Use of 5G Technology in Manufacturing Processes and Systems

Miha Pipan, Marko Šimic, Leon Vončina, Niko Herakovič

Abstract:
The advent of 5G technology opens up new opportunities for universal connectivity in manufacturing processes. This technology has the potential to play a crucial role in industrial environments by enabling faster, more reliable and more flexible connections between different subsystem of manufacturing systems. In the LASIM lab, we implemented 5G technology in the SMART FACTORY demo centre to demonstrate its potential. Our focus was to achieve better connectivity and efficiency in industrial environments to increase flexibility and agility of manufacturing systems, smart maintenance and logistics processes to achieve connectivity and efficiency in industrial environments. We conducted experimental analysis of 5G connectivity with different industrial subsystems and communication protocols to evaluate the universality and applicability of current 5G technology for implementation in manufacturing environments.

Keywords:
5G, connectivity, manufacturing systems, compatibility testing, communication protocols

1 Introduction

To understand the potential of 5G technology, we have conducted thorough tests in the LASIM Demo Center SMART FACTORY (DCSM) laboratory. These tests were conducted with specific industrial applications that represent a step towards a more connected and agile industrial environment. We tested different industrial assets such as industrial robots, collaborative robots, smart warehouses, smart manual assembly stations and other industrial and research subsystems and their communication protocols. During these tests, we examined the speed of data transfer, the stability of the connection and compatibility with industrial protocols, which gave us a comprehensive insight into the potential of 5G technology for industrial applications. By combining technological and practical aspects of 5G implementation, we are opening the door to the future of connected and efficient manufacturing.

2 Potential Applications of 5G Technology in Industry

Batch production processes are crucial for the efficient manufacture of various subsystems and end products and have the potential to be further optimized by the ongoing development and introduction of 5G technology. Modern manufacturing systems and processes require continuous adaptation and optimization to achieve maximum productivity, and advances in 5G technology promise fast and reliable data transmission and thus an increase in operational efficiency [1].

Improving the flexibility and agility of systems remains central to achieving these goals. While 5G technology offers considerable potential because of its speed, stability and latency, its current use is still limited in some areas. Nevertheless, ongoing advances are paving the way for faster responses to changing market demands and improved adaptability of manufacturing processes [2].

Smart maintenance practices, including real-time monitoring of machine performance, will benefit from advances in 5G technology. While the full potential of 5G-enabled smart maintenance is yet to be realized across the board, advances in this area should help prevent unexpected breakdowns and reduce equipment downtime. As current 4G and even 5G networks are still geared towards mobile users who require higher download speeds and lower upload speeds, providers need to implement real-time slicing to enable fast response times and equal upload and download speeds [3].

For both external and internal logistics processes, the integration of technologies such as automated guided vehicles (AGVs) and autonomous mobile

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robots (AMRs) can leverage the capabilities of existing connectivity infrastructure while preparing for future improvements through 5G technology. As 5G technology becomes more widespread and matures, improved efficiency in freight transportation can be expected. In this context, numerical tests were conducted on the use of 5G technology to control AGVS or AMRs in real time using private and campus 5G networks to see what latencies can be achieved in these 5G networks for the transmission of time-critical and sensitive data in the production environment. All researchers concluded that further studies on the cost-effectiveness of 5G deployment are lacking and need to be supplemented by a comparison of 5G with Wi-Fi to enable an evaluation [4].

Warehouse operations, especially those that rely on real-time product tracking, will benefit from advances in 5G technology. Although widespread adoption of 5G-enabled inventory control is still underway, ongoing developments indicate significant potential for improvement. The literature review describes various prospective applications of 5G technology in both internal and external logistics, which offer numerous opportunities to improve material and information flows for more efficient, intelligent and sustainable logistics and supply chain management systems. Nevertheless, the industrial applications of 5G technology in the logistics sector are still sparse [5].

