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Scope of Private 5G and Edge Computing for Manufacturing Industry 4.0- A Review

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Abstract: Manufacturing industry is moving towards new advances in Operational Technology, Information Technology & their integration, which improve overall productivity of the manufacturing process, quality of the ultimate product delivered and reduce cost of production which suggests that manufactures are looking to enhance efficiency of the processes of the manufacturing value chain from sourcing of stuff to final product delivery and long-term service of the delivered product by the implementation of machine vision, AI and advanced robotics technology and interconnectivity of them to make new use-cases and improved commercial outcomes. Current systems usually depend upon wire-line technologies to attach sensors and actuators, but new use cases like moving robots or drones demand a better flexibility on communication services where 5G is best suited to deal with these new requirements. The demands in Manufacturing sector and more generally, the Industrial Internet of Things (IIoT) has been one among the driving verticals for the planning and development of latest 5G concepts and technologies. In this study, we are exploring different aspects of manufacturing Industry 4.0 in terms of 5G and states it current implementation status and analyses the gap between current manufacturing Industry and therefore the predicted future manufacturing Industry to beat the shortcomings of current communication technologies.

Keywords: Industry 4.0, manufacturing Industry 4.0, Cyber-physical system, IoT, Industrial Internet of things, Future Factory, 5G, industrial communication.

1. Introduction

Manufacturing has changed over generations, from the days of handcrafted goods to the adoption of water and steam powered machines, mass manufacturing, electronic automation, and beyond. During the pandemic, structural challenges in the industry were amplified as manufacturers tried to maintain operations safe and manage supply chain disruptions. Globally, there are 14.5 million industrial establishments. This comprises 10.7 million industries, 3.3 million warehouses, and 0.5 million oil and gas fields, as well as 50 thousand transportation and ports, ten thousand military bases, 54 thousand mines, and 263 thousand hospitals and labs. Put together they hold more than billion varieties of assets. Manufacturing Industry 4.0 offers a chance to maximise the value of $4.5 trillion assets. Only 3% of factory data is used for Industry use cases, one of the main causes is a lack of suitable and dependable industrial network infrastructure. The Network Infrastructure, which serves as the backbone and is the single most important aspect for manufacturing process empowerment, is a critical component in achieving the industrialization of future manufacturing solutions. Manufacturing Industry 4.0, which goes beyond simple connectivity to communicate, analyse, and use acquired data to drive additional intelligent actions, is today's benchmark for organisations to keep up with. Because of the important qualities technology holds for distinct use cases, we predict that there will be a shift towards wireless networking technology (Wi-Fi, 4G LTE, 5G) as well as the mobilisation of superior wired networks in place across different layers in the Manufacturing IT-OT arena. Factory data is essential to any successful manufacturing Industry 4.0 initiative. Little optimization can happen unless data is collected from numerous sources and supplied to the relevant application at the right time. Furthermore, production equipment contains a wealth of useful information. The productivity of their systems has been observed to grow by 17-20% [1] with improved machine utilisation and energy usage optimization by manufacturing systems in newly created manufacturing industries that are adopting more intelligent and smart technology.Manufacturing Industry 4.0 is a German initiative that has been adopted by many countries as the next-generation technology for revolutionising the industrial sector. It combines IoT, analytics, additive manufacturing, robotics technologies, artificial intelligence, advanced materials, augmented reality, Cyber-Physical Systems (CPS), digital manufacturing, smart manufacturing technologies, 5G mobile communications, big data processing, data analytics and system integration, simulation and supporting them with 5G wireless infrastructure has profound advantages in delivering faster speeds and highly reliable connectivity, the network offers the promise of factories that could be safer, more efficient and environmentally friendly than ever before [2].Plants can be wireless, allowing connected gadgets to be moved and manipulated more readily. 5G will also be utilised to support apps for wearable and mobile devices focused toward quality control and worker safety. According to a recent economic analysis commissioned by Qualcomm Technologies, Inc., 5G in manufacturing might result in "a direct GDP impact of up to $159.2 billion and as many as 1.2 million employment" in the United States. The breadth of 5G's features has had a seismic impact; the network delivers quicker download speeds, more seamless data sharing, and increased network capacity than prior generations. Manufacturers compete in innovativeness, quick response time to market changes, cheap cost, and reliable products to meet end customer wants, and this competition eventually leads to the digitalization of processes and cyber-physical control in manufacturing plants to commercial outlets. 5G enables the deployment of autonomous and semi-autonomous machines, sensors embedded in physical infrastructure and objects, quicker data processing, and even mixed reality applications on factory floors. Some of the world's most powerful countries, which have a significant impact on the global economy, have already announced their plans for next-generation industries. China has also unveiled a 2025 strategy dubbed "Made in China 2025" as well as an internet plus programme to propel the manufacturing industries forward [3]. In manufacturing, the value of these 5G-enabled services and functionalities is enormous. Automation can help to streamline the manufacturing process and free up time for staff to be more productive. This paper briefly describes the scope and necessity of smart manufacturing systems, as well as the smart manufacturing system's future directions with the arrival of 5G, which will enable greater and better industrial automation adoption by enabling its many elements networking capabilities.

