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URLLC and eMBB in 5G Industrial IoT: A Survey

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***Abstract*—Fifth generation (5G)-industrial Internet of things (IIoT) is the integration of IIoT and a private 5G network. The IIoT is a concept that involves incorporating smart objects, gadgets, and solutions into cutting-edge industrial operations to increase reliability, efficiency, and over-production costs. Furthermore, the integration of IIoT and 5G/beyond 5G (B5G) provides the potential for ubiquitous and instantaneous connectivity. The 5G architecture can handle the IIoT's stringent ultra-low latency, real-time processing, high data rate, nearby storage, and reliability requirements. A new era of economic growth is predicted for IIoT-assisted 5G/B5G wireless networks. It should be noted that the majority of the work in IIoT is focused on the architecture, with reliability and throughput being largely ignored. This paper provides a comprehensive review of B5G assisted IIoT wireless networks, with a focus on enhanced mobile broadband (eMBB) and ultra-reliable low latency communication (URLLC) services. Furthermore, it provides insights into various applications and key enabling technologies from the perspective of URLLC, eMBB, and their tradeoff.**

***Index Terms*—Fifth generation (5G), beyond 5G (B5G), sixth generation (6G), industrial Internet of things (IIoT), ultra-reliable low latency communication (URLLC), enhanced mobile broadband (eMBB).**

I. INTRODUCTION

THE emergence of industrial Internet of things (IIoT) has revolutionized industrial operations such as manufacturing and production by automating a huge number of connected components and devices. IIoT is a sub-category of Internet of things (IoT) that focuses on the use of IoT techniques and technologies [1]–[4] in industries such as smart cities, smart transportation, smart grid, smart health services, forestry, food, weather, agriculture, monitoring, and surveillance [5]–[18]. The machines/devices in IIoT are connected to capture smartness and autonomy in legacy systems [19]–[21]. It is estimated that by the end of 2030, roughly 80 billion devices will be connected to the Internet [22]–[24]. In IIoT, an increased degree of connectivity is involved, which has special requirements for high reliability, low latency, high speed, more flexibility, and secure communication [25]–[27].

Forth generation (4G) wireless networks have gained popularity over the past decade as a reliable communication technology [27]–[29]. Many industrial applications are supported by long term evolution (LTE) and wireless fidelity (WiFi), but with more demanding performance needs from users in terms of reliability, latency, and throughput, fifth generation (5G) has emerged as a promising alternative that can satisfy these requirements [30]. 5G started becoming commercially available in 2019. It is used in a wide range of applications from IoT to smart homes to Industry(4.0). Moreover, the International Telecommunication Union (ITU) defines three usage scenarios: ultra-reliable low latency communication (URLLC), enhanced mobile broadband (eMBB), and massive machine type communication (MTC) (mMTC) [31]–[34]. To sustain/ achieve the competitive requirements for the applications of wireless networks, the industry and academia have started to conceptualize the next generation of wireless communication systems (sixth generation (6G)) [35]–[37]. The 6G is expected to have a data rate of 20 Gbps, admit 10^6 devices per km^2, and have a latency/delay of less than 1 ms. Thus, 5G/6G enhancements are capable of providing the essential services and meeting the performance metrics of IIoT.

For the integration of 5G/6G with IIoT, a private 5G network can be designed and deployed [38]–[40]. The requirement for a private network has been addressed in the 5G standards, rather than being an add-on capability in previous generations. The primary motive for establishing a private 5G network is the guaranteed coverage as well as the better performance profile over legacy wireless technologies. Because most industries are located in distant places where public network coverage is limited or non-existent, a private network can provide the assured service required by IIoT. It is a secure network customized for a certain industry, with a dedicated radio access network (RAN) and core mobile network for mobile communication. As a result, a private 5G network for IIoT known as 5G-IIoT could be a promising solution.

5G-IIoT can be used to complement the existing communication solutions for IIoT and can be used based on application requirements. The two most characteristic features of 5G-IIoT are a) URLLC, which requires a latency of less than 1 ms and reliability of 99.99%, and b) eMBB, which requires a data rate of giga bits per second. Therefore, 5G-IIoT may achieve extremely high data rates, low latency with wide coverage, and relatively low power consumption [41], [42].

A. Existing Surveys

Table Iprovides a summary of the existing surveys on the IIoT. Xu *et al.* [43] outline a comprehensive survey work for IIoT. This work covers current research in IoT technology,

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TABLE I: An overview of existing surveys on IIoT. Rel.: Reliability, Tp.: Throughput, Appl.: Applications, Chall.: Challenges.

Ref.	**Title**	**5G / 6G**	**Techniques**	**Rel. (URLLC)**	**Tp. (eMBB)**	**Trade-off**	**Appl.**	**Chall.**
[19]	Industrial IoT in 5G environment towards smart manufacturing	✓	✓					✓
[20]	URLLC wireless communication: Tail, risk and scale			✓		✓	✓	
[21]	A comprehensive survey on IoT towards 5G wireless systems	✓	✓				✓	✓
[43]	IoT in industries: A survey		✓				✓	✓
[44]	IIoT: Challenges, opportunities, and directions							✓
[45]	Communication protocols of an IIoT environment: A comparative study		✓					
[46]	Creating values out of IoT: An industrial perspective							✓
[47]	5G URLLC implementation challenges and operational issues with IoT devices	✓		✓	✓		✓	
[48]	A Energy-Efficient IIoT: Overview and Open Issues		✓					✓
[49]	A Comprehensive Survey on the Internet of Things with the Industrial Marketplace						✓	✓
[50]	A Survey on Information and Communication Technologies for Industry 4.0: State-of-the-Art, Taxonomies, Perspectives, and Challenges		✓					✓
This work	URLLC and eMBB Support for IIoT: Techniques, Challenges, Applications and Research Gaps	✓	✓	✓	✓	✓	✓	✓

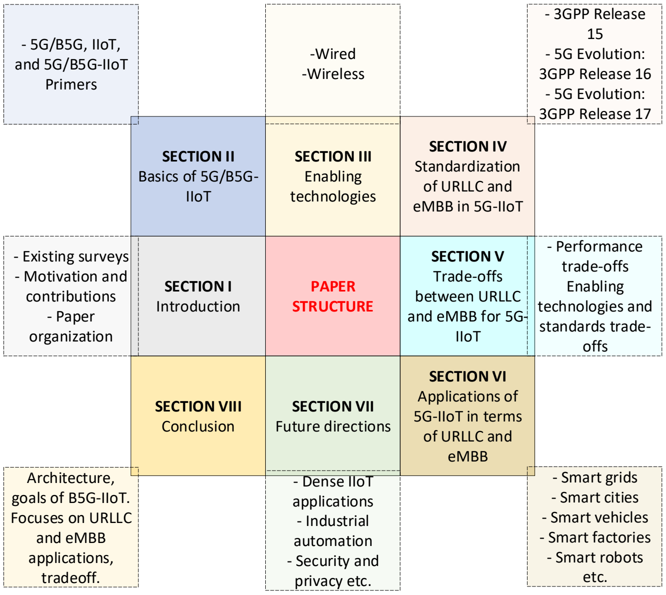

Fig. 1: Structure of paper.

applications, and industry issues. In [44], a brief introduction to IoT, IIoT, and industry 4.0, with emphasis on performance, parameters, research efforts, and future directions in the domain is provided. The implementation methods, manufacturing technologies, and scenarios of beyond 5G (B5G)-IIoT based cyber-physical manufacturing systems (CPMS) are discussed in detail in [19]. Event-based polling protocols for IIoT are briefly discussed in [45]. Various applications in the domains of IoT cloud platform with an industrial perspective are debated in [46]. Further, the challenges of cloud-based IoT are investigated to generate potentially more business opportunities in industries. In [47], the progress in third generation partnership project (3GPP), and implementation issues of URLLC in IoT devices are briefly addressed. In [20], the main focus is on requirements, techniques, and methodologies related to URLLC to ensure the goals of 5G wireless networks. A comprehensive survey of IoT in 5G system is provided in [21]. It provides a review of enabling and emerging technologies of 5G in IoT with research gaps. Finally, in [48], challenges and technologies in perspective of energy efficiency are discussed for IIoT. The survey papers mentioned in the Table I are all related to IIoT, there are also a few surveys in the direction of URLLC and eMBB, and their coexistence or tradeoff. However, a detailed study of IIoT from the perspective of URLLC and eMBB is missing.

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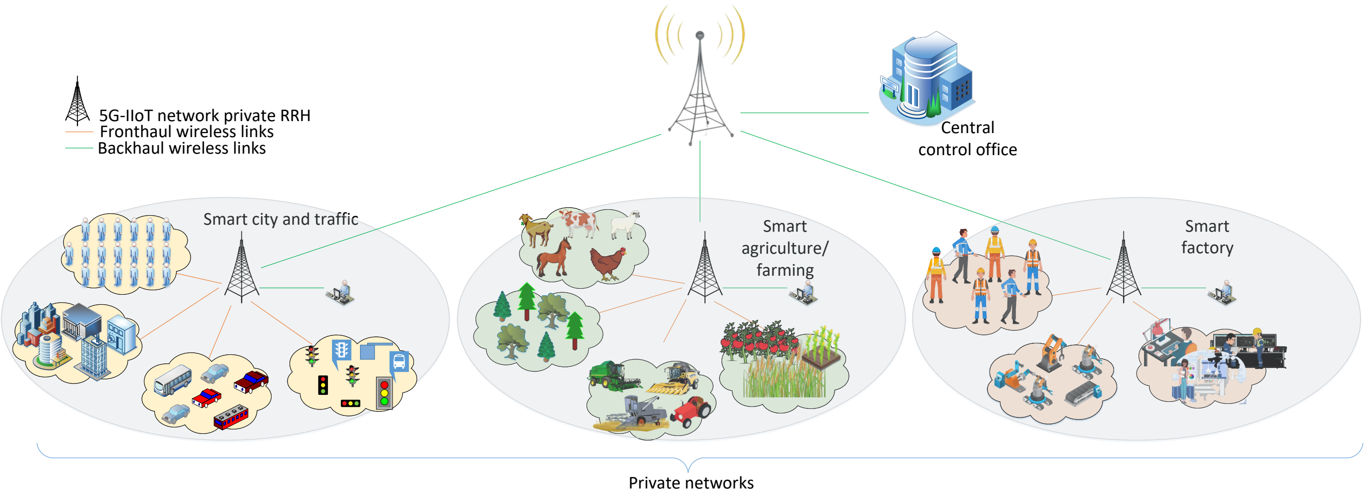

Fig. 2: A depiction of 5G-IIoT private network.

B. Motivation and Contributions

Although there exist other surveys on IIoT, none of them primarily focus on the latency, reliability, and throughput aspects of IIoT. URLLC and eMBB are two emerging 5G services with conflicting requirements. The primary objectives of URLLC services are low latency and high reliability, whereas eMBB services focus on higher data rates. These two services have a high potential and a promising future in 5G-IIoT since they involve both mission-critical aspects, such as autonomous vehicles and tactile internet, as well as high data rates, such as augmented reality (AR) and virtual reality (VR). However, URLLC and eMBB have a trade-off, which motivated us to examine IIoT features and requirements, as well as its enabling technologies, in the context of URLLC and eMBB applications.

The major contributions of this work are:

- Present a comprehensive literature review for IIoT in 5G to determine the capability of 5G to satisfy the requirements of IIoT.
- Identify research gaps in the URLLC and eMBB aspects of IIoT in 5G.
- Provide insights into diverse applications and requirements, where we investigate the key enabling technologies for 5G-IIoT, particularly the communication technologies for URLLC and eMBB.
- Investigate the trade-offs between URLLC and eMBB for 5G/IIoT.
- Outline the challenges and future directions of 5G-IIoT for URLLC and eMBB.

C. Paper Organization

The organization of the paper is as follows: The primer of B5G and IIoT and their relationship is briefly discussed in Section II. The enabling techniques for URLLC and eMBB, and their role in IIoT is provided in Section III. Section IV presents 5G standardization for IIoT with respect to URLLC and eMBB. Section V describes the trade-off between URLLC and eMBB. The applications of B5G-IIoT are discussed in Section VI. The challenges and future directions are debated in Section VII. The paper is summarized in Section VIII. The overall structure of the paper is shown in Fig. 1.

II. BASICS OF 5G/B5G-IIOT

The core architecture of 5G/B5G and IIoT is covered in this section, as well as the 5G-IIoT design and objectives.

A. 5G/B5G Primer

The ecosystem of 5G/B5G connects the entire society through digital devices and gadgets, driving the economic development of innovative services. Aside from network virtualization, the flexible and dynamic architecture of 5G/B5G offers numerous access technologies with unlicensed and licensed users and devices. The 5G/B5G network may be scaled and extended in cost-effective and automated models to support revolutions in the automotive, manufacturing, utilities, transportation, public safety, healthcare, media, and other industries. The 5G/B5G architecture supports a wide range of advanced access technologies, including WiFi, B5G, new radio (NR), low power wide area (LPWA), and cellular with inter-access mobility [26], [51], [52]. The main features are built on software-defined-networking (SDN) and cloud/virtualization native principles, with full orchestration to provide flexible deployments.

Potential use cases for 5G with varying requirements have been identified by standard bodies and industrial parties. These prospective use cases can be divided into three categories:

- **eMBB:** can be used to service large-scale events and compact metropolitan areas that have high data rate requirements but restricted bandwidth. Virtual and augmented reality, smart offices, 8K/4K video streaming, and cloud applications all require broadband connectivity with a minimum data rate of 50 Mbps everywhere. Furthermore, mobile-enabled eMBB services are necessary for enhanced navigation, in-vehicle infotainment, telematics support for diagnostics and safety, and commercial aircraft on-board entertainment.