Real-time guidance of workers and tracking of work processes, while promising, are currently limited in their application due to the evolving nature of 5G technology. Nevertheless, ongoing advances in connectivity solutions promise to improve the efficiency and accuracy of manufacturing processes [6].

The stability and speed of the connectivity provided by 5G technology is becoming increasingly important for business operations. While challenges in achieving ubiquitous coverage and reliability remain, ongoing efforts to expand and improve 5G infrastructure are expected to increase market competitiveness and agility. Currently, most research efforts are still in the early stages, so further investigation is required to achieve advanced goals. Possible future research directions include: (1) the operational mechanisms of a digital twin in manufacturing, (2) methods for managing and analysing Big Data, and (3) the integrated application of edge computing and cloud computing in manufacturing, supported by 5G technology [7].

3 Experimental setup and Methods

With the aim of helping companies understand 5G technology and presenting practical examples of its use, we have upgraded the DCSM with 5G technology with the help of our partner Telekom Slovenije d.d. The DCSM has several manufacturing control nodes (Node 1 – 8, Robot 1, Robot 2 and cobot)

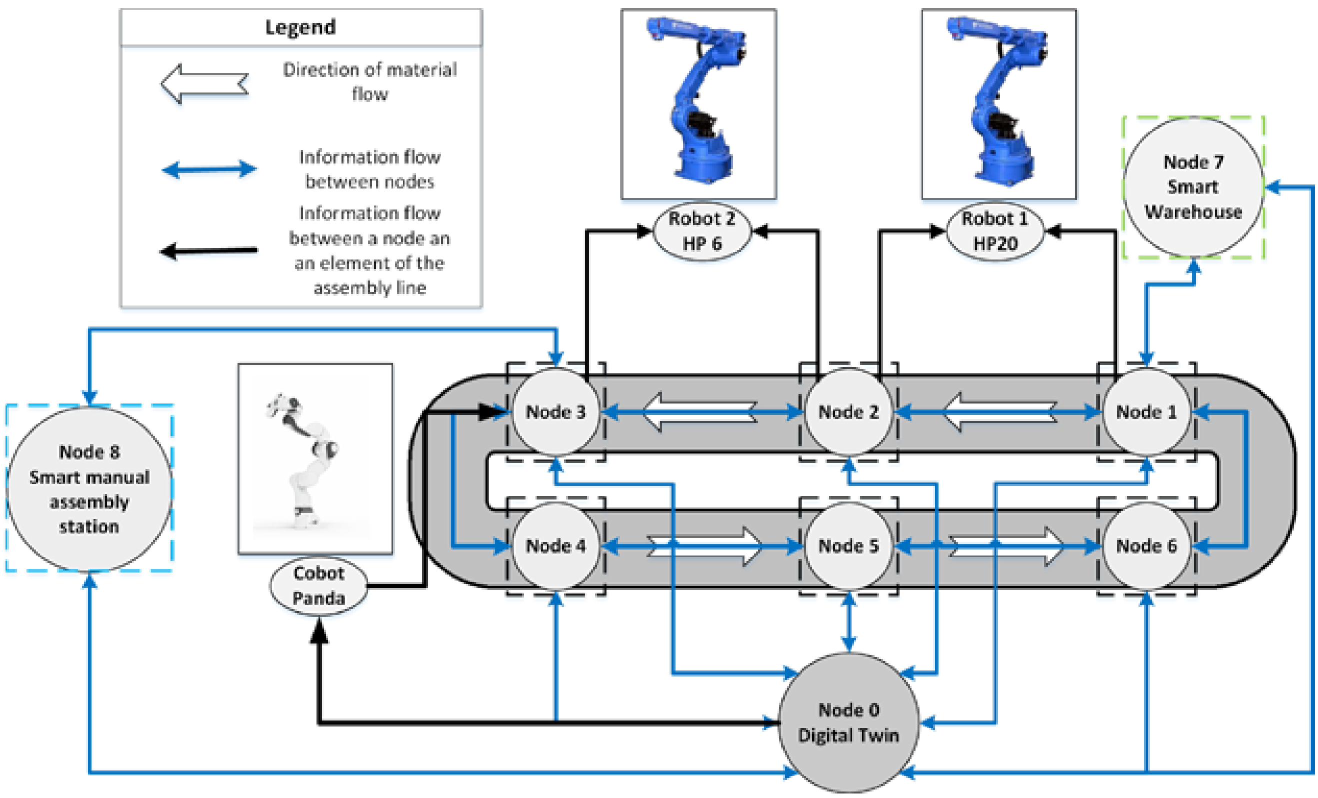

Figure 1 : *Demo Center SMART FACTORY (DCSM) subsystems and its interconnections via LAN network*

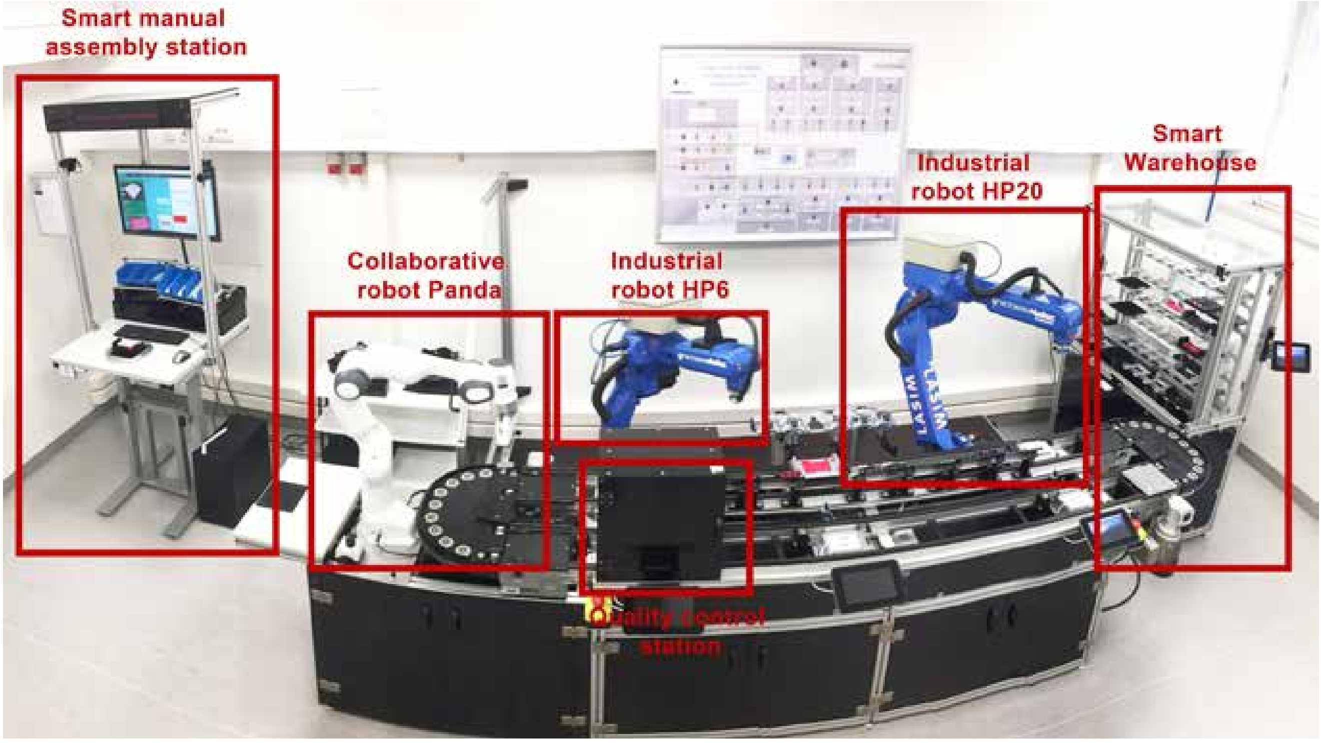

Figure 2 : *Subsystems being tested over 5G network (excluding PC with Digital Twin)*

that were connected to the manufacturing resources via a LAN network to enable communication between local and the global digital twin (Node 0). Once the local 5G network has been installed, this enables the individual subsystems (Nodes) to communicate via LAN, Wi-Fi or 5G networks (*Figure 1*). Each manufacturing node represents an edge computing device that has its local digital agents for communication, data collection, decision making and control of manufacturing resources.