2. Background of modern manufacturing

Since its beginning at the start of the industrial revolution in the 18th century, modern industry has come a long way. For centuries, most products, including as weapons, tools, food, clothing, and housing, were made by hand or with the help of labour animals. With the development of manufacturing technologies around the end of the 18th century, this began to change. After that, it was a steep uphill journey to the next industrial era, Industry 4.0. We'll go through the big picture of this evolution here.

2.1 Evolution of Industrial Revolution 4.0:

Manufacturing has a long history, from man-made to man-and-machine-made, and to comprehend Industry 4.0, let us take a look at the evolution of manufacturing and the industrial sector in general:

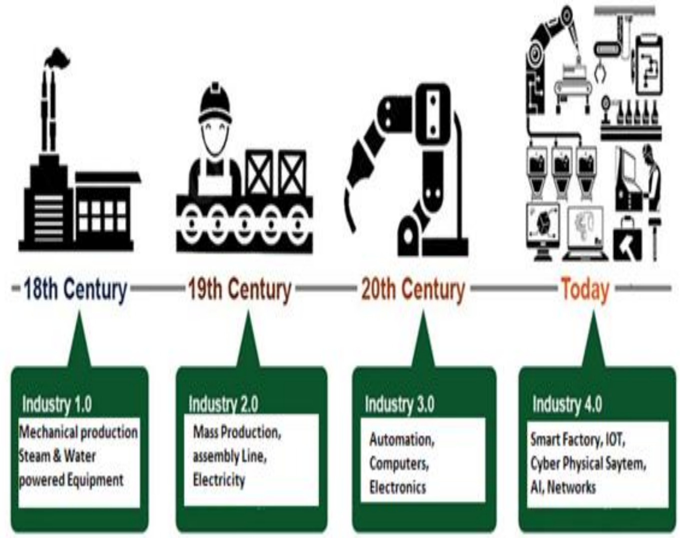

Figure1. Evolution of manufacturing Industry 4.0

a) *First Industrial Revolution 1.0 (1760–1840):* The first industrial revolution began in the 18th century with the use of steam power and the mechanisation of industry. 'Industry 1.0' began with the invention of steam engines. It had a huge impact on agriculture, and the term "factory" became commonly used as a result. Revolution 1.0 represents the shift from manual to machine manufacture through the utilisation of steam and water power. The 'Textile Industry,' which was the first to use the processes, specified in Industry 1.0, was one of the industries that benefited tremendously from this breakthrough[4]. The steamship and the steam-powered train, which allowed people and goods to travel large distances in less time, ushered in even more significant changes.

b) *Second Industrial Revolution 2.0 (1870 – 1914):* The Second Industrial Revolution began in the 19th century with the discovery of electricity and assembly line production[4]. Industry 2.0 is referred to as the 'Technological Revolution.' Large railroad networks and the telegraph, which allowed for faster information and people exchange, made it possible. Industries were able to create modern manufacturing lines because to the use of 'Steel' and the arrival of 'Electricity.' Factory electrification significantly reduced production costs. Steel was mass-produced in vast numbers, making it easier to introduce trains into the system. The rise of 'Mass Production' as a basic mode of production in general was a defining feature of this period. It's an era of rapid economic expansion and increased productivity. However, because many factory workers have been displaced by automation, it has a negative impact.

