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# Cost Characteristics In The Construction Of 5G-Campus Networks For Production

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**Abstract**

5G continues to develop as a key technology for digital transformation in production. This wireless, fast and secure transmission technology with long range, low latency and the ability to connect a large number of devices will enable companies to gradually overcome the hurdles of the fully connected enterprise of the future. At the same time, as a new and innovative technology, 5G still presents companies with a number of challenges. In particular, the issue of non-transparent cost calculation is still causing uncertainty for companies, especially in the decision-making process. The uncertainty of companies regarding the cost factors of private 5G networks, known as private 5G-Campus networks, results from limited experience. The lack of knowledge about aspects such as license fees, hardware costs and maintenance expenses make budgeting difficult. A systematic analysis is necessary to make informed decisions and maximize the benefits of 5G-technologies. This article presents an overview of the cost factors of private 5G-campus networks, including the implementation phases and the stakeholders involved, through case study research. Furthermore, in addition to identifying the specific characteristics of the 5G-cost factors and implementation phases and stakeholders, the dependencies between these are also evaluated. The aim is to verify the identified 5G-cost factors so that a precise and transparent calculation is possible and well-founded decisions can be made regarding the implementation and use of 5G-technologies.

**Keywords**

5G-Technology; Cost calculation; Industry 4.0; Network; Production

## 1. Introduction

The digital transformation entails a multitude of new requirements in which the communication network plays a decisive role [1]. It is leading to the networking of machines, tools, products and the people involved in the value chain. This fundamental change makes up-to-date knowledge and insights about processes, production and products available throughout the entire company, while computing power is reliably routed to where it is needed [2]. The exponential growth in the number of intelligent devices and systems as well as the evolution of business applications require significantly increased bandwidth to provide more comprehensive information on the system status and the operating environment. Business-critical applications that require remote access - such as the control of production systems in industrial automation, as well as the control of autonomous vehicles - demand much higher reliability of communication services and significantly lower latency times [3]. In order to meet these requirements and achieve industrial productivity gains, communication networks must further develop fundamental properties [4].

5G offers a level of security, reliability and speed that did not previously exist in mobile networks, so that it can be used for Industry 4.0 [5]. The upcoming era of 5G as an advance over 4G/LTE Advanced is no longer limited to conventional telephony and data services as in previous mobile communications standards [6].

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Instead, the 5G-standard opens up new horizons for the networking of devices that go far beyond previous smartphone applications. The aim is to realize the concept of the Internet of Things with 5G, so that devices such as sensors, motors and controllers can communicate with their direct and indirect environment [7]. The service-based architecture of 5G-networks will also make it possible to quickly and efficiently provide differentiated communication services that meet the diverse requirements of industry. This is done by providing users with customized "network slices" that can be operated on a shared physical infrastructure. As a result, the different requirement profiles for network communication can be met without conflict and at the same time in an integrative manner [8].

In addition to the multitude of potentials that are repeatedly mentioned in the scientific literature, there are also several challenges that companies have to overcome with 5G-campus networks (definition of terminology in chapter 2). Typical challenges in implementing 5G-campus networks include selecting suitable sites and infrastructure, managing high investment costs, complex integration with existing networks, security and privacy concerns, potential interference and coverage issues, managing and maintaining the network as well as complying with regulatory requirements. Overcoming these challenges requires careful planning, technical expertise and collaboration with various stakeholders. [9]

The introduction of 5G-campus networks poses a variety of challenges, particularly in terms of costs. Companies are often faced with the difficulty of fully understanding the total cost of building and operating such a network [10]. This is partly because the complexity of 5G-networks and the large number of variables that influence the costs make it difficult to estimate the costs accurately. Requirements for hardware, infrastructure, skilled personnel, licenses and ongoing operational costs can vary greatly depending on a company's specific needs and requirements [10]. In addition, there may be unexpected costs associated with integrating 5G into existing IT infrastructures or addressing security and privacy concerns. To address these challenges, a thorough cost analysis and planning is essential to avoid potential budget overruns and ensure the financial feasibility of the 5G-campus network [11].

## 2. Basic terminology

In the following, an overview of the most relevant terms within the paper is listed and briefly described individually.

