration with VŠB – Technical University of Ostrava and Brno University of Technology, submitted and successfully completed a project proposal aimed at developing its own platform for controlling autonomous robots and other advanced technologies using a 5G network. For this purpose, the first private 5G network in the Czech Republic was built at the Paskov logistics warehouse for commercial use in conjunction with Industry 4.0 elements.

Development and deployment of a platform for so-called Fleet Management, which enables the comprehensive management of individual robots with a high degree of reliability:

In the implementation of Fleet Management, as part of the solutions supplied by KVADOS, the controlling master system is WMS mySTOCK, which utilises Fleet Management for the control, coordination and optimised collaboration of technologies within the warehouse, e.g. in Paskov. However, Fleet Management is not rigidly linked to the KVADOS mySTOCK WMS solution; it can also be used with software from other manufacturers via an implemented REST API interface utilising message exchange in JSON format. In this way, Fleet Management is easily accessible to a wide range of software from different manufacturers. By encapsulating communication with multiple robots and wrapping it in a standardised API, it offers the possibility of further expansion with new technologies in the future without the need for the user to program new integrations. Overall, it creates an ecosystem that streamlines the deployment of logistics solutions using modern automation elements.

The innovation and value of the resulting product are evidenced by the 'Best Czech and Slovak Logistics Product' award it has received.

The private 5G network that has been built is primarily used for wireless communication between the WMS system and autonomous devices that handle pallets or crates.

The company has implemented a state-of-the-art 5G SA private mobile network in its logistics ShowRoom for the control and processing of data from logistics robots. The 5G SA network was supplied by T-Mobile Czech Republic a.s. Several types of robots for handling pallets, KLT boxes and mobile racks are installed in the ShowRoom. The robots were equipped with 5G modems, and data transmission, which was originally carried out via Wi-Fi, is now carried out via the 5G network. The network was built not only in the logistics hall, where commercial operations of a fulfilment operator providing services for e-shops take place outside the ShowRoom, but also in the neighbouring production areas and in outdoor operations.

The aim of the ShowRoom project in Paskov was to build and verify the qualitative and technological benefits of a 5G private mobile network for real-world use in logistics and manufacturing operations. To measure the performance parameters of two-way data transmission in real time, particularly latency – the reliability of transmission, which is key to solving any real-time control tasks.

Replacing the original Wi-Fi network throughout the defined area and improving coverage quality is intended to enable data transmission at significantly higher speeds and with low latency. This makes it possible to control robot operations in real time and offload some of the computational load from the robot to the server.

DEXTRUM FULFILLMENT: a 2,000 m² warehouse equipped with a private 5G network

Reasons for and forms of using a private 5G network

Figure 23: Example of AGV/AMR use in practice. Source: KVADOS, 2023.

The operation of AGVs or AMRs is a relatively frequently mentioned use case in connection with the use of private 5G networks. However, a superficial description usually fails to explain why 5G is needed in this context.

Why would an autonomous vehicle need a connection? And if a connection is required, why should it be 5G – and a private one at that – rather than the more readily available Wi-Fi?

An AGV typically moves along a defined route. Its spatial orientation is ensured, for example, by QR codes placed on the floor and by LIDAR. From a safety perspective, an AGV must be able to react to an obstacle, for instance, regardless of connectivity, relying solely on the sensors mounted on the vehicle.

The next level of AGV control involves communicating the tasks the AGV is to perform. These tasks (the programme) are communicated remotely via control software and connectivity. Task communication involves a relatively small amount of data. At first glance, therefore, this is not a task that necessarily requires 5G connectivity. On the other hand, 5G does offer certain advantages for this task as well. In the case of AGVs, the scenario is, in principle, always a mobile one. A fixed connection is therefore not an option, and a WiFi connection always has a weakness in mobile use, which stems from the fundamental functioning of WiFi technology, which lacks the ability for reliable handover between individual access points (APs).

