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A Review of 5G Technology for Industrial Automation Applications

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Abstract: High performance millimeter-wave 5G antenna solution is required in industrial automation which can effectively mitigate the problems associated with currently used wireless technologies such as high latency or response time, insecure communication, low transmission and reception speed, limited bandwidth, lower capacity of network, connectivity issues due to multiple devices on network, congestion in the radio channels, higher energy consumption and higher cost of wired circuits and maintenance. Cost efficient solution is needed, which could replace the computer based or programmable logic controller based hard wired automation. To execute a highly flexible wireless automation of industries, technology must be support mission-critical services which needs high reliability, deterministic traffic properties and very low communication delays. Further, should enable process optimization and communication for time critical/ non-time critical, Intra/inter-enterprise communication between connected products, remote control, video driven interaction between robots and humans.

Keywords: 5G, Industry 4.0, Antenna, Wireless Technology.

1. Introduction

Industry 4.0, Industrial IoT, and the smart factory are the future technologies of industrial production [1]. Manufacturing plant and intra logistics planning should be more flexible, automated, and efficient, which necessitates the use of the appropriate communication architecture and complete connectivity. The implementation of 5G in the industry will offer up a lot of new capabilities [1], [2]. Researchers are extremely interested in 5G-based industrial automation. Collaborative industrial robots (cobots) are in high demand. It is critical to integrate 5G with robots. In robotics, real-time control is implemented through the use of sensors for a variety of functions. It necessitates the use of several complicated protocols, numerous sensors, and more flexible and intelligent motion control. Due to severe connection latency, implementing real-time control utilizing an external PC is extremely difficult, if not impossible. A 5G-based public network / personal network might close this gap, thus further research is needed in this area [2].

5G is the most recent improvement in future wireless communication technology that has yet to be introduced in India. The ideal millimeter wave antenna for 5G has yet to be discovered. High data rates, large bandwidth, and low latency services will be provided via millimeter wave bands [3]. The strength of 5G mobile networks will enable ultra-high definition video streaming, conferencing, and broadcasting at higher mobility without losing connection, industrial automation using billions of device-to-device connectivity, mission-critical applications such as tele-surgery and driverless cars due to low latency and highly reliable 5G networks, and increased 21 productivity due to real-time, high-quality data analytics [4]. In all of these applications, a low-cost planar mm wave antenna will be utilised to transmit and receive millimeter wave signals, which is appealing to automated smart industries due to the high data rate and low latency that can be obtained [5].

The fourth industrial revolution is underway in the automation business, with fully networked and automated "cyber-physical" plants in the works. This transformation requires efficient plant networking and media-free communication of commodities and equipment, and effective digitization is a vital component of that. The 3rd Generation Partnership Programme (3GPP) is sponsoring the 5G system, which will provide concepts and technologies that will make manufacturing businesses more efficient. Wireless automation now accounts for 4% of the industrial automation industry [1], [2]. Technology must enable mission-critical services that require high dependability, predictable traffic characteristics, and extremely minimal communication latency in order to implement a highly flexible wireless automation of industries. Process optimization and communication for time-critical/non-time-critical, intra- /inter-enterprise communication between linked goods, remote control, and video driven interaction between cobots and humans should also be possible [6].

2. Requirements of Industrial Automation

There are various operations and application which is required in Industry 4.0 or future generation wireless industrial automation [1]–[3].

• Controlling or Operating the instruments from remote place, like assembly line robotic systems on the manufacturing plant. Welding, painting, and assembling are examples of typical uses [1].

• Remotely managing supply chain equipment, for example, an employee can manage untethered robots; common examples include unmanned ground vehicles or forklifts [3].

• Monitoring the instruments from remote location, like the transmission of diagnostic information, promises that maintenance team are ready to perform repair work as needed [2].

• Machine-to-machine communication: machine-to-machine communication in a closed loop to improve industrial processes [1], [3].

• Intra- and inter-enterprise information exchange: allowing monitoring assets scattered across wider geographical locations across the production process [3].
• Assistance towards augmented reality in designing, service, and repairing (through simulations): augmented reality can be used to support in the accomplishment of procedural tasks in the design, servicing, and maintenance
domains [2].
• Wireless networks for transmission [1].