**Industry 4.0**: Industry 4.0, also known as the fourth industrial revolution, marks a significant advance on previous industrial upheavals. It is based on historical and technological concepts such as the smart factory and computer-integrated production. At the heart of the fourth industrial revolution is the holistic connection of people, machines, products, systems and companies across the entire value chain and product life cycle. The overarching goal is to increase productivity and create added value for customers. [11,12]

**Mobile radio:** The definition of mobile radio encompasses wireless communication between different nodes, at least one of which is mobile. This includes the transmission of data, voice or other information between mobile and fixed units. Among the many challenges associated with this area, seamless handling of network changes, continuity of communication after failures, integration with other layer protocols and efficient scalability and resource utilization are of particular importance. [13]

**5G:** The current development in the field of wireless communication concerns the introduction of 5G, which is considered the next generation of mobile communications and includes the New Radio (NR) standard. Since 2016, the International Telecommunication Union (ITU) has defined comprehensive performance requirements for 5G. These include improving download and upload speeds, reducing latency times and supporting a higher number of devices per square kilometer. In addition, increased movement tolerance of end devices and a reduction in energy consumption are also required. [11,14]

**5G-frequencies:** In addition to the standard frequency ranges of 0.7 to 2.4 GHz, 5G can also access frequencies of up to 100 GHz. However, the frequencies in the 3.4 to 3.7 GHz range, which are specifically reserved for 5G, will be used first. In addition, the frequencies between 3.7 and 3.8 GHz will remain reserved for use in private 5G-campus networks for companies or organizations and will not be used for public networks. [15]

**5G-campus network:** The term "5G-campus network" refers to a geographically limited, local mobile network adapted for special requirements such as industrial communication. Thanks to 5G-technology and the use of dedicated frequencies, it can meet the highest quality of service requirements in terms of latency, reliability and availability of communication networks. [16,17]

## 3. Research method

In this study, an exploratory multiple case study was chosen as the research method, with the research design following the phenomenological approach of qualitative research. The study is based on a non-random, purposive sample. Diversity was taken into account when selecting the participating companies to ensure that all conflicts of interest were taken into account. A total of six SMEs, three large companies and two telecommunications companies were interviewed, with the majority of interviewees belonging to middle and senior management. The aim of the interviews conducted was to identify and validate relevant 5G-cost characteristics, relevant implementation phases for 5G and all involved stakeholder. On this basis, a further evaluation of 5G-campus networks can be carried out. The interviews followed a semi-structured approach with a duration of 60 minutes per interview. Due to the extensive experience with video calls within the pandemic, both virtual and non-virtual interviews were conducted.

A three-stage approach was chosen as the basis for the interview structure, in which the 5G-technology and its description were first discussed in general terms. This was followed by an analysis of the 5G-cost drivers, the implementation phases and all stakeholders. Finally, the relationships between the cost drivers, the implementation phases and the stakeholders were considered and evaluated. This research method was chosen in order to fully capture the specific expert knowledge of the individual test subjects and to be able to determine their individual perspectives.

## 4. Results

In the following, the 5G-cost items collected on the basis of the case study research are presented and described in more detail. In a second step, the 5G-implementation phases identified on the basis of the case study research are outlined and thoroughly explained. Subsequently, the stakeholders involved in the process, as identified from the case study research, are described. Finally, the 5G-cost items are assigned to both the 5G-implementation phases and the stakeholders in the form of strong and weak dependencies on each other.

### 4.1 5G-cost characteristics

Once the cost factors for the construction of a private 5G-network have been recorded in detail, various analytical and planning tools are available. A precise budget can be drawn up, risks can be identified and weighed up, various options can be compared and an ROI analysis can be carried out. This data enables well-founded decisions to be made about the viability and profitability of a private 5G-network. In addition, the recorded cost factors can be used for long-term planning of the operation and maintenance of the network. Overall, the comprehensive recording of cost factors enables effective strategic planning and implementation of a private 5G-network. The following table lists and describes the 5G-cost items including the various cost drivers

Table 1: 5G-cost characteristics

| 5G-cost item | Cost drivers |
|---|---|
| Planning costs [18,19] | All costs incurred for preparatory processes |
| License costs [20,21] | Costs for issuing the licenses |
| Implementation costs [22] | Costs for the implementation and administration of network management tools and systems |
| | Commissioning of the network, including testing, verification and optimization |
| | Training costs for IT staff to manage the 5G-network |
| Infrastructure costs [23] | Number and type of base stations and antennas |
| | Setting up data centers and implementing core network components such as routers and switches |
| Operating costs [24] | Costs for the energy consumption of base stations, antennas and other network components |
| | Personnel costs for monitoring, maintaining and troubleshooting the network |
| | Costs for software updates and patches to maintain security and performance |
| | Costs of operating mobile infrastructure, including backhaul connections and core network components |
| | Cost of insurance covering various aspects of network operations, including damage, outages and liability |
| Use case costs [2,9] | Costs for the implementation & operation of use cases |
| | Use case identification |
| | Use case implementation |
| | Use case operation & maintenance training |