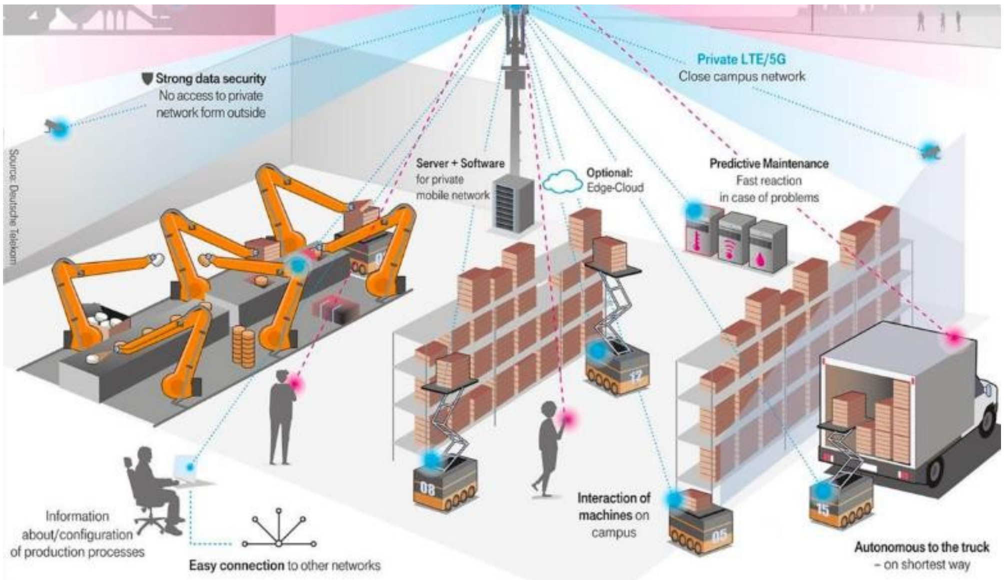
The need for 5G technology for AGV/AMR connectivity is then fully realised in another scenario involving advanced recognition. This involves equipping the vehicle with high-resolution cameras, from which the image is transmitted to a central unit and processed there. Depending on the purpose, this may involve processing to assess obstacles and select a suitable detour route, processing to assess quality, or, for example, to count specific items.

In any case, such a scenario requires very high-quality connectivity in terms of capacity, stability and low latency, all under conditions of fully mobile use. When we add to this the fact that a large number of such vehicles (these will be AMRs rather than AGVs, see the definition above) will be moving around the warehouse, it is clear that the use of 5G is entirely logical and, conversely, the weaknesses of Wi-Fi would certainly have a negative impact here.

In this scenario, there is also a logical requirement to use MEC for computing tasks whilst maintaining low latency.

The use of a private 5G network in a smart warehouse would, of course, not be limited to connecting AMRs. It would be advantageous to connect virtually all other devices in the warehouse as well. These include mobile devices such as pickers, automatic cleaning machines, and even drones. But also semi-stationary equipment such as cranes, which need to be moved when the warehouse layout changes.

Figure 24: Illustration of the use of a private 5G network in a smart warehouse. Source: Deutsche Telekom, 5G technology in industrial campus networks.



Project evaluation and benefits

According to DEXTRUM FULFILLMENT's evaluation, the increase in reliability—primarily due to the 5G network—led to a reduction in warehouse operating costs, optimisation and a reduction in operational demands, whilst also resulting in an overall increase in operational reliability.

Real-world operation confirmed that all key network parameters were met, both in terms of transmission speed in both directions and, above all, their reliability. This makes it possible to implement even the most demanding use-cases for real-time image processing using AI.

Potential uses and future applications

The resulting product is currently being showcased in a logistics showroom concept, on which KVADOS is collaborating with other members of the Association for Innovation in Logistics. This is a space where a private 5G network is installed alongside robots from various manufacturers and Industry 4.0 elements. These premises showcase the real-world possibilities for the cooperation of individual technologies, the use of the 5G network, and the measurement of actual logistics performance achieved. The showroom is open to visitors including secondary school and university students, teaching staff, journalists, and, last but not least, potential customers.

Thanks to KVADOS's innovative efforts, it is already possible to operate a warehouse using a platform for controlling autonomous robots and other advanced technologies via a private 5G network. An increase in demand for solutions utilising private 5G networks can be expected once AMRs with advanced image recognition become widely available, as potential users will have a strong need to ensure the functionality of the entire solution through sufficiently high-quality connectivity with high capacity, low latency and support for mobile use cases.

Appendix 7 – Case study: Twinzo – digital twin in logistics

Basic information about the solution provider.

Twinzo began as a project under the wing of its parent company, INFOTECH s.r.o., in 2014. It was originally focused on indoor positioning technology. Through collaboration with its first customers, Twinzo developed an increasing number of solutions for everyday problems in manufacturing and focused more on the aspect of 3D visualisation. In 2019, these efforts culminated in Twinzo – a 3D live digital twin that runs on any device. During this process, Twinzo won several competitions, notably the Microsoft Awards in 2017 and 2019.

Customers, users and their needs

Twinzo is, in principle, a universal platform for creating a digital twin and using it to streamline processes. Therefore, this solution can be utilised in various use cases for a wide range of customers. It is currently used, for example, in the following scenarios:

- Smart office – optimisation of office space utilisation
- Smart city – complete city visualisation
- 3D indoor navigation, for example in shopping centres
- Order system automation
- Digital twin in manufacturing
- Digital twin in logistics

Use Case

In this case study, we will focus on a use case involving the optimisation of internal logistics at an automotive supplier. Specifically, the twinzo solution is used to optimise the operation of forklifts.