To test the compatibility of different DCSM manufacturing subsystems from industry and research perspective, we selected the subsystems that are based on different communication protocols and work over a LAN network. The selected subsystems are shown in *Figure 2*.

The 5G network has also provided us with a test site, which we are using to test the characteristics of the 5G network to see if it meets the necessary basic requirements such as upload and download speed, latency, jitter and the like [8]. The 5G network was installed by our partner Telekom Slovenije d.d. and operates in non-standalone mode (NSA), which means that it uses the 4G network for connecting the devices and the 5G network for data transmission. The following base station equipment is installed in the demo center (it is set up on channel N78, i.e. in the 3.5 GHz band):

- ERRICSSON radio system RAN 6507,
- ERRICSSON 5G-network cell,
- ERRICSSON 4G-network cell.

During the implementation phase, we conducted experimental tests of the installed 5G network with different IT tools to decide whether the installed 5G network is sufficient for industrial and our use. In order to conduct experiments on the compatibility of industrial and research productions with the 5G network, we had to analyse which communication protocols and communication ports are used in each individual device. The selected devices with their communication protocols and connections are listed in *Table 1*:

The connectivity of each selected subsystem to the installed 5G network was based on its connectivity. On this basis, we used two different 5G modems (all SIM modems are set to provide the static IP of the 5G modules in the network):

- Teltonika Networks TRB500 gateway (connects directly to LAN port of industrial subsystems),
- QUECTEL RMU500-EK (connects via USB port).

In cases where the selected manufacturing subsystem only has a LAN connection, we have used a TRB500 modem. In our cases where the manufacturing subsystem has a USB connection, we used the RMU500-EK as no additional tasks such as port forwarding and communication debugging are required after connection. Therefore, the TRB 500 was used on both the HP6/HP20 industrial robots and the Collaborative robot Panda. Both 5G modems used support the 5G NSA mode, which is currently installed in the DCSM.

Table 1 : Subsystems used for 5G module upgrade experiment

Name	Manuf.	Connectivity port	Internet protocol	Communication protocols and ports
Industrial robot HP20 [9]	Motoman	LAN	UDP and TCP	http (80), AUI (3501), SNMP (161 and 162), ssh (22)
Industrial robot HP6 [9]	Motoman	LAN	UDP and TCP	http (80), AUI (3501), SNMP (161 and 162), ssh (22)
Collaborative robot Panda [10]	Franka Emica	LAN	TCP	Modbus (502), https (8080)
Smart Warehouse	Laboratory LASIM	LAN / USB	TCP	OPC UA (4840), MQTT (1883)
Smart manual assembly station	Laboratory LASIM	LAN / USB	TCP	OPC UA (4840), https (8080)
PC with Digital Twin	Laboratory LASIM	LAN / USB	TCP	OPC UA (4840), Modbus (502), https (8080), ssh (20)
Quality control station	Laboratory LASIM	LAN / USB	TCP	OPC UA (4840), https (8080)

4.1 Communication testing protocol

The first part of the test consisted of checking the data transmission speed with 5G modems and performing a comparative analysis with the current LAN and Wi-Fi network used in the DCSM. The test was performed using the iperf3 tool (network performance measurement and tuning tool), which tests the maximum download and upload speed of the network between server and client using the TCP or UDP protocols and their different settings. We used the TCP protocol with open 10 parallel streams, which gave the best performance in all different networks (LAN, Wi-Fi and 5G) [11].

