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Foreword

The purpose of this report is to provide the membership of NEMA with a technical guidance document on 5G technology and will describe use cases/applications that apply across markets for electrical equipment and medical imaging manufacturers. The report will also identify emerging Standards and regulations related to 5G as well as appropriate end-users and the benefits they will receive from implementing 5G technology to assist NEMA in prioritizing future 5G activities.

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This document was developed by ABI Research on behalf of NEMA**.**

1. Introduction

Fifth Generation (5G) cellular connectivity is here: As of September 2020, we are counting more than 15,000 full commercial 5G deployments globally, with 137 communication service providers (CSPs) who have launched 5G services in the consumer domain. China, South Korea, Japan, and the United States are currently leading the world in 5G deployment. Partnerships and collaboration amongst regulators, network operators, and infrastructure providers have paved the way for China Mobile, China Unicom, and China Telecom to offer their 5G services at affordable prices. In South Korea, 5G subscriptions have reached 7 million at the end of May 2020, with an increase of around 535,000 subscribers—a figure that surpasses the monthly record of 521,000 additional subscribers.

Meanwhile, in the United States, AT&T, Verizon, and T-Mobile are steadily progressing their 5G coverage. ABI Research is projecting a total of 244.4 million U.S. 5G subscribers by 2024. Aside from benefitting the end-user market, 5G's true potential lies in its ability to facilitate a wide range of applications and services in the enterprise vertical domain.

Considering enterprise verticals, 5G is much more than just “4G + another G.” The distinct features of 5G allow for completely new applications for connectivity on several enterprise verticals:

- The supported bandwidth of 10 Gigabits per Second (Gbps) in the uplink and 20 Gbps in the downlink (through Enhanced Mobile Broadband Capabilities (eMBB) will furthermore enable automating, particularly data-intensive processes.

- Massive Machine Type Communication (mMTC) capabilities will support the connectivity of up to 1 million devices per Square Kilometer (km^2). Increased pervasiveness of connected equipment and devices in enterprise settings would create highly contextualized decision-making in processes like predictive maintenance and energy management in smart grids.

- Even though 5G on its own will not solve every single pain point that potential enterprise vertical implementers are facing, several new capabilities, including Ultra-Reliable Low-Latency Communication (URLLC), as well as support for Time Sensitive Networking (TSN) and deterministic networking, make 5G particularly useful for enterprise applications.

- To quantifying the revenue opportunity for 5G in the enterprise domain, ABI Research has recently undertaken an ROI study, which shows that enterprise 5G deployments will reach ROI much faster than in the consumer domain.

Even though revenue opportunities in the enterprise vertical domain are much higher than in the consumer market, different industries are highly fragmented and, therefore, hard to address with a traditional telco approach. To unlock new revenue streams and achieve new optimized efficiencies, tighter collaboration between all parties will be necessary to address enterprise client connectivity needs. Manufacturers can leverage system integrators to help orchestrate the specific roles of the network operator, network infrastructure vendors, and webscale companies in optimizing their processes and obtaining tangible business value.

1.1. Report Objectives

The report aims to provide the membership of NEMA with a technical guidance document on 5G technology. This document will provide relevant use cases/applications that apply across markets for electrical equipment and medical imaging manufacturers as well as those that are unique to a specific industry.

The report will also identify emerging Standards and regulations related to 5G as well as appropriate end-users and the benefits they will receive from implementing 5G technology. The ultimate goal is to assist NEMA in prioritizing future 5G activities. The extension of cellular connectivity to new use cases and verticals has important implications on existing networking technology as well as the sale of auxiliary products. Table 1 gives an overview of the major implications for the main markets the NEMA is serving.

Table 1: 5G Implications on NEMA Markets

(Source: ABI Research)

NEMA Markets	5G Implications
Building Infrastructure	To address backhaul considerations resulting from the high data throughput, cable trays, busses as well as ties need to be designed to accommodate additional fiber deployments.
Building Systems	In-building systems will be upgraded to 5G, driving demand for new components, including cables, connectors, and other peripherals.
Industrial Products & Systems	TSN, CoMP, mMTC, and URLLC transmissions will increase reliability and efficiency in manufacturing through integration IT, OT & CT domains.
Lighting Systems	Integration of sensors, networks and LED infrastructure in 5G Smart Grid applications will increase demand for connected lighting controls, light sources and emergency lighting.
Medical Imaging and Technology	Anticipating a lifecycle of >10 years for medical equipment, the deployment of cellular connectivity will require retrofitting of medical equipment & devices, increasing demand for chipsets and processors. Furthermore, existing patient data management Standards (e.g., FHIR, HL 7) might need to be adjusted to guarantee full functionality when being applied to a cellular network.
Utility Products & Systems	Smart 5G connected microgrids require the combination of intelligence (AI) with conventional utility products & systems: The demand for smart meters and intelligent capacitor solutions will rise. The powering of necessary infrastructure for cellular network deployments will increase demand for electrical connectors.
Transportation Systems	5G enabled Intelligent Transportation Systems (ITS) will increase the demand for data processing capabilities in the car & the network infrastructure, requiring more powerful chipsets and processors. To guarantee full interoperability between LTE-V2X and NR-V2X, dual chipsets will be required, supporting both 4G LTE and 5G NR.

2. 5G Technology Background

2.1. The Road to 5G Enterprise

5G wireless technologies are the next step in meeting the rising demand for increased data throughput, enhanced signal reliability, better coverage, and improved network efficiencies. Most notably, 5G brings forward more versatile connectivity scenarios relative to previous network generations. This increased versatility allows for connectivity scenarios that can go beyond the end-user and can make a meaningful business impact on multiple industry verticals.

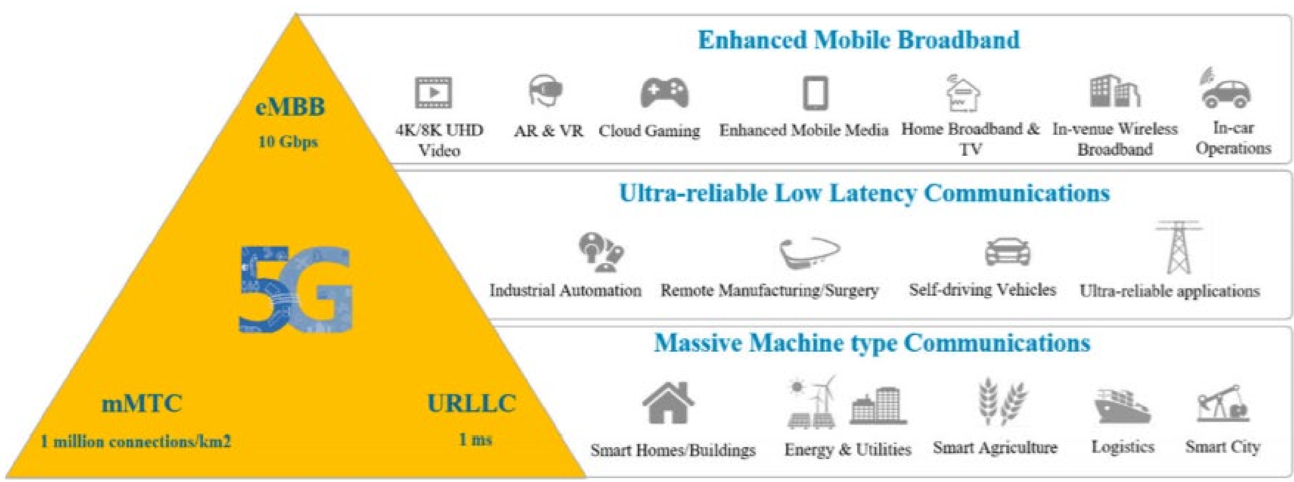
The factory floor stands to gain considerable value from 5G. The need for more adaptive, agile processes requires a shift to networks that can provide higher data rates, lower latencies, and support ubiquitous connectivity to more devices and machines.

2.1.1. Distinct Connectivity Scenarios of 5G

The International Telecommunications Union (ITU) has established 3 main 5G connectivity scenarios that can satisfy a diverse scope of use cases and specific communication requirements of consumers and enterprises. These 3 scenarios, as summarized in Figure 1, are Enhanced Mobile Broadband (eMBB), Ultra-Reliable Low Latency Communications (URLLC), and Massive Machine Type Communications (mMTC).

Figure 1: Key Features of 5G

(Source: University of Limerick)



2.1.2. Enhanced Mobile Broadband

Enhanced Mobile Broadband (eMBB) is on data-driven scenarios that impact the end-user market. It focuses on the data-driven use cases that require high rates of data across a large coverage area by mobile devices, including smartphones, wearables, tablets, laptops, mobile broadband devices, and more. eMBB would enable data-intensive applications such as 4K/8K Ultra High-Definition videos, Augmented Reality (AR)/Virtual Reality (VR), cloud gaming, and enhanced mobile media.

In early Non-Standalone (NSA) 5G deployments, eMBB builds on the established Long-Term Evolution (LTE) Standards and technology to provide higher capacity communications to cater to densely populated indoor and outdoor areas, enhanced all-inclusive connectivity (especially to rural areas), and improved connectivity in mobile scenarios. IMT-2020 minimum technical performance requirements state that eMBB must support capacity of 10 megabits per second (Mbps) per square meter (m^2); 20 Gbps downlink and uplink of 10 Gbps, and data exchange latency of 4 microseconds (ms). The advent of eMBB services would further increase the demand and consumption of mobile data. Over the course of ABI Research's forecasts across 30 countries, mobile data traffic is anticipated to grow to around 2,700 exabytes by 2025. 5G mobile subscribers would be estimated to grow to 1.8 billion by 2025 and account for 49% of the total traffic generated in 2025.

Operators across the world have already been making large strides in rolling out their respective 5G networks. 5G networks have been deployed in 378 cities across 34 countries. Emerging markets are also exhibiting a similar pace towards 5G when compared to developed countries, with regulators pushing for accelerated spectrum auctions, initiating coverage commitments from Communication Service Providers (CSPs), and encouraging network infrastructure sharing. These initial NSA 5G networks are, however, mainly focused on delivering eMBB services to consumer end-markets.

2.2. 5G Capabilities for Enterprise Verticals

The transformational features of 5G that can impact the connectivity scenarios of enterprise verticals are Massive Machine Type Communication (mMTC) and Ultra-Reliable Low Latency Communication (URLLC).

These two features are essential for the wireless, deterministic, and time-sensitive nature of Industry 4.0 processes that include predictive maintenance, autonomous robotics, and streamlined product lifecycle management.

2.2.1. Massive Machine Type Communication (mMTC)

Massive machine type communication (mMTC) plays a vital role in providing cheap and stable connectivity to an exponentially larger number (millions, potentially billions) of small Narrowband Internet of Things (NB-IoT) devices and sensors across a wide range that do not transmit a large amount of data traffic, without overloading the network. These devices and modules include sensors that help monitor various performance metrics from an object, machine, person, or environment to help automate systems, improve data collection, and process efficiency within an industry.

As such, the high device density objective of mMTC can be seen in IMT-2020 5G Standards, with the minimum requirement for connection density being 1,000,000 devices per km^2. mMTC applications will provide increase revenue opportunities by unlocking new business models (as-a-service), enhancing efficiency (thereby increasing productivity and expediting time to market), and by reducing costs through streamlined processes enabled by automated data collection and instantaneous decision-making (pertaining to maintenance, healthcare diagnoses, etc.).

2.2.2. Ultra-Reliable Low-Latency Communication (URLLC)

Ultra-Reliable Low-Latency Communication (URLLC) is arguably the key enabler for 5G to support innovative use cases for enterprise verticals. URLLC services are characterized by robust reliability (<1 packet loss in 10^5 packets; 99.999%) and latency rates—the acceptable end-to-end waiting time from the moment the data packet is generated to when it is received at its intended destination - of 1 ms.

URLLC low-latency and high-reliability capabilities provide a firm foundation to create value in enterprise verticals such as manufacturing, healthcare, transport, and energy sector. Specific use cases include the connected vehicle (including car platooning and car avoidance), human-robot collaboration, collaborative robotics, and smart AR glasses. Indeed, the automotive and manufacturing sectors are set to be prime verticals for 5G URLLC given their stringent connectivity requirements. ABI Research forecast that the transport and manufacturing markets are projected to be worth around US$ 17.9 billion by 2028.

