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Contribution to the 5Guarantee project

Diffusion of 5G campus networks in Germany

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1 Introduction

The fifth generation of mobile communications (5G) is a radio standard that will be used for a wide range of digital radio services.[1] 5G offers the opportunity to significantly support the digital transformation of the economy and society in Germany. In parallel to public mobile networks, telecommunications services based on 5G will be realised in campus networks. The construction and operation of campus networks is currently taking place in a significant number of projects with an industrial background.

In the following, this article will highlight current developments in campus networks. The explanations are based, among other things, on findings from the 5Guarantee project, which is supported by the state of North Rhine-Westphalia.

2 Spectrum regulation in Germany with a view to 5G campus networks

Current situation

For the construction and operation of 5G campus networks, the usability of frequencies is essential. The Federal Network Agency recognised this at an early stage and implemented it in its frequency regulation. When assigning frequencies in the 3.6 GHz range, an innovative approach was taken to strengthen Germany as an industry location.[2] Not only mobile network operators could implement 5G services. Companies and/or institutions with the necessary expertise, conductivity and reliability were given the opportunity to apply for local frequency usage rights. The reserved area is in the 3.7 - 3.8 GHz frequency band.[3]

This innovative approach to spectrum regulation has prompted many national spectrum regulators in other European countries to follow suit.[4] In order to incentivise innovation for the deployment of 5G campus networks, as well as to achieve economies of scale and associated cost reductions, a broadly harmonised international use of spectrum for similar 5G services in the same frequency locations is important. Low-cost equipment for the deployment and operation of 5G campus networks will have a significant impact on the diffusion of 5G campus networks.

1 WIK discussion paper 488, No. 488 Flexibilisation of frequency regulation and the frequency plan (wik.org), last accessed 264.07.2023.

2 International Mobile Subscriber Identifiers (IMSIs) are needed to address terminal equipment in campus networks with mobile technology available today. The Federal Network Agency has implemented a demand-based number allocation procedure. (See https://www.bundesnetzagentur.de/DE/Fachthemen/Telekommunikation/Nummerierung/Campusnetze/start.html, last accessed on 26.07.2023.)

3 See https://www.bundesnetzagentur.de/DE/Fachthemen/Telekommunikation/Frequenzen/OeffentlicheNetze/LokaleNetze/lokalenetze-node.html, last accessed on 26.07.2023.

4 See https://www.wik.org/fileadmin/Aufsaetze/Entwicklung_von_5G-Campusnetzen_in_Deutschland_NuR_6_2021_275-281.pdf, last accessed 26.07.2023.

Complementary to the 3.7 GHz frequencies, the Federal Network Agency has opened the possibility of applying for 26 GHz frequencies for use in the context of 5G campus networks.[5]

Stakeholders are already expressing the need for further spectrum rights in connection with the pending standardisation of 6G. With relevance for campus networks, a need has been expressed in the 7-15 GHz range (between mid-band and mmWave)[6] and in the terahertz band (enabling very high data rates of several GB/s over short distances with high bandwidths).

3 The motivation for and the possibilities of setting up 5G campus networks

The main motivation for those interested in deploying 5G campus networks is the possibility of implementing "Massive IoT" / "Massive Machine Type Communication" and "Ultra Reliable and Low Latency Communication" with high data rates in the uplink and downlink. As a high-performance wireless technology, 5G is seen by business and science as a key technology for the digital transformation of value creation processes. The technical potential of cellular mobile technologies, and 5G, will enable a wide range of new, innovative applications in vertical markets, enabling users of radio technologies to increase their competitiveness. In intralogistics, for example, 5G campus networks will enable optimised logistics through driverless transport systems. Other concrete applications include development, remote maintenance and repair using augmented reality (AR)[7], or faster inventory taking using connected mobile devices and scanners.[8]