The second part of the experiment was to test the connectivity in several steps to set up the devices and 5G modems correctly:

- **STEP 1:** Connecting the 5G modem to the device.
- **STEP 2:** Setting up the device to ensure that communication between the 5G modem and the device is established and that the IP of the device and the IP of the 5G modem are compatible. In the case of the TRB500 modem, this means that it must be set to pasture, bridged mode or even port forwarding to achieve connectivity. In the case of the RMU500-EK, the correct IP is automatically defined after installing all drivers (different for Linux and Windows).
- **STEP 3:** Checking the availability of the industrial device in the 5G network by running ping commends with the target IP of the device.
- **STEP 4:** Connecting to the device with any protocol and check the connectivity status.
- **STEP 5:** Operating the device in run mode. This means that we used robots to perform pick & place operations, a smart manual assembly station was used to guide the worker in his assembly tasks, and other devices were used to check all their functions controlled by internal algorithms and the global digital twin.

5 Results

The basic download and upload speed test was carried out using the iperf3 tool. Since the toll requires a server and a client to perform the measurements and we wanted to test the maximum possible download and upload rates, we used the public iperf3 server as the server and our PC with the two 5G modems as the client. We performed tests over LAN, Wi-Fi and 5G network, each lasting 10 minutes. The test time of 10 minutes was used to get a good average value of the speed, as this fluctuates. *Figure 3* shows the download speed results for the TRB500 gateway connected to the PC with Digital Twin.

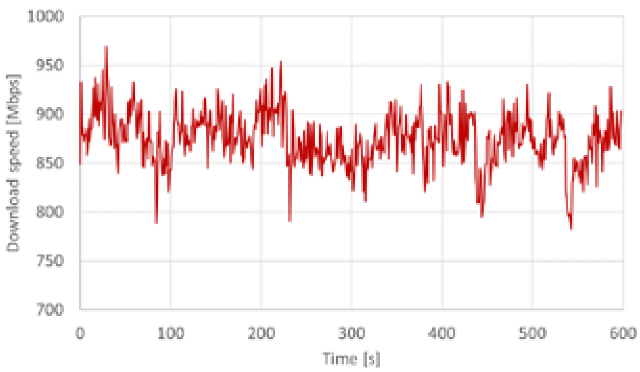

Figure 3 : *Results of iperf3 tool download speed testing for TRB500 gateway connected to PC with Digital Twin*

The analysis of data transfer speed with LAN, Wi-Fi and 5G network is shown in Figure 4. We must note here that the download speeds of 5G networks come close to and can exceed Gigabit Ethernet connections when using a cell phone, for example. When using the TRB500 5G gateway, the

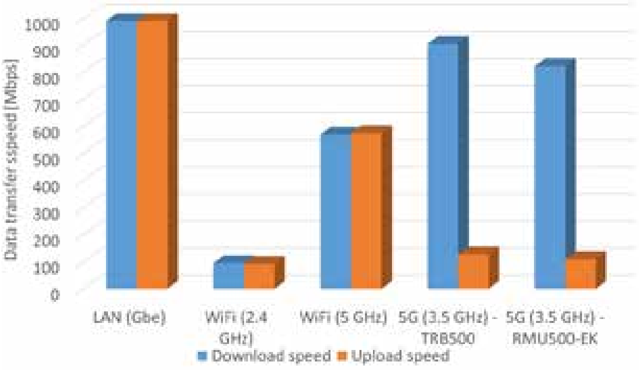

***Figure 4 :** Results of iperf3 download and upload speed test over LAN, Wi-Fi and 5G network*

bottleneck is not the 5G network, but the Gigabit Ethernet connection between the 5G modem and our DCSM devices. On the other hand, the upload speeds are more in the range of Wi-Fi at 2.4 GHz. The reason that download speeds are much higher than upload speeds is that the 5G network is mainly designed to support mobile users, while the majority of users do not produce data that needs to be sent, but download large amounts of data (video streaming, games and social networks).