c) *Third Industrial Revolution 3.0 (1950 – 1970):* The industrial revolution 3.0 occurred in the late 20th century, following the two world wars. The 'Digital Revolution' refers to the transition from mechanical and analogue systems to digital systems with partial automation using memory-programmable controls and computers. At the centre of this era is the mass manufacture and widespread use of digital logic, MOS transistors, and integrated circuit chips, as well as their derivative technologies like computers, microprocessors, digital cellular phones, and the Internet. Massive breakthroughs in "Information and Communication Technology" (ICT) and Supercomputers have ushered in the third revolution, dubbed the "Information Age."

d) *Fourth Industrial Revolution 4.0:* The 4th industrial revolution began in 2011 with German government's Industry 4.0 initiative, which promotes the digitalization of industries—a fusion of physical assets and modern digital technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), robots, drones, autonomous vehicles, 3D printing, cloud computing, and others that are networked and capable of communicating, analysing, and acting. It entails a complete redesign of manufacturing processes, with analogue and centralised workflows being replaced with digital and decentralised workflows. Digitalization will reduce manufacturing costs, increase resource efficiency, and improve customer focus. Industry 4.0 organisations are more adaptive, responsive, and intelligent, and so more positioned to make data-driven decisions. Industries are transitioning away from the Internet and client-server architecture towards ubiquitous mobility, Cyber Physical Systems, IT-OT convergence, and all of the previously stated technologies with added boosters like advanced robotics and AI/cognitive, which empower Industry 4.0 with intelligent automation in whole new ways, resulting in a wide range of options to innovate and actually completely automate, bringing the industry to new heights. Internet-driven self-controlling and sensor-assisted manufacturing systems will influence the future of cyber-physical machines.

Industry 4.0 has four design principles:

- *Interconnection:* The Internet of Things' ability for machines, devices, sensors, and humans to communicate and interact with one another.
- *Decentralized decision-making*: The ability for cyber physical systems to make independent decisions and complete tasks as needed.
- *Technical assistance:* The ability of systems to assist humans with difficult or dangerous activities, as well as their ability to support persons in making decisions and solving issues.
- *Information transparency:* The transparency of Industry 4.0 technology provides operators with a lot of data to base their decisions on.

3. Key Technologies driving Industry 4.0?

Industry 4.0 is transforming the way businesses produce, improve, and distribute things. Some of the technologies that have contributed significantly to the fourth industrial revolution are as follows:

Figure 2. Key technologies of manufacturing industry 4.0

a) ***IoT and IIoT:*** IoT is utilised in common domestic applications such as smart homes, transportation, logistics, healthcare, agriculture, and vehicle monitoring, whereas IIoT is used in the manufacturing world when data, machines, and people are interconnected and cooperated. It essentially integrates the Internet of Things (IoT) to production, with sensors, equipment, and data all connected and fluidly interacting.

b) ***Cyber-Physical Systems****:*Cyber-physical systems are networks of intelligent physical components, objects, and systems with embedded computing and storage capabilities that enable Industry 4.0's smart factory concept in a setting of Internet of Things, Data, and Services with a focus on processes[5]. The bridging of digital (cyber) and physical in an industrial setting is referred to as CPSs.

c) ***Artificial Intelligence and Machine Learning:*** Artificial intelligence and its subset machine learning are fundamental requirements for an Industry 4.0-enabled smart factory. The whole point of this new industrial revolution is to get rid of manual processing, and AI is the main tool for doing so. AI may use data from a connected factory to optimise machinery, re-programme procedures, and uncover general adjustments that could improve efficiencies and revenue.

d) ***Automation:*** The ultimate goal of a connected factory is to boost productivity and thereby revenue. To do this, automation must be applied in some or all manufacturing processes. Automation via robots or artificial intelligence is enabled by the interconnection and communication that occurs across an Industry 4.0 optimised plant.

e) ***Big Data Analytics:***Every activity in a production unit creates data. Massive amounts of pure, unadulterated data can be transformed to accurate, meaningful intelligence that can drive industrial leaders' decision-making with today's current computer capabilities. Machine learning and artificial intelligence (AI) can be used in big data analytics systems to efficiently analyse data and provide decision makers with the information they need to enhance a manufacturing as a whole.

f) ***Cloud Computing:*** Manufacturers either don't have or don't want to use the massive quantities of storage space required to physically store vast amounts of data created by an industry. This is why cloud storage and computing are essential in a connected factory. Cloud computing also allows for a single source of information and lightning-fast data sharing across the company. Finally, cloud storage allows for remote access and monitoring of all data and machine operating systems, which increases visibility and efficiency.