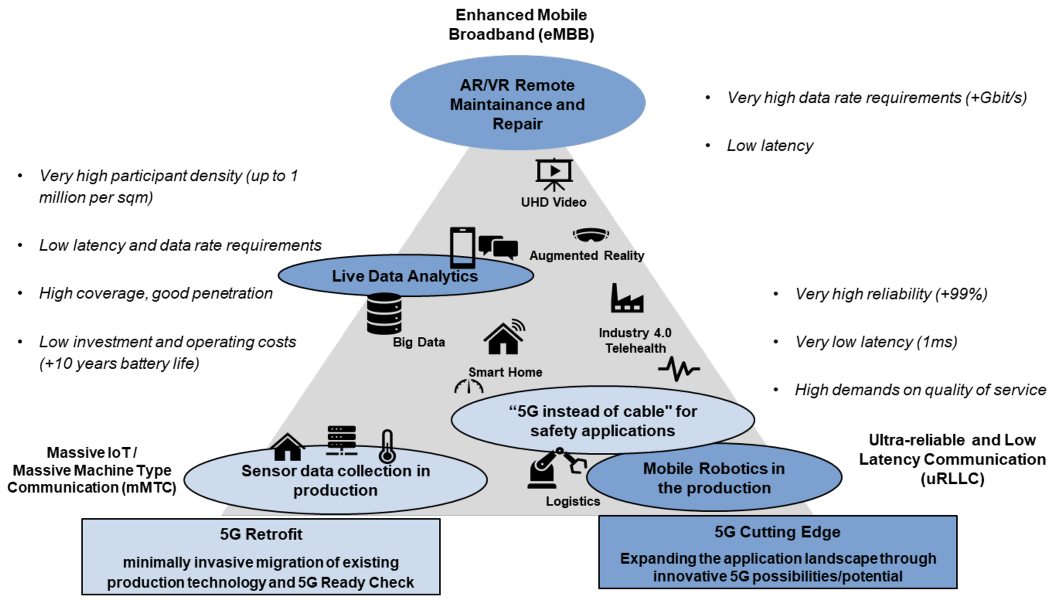
5 See https://www.bundesnetzagentur.de/DE/Fachthemen/Telekommunikation/Frequenzen/OeffentlicheNetze/LokaleNetze/lokalenetze-node.html, last accessed on 26.07.2023.

6 Due to the high bandwidth available, millimetre wave (mmWave) spectrum enables 5G data transmissions at Gbit/s speeds. Precisely aligned antennas are always required. This poses a challenge in mobile application scenarios.

7 For an explanation of AR and the distinction from VR (virtual reality), see What is Augmented Reality? Simply explained | Deutsche Telekom, last accessed on 26.07.2023.

8 For other possible fields of application, see, 5G campus networks: What's behind them and how they work (vodafone.de), last accessed 26.06.2023.

Figure 1 New applications through 5G campus networks



Source: 5Guarantee

5G is therefore a technology that can replace existing technologies and, due to its improved characteristics, can also be used to complement existing wireless technologies such as WLAN, (industrial) Ethernet and Bluetooth Low Energy applications. Instead of cable/fibre, 5G is also a way to achieve both greater flexibility in the use of robots in manufacturing and more mobile application options. However, this requires not only an appropriately designed 5G campus network, but also that all devices and people integrated into the process flow via the 5G campus network have appropriate 5G modules with which they can communicate.

A WIK survey of spectrum owners revealed that technical performance is the most important factor in adapting 5G for campus networks. In this context, high downlink and uplink data rates and low latency are cited as being significant. Currently, 5G use cases include remote control, video transmission, localisation, mobility, and AR/VR applications. In a transition phase to 5G, it is not surprising that 5G will initially be used primarily as a complement to existing communication technologies, for example to realise AR/VR (augmented reality/virtual reality)[9] transmissions, which will then be used to monitor and control processes.[10] In the long term, it is conceivable that 5G connectivity will replace alternative forms of connectivity for a wide range of applications to a much greater extent than in the past. Data sovereignty, independence from the public network, resilience, and