After the initial testing of data transfer speed, we conducted 5 STEP connection experiment on all chosen equipment. The results of 5 step connection process and results are presented in Table 2. We successfully achieved stable connectivity, enabling all subsystems to operate under control over the 5G network. Using the QUECTEL RMU500-EK to connect devices to 5G required no special setup. The installation of drivers and setting up the connection was sufficient.

The collaborative robot was connected via the TRB500 5G gateway using the "bridged mode" settings, which sets the robot controller to the same IP address as the gateway and then forwards the data only to the required ports.

The most difficult part was connecting two Yaskawa industrial robots (HP6 and HP20 with NX100 controller) to 5G network. The reason for this is that the robots' controllers are 20 years old and are not directly compatible with the TRB500 gateway (they cannot be used in "bridged" or "pass-through" mode). The only way to establish a connection is to set the robots to their IP addresses (192.168.1.101) and their default gateway IP addresses (192.168.1.1) along with IPv4 netmask (255.255.255.0) directly in the module and with that bypass the modem interface IP (169.254.4.1). The presented procedure is important since many companies have similar old robots and controllers and would like to upgrade the systems with 5G. Furthermore, using the NAT setting of the TRB500 gateway and set up "port forwarding" for all ports used by the robot controller software and the NX100 robot controller. After this step, stable communication is achieved. We would also like to point out that when using the TRB500 5G gateway during the testing and device is visible in 5G network, the "ping" test of device availability is questionable as you might get a response from the TRB500 gateway and not from the robot controller or PLC itself (if not in "bridged" or "pass-through" mode), this is why in our case "port forwarding" was essential.

***Table 2 :** Results of testing steps for each tested manufacturing subsystem*

Name	5G modem	Connecting (STEP 1)	Setting (STEP 2)	Ping test (STEP 3)	Com. test (STEP 4)	Work test (STEP 5)
Industrial robot HP20	TRB500	Successful	Successful *	Successful **	Limited	Successful
Industrial robot HP6	TRB500	Successful	Successful *	Successful **	Limited	Successful
Collaborative robot Panda	TRB500	Successful	Successful*	Successful**	Successful	Successful
Smart Warehouse	RMU500-EK	Successful	Successful	Successful	Successful	Successful
Smart manual assembly station	RMU500-EK	Successful	Successful	Successful	Successful	Successful
PC with Digital Twin	RMU500-EK	Successful	Successful	Successful	Successful	Successful
Quality control station	RMU500-EK	Successful	Successful	Successful	Successful	Successful

* Tried different modes to find correct one for industrial robots connected to TRB500 (NAT with port forwarding, Bridged, Pass-through).

** Ping testing of industrial robots and collaborative robot connected to TRB500 is questionable since the ping response can be from modem and not the robot itself.

6 Discussion

The integration of 5G technology in the LASIM Demo Center SMART FACTORY offers considerable potential for improving industrial applications. Our experiments with industrial robots, collaborative robots, smart warehouses and manual assembly stations have shown that 5G networks can achieve superior download speeds, often matching or exceeding Gigabit Ethernet. This performance supports high-bandwidth applications such as real-time data analytics and digital twin implementations. However, upload speeds were closer to those of Wi-Fi, indicating a current limitation in symmetrical data transmission, which is essential for some industrial applications.

Challenges were identified when integrating legacy industrial subsystem into 5G networks. The Yaskawa robots, for example, required specific network configurations, indicating the need for careful planning when retrofitting legacy systems. Various 5G modems also highlighted practical aspects of connectivity, with some requiring more complicated configurations than others. The 5G network operating in non-standalone (NSA) mode with a 4G backbone offered improvements in data transfer rates and latency, but indicated that further improvements are required to realize its full potential.

Overall, while 5G technology is promising in terms of improving operational efficiency, current limitations in upload speeds need to be overcome and compatibility with existing systems needs to be ensured for widespread adoption.