2.3. Implications on Legacy Industrial Networks

Up until the 1980s, industrial automation was achieved by parallel wiring (where all devices were wired individually). With an increasing degree of automation, resulting in a constantly growing number of connections, this led to more and more complex wiring systems and higher wiring expenditure. As a result, the fieldbus system created in the 1980s was developed to limit these expenses, offering clear advantages in terms of speed, reliability, uniformity, and flexibility, as compared to parallel wiring. However, the development of several competing proprietary protocols (INTERBUS, PROFIBUS, or MODBUS, to name just a few) resulted in a more fragmented market and could not deliver on the expected uniform communication infrastructure. Much as with fieldbuses, several competing proprietary protocol Standards have been developed for its successor, Industrial Ethernet (Sercos III, PROFINET, or EtherCAT, for example). The formation of Fast Ethernet as a common core allows for the simultaneous transfer of Information Technology (IT) data and real-time data, as well as the transfer of larger data quantities. Industrial Ethernet is, therefore, increasingly used in production processes where performance and clock synchronicity matter.

Industry 4.0 calls for a progression from the legacy methods, establishing a more connected factory through wireless cellular connectivity. Connectivity is a key piece for a hyper-efficient supply chain, and it is crucial to have a singular connectivity protocol that provides a ubiquitous connection to all the devices and machinery on the factory floor. The more Industry 4.0 adopts common Standards in its connectivity solutions, the more it eliminates points of friction between robots, systems, and controls to connect to mission-critical processes. Connectivity within the context of smart manufacturing should enable the combination of high mobility and high throughput to support growingly sophisticated production processes. As shown in Table 1 below, 5G pairs high mobility, high throughput connectivity, and massive connection with lower latencies and cost per bit. Conversely, aside from solely giving high throughput and low latency, fixed-line technology does not provide any of the other important prerequisites in establishing an Industry 4.0 factory.

Table 2: Wireless Technology Comparison

(Source: ABI Research)

Wireless Technology	Advantages	Limitations
5G	• High data throughput • High reliability • Low latency • Network slicing • High device connection density	• Spectrum availability and allocation for enterprise verticals • Requires extensive network densification • Evolution of Standards must accommodate vertical-specific requirements
LTE	• Private LTE networks allow for customizability and mobility across different industry verticals	• Inadequate reliability and latency rates to support URLLC applications • Does not support network slicing • Low device connection density to support massive amounts of sensors
Wi-Fi	• Low cost • Highly available • Quick deployment	• Low mobility • Low security • High interference risks due to unlicensed spectrum • Low reliability • Unable to support mMTC
LPWAN	• Low cost • Longer battery life • Wide coverage	• Would need to accommodate higher bandwidth use cases • Low data throughput rates • High latency
Fixed	• High data throughput rates • Low latency	• Inflexible, rigid layout of factory • Longer deployment time • More costly to install and requires recurring replacement costs

With production processes becoming more and more complex, the number of components requiring a connection is constantly increasing. With costs around US$225 per cable drop, this also increases the overall costs of wiring a factory floor to serval hundred thousand dollars. Furthermore, wired connections on constantly rotating machine components need to be replaced every 2 to 3 months, incurring additional deployment costs. All this underlines the growing importance of wireless connectivity on the factory floor (with the number of wireless connections expected to grow by to 4.75 billion by 2026).

A Wireless Local Area Network (WLAN) provides one of the possibilities for wireless connectivity on the factory floor, based on the Institute of Electrical and Electronics Engineers (IEEE) 802.11 Standard. Given its compatibility with wired Ethernet (often referred to as Wireless Ethernet) and the fact that Ethernet-based automation networks, such as PROFINET or MODBUS, are still significantly utilized on the factory floor these days, one of the clear advantages of using Wi-Fi is that it allows any of those Ethernet-based machines or devices to be configured wirelessly.

However, using Wi-Fi does have risks of interferences as the Wi-Fi frequencies allocated on the Industrial, Scientific, and Medical (ISM) bands are used by about 25% of industrial devices. Furthermore, devices using the ISM bands are required to employ what is often referred to as “listen before talk” (or “listen before transmit”), whereby a radio transmitter first needs to sense its radio environment before it starts a transmission. Waiting for this sensing of the environment introduces an additional source of latency in the machine communication and results in a breakdown of the network in case of a jamming incident.

2.3.1. Private LTE and 5G

While there are a number of connectivity technologies that can deliver some of these requirements (most importantly, private LTE can support 85% of automation use cases in industrial manufacturing), this would result in the factory operator having to employ a multitude of different connectivity solutions on the factory floor, resulting in an unnecessarily high amount of infrastructure investment needed to deploy each of these connectivity systems, while interoperability and, therefore, seamlessly holistic automation would not be possible.

Critically, with a latency of around 50 ms, private LTE connectivity solutions can only be used to provide mobile control panels for 30% of production machines on a typical factory floor, due to external security regulations (specified in International Organization for Standardization (ISO) 13850, *Safety of machinery — Emergency stop function — Principles for design*, as well as International Electrotechnical Commission (IEC) 61355, *Classification and designation of documents for plants, systems, and equipment*) regarding the latency in case of an emergency stop. By guaranteeing sub-10 ms latencies with 5G deployment, 100% of a factory’s machines can be fitted with mobile control planes, thereby offering considerable efficiency enhancements to the factory operator. Furthermore, considering the key performance indicators of 5G discussed in Section 3.3, a 5G-based connection system would be able to support all use cases. More importantly, using network slicing capabilities, the network can dedicate different slices to different use cases depending on their requirements, and therefore enables them to be addressed within the same physical network infrastructure, minimizing the amount of Capital Expenditure (CAPEX) needed to achieve comprehensive connectivity.

2.4. Standards Update

The 3rd Generation Partnership Project (3GPP), hosted by the European Telecommunications Institute (ETSI), defines the Standards for 5G connectivity. Release 15 is the first full set of 5G Standards with the main focus on eMBB Standards. Release 15 also sets the basis for mMTC and URLLC requirements as well.

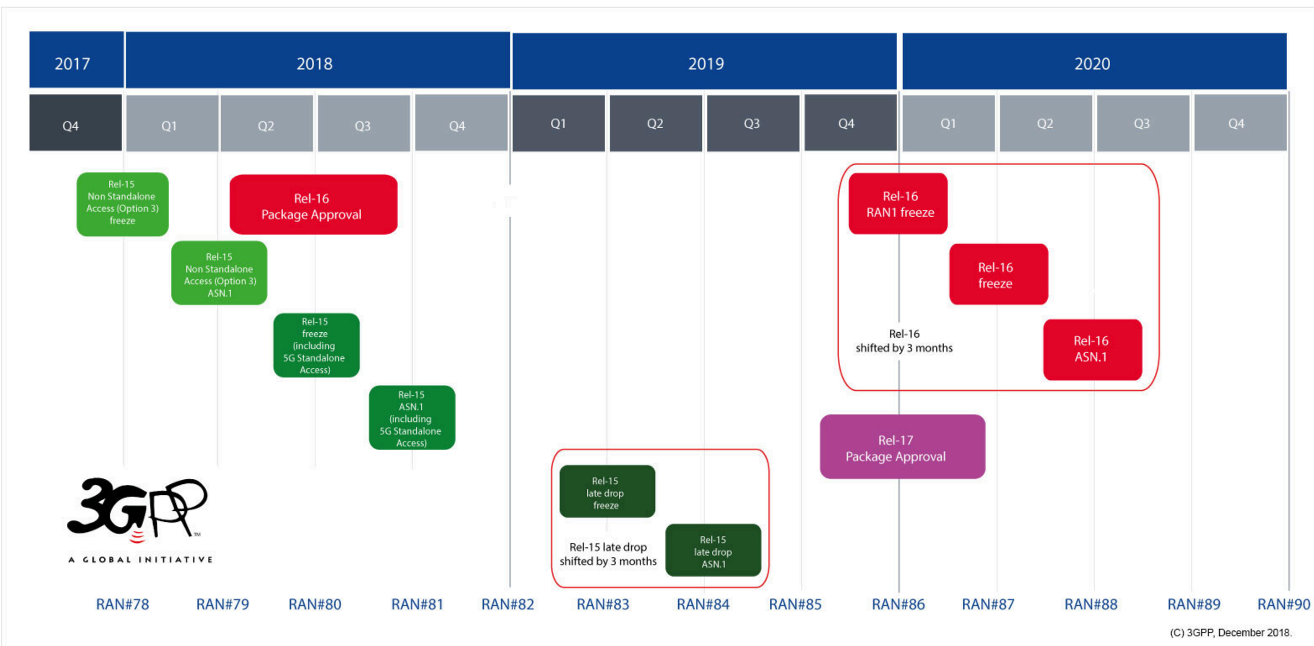
However, it is in Releases 16 and 17 that would provide critical updates and formalized Standards for the enterprise-oriented URLLC and mMTC scenarios. Sections 2.4.1.2 and 2.4.1.3 will elaborate further on the enterprise-related updates of Release 16 and 17.

Leading the charge in generating consensus on Standards and connectivity technologies within industry verticals are the vertical-specific organizations like 5G-ACIA (Alliance for Connected Industries and Automation) and 5GAA (Automotive Association). Including the requirements of these organizations at the Standards definition phase allows for a more aligned ecosystem that takes all stakeholders (enterprises, CSPs, network equipment vendors, etc.) into account. Having alignment will pave the way for solutions and products that have quicker time-to-market and have maximum compatibility.

2.4.1. Release Timeline

Figure 2: 3GPP Release Timeline for R15 and R16

(Source: 3GPP)



2.4.1.1. Release 15

The first introduction of 5G New Radio features was in **Release 15** (R15), primarily focusing on eMBB using NSA access (a 5G radio network leveraging on legacy 4G core network). Release 15 also set the foundation for URLLC, introducing features such as:

- **Grant-Free Uplink Transmission**: This saves time on the uplink, negating the need for signaling messages before the device can transmit to the network. Grant-Free Uplink transmissions have lower link latencies.

- **Multiple Modulation and Coding Schemes (MSC)**: These schemes define the capacity of a link, meaning that further granularity introduces flexibility for different types of devices and use cases.

- **Flexible Hybrid Automatic Repeat Request (HARQ) and HARQ-Less Repetition**: This feature caters to retransmissions if a packet is received erroneously over the wireless link. Flexible HARQ reduces the delay between packet reception and transmission. HARQ-less repetition introduces feedback to improve wireless link reliability.

2.4.1.2. Release 16

The Release 16 (R16) specification was frozen on July 3, 2020. A milestone that signifies the completion of the first phase of 5G NR Standards.

Release 16 introduces major features, especially for enterprise verticals:

- **Support for Time-Sensitive Networks (TSN):** The most important aspect of 5G NR R16 is that it introduces support for hard, non-negotiable time boundaries for latency in 5G networking. Previously, all communications have been performing on a best-effort basis, with good latency performance achieved through redundancy and over-provisioning.

  Using TSN alongside Open Platforms Communications - Unified Architecture (OPC-UA) allows for seamless interoperability between devices and cloud computing. OPC-UA is an open Standard, information model that specifies information exchange for industrial communication while TSN is a collection of IEEE802.11 Standards that promote Quality of Service (QoS) for ethernet communication and allows different applications and protocols to share the same network infrastructure.

- **URLLC Transmission Prioritization**: The inter-user equipment (UE) downlink (DL) preemption that is already supported in Release 15 is extended in Release 16 to include the Uplink (UL), such that a UE's previously scheduled lower-priority UL transmission can be preempted (that is, canceled) by another UE's higher-priority UL transmission.

- **Coordinated multi-point (CoMP):** CoMP, when used in tandem with TSN technology, can enable reliable 5G communications and offset the performance degradation problem of cellular network operations in various frequency bands, including the unlicensed ones.

  This is done through CoMP technologies' utility of multiple transmission and reception points (multi-TRP) to introduce redundant communication paths with spatial diversity. This ensures reliability due to the introduction of multiple communication paths.

- **5G NR Unlicensed (NR-U)** and **Non-Public Networks (NPN)**: Release 16 introduces 5G NR operating in unlicensed spectrum (NR-U). Release 16 is the first global cellular Standard that supports both license-assisted and standalone use of unlicensed spectrum.