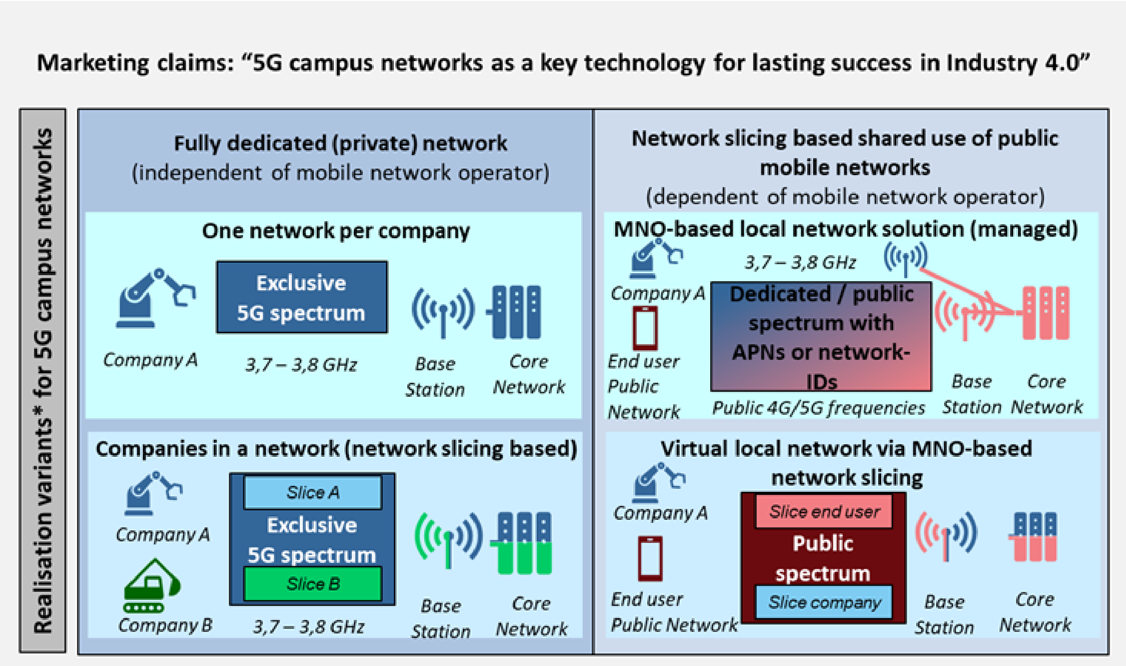
9 See 5G Retrofit of Machines for Real-Time Applications of Augmented Reality (oculavis.de), last accessed 26.07.2023.

10 See also https://www.bitkom.org/Presse/Presseinformation/Viertel-deutscher-Industrie-5G-Campus-Netze, last accessed on 26.07.2023.

scalability in the context of a 5G campus network are also important to users. The density of connections (devices/sq km) and energy efficiency will increase.

There are different alternatives for the deployment of 5G campus networks due to spectrum regulation and other institutional possibilities.[11]

Figure 2: Possibilities for the establishment of 5G campus networks



Source: 5Guarantee

According to a WIK survey of stakeholders, data sovereignty and data security are often considered very important in the context of 5G campus networks. The lower the number of interfaces to the outside world, the higher the level of data security. A network based on exclusive frequencies, managed largely independently by users on their own campus, without the involvement of third parties, takes these two aspects into account to a high degree.

4 5G Campus Networks – State of the art

The Federal Network Agency provides an overview of the current holders of frequency usage rights in the 3.7 - 3.8 GHz range. As of 17 July 2023, there are 331 frequency assignments.[12] These include many research institutions. The number of frequency

11 A video lecture on All you need to know about 5G campus networks - Ericsson, last accessed 26.07.2023.
12 The list of frequency holders can be found at Bundesnetzagentur - Regional Networks, last accessed on 26.07.2023.

users in the 26 GHz range is comparatively low at 17 (as of 17 July 2023).[13] The focus of applications and use is therefore currently on frequencies in the 3.7 GHz range, which have better propagation characteristics than higher frequency positions and require a less dense network infrastructure.