Product/solution and its implementation

Initial situation:

Static definition of the area of responsibility for forklift drivers, with no real monitoring of compliance with rules. Everything depends on the driver's experience. It is impossible to actively monitor the movement of every forklift – attempts at manual tracking were made, but these were very time-consuming. No database containing the forklift truck movement history and no tracking of routes and data => therefore, optimisation and cost savings are not possible. A technician manually calculates the efficiency of each forklift truck based on data provided by a part-time employee using a stopwatch. The employee spends 4 days on measurements – it is not possible to carry this out daily across all shifts.

Push system for forklift operations – inefficient

- No real-time system for loading/unloading boxes/racks

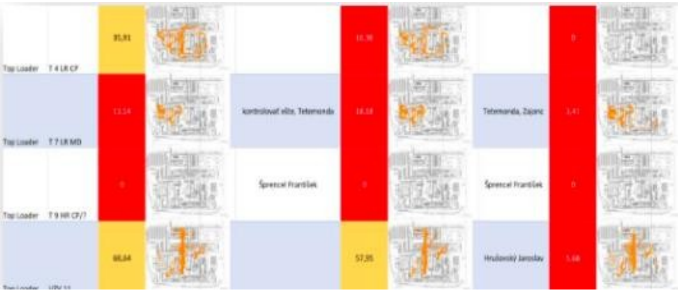
Loading/unloading is carried out based on experience

- All forklift drivers 'patrol' the production floor
- Depends on the experience of each driver
- Time wasted driving empty or wasting space on the production line because the driver uses the PUSH system and delivers more boxes than necessary.
- Long training period for new drivers

The Twinzo solution

Figure 26: Demonstration of the Twinzo solution. Source: Twinzo.

- 24/7 online status of all forklift trucks on site. Including a dynamic heatmap and display of problem areas.
- Clearly defined responsibilities within the production area and dispatch zone.
- Live 3D digital version of the site with online forklift movements. Real-time transport status.
- App available for PC, Android or Apple.
- Daily reports including spaghetti diagrams for all forklifts with downtime and tracking information for the last 24 hours.
- A complete overview and database of efficiency with the option to export data to Excel.



Introduction of a pull system (instead of an inefficient push system):

- The operator orders a forklift online at the touch of a button to collect an empty/full box
- Production line requirements are visible in real time on the tablet in the forklift
- Increased forklift productivity (90% reduction in phone calls between the project team and the driver).

Systematic loading/unloading:

- Elimination of more than 95% of forklift patrols and delivery of the right parts at the right time to the right place.

Figure 27: Example of hardware for the Twinzo solution. Source: Twinzo

5G/P5G + MEC – reasons and potential applications

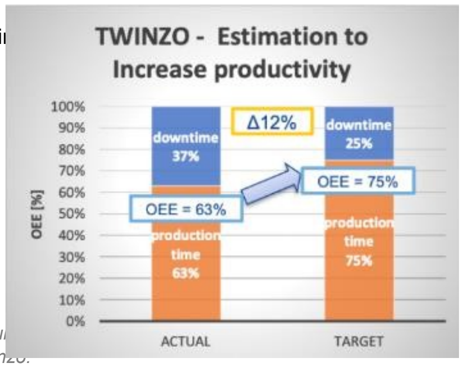
The Twinzo solution is generally technology-neutral. To obtain location data for the relevant devices, various RTLS technologies can be used, such as BLE (Bluetooth Low Energy) in either active or passive modes, the latter being particularly suitable for tracking forklift trucks. Other options include UWB and RFID.

Existing Wi-Fi networks can be used for data transmission. On the other hand, it is clear that private 5G networks offer a higher degree of reliability than Wi-Fi, particularly for data transmission in mobile scenarios.

Another argument in favour of using a private 5G network will be a solution that includes native localisation on the 5G network. The urgency of using a private 5G network will also be greater when we wish to further develop the solution, utilise cameras mounted on forklift trucks, and transmit this data to a central hub.

Project status and assessment of benefits

Figure 28: Twinzo productivity assessment. Source: Twinzo.



The Twinzo solution will enable the efficiency of forklift utilisation to be increased from the origi %. As a result of this increase in efficiency, it is possible to reduce the number of forklifts by 2 and the number of FTEs by 4. With software and hardware implementation costs of EUR 80,000, the expected return on investment is 4 months from implementation.

Usage possibilities and future applications

The Twinzo digital twin is a fully functional solution, and the use case described here can be implemented in logistics operations regardless of the technology currently used by the potential customer. Various RTLS technologies can be used to obtain data on the location of the relevant equipment. Existing Wi-Fi networks can then be used for data transmission.

Figu Twinzo.

This is clearly not a use case that would, on its own, trigger the implementation of a private 5G network, but it is certainly a relevant scenario that will leverage the benefits of private 5G for greater reliability and security of the solution, as well as for the prospect of its future development.

Combined with other use cases for private 5G, it can thus help to justify the investment economically.