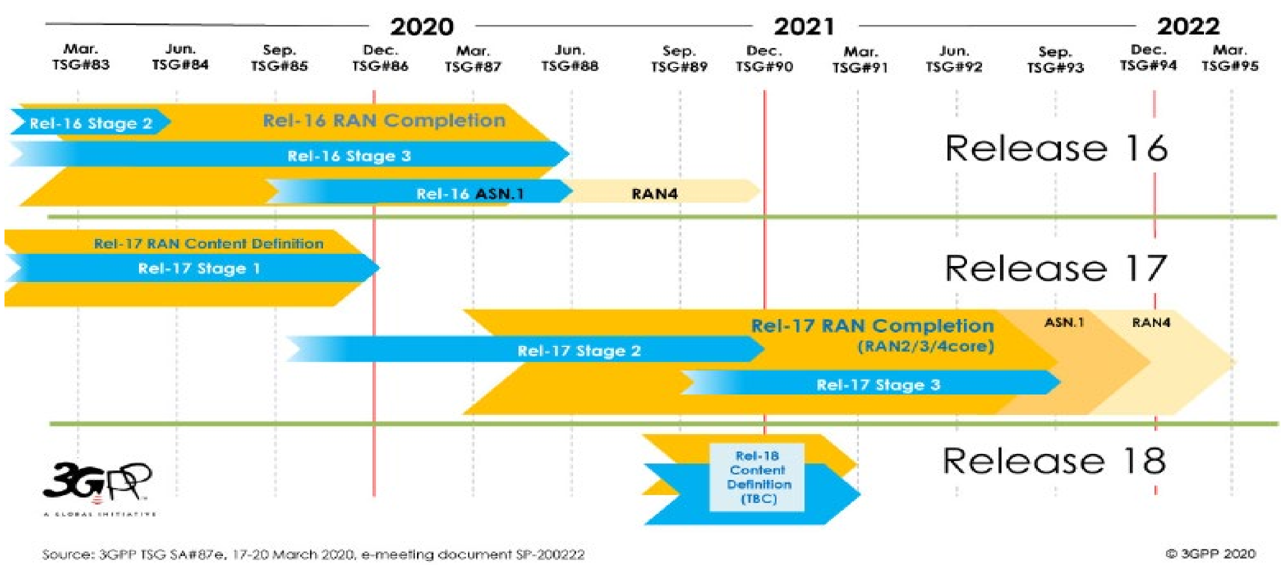
Release 16 also expands support for Non-Public Networks (NPN). As defined by the ACIA, Non-public networks or private networks provide 5G network services to a clearly defined user organization or group of organizations. NR-U can reduce NPN complexity as organizations would not need to procure their own spectrum resources and use free, unlicensed spectrum. NR-U can also support 5G enterprise-related enhanced URLLC (eURLLC) functionalities such as TSN networks and multi-TRP with CoMP. NR-U in 6 GHz can also be expected to play a major role for IIoT due to the wide bandwidth the new 6 GHz unlicensed bands have to offer.

2.4.1.3. Release 17

Release 17 was scheduled to be completed in 2021. The COVID-19 pandemic, however, has delayed key approval dates to September and December 2021. Further additional delays are also being considered, with Release 17 finalization possibly delayed to 2022.

Figure 3: 3GPP Release Timeline for R16, R17, and R18

(Source: 3GPP)



Release 17's contribution to enterprise-related enhancements include:

- **Improved Positioning Capabilities**: Positioning enhancements to better address industrial scenarios with stringent accuracy and latency requirements. Enhancements include centimeter-level accuracy, lower positioning latency, and allowing for higher capacity to millions of devices.
- **Sidelink Enhancements**: Unifying commercial, Vehicles to Everything (V2X), and mission-critical communication usage of sidelink. Rel-17 will focus on sidelink power and spectral efficiency optimizations. Rel-17 will study how the Rel-16 sidelink can provide relay capabilities and the efficiency of Release 16 NR V2X operations.
- **NR-Light**: A category of consumer-driven devices that is more capable than eMTC/NB-IoT but supports different features and smaller bandwidth than higher-end 5G NR eMBB/URLLC. For

example, NR-Light can occupy just 10 or 20 MHz of bandwidth and deliver 100 Mbps of downlink and 50 Mbps of uplink throughput, making it a suitable technology for use cases such as high-end wearables or industrial IoT cameras and sensors.

2.4.2. Device Classes

Industries such as automotive, manufacturing, and energy have a wide-ranging set of use cases and applications that can greatly benefit from a device class that has improved latency and coverage relative to traditional NB-IoT devices.

Figure 4: 5G Device Classes

(Source: QUALCOMM)

In 3GPP, 5G Low Power Wide Area (LPWA) IoT communication is based on the LTE enhanced Machine Type Communication (eMTC) technologies: LTE-M and NB-IoT. These technologies cover massive volumes of IoT devices across multiple use cases, such as asset tracking, IIoT sensors, and low-end wearables. These devices have the lowest complexity, lowest power requirements, and have higher latency tolerance.

On the other end of the spectrum, there are high-end devices used in eMBB and URLLC scenarios that require higher throughput and extremely low latency, such as high-end smartphones and robotics used in industrial scenarios.

In between, these offerings could be complemented by NR-Light to support industrial wireless sensor networks (IWSN) and low-end wearables to address more sophisticated use cases that require higher data rate/reliability. NR-Light has lower latency than eMTC/NB-IoT devices while not requiring as much bandwidth of eMBB/URLLC devices.

Table 3: Device Class Comparison

(Source: ABI Research)

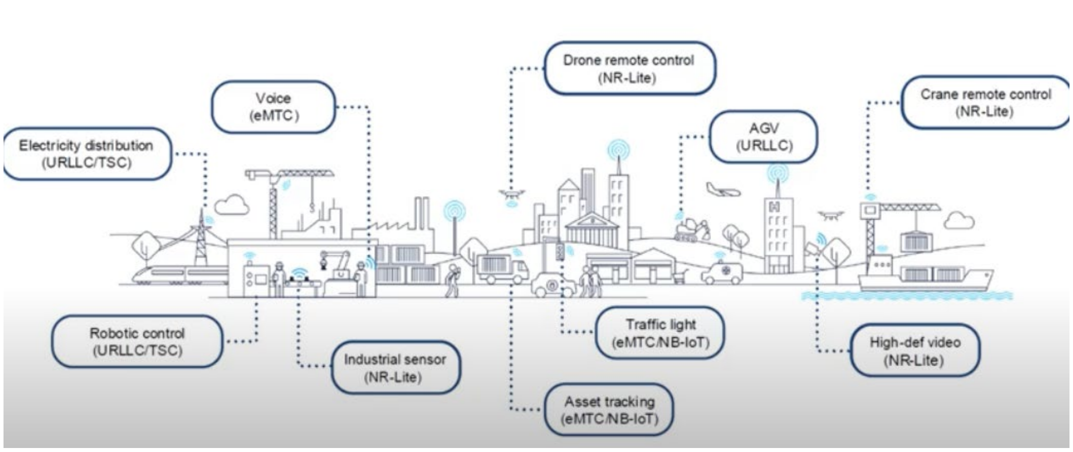
	NB-IoT	LTE-M	NR-Light	eMBB/URLLC
Peak Downlink Data Rate	127 Kbps	1 – 10 Mbps	100 Mbps	20 Gbps
Peak Uplink Data Rate	159 Kbps	1 – 7 Mbps	50 Mbps	10 Gbps
Latency	1.6 – 10s	100 ms	50 ms	1* - 4 ms

As seen in Table 2, the wide disparity in data rate and latencies highlight the diversity of use cases that LTE-M (Cat-M1, Cat-M2) and NB-IoT (LTE Cat NB1 and NB2) devices handle, respectively. NB-IoT is mainly used in low data rate applications in challenging radio conditions—providing improved indoor coverage and supports an increased number of low throughput devices, high battery life at lower costs. LTE-M, on the other hand, functions at higher data rates, device complexity, higher cost, and lower latency than NB-IoT; its accurate device positioning capabilities allow it to support connected vehicles.

Manufacturers must understand that the varying complexity, data rates, and latency performances of these devices classes contribute to an expansive industrial eco-system (as seen in Figure 5). Rather than prioritizing a singular device type over the others, manufacturers should leverage each device class based on use case requirements.

Figure 5: Role of NR-Light in the IIoT Ecosystem

(Source: ABI Research/Nokia)



2.4.3. Digital Enhanced Cordless Telecommunications and 5G

Digital Enhanced Cordless Telecommunications (DECT) was first developed within the European Telecommunications Standards Institute (ETSI) in the late 1980s. The technology was primarily for domestic cordless telephony, enterprise premises' cordless Private Automatic Branch Exchanges (PABXs), and wireless Local Area Networks (LANs). The DECT Forum, charged with developing the Standard, formed the ULE Alliance in 2013 with the goal of promoting and developing a ULE protocol based on DECT.

The DECT Forum has pushed forward a radio interface technology, DECT-5G, that would allow interoperability between DECT and ULE with the 3GPP's 5G Standards. The Ultra-Low Energy (ULE) specification in the DECT protocol makes it a strong contender to support the low-power, data-collecting sensors in 5G enterprise mMTC applications. The combination of DECT and ULE has traditionally supported smart home applications through its low power, low cost, and security. DECT-5G aims to extend these existing features to support URLLC and local mMTC scenarios in manufacturing.

DECT-5G builds on legacy DECT/ULE specifications by allowing higher data throughput to support mission-critical URLLC use cases, quicker synchronization times, open interfaces, and using smaller chip geometries that can streamline energy consumption (a node size reduced by 50% is estimated to lower energy consumption by 2x for analog and 5x for digital processes).

Using DECT-5G in parallel with legacy DECT/ULE products is also possible as both protocols can share existing network infrastructure and spectrum resources. The dedicated spectrum of DECT-5G is particularly useful for private networks as manufacturers can bypass the leasing spectrum from CSPS. The allocated spectrum for DECT operates in the 1880 MHz to 1900 MHz band depending on the country/region. DECT-5G manages spectrum assignment with the compatible timeslot, RF channel protocols that ensure URLLC with ensuring the avoidance of packet collision and signal interference. DECT-5G base stations also serve both new DECT-5G and existing DECT devices. This embedded support across both DECT generations further enhances roaming and hand-over capabilities of the DECT network – an important prerequisite for continuous coverage in the industrial environment.

Using DECT-5G in isolation will not address all data-intensive requirements of Industry 4.0. Diverse wireless technologies and devices are required to cover the multiplicity of latency, bandwidth, and reliability requirements of each respective vertical. Manufacturers should view DECT-5G as a complementary piece that has its place in the wider eco-system of 5G devices. Leveraging on DECT's maturity in voice and data capabilities, supplier maturity, and open interface would allow manufacturers (especially SMEs that are sensitive to the high CAPEX requirements) to have quicker and cost-effective industrial automation initiatives at reduced levels of risks.

2.5. Network Architecture Considerations

5G networks are particularly fitting for enterprise use cases that need assured and reliable quality of service (QoS). Enterprise verticals such as chemical processing, energy, utilities, and airports can benefit from the digitization of their respective processes within each industry.

Manufacturing and the trend towards Industry 4.0 have created a demand for more deterministic networks, tailor-made security mechanisms, and proliferation of edge computing distributed across the industrial environment. Flexible deployment models give more autonomy to enterprises in implementing the specific network requirements of their business.

These varying forms of Private or Non-Public Networks (NPN) maintain high QoS, ensure high-security Standards, and enhance operational efficiencies by providing better surveillance and control over the elements within the network.

2.5.1. Network Deployment Scenarios

Network deployment scenarios vary depending on specific network requirements, security considerations, and accessibility of user plane gateways and control plane functions. Generally speaking, NPNs can be classified either as a fully isolated, standalone NPN or an NPN that is working in tandem with a public network.

In the case of a completely isolated NPN, all necessary network functions remain within the defined premises of the factory floor and an optional communication path between the NPN and a public network via a clearly defined firewall. The implementer would operate the NPN completely independently (without a CSP) and remains in full control of all network functions. This rests on the assumption of enterprises being able to acquire 5G frequencies without operator involvement, so it requires having respective spectrum arrangements in place. This deployment scenario would not require CSPs in the 5G value chain, and infrastructure vendors would have complete control in managing and customizing networks. Examples of standalone NPN deployments would be Nokia and Telefonica Peru's private LTE network deployment for Minera Las Bambas, a copper mine in Apurimac, Peru, as well as Ericsson and Telia's private LTE network deployed for Ericsson's 5G radio manufacturing plant in Tallinn, Estonia. In this scenario, data is localized, very secure, and can guarantee very low latencies as the RAN and core network are co-located. For factories, the distance from the core network to the RAN affects the latency, with every 5 to 10 km of distance reduced between the RAN and core network able to reduce 10 milliseconds of latency. This usually includes an additional installment of radio infrastructure within the campus and, sometimes, surrounding it.

NPNs used in conjunction with public networks come in more varied scenarios. The NPN and the public network could share only the Radio Access Network (RAN) within the enterprise location, where all the NPN's control functions remain within the premises of the NPN. In another deployment type, NPN and public networks also share both the RAN in the defined premises and while the network control functions are in the public network.