At present, the technical potential of 5G is being considered, tested, and evaluated mainly by larger companies, which usually have their own IT and R&D departments. These include companies such as BASF[14], Daimler[15], Siemens[16], Bosch[17], VW[18], BMW[19], Fraport[20] and Deutsche Messe[21]. The know-how required to implement a 5G network is more readily available in these companies than in small and medium-sized enterprises, which usually have to buy it in. Large companies also have greater financial strength. This enables them to purchase comparatively expensive and more powerful equipment from leading manufacturers for testing purposes or (in the future) for real operation. In addition, the potential rewards for such companies are higher than for smaller or medium-sized companies, provided they identify an application for 5G. The higher the volumes, the greater the potential cost savings. However, SMEs that want to use 5G modules in their own products in the short to medium term also have incentives to look at 5G in an operational context. To our knowledge, however, the use of 5G campus networks in SMEs is often not yet taking place, or if it is, it is very much focused on specific applications in real operations, e.g., for locating mobile devices such as forklifts or mini-robots, or for monitoring the wear and tear of milling machines. As a result, it is mainly field and test trials that are carried out.[22]

5 The importance of standardisation for the development of 5G campus network

The standardisation process will develop specifications for specific applications and services, which will form the essential basis for the development, production, and marketing of 5G hardware and software. The terminals (especially chipsets) currently on

13 The list of frequency holders can be found at Bundesnetzagentur - Regional Networks, last accessed on 26.07.2023.
14 See 5G campus network for BASF Schwarzheide plant (vodafone.de), last accessed 26.07.2023.
15 See Mobile network of the future: World's first 5G network for automotive production | Mercedes-Benz Group > Innovation > Digitalisation > Industry 4.0, last accessed 26.07.2023.
16 See Industrial 5G - Das Funknetz der Zukunft | Industrie | Siemens Deutschland, last accessed 26.07.2023.
17 See Bosch launches first 5G campus network - Bosch Media Service (bosch-presse.de) and Bosch Engineering sets course for automated construction site with 5G campus network - Bosch Media Service (bosch-presse.de), last accessed 26.07.2023
18 See On the way to the Smart Factory: Volkswagen tests 5G for production (volkswagenag.com), last accessed 26.07.2023
19 See 5G technology: BMW launches its 5G campus network in Lower Bavaria (hannovermesse.de) and Locating tools, machines and parts: BMW relies on 5G at Leipzig plant - computerwoche.de, last accessed 26.07.2023.
20 See Fraport and NTT build Europe's largest private 5G network at Frankfurt Airport, last accessed 26.07.2023.
21 See Hannover Messe: Siemens provides 5G campus network | FUENF-G, last accessed 26.07.2023.
22 Campus networks: Few industries have 5G frequency - Golem.de, last accessed 26.07.2023.

the market primarily support services that can be classified under the generic application area of "Enhanced Mobile Broadband". They do not yet support all the applications that will be possible with 5G, especially in the areas of Massive IoT (Internet of Things) and Ultra Reliable and Low Latency. The importance of 5G for industrial applications, for example, is increasing with the recently adopted Release 17[23] and the upcoming Release 18.[24] Here, the focus is shifting to the networking of machines and sensors, i.e., M2M (machine-to-machine) networking or IoT, which is also important for 5G campus networks. Energy efficiency will also be improved.

The importance of Release 17 for IoT applications is illustrated in the figure below.

Figure 3: Importance of Release 17 for IoT applications

- RedCap (Reduced Capacity) for 5G devices with reduced capacity, positioned between high-value eMBB services and low-complexity services based on LTE-MTC (Machine Type Communications) and NB-IoT, with higher transmission data than NB-IoT (Narrow Band - Internet of Things) but lower costs than multi-bit devices.
- Enhanced Dynamic Spectrum Sharing, which increases the number of terminals that can be served by using a secondary cell.
- Improvements in spectral efficiency and system capacity, support for URLLC in unlicensed spectrum environments, and measures to support real-time networks.
- Improving 5G positioning accuracy to 20-30 cm for specific use cases such as factory automation, as well as reducing latency to enable positioning in time-critical use cases and introducing new performance indicators to ensure the reliability and integrity of positioning functions.
- Expanding the ability to integrate end devices into Non-Public Networks (NPN) so that campus networks can be used in a similar way to public networks.
- Detection of edge functions in the network to dynamically route local application and data storage servers.
- Advanced side link communications, such as for V2X (Vehicle to X) applications in vehicles.
- Higher transmission speeds, better coverage, and lower power requirements for small data services (LTE-MTC, NB-IoT).
- Improvements in beamforming and MIMO (multiple-input, multiple-output);
- Support for multi-SIM devices.
- Extension of usable spectrum to frequencies above the existing mmWave range (24.25 to 52.6 GHz, "high band") up to 71 GHz.