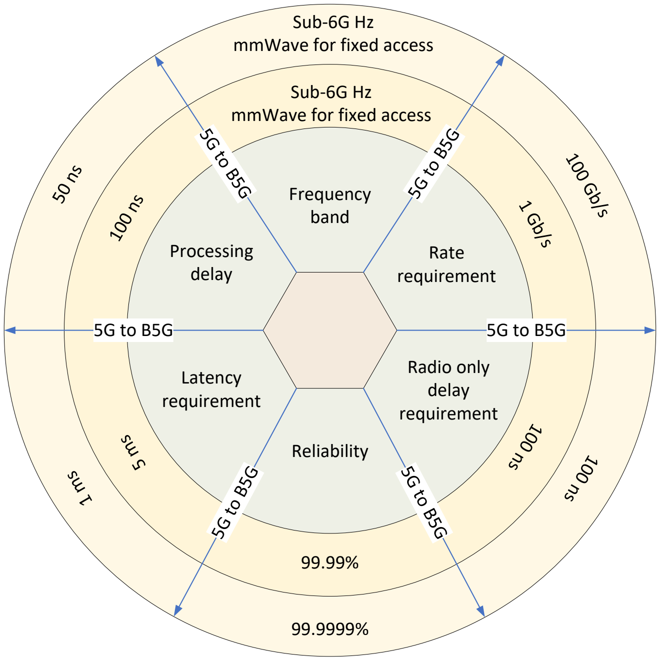

Fig. 3: Requirements of 5G and B5G.

- **URLLC:** Mission-critical communication is required for emergency services such as disaster response, public safety, and location services. URLLC provides real-time services for scenarios requiring a response time of less than 1 ms. Among the use cases covered by URLLC are robotic control-based industrial automation, autonomous driving, remote surgery, and drones [53].
- **Massive IoT (mIoT):** Long-range, low-cost, and ultra-energy-sensitive devices that require infrequent and periodic connectivity from cloud applications and remote locations are examples of mIoT. LPWA cellular technologies were provided in 3GPP release-13 with long term evolution for machine (LTE-M) and narrowband Internet of things (NB-IoT), and further advances were proposed in release-14, which are aligned with the improvements of the 5G/B5G architecture.

5G is in its deployment phase for the last few years and its limitations have been highlighted and researched as well. B5G is the evolution of 5G as opposed to 6G which is expected to be a revolutionary step [54]. Fig. 3 presents the requirements of the 5G and B5G systems.

B. IIoT Primer

The emergence of digital and smart manufacturing in industries aims to merge operational technology (OT) and information technology (IT). In general, the IIoT will connect industrial assets, such as machinery and control systems, to the IT and business processes. This integration results in massive data generation and collection. This data could be used to develop analytic solutions to improve industrial operations [55]. Smart manufacturing, on the other hand, concentrates primarily on the production stage of a smart product's life cycle, with the aim of responding quickly and dynamically to demand changes. As a result, IIoT has an impact on the industrial value chain and meets the standards for smart manufacturing. In general, the machines in IIoT are meant to communicate autonomously with one another. The IIoT comprises situations such as legacy monitoring applications, i.e., process monitoring in manufacturing plants, and novel ways for self-organizing systems, i.e., autonomic industrial plants with minimal human intervention.

Typically, IIoT systems are envisioned as a layered modular architecture of digital technologies. The physical components, such as cyber-physical systems (CPS), sensors, or machines, are referred to as the device layer. The network layer consists of physical network buses, cloud computing, and communication protocols that collect and transfer data to the service layer, which consists of applications that transform and combine data to display information on the driver dashboard. The content layer, also known as the user interface, is the topmost layer of the stack. The user interface devices, such as computer screens, point of sale (PoS) stations, tablets, smart glasses, and smart surfaces, are included in this layer. The service layer follows, which includes applications and software for analyzing collected data and transforming it into usable information. It then proceeds to the network layer, where several communication protocols such as WiFi, Bluetooth, and low range (LoRa) operate. The device layer contains the physical hardware of the IIoT network, including devices such as CPS, machines, and sensors.

Standard bodies and industry stakeholders have identified a variety of potential use cases for IIoT. The following are the general requirements and objectives of IIoT:

- Quality of service (QoS) requirement with low latency, and ultra-high reliability is vital.
- Low-cost scalable network with esteemed security and privacy is desired.
- The emerging standards should be smoothly implemented and integrated on the IIoT devices in a flexible way.
- Inter- and Intra-connection of networks and IoT devices should be possible frequently.

C. Does 5G/B5G Satisfy IIoT Requirements?

After understanding the fundamental and necessary needs of IIoT, it is critical to establish if present and future wireless communication standards meet these requirements. The current standard, 5G, provides use cases that make industrial systems more flexible, beneficial, and autonomous while meeting QoS requirements of both 5G/B5G and IIoT. Some of the goals that can be reached with B5G in IIoT are as follows:

- Optimized services can be provided through the use of a dedicated network and unified connectivity.
- The standard guarantees 99.999% reliability with less than 1 ms latency in radio frequency (RF) environments.
- It substitutes fixed-wired Ethernet lines with re-configurable communication technology.
- Private networks can operate on both licensed and unlicensed spectrum.

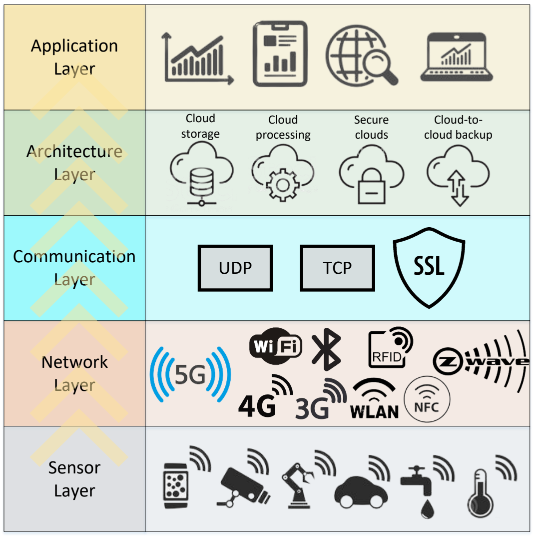

Fig. 4: 5G-IIoT architecture.

D. *5G/B5G-IIoT Primer*

The system model in Fig. 2 depicts the high-layer connectivity found in a 5G-IIoT network. 5G/B5G-IIoT is an integration of 5G/B5G with IIoT over a private 5G network. The inclusion of 5G/B5G in IIoT can provide the required ubiquitous and instantaneous connectivity for IIoT applications. A private network is one that has its own dedicated RAN and core mobile network. It is an easily deployed and independently managed local network. It requires a framework to process and analyze the obtained data using inter- and intra-industrial/device units. As shown in Fig. 4, the B5G-IIoT architecture is primarily separated into five levels [26], [27], [52], [56].

- **Application Layer** This layer includes IIoT applications in B5G, such as smart grids, smart factories, smart cities, smart cars, traffic management systems, health, and education. Devices and machines that send data via the internet are also included in the application layer.
- **Architecture Layer** This layer incorporates big data analytic (BDA) cloud computing and edge computing for data processing.
- **Communication Layer** The communication layer of the IIoT network transports information between all layers and is considered a critical component of the network.
- **Network Layer** This layer includes communication technologies such as low power wide area network (LPWAN), Bluetooth, WiFi, and 802.11.x, depending on the range and various required factors.
- **Sensor Layer** In the physical layer, sensors and actuators are available. These sensors are in charge of collecting data and transmitting it to the upper layer, i.e., the network layer.

The sensing layer is regarded as the most important layer in the IIoT network. The main reason for this is the large number of tiny sensing devices in a system that injects massive amounts of data into the network. As a result of the limited performance of these sensing devices, the tendency or performance of the upper layers may be compromised. In addition, the sensing capabilities of various sensing devices influence the overall system. Due to the massive connectivity and data flow, the IIoT's bottleneck is its limited network capacity. To overcome the limited processing capabilities of IIoT devices, recent advances in edge, fog, and cloud computing are exploited. Moreover, the sensors should have a rapid response time to facilitate real-time operations. In addition, the response must be reliable for accurate prediction and projection of future decisions.

The modern industrial industry is undergoing a technological transformation. Meanwhile, the IIoT proposes new communication technology requirements. Every IIoT application has essential design goals to improve QoS requirements. The key design goals for these critical IIoT applications are depicted in Fig. 5. The key design objectives are briefly stated here.

- **Energy:** Typically, IoT devices are classified as low power devicess (LPDs), with limited on-board energy sources. As a result, in order to improve the performance of the IIoT network, these LPDs should make efficient use of their available power resources to extend their life.
- **Latency:** In general, the B5G-IIoT applications are time-sensitive. As a result, a minimum end-to-end latency of less than 1 ms must be reached in all sorts of processing, computation, and propagation in the B5G-IIoT applications.
- **Throughput and coverage:** The QoS requirements vary for different B5G-IIoT applications and can be fulfilled by utilizing several efficient protocols. Typically, B5G-IIoT applications require a throughput in Gbps. For efficient transmission, long-range IIoT devices with long-life batteries must be used.
- **Network topology:** The number of devices connected to other devices, as well as to cloud and fog architectures, must be carefully determined for improved QoS. Furthermore, network topology has a significant impact on QoS performance.
- **Security & safety:** Nowadays, security and privacy are key concerns. To avoid the leakage of confidential information or data loss, data collection and processing between inter- and intra-B5G-IIoT applications require strong privacy and security.
- **Reliability:** Many B5G-IIoT applications require ultra-high reliability. For example, in a smart healthcare system, it is critical to delivering data reliably. Furthermore, the QoS requirements of URLLC in B5G-IIoT demand high reliability in a variety of real-time applications.
- **Cost effective:** Low-cost B5G-IIoT smart devices and applications must be installed and used to reduce capital expenditure (CAPEX)/operating expenditures (OPEX). Deployment of applications such as smart factories and industries must satisfy market demands.
- **Standardization:** In IIoT, the many B5G standards are employed. These standards' implementation must be flexible and compatible with IIoT devices.
- **Device maintenance:** In an industry 4.0 environment, heterogeneous devices require constant management due to their connectivity to one another and to the Internet.

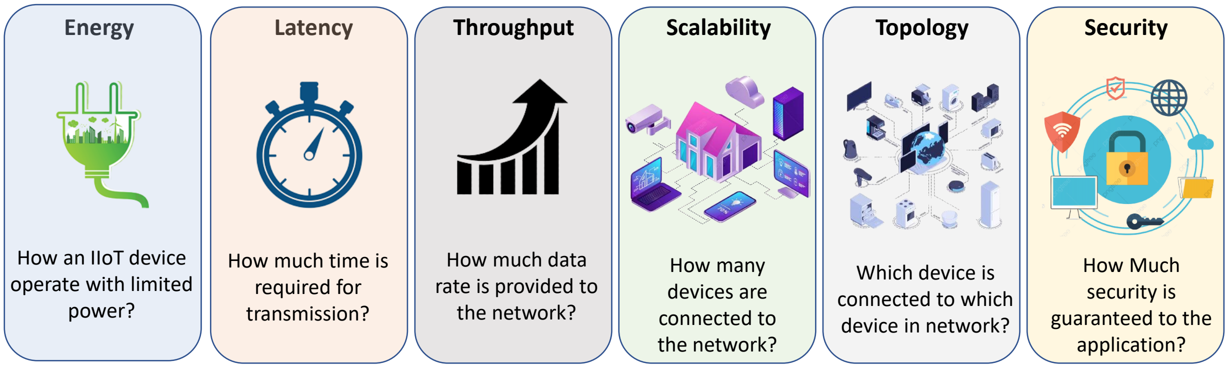

Fig. 5: Design goals for 5G-IIoT.

SDN is used to describe such failures and the evolution of IIoT device maintenance issues.

- **Monitoring network:** Mobility, congestion, and overload of IIoT devices within a wireless network can all affect the network topology. As a result, continual and frequent monitoring of the system is unavoidable. The number of smart devices in an IIoT application will grow over time. Thus, to avoid traffic congestion and overload, the system's settings should be capable of being adjusted in response to the traffic load and data requirements.
- **Configuration & system management:** It is critical to empower devices with self-configuration and control capabilities, as well as to reconfigure the network to accommodate new devices.
- **Scalability and integration:** Scalability poses various problems, such as how many smart devices are required to support an industrial application environment, how many devices can be comfortably handled by a server, and how to design a system efficiently within energy/spectrum constraints. Additionally, the integration of hybrid SDN and IIoT devices must be seamless and optimal.
- **Heterogeneity & interoperability:** Heterogeneous intelligent IIoT devices must communicate and exchange data with other devices, as well as share it through the Internet. This integration raises some serious challenges that must be addressed. Furthermore, standardization is desired for IIoT device interoperability.

III. ENABLING AND EXISTING TECHNIQUES FOR 5G-IIOT

IIoT networks have a wide range of applications in electronic devices and industrial equipment and are connected to billions of people. These numerous devices support a variety of network protocols and communication technologies; additionally, they are equipped with a variety of data processing and storage units and operate at a range of power levels. Each device is constrained by QoS, energy efficiency (EE), and spectral efficiency (SE)/throughput, cost, power, security, reliability, and latency/delay. Following this, we will summarize legacy technologies and present the 5G technologies for the IIoT.