g) ***Edge computing:*** Some data analysis must be done at the "edge," or where the data is created, due to the requirements of real-time manufacturing. As a result, the time between when data is generated and when a response is required is shortened. Detecting a safety or quality issue with equipment, for example, may need a near-real-time response. The time it takes to move data from the manufacturing floor to the enterprise cloud and back could be exorbitant, and it is dependent on network reliability. By allowing data to stay close to its source, edge computing decreases security risks.

h) ***Cyber security:*** Industry 4.0 needs more cybersecurity since it connects and digitises every point of interaction in the manufacturing process. Manufacturing equipment, computer networks, data analytics, the cloud, and any other system connected to the internet of things all need to be safe.

i) ***Simulation:*** Manufacturing company operations simulation in a virtual environment to enhance machine settings for prior production lines without testing in the physical world would save time and money in manufacturing system testing. Simulations are used to create a virtual model of the real world that may then be used to plan and schedule production based on the results of the simulation.

j) ***Virtual Reality:***In manufacturing systems, virtual reality has been utilised to train young engineers and technical graduates who are unprepared to deal with industrial operations. Young engineers and technical graduates have been introduced to the manufacturing process, mechanisation procedures, troubleshooting, and maintenance systems using virtual reality, which has proven to be more effective than traditional classroom learning. It also helps to reduce the cost of designing and testing any product by allowing you to see the concept without having to build it physically.

k) ***Augmented Reality:***AR combines a real-world environment with computer-generated pictures to allow users to see artificially added components to a real-world scenario for training, simulation, or validation of industrial designs before they are put into production. This mix of simulated computer visuals and real-world situations aids in the product's implementation in an existing environment. In the augmented environment, new staff training and product testing have been found to be more efficient and time-saving.

l) ***Additive Manufacturing:***Along with robots and cognitive systems, additive manufacturing, also known as 3D printing, is one of the key technologies driving Industry 4.0 [6]. This is how additive manufacturing works: digital 3D models are used to layer by layer create parts with a 3D printer. In the context of Industry 4.0, 3D printing is quickly becoming a valuable digital manufacturing technique. Previously utilised exclusively for fast prototyping, additive manufacturing is now used in practically every industry for a wide range of production applications, from tooling to mass customisation.

4. Manufacturing Industry: Present Challenges

Smart manufacturing systems are capable of coping with a wide range of issues and complexities encountered in existing industries, but there are still some challenges to solve during implementation. Security challenges, a lack of system integration, a lack of return on investment in new technology, and financial issues are all assumed to be present during the installation of new smart manufacturing systems and/or the updating of existing industries with smart manufacturing technologies. Smart manufacturing systems face a number of obstacles, which are listed below.

- *Growing Technical skills gap:* Industrial companies are struggling to search for people who can understand both manufacturing operations and the digital systems that enable them. Companies were having difficulty hiring and keeping motivated employees with a strong work ethic who consistently showed up. As a result, there has been a higher rate of turnover, as well as more time/money spent on hiring and training new workers, lowering output.
- *Data Sensitivity and Cybersecurity:* With the rise of technology, concerns regarding data and IP privacy, ownership, and management have increased. In order to train and test an AI model, data is needed. As technology advances, so do cybercriminals' talents and efforts.

- *Interoperability:* Another major challenge is the separation of protocols, components, products, and systems. Unfortunately, interoperability restricts a company's potential to innovate [8]. Because customers can't simply "swap out" one vendor for another or one piece of the system for another, interoperability limits the possibilities for upgrading system components.
- *Security:* Because of the physical and digital components that make up smart factories, real-time interoperability is feasible, but it comes with the risk of a bigger cyberattacks [7]. When a smart factory's different machines and gadgets are connected to a single or multiple networks, a weakness in one of them could expose the entire system to attack.

4.5. Handling Data Growth: As more companies use AI, they will be dealing with more data, which will be generated at a faster rate and distributed in a various formats. In order to filter through these vast volumes of data, AI systems must be simpler to understand

5. Scope of 5G in Manufacturing Industry 4.0

Manufacturing companies all around the world are under severe strain as a result of shorter business and product lifecycles in an era of extreme volatility.Competitiveness is key for manufacturers, and new process innovations will be required to achieve much-needed improvements in efficiency and profitability. Continued automation of robots and warehouse transportation, as well as the reduction of wires to become really flexible, are instances of this. 5G and the Internet of Things will be critical in strengthening and enabling these manufacturing breakthroughs [9].