Source: 5G Release 17 and 18: 3GPP gives go-ahead for 5G Advanced (fuenf-g.de)

It typically takes 2 years for the technical features to be implemented in available, potentially usable network equipment. The components currently available from network manufacturers therefore only partially support the applications that will be possible with

23 See Release 17 (3gpp.org), last accessed 26.07.2023.
24 See Release 18 (3gpp.org), last accessed 26.07.2023.

5G.[25] In the context of campus networks, however, this does not mean that innovative applications in the field of Industry 4.0 or intralogistics cannot be supported by 5G today. However, it does show that the technical potential of 5G will continue to grow, meaning that the development of 5G is still in its infancy. As a result, it will be several years before certain applications around URLLC or mMTC are available on the market and the full potential of 5G (including in 5G campus networks) can be fully developed.

Regarding 6G, the focus is on the following aspects.[26] The development of backward compatible solutions to protect the investment of industrial equipment in 5G (in some cases > 20 years):

- Flexible and modular hardware and software components that support customised, energy-efficient, and cost-effective applications.
- Further developments to integrate sensor technology to enable better use of infrastructure and use of additional bandwidth at higher frequencies, especially for campus networks, considering EMF exposure.
- Supporting requirements such as sub-millisecond latency in specific scenarios and high-precision positioning.
- The further development of open interfaces, architectures, and APIs (Application Programming Interface)[27], combined with consistent virtualisation of the entire network infrastructure, to enable highly modular and industry-optimised solutions.
- The integration of additional functionalities, such as sensors or image processing, to provide additional value to the manufacturing industry.
- Accelerating automation and digitalisation to improve resource efficiency in conjunction with the introduction of green technology in production.
- Accelerate automation and digitalisation to improve resource efficiency in conjunction with the introduction of green technology in production.

6 Current categorisation of communication links for IoT in the development of 5G campus network solutions

Unlike mass-market eMBB, the connectivity needs of industry are extremely diverse. Therefore, there will not be a single network configuration for 5G campus networks. In particular, the design of a public mobile network is not the benchmark for a 5G campus network. For example, the critical variable is not the download speed, but the upload speed that needs to be guaranteed for camera-based environmental monitoring. Latency requirements may also be much higher.

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25 Quotes for 5G campus networks from COCUS, for example, are currently (as of 03.02.2023) based on 3GPP Release 16, https://www.cocus.com/cocus-5g-campus-netz-deep-dive/, last accessed 26.07.2023.
26 See Position Paper - Our view on the Evolution of 5G towards 6G - 5G-ACIA last accessed 26.07.2023.
27 For an explanation, see What is an Application Programming Interface (API)? | IBM, last accessed on 26.07.2023.