A. Legacy Technologies

Industrial communication technologies are classified into wired and wireless categories based on transmission procedures, and account for 85% of the global market [57]–[60]. Fig. 6 depicts IIoT communication technologies.

Wired technologies include industrial field-bus and industrial Ethernet. These technologies provide reliable communication between the floor's control system and the higher-level control system. For cross-region communication between floors, control systems, and data centers, traditional Ethernet with its complex line topology is used, resulting in significant delays and inadequate security. Field-bus communication has been used to connect actuators, sensors, and instruments. Moreover, data was transferred through a field bus between these devices and higher control systems. It is the most extensively used wired industrial communication technology, consisting of RS485, DeviceNet, controller area network (CAN), process field bus (ProfiBus), and highway addressable remote transducer (HART). For IIoT, industrial Ethernet is a suitable wired technology when huge amount of data needs to be conveyed as it gives a greater bandwidth than field bus technology. Industrial Ethernet protocols include process field net (ProfiNet), ethernet for control automation technology (EtherCAT), Ethernet/internet protocol (IP), modbus transmission control protocol (TCP)/IP, serial real-time communication system (SERCOS)-III, and Power-Links.

Wireless technologies for IIoT are classified into long and short-range technologies based on their coverage range. Fig. 6 illustrates the major wireless technologies. The technologies are further categorized according to the services they offer, the requirements they fulfill, and the characteristics they possess [41], [61]–[66]. Table II compares the major parameters of the existing wireless technologies used in IIoT by classifying them based on the coverage they provide.

B. 5G Enabling Techniques

5G/6G key objectives are largely consistent with the IIoT requirements and are as follows: 1) URLLC: delivering high reliability and low latency to time-critical, real-time mission-critical applications such as disaster management. 2) eMBB: significantly increase the bandwidth and speed of smart city applications. 3) mMTC: connects millions of devices over long

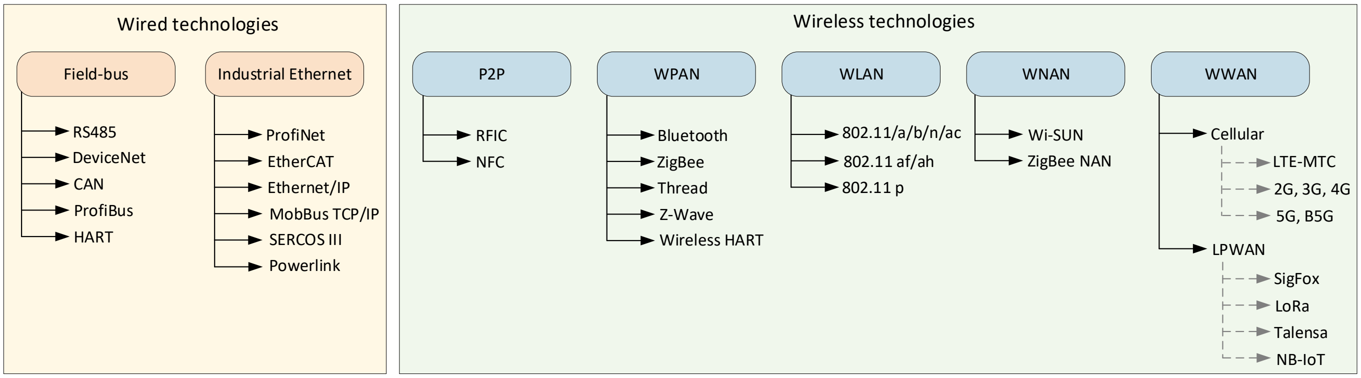

Fig. 6: IIoT communication technologies.

TABLE II: Wirless technologies used in IIoT.

Technology			Range (m)	Frequency	Max. Bandwidth	Data Rate	Power	Cost
P2P	RFID		10 m	13.56 MHz	1 MHz	640 Kbps	Low	Low
	NFC		20 m	13.56 MHz	1 MHz	848 Kbps		
WPAN	Bluetooth		60 m	2.402-2.480 GHz	2 MHz	1 Mbps	Medium	Low
	ZigBee		140 m	ISM <2.4 GHz	5 MHz	40 Kbps, 250 Kbps	Low	
	Thread		140 m	ISM <2.4 GHz	5 MHz	40 Kbps, 250 Kbps		
	Z-Wave		100 m	868.42 MHz - 908.42 MHz	200 KHz	9.8-100 Kbps		
	Wireless-Hart		225 m	2405-2480 GHz	5 MHz	250 Kbps		High
WLAN	802.11	a	Indoor 35 m, Outdoor 120 m	2.4 GHz	20 MHz	1.5-54 Mbps	Low	Low
		b	Indoor 35 m, Outdoor 140 m	2.4 GHz	20 MHz	1-11 Mbps		
		n	Indoor 70 m, Outdoor 250 m	2.4-5 GHz	20-40 MHz	72-600 Mbps		
		ac	100-1000 m	5 GHz	20,40,60,80 MHz	433-6933 Mbps		
		af	1000 m	0.054-0.799 GHz	6-8 MHz	< 568.9 Mbps		
		ah		Sub GHz	1-16 MHz	150 kbps - 78 Mbps		
		p		Sub GHz	5/10/15 MHz	1.5-54 Mbps		
WNAN	Wi-SUN		1000 m	ISM < 2.4 GHz	200 KHz - 1.2 MHz	50 Kbps - 1 Mbps	Low	Low
	ZigBee-NaN		5-10 km	868 MHz Europe, 915 MHz USA, 2.4 GHZ ISM World Wide	-	200 Kbps		
WWAN	LPWAN	SigFox	30 miles rural area, 2-6 miles urban area	868 MHz Europe, 915 MHz North America, 433 MHz Asia	100 Hz	100 bps	Low	Low
		LoRa	15-20 km	868 MHz Europe, 915 MHz North America, 433 MHz Asia	250 KHz and 125 KHz	50 Kbps	Device dependent	
		Telensa	2 km urban area, 4 km rural area	Sub GHz	-	62.5-500 bps	Low	
		NB-IoT	1 km urban area, 10 km rural area	Licensed LTE	200 KHz	200 Kbps		
	Cellular	LTE-MTC	< 100 km	4G-LTE Band	20 MHz	10 Mbps	PSM	High
		4G	< 100 km	LTE Band	5-20 MHz	100 Mbps	High	
		5G	< 100 km	Sub 6 GHz, mmWave	100-200 MHz	10 Gbps	High	

distances [64], [67]–[70]. Thus, the key objectives of B5G-IIoT are summarized as follows:

- URLLC, for real-time communication.
- eMBB and mMTC are used to increase the bandwidth and connectivity of a large number of devices.
- Security through network slicing.
- Edge computing is used to ensure proper edge functionality and to share local computations with edge devices.

From the perspective of IIoT, the use cases of 5G include robotics, AR, VR, process control, augmented guided vehicle, and factory automation. Table III summarizes the key enabling communication technologies. These URLLC aided B5G-IIoT key enabling technologies are multi-radio access technology (RAT), 4G, LTE, 5G/B5G, and vehicle-to-everything (V2X). Multi-RAT and coordinated multi-point transmission and reception (CoMP), 4G, and LTE are all included in the B5G standard as latency reduction techniques for URLLC. These techniques are based primarily on millimeter wave (mmWave) communication, ultra dense small cell network (UDN), and 3GPP Release 16 in device to device (D2D). Similarly, V2X is an application-oriented communication technique that includes vehicle-to-vehicle (V2V), vehicle-to-network (V2N),

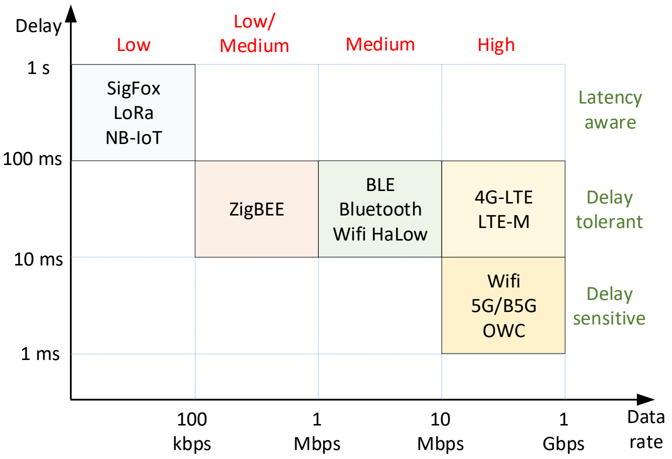

Fig. 7: Data rate vs. latency for various 5G-IIoT communication technologies.

and vehicle-to-infrastructure (V2I) communications. V2X adheres to multiple protocols to reduce latency and increase reliability, as well as to ensure compatibility with mission-critical IIoT applications. Similarly, 3GPP Release 15 and 16 employ a range of licensed and unlicensed spectrum techniques, such as LPWAN and wireless wide area network (WWAN), to enable the use of B5G-NR, UDN, 4G-LTE, and 5G new waveforms to deliver attractive multi-Gigabit data rates and multi-point connectivity to industry end consumers. Following are a few enabling technologies for URLLC and eMBB for 5G-IIoT:

1) Network function virtualization (NFV): The software implementation of virtualization creates a logical abstraction of the underlying hardware devices within a network [71] . By decoupling it from the hardware, the modifiable, management, and upgrading are simplified. Virtualization has not been limited to hardware alone, but also software embedded in hardware. Traditional networks are typically rigid and fixed. A major challenge of the Internet's rapid growth has been its heterogeneity, scalability, and interoperability. There are two main solutions to virtualize communication: NFV and SDN. One of the key benefits of NFV is that it replaces dedicated hardware with commodity servers [72]. Using it, users can run security applications, load balancing applications, data collection, and analysis applications, etc., using on-demand virtual network functions (VNR). In addition to enabling scalability and elasticity for the deployment of vendor-independent commodities at lower costs, this also optimizes the computing, memory, storage, and networking capabilities of network devices. IIoT devices and ecosystems can also benefit from virtualization by making their network functions [73] more agile, robust, and cost-effective. Thus, physical devices will be reduced, networks can be easily segmented, and security policies can be enforced on physical devices.

2) Massive MIMO: Before going into "massive multiple-input multiple-output (MIMO)," a potential enabler of 5G, it is important to understand the technology behind it. The concept of massive MIMO is different from that of traditional MIMO. A traditional MIMO system generally uses almost the same number of transmitter and receiver antennas to achieve high channel capacity because the channel capacity can be maximized with the same number of transmitting/receiving antennas from a system configuration perspective. Increasing one side of transmitting/receiving antennas increases power gain, but is of little help in increasing channel capacity.

However, in the IIoT era, it is impossible to configure the same number of transmitting antennas at the transmitter and receiving antennas at the receiver because the data center and/or base station (BS) can increase the number of transmitting antennas, but distributed entities and/or IIoT devices can't due to space constraints. Massive MIMO also sends signals from a single data center to several single-antenna IIoT devices. Massive MIMO has far more transmitting antennas at the transmitter than receiving antennas at the receivers; in fact, it often has several times the number of active user equipment (UE) devices with only one antenna piece. Precoding, decoding, scheduling, and power allocation algorithms become substantially easier to implement when channel gain and asymptotic orthogonality of channel vectors employing numerous transmitting antennas are taken into account. The ability to quadruple the capacity of antenna links has made it a vital component of wireless standards such as 802.11n, 802.11ac, high speed packet access (HSPA)+, worldwide interoperability for microwave access (WiMAX), and LTE.

The next generation of wireless data networks, known as B5G-IIoT, must address not just future capacity restrictions, but also existing difficulties with current communication systems, such as network stability, coverage, energy efficiency, and latency. Massive MIMO improves wireless data throughput and network dependability significantly. It allows more IIoT devices in a dense area to consume data without consuming more radio spectrum or producing interference. This results in fewer dropped calls, a significant reduction in dead zones, and higher-quality data transfer without extending the radio spectrum, which is becoming increasingly scarce.

3) New radio frequency: 5G NR access technology is a component of its RAN architecture, which is made up of LTE evolution and NR technology that will operate in a range of low, mid, and high band frequencies from sub-1 GHz to 24+ GHz. original equipment manufacturers (OEMs) and network operators will see considerable revenue growth as a result of IIoT enabled by B5G networks. Industrial automation on a shared, highly adaptable, virtualized, and scalable infrastructure will boost efficiency. Key 5G NR technologies including URLLC, 5G positioning, time-sensitive communications (TSC), and, to a lesser extent, eMBB will drive it. MTC technologies designed for LTE, such as enhanced MTC and NB-IoT, will complement IIoT. The Rel-15 3GPP specifications set the groundwork for URLLC. Later revisions of 3GPP specifications (Rel-16 and Rel-17) with new capabilities will improve IIoT networks even more.

4) Mobile edge computing (MoEC): MoEC, which was first proposed by the European telecommunications standards institute (ETSI) in 2014 [74], is thought to be a good alternative to the current centralized cloud by geographically distributing resources close to edge IIoT devices. MoEC aims to relieve network congestion, speed up response, attain high energy efficiency, and maintain context-awareness in 5G and beyond [75], [76]. MoEC has received a lot of attention from technology-based companies such as Huawei, Ericsson, and AT&T in recent years, and it has been recognized as a crucial technology in future IIoT by the industrial internet consortium (IIC). Although MoEC is not a new idea and has been thoroughly investigated, its application to the IIoT scenario is a novel path due to the heterogeneity of IIoT devices, the time-varying environment, and the need for scalability [77]. IIoT is intended to support a large number of small and low-cost devices to run in a self-sufficient way for a long time, to increase automation and lowering manufacturing costs. Edge computing can be combined with real-time automation to eliminate communication and processing delays. As IIoT networks get more congested, the role of edge computing in achieving the latency and reliability requirements becomes more prominent.

