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5G for Industry 4.0: Enabling Features, Deployment Options and Test Considerations

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Cellular technology is expanding beyond traditional consumer applications, with 5G's foray into the industrial space garnering increasing support across the world. Four countries—France, Germany, Japan and the U.K.—have allocated 5G spectrum for private networks. Another 12 are considering taking the same measures.[1]

In the last few years, the manufacturing and cellular industries have invested much effort into defining the use cases needed to implement Industry 4.0.[2-4] For this new phase in the industrial revolution, 5G enables several exciting applications, including:

- Advanced predictive maintenance, which could potentially reduce equipment downtime by as much as 9 percent
- Precision control and monitoring, which leverages wireless connectivity between sensors to increase machines' range of motion
- Augmented reality and remote experts, which enable humans to be involved in specific tasks remotely, potentially reducing equipment downtime by 25 percent
- Remote robot control, which refers to the control logic of a robot

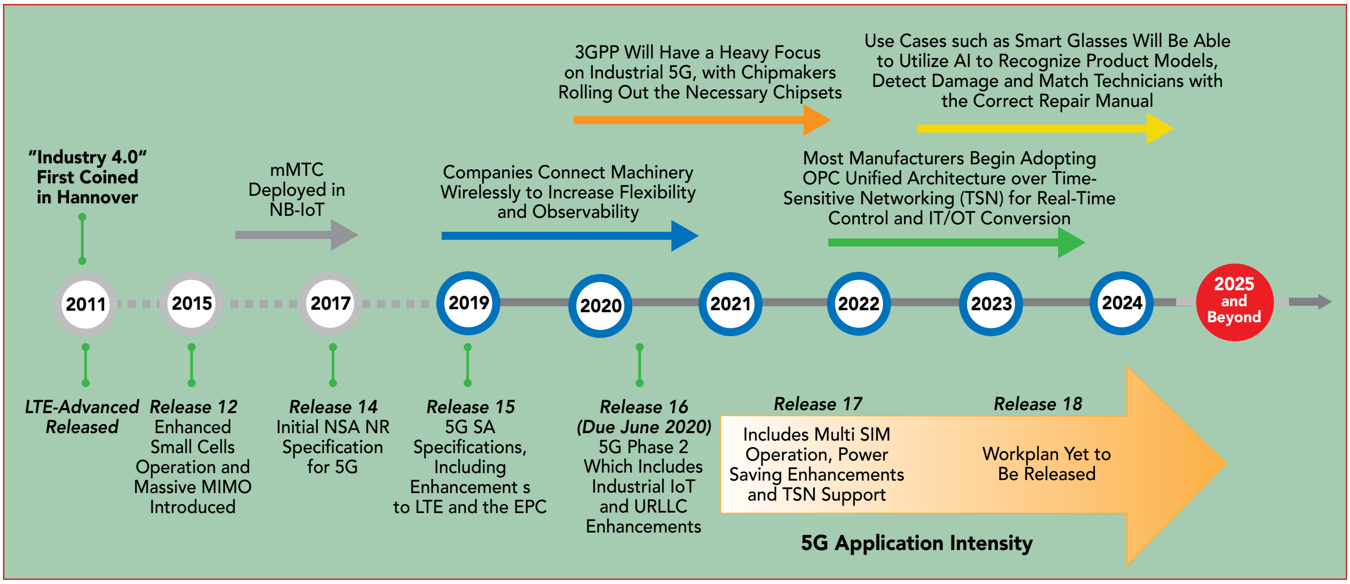

Fig. 1 3GPP timing for 5G industrial features. *Source:* ABI Research.

running remotely in a high performance compute environment
- Autonomous guided vehicles (AGV) and autonomous mobile robots, which 5G enables to operate in an unstructured environment

Various industry groups have worked on defining the use cases for 5G in industrial applications, with the 5G Alliance for Connected Industries and Automation (5G-ACIA) at the forefront of these initiatives.[5,6] The use cases have played a significant role in the development of 5G performance targets. The first standard release for 5G from the 3rd Generation Partnership Project (3GPP) mainly focused on consumer services, but subsequent releases offer specific capabilities for the industrial space (see ***Figure 1***). The newly completed release 16 enhances low latency features. Release 17 will increase 5G integration into time-sensitive networks, a key enabling factor for factory automation.