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2.5.1.1. Network Slicing

Lastly, an NPN could be hosted by the public network using network slicing, whereby both the public and the private network traffic portions are outside of the defined premises of the factory. Even though both traffic flows remain in the public, they are treated as if they were part of entirely different networks, with the non-public slice being able to be customized according to the implementers' requirements, while the network operation and management would fall under the MNO's responsibility.

Network slicing is considered as a key technology for 5G cellular connectivity in manufacturing plants and warehouses. Network slicing enables manufacturers to run multiple logical networks on a commonly shared infrastructure spanning multiple domains (radio, transport, core, and edge). Network slicing marks a departure from this rigid arrangement by promoting flexibility and dedicated capabilities tuned to different manufacturing use cases. According to ABI Research, network slicing is forecasted to generate US$22 billion in value for manufacturing, at a Compound Annual Growth Rate (CAGR) of 96% through 2026.

2.5.2. Edge Computing Capabilities & Process Distribution

The first step that goes into making a holistically integrated, IIoT factory floor is establishing connectivity between machines and the underlying software. Manufacturers need to introduce new connections between their PLC/HMI hardware, SCADA systems, Manufacturing Execution Systems (MES) and Enterprise Resource Planning (ERP) systems and to the cloud (for the accumulation and synthesis of big data). Having a tight loop of communication between hardware and software is crucial for data collection. Collected data points such as temperature, proximity, vibrations, etc. from the physical endpoints are the cornerstones of highly accurate context-driven decisions that boost operational efficiency. Besides increasing connectivity, there is also a need for edge computing capabilities and process distribution – an intermediary layer that provides localized computing capabilities.

The edge for manufacturing can be considered as the intersection of the existing physical assets with digital platforms and processes. Edge computing enables a distributed, low-latency infrastructure located within proximity to where the data are created, processed, protected, and consumed. IoT applications and local computing are being deployed to establish an overarching technology layer that promotes consistent management with more sophisticated, low-latency processing spread across the factory floor.

The smart manufacturing equipment feeds data to an edge layer, which may preprocess or aggregate data to be used as training data locally or be sent to the cloud (public or telco) to train Artificial Intelligence (AI) models. The cloud provides a training model to the edge server, which, in turn, provides inference using sensors and other equipment data in near-real-time.

In smart manufacturing and warehouses, workloads can be executed at the edge where the bulk of the data would be processed. Decentralized data processing

This local compute processing would enable single-digit millisecond latency that could not otherwise be obtained with Round-Trip Delays (RTD) associated with traffic to and from public cloud and data center back ends. This reduced transport latency can, therefore, deliver optimal data accuracy in a timely manner —allowing decision-makers to have a clearer overview of real-time operations on the factory floor.

In addition, the ubiquity of 5G edge computing serves as the bedrock for reliable uptime of the operations in the factory. Edge deployments can be deployed autonomously; enterprises can operate in a diverse—

but not necessarily interconnected—ecosystem while still running distributed production processes and operations in a seamless fashion.

2.5.3. Network Traffic & Backhaul Aspects

CSPs are coming under increasing pressure to manage data and voice traffic loads, extend high-speed data coverage into mostly or completely rural communities, and take on critical service provisions for police, ambulance, fire brigade, and natural disaster responses. This data increase is also spurred by enterprise-specific use cases found in smart manufacturing and Industrial Internet of Things (IIoT) scenarios.

To be able to offer a deterministic network that can support high bandwidth applications, enterprises would need access to more spectrum from either the CSPs or government regulators. There has been progress from regulators like the Citizens Broadband Radio Service (CBRS) Alliance in the United States and Office of Communications' (Ofcom) spectrum sharing arrangements in the United Kingdom.

A crucial aspect of managing the inevitable influx of enterprise data consumption in a non-public network is to densify network coverage within the factory floor by adding more base stations. Network densification is especially important for enterprises using higher millimeter-wave frequencies for coverage due to their limited propagation distances.

Another factor to consider in the IIoT context is that the machines and devices are connected to an overarching cloud system that collects/manages the data going back and forth between these components. "*Fog streaming analytics*" is an emerging model that balances the low latency benefits of streaming at the edge (device or machine) against the massive computing benefits of the cloud. The fog nodes can be gateways positioned near the data-generating equipment or servers located in nearby network aggregation points, such as a Content Delivery Network (CDN) or a cell site. The proliferation of connected machines and devices in 5G (especially in factories with a large area of operations) requires more nodes to backhaul data streams from the machines to the cloud.

Besides enabling high bandwidth applications and high connection density, densifying the factory floor with more IoT gateways can provide a pre-processing layer to enhance network efficiency. Gateways can provide distributed processing functionality to the edge, locally filtering and processing the data and thereby decreasing latency by cutting round-trip transmission and processing time. This is especially useful for URLLC, time-critical processes such as real-time, closed-loop robotic control, video-driven human and machine interaction, and extended reality (xR) for training and maintenance.

2.6. Energy Consumption Aspects

The Information Communications Technology (ICT) sector is placing a large emphasis on the energy efficiency of 5G networks. The GSM Association (GSMA), an industry organization that represents the interests of Communication Service Providers (CSPs), recognizes that the evolution to 5G serves as a great opportunity for networks to explore ways in identifying and employing more environmentally sustainable methods to support the exponential increase in global data consumption and connected devices. Indeed, 3GPP's 5G Standards also outlines a 90% reduction in energy consumption relative to LTE.

CSPs have a plethora of strategies they can use to be more energy efficient. CSPs should ensure cell-site equipment is properly configured and fully optimized to minimize power consumption. This can be done by reducing energy dependency on polluting and/or excessive CO_2 generating sources like diesel generators and lead acid batteries and exploring alternative energy sources such as hydrogen fuel cells, solar energy, and lithium energy. Service providers can also utilize recent innovations in Network Function Virtualization (NFV) and Software Defined Network (SDN) that allow for dynamic resource allocation from sites with low energy usage to sites that have higher resource demand.

2.6.1. Enterprise Energy Mitigation Strategies

5G can also provide a sizable impact on the energy efficiency of the respective processes within enterprise verticals. In the context of smart manufacturing, low-latencies and high reliability can streamline various operations on the factory floor. These added functionalities can help manufacturers be more energy efficient through a detailed, real-time understanding of the processes and energy consumption patterns on their factory floors.

Factory automation allows for predictive maintenance and quality control measures. Manufacturing sites can apply edge or cloud-based AI processing to product packaging and inspection, improving quality and yield whilst reducing resource consumption (i.e., human inspections, transporting accurately identified defective products) to only essential actions.

Asset tracking is another important IoT segment that can help to establish closed-loop reuse models. From a physical waste perspective, asset tracking's ability to gather data and enable strong logistics processes will play a significant role in understanding where synergies lie and optimizing closed-loop designs.

Data analytics can also be used to analyze real-time factory data such as power output, efficiency, and consumption, giving factories a clearer overview of potential energy wastages, bottlenecks, and redundancies. IoT-supported smart grids, for example, aim to effectively distribute power consumption across the network efficiently through real-time communications of energy data from machinery back to the network core or edge processors. Having an intelligent energy distribution system allows factories to account for the varying operational habits and energy-usage fluctuations of different production lines.

For example, Daimler in Germany has reported its new Factory 56 in Sindelfingen is 25% more energy efficient than its previous Mercedes-Benz S-Class assembly plant through its MO360 digital ecosystems that streamline production. Canadian Forest Products has also attained a 15% reduction in energy consumption through real-time alerts for energy consumption that deviates from baseline Standards.

The evolution of business models considering Industry 4.0 can also help manufacturers be more prudent with their resource and energy usage. The classic product sales model based on mass production, standardized, and repeatable commercial arrangements will slowly be replaced by consumption business models in which factory floors are agile, adaptable, and capable of coping large or small volume production without sacrificing Overall Equipment Effectiveness (OEE). This can help reduce resource consumption as factories can flexibly accommodate demanded output with a commensurate allocation of resources.

2.7. Cybersecurity Aspects

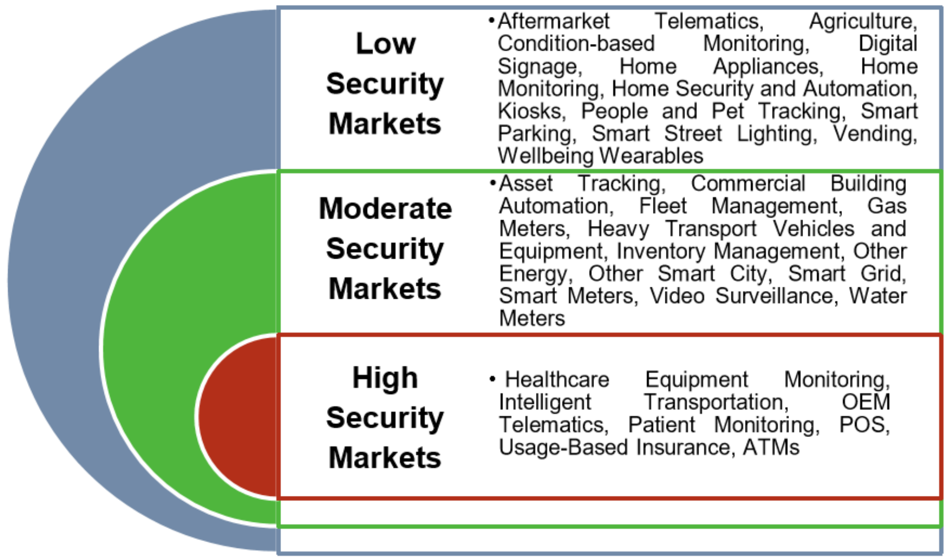
A recent Ericsson survey illuminated that data security and privacy weighs heavily in the reservations of traditional manufacturers considering adopting Industry 4.0 practices. This concern is shared by 79% of the respondents, concerns about lack of Standards, at 76%, and challenges of end-to-end implementation, at 69%, follow close behind. ABI Research predicts that IoT connections will exceed 28 billion by 2026 across all major IoT markets. Unless organizations take the appropriate measures, the majority of these connections might be prone to increasingly sophisticated cyberattacks and threat actors.

Security is an important consideration for all players in the 5G mMTC market, as the introduction of more devices and modules that have access to data about the company, its employees, internal processes, and consumer behavior. New devices and proliferated edge processors introduced into the network expands the overall threat surface; organizations would thusly have to implement more sophisticated security solutions to ensure tighter end-to-end security protocols across all connected models and devices. Organizations must adapt their market IoT deployment strategies to coincide with all evolving authentication services, considering different options, including security technologies, connectivity, infrastructure, cloud hosting, and operational costs, among many other variables.

As shown in Figure 6 below, ABI Research has segmented IoT markets into three distinct clusters depending on their security risks. Connected items in those clusters share similar technical characteristics both on a hardware and software level and are defined by similar security technologies, requirements, and restrictions. They also share similar operational options when it comes to device security like the presence (or lack thereof) of a hardware security element, the ability to host an encryption key, and all related management services.

Figure 6: Cybersecurity Risks in IoT Markets

(Source: ABI Research)



Realistically, this is not to suggest that security should always be the top priority across all markets, verticals, and IoT endeavors. Rather, security must accompany each application depending on the level of authentication and protection needs, the underlying risk of cyberattack, and whether there is a critical service involved. Organizations must not overburden hardware or software services with non-essential applications, thus increasing the already heavy implementation and deployment cost, but rather focus on smart choices regarding what is essential and what can be discarded.

2.8. Health & Human Safety Concerns

The demand for connectivity in the 5G era is more fragmented than ever before, and the current spectrum is simply not robust enough to satisfy the huge variety of connectivity needs of both end-users and enterprises. The experienced bandwidth shortage has motivated the wireless ecosystem to start using the relatively under-utilized spectrum over 24 GHz, which are referred to as millimeter waves. This set of higher spectrum bands promises to unleash a large bandwidth opportunity for cellular mobile communications. The use of these high-band frequencies not only opens doors to a vast amount of network capacity but would also provide lower cost-per-bit attribution and fiber-like speed, which can bring enhanced mobile experiences to a huge variety of different use cases. Stadiums, concert halls, airports, train stations, and dense urban areas are expected to be the first locations to use millimeter wave technology.

In order to exploit the high capacities of millimeter waves, CSPs would need to overcome the inherent drawback of limited coverage by proliferating more macro and small cell sites (especially in dense urban areas) to ensure coverage. Aside from informing the public on the broad potential of 5G, more needs to be done in educating the wider public on how telecommunications usage of millimeter waves are non-ionizing and are also within approved health and safety margins.