### 4.2 Phases of 5G-implementation

The introduction of 5G-campus networks requires a strategic approach that is tailored to the specific requirements and objectives of the respective company or organization. Such an approach is crucial to make the most of the full range of opportunities that 5G offers while overcoming potential challenges. The introduction of a 5G-campus network usually goes through four different main phases. The following table introduces and describes the different phases of 5G-implementation.

Table 2: phases of 5G-implementation

| Phase of 5G-implementation | | Description |
|---|---|---|
| 1. | Planning and preparation [25] | In this phase, the requirements of the campus network are defined and the locations for the installation of the 5G-base stations are selected. The required infrastructure is prepared and technical specifications are defined. |
| 2. | Installation and configuration [26,27] | The 5G base stations are installed and configured to meet the network coverage and capacity requirements as specified in the planning guidelines. |

| | | |
|---|---|---|
| 3. | Integration, testing and application deployment [28] | The newly installed base stations are integrated into the network, comprehensive tests are carried out and the specific applications and services are deployed and optimized. |
| 4. | Training, user acceptance and maintenance [29] | Training is provided to IT staff and end users to ensure effective use of the network. User acceptance is monitored and regular maintenance is carried out to ensure the operational readiness and security of the network. |

### 4.3 Stakeholder

Identifying the stakeholders in the implementation of 5G-campus networks is crucial, as the large number of parties involved makes the task complex. In addition to technical aspects, interpersonal skills also play a crucial role in successful implementation. Internal departments such as IT, engineering and management as well as external groups such as regulators and suppliers have different interests and expectations. The challenge is to identify all relevant stakeholders, understand their needs and coordinate them effectively to ensure the project runs smoothly. This requires careful analysis, prioritization and proactive communication to minimize potential conflicts and maximize support for the project. The following table introduces the 5G stakeholders and describes them one by one.

Table 3: 5G-stakeholder

| 5G-stakeholder | Description |
|---|---|
| Company [30,31] | Main player that sets up and uses the 5G-network for internal communication and applications |
| Funding consultant [32] | Expert who supports companies in identifying and applying for funding for 5G expansion |
| System integrator [33] | Responsible for the integration of various network components and technologies to implement the 5G-network |
| Consultant as control authority of the system integrator [34] | Monitors and controls the work of the system integrator to ensure that standards and requirements are met |
| Fiber optic provider [35] | Responsible for the provision of fiber optic networks, which form an important part of the 5G-infrastructure |
| IT and network team [36] | Team responsible for the maintenance and operation of the 5G-network and IT infrastructure |
| Management and executive level [37,14] | Decision-makers in the company who define the strategic guidelines and investments for the 5G expansion |
| End user/employee [38] | People who use the services of the 5G-network, e.g. employees of the company |
| 5G-suppliers and providers [25,39,40] | Companies that provide 5G-technology equipment and services |
| Network operators/telecommunications companies [31,41] | Responsible for the operation and maintenance of telecommunications networks, including the 5G-network |
| Federal Network Agency [20,42–44] | Regulatory authority responsible for the licensing and monitoring of telecommunications services |

| | |
|---|---|
| Consultant for application to the Federal Network Agency [45] | Expert who supports companies in the preparation and submission of applications to the Federal Network Agency |
| Suppliers of software and applications [46] | Companies that provide software solutions and applications for the 5G-network. |

### 4.4 Merging of cost items into 5G-implementation phase and stakeholder

For reasons of clarity, the dependencies between the cost factors and the implementation phases or stakeholders were considered separately. In the following, the dependencies between the 5G-implementation phases and the cost factors are presented first, while the dependencies between the cost factors and the stakeholders are explained in the second step. A distinction is also made between strong and weak dependencies. The presentation of strong and weak dependencies underlines the need for detailed analysis to plan resources efficiently and avoid potential cost traps. The early recognition and consideration of dependencies ultimately leads to the successful implementation of 5G-campus networks. Strong dependencies between cost factors and implementation phases or stakeholders are reflected in direct and immediate interactions that can have a significant impact on the success or failure of a project. Weak dependencies, on the other hand, are less direct and can be regarded more as indirect influences.