7 Conclusion

The experiments at the LASIM Demo Center SMART FACTORY illustrate the transformative potential of 5G technology in an industrial environment. 5G networks can provide superior download speeds, enabling high-bandwidth applications that are critical to modern manufacturing. However, limitations in upload speeds and the complexity of integrating legacy subsystem present challenges.

Despite these hurdles, the benefits of 5G (higher data transfer rates and lower latency) can significantly improve real-time monitoring, machine control and operational efficiency. These findings provide a roadmap for future deployments and underscore the need for advances in network infrastructure and device compatibility.

In summary, while the use of 5G in industrial environments is still in its infancy, our findings are promising. They point to areas where further research is needed, particularly in achieving symmetrical data transmission rates and seamless integration into existing systems. With continued progress, 5G technology has the potential to revolutionize manufacturing and make processes more connected, efficient and responsive to market demands.

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Uporaba tehnologije 5G v proizvodnih procesih in sistemih

Razširjeni povzetek:
Članek predstavlja celovito raziskavo o potencialu tehnologije 5G v kontekstu industrijskih aplikacij, ki je bila izvedena v laboratoriju LASIM Demo Center SMART FACTORY (DCSM). Raziskava je bila osredotočena na testiranje in preizkušanje različnih vidikov uporabe tehnologije 5G v industrijskih okoljih, pri čemer so bile izvedene temeljite analize hitrosti izmenjave podatkov, stabilnosti povezave ter združljivosti s komunikacijskimi protokoli. Namen študije je bil razumeti, kako lahko tehnologija 5G prispeva k izboljšanju učinkovitosti, povezanosti in agilnosti v proizvodnji ter industrijskih procesih.

V eksperimentalnem delu raziskave so bili preizkušeni različni industrijski sistemi, kot so industrijski roboti, sodelujoči roboti, pametna skladišča, pametne ročne montažne postaje in druga industrijska oprema. Preizkusi so potekali v laboratorijskem okolju DCSM, kjer so bile analizirane ključne lastnosti 5G-omrežja v industrijskih pogojih, kot so hitrost prenosa podatkov, stabilnost povezave ter združljivost s specifičnimi industrijskimi protokoli.

V sklopu raziskave je bila izvedena tudi namestitev 5G-omrežja v laboratoriju DCSM, kar je omogočilo komunikacijo med različnimi industrijskimi komponentami prek LAN, Wi-Fi ali 5G- omrežij. Tako je bila ustvarjena infrastruktura za testiranje in analizo združljivosti različnih industrijskih naprav z 5G-omrežjem ter njihovo povezljivost v realnem industrijskem okolju.

Pomemben del raziskave je bil preizkus učinkovitosti in stabilnosti povezave med 5G-omrežjem ter različnimi industrijskimi napravami. Preizkusi so vključevali primerjavo hitrosti in stabilnosti povezave med 5G-omrežjem ter obstoječimi LAN- in Wi-Fi-omrežji, kar je omogočilo celovit vpogled v prednosti in izzive uporabe tehnologije 5G v industriji.

Na podlagi rezultatov raziskave je bilo ugotovljeno, da tehnologija 5G ponuja velik potencial za izboljšanje operativne učinkovitosti, povezanosti in agilnosti v industrijskih okoljih. Kljub temu pa so bili izpostavljeni tudi nekateri izzivi, kot so potreba po nadaljnjih raziskavah in razvoju ter zagotavljanje združljivosti s specifičnimi industrijskimi protokoli.

Končni zaključki raziskave so, da je tehnologija 5G ključna za prihodnost industrije in da lahko pravilna implementacija in uporaba te tehnologije prispevata k večji produktivnosti, učinkovitosti ter konkurenčnosti industrijskih procesov.

Ključne besede:
5G, povezljivost, proizvodni sistemi, testiranje združljivosti, komunikacijski protokoli

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