5) Non-orthogonal multiple access (NOMA): IIoT has increasing demands for large connectivity and high spectrum efficiency, however, finite wireless resources or even wired connections have limited the tendencies of the IIoT greatly. For IIoT involving wide-area coverage, long-distance transmissions and remote area information collection such as forest harvesting, geolocation exploration, marine development, satellite industry [78], [79], NOMA can be considered a key technique. NOMA promises to provide high spectral efficiency under limited spectrum scenarios. The combination of NOMA and successive interference cancellation (SIC) allows for the simultaneous delivery of packets from different sensors on the same resource block while reducing interference and increasing spectrum usage [80].

IV. STANDARDIZATION OF URLLC AND EMBB IN 5G-IIOT

IIoT requires stringent QoS requirements in both wired and wireless environments, including throughput, latency, reliability, coverage, power efficiency, and mobility [143], [144]. The enabling features and services provided by 5G/B5G, such as URLLC, eMBB, and mMTC, can assist IIoT in achieving the aforementioned QoS requirements. As a result, B5G-IIoT is regarded as an optimal solution. As a result, we classify technologies according to the QoS requirements of IIoT in URLLC and eMBB. This section discusses technologies in terms of standardization.

Table III summarizes the key enabling communication technologies. The key enabling technologies in B5G-IIoT which have been aided by URLLC are multi-RAT, 4G, LTE, 5G/B5G, and V2X. Multi-RAT and CoMP, 4G, and LTE are all included in the B5G standard as latency reduction techniques for URLLC. These techniques are based primarily on mm-Wave communication, UDN, and 3GPP Release 16 in D2D. Similarly, V2X is an application-oriented communication technique that includes V2V, V2N, and V2I communications. V2X adheres to multiple protocols to reduce latency and increase reliability, as well as to ensure compatibility with mission-critical IIoT applications. Similarly, 3GPP Release 15 and 16 employ a range of licensed and unlicensed spectrum techniques, such as LPWAN and WWAN, to enable the use of B5G-NR, UDN, 4G-LTE, and 5G new waveforms to deliver attractive multi-Gigabit data rates and multi-point connectivity to industry end consumers.

B5G-NR specifies three primary objectives, namely increased network density, increased SE, and access to high spectrum bands. Nonetheless, eMBB integrates multiple techniques, such as B5G-NR communication with UDN, mm-Wave, and FD communication. mm-Wave communication supports a wide variety of IIoT applications, including time-sensitive ones, with a data rate of up to Gbps. In Fig. 7, we compare various B5G-IIoT communication technologies in terms of their data rate and latency requirements. 5G/B5G-IIoT aims to provide industrial infrastructure with flexibility and scalability. As a result of the extremely low latency, high reliability, and high throughput of IIoT, it is more effective in automation control and monitoring systems. Following that, this section discusses technologies and their standardization. The key technologies in 5G standardization that can assist in 5G-IIoT compatibility are illustrated in Fig. 8.

A. 3GPP Release 15

In Release 15, the first phase of the 5G system is referred to as New Radio, or NR. With this 5G-NR standard, eMBB and eMBB can operate at frequencies up to 52.6 GHz. Release 15 of RAT release will include support for both non-standalone (NSA) and standalone (SA) connectivity. The Release 15 system will include critical features such as network slicing, access and mobility management, a QoS framework, a policy framework, and network sharing, as well as the interoperability of unauthorized 3GPP networks, i.e. WiMAX, WiFi, and integration with evolved packet system (EPS). The 5G system architecture and procedures will be described in detail in Release 15 specifications.

There is a discussion in 3GPP Release 15, which established the basic framework for URLLC in NR, primarily in support of IIoT. Powered by B5G networks, the IIoT enables new value creation and significantly increases revenue opportunities for OEMs. IIoT will improve efficiency through industrial automation, while also utilizing a highly flexible, scalable, and virtualized infrastructure. URLLC is based on Release 15 of the 3GPP specification. Two critical requirements for URLLC have been specified in 3GPP:

- Target user plane latency of 0.5 ms for the downlink (DL) and uplink (UL).
- Packet accuracy of 99.999% for a 32-byte packet with a 1 ms user plane latency.

Satisfying URLLC specifications is extremely difficult due to the coupling of high accuracy and low latency. To accomplish this, 3GPP Release 15 defines two distinct physical layer (PHY) feature groups for URLLC support.

The first group contains PHY features that are used to reduce latency. Additionally, features such as flexible slot structure, flexible scheduling, and fast are included. In the second group, PHY features are used to increase reliability. The following features pertain to data enhancements:

- To improve reliability, identical data packets are transmitted from multiple transmission points. This is accomplished through the use of the packet data convergence

TABLE III: Enabling technologies for URLLC and eMBB in 5G-IIoT.

Services for 5G/B5G-IIoT	**Enabling Technologies**	**Communication Standards**	**References**
URLLC	V2X communication	5G/B5G, NB-IoT	[81]–[93]
	Multi-RAT: CoMP, 4G-LTE,WiFi, 5G NR	LTE-M, WiFi/WiFi Halow, NB-IoT	[37], [53], [94]–[100]
	Instant and reserved scheduling	LoRa, NB-IoT, cellular	[34], [101]
	5G/B5G, 5G/B5G-NR	Cellular, LPWAN	[102]–[106]
	Packet and frame structure	LoRa, B5G	[53], [53], [107]–[113]
eMBB	B5G, B5G-NR	NB-IoT, LoRa	[114]–[120]
	Flexible data-rate (FD) communications	WWAN, WiFi/WiFi Halow, Bluetooth, ZigBee	[115], [121]–[125]
	NW techniques	B5G	[25], [53], [109], [126]–[132]
	Unlicensed spectrum based techniques	LTE-M, NB-IoT, LoRa, Talensa, Sigfox	[28], [29]
	Dense small cell network	WWAN, WiFi/ WiFi Halow, Bluetooth, ZigBee	[133]–[137]
	mm-Wave	B5G	[53], [114], [138]–[142]

protocol layer, which duplicates the data packet. It can be used to send the same packets to the UE from two different next generation nodeBs (gNBs) to improve reliability. Repetition with multiple data channel slots – Two, four, or eight repetitions can be used to increase reliability.

- The URLLC enables extremely high reliability through the use of special modulation and coding values.

The major characteristics of NR Release 15, which enables eMBB (10 Gbps - 20 Gbps), are as follows: Ultra-wide bandwidth (up to 100 MHz in < 6 GHz, up to 400 MHz in > 6 GHz), multiple numerologies for optimal operation at various frequencies, native forward compatibility mechanisms, new channel coding, native support for low latency and ultra-reliability, flexible and modular RAN architecture that supports split fronthaul, split control- and user-plane, and native end-to-end network slicing support.

B. 5G Evolution: 3GPP Release 16

The enhancements to 5G-NR in 3GPP release 16 include both extensions to existing features and new verticals and deployment scenarios. Unlicensed spectrum operation, intelligent transportation systems, IIoT, and extraterrestrial networks are a few of the highlights [145], [146].

Among them is the capabilities of 5G to support a large number of mobile and fixed IIoT devices with varying speeds, bandwidths, and QoS requirements. With the expansion of IIoT, the flexibility of 5G will become even more critical for enterprises that require support for the stringent requirements of critical communications. Due to the ultra-reliability and low latency of B5G, self-driving cars, smart energy grids, enhanced factory automation, and other demanding applications will be possible. As 5G improves network performance, cloud computing, artificial intelligence (AI), and edge computing all contribute to the handling of the data volumes generated by the IIoT. Additional 5G enhancements, such as network slicing, private networks, and 5G core, will ultimately contribute to the realization of the vision of a IIoT network capable of supporting a massive number of connected devices. The most significant enhancements in release 16 are in the areas of MIMO [147], [148] and beamforming enhancements, dynamic spectrum sharing (DSS) [149], dual connectivity (DC) and carrier aggregation (CA) [150], and power savings in UE [151], [152].

This release is targeted at industrial automation use cases. The 5G-URLLC foundation has been enhanced in Release 16 to ensure more reliable communication of up to 99.99%. Increased retransmissions are insufficient for these use cases, as there is a strict latency constraint as well. CoMP can be used in conjunction with other technologies to overcome this constraint. Multiple transmission and reception architecture (Multi-TRP) establishes redundant communication paths with spatial diversity, ensuring that communication is maintained even if one of the paths is temporarily blocked by using the remaining paths [32], [33]. Moreover, this release addresses new vertical and deployment scenarios, such as integrated access and backhaul (IAB) NR in unlicensed spectrum features related to IIoT and URLLC.

The IIoT is a significant vertical focus of NR Release 16. It includes latency and reliability enhancements on the already existent Release 15's work on high reliability and low air-interface latency. This release expanded IIoT use cases such as factory automation and electrical power distribution. Additionally, there is support for time-sensitive networking (TSN), which is critical for time synchronization. When the

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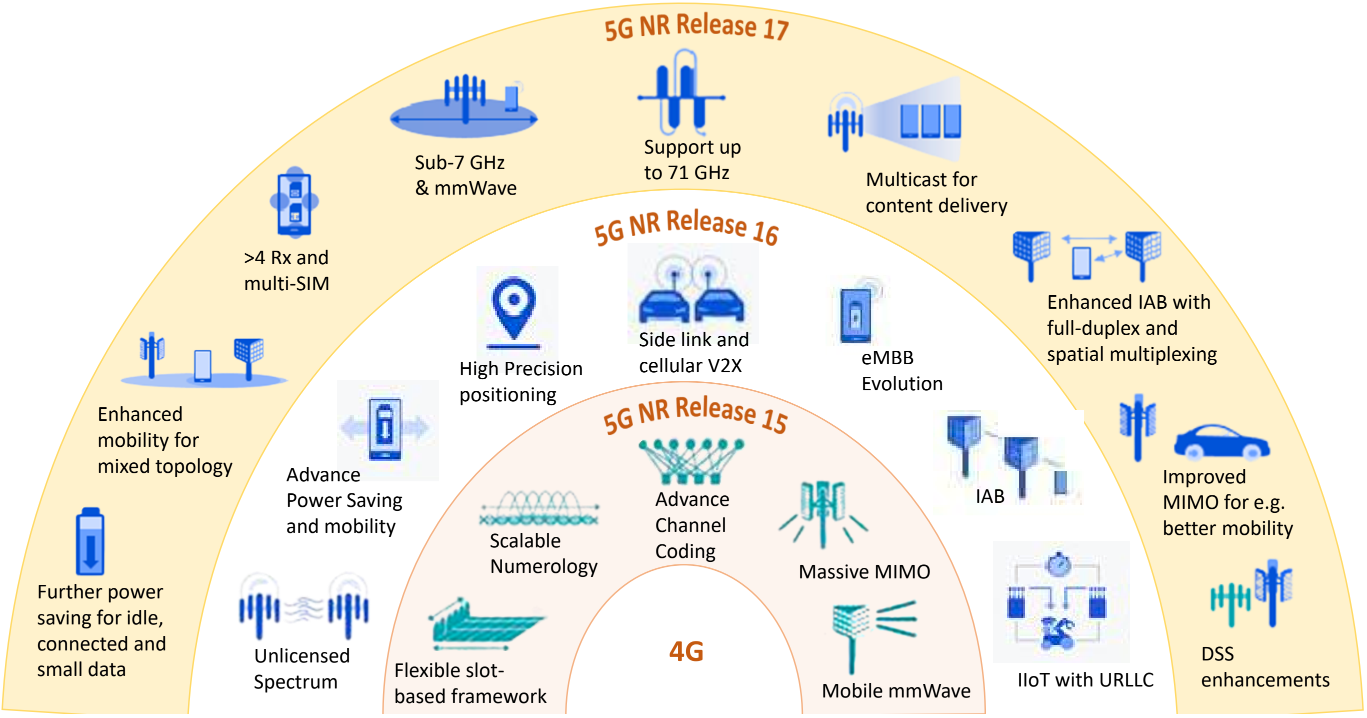

Fig. 8: Techniques in 5G standardization that can assist 5G-IIoT.

URLLC-related improvements are added together, they have a significant effect on NR. Release 16 extends the inter-UE DL preemption support introduced in Release 15 to the UL, allowing a UE to cancel a lower-priority UL transmission in favor of a higher-priority UL transmission from another UE. Additionally, Release 16 supports standardizing the resolution of intra-UE UL resource conflicts. Control-channel monitoring is more frequent in this release to reduce latency. Moreover, multiple configurations for both UL configured grants and DL semi-persistent scheduling can be active concurrently. The enhancements are especially beneficial for TSN traffic, where the BS is aware of the traffic pattern [153].

C. 5G Evolution: 3GPP Release 17

The 3GPP release 17 includes support for new use cases, such as public safety, non-terrestrial networks, and private networks, as well as enhancements to existing ones, such as mobile broadband, industrial automation, and vehicle-to-everything. Moreover, this release includes improvements to existing services and use cases, as well as new deployment alternatives and use cases.