2.8.1. Ionizing versus Non-ionizing Transmissions

The determinant of whether a frequency is harmful to humans is if it is ionizing or non-ionizing radiation. The radio waves that can cause harm are frequencies above ultraviolet rays—like X-rays and gamma rays. Ultraviolet, microwave, visible light, and millimeter waves, on the other hand, are non-ionizing radiation. Non-ionizing radiation is not strong enough to break chemical bonds and incapable of causing health risks such as cancer. The physical effect of millimeter waves is negligible—there is only minimal penetration to human tissue (at most 1 mm), and the effects of this exposure manifest as merely thermal effects.

Furthermore, the increased presence of smaller cell sites and base stations would equate to lower power transmission levels compared to current cell sites due to the small coverage footprint. The multiple-input multiple-output (MIMO) and beamforming capabilities of 5G antennas would also mitigate radiofrequency exposure to non-users as the transmission is directly 'beamed' to the mobile device rather than indiscriminately emanating omnidirectionally.

There are already existing regulations and limits that have been established to protect consumers from potentially harmful radiofrequency exposures. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz are regularly updated and vetted by industry experts to ensure the safety of consumers. Based on scientific recommendations to the World Health Organization (WHO), the European Commission, and other authoritative bodies, the ICNIRIP recently updated their guidelines. The revised guidelines reinforce the high standards of protection, with limits set far below the thresholds for established hazards for all radio frequencies from 2G to 5G.

3. 5G Opportunities in the Enterprise Verticals

To illustrate the immense benefit that 5G will bring to overall society as a whole and different enterprises, it is important to adopt a vertical-specific perspective. The following section will provide a deep look into the energy & utilities, healthcare, manufacturing, transportation, as well as smart city verticals to highlight what requirements these verticals pose towards cellular connectivity and how 5G can enhance existing operations both from a technology as well as from a business economics point of view. The selection of verticals is based on two different considerations: On the one hand, these verticals are expected to be the drivers behind 5G deployment for enterprises. On the other hand, these verticals illustrate the variety of use cases that can be addressed by 5G deployments.

3.1. Industrial Manufacturing

One of the most interesting 5G application scenarios lies in industrial manufacturing, in the context of Industry 4.0. While deploying 5G on the factory floor will enable automation of preexisting workflows and processes, it will also enable new use cases like *cloud vision* and *cloud testing* to improve and automate final quality control of the finished products. Furthermore, 5G connectivity will be an important enabler for a flexible factory layout.

3.1.1. Use Case Overview

While use cases for cellular connectivity in the industrial manufacturing domain are rather heterogeneous in terms of requirements, they can broadly be distinguished into mission-critical and non-mission-critical use cases. While mission-critical applications refer to use cases centrally important to the continuous operation of a factory (such as any kind of remote operation as well as use cases around predictive and preventative maintenance), non-mission-critical use cases refer to factory automation scenarios that do not necessarily endanger the operation of the whole factory site in case of a network outage. Consequently, network performance requirements for mission-critical use cases are much more stringent than for non-mission-critical ones (especially with regards to network availability and reliability).

Predictive & Preventative Maintenance

One of the most important use cases for 5G in industrial manufacturing will be the enablement of predictive and preventative maintenance of production machines. Massive machine type communication (mMTC) capabilities will be used to equip every production machine with sensors that monitor the equipment's condition based on a set of pre-defined parameters. As soon as one or more of these parameters pass a critical threshold, the machine can then automatically send a signal to any maintenance engineer in the vicinity, which can then attend to the machine before a breakdown occurs (which would result in a forced standstill of the whole production). Alternatively, the maintenance engineer can then assess the condition of the machine and schedule a shutdown of the respective production line, which would allow maintenance of the respective equipment to take place.

Remote (AR & VR assisted) Maintenance

In addition to predictive and preventative maintenance, 5G connectivity can also be used to enable remote maintenance using additional technologies such as artificial or virtual reality technologies. This scenario will be particularly interesting for manufacturers operating a multitude of factory sites in different locations: Utilizing the peak data throughput (10 Gbit/s uplink and 20 Gbit/s downlink) that come with enhanced mobile broadband (eMBB) capabilities, 5G connectivity will enable the transmission of data-rich video files. Crucially, this can be used to transmit video footage for the maintenance of production machines between different factory sites. This becomes particularly interesting for manufacturers operating separate factory sites for product planning/design and for mass production, where the technical and maintenance know-how is concentrated in one site, while factory sites for mass production are not equipped with the same level of maintenance know-how.

Automated Quality Control & Visual inspection

In addition to automating previously existing processes and workflows, cellular connectivity will also be an important enabler for automated quality control of products, utilizing mobile edge computing (MEC) as well as cloud capabilities in combination with artificial intelligence (AI) technologies. To enable automated quality control and visual inspection, sensors and cameras are mounted towards the end of a factory production line. Sensor data, as well as video inspection footage, can then be sent to either an edge computing device (located on the factory premises) or the cloud, where all the necessary processing and analytics takes place automatically. Since the deployment of an on-premise edge computing device is a key component to guarantee sub-10 ms latencies, this automated inspection can be applied to a real-life production environment without causing costly delays in the process.

Flexible Factory

In addition, 5G connectivity will allow the departure from a rigid production line layout towards a flexible factory. While in a traditional factory, manufactured goods move along a pre-defined production line, 5G will allow setting up mobile workstations (assisted by AGVs and AMRs) that automatically move towards the manufactured items. The mobilization of production assets and infrastructure dramatically increases the efficiency of a single factory since it allows the production of different components concurrently within the same production environment.

Mobile Control Panels

Given the importance of machine control panels, the fitting of these panels for emergency machine shutdown is governed by several different external security regulations (most importantly, International Organization for Standardization (ISO) 13850, *Safety of machinery—Emergency stop function—Principles for design*, and International Electrotechnical Commission (IEC) 61355, *Classification and designation of documents for plants, systems, and equipment*). These regulations specify the maximum acceptable delay between operating emergency shutdown buttons and the complete shutdown of the machine. Currently, these requirements can only be fulfilled by deploying fixed-line connections, but 5G will enable the installation of mobile control panels by guaranteeing sub-10 millisecond latencies.

3.1.2. Technology Aspects

When looking at network performance requirements, there is an important distinction to make between mission-critical use cases (predictive and preventative maintenance as well as any kind of remote operation of production equipment) and non-mission critical applications (such as the operation of AGVs). While mission-critical applications have distinct requirements when considering network availability and reliability (with five-nines reliability offered by URLLC capabilities considered as “just enough”), non-mission-critical applications primarily rely on the particularly high number of sensors and devices that can be connected via a 5G network.

Table 3 provides an overview of the key requirements for a cellular network by application scenario, highlighting the heterogeneity of use cases.

Table 4: Industrial 5G Use Cases Network Requirements
(*Source: 5G-ACIA*)

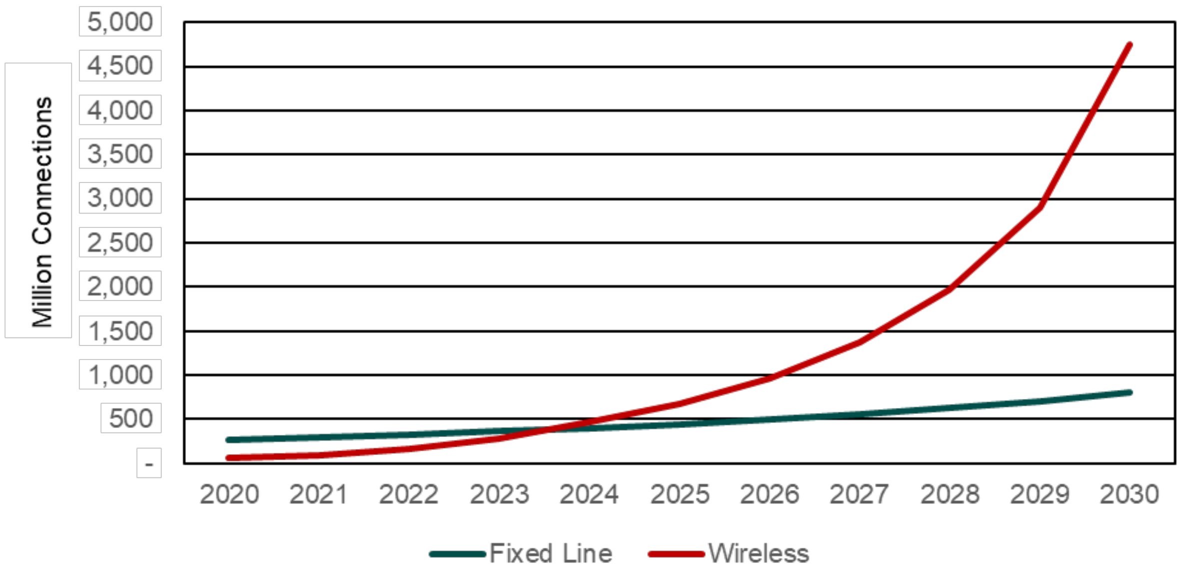
Use Case		Availability	Cycle Time (Latency)	Typical Payload Size	Number of Devices
Motion Control	Printing Machine	>99.9999 %	<2 ms	20 bytes	>100
	Tooling Machine	>99.9999 %	<0.5 ms	50 bytes	~20
	Packaging Machine	>99.9999 %	<1 ms	40 bytes	~50
Mobile Control Panels	Assembly Robots/ Milling Machines	>99.9999 %	4-8 ms	40-250 bytes	4
	Mobile Cranes	>99.9999 %	12 ms	40-250 bytes	2
Process Automation		>99.99%	>50 ms	Varies	10,000 devices per km^2

From a network architecture point of view, the deployment of a private network offers manufacturers the opportunity to ensure that no production data is forced to leave the factory floor. Furthermore, private networks offer a deterministic cellular network, which is important for manufacturers aiming to deploy 5G cellular connectivity for mission-critical applications. In addition, the support of time-sensitive networking (TSN) and the resulting capabilities of network slicing allow manufacturers to dedicate individual network slices to different use cases, allowing them to address a multitude of use cases with radically different requirements within the same physical infrastructure.

3.1.3. Business Case Aspects

Looking at the factory floor of today, the predominant way of connecting machines with each other is via fixed-line connections. According to figures published by ABI Research, more than 85% of all connections on the factory floor are fixed-line connections, as Figure 7 below shows.

Figure 7: Number of Factory Floor Connections
2020 - 2030
(Source: ABI Research)



With production processes becoming more and more complex, the number of components requiring a connection is constantly increasing. With costs around US$ 225 per cable drop, this also increases the overall costs of wiring a factory floor to several US$ 100,000s. In addition, the costs of renewing the fixed-line connection, especially when it comes to equipment that needs to be reconfigured on the factory floor on a regular basis. Connecting cameras, as well as other machines via fixed line, results in a somewhat rigid production layout based on fixed production lines, while manufacturers demand greater flexibility in designing their production processes to be able to produce different models within the same factory. To provide this flexibility, connecting production machines wirelessly is, therefore, of key importance.

To connect production machines wirelessly, manufacturers require a deterministic and dedicated channel for machine communication, with frequencies that should not be used by anyone else around the factory: While cellular connectivity offers this, Wi-Fi uses frequencies on the Industrial, Scientific, and Medical (ISM) bands, which is used by 25% of industrial devices, resulting in a high risk of interference. Even though Wi-Fi offers the use of proprietary protocols to prevent this, manufacturers are eagerly waiting for an industry-wide Standard, which 5G will offer.

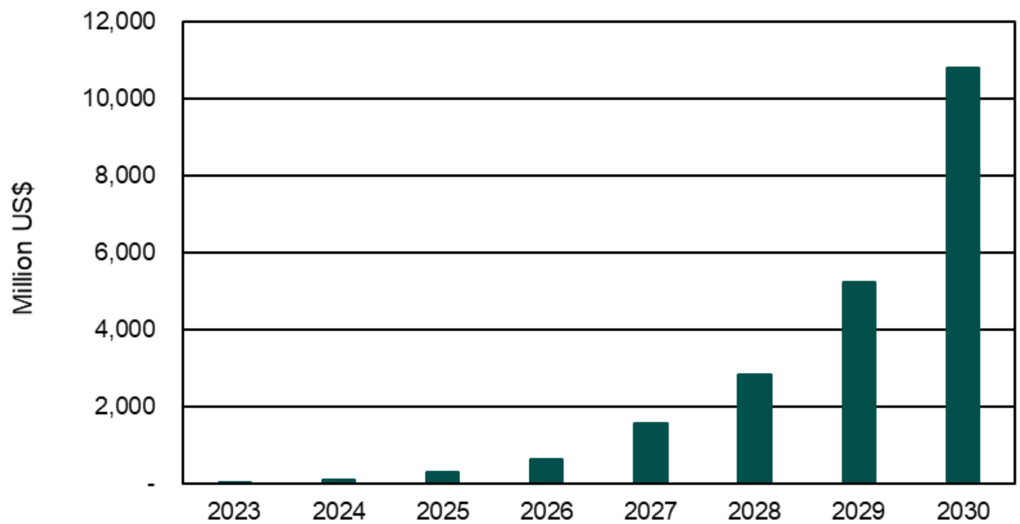
While ABI Research estimates that 85% of industrial applications can be supported with LTE (4G) connections, 5G enables the manufacturer to address different use cases with different QoS requirements within the same physical network infrastructure. Therefore, any use-case-by-use-case comparison should bear in mind additional efficiency gains from just having to deploy one single network infrastructure.