3. Challenges of Industrial Automation

Predictive and prescriptive maintenance plans, self-healing manufacturing lines with near 0% downtime, remote control procedures, autonomous robots, and augmented reality systems are all part of Industry 4.0. These capabilities necessitate improved factory-floor connection. As a result, wireless communication is becoming more business and mission important, necessitating increasingly demanding dependability, latency, and security requirements. Not all wireless technologies can keep up with today's smart industrial demands [1], [2].
Wireless solutions that are now accessible have a slew of issues. Manufacturing nowadays is based on the integration of several systems, which results in large amounts of data being produced. This massive growth in data collecting requires quicker transmission and analysis with broadband capability and small response time (latency), which is a significant problem for present technology. The current frequency range employed in wireless technologies such as Bluetooth and WLAN has a significant risk of being hacked. Because of the complexity of these wireless protocols, there are unforeseen dangers in wireless equipment solutions which could enable hackers to take control of a machine. The lack of available bandwidth on wireless networks, as well as interference from competing services, is a major concern [1], [3], [7].
With billions of devices, radio channel congestion is a major issue. Adaptive frequency hopping (AFH) allows a Bluetooth device to discard channels with a lot of data collisions. The effectiveness in a mixed-signal environment is unclear, and collisions and data losses will occur if the radio formats do not identify one other. Due to interference from the environment, an industrial sensor that loses its control signal or ceases operating might have disastrous effects. Realtime control is difficult, if not impossible, due to communication latency. For a machine with more than 100 sensors and/or actuators, factory automation necessitates a response time of less than 10 milliseconds. The transmission of raw sensor data at a rapid update rate necessitates a lot of bandwidth. The proper operation of most enterprises relies heavily on equipment maintenance. Depending on how long a process is paused, an unexpected breakdown of equipment can cost a company a lot of money. It is necessary to have a device or technology that can support augmented reality solutions. Costly programmable logic circuits (PLCs), PC-based automation, and hardwired circuits are being replaced by low-cost 5G-based antenna receivers [1], [2].

4. Role of 5G in Industrial Automation

Upcoming communication systems are projected to transform present industry structure by meeting demanding standards for ultra-high dependability and ultra-low latency. In this vein, Millimeter-wave communication, which runs at frequencies from 30 to 100 GHz, is the essential to execute future industrial automation. 5G is quickly becoming the preferred link, acting as a conduit for data flow across all elements of the industrial environment. To address the aforementioned issues, a high-performance millimeter-wave 5G antenna should be used in 5G-based industrial automation processes. Wide band and high gain millimeter-wave antennas with narrow beamwidth and scanning capabilities will be developed, allowing for high speed, low latency, low jitter, enhanced connection, increased capacity, costeffective, low power consumption, and highly dependable systems [7]–[10]. Because of their simplicity of manufacture on PCB (printed circuit board) together with other electronics components and circuitry, microstrip antennas are becoming increasingly popular. These are increasing at a faster rate in the communication sectors because to their light weight and small size. Because of their cost-effectiveness, planar construction, low profile, and simple production procedures, they may be incorporated and suitable for embedded antennas. These antennas may be used to get linear and circular polarisation radiation characteristics as well as multiband operations [11]. The use of a high-performance millimeter-wave 5G antenna can alleviate problems in the wireless automation sector. The millimeter-wave spectrum's wide bandwidth will allow for minimal latency and speedier transmission [12],[13]. Since of their narrow coverage range, millimeter-wave frequencies are a preferable choice for interior communication because they have a lower risk of being hacked. Numerous devices can access multiple channels and interact without interference or radio collisions due to the lack of other services in the millimetre wave range and the availability of free spectrum. It also offers improved connection, more capacity, and a lower risk of interference. The 5G spectrum can help minimise response time. The use of millimeter-wave antenna systems can allow a high update rate. 5G will provide ultra-high-definition video services and ultra-fast internet speeds, allowing for augmented reality solutions such as video broadcasting to deliver real-time help and services from professionals. By replacing hefty PCs and hardwired electronics with millimeter-wave 5G antenna receivers, the overall system cost will be decreased [1], [2], [14].