Together with previously established use cases and deployment options, 5G will incorporate intelligent network technologies and support a large number of new use cases. One of the important components of 5G is the application of AI based on machine learning (ML) techniques. The implementation of AI/ML in future wireless networks will trigger a paradigm shift. AI and ML will be used to solve multi-dimensional network optimization problems in an online or offline manner, enabling the introduction of intelligent network management. By optimizing the performance of multi-antenna systems with AI/ML, for example, the radio interface can be enhanced as well. Wireless networks will enable immersive experiences in virtual and physical environments, as well as human-machine interaction with devices and wearables in IIoT, through extended reality communication.

A significant portion of the functionality already implemented in live NR networks will be enhanced in Release 17, which mark the beginning of the transition to 5G Advanced or B5G.

1) Beamforming and MIMO: Enhancements in Release 17 MIMO focus on four areas: beam management; Multi-TRPs to enable URLLC; Multi-TRPs to enable eMBB; and reciprocity in time division duplex (TDD) and frequency division duplex (FDD).

The goal of streamlining signaling and optimizing operator equipment (UE) with multiple antenna panels is to increase performance while maintaining high mobility. Multi-TRP has been added to the physical downlink control channel (PDCCH), physical uplink shared channel (PUSCH), and physical uplink control channel (PUCCH). Along with providing more detailed channel state information (CSI) feedback for non-coherent joint transmission, the new algorithms improve performance for high-speed train communications. Enhancements to reciprocity-based operation include the creation of new codebooks with reduced feedback overhead, the availability of channel information at gNB, and enhancements to the sounding reference signals.

2) Dynamic spectrum sharing: Using the DSS included in Release 15, it is now possible to deploy both a LTE and a NR cell from the same BS. Release 16 primarily increased the capacity of the physical downlink shared channel (PDSCH). Moreover, the release enables operators to better manage

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PDCCH resource shortages in the NR cell that occur as the number of NR UEs increases. Cross-carrier scheduling, introduced in Release 17, schedules data channels on the shared primary cell via the PDCCH of a DL secondary cell.

3) User equipment power savings: Release 17 includes power-saving enhancements for UEs operating in connected, idle, or inactive radio resource control (RRC) modes. Both eMBB UEs and RedCap devices are specified with power-efficiency enhancements. Several power-saving enhancements are included in this release's features, including relaxed radio resource monitoring for devices operating at low mobility or under ideal radio conditions, extended discontinuous reception for devices with a low latency tolerance, reduced PDCCH monitoring during active time, and power-efficient paging.

4) Positioning: NR added support for positioning via LTE (for non-standalone deployments) and RAT-independent positioning (Bluetooth, wireless LAN, pressure sensors, etc) in Release 15. A new version of Release 16 introduced time-based positioning methods for NR standalone deployments (multi round trip time (RTT), the DL time difference of arrival, and the UL angle of arrival), which can be used in conjunction with timing-based solutions to improve accuracy.

Release 17 further improves NR positioning for specific use cases such as factory automation by aiming for 20-30 cm accuracy in certain deployments. Additionally, Release 17 improves latency reduction, enabling positioning to be accomplished in time-critical applications such as remote control. Along with high-accuracy positioning, the integrity of location information is critical in IIoT and automotive use cases. The purpose of this release is to introduce key performance indicators to demonstrate the reliability/integrity of a measurement report that addresses the global navigation satellite system (GNSS) positioning procedure.

5) Ultra-reliable low-Latency communication: Using URLLC, 5G has penetrated into multiple vertical markets. Release 15 established a strong foundation, and Release 16 added enhancements by the 3GPP's system architecture and RAN groups to improve support for vertical industries such as factory automation, shipping and transportation, and electrical power distribution. Several redundancy schemes were added to the user plane as part of these enhancements, as well as improvements to reliability, latency reduction, and support for TSC. Enhancements in Release 17 are intended to increase SE and system capacity, while also supporting URLLC in unlicensed spectrum environments and strengthening the framework for supporting TSC. Additionally, enhancements to hybrid automatic repeat request (HARQ), CSI, intra-UE multiplexing, and service survival time will be included in the assistance information provided by the TSC.

6) NR coverage: The coverage of a company or organization has a direct impact on service quality, operating expenses, and capital expenditures, making it a critical factor in commercialization and competition. The PUSCH is identified as a potential coverage bottleneck in Release 17. As part of the 3GPP initiative to expand PUSCH coverage, mechanisms for transport block processing repetition and support for multiple slots are being investigated. Additionally, Release 17 specifies mechanisms for grouping demodulation reference signals (DMRS) and indicating dynamic PUCCH repetition factors.

7) Small data transmission: The existing NR RRC inactive mode promotes power-efficient connection establishment by allowing UEs to resume a previously established RRC connection. According to Release 17, data transmission in RRC inactive mode further reduces the power consumption of UEs during system access. This is especially important for low-power devices that transmit data infrequently and in small amounts in order to minimize control plane signaling overhead by avoiding the need to resume an RRC connection.

8) Non-Public networks: 3GPP Release 16 defined non-public networks (NPN) as those that provide access to a subset of users, such as devices belonging to a particular factory. The 3GPP specified two options for NPN deployment as part of its support for industrial verticals. An NPN that is integrated into the public network enables operators to support NPNs by directly integrating them into their networks. A standalone NPN is another option for deployment. As a general rule, a standalone NPN is functionally and characteristically comparable to a standard public network. Standalone NPN receive additional enhancements in 3GPP Release 17. The enhancements include the ability for a UE to attempt access to a standalone NPN using external credentials (such as those from a public network or another standalone NPN), UE onboarding to the standalone NPN (for example, by providing it with NPN credentials and/or subscription parameters), and support for emergency services.

9) Edge computing: Release 15 of 3GPP enables operators and third parties to host services close to the UE's access point of attachment. The baseline architecture reduces end-to-end latency and the load on the transport network. In Release 17, mechanisms for discovering edge application servers are introduced. For instance, it defines an edge application server discovery function (EASDF) whose primary purpose is to facilitate the session breakout connectivity method. In addition to acting as a domain name system (DNS) resolver, the EASDF can respond to DNS queries with UE location information. The UE locations can then be resolved to nearby application servers via the DNS.

Release 17 clarifies and enhances the use of user-equipment route-selection policy (URSP) rules in the distributed anchors and multiple protocol data unit (PDU) session connectivity models. When configuring URSP rules in the UE, application server information can be taken into account. As a result, the UE can establish PDU sessions dynamically for specific application servers, obviating the need for complex session breakout solutions. Additionally, Release 17 introduces new mechanisms for exposing QoS monitoring results and enhances support for application server relocation in the event of a UE's mobility.

V. TRADE-OFF BETWEEN URLLC AND EMBB FOR 5GS/B5G-IIOT

B5G-IIoT features various use cases related to high definition (HD)-video, VR, AR, smart cities, smart cars, smart factories, smart grid, remote control and autonomous robots

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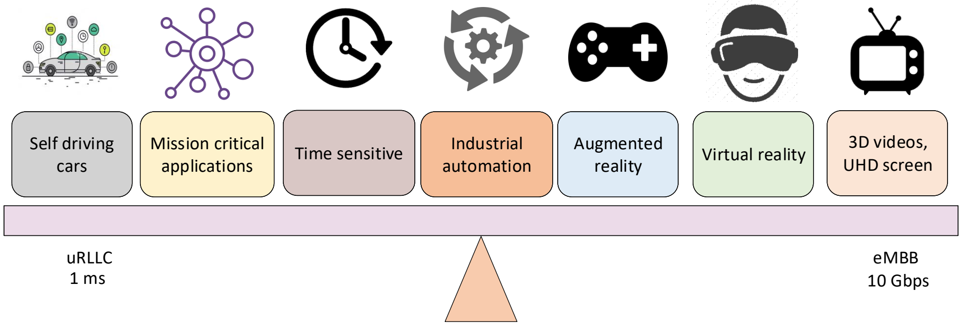

Fig. 9: Trade-off between URLLC and eMBB.

and AI networks. These use cases possess sensors, actuators, and processors along with massive IIoT applications. However, EE, SE, latency, reliability and throughput requirements vary for different IIoT applications. ITU has defined the QoS requirements for URLLC, mMTC, and eMBB in B5G standard. For URLLC, a reliability of 99.99% and less than 1 ms latency is required. EE and connection of massive IIoT devices is a parameter for mMTC, and throughput of up to Gbps is desired for applications categorized under eMBB. Therefore, B5G provides effective services to the IIoT applications and their corresponding use cases under varying QoS requirements. However, use cases that achieve URLLC suffer from a degradation of eMBB. On the contrary, if eMBB is achieved URLLC would be degraded. Therefore, a trade-off between the two is of particular emphasis, i.e., to achieve URLLC and eMBB simultaneously with the same resource-efficient method to satisfy the QoS requirement defined by ITU. Thereby, the coexistence of URLLC and eMBB open the doors to new technologies and research directions [31], [36], [179]–[183].

A. Performance Trade-off between URLLC and eMBB

Design trade-off between URLLC and eMBB is widely investigated by the research community. Some key trade-offs determined by the researchers are discussed herein.

1) Finite- vs. large-block length: In the recent past, the study of the effective capacity of fading channels has caught the attention of many researchers in order to understand the performance of wireless systems under the influence of statistical queuing [184]. Although channel coding is performed using a finite block of symbols, in almost all prior studies the service rates of the queuing model were assumed to be equal to the instantaneous capacity values. In addition, transmissions are assumed to be error-free with no decoding errors. However, it is important to note that error-free communication at the rate of channel capacity can be achieved as code-word length increases without limit. In order to achieve high reliability or lower error probability, finite blocklength codes will suffer from coding errors and will transmit at a lower rate than the channel capacity [185]. The low-density parity-check (LDPC), Polar, tail-biting convolution code (TBCC), and Turbo codes were considered potential codes for eMBB and URLLC data channels. While LDPC, Turbo codes, and Polar codes have similar performance at larger block sizes, the performance varies for lower block sizes [186]. The data channel for eMBB employs LDPC, whereas the control channel employs Polar Codes. Recently, it is demonstrated that error floors can exist for LDPC codes generated using base graphs 2 (BG2), an approach that has been investigated for short block low rate scenarios [185]. Polar codes are more accurate than LDPC codes without any evidence of error floor [185]. As a result, because the latency and data rate requirements for URLLC are so diverse, altering eMBB channel coding is challenging. The trade-off between eMBB and URLLC is being studied using infinite-block length information theory. In general, due to noise, deep fading, collisions, and interference, low-latency applications with small block lengths are prone to failure. If k information bits are transmitted using coded packets over n channel uses, the maximum coding rate $R = \frac{k}{n}$ is lower than the Shannon rate. Additionally, in order to ensure high reliability, encoded data must be transmitted at a lower rate than Shannon's capacity. With a large block length, no errors occur and the additive white gaussian noise (AWGN) channel's achievable rate is equal to Shannon's known capacity $R = \log_2(1+\gamma)$, where γ is the achieved signal to noise ratio (SNR) [187] . Shannon's capacity model has been shown to significantly overestimate delay performance for these applications, resulting in an insufficient allocation of resources. A theoretical framework is needed to model the performance of such systems for short time spans, finite block lengths, and interference [188], [189].

2) Spectral efficiency vs. latency: Additionally, transmission schemes must be capable of supporting a significant number of devices within a given bandwidth while maximizing battery life. With this approach, effective bandwidth has the potential to provide a good balance between SE and transmission time for a given coverage. To avoid excessive transmission time, the allocated bandwidth for a device should not be much less than the effective bandwidth. To be able to accommodate more B5G-IIoT devices while utilizing the available bandwidth without significantly increasing transmission time, it is preferred to allocate bandwidth that is not greater than the device's effective bandwidth for a given sensitivity level. Due to the short transmission time interval (TTI), low latency incurs a SE penalty. SE and latency are not characterized in a multiple access and broadcast system that takes into account: a) bursty packet arrivals; b) traffic that is low latency and delay-tolerant; and c) channel fading and multipath. To effectively support the huge number of B5G-IIoT devices

TABLE IV: URLLC and eMBB based B5G-IIoT applications; Lat.: Latency, Rel.: Reliability, Tp.: Throughput, Cell dens.: Cell density.

Smart applications	**Use cases**	**Lat. (ms)**	**Rel.**	**Tp.** (Mbps)	**Cell dens.** (Gbps/km^2)	**Ref.**
Factories	Printing & packaging machines	2 & 1	10^{-9}	1,< 100	10	[19], [154]–[166]
	Machine tools & manufacturing	0.5 & 5	10^{-9}	< 100	< 10	[154], [159], [166]
	Monitoring automation & remote control	50	10^{-3}-10^{-5}	1, < 100	< 10	[19], [159]–[165], [165], [166]
	Remotely operated video & motion control	10-100 & 1	10^{-9}	< 100	14	[155]
	Industrial robots	4-8	10^{-9}	< 100	10	[167]–[170]
	Milling machines & cranes	4-8 & 12	10^{-9}	1,< 100	10	[167]–[170]
Autonomous vehicles	Accidental warnings	10	10^{-3}-10^{-5}	0.1-29	N/S	[82], [165], [171], [172]
	High speed train	10	N/S	25-50	12.5-25	[19], [157], [158]
	Automated driving	5	10^{-5}	0.1-29	N/S	[19], [157], [158]
	Drone	150	10^{-3}	$20 - 40$	-	[173], [174]
Grid Stations	Medium electricity distribution	25	10^{-3}	10	10	[19], [157], [158]
	High electricity distribution	5	10^{-6}	10	100	[19], [157], [158]
Cities	Outdoor industrial events	1-2	10^{-2}	30	900	[158], [165], [171], [172], [175]–[178]
	Public gatherings	10-100	10^{-2}	0.3-20	100-10000	[158], [165], [171], [172], [175]–[178]
	Shopping centers	10-100	10^{-2}	60-300	60	[158], [165], [171], [172], [175]–[178]
	Mass communication	200-5000	10^{-2}	15	60	[158], [165], [171], [172], [175]–[178]
	Urban area	1-2	10^{-2}	60-300	700	[158], [165], [171], [172], [175]–[178]
Roadside traffic management	Traffic congestion	8	10^{-3}	20-100	480	[157], [158]
	Traffic management efficiency	<100	10^{-3}	10	10	[19], [156]–[158]
	Urban crossings	< 100	10^{-5}	10	10	[19], [156]–[158], [171], [172], [175]–[178]
	Safety measures for highway	10-100	10^{-3}-10^{-5}	10	10	[19], [156]–[158]
	safety measures for urban area	10-100	10^{-3}-10^{-5}	10	10	[19], [156]–[158]

in 5G and beyond cellular networks, advanced transmission scheduling techniques and low signaling overhead medium access control (MAC) protocols need to be investigated [190].