Early deployment projects in factories in China show that cloud vision and testing facilities have led to an 80% efficiency increase of machine-based quality control, with material savings of around 92%. Furthermore, cloud-based monitoring of the condition of production machines can lead to a decrease in maintenance costs by up to 30%, as well as decreasing machine breakdowns by 70%. In addition, automating product quality control will increase efficiency both in terms of personnel as well as necessary floorspace. While two workers were needed for manual tasks, no workforce is needed for this kind of task with a cloud-based automated system running on 5G. Furthermore, cloud-based quality testing will increase the daily capacity for quality inspection by 25%, while the area needed for this testing procedure could be reduced by 2/3 to 4 meters.

Taking all of this into account, ABI Research expects 5G connections in Industrial manufacturing to amount to US$ 10.79 billion by 2030, as Figure 8 below reports.

Figure 8: 5G Digital Factory Connection Revenues
2020 - 2030

(Source: ABI Research)



3.1.3.1. Manufacturing ROI Analysis and Examples

To quantify the efficiency and quality enhancements that the deployment of cellular connectivity offers, ABI Research published a study concluding that deployment of cellular connectivity on the factory floor would return benefits and enhancements in the value of 9 times the initial investment during five years. Assuming a manufacturer fails to deploy cellular connectivity on the factory floor, the same study suggests that a tier 1 automotive manufacturer (with a factory size of 500,000 square meters) in Germany would miss out on additional revenues of US$ 495 million (translating into 17,500 vehicles), while the average electronics manufacturer would miss out on US$ 646 million in additional revenues (translating to 986,400 electronics devices) during a five-year period.

ABI Research extracted internal data from a modeling exercise to understand the ROI horizon for 5G deployments for automotive and smartphone electronics manufacturers. To be able to provide accurate ROI forecasts, the model assumes the automotive manufacturer to be situated in Germany & the smartphone electronics to be situated in Japan.

The data points listed in this report are drawn from early deployment projects from a range of different infrastructure vendors that are in the public domain. The respective vendors have publicized key findings as well as extensive surrounding information around these deployment projects.

Cloud Quality Control: This assessment follows an early deployment project in Huawei's Songshan Lake Factory.

Automatic Guided Vehicle (AGV) & Flexible Factory: The estimated cost in cabling a factory has been obtained through various primary research discussions with industrial manufacturers directly and therefore does not make any explicit assumption regarding the size of the factory. During discussions, ABI Research received feedback regarding cable drop costs of around US$ 200 per instance, which means that even for small manufacturing sites the total cost for cabling will easily amount to several US$ 100,000.

Regarding the use of AGVs on the factory floor, Nokia has drawn first conclusions from connecting AGVs on their own factory floor in Oulu. Since default Wifi offers no robust handovers between access points, Wifi-connected AGVs would have to be operated at reduced speed to avoid collisions or stoppages when their signal is handed over to a new access point. Since cellsular connectivity has implemented a more robust handover, this allows factory owners to operate AGVs at a 30% higher speed.

Smart Warehousing: The profit increase & Operational Expenditure (OPEX) reduction predictions were extracted from ABI Research's work on a document commissioned in cooperation with Ericsson on the effect of 5G cellular deployments for smart manufacturing and smart warehousing. The model assumes a tier-1 warehouse with a floor space of 50,000 m^2.