#### 4.4.1 Merging of 5G-implementation phases into cost items

In a first step, the dependencies between the 5G-implementation phases and the 5G-cost factors were examined. It quickly becomes clear that all 5G-cost items are reflected in the planning and preparation phase. The planning costs and license costs are particularly significant, as the comprehensive strategy development and the application for the necessary licenses must take place in this phase. These costs form the basis for the successful launch of the 5G-project and have a significant influence on the further course and efficiency of the following phases. While the license costs are already incurred in the planning phase and the operating costs only become relevant in later phases, the other cost items play a central role in the configuration and installation phase. Once the configuration and installation phase is complete, only planning and implementation costs are incurred in the integration, testing and application development phase. In this phase, the already configured systems are integrated, comprehensively tested and specific applications are developed to run on the 5G-network. The main focus here is on fine-tuning the systems, quality assurance and adapting the applications to the 5G-environment. In the final phase, the training, user acceptance and development phase, only planning and operating costs are incurred. Here, training is provided for operating personnel to ensure that they are familiar with the new 5G-technology and can use it effectively. The operating costs relate to the implementation of operating procedures and processes to ensure the smooth operation of the 5G-network. Furthermore, it can be seen that use case costs arise in all phases. As the 5G-campus networks are designed specifically for the use cases at hand, these are at the forefront in all phases and represent a significant cost driver. An overview of the strong and weak dependencies can be seen in the following figure.