Another tackle design option is to choose between unlicensed industrial, scientific, and medical (ISM) bands and licensed bands. The global unlicensed operation is cheaper in terms of time, but there are no legal protections against interference from other wireless networks using the same frequency band. Licensed bands, on the other hand, prevent interference by relying on an outside operator. As a result, it is not possible to handle network difficulties on-site; instead, an external operator must do it. As a result, time-critical industrial applications in 5G/B5G-IIoT cause unavoidable administrative delays. Communication technologies that operate in an unlicensed spectrum are maintained locally. There will be interference between co-located or overlapping wireless networks operating in the same frequency band, which might result in degraded QoS and substantial packet loss [191]. Several norms have been imposed by regulatory authorities to reduce coexistence concerns in unlicensed spectrum, including a clear channel assessment (CCA) check before each transmission by all devices, where devices verify if the channel is free by energy detection or other means [191]. Despite the improved coexistence provided by the detect and avoid (DAA) mechanism, collisions between competing wireless nodes and networks are still possible. A medium sense, in addition to collisions, introduces latency and non-determinism as a result of medium congestion [192]. The aforementioned facts greatly limit the use of wireless solutions for closed-loop control applications in the automation industry. A restricting rule also applies to sub-GHz spectrum. If an access point (AP) supports listen-before-talk (LBT) and adaptive frequency agility (AFA), the maximum duty cycle limit for devices operating in Europe between 863 and 868 MHz, 916.5 and 927.5 MHz for devices operating in Japan, and 902 and 928 MHz for devices operating in the US is 2.8% [193].

3) Energy efficiency vs. latency: An important trade-off that needs to be identified is energy consumption versus latency. The battery life of B5G-IIoT devices is extended by placing them in sleep mode or deep sleep mode while they are not in use. The device needs to check periodically for packets sent by applications on the network, since applications sending packets to the device may wake it up. In addition to the latency of the packets, the device checks frequency, determining how much energy is consumed. As the frequency increases, the latency will decrease, but energy consumption will rise. When reliability deteriorates, re-transmissions are necessary, which means more energy is consumed to provide a target level of reliability. Energy is measured generally using $\sqrt{d^{-1}}$ or $\sqrt{d^{-1}\log d}$, where d is the delay. This means that the energy decreases quite slowly with increasing delay [187].

Another parameter for the energy efficiency of B5G-IIoT devices is throughput, MAC design, and hardware topology. Low data rates lead to long transmission times, which increase the node's energy consumption and battery life. Long single-hop transmission delays result in higher latency and a decrease in the node's energy consumption and battery life. However, with multihop transmission, latency can be lowered at a higher energy cost [194]. The energy efficiency of forwarding paths provides a robust effect on energy usage for routing protocols. Complex coding, data packet forwarding, and decoding procedures all require energy, i.e. commercial networks of 802.15.4 in B5G-IIoT exclude forward error correction (FEC) due to energy consumption in the decoding process. However, adopting FEC should lower overall energy consumption because less energy is wasted on retransmissions and rescheduling [192] and latency can be addressed as a function of frame size. However, MAC configuration has a significant impact on energy consumption because it specifies scheduling and, as a result, radio on and off instances [195].

4) Reliability vs. latency vs. data rate: IIoT and next-generation wireless communication standards, including 5G and B5G, provide applications which require rethinking the communication stack, practical codes, networking architecture, and control design to provide ultra-low latency of 1 ms, extremely high reliability of more than 99.99%, and 20 Gbps peak data rates. However, higher reliability comes at a cost of higher latency. Typically, the reliability is ensured with re-transmissions which induce additional delays. However, higher data rates is achieved at the expense of lower reliability, and vice versa.

Latency decreases as data flow increases, allowing for more complex coding and higher bandwidths. Furthermore, multi-hop topology increases latency owing to routing and forwarding delays. When a link fails in low-latency time-critical IIoT applications, a new route is computed and a delay is introduced, rendering multi-hop topology ineffective [196]. MAC design also influences latency in IIoT technologies, in which devices sleep as long as possible to conserve energy [197]. In MAC, there are four types of protocols: a fixed assignment protocol that divides resources among nodes over a predetermined time period, an adhoc assignment protocol that distributes resources based on demand, a random access protocol that distributes resources randomly, and a hybrid protocol that combines fixed and ad hoc assignment. Under extremely high loads, fixed assignment protocols such as time division multiple access (TDMA) and deterministic protocols such as transmission division multiple access (TrDMA) provide more deterministic performance and lower latency. However, under low loads, they waste resources through inefficient channel utilization, whereas random access protocols achieve lower latency. Demand-based protocols cannot be utilized for low-latency time-critical communications since explicitly requesting for resources each time adds latency and bandwidth. Heterogeneous IIoT applications require hybrid techniques because they seek to utilize the benefits of both fixed assignment and random access protocols while exceeding their limits and adapting to network conditions at the same time. Furthermore, retransmissions should be kept to a minimum to reduce delays.

Higher reliability, however, comes at the expense of increased latency. Re-transmissions, which cause extra delays, are commonly used to ensure reliability. The reliability of a system is determined by its topology, MAC design, and modulation and coding scheme (MCS). One of the fundamental disadvantages of wireless technologies over their wired equivalents is inter- and intra-technology interference, which causes packet loss and collisions. If the technology operates in a licensed band, the use of a licensed spectrum mitigates this issue. Spectrum is a limited resource that is costly to obtain. Private deployment is not allowed in the reserved spectrum, which means that local network control is not possible. Nonetheless, the shared spectrum can be utilized by several technologies to prevent interference, such as channel hopping and LBT. In single-hop networks, a single link affects the success probability, as opposed to multiple links in multi-hop networks. Retransmissions and repetitions can improve reliability at the MAC layer, but they can increase latency. FEC is a technique that can lower the number of retransmissions, where the coding scheme and modulation are critical components for reliability. The coding rate enhances the reliability of modulation by adding additional error-checking bits. Because there are fewer points on the constellation diagram, modulation systems are more reliable, but they are also slower. As the number of constellation points increases, the distance between them decreases, resulting in reduced error margins. quadrature amplitude modulation (QAM) is the quickest modulation scheme, although it is less reliable over long distances.

Nevertheless, increased data rates are achieved at the expense of decreased reliability. As data rate is directly proportional to available bandwidth and, consequently, frequency range, modulation and coding method are also important. More bandwidth permits greater data rates, while modulation techniques and coding schemes can aid in increasing the data rate by incorporating more data into the signal [196]. Unlicensed wireless technologies operate in the frequency ranges of 400 MHz, 800–900 MHz, 2.4 GHz, and 5 GHz. In general (but not always), sub-gigahertz technologies employ narrower channels (a few hundred kHz) than those in GHz frequency bands (22 MHz Wi-Fi, 2 MHz 802.15.4), resulting in lower data rates.

5) SNR vs. diversity: Diversity is typically defined when plotted against the SNR on a logarithmic scale as the slope of the probability of error. The key question is: how does the SNR requirement decrease with increased diversity and nodes in the network? How does the use of higher frequency bands affect diversity? It's important to know how much SNR is needed to balance time-varying channels and bad fading events. SNR significantly affects the diversity but compensates for the time-varying channels.

As a result, combining many sources in the time, frequency, and/or geographic domains leads to improved dependability and rates and decreased latency. Cooperative diversity is a well-known strategy in the literature where several communication nodes assist one another in the transmission process to improve communication reliability [198]. A 5G NR mini-slot is used to share a pool of radio resources in the time and frequency domains among the devices at cloud radio access network (CRAN), and selected cooperating nodes are assigned based on the availability of resources [199]. This is motivated by the fact that exploiting diversity in the time or frequency domain to support URLLC transmissions is a viable option for future network reliability and latency requirements.

6) Open vs. closed loop: In a closed-loop system, low data rates are obtained due to the utilization of limited resources. In an open loop, the cooperative devices, such as the relay nodes, broadcast the packets for transmission which results in a reduced delay. Moreover, diversity puts a positive impact on reliability. Multiplexing techniques, such as open-loop MIMO, maximize multiplexing gains. Despite this method's ability to transmit multiple data streams using multiple transmit antennas, it requires a complicated detection algorithm in the receiver. Unlike open-loop MIMO, closed-loop MIMO techniques build capacity or improve SNR based on channel knowledge. Since closed-loop MIMO in highly mobile environments experience a delay between transmitting and receiving channel information, designers should be careful when using it. In addition, MIMO with closed-loop feedback and limited uplink sounding performs poorly due to incomplete channel knowledge.

B. Enabling Technologies and Standards for Trade-off between URLLC and eMBB

Many existing enabling technologies cope with the trade-off between URLLC and eMBB. However, this is still an open research question to obtain an optimal trade-off point.

1) TTI: The TTI in 5G NR and LTE is reduced to 1 ms and 0.125 ms, respectively, by introducing wider spacing between sub-carriers. Further improvement is realized by reducing the RTT during HARQ retransmissions, which eventually leads to a significant reduction in latency. To satisfy the QoS constraint of reliability, minimum time should be consumed during HARQ retransmissions. Having said that, the reduction in symbol duration and growing spaces between the sub-carriers also lessen the achieved rate and available resources for the transmission. Therefore, a trade-off is imperative between the latency and sub-carrier resources.

2) Multiplexed eMBB and URLLC: For an efficient and optimized system, the resource partitioning is static or semi-static between eMBB and URLLC. Typically, high frequency is required to achieve a high degree of reliability besides low latency. However, intelligent and optimized scheduling schemes are used to transmit low latency packets, while relaxing the eMBB.

3) Network slicing and edge caching: Edge caching and cloud computing have shifted and shared the network load to the edges, thereby, reducing the latency of URLLC. In parallel, additional bandwidth and caching resources are gained through network slicing. These techniques have provided a boost to sensitive applications such as AR and VR.

4) ML & AI: ML has gained overwhelming attention from the scientific community during the last decade. Typically, the ML executes the global data sets for classification and regression to approach a solution. ML, together with AI, has delivered a notable gain to the QoS requirements of URLLC by solving a problem in a distributed fashion, and also referred to as AI and ML on the edge and on the device.

As IIoT is rolled out, the business world is changing rapidly [200]. The combination of ML/AI and IIoT has the potential to reshape how industries, companies, and economies function. ML/AI inference can complement or replace manual processes by automated systems utilizing statistically derived actions in critical processes. Companies use ML/AI for IIoT to perform predictive abilities on a wide variety of use cases that allow the company to gain new knowledge. ML/AI for IIoT can integrate and transform data into a coherent format. It can build an ML/AI model for beneficial information. ML/AI in IIoT can enhance operational efficiency by revealing which steps are redundant and time-consuming, and which tasks can be optimized and made more efficient [201]. It can also provide machine and software control without human intervention, eliminating errors and improving accuracy [202]. It is no exaggeration to say that IIoT and ML/AI are the foundations of predictive maintenance. Predictive analytics is a type of analysis that examines existing data and predicts possible future events based on insights.

5) Grant free access: In persistent scheduling, rapid access to the resources on high priority is mandatory. However, in semi-persistent unused resources must be allocated to the eMBB applications. In grant-based access, the BS control the resources. However, in grant-free access, the resource assignment procedure is skipped which eventually enhances the latency of URLLC.

VI. APPLICATIONS OF 5G-IIOT IN-TERMS OF URLLC TO EMBB

With the emergence of 5G/B5G, several IIoT applications such as smart cities, smart industry to smart grid and intelligent networks gain benefits from its distinguished features, e.g., URLLC and eMBB are two notable services for IIoT applications. eMBB fulfils the bandwidth requirement of data-intensive IIoT applications, e.g., AR, industrial video surveillance and VR. However, applications such as robotics, motion control, and autonomous driving controls are time-sensitive and mission-critical applications and are, therefore, served by URLLC. Moreover, eMBB provides a much higher data rate of up to Gbps with better coverage, while URLLC reduces the delay and provides the latency of 1 ms to the IIoT applications. Table IV provides IIoT applications along with their throughput, latency, and reliability bounds.

Various B5G-IIoT applications are shown in Fig. 9. These applications are self-driven cars, mission-critical applications, i.e., remote control robots and machines, time-sensitive applications in which latency is a grave concern, industry automation AR, VR and HD-video. These applications are categorized from URLLC to eMBB. Each application has its own QoS requirement which needs to be satisfied via different enabling and communication technologies. These important IIoT applications are discussed herein.