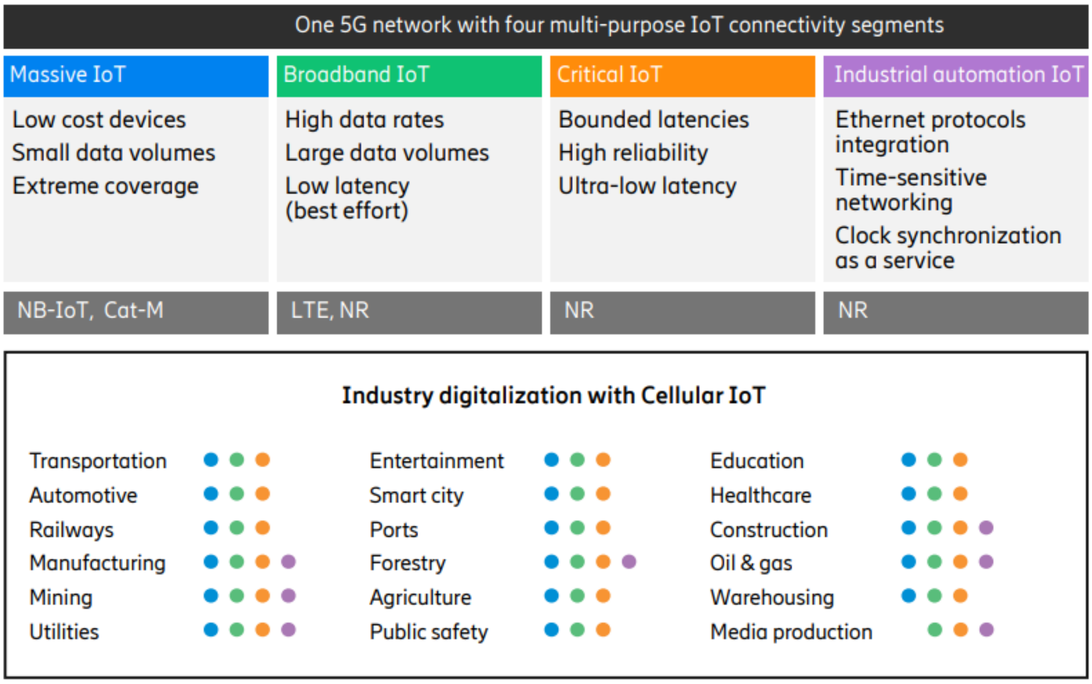
Ericsson sees four segments for campus network solutions:[28]

- *Segment 1:* ***Massive IoT***, where connectivity connects many (low-cost) devices characterised by low transmission bandwidths and long battery life. The IoT ecosystem is currently based on narrowband IoT (NB-IoT) and LTE-Cat-M.
- *Segment 2:* ***Broadband IoT***, where connectivity has higher data rates and lower latencies than Massive IoT, while enabling longer device battery life and better coverage for devices with a much wider bandwidth than Massive IoT devices. Based on a wide range of LTE device categories (LTE Cat-1 and above) in frequency division duplex (FDD) and time division duplex (TDD) bands, Broadband IoT has more than 500 million users worldwide. Broadband IoT is currently being used in vehicles, wearables, gadgets, cameras, sensors, and actuators.
- *Segment 3*: **Critical IoT connectivity**, providing time-critical communications for data transmission with specific latency targets and guarantees. Critical IoT connectivity will be introduced in all 5G bands together with the advanced time-critical communications capabilities of 5G New Radio. Typical time-critical use cases include cloud-based AR/VR, cloud robotics, autonomous vehicles, real-time fault avoidance, haptic feedback, real-time control and coordination of machines and processes.
- *Segment 4*: **IoT for industrial automation**, which enables the seamless integration of cellular connectivity into the wired industrial infrastructure used for advanced real-time automation. This includes the ability to integrate 5G systems with real-time Ethernet and time-triggered networks (TSN). These capabilities require 5G NR and 5GC. The IoT connectivity segments are designed to be cost-effective, frictionless, and future proof to accelerate ecosystem adoption and minimise total cost of ownership (TCO).

28 The following is taken from Ericsson's white paper (see 04292022-5g-spectrum-for-local-industrial-networks.pdf (ericsson.com)), last accessed 26.07.2023.

Each IoT segment has a set of connectivity requirements.

Figure 4: Performance requirements of different IoT applications on the 5G campus network



Source: Ericsson, April 2022

Depending on the type of application, different frequency bands and technologies can be used to transmit IoT services.

7 Proliferation of 5G campus networks in small and medium-sized enterprises of economic importance

At 99.4%, SMEs (small and medium-sized enterprises) make up most companies in Germany.[29] Around 400,000 of them are classified as medium-sized enterprises. By comparison, the number of large companies is 16,000. If 5G campus networks are to be a full success story in Germany (i.e., if they can initiate a 5G ecosystem), it is essential that campus networks are also deployed in larger numbers in this enterprise segment.