Features for ultra-reliable low latency communications emerged in 3GPP release 15 and were extended in release 16. High-reliability aspects revolve around redundancy. 5G technology uses multiple antennas and dual connectivity to ensure robust connections. Low latency features focus on the design of the 5G interface to enable super-fast transmission. Release 16 improves 5G's latency performance by introducing several new features, including pre-emption and grant-free transmission (see ***Figure 2***). Pre-emption provides the ability to interrupt transmissions with higher priority traffic. This feature is implemented in the low level of the communication stack, enabling more effective, higher layer quality of service. Grant-free transmission eliminates the signaling handshake used in traditional communication infrastructure for the user equipment to enable the transmission. The device can transmit data once it becomes available.

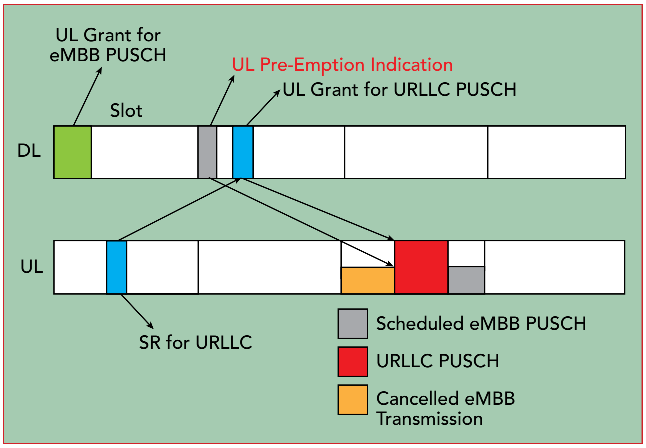

Fig. 2 **Uplink pre-emption and grant process in release 16.**

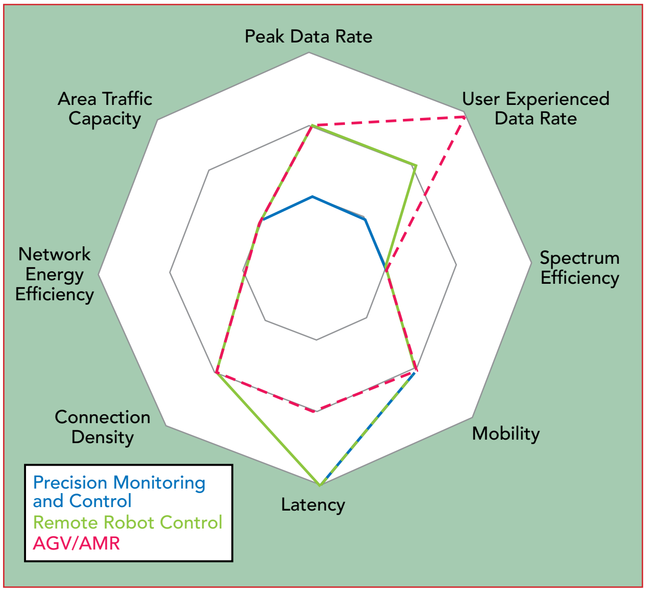

Fig. 3 **5G capabilities for precision monitoring, remote robot control and AGV/AMR applications.**

5G's high data throughput capability is also essential for several industrial applications, particularly for remote experts and AGVs that require the transmission of instant video streams (see ***Figure 3***). Massive MIMO, high-order modulation and greater bandwidth are key technologies enabling 5G to deliver such high throughput. Massive MIMO allows many antenna elements to transmit data at the same time. Higher-order modulation enables the encoding of more bits into the available spectrum. Lastly, higher frequencies provide more spectrum bandwidth.

5G enables several industrial applications through massive machine-type communications. Preventive maintenance applications, for example, leverage machine learning (ML) and artificial intelligence (AI). The volume of data and its variety have a direct impact on the effectiveness of ML and AI algorithms, making gathering data from many sensors attractive for manufacturers (see ***Figure 4***). Removing cables also increases flexibility, enabling sensors to be placed across the production line—even building a digital twin of the equipment to take manufacturing performance to the next level.