Manufacturers and telecom organizations can employ 5G networks to build smart factories which take full advantage of technologies like automation, artificial intelligence, augmented reality, and the Internet of Things (IoT). 5G development is aimed at improving wireless connectivity in a range of vertical industries, such as manufacturing, automotive, and agriculture. Mobile broadband (eMBB), ultra-reliable low-latency communications (URLLC), and massive machine-type communication (mMTC)/Massive Internet of Things are three major characteristics of 5G. (mIoT).

- *eMBB*: Enhanced mobile broadbandoutperforms 4G in terms of data throughput and coverage. This will help to develop existing mobile broadband use cases, like UltraHD or 360-degree streaming video, AR/VR media and applications, and so on.
- *mMTC)/(mIoT:*Massive machine-type communication/Massive Internet of Things is a technology that can support hundreds of thousands of IoT devices per square kilometre while simultaneously enabling broad coverage and deeper indoor integration. It is also designed to provide seamless connectivity with minimal device software and hardware requirements, as well as low-energy operation to conserve battery life.
- *URLLC:* ultra-reliable low latency communications can enable mission-critical applications that demand high end-to-end latency, dependability, and availability. In this situation, a high-reliability, low-latency link is required. The data rates are irrelevant in this circumstance. Higher frequencies provide greater data rate and latency performance in 5G networks.

5.1 5G benefits for manufacturing Industry 4.0

a) *Ultra-low Latency:* 5G's low latency allows for real-time monitoring of operations, allowing faults to be detected within milliseconds. It also helps to know when and how to make changes or update parameters.

b) *High Bandwidth:* Due to high data rates, the industry can stream HD and UHD videos in near-real time. Average data rates of 100MB/s and peak data rates of 20GB/s are projected with 5G.

c) *Increased device density*: The 5G network can accommodate up to one million sensors per square kilometre, as well as ultra-low latency for real-time data from sensor-equipped devices, which aids productivity, decision-making, and failure prevention.

d) *High Reliability:* Industry has accepted the use of 5G for mission-critical procedures where downtime is not an option. According to estimates, 5G achieves an average network dependability of 99.999%.

e) *Ultra Mobility & Seamless Handover:*5G enables infrastructure to support speeds ranging from 0 to 500 km/h, allowing for long-term functioning while on the move.

f) *Low-power consumption:* 5G can provide up to 10 years of battery life for low-power (IoT) devices, resulting in lower IoT device maintenance.

g) *Predictive maintenance*: Advanced predictive maintenance powered by 5G and equipped with a larger number of sensors can aid in the prediction and avoidance of failures before they occur.

h) *Secured Connection:* As connectivity grows, security measures must be considered to ensure that connections are ultra-reliable and secure to prevent data loss. Because the 5G network can be sliced, speed, capacity, coverage, and encryption can all be tailored to meet specific needs while keeping prices low.

5.2. 5G and Edge Computing for Manufacturing 4.0

While more sectors are turning to cloud computing for cost savings, scale, self-service automation, and centralised functionality, concerns about data security, privacy, network latency, and network stability are preventing mainstream adoption. Latency is one of the most crucial challenges for companies, especially in highly critical occupations where a millisecond delay may cost a corporation a large amount of money. In a cloud-only design, data travels hundreds or even thousands of miles, therefore Edge Computing represents a paradigm shift in cases where latency is critical. Edge Computing allows businesses to maintain sensitive data on-premises for real-time decision-making while simultaneously taking advantage of the elasticity of the central cloud for comparative analysis without losing privacy or data security [10].According to one prediction, nearly 67% of data will be on edge by 2023. According to Grand View Research, the market for edge computing is expected to reach USD 29 billion by 2025. The following are some of the benefits of 5G with edge computing:

- Edge computing allows 5G networks to achieve the low network latency required for real-time operations.
- Edge computing, as well as open source projects and standards, are integrated into 5G wireless networks to distribute data throughout the network, from radio access and transport to new core-enabling features such as network slicing.
- Using artificial intelligence (AI) and machine learning technology, edge computing optimises data management across networks.
- Edge computing will also be important in rethinking network security. The speedier communication and interconnection provided by 5G also imply highly secure connections from cyber-attackers.