The 5G networks are emerging as the foundation for industrial transformation in terms of digitalization and advance communication. It has promised to provide reliable services at ultra-high speed with very low latency. 5G will deliver both fixed as well as mobile broadband services anywhere to anyone at any time. Previous generation wireless network has various challenges related to the data rates, connectivity, and latency. For example, the 4G LTE-A system ensures the DL data rate of up to 3Gb/s and UL data rate up to 1.5Gb/s with the connectivity

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of 600 users per cell approximately and latency of around 30-50 milliseconds [1]. Due to these challenges, 4G networks were not capable of supporting various applications like VR, AR, HD screening, video conferencing, and 360◦ video streaming. Whereas in the 5G network, these challenges are mitigated by introducing various new features, services, and technologies. The technologies of 5G network are Massive MIMO, mmWave, Full-duplex Radio, D2D communication, UDN, Multi-RAT, and Cognitive Radio. In [1], the author has surveyed several eminent technologies of 5G network and on the basis of these technologies, a 5G architecture is proposed. These technologies have opened up many possibilities to fulfill the requirements of 5G given in Table 1. These requirements are defined as the 2020 minimum requirements laid by the ITU [2]. In order to achieve the requirements of the 5G network, an entirely new radio air interface has been developed, that is named as the 5G New Radio or 5G NR air interface. For defining the 5G standard properly, the 3GPP in its two provide the service of mobile broadband which will help in ensuring consistent user experience. The mMTC will furnish the 5G network with massive connectivity. The uRLLC services will open up various new capabilities of the network by extending its limits for reliability and latency. The diverse deployment of the 5G network is due to the addition of various new features. These features are scalable numerology, flexible spectrum, forward compatibility, and ultra-lean design. The present technologies of 5G systems form the basis for many new technologies in beyond 5G/ 6G network.

5. Related Work:

The massive demand for higher data rates and bandwidth with the increased number of users led to the deployment of the 5G network in the coming future. 5G networks are expected to support higher connectivity, improved capacity, high-speed data rates, and low latency. Various emerging technologies that will be employed in the 5th generation network include UDN, massive MIMO, D2D communication, SCA, Full-Duplex Radio, and Cognitive Radio. These technologies have enabled various features of the 5G network. In [4], several new channel estimation models like hybrid channel models are discussed for carrying out channel measurements. These models will be adaptable to the different scenarios of 5G networks. In [5], various trails that are being carried out for enabling 5G scenarios are overviewed. The author has concluded that researchers have mainly focused on eMBB. Whereas, other KPIs like mMTC and uRLLC has left untouched because the connection density for validating mMTC is very high, which is very difficult to attain for trial purposes. Next-generation systems will enable various applications that may require high QoS. Thus Power optimization will be the primary requirement [6]. The use of relays and small cells increases the efficiency of the system and supports green communication. There are various key features of 5G NR systems, which include Forward Compatibility, Ultra-Lean Design, and flexible spectrum [7]. Forward compatibility allows the network to support future applications that are not yet discovered. The ultra-lean design incorporates the reduction of 'always on' signals so that the performance of the system can be enhanced, and the power utilization can be reduced. The flexibility of the spectrum helps in enabling numerous applications of 5G network in different scenarios.

In [8], the author has discussed the deployment scenarios of 5G system with NR waveforms, access techniques and frame structure. New Radio will operate both as Standalone (SA)NRand Non-Standalone (NSA) NR. The SA NR network will make use of a Next-Generation Core (NGC) network, and it will require new infrastructure for its deployment. Whereas the NSA NR network will use the LTE- EPC as the core network and will utilize the already installed infrastructure for carrying out its operations. NR networks will employNOMAas multiple access technique, and OFDM based new waveforms that have additional functionalities.

OFDM is associated with a high Peak to Average Power Ratio(PAPR) and Out of Band Emission (OOBE), which deteriorates the expected spectral efficiency of the system. Several techniques like Filtering, windowing, and precoding are used in 5G NR for reducing these issues. 5G NR will enable various new applications with the deployment of several new technologies. The existence of 5G network with the existing network and next-generation wireless network in real-time scenarios is one of the critical challenges that needed to be considered.