In the case of large companies, it can be assumed that they have the necessary resources to make use of 5G for their processes or production, provided that 5G offers added value. These companies also can bear the costs of a learning curve. It remains to be seen whether SMEs can also benefit from the knowledge and experience gained.

29 See https://www.destatis.de/DE/Themen/Branchen-Unternehmen/Unternehmen/Kleine-Unternehmen-Mittlere-Unternehmen/aktuell-beschaeftigte.html, last accessed 26.07.2023.

Manufacturers of network equipment,[30] production and manufacturing equipment, etc. can incorporate the knowledge gained from working with large companies into their offerings and the corresponding network and equipment design for SMEs.

SMEs are currently reluctant to test and deploy 5G campus networks in real-world conditions. The high cost of setting up a 5G testbed for subsequent deployment and the current lack of availability of software and hardware are seen as major barriers to 5G in the context of campus networks. In addition, there is still a great deal of uncertainty when it comes to exploring possible applications and subsequent implementation. According to the information available to us, the administrative effort required to clarify legal issues relating to data use within the company also appears to be not insignificant. Expert discussions and experiences from pilot projects show that users want "plug & play"[31] components both on the network side and on the application side. Turnkey products that are compatible with products from other manufacturers where appropriate will make an important contribution to the acceptance of 5G and digital value creation processes in general in the enterprise environment. Flexible network solutions that can be precisely configured to meet specific needs are required.

The interoperability between the different types of equipment is a key factor in this respect. The extent to which open RAN[32] network configuration or proprietary solutions (network components from a single source) will prevail will emerge as part of the market process. The same applies to the implementation and location of computing power in a company's 5G campus network. Whether the computing power is provided in the terminals themselves, in a near-edge cloud or in a far-edge cloud will certainly depend on the use case and the IT expertise available in the enterprise.

The size of companies and their resources also suggest that in the future there could be "high-end solutions" (cloud on-premises, specialised applications, first movers) and "low-cost solutions" (cloud off-premises, standardised solutions). Network technologies that increase the complexity of 5G campus networks are a clear barrier to entry, especially for SMEs. Instead, more work should be done to simplify technical solutions.

In addition to a diverse and flexible range of network technologies for deploying 5G campus networks, the range of terminals is also crucial. On the equipment side, easy to integrate modules such as chipsets must be available. In parallel, it must be possible to

30 Providers of 5G network infrastructure in Germany include, for example, Siemens: Industrial 5G | Industrial Communication | Siemens Germany; Nokia: 5G standalone campus network for robots | FUENF-G; MECsware: Company Profile - MECSware; Cocus: COCUS | 5G Campus Network; KMU Campusnetz | Das private 5G Campusnetz | becon GmbH; and last but not least Ericsson (for example, also in cooperation with Mugler (5G Campus Networks: Mugler and Ericsson deepen partnership (industrie.de)). Mobile network operators are also making 5G campus network offers for verticals.

31 See https://de.wikipedia.org/wiki/Plug_and_Play, last accessed 26.07.2023.

32 On this, see What is Open RAN? (ip-insider.de), last accessed on 26.07.2023 and No. 478: Open RAN and SDN/NFV: Perspectives, Options, Restrictions and Challenges (wik.org), last accessed on 26.07.2023.

integrate existing production and manufacturing infrastructures into a 5G campus network with minimal effort by upgrading them with 5G modules (5G retrofit).

8 Conclusion

It is still early in the life cycle of 5G campus networks. The widespread implementation and use of advanced, high-performance wireless technologies cannot reach an extremely high level in a short period of time. Rather, a continuous process of development and adaptation can be expected. The full potential will only be realised with the further standardisation of 5G/6G.

One of the key challenges in implementing 5G campus networks is to design flexible 5G network solutions that are tailored to the specific needs of businesses, while reducing the overall complexity of the technical implementation.

The exact specification of the applications in a company and the comparison with alternative communication transmission solutions is a key aspect. If enterprises want to deploy 5G campus networks, they need to know in advance what applications they will use them for or what future services they want to deploy in the medium term. Can 5G replace existing forms of communication via cable or other wireless technologies, or is 5G additive or complementary to existing transmission technologies?