5G deployment in a factory environment can take multiple forms, ranging from dedicated standalone non-public networks (NPN) to various hybrid models involving network operators (see ***Figure 5***). A network operator can host a non-public network on the same

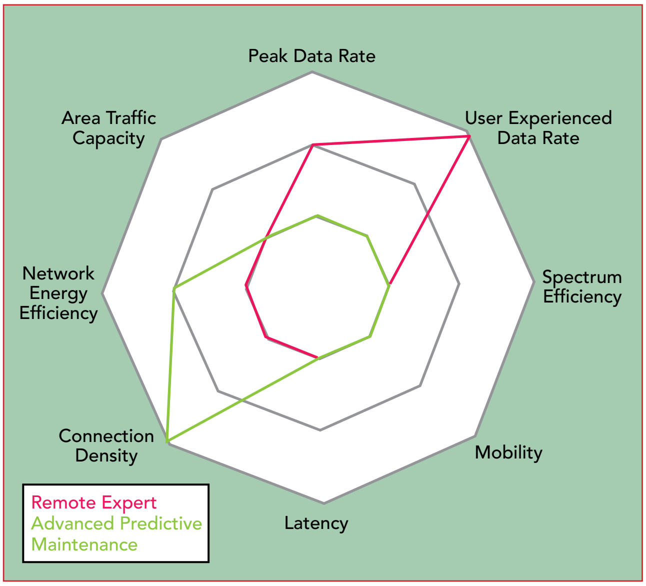

Fig. 4 **5G capabilities for remote expert and advanced predictive maintenance use cases.**

physical infrastructure used for public services by implementing network slicing, a concept that enables operators to tailor the network to deliver customized services to specific customers. Some hybrid models share the radio access network infrastructure, but not the edge computing infrastructure. All options have implications for data privacy and service management. The choice in deployment depends on the use case and business strategy. As mentioned, several countries have made spectrum available exclusively for industrial use, and many others are considering spectrum access models for industrial purposes. In Germany, for example, more than 40 enterprises and institutions have received industrial spectrum. Spectrum availability is increasing the interest in NPNs.

Industrial 5G network deployments largely involve replacing relatively costly communication infrastructure based on wired connections with a complicated system that requires various infrastructure components to work together smoothly. Testing becomes an integral part of the system lifecycle (see ***Figure 6***). Pre-deployment testing for security and performance is critical at the application level, requiring different types of traffic, network and device emulation before new features go live in the infrastructure to avoid issues. Test automation is key before adding a new device in the system, requiring coverage planning and spectrum clearance in the design and planning phase. Depending on the use case, channel measurements and emulation to understand future network performance may be warranted.

During deployment and acceptance, application and network load scenarios are used to stress the network with industrial traffic before implementation, and simulating network impairments to understand application performance under various conditions should be considered. Security conformance and performance testing for new devices or device types is strongly recommended before adding them to the network. In the operation and optimization phase of the lifecycle, spectrum and network analysis, troubleshooting and optimization are essential tasks. In parallel, a solution for ongoing monitoring of key performance indicators (KPI) and service levels is required. The critical nature of many 5G industrial use cases makes monitoring KPIs for end-to-end latency and security essential for success.

5G is unlike any previous generation of cellular technology. It encompasses a greater number of attributes that are step functions above the