5.3. Private 5G Networks for Manufacturing 4.0

Private 5G networks are one of the key drivers for 5G adoption in industrial use cases, and spectrum access is among the keys to unlocking the private networking industry. The 3.5GHz CBRS band has been designated for shared private network usage by US regulators, while 3.7GHz and 1.7GHz have been designated for private network use by Germany and Japan, respectively. Sweden, the United Kingdom, Hong Kong, and Australia have all declared plans to discover and assign spectrum for localised, private 5G networks, with a focus on the 3.7 GHz, 26 GHz, and 28 GHz frequency bands.

Private 5G networks have the ability to help businesses optimise and reinvent business processes in ways that wired networks and public wide-area cellular services cannot. They claim to have ultra-low latency and ultra-fast data rates, and they're easy to set up and configure. Because of the operator's capacity to define security policies, private 5G networks are expected to beat current private wireless networks in terms of security.

To boost operations, manufacturing industries design and deploy private 5G networks[11]. In the industrial sector, there are three reasons to establish a private mobile network:

- Allows for 5G availability in areas with severe radio frequency (RF) or operational conditions, or where public network coverage is limited or non-existent (e.g., industries in remote locations).
- Complete network control: Allows you to use configurations that aren't available on a public network. Data security and privacy are also essential.
- Achieving appropriate results: 5G outperforms LTE and Wi-Fi in cyber-physical industrial systems.

6. Discussion and Conclusion

In this paper,we studied that 5G has unique advanced capabilities that can be used by the manufacturing industry to introduce innovative approaches and eventually help the industry continue to increase productivity and improve efficiencies, as well as fundamentally transform business strategies.

The capacity to collect more data by connecting more devices and increasing bandwidth, ensuring data collection is reliable and safe, and lowering latency to new levels in wireless technology are the most crucial aspects that 5G provides to the corporate world.

5G has the potential to have a social impact in addition to assisting manufacturing expansion. Increased knowledge access can benefit society as a whole, whether it's for greater resource utilisation, lower energy usage, or improved safety and health.

To take advantage of 5G, the manufacturing industry will need to be proactive in ensuring that the technology advances quick enough to support new use cases (such as those demanding ultra-reliable low latency) and that it is implemented in (remote) places near industrial centres. This involves learning more about 5G and its benefits, as well as participating in the development of 5G standards and regulations and partnering with telecoms businesses.

Declaration of Competing Interest

There are no any competing interests.

References

1. N. Tuptuk, S. Hailes. Security of smart manufacturing systems. Journal of Manufacturing Systems, 47 (2018), pp. 93-106.
2. H.S. Kang et al. Smart manufacturing: Past research, present findings, and future directions. International Journal of Precision Engineering and Manufacturing-Green Technology, 3 (1) (2016), pp. 111-128.
3. W. Lidong, W. Guanghui. Big Data in Cyber-Physical Systems, Digital Manufacturing and

Industry 4.0. International Journal of Engineering and Manufacturing, 6 (4) (2016), pp. 1-8.
4. C. Zhang, J. Yang. A History of Mechanical Engineering. Springer (2020).ISBN: 978-981-15-0832-5.
5. E. Lee. The past, present and future of cyber-physical systems: A focus on models Sensors, 15 (3) (2015), pp. 4837-4869.
6. Y. Lu. Industry 4.0: A survey on technologies, applications and open research issues. Journal of Industrial Information Integration, 6 (2017), pp. 1-10.
7. K.-D. Thoben, S. Wiesner, T. Wuest. "Industrie 4.0" and smart manufacturing-a review of research issues and application examples International Journal of Automation Technology, 11 (1) (2017), pp. 4-16.
8. D. Chen, G. Doumeingts, F. Vernadat. Architectures for enterprise integration and interoperability: Past, present and future Computers in industry, 59 (7) (2008), pp. 647-659.
9. T. Tommila, O. Ventä, K. Koskinen. Next generation industrial automation–needs and opportunities Automation Technology Review, 2001 (2001), pp. 34-41.
10. S. Nunna et al., "Enabling real-time context-aware collaboration through 5G and mobile edge computing," in Proc. Int. Conf. Inf. Technol. New Gener., 2015, pp. 601–605.
11. 18] Harbor Research, "The Private LTE Opportunity for Industrial and Commercial IoT," Report, July 2017.