A. Smart Factory

Smart factory design parameters are mission-critical, with closed-loop control system which requires a latency of less than 1 ms and 99.99% service availability. Specifically, industrial and health robots with motion control are categorized as URLLC, as they are delay-sensitive and require high reliability and low latency. However, eMBB based AR and VR need a high data rate and throughput. Therefore, in general 5G/B5G-IIoT provides communication between inter and intra industrial factories with constraint requirements.

Certain use cases for smart factories are discussed in Table IV with corresponding parameters. These use cases include printing and packaging machines, remote control automation and monitoring, industrial robots, video and motion control, milling machines, and cranes. Moreover, the latency and throughput requirements of the aforementioned use cases are also listed. URLLC use cases include automation, industrial robots, and motion control [154]. These use cases seek a latency of less than 10 ms and 99.9999% resources availability. While eMBB applications include virtual and augmented reality which need a high data rate universal connection [19], [155], [159], [166]–[170].

Smart Factory is an application of B5G-IIoT. To get maximum benefits from it, the key implementation and QoS maintaining issues are discussed. Smart factories have many interconnected networks, industries, and devices including industrial wireless sensor networks (WSNs) which need connections with minimal delays, must be power efficient for continuous processing, and provide no queuing of data. To jointly exploit all these services and features in a smart factory is a big challenge for the research community. Licensed and unlicensed spectrum is used for communication between devices to gain maximum possible data rates. In B5G, the mm-Wave is considered a suitable choice for high throughput, reliability, and low latency. However, it suffers from various attenuation.

B. Smart Autonomous Vehicles

Smart vehicles require an efficient real-time exchange of data acquisition and processing. Smart vehicles are designed with many sensitive sensors which can be efficiently controlled and monitored to fulfill the requirements of URLLC and eMBB. The efficient control of sensors ensures the safe exchange of real-time secure transfer of a large volume of data at a high rate. The latency requirement of less than 10 ms and a throughput of up to Mbps encourages partially or fully shifting the data processing to the cloud and the edge. To design a smart autonomous vehicle system, data sensing and transmission can be done from vehicle to vehicle and from vehicle to traffic using diverse communication technologies including ZigBee, WiFi, and 5G/B5G.

Several smart autonomous vehicle use cases are discussed in Table IV. These use cases are accidental warnings, high-speed trains, and automated driving. These use cases are time-sensitive and need a high-speed data exchange. For example, in an accidental scenario, ultra higher throughput with minimal latency is desired [157], [158], [171], [172].

C. Smart Grid

Smart grid is among the most monitored and controlled IIoT applications. Owing to B5G, the smart grid generates, transmits, and distributes electricity with additional reliability, scalability, sustainability, and safety. From the consumer perspective, the usage of electricity is more adaptive in high-speed vehicles, storage units, wireless sensors, and IIoT devices. B5G-IIoT drives the smart grid more efficiently due to reduced delays and enhanced reliability. Moreover, B5G-IIoT connects low-voltage grid stations to other elements of the smart grid, and the backbone networks of B5G to medium and high power voltage grid stations.

Typical use cases for smart grids include medium and high electricity distribution stations are provided in Table IV. These use cases have different latency and throughput requirements according to their targets, i.e., future and sudden disturbance in normal grid stations need less than 5 ms of latency and a data rate of up to 30 Mbps for up-link and 3 Mpbs for down-link receptions. Thus, it is expected that up to 100 customers can be simultaneously supported with less than 1 ms delay and 99.999% resources availability. Similarly, B5G-IIoT uses mm-Wave for smart meters for accurate prediction of the energy usage of the consumers and to effectively transmit the information to the micro-grid [157], [158], [203]. The problems often occurring in the industrial smart grids are required to be timely controlled. Moreover, the seamless power transmissions between city areas need to be real-time, time-sensitive, and should be monitored and controlled to avoid disruptions in connectivity.

The Smart Vehicle IIoT applications suffer from wireless connectivity and other QoS related challenges. Some of the challenges such as system performance reliability, connectivity, and passenger's internet availability are the main concerns. The process of acquisition and processing of real-time data in a small vehicle, global positioning system (GPS) connectivity, fuel, and hazard monitoring applications need efficient communication, while jitters and latency can cause serious hazardous situations. Thus, real-time data acquisition and time-sensitive applications are challenging to deal with. Allocation of resources in a smart vehicle is also challenging because of its mobility and constantly changing geographical locations. Thus, efficient implementation of V2X infrastructure with multi-RAT technology for low latency, high throughput, and high reliability makes it more challenging for smart vehicles.

D. Smart Cities

The concept of smart cities is trending for the last decade. Typically in a smart city, the services such as transportation, health care, and schooling are integrated with the communication infrastructure. Traffic update is another modern time-sensitive smart city application and, therefore, can be implemented using URLLC. Thus, IIoT plays a pivotal role in building smart cities by integrating different applications at a high data rates, high reliability, and low latency. Communication technologies LoRa wide area network (LoRaWAN), SigFox, WiFi, 802.11x, Bluetooth and LTE are used data collection and processing of data from smart city sensors'.

Use cases for smart city include managing of larger events such as football matches, shopping malls and media. High-quality live coverage is needed for media activation and at ultra higher data rate. Similarly, health and traffic systems seek real-time monitoring and should be communicated with less latency and high reliability to the consumer end. B5G-IIoT supports high reliability, higher data rate with less than 1 ms latency for smart cities [158], [165], [171], [172], [175]–[178].

The concept of smart cities corresponds to the large-scale deployment of various sensors and actuators to achieve a high degree of monitoring and management for various aspects of modern cities. Intelligent transportation systems, smart highways, and smart homes are a few examples to mention. Almost all these applications the QoS requirements of URLLC and eMBB need to be implemented in different ways, using different communication and enabling technologies. Real-Time and time-sensitive monitoring and control applications, including accidental cases, highways, and traffic, are susceptible to low latency and high reliability. However, for large gatherings in shopping malls and stadiums, real-time coverage with high throughput and low latency is required. Thus, joint optimization of multiple QoS constraints is a challenging task.

E. Smart Healthcare Service

New opportunities in healthcare improvement are discovered through the IIoT [204], [205]. Owing to ubiquitous identification, sensing, and communication capabilities in IIoT, all objects in the healthcare system can be continuously tracked and monitored [206]. These objects comprise the people, medical equipment, and medicine. Healthcare-related information can be collected, managed, and shared through global connectivity. This information is related to the logistics, diagnosis, therapy, recovery, medication, management, finance, and even the daily activities of the patients. For example, the doctors can periodically monitor the heart rate of a patient under an IIoT aided healthcare facility. The IoT-based healthcare services can be formed as mobile and personalized using personal computing devices, e.g., laptops, mobile phones, tablets, and mobile internet access [207]. The universal availability of mobile internet has accelerated the development of IoT-based at-home healthcare (AAH) services [205]. Security and privacy are the major concerns and challenges in smart healthcare services.

In smart hospitals, B5G-IIoT plays an important role and provides services for living and the health care system. Remote health monitoring of the devices and patients must be quick with minimum latency and high reliability. Similarly, a robot that assists in surgery requires minimum end-to-end latency, high reliability, and throughput which makes it more sensitive and challenging.

F. Smart Homes

Smart homes are intelligent buildings, equipped with smart devices and sensors that are connected to the internet, and are able to make instantaneous and distributed decisions. Besides, the users can control the electrical appliances with smart and intelligent technologies, including bilateral computer interfaces (BCI) and AI. These technologies analyze human behaviors to create a safer, more convenient, and easier environment for the end-users. The smart home will become a reality with 5G and B5G.

G. Smart Robots

Autonomous robotic systems allow the development of the capabilities of individual robots, their integration into platforms, and enable the development of fleets of heterogeneous robots for collaborative applications. Usually, robotic applications require robust and resilient wireless/cellular communication. The applications use a variety of communication channels, including cellular, optical, audio, and video. In communication networks, protocols for many purposes may be used, including 802.15.1, 802.15.4, 802.11, 4G/LTE/5G, and more. Edge-distributed processing, instead of centralized processing, is more suited for mission- and safety-critical robotic applications. These applications include analytics based on AI methods. Edge-distributed processing makes use of multi-access edge and fog computing technologies, as well as wireless and cellular communication, i.e., 4G, 5G, and B5G. The use of intelligent networks can facilitate the transfer and processing of information in an energy-efficient manner. The artifical neural networks (ANNs), ML, and other AI techniques further improve the efficiency of decentralized data analytics, automated network management, and context and knowledge sharing for robots and IIoT applications.

H. Smart Industrial Manufacturing

Industries are always in dire need of smart, efficient, and cost-effective manufacturing solutions to increase their revenues, and simultaneously fulfill the market's demand and supply needs. Modern technologies including robotics, warehouse automation, and smart factories play a vital role in the industries to accomplish the manufacturing goals. These advancements are further enhanced through B5G wireless networks and IIoT. With B5G, manufacturing industries will be quickly transformed into smart industries by automation, AI, and AR techniques. The B5G revolution in industry digitization is upgrading connectivity, speed, quality, and latency. The B5G can successfully handle the manufacturing challenges, including bandwidth, speed, and latency. Owing to the benefits offered by B5G, factory floor machines and robots will be connected for better predictive maintenance. For factory floor layout changes and adjustments, B5G networks will offer higher flexibility, lower costs, and shorter lead times. With advanced B5G networks and information processing technologies, smart factories can be streamlined, internal and external communications can be improved, and product life cycle management can be unified on a single network.

I. Smart Forestry

Digital forestry is turned into smart forestry with characteristics such as perception, materialization, intelligence, and ecology. Research, production, management, and services in forestry are heavily dependent on private wireless communication networks. In the forest environment, wireless connectivity is the main challenge. Typically, distinct wireless communication technologies are used to overcome the challenges in smart forests. These technologies comprise global system for mobile communications (GSM), general packet radio service (GPRS), Zigbee, bluetooth low energy (BLE), IPv6 over low-power wireless personal area networks (6LoWPAN), radio-frequency identification (RFID), LoRa, Sigfox, NB-IoT, LTE, WiFi, near field communication (NFC), and Z-wave. With smart forestry, the management and service values of forestry will be deeply explored and the forestry economy will become more prosperous.

J. Smart Traffic Control

Smart traffic management is susceptible to low latency and high reliability for proper management and observation of traffic, between cities, and on highways. Data exchange must be with high reliability and low latency to reduce hazards and emergencies. URLLC and eMBB play an important role in road safety management [19], [156]–[158].

K. IIoT in Mining Industries

According to IBM data, the average person consumes 3.11 million kilograms of metallic materials and fuels in their lifespan source [208]. These metallic materials are extracted from the earth through the mining process, which is a risky and expensive process. According to the US Department of Labor report [209], there were 29 mine-related deaths in the year 2020. Accordingly, mining fatalities are even higher in under-developed countries. Moreover, the workers involved in the mining industries may suffer from various deceases, such as coal workers' pneumoconiosis (CWP), mixed dust pneumoconiosis (MDP), silicosis (a form of pneumoconiosis from silica dust), chronic obstructive pulmonary disease (COPD), asbestosis, and cancer [210]. Adoption of IIoT in the mining industry will increase output, decrease waste, improve worker and laborer safety, and reduce costs. For instance, collecting and analyzing records before drilling can save both time and money. Similarly, IIoT models improve the safety of the mining industry by reducing the probability of suffocation, rock sliding, and other accidents [211]. Furthermore, by integrating operational technology and information technology, an efficient IIoT architecture could improve mining workers' safety and predictability, create an environment where old and new systems and devices can interoperate, automate tasks so that people perform certain tasks less frequently, and enable underground surveillance [212].

L. IIoT Assisted Smart Education

A new industrial production paradigm that focuses on digitization, system connectivity, virtualization, and data exploitation has recently evolved. Smart education, as it evolves through IoTs, enables students to reinforce theoretical knowledge through hands-on experience with professional-grade technology. With this new IoT-based education, students can engage in hands-on work using a range of technologies. Starting with the purpose of immersing students in the learning of practical information resulted in an interactive instruction technique that has proven academic and practical benefits [213]. As a result, the Industry 4.0 Technologies Laboratory (I4Tech Lab) [214] provides an interactive learning platform to encourage the use of new technologies in academic institutions, industry settings, and research settings. The laboratory in this hypothetical scenario makes use of technological advances such as AR and the IoTs. Tom *et. al.* [215] depict not only a modern laboratory for automation but also an attempt to include distance learning via remote access. In addition, the Reference [216] emphasizes the use of digital twin technology in engineering education, which is a major Industry 4.0 focus area. An educational environment on Industry 4.0 that incorporates the cutting-edge technologies reproducing realistic industrial conditions is presented in [217].