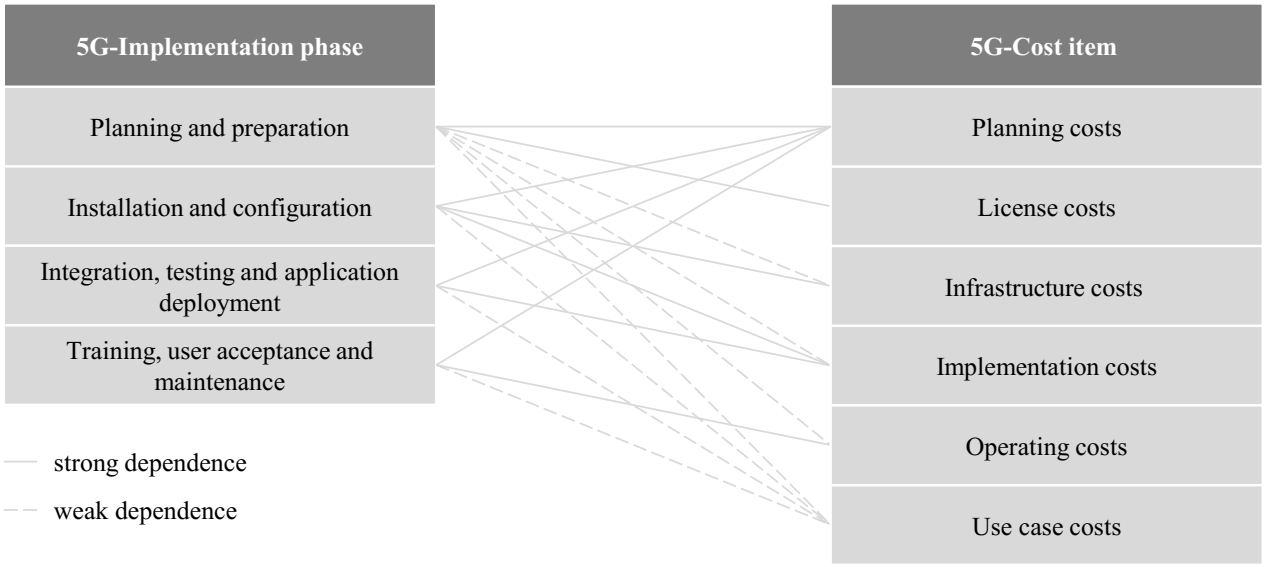


Figure 1: Dependencies between implementation phase and cost item

### 4.4.2 Merging of cost items into 5G-stakeholders

In this step, the dependencies between the 5G-cost factors and the 5G-stakeholders are examined. It quickly becomes clear that the company is involved in all 5G-cost factors as a stakeholder. Although the company can outsource work, the responsibility remains with the company itself, meaning that the company must at least maintain an overview of all cost factors. Furthermore, it quickly becomes apparent that the planning costs are distributed across all stakeholders. This study therefore also confirms that careful planning is an essential basis that is of great importance for all stakeholders. Compared to the planning costs borne by all 5G stakeholders, the license costs are incurred only when applying for frequency bands from the Federal Network Agency. These license costs are therefore an one-off expense at the start of the project and can be regarded as part of the regulatory requirements, while the planning costs are incurred continuously throughout the entire implementation process. The infrastructure costs for the implementation and operation of 5G arise primarily from the expansion and maintenance of fiber optic provider, as well as the provision of 5G-hardware by suppliers and service providers. These investments are crucial for the provision of a reliable and high-performance 5G-infrastructure. In addition, the implementation costs of 5G-technology are incurred in particular by the system integrator, who is responsible for the seamless integration of various components, and by the 5G-supplier, who provides the hardware and technical solutions. However, implementation costs are also caused by the IT and the network team of the respective company. Nevertheless, as these only represent a small proportion of the costs, they are only shown here as a weak dependency. In terms of operating costs, the system integrator, the 5G-supplier, the network operator and the providers of software and applications are primarily responsible for the main costs, as they are responsible for the operation and maintenance of the 5G-infrastructure and services. In addition, fiber optic providers, the company's IT team, the employee himself and the management team bear secondary costs that relate to specific support functions and strategic decisions. Finally, the suppliers of software and applications in particular account for the majority of 5G-use case costs, as they are responsible for the development, implementation and maintenance of the specific applications that are operated on the 5G-network. A detailed overview of the dependencies between the 5G-cost parameters and the 5G-stakeholders is summarized in the figure below to provide a comprehensive understanding of the role and relationship of the stakeholders to the cost factors.