Figure 9: Smart Manufacturing Financial Analysis – Automotive Part 1

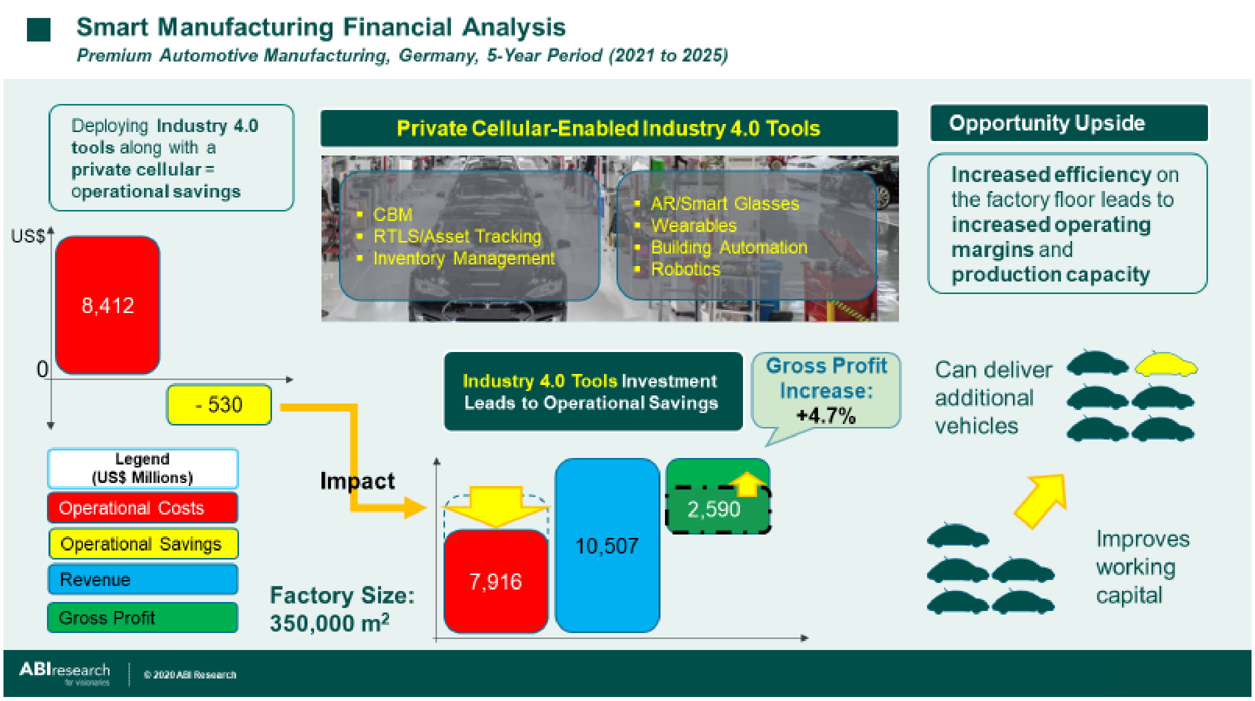


Figure 10: Smart Manufacturing Financial Analysis – Automotive Part 2

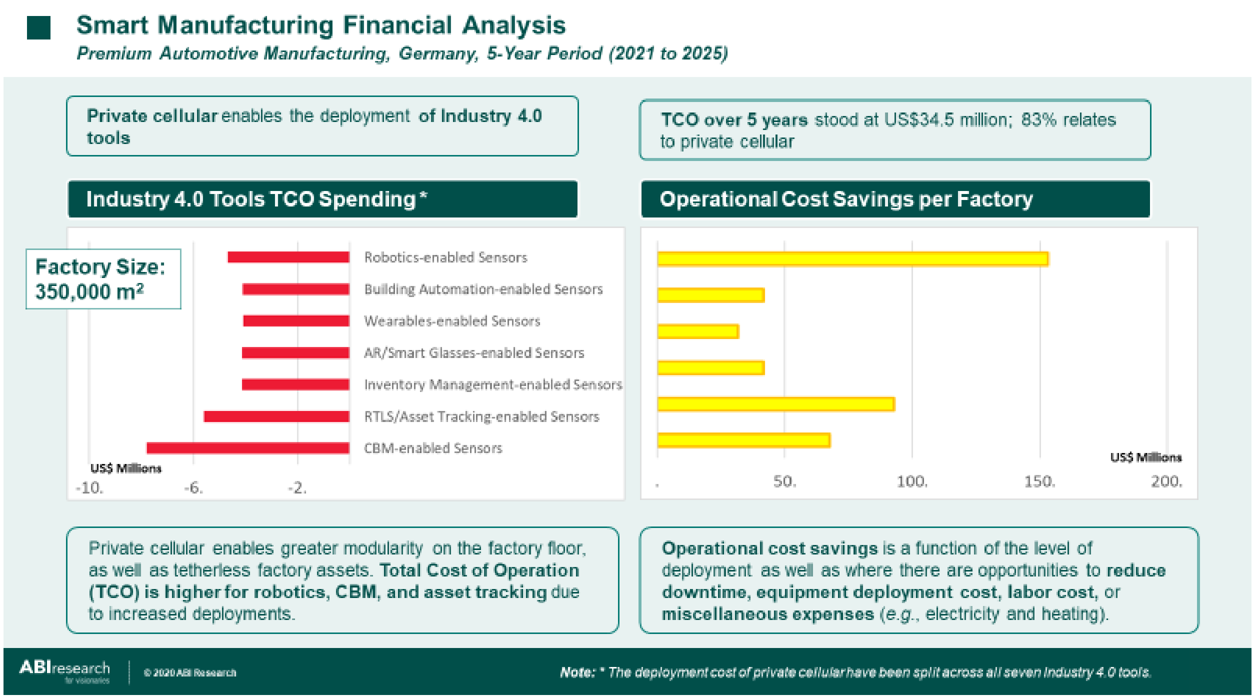


Figure 11: Smart Manufacturing Financial Analysis – Smartphone Part 1

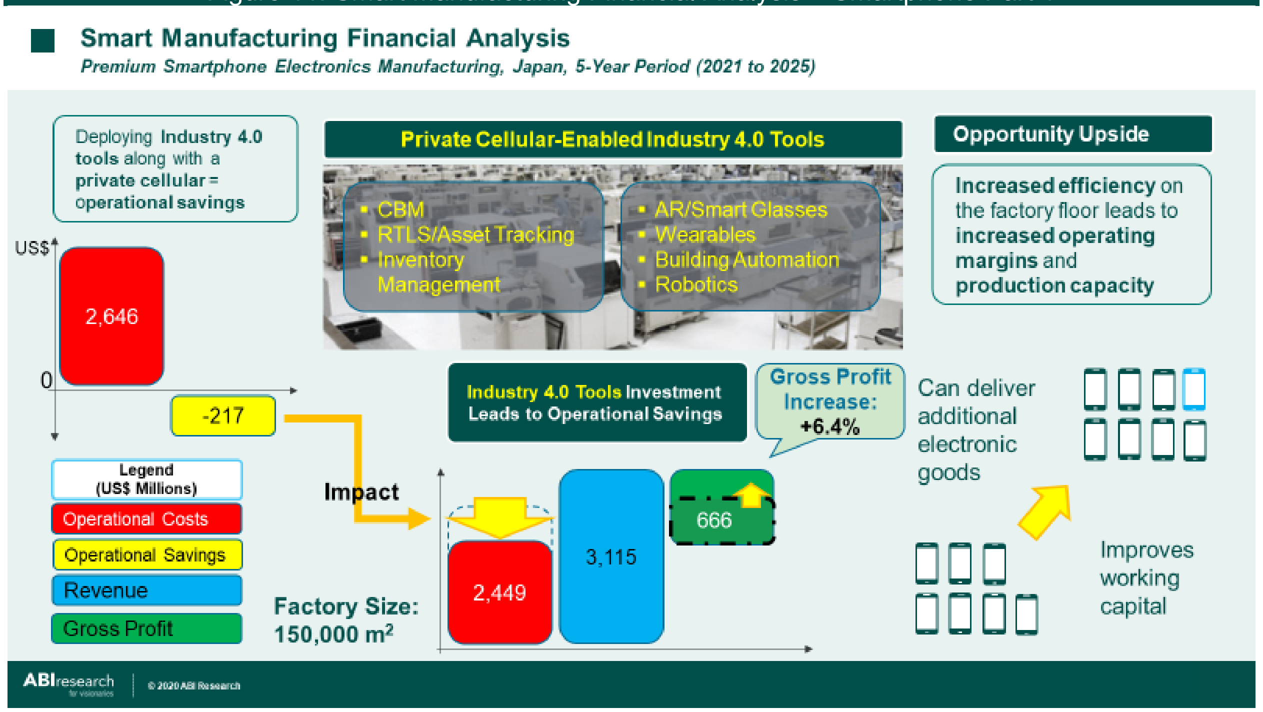
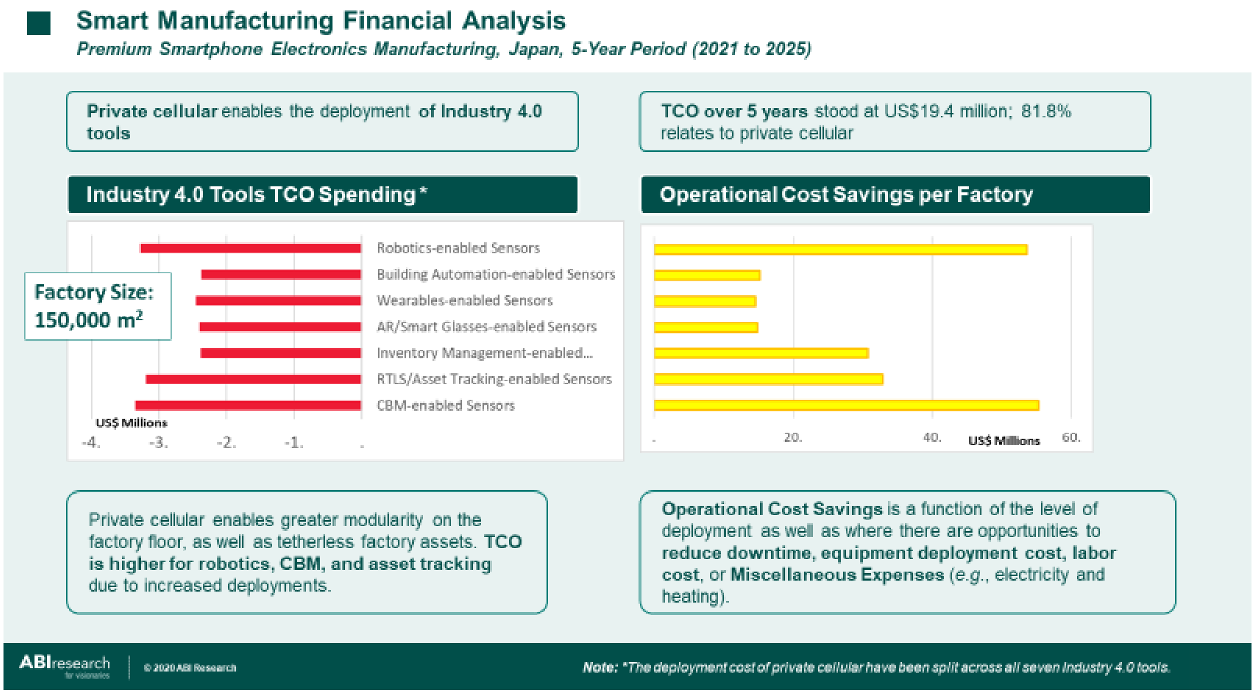


Figure 12: Smart Manufacturing Financial Analysis – Smartphone Part 2



3.2. Energy Sector

Energy resourcing sites (such as power plants, oil fields, or mines), as well as power plants, are characterized by two main aspects that carry important implications: hazardous environments and a multitude of concurrent processes. While the hazardous environment means that site operators do not want to send people in unless necessary (because of security concerns), the multitude of concurrent processes means that beneficial effects from automating these processes are comparatively large.

3.2.1. Use Case Overview

Use cases within the energy production industry (such as oil & gas, mining) largely center around the reduction of operational expenditure (OPEX). Given the particularly hazardous environment, these mostly consider automating workflows and increase remote operations in order to reduce dependency on the availability of labor. Furthermore, cellular connectivity can be a major component for utility operators to instantly react to volatility in energy demand to adjust production accordingly and guarantee price stability.

Automated and Remote operations

As one of the most important use cases, 5G connectivity will allow the automation of workflows within energy resourcing sites and allow processes to be operated remotely: Production vehicles are equipped with a number of cameras and sensors, which will transmit their data to an operation room, from where these vehicles are operated. While the high throughput both in the up- as well as in the downlink (eMBB capabilities) enable the transmission of particularly large data (such as video camera footage), sub-10-ms latencies (as guaranteed by URLLC capabilities) are critical to apply remote operations in a real-life scenario, since it is critical that operators can react immediately to any complication that might occur in mines or an oil field.

Condition Monitoring in oil & gas fields and mines

In addition, the ability of connecting 1,000,000 devices per square kilometer (km^2) can also be used for setting up massive wireless sensor networks. These networks can be used to monitor a range of different conditions within the site. One of the most prominent use cases in this context is the set-up of a wireless network to be able to monitor the air quality inside a mine. Sensors are fitted in different places throughout the mine and connected with a centralized computing unit, to which they send the measured sensor data on a continuous basis. Since 5G will allow processing capabilities to move from the core network into the edge, these sensor data can be processed in an on-premise edge, which subsequently can warn the mining operator about deteriorating air quality within the mine or initiate an emergency shutdown.

Automated End-to-End Supply Chain Visibility

By increasing the visibility along the whole supply chain, energy producers will be able to anticipate fluctuations in energy demand quickly and react instantly to adjust production in an automated way. Automated end-to-end supply chain visibility will be important to react to demand fluctuations more efficiently.

This is an important move away from the current manual calibrations of field operations used to adjust to demand, which could take weeks of planning. In contrast, automated supply-chain visibility will enable suppliers to immediately scale up oil & gas production once industries start to recover (and demand for oil & gas will surge again) or scale down production to react to reduced demand and guarantee a stable price level in the future.

5G as an Enabler for AI for Enhanced Predicted Energy Consumption

By enabling the large scale adoption of artificial intelligence (AI) technologies, 5G will allow predicting of future energy consumption and therefore adjust the production not only based on full visibility along the supply chain but also based on enhanced predictions, which will enable energy plant operators to preemptively react to demand fluctuations and therefore guarantee stable pricing level for energy products.

Smart Grid Applications

In addition to enabling the large scale application of Artificial Intelligence to improve predictions around future energy consumption, 5G can also be applied within a smart grid to improve demand response (DR), which is important giving recent advancements in the energy domain: With renewable energy sources on the rise, distribution networks are changing from one-way power flow to bi-directional power flow. In addition, the increased use of electric vehicles and energy storage batteries are fundamentally changing power utilization characteristics. Furthermore, liberalization of energy markets, as well as increased overall energy consumption, increase the need for communication overlay on the utilities grid for three purposes: Firstly, to measure the system state, secondly, to collect sensor information and propagate control signals, and thirdly, to allow distributed smart applications to control power flows within the network. By guaranteeing low network latency, five-nines network reliability, robust security, and low power consumption, a 5G network can contribute to reducing the DR and therefore guarantee network stability by preventing overloads. Other use cases include intelligent distributed feeder automation, millisecond-level precise load control, the acquirement of information around Low Voltage Distribution Systems, and distributed power supplies.

3.2.2. Technology Aspects

When considering applications in the energy and utilities domain it is important to understand that most of these applications are mission-critical, meaning that if the cellular network fails to support these use cases (by low availability or reliability) the operation of the whole energy excavation site would need to be stopped. As a result, use cases in the energy and utilities domain require particularly high degrees of network availability and reliability (at least 99.9999%, which is guaranteed by 5G URLLC capabilities). Furthermore, the remote operation of assets and vehicles within the respective excavation site requires latencies of below 10 milliseconds to ensure that remotely given instructions are received without any additional delay which could cause accidents or other operational disruptions which could in the worst case result in a forced shutdown of the whole excavation site.

Looking at network architecture aspects, the deployment of a private network makes cellular connectivity technology even more attractive to energy producers. Since private networks (if operated in standalone mode, which has been standardized in 3GPP's release 16) do not require any connection to a public cellular network, all network traffic (including highly sensitive data on production infrastructure) can remain on the premises of the energy excavation site. Furthermore, by offering deterministic networking, the operation of a private network using licensed mobile network spectrum safeguards network integrity and ensures non-interference from any unauthorized party.

Given the heterogeneity of smart grid use cases (reported in table 5), 5G's network slicing capabilities allow addressing all these use cases within the same physical infrastructure.

Table 5: Smart Grid Use Case Requirements

Use Case	End-to-End Latency	Reliability	Number of Terminals	Isolation Requirements
Intelligent distributed feeder automation	Millisecond level	99.999%	low	Complete isolation required
Precise load control	Millisecond level	99.999%	low	Complete isolation required

Information Acquirement of Low Voltage Distribution Systems	Millisecond level	<99%	>10 mio	No requirements
Distributed Power Supplies	Millisecond level	99.999%	>10 mio	No requirements

(Source: ABI Research)

3.2.3. Business Case Aspects

The benefits of remote operations in the energy production domain are threefold. Firstly, it increases workplace security, since it reduces the number of people that must be sent into a hazardous environment. Secondly, it increases the efficiency of operations, as one operator can monitor more than one production vehicle. Thirdly, it makes energy companies less reliant on the availability of a manual workforce. In a situation with social distancing where measures are introduced to inhibit the outbreak of the coronavirus disease (Covid-19), this is critical to ensure business continuity in circumstances with low availability of manual labor.

Furthermore, the remote operation of production assets will increase efficiency, since it allows the simultaneous operation of up to 4 production assets per operator, while in a traditional setting one operator would be needed for each of the production assets.

Furthermore, condition monitoring enabled by cellular connectivity is expected to decrease a mine's energy consumption by more than 50%. In addition, by coordinating and automating workflows, energy site managers can reduce production vehicle's fuel consumption by around 10% per year. For operators of oil rigs, the automation of workflows can increase the annual capacity of oil rig operations by 40%.

In comparison to other wireless connectivity solutions (like Wi-Fi) one of the most important advantages is the robust handover between base stations: To illustrate this, consider the exemplary cellular deployment in the Mine Minera Las Bambas in Peru, where mining operator Rio Tinto managed to replace 17 WIFI access points (AP) with 3 private LTE base stations. While a single LTE base station is reported to cover up to 6 km of tunnel, it would take 60 WIFI AP's for the same area of coverage. In addition, the price advantage of cellular connectivity over WIFI also holds when considering the cost per base station (or WIFI access point).

3.3. Health Care

Since the beginning of 2020, the global outbreak of COVID-19 has put incredible pressure on every national healthcare system in the world, highlighting the imminent need for modernization and digitization of the sector. To advance towards a smart and agile healthcare system, 5G cellular connectivity can be a critical enabler.

3.3.1. Use Case Overview

When considering use cases in the healthcare domain, you must distinguish administrative from medical use cases, as they substantially differ in terms of network requirements and their ways of measuring performance.

3.3.1.1. Administrative Use Cases

Since administrative applications target efficiency enhancements of large operations, they rely on the 5G's capability to connect to 1,000,000 devices and sensors per km^2 with each other. In contrast to medical use cases, administrative use cases are rarely mission critical, meaning there is less emphasis on indicators like network availability and reliability.

Track & Trace

Enabling device-to-device connections will dramatically improve the ability of phones to communicate with each other without having to rely on the external network. In a situation of a global pandemic, this direct device-to-device communication can be used to detect proximity to other users' phones. By developing specifically designed software applications, this ability can then be used to track and trace the outbreak of diseases, such as the current Covid-19 pandemic: As soon as a user either develops symptoms or is officially tested positive for the respective disease, this would be noted inside the app, which would trigger an automated message to every other mobile phone that the respective user was in close proximity to over a pre-defined period of time.

Asset Tracking & Personnel Management

In addition, 5G will also be able to increase the efficiency of hospital processes and workflows by enabling automatic tracking of surgical instruments and any kind of additional hospital assets.

With the proposed centimeter-level accuracy (that will come with Release 17) 5G connectivity will be a perfect fit for asset localization. While realistically speaking, there are other, more affordable wireless technologies that could be used for localization purposes (mainly Radio frequency identification, RFID), the benefit of cellular connectivity is that it can be used for a variety of different use cases, with asset localization being just one of the application scenarios.

In addition to tracking assets, 5G connectivity can also be used by hospital staff management to allow more accurate planning of shifts and distribute tasks and workload more efficiently between hospital staff based on their location within the hospital.

Patient Data Management

In addition to tracking hospital staff and assets, a 5G based healthcare communication system will also be able to manage patient data more efficiently.