VII. FUTURE RESEARCH DIRECTIONS

Despite the promises IIoT offers, there are challenges that need to be addressed to utilize the full benefits. To fulfill the requirements of the industry, some of the research gaps are identified and discussed in this section. The major future research topic in 5G/6G-IIoT are presented in [26], [44], [51], [218], [219]. Following are some of the research directions for IIoT discussed from the perspective of the tradeoff between URLLC and eMBB that needs attention

A. ML/AI

Many applications need real-time monitoring with closed-loop controls in which the industry can monitor itself and adapt automatically to provide benefits. This gives rise to a new research domain of the integration of industry with machine learning solutions. Many 5G/B5G-IIoT applications consume excessive energy. Thus, spectrum sharing and making energy-efficient B5G-IIoT applications give new directions to the research community. In IIoT applications with extensive and detailed simulation environments, reinforcement learning (RL) has been especially successful. In addition, the traditional applications of RL have been comparatively simple. Further research is needed to extend to more complex problems. At present, there is no consensus or consolidation on how physics-induced ML can be applied to industrial applications, despite several directions being pursued. This research needs to be developed and consolidated to improve the interpretability of the developed models and methods. Most studies, however, focused on vibration data that was preprocessed into image-like signals. An important question is if these approaches can be extended to complex data sets and time series. The plausibility of the generated samples and the effect of the generated faults on the accuracy of the algorithms needs to be evaluated further. In future studies, the composition and selection of the training datasets must also be addressed. It is necessary to decide continuously if new measured data should be incorporated into the training data and algorithms updated, or if the data is redundant or already contained in the dataset used for training algorithms. In addition, this becomes even more complex if the decision to include the new measurement data is made on a fleet level in IIoT systems rather than solely on an individual unit level. Furthermore, the algorithm is improved by selecting those observations that will lead to the closest improvement in performance. In recent years, ML/AI have been increasingly used in several elements of wireless communications. IIoT applications need high bandwidth, data rate, reliability, and low latency. These problems could be tackled using ML/AI, which offers more opportunities and possibilities than traditional IIoT solutions. Flexible TTI scheduling in ML/AI for IIoT reduces the URLLC services' delay and packet loss rate. The eMBB services do not have traditional classification qualities, and they prefer the TTI with the highest value. The transmission time for eMBB services is relatively long due to the big packet sizes. Frequent scheduling will not improve performance because it is not sensitive to delays, but it will increase overhead. IIoT applications arise as new and novel methods for humans and machines to collaborate, communicate, and interact. The trade-off between energy savings and quality of experience (QoE) can be achieved by using ML/AI algorithms to characterize the behavior of quiet periods in a voice over internet protocol (VoIP) session in order to reduce energy consumption without harming the scheme's performance due to the low computational cost.

B. Network Slicing Optimization

Network slicing technique can enable the multitude QoS requirement (URLLC, eMBB) for the IIoT. Implementation of network slices for an IIoT application with URLLC and eMBB requirements needs fine granularity. A redesign of the RAN is needed to ensure the QoS of the IIoT slices are achieved. Research in the direction of optimizing the resources and RAN redesign is required. Network slicing along with network coding can be explored to achieve configurable slices to achieve the requirements of the application.

C. Dense IIoT Applications

In 5G/B5G-IIoT, small applications are interconnected to make IIoT network. Research studies are required to make a dense IIoT network with feasible network infrastructure and integration of communication technologies in 5G/B5G-IIoT. B5G-IIoT refers to a network of connected objects that form a network of interconnected smart factories. Hardware refers to the physical existence of devices, while software refers to the capability of IIoT applications to provide services for everyone at the same time at different locations. It is not common for industrial devices, such as sensors, actuators, and controllers, to run learning algorithms. Nevertheless, smart industrial devices can potentially provide learning platforms by leveraging their computing capabilities. Learners can run learning tasks on those platforms that require fewer resources (e.g., computing, energy, etc.). By enabling the learning on industrial devices, the intelligence and performance of IIoT can be improved. A practical approach is to design an IIoT device in-loop with a simulation platform for the internet of everything, which integrates computer simulations with IIoT device testbeds. Simulating IIoT hardware testbeds from real-world data is what makes IIoT device in-loop simulation feasible. A further avenue is to develop an integrated simulation framework for IIoT that can capture the interactions and reciprocal effects between cyber and physical systems.

D. Integration of Cloud and Edge Computing

In cloud computing, the computing resources are leveraged from the cloud to assist an industrial unit, on the other hand, edge computing leverages computing resources from network edge devices. Edge computing is for time-sensitive applications and cloud computing is for applications not driven by time. The hybrid cloud and edge computing platform provides IIoT computing infrastructure with the required capability and efficiency. Due to limitations on complexity, storage, and processing power, it may be impossible to carry out training on a device for a sufficiently complex learning problem. By reducing network latency through edge computing, it will be possible to cut the effectiveness of the learning process. Integrating edge computing with cloud computing boosts the B5G-IIoT applications' performance both in terms of latency, reliability, and data rate. Data analytics, storage, caching, and computing are yet the open research directions for this integration. Open research problems also include implementing and optimizing self-organization, efficiency, and run-time features of edge-cloud-based learning The research also focuses on machine learning algorithms with configurable parameters and platforms that will aid decision-making in 5G-IIoT.

E. Industrial Automation

Manufacturing, supply chain management, energy management, and human resources are all industrial processes that heavily rely on OT and their expertise. Combining AI and B5G-IIoT will allow these operational processes to be enhanced and taken to a whole new level of precision. The integration of B5G-IIoT with AI, big spectrum data, and data analytics enhance the services of B5G-IIoT. AI in B5G-IIoT connect the automotive industry, smart homes, and machine tools to make things digital and more productive.

Everything in today's world is data-driven, whether industrial processes or smart home devices. Industrialists are currently unable to manage the massive amounts of data generated in an industrial complex or the B5G-IIoT ecosystem as a whole due to a lack of skilled human resources and reliable tools for productively utilizing big industrial data. AI is capable of autonomously managing itself and will be able to overcome the limitations of skilled human resources or tools, allowing for optimal utilization and optimization. A connected IIoT ecosystem of devices coupled with AI-powered analytical models can enhance not only the manufacturing operation, but the entire industrial process as well. The combination of AI

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and IIoT presents too many advantages to ignore or overlook in terms of dependability and reliability.

Automated mobile robotss (AMRs) are becoming more important for manufacturing companies to support their logistics operations. An AMR can move flexibly in a factory and can recognize and avoid obstacles at the highest safety level, and they can be programmed easily. Furthermore, the following two factors need to be addressed as efficiently as possible: (a) unpredictable delivery times and downtime, and (b) vulnerability to network attacks. The fierce competition in IIoT and market maturity give many legacy companies in infrastructure management a stronghold throughout the value chain by selling software. Take advantage of a hybrid cloud designed to offer manufacturers and plant operators a more open, flexible, and secure alternative for capturing and analyzing real-time data from IIoT [219]. The industrial sector must pass this transformational and evolutionary phase in order to survive, and only those who gain the most from the change will be able to survive.

F. Security and Privacy

Security and privacy solutions for B5G-IIoT is always an open research topic and it is deemed as one of the major obstacles to the widespread adoption of this network. Owing to the increase in the interconnectivity of the IIoT network, there is a need for a robust and secure transmission between the nodes. Standard IoT solutions can in general be applied to some of the applications of IIoT, however, some sophisticated techniques are required for applications with stringent safety concerns and resource constraints. Research in the direction of network security, data sharing and security, authentication, and security monitoring for specific applications of IIoT is required.

In order to support industrial systems, which require real-time information, e.g., sensor data, and commands, security mechanisms should guarantee both security services and timely communication. Since most B5G-IIoT systems rely on large amounts of data, storing data in a third-party system is logical. Data confidentiality and the privacy of important assets should be the top concerns regarding the transfer of data to a third party. Several potential solutions to these problems have been identified, including homomorphic encryption and searchable encryption, but more research is needed with regard to scalability, the delivery of data from the cloud in time-critical applications, and reliable recovery mechanisms when third-party storage systems are compromised. Another important area for cryptographic research is the development of quantum-safe cryptosystems that scale with resource-constrained devices. A quantum-safe security scheme suitable for the IIoT is urgently needed, given the significance of the IIoT, and the benefits of public-key cryptography for managing key material for a large number of devices.

B5G-IIoT deployments often employ heterogeneous hardware and software solutions. This poses another research challenge. It is challenging to ensure that required security services are maintained as data spread across multiple layers and an array of hardware and software. It is especially essential in situations where end-to-end encryption is required since data may travel across multiple hardware devices and software implementations, as well as across multiple vendors' hardware and software. Research into designing tamper-resistant hardware and maintaining operational safety in the face of such physical attacks is crucial for IIoT deployments in which an attacker may physically tamper with a device. It may be necessary to perform more research on the development of specific safety guarantees to be implemented with a complex IIoT system in safety-critical applications.

Another area of research is developing a privacy-preserving data collection and analytics approach. This can be accomplished by anonymizing data. Additionally, it may become necessary to verify the identities of devices by requesting that they self-identify without disclosing anything. Therefore, it is necessary to research and develop techniques for (pseudo) anonymization and zero-knowledge proofs that are suitable for the IIoT. The integration of the IIoT with other emerging technologies such as B5G-IIoT and blockchain is another important research direction.

VIII. CONCLUSION

IIoT has the potential to transform many aspects of our daily lives, including the environment, business, infrastructure, and lifestyle. This survey provides an in-depth assessment of IIoT, including the architecture and goals of the B5G-IIoT. The majority of the earlier literature focused on the architecture of IIoT. The primary focus of this paper is on the URLLC and eMBB techniques for 5G/B5G-IIoT applications. The trade-off between URLLC and eMBB for 5G-IIoT is presented, and insights for various applications are discussed. Future wireless communication is expected to play a significant role in optimizing the reliability and throughput of IIoT.

APPENDIX I: ACRONYMS

3GPP	third generation partnership project.
4G	forth generation.
5G	fifth generation.
6G	sixth generation.
6LoWPAN	IPv6 over low-power wireless personal area networks.
AAH	at-home healthcare.
AFA	adaptive frequency agility.
AI	artificial intelligence.
AMR	automated mobile robots.
ANN	artifical neural network.
AP	access point.
AR	augmented reality.
AWGN	additive white gaussian noise.
B5G	beyond 5G.
BCI	bilateral computer interfaces.
BDA	big data analytic.

BG2	base graphs 2.
BLE	bluetooth low energy.
BS	base station.
CA	carrier aggregation.
CAN	controller area network.
CAPEX	capital expenditure.
CCA	clear channel assessment.
CoMP	coordinated multi-point transmission and reception.
CPMS	cyber-physical manufacturing systems.
CPS	cyber-physical systems.
CRAN	cloud radio access network.
CSI	channel state information.
D2D	device to device.
DAA	detect and avoid.
DC	dual connectivity.
DL	downlink.
DMRS	demodulation reference signals.
DNS	domain name system.
DSS	dynamic spectrum sharing.
EASDF	edge application server discovery function.
EE	energy efficiency.
eMBB	enhanced mobile broadband.
EPS	evolved packet system.
EtherCAT	ethernet for control automation technology.
ETSI	European telecommunications standards institute.
FD	flexible data-rate.
FDD	frequency division duplex.
FEC	forward error correction.
gNB	next generation nodeB.
GNSS	global navigation satellite system.
GPRS	general packet radio service.
GPS	global positioning system.
GSM	global system for mobile communications.
HARQ	hybrid automatic repeat request.
HART	highway addressable remote transducer.
HD	high definition.
HSPA	high speed packet access.
IAB	integrated access and backhaul.

IIC	industrial internet consortium.
IIoT	industrial Internet of things.
IoT	Internet of things.
IP	internet protocol.
ISM	industrial, scientific, and medical.
IT	information technology.
ITU	International Telecommunication Union.
LBT	listen-before-talk.
LDPC	low-density parity-check.
LoRa	low range.
LoRaWAN	LoRa wide area network.
LPD	low power devices.
LPWA	low power wide area.
LPWAN	low power wide area network.
LTE	long term evolution.
LTE-M	long term evolution for machine.
MAC	medium access control.
MCS	modulation and coding scheme.
MIMO	multiple-input multiple-output.
mIoT	massive IoT.
ML	machine learning.
mm-Wave	millimeter wave.
mMTC	massive MTC.
MoEC	mobile edge computing.
MTC	machine type communication.
Multi-TRP	multiple transmission and reception architecture.
NB-IoT	narrowband Internet of things.
NFC	near field communication.
NFV	network function virtualization.
NOMA	non-orthogonal multiple access.
NPN	non-public networks.
NR	new radio.
NSA	non-standalone.
OEM	original equipment manufacturer.
OPEX	operating expenditures.
OT	operational technology.
PDCCH	physical downlink control channel.
PDSCH	physical downlink shared channel.
PDU	protocol data unit.
PHY	physical layer.
PoS	point of sale.
ProfiBus	process field bus.
ProfiNet	process field net.
PUCCH	physical uplink control channel.
PUSCH	physical uplink shared channel.

QAM	quadrature amplitude modulation.
QoE	quality of experience.
QoS	quality of service.
RAN	radio access network.
RAT	radio access technology.
RF	radio frequency.
RFID	radio-frequency identification.
RL	reinforcement learning.
RRC	radio resource control.
RTT	round trip time.
SA	standalone.
SDN	software-defined-networking.
SE	spectral efficiency.
SERCOS	serial real-time communication system.
SIC	successive interference cancellation.
SNR	signal to noise ratio.
TBCC	tail-biting convolution code.
TCP	transmission control protocol.
TDD	time division duplex.
TDMA	time division multiple access.
TrDMA	transmission division multiple access.
TSC	time-sensitive communications.
TSN	time-sensitive networking.
TTI	transmission time interval.
UDN	ultra dense small cell network.
UE	user equipment.
UL	uplink.
URLLC	ultra-reliable low latency communication.
URSP	user-equipment route-selection policy.
V2I	vehicle-to-infrastructure.
V2N	vehicle-to-network.
V2V	vehicle-to-vehicle.
V2X	vehicle-to-everything.
VNR	virtual network functions.
VoIP	voice over internet protocol.
VR	virtual reality.
WiFi	wireless fidelity.
WiMAX	worldwide interoperability for microwave access.
WSN	wireless sensor network.
WWAN	wireless wide area network.

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