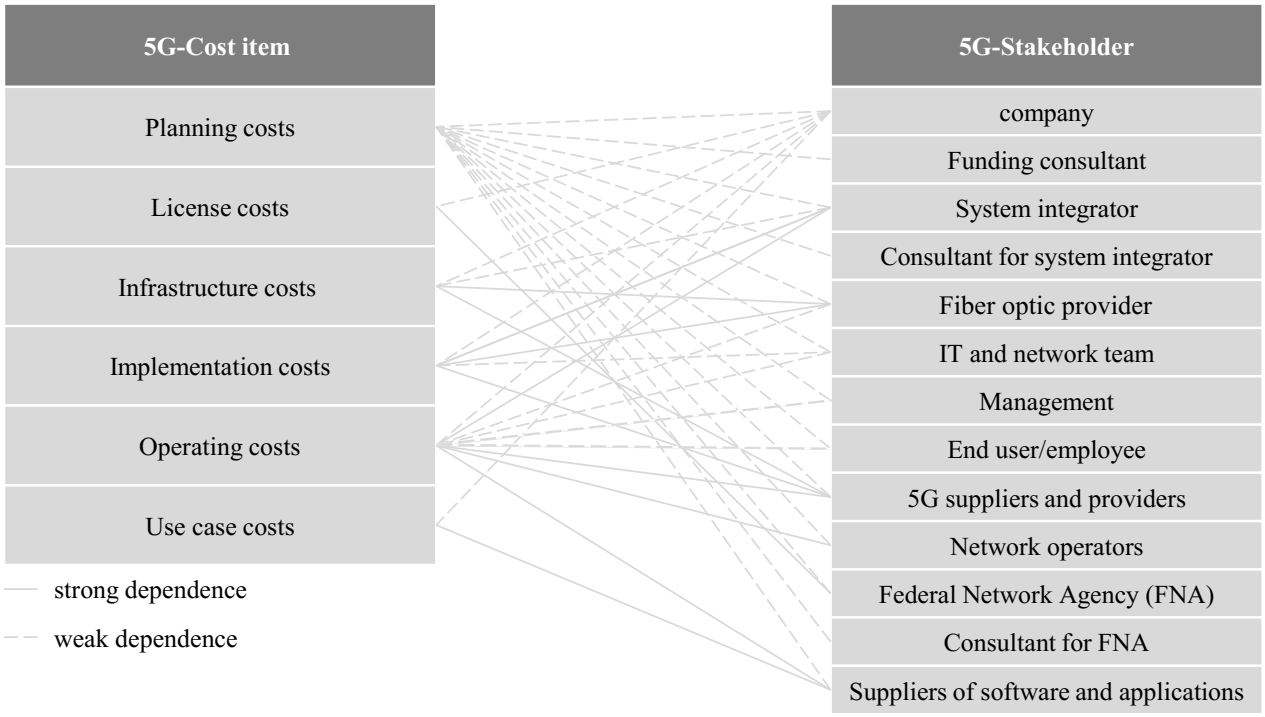


Figure 2: Dependences between cost items and 5G-stakeholder

## 5. Discussion, conclusion, and outlook

The six 5G-cost items identified in this paper could be linked in strong and weak dependencies with both 5G-implementation phases and 5G-stakeholders. By clearly linking the 5G-cost items to the 5G-implementation phases and the 5G-stakeholders, it was possible to show that assessing the financial cost of introducing a 5G-campus network is a complex undertaking. Not only are monetary expenses required across the entire 5G-implementation items, but the various stakeholders are also involved in the different phases and cause further monetary expenses. This complexity leads to a multi-layered analysis of the financial effort involved in the introduction of 5G-campus networks. In order to be able to fully measure the cost of 5G in a company, the individual 5G-implementation phases must not be viewed in isolation, but must always be seen in the context of all 5G-stakeholders involved. This requires a holistic approach that takes into account both the technical and interpersonal aspects of implementation and enables a comprehensive cost assessment. However, even in an already implemented and functioning system, the study shows that the company will continue to work with many 5G-stakeholders long after the rollout of a 5G-network. In addition to the system integrator, these include in particular the 5G-equipment supplier and provider, the network operator and the provider of software and applications. This shows that the complexity of cost considerations is not only carried over into the introduction phase, but also well into the operational phase. Simultaneously, dynamic changes are currently taking place in the further development of 5G-technology, which in turn have an impact on cost factors. An example of this are new providers with open RAN solutions and open source solutions, some of which no longer charge license fees. The integration of new stakeholders leads to increased complexity in the short term and results in a need for further research, but is enormously important for reducing the costs of 5G-technology in the long term.

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## References

[1] Delshi Howsalya Devi, Kumutha Duraisamy, Ammar Armghan, Meshari Alsharari, Khaled Aliqab, Vishal Sorathiya, Sudipta Das and Nasr Rashid, 2024. 5G Technology in Healthcare and Wearable Devices: A Review.

[2] Abbas, M., Stratmann, L., Dresen, M., Mbaya, C., Stroh, M., 2023. 5G als Chance für IoT-Plattformen der Zukunft: Ein Visionspapier.

[3] Aijaz, A., 2022. Private 5G: The Future of Industrial Wireless. http://arxiv.org/pdf/2006.01820v2.

[4] Arjoune, Y., Faruque, S., 2021. Artificial Intelligence for 5G Wireless Systems: Opportunities, Challenges, and Future Research Direction, in: 2020 10th Annual Computing and Communication Workshop and Conference (CCWC). 2021 10th Annual Computing and Communication Workshop and Conference (CCWC), Las Vegas, NV, USA. 06.01.2020 - 08.01.2020. IEEE, pp. 1023–1028.

[5] 5G-ACIA, 2021. White Paper: "Key 5G Use Cases and Requirements From the Viewpoint of Operational Technology Providers".

[6] Karsten Heimann, Benjamin Sliwa, Manuel Patchou, and Christian Wietfeld, 2023. Modeling and Simulation of Reconfigurable Intelligent Surfaces for Hybrid Aerial and Ground–based Vehicular Communications.

[7] Attaoui, W., Sabir, E., Elbiaze, H., Guizani, M., 2023. VNF and CNF Placement in 5G: Recent Advances and Future Trends. IEEE Trans. Netw. Serv. Manage. 20 (4), 4698–4733.

[8] Angerer, H., Bahr, M., Bergmann, A., 2020. Leitfaden 5G-Campusnetze: Orientierungshilfe für kleine und mittelständische Unternehmen, 52 pp. https://www.bmwi.de/Redaktion/DE/Publikationen/Digitale-Welt/leitfaden-5G-campusnetze-orientierungshilfe-fuer-kleine-und-mittelstaendische-unternehmen.pdf?__blob=publicationFile&v=10. Accessed 1 November 2022.