In order to accomplish this, the network needs to be deployed as a platform, so that specialist healthcare software developers can build their applications on top of that network infrastructure to ensure seamless interoperability with existing healthcare communication Standards.

3.3.1.2. Medical Use Cases

In addition to administrative use cases, 5G can also be applied to enhance quality and reach of medical applications for patients. Since these use-cases affect patients' health directly (and often are even life-critical), these uses cases mainly rely on URLLC capabilities, as they require particularly high network reliability and availability, as well as low latency communication. mMTC and eMBB capabilities add to this foundation.

Patient Monitoring for Preventative Medicine and Prescriptive care

Since 5G New Radio (NR) allows the transmission of large data sizes, as well as the connection of a large enough number of devices, this allows measuring of healthcare data to transform from one or more individual, isolated measurements during the day into one continuous measurement. While this is already possible for in-hospital patients (in the form of a long-term electrocardiogram, ECG), by utilizing 5G connectivity, this continuous monitoring of healthcare data can also be performed for patients that are well enough to stay at home.

Enhanced Diagnostics

By guaranteeing high enough bandwidth as well as low latencies, 5G will enable the large-scale application of Artificial Intelligence (AI) technologies in the healthcare domain. While AI will certainly help to manage patients and hospital staff, from a medical point of view AI technologies will assist hospital staff in medical diagnosis.

By providing edge capabilities and decentralizing medical processing, 5G will enable AI to decentralize towards the network edge. Algorithms could be trained to automatically detect anomalies in medical imaging procedures (such as X-Rays or magnet resonance imaging, MRI) and automatically transmit the findings to the respective medical consultant immediately

Connected Ambulance

When looking at the *connected ambulance* use case, this often refers to two different types of applications. The communication of the ambulance car with other cars and roadside infrastructure (C-V2X connected car use cases) on the one hand and medical use cases on the other. While C-V2X use cases will be explored in Section 3.5, medical applications describe the connection of on-board medical equipment with a nearby hospital information system (HIS).

By transmitting important patient data to the hospital well before arrival of the patient, it allows hospital staff to prepare in the best possible way for the newly arriving patient by preparing diagnostic cabinets, specific medical diagnostic devices or putting out a call for relevant specialist consultants. Furthermore, transmitting ultrasonic medical image data could enable hospital staff to help emergency response personnel perform an initial diagnosis.

Remote Operations: Remote Care, Remote Diagnostics, Remote Surgery

By guaranteeing bandwidths of 10 Gbps in the uplink and 20 Gbps in the downlink (with eMBB capabilities) as well as sub-10ms latencies (as part of URLLC capabilities), the deployment of 5G will enable a range of different remote real time operations in the healthcare domain.

Firstly, 5G can be used to reorganize care for elderly or particularly vulnerable people by allowing some duties of care to be carried out via video connectivity. Since this does not necessarily require particularly low latencies or many devices to be connected, but only needs enhanced mobile broadband to transfer video data between care giver and patient, this could easily use the public cellular network infrastructure that has been deployed for consumer rollout. Since care recipients do not necessarily have access to fixed broadband or fixed wireless, utilizing the public cellular network infrastructure would be the only cost-efficient way of reaching patients without having to deploy an additional connectivity network.

Secondly, enhanced mobile broadband can be used to enable video consultation between patients and doctors for a first diagnosis. The benefits of such a solution are rather clear, since this prevents diseases from spreading easily in the population by decentralizing diagnostic options. But there are two problems with people going to a doctor for diagnosis, both stemming from the fact that they are most probably sick. Firstly, sick people bring new diseases to a hospital or a doctor's practice and therefore increase the risk of infecting others. Secondly, since most people visiting a doctor are sick themselves and therefore suffer from a weakened immune system, they are more susceptible to catching a new illness by visiting an area highly concentrated with bacteria and viruses.

Thirdly, by combining the high bandwidth guaranteed by eMBB as well as the low latencies and high reliability guaranteed by URLLC, 5G will enable carrying out remote surgeries, where the operating surgeon does not have to be in the same location as the patient, but operates a robot conducting the surgery on the surgeon's behalf.

While the vision of an entirely remote operated surgery using robots is a very long-term vision, an intermediary step could be a remotely located specialist advising or instructing a junior surgeon on how to conduct the surgery. This would ensure a human surgeon being present during the surgery and would increase the subjective (and somewhat irrational) feeling of safety for the patient.

3.3.2. Technology Aspects

Following the distinction in Section 3.2.1, the requirements on network performance differ between administrative and medical use cases. Since administrative applications target efficiency enhancements of large operations, they rely on 5G's capability to connect to 1 million devices and sensors per km^2 (as guaranteed by 5G's massive machine type communication, mMTC capabilities) with each other. Administrative applications are rarely mission-critical, so there is less emphasis on indicators like network availability and reliability.

Since medical applications in contrast are often life-critical, the performance of any communication technology will have direct effect on the health condition of patients. As a result, these use cases require network reliability and availability of at least 99.999%. Furthermore, to avoid any delays in transmitting life-critical patient data across the network, sub-10 millisecond latencies are of key importance.

From a network architecture perspective, these critically low latencies can be enabled by deploying mobile edge compute capabilities (MEC) on hospital premises to enable data processing to occur as close to the device level (and therefore the data source) as possible.

In order to safeguard the integrity of the cellular network used to transmit highly sensitive and life-critical healthcare data, the deployment of private networks offers hospitals and healthcare providers the opportunity to operate their own fully customized network without any necessary connection to the public cellular network infrastructure.

3.3.3. Business Case Aspects

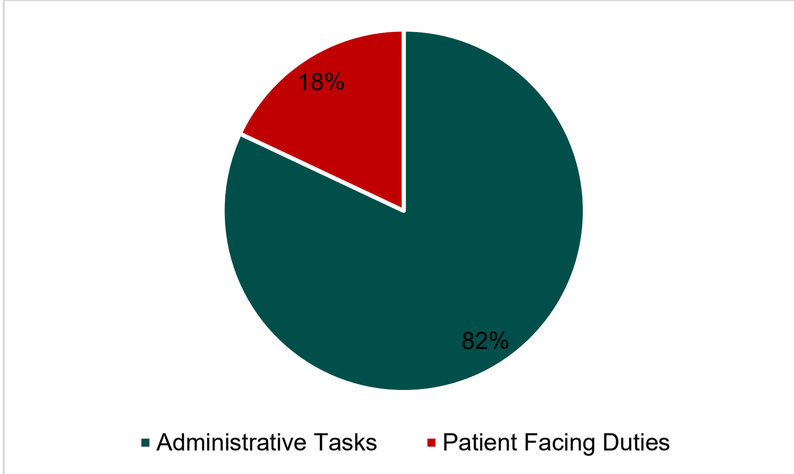
At present, the healthcare sector is characterized by a high degree of technology fragmentation that prevents different healthcare units from communicating efficiently with each other and exchanging patient data across different medical domains. In addition, most connections within a hospital use fixed-line connectivity. Considering that patients are moved constantly within a hospital (to and from surgical theatres, between different wards or diagnostic rooms), relying on fixed-line connectivity limits the transmission of patient data.

When looking at the business case of 5G deployments in the healthcare domain, a broad horizon is needed to quantify the benefits that a smart healthcare system relying on cellular connectivity will bring to society as a whole, rather than just looking at individual healthcare providers. Looking at administrative use cases, the benefits will enhance the efficiency of the healthcare system. To quantify this, the average working day for a nurse is considered:

Different studies suggest that each nurse spends up to 82% of their day performing administrative tasks (translating to an average of 6.5 hours, assuming an 8-hour working day) performing administrative tasks (*e.g.*, walking to/from different patients, retrieving medication and supplies, and recording information into the Electronic Health Records (EHR) system), while only 18% (1.5 hours) is spent with patients.

Figure 9: Typical Composition of Nursing Duties

(Source: Zebra Healthcare)



Extrapolating these numbers over a typical working year shows that a single nurse spends a total of 1,560 hours in an average working year (assuming 240 working days per year and a typical working day of 8 hours) performing administrative tasks. By providing automated personnel and asset management, a 5G-enabled smart healthcare system would minimize this proportion and allow nurses to spend most of their day with patients. Automating administrative use cases will streamline the healthcare system and lead to substantial efficiency enhancements.

Medical use cases, on the other hand, increasingly target the quality of the healthcare system, which is somewhat harder to translate into economic benefits.

Considering the remote monitoring of patients' health conditions, for example, several studies have investigated the value of continuously monitoring patients with heart conditions. Their findings suggest that continuously monitoring patients' heart data could identify anomalies 11 days before the patients would normally be admitted to a hospital. In the case of problematic heart conditions, for which the application of the right treatment is extremely time-critical (several minutes or even seconds in the case of a stroke), gaining insight about anomalies several days before the patient would have been admitted to a hospital is absolutely critical to maximizing the likelihood of the patient fully recovering from the condition.

Therefore, enhancing the quality, as well as the reach of a healthcare system, will reduce the number of patients requiring hospitalization in the first place. For those patients requiring admittance to hospitals, 5G enabled smart healthcare system will shorten the hospital stay.

3.4. Smart City & Buildings

In the context of modern society, the smart city will become increasingly important, especially considering intelligent transportation systems (connected car use cases), smart grid management, or increasing energy efficiency.

3.4.1. Use Case Overview

To provide a comprehensive overview of use cases, you can distinguish three different sub-classes of applications: enabling new individual applications, combining existing applications, and utilizing enhanced massive machine type communication (mMTC) capabilities to establish dense, massive wireless sensor networks. Individual applications in the smart city and buildings context require 5G specific performance indicators, while the combination of existing use cases is enabled by network architecture features.

3.4.1.1. Individual Use Cases

The most immediate opportunity for 5G deployments in the smart city & buildings sphere lies in enabling new individual use cases. These center around the provision of particularly high bandwidth to enable transmission of data-intensive footage, high-resolution video data, for example. Furthermore, network reliability and availability are important enablers of the application of cellular connectivity to use cases that require constant connectivity (which previously could not be served by cellular connectivity).

Drones for Surveillance & Social Distancing

Most interestingly, the high bandwidth in the up- and downlink enabled by enhanced mobile broadband capabilities allow for the transmission of data-intensive video footage that could be used to remotely operate drones to increase public safety. These drones can then be used to monitor different aspects, ranging from traffic flow to crowd control for event locations or emergency response units in the aftermath of a natural disaster (such as earthquakes).

When it comes to emergency response applications, drones can be used for different scenarios. Firstly, they can be used to identify survivors in remote locations (with the help of either regular or thermal imaging cameras). Secondly, they can be used to deliver necessary goods like medication or essential food supplies. Furthermore, with social distancing in effect, remotely operated drones can be used to monitor compliance with social distancing measures and would contribute to the containment of the pandemic. By fitting remotely operated drones with thermal imaging cameras, people’s body temperature can be monitored from a distance, contributing to the restriction of the spread of COVID-19 by detecting the first symptoms of the disease before they become apparent to the person.

Increased Public Safety and Security

In addition to increasing public safety and security through remotely operated drones, 5G connectivity can also increase security by connecting stationary cameras with each other. The new device category NR-Light that will be standardized with 3GPP’s Release 17 is directly aimed at devices like security cameras, which require slightly higher bandwidth than narrowband IoT (NB-IoT) devices, but not nearly as much as enabled by eMBB capabilities. In combination with Artificial Intelligence and the ability to decentralize processing capabilities to the network edge (closer to the device level), 5G connectivity can enhance the degree of automation in analyzing video footage and therefore increase both the quality as well as the efficiency of analyzing CCTV camera footage for public safety and security purposes.

5G as an Enabler for Digital Twins

With eMBB capabilities allowing the transfer of data-intensive files in the smart city concept, this allows the implementation of digital twins of neighborhoods or whole cities. These can be used to model the impact of different urban planning and architecture projects or impacts of certain public safety measures on the behavior of citizens to predict whether measures would have the desired effect. Therefore, it will make planning processes more efficient and more cost-effective since the ability to test on a digital twin would ensure that projects will receive the necessary investment only if they display the desired impact.

Smart Buildings & Event Locations

From a more consumer-focused perspective, 5G will be able to transform buildings, stadiums, and event locations into smart venues, where cellular connectivity can be used to enhance both enterprise use cases as well as consumer applications within the same physical network infrastructure.

In the media broadcasting domain, the most prominent use case centers around utilizing 5G capabilities to enhance live broadcasting. In this scenario, video cameras would be equipped with 5G modules that would allow them to transmit video footage directly to the respective studio, so there is no need for an Outside Broadcasting (OB) vehicle anymore. Most of the image processing would