NR will operate in themmWave band, and for the enhancement of gains, beamforming will be an eminent technology.

Beamforming is essential for increasing the link budget in the environment of mmWave communication [9].

It manages the transmission of data in highly mobile scenarios.

In [10], a multi-beam operation based on the process of initial access is used for getting system information, performing synchronization, and providing random access in the NR system. The author has also highlighted the handover procedures for Inter-cell mobility. It is suggested that the handover will be based on the measurements of the downlink channel which also compensates the requirement of always-on signals in NR.

In [11], conventional Beam management and Interference coordination algorithms are modified into a deep neural network based method. It is concluded that a deep neural network requires fewer calculations and thus reduces computational complexity with comparable sum-rate concerning the conventional method. In [12], the author has discussed that with the evolution in modulation scheme, a modified receiver must be used that can be reliable for handling denser constellations. Computational complexity is reduced by employing the receivers that can directly work on digitalized observations and can consider error variance. 5G systems will rely on mmWaves, but the beyond 5G/6G network will operate on Terahertz (THz) frequencies. For the deployment of mmWaves, new Channel estimation models are required for carrying out communication. In [13], the channel gain coefficients are calculated by using least square estimations in mmWave MIMO systems. The author focuses on achieving

better performance as compared to the conventional Bayesian compressive sensing.
The authors in [14] proposes general mechanisms for strengthening 5G security. By reviewing the security requirements of LTE, the author outlined the security requirements for 5G in [14]. A good analysis has been presented on the security of current 4G network and future 5G network in [15]. The privacy protection solutions and the existing authentication for 4G and 5G networks is focused in the article. Paper [16] proposes possible mitigation techniques for the security challenges as well as standardization work for 4G and previous generations. The security threats and attacks on mobile networks have been investigated in [17]. Thorough analysis on security threats m, challenges in mobile access and core networks are focused in the article [103], however, the main challenge is related to the 4G network architecture. The paper [18] also considers various wireless access technologies, such as Bluetooth, Wi-Fi, WiMAX, and LTE, and discusses the inherent security restrictions and future trend for enhancing the security of each technology. Literature [19] investigates the security technology of 5G wireless networks for physical layer, the key area of this paper is the physical layer security coding, massive MIMO, non-orthogonal multiple access technology (NOMA), millimeter wave (mmWave) communication, heterogeneous networks (HetNets) and fullduplex technologies. In [20], a 5G security study compared to current or traditional cellular networks was conducted, here the security of 5G is investigated in terms of usability, confidentiality, key management and privacy identity verification. In [21], interesting work on future mobile network security research is presented, this work aims to deliver a comprehensive understanding of the security of mobile networks and to present some research challenges. However, because of the integration of large-scale Internet of Things and the collection of new technology concepts, the security challenges in 5G will be more diverse. The extended concepts of SDN, NFV, and cloud computing like multi-access edge computing (MEC) have many advantages in terms of their performance and total cost of efficiency, but these technologies all have their own security weaknesses [22]. The articles mentioned in the related work focus on particular areas. For example, [21] and [22] focus on authentication, [19] and [20] respectively address the security of the physical layer and air interface, [20] proposes access and core network security, and proposes LTE security. The security requirements of 5G [15] cover the privacy issues in future networks.

5. Conclusion

With millimeter-wave 5G antennas, machine-to-machine communication with ultrahigh dependability and lowest latency is conceivable. The millimeter-wave spectrum's huge bandwidth can open the path for many other modern factory automation services. Automated visual tracking and surveillance, smart logistics inventory control, image guided robotic assembly, and fault identification are among uses that can benefit from wireless smart cameras technology. Robots, machines, and other factory automation systems having vision capabilities can engage meaningfully with things and travel safely through their environments. Antennas use a range of technologies to provide multipath communication, a high signal quality, noise suppression, and the capacity to manage a higher number of devices in a noisy environment, including multiple input multiple output, advanced beam formation, and smart solutions. Antennas which have good gain and efficiency are utilized to decrease millimeter-wave losses. Directional antennas are used for outdoor communication, whereas omnidirectional antennas are used for internal communication.

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