[9] Seelmann, Abbas, Henke, Stratmann, Leidinger, Knebel, 2020. 5G für die vernetzte Industrie, 4 pp. http://library.fes.de/pdf-files/wiso/16838.pdf. Accessed 1 November 2022.

[10] Engel, A., Gatzke, M., Amler, J., Horn, H., 2022. Facts & Figures 2022: Der IKT-Standort NRWs.

[11] Golz, J., 2023. Evaluation der Bedeutung von 5G-spezifischen Anwendungsfällen anhand eines Anwendungsfallradars.

[12] Grotepass, J., Eichinger, J., Voigtländer, F., 2021. Mit 5G zu neuen Potentialen in Produktion und Logistik. Accessed 1 November 2022.

[13] Fraunhofer-Gesellschaft, 2022. Messdaten mit 5G kabellos in Echtzeit übertragen. https://www.fraunhofer.de/de/presse/presseinformationen/2018/April/messdaten-mit-5G-kabellos-in-echtzeit-uebertragen.html. Accessed 1 November 2022.

[14] Zeyad Ghaleb Al-Mekhlafi, Mahmood A. Al-Shareeda, Selvakumar Manickam, Badiea Abdulkarem Mohammed, Abdulrahman Alreshidi, Meshari Alazmi, Jalawi Sulaiman Alshudukhi, Mohammad Salih Alsaffar, Taha H. Rassem, 2024. Efficient Authentication Scheme for 5G-Enabled Vehicular Networks Using Fog Computing.

[15] Ennemann, M., Holt, A., 2020. Wertschöpfung durch 5G, 10 pp. https://home.kpmg/de/de/home/themen/2020/05/wertschoepfung-durch-5g-wie-sich-weltweit-ueber-4-billionen-us-dollar-generieren-lassen.html. Accessed 1 November 2022.

[16] Engel, A., Horn, H., 2023. Zwischen Forschung und Praxis: Die Projekte des 5G.NRW Wettbewerbs im Überblicks.

[17] Varga, P., Peto, J., Franko, A., Balla, D., Haja, D., Janky, F., Soos, G., Ficzere, D., Maliosz, M., Toka, L., 2020. 5G support for Industrial IoT Applications - Challenges, Solutions, and Research gaps. Sensors (Basel, Switzerland) 20 (3), 1–43.

[18] Jerichow, A., Covell, B., Chandramouli, D., Rezaki, A., Lansisalmi, A., Merkel, J., 2022. 3GPP Non-Public Network Security. JICTS 8 (1), 57–76.

[19] Liu, S., Liu, L., Yang, H., Yue, K., Guo, T., 2020. Research on 5G technology based on Internet of things, in: 2020 IEEE 5th Information Technology and Mechatronics Engineering Conference (ITOEC). 2020 IEEE 5th Information Technology and Mechatronics Engineering Conference (ITOEC), Chongqing, China. 12.06.2020 - 14.06.2020. IEEE, pp. 1821–1823.