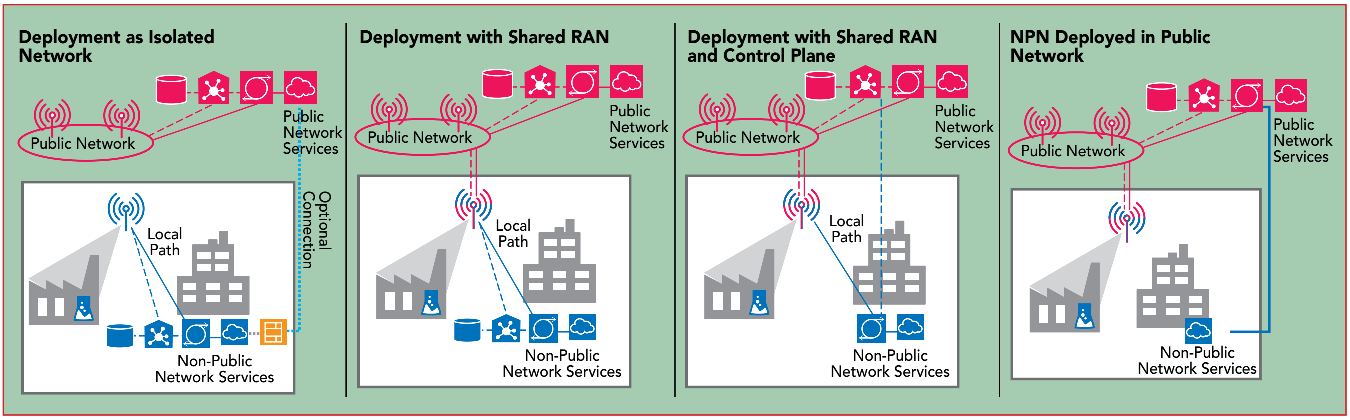

Fig. 5 Deployment options for industrial 5G networks. *Source:* 5G-ACIA.

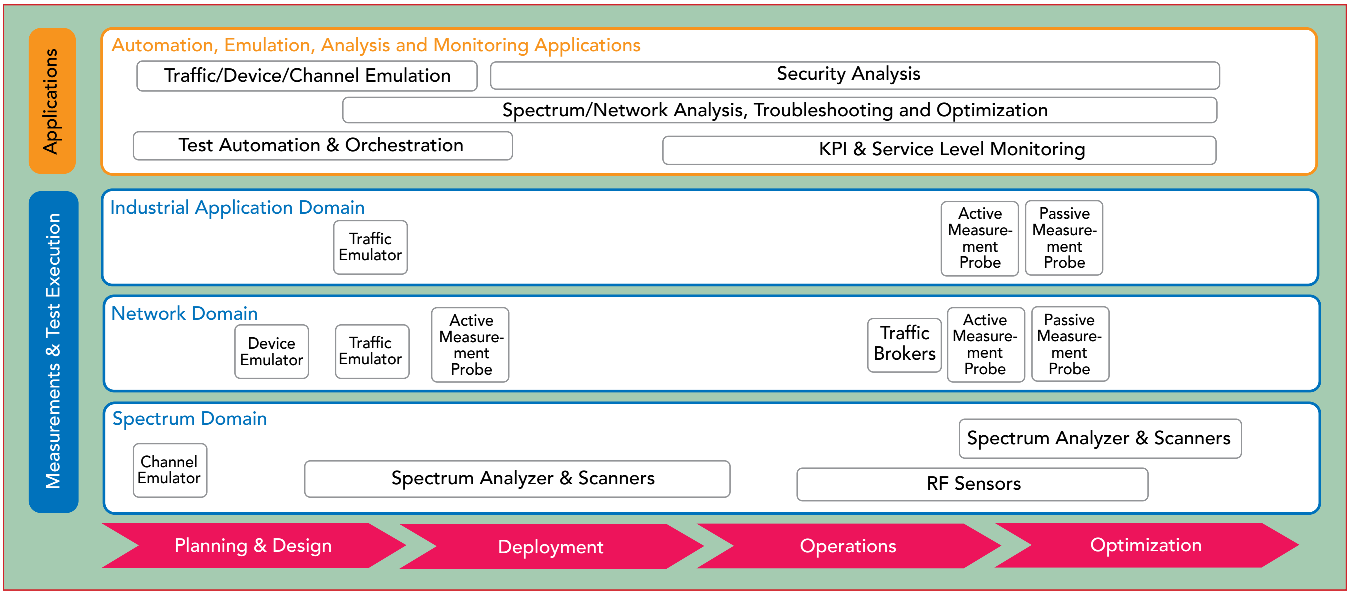

Fig. 6 Test and measurement across the lifecycle of a 5G industrial system.

capabilities of previous generations. These features enable 5G to expand into industrial applications, which will introduce major changes in the industrial space—posing challenges that require deep expertise in wireless communication technologies. It's the start of a very exciting journey for design and test engineers.■

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