[20] Barakabitze, A.A., Ahmad, A., Mijumbi, R., Hines, A., 2022. 5G network slicing using SDN and NFV: A survey of taxonomy, architectures and future challenges. Computer Networks 167 (106984), 1–40.
[21] Jasperneite, J., Lohweg, V., 2022. Kommunikation und Bildverarbeitung in der Automation. Springer Berlin Heidelberg, Berlin, Heidelberg, 374 pp.
[22] Schäfer, S., Elbanna, A., Neu, W., Thomas Plückebaum, 2020. Mögliche Einsparungspotentiale beim Ausbau von 5G durch Infrastructure Sharing. WIK Wissenschaftliches Institut für Infrastruktur und Kommunikationsdienste, 127 pp. https://www.econstor.eu/handle/10419/228685. Accessed 1 November 2022.
[23] Mao, W., Akgul, O.U., Cho, B., Xiao, Y., Ylä-Jääski, A., 2023. On-Demand Vehicular Fog Computing for Beyond 5G Networks. IEEE Trans. Veh. Technol. 72 (12), 15237–15253.
[24] Hompel, M. ten, Bauernhansl, T., Vogel-Heuser, B. (Eds.), 2022. Handbuch Industrie 4.0. Springer Berlin Heidelberg, Berlin, Heidelberg, 631 pp.
[25] Häger, S., Böcker, Stefan, Shahin, Jamali, Reinsch, T., Wietfeld, C., 2023. A Novel System Architecture for Small-Scale Motion Sensing Exploiting 5G mmWave Channels. IEEE, Piscataway, NJ, 1 p.
[26] Schürrmann, T., 2023. Anwendungs- und Nachhaltigkeitspotenzial von 5G in der digitalen Transformation.
[27] Schuster, D., 2023. Edge Computing: An Overview.
[28] Almazroi, A.A., Aldhahri, E.A., Al-Shareeda, M.A., Manickam, S., 2023. ECA-VFog: An efficient certificateless authentication scheme for 5G-assisted vehicular fog computing. PloS one 18 (6), e0287291.
[29] Jurva, R., Matinmikko-Blue, M., Niemelä, V., Hänninen, T., 2023. Smart Campus 5G and IoT network preparations for operational mode: Specification to deploy data and network management. International Telecommunications Society (ITS)., 14 June 2023.
[30] Audi MediaCenter, 2023. 5G in der Produktion: Audi und Ericsson gehen den nächsten Schritt. https://www.audi-mediacenter.com/de/pressemitteilungen/5g-in-der-produktion-audi-und-ericsson-gehen-den-naechsten-schritt-12578. Accessed 1 November 2022.
[31] O'Connell, E., Moore, D., Newe, T., 2020. Challenges Associated with Implementing 5G in Manufacturing. Telecom 1 (1), 48–67.
[32] Gold, J., Bremmer, M., 2022. IoT-Unterstützung und mehr Frequenzeffizienz. COMPUTERWOCHE, January 24.
[33] Steinberg, P., Roser, G., 2020. Wirtschaftspolitische Herausforderungen der Digitalisierung. Wirtschaftsdienst 100 (S1), 54–56.
[34] RWTH Aachen - Lehrstuhl für Informatik 4, 2020. Kommunikation und verteilte Systeme: Anforderungen an ein mobiles IP. Lehrstuhl für Informatik 4. Accessed 1 November 2022.
[35] Heimann, K., 2023. "NRW-Perspektive 6G Technologie".
[36] Wietfeld, C., Böcker, S., Kurz, F., 2023. Open RAN – neue Spielregeln für den Mobilfunk.
[37] Taraba, T., 2020. Akzeptanz von Enterprise Mobility: Empirische Analyse und praxeologische Implikationen, 1. Auflage ed. Springer Gabler, Wiesbaden, XXV, 318 Seiten.
[38] Seichter, H.M., 2023. Elektromagnetische Verträglichkeit (EMV) bei der Nutzung von 5G im Gesundheitswesen.
[39] Lagorio, A., Cimini, C., Pinto, R., Cavalieri, S., 2023. 5G in Logistics 4.0: potential applications and challenges. Procedia Computer Science 217, 650–659.
[40] Ranaweera, P., Jurcut, A., Liyanage, M., 2022. MEC-enabled 5G Use Cases: A Survey on Security Vulnerabilities and Countermeasures. ACM Comput. Surv. 54 (9), 1–37.
[41] Pathak, R., 2023. 5G Core Network Architecture - A Beginners Guide. https://www.rajarshipathak.com/2020/01/beginners-guide-for-5g-core-network-architecture.html. Accessed 1 November 2023.
[42] Bundesnetzagentur, 2022. Pressemitteilung, 2 pp. Accessed 1 November 2022.
[43] Bundesnetzagentur, 2022. Übersicht der Zuteilungsinhaber: Frequenzzuteilungen für lokale Frequenznutzungen im Frequenzbereich 3.700-3.800 MHz, 6 pp. https://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Sachgebiete/Telekommunikation/Unternehmen_Institutionen/Frequenzen/OffentlicheNetze/LokaleNetze/Zuteilungsinhaber.pdf?__blob=publicationFile&v=5. Accessed 1 November 2022.
[44] LSU Schäberle, 2022. LSU Schäberle erhält als erster Logistikdienstleister eigene 5G-Lizenz. https://lsu-schaeberle.com/de/lsu-schaeberle-erhaelt-5g-lizenz. Accessed 1 November 2022.
[45] Hartmann, E.A., 2021. Digitalisierung souverän gestalten. Springer Berlin Heidelberg, Berlin, Heidelberg, 160 pp.

[46] Barakabitze, A.A., Ahmad, A., Mijumbi, R., Hines, A., 2020. 5G network slicing using SDN and NFV: A survey of taxonomy, architectures and future challenges. Computer Networks 167 (106984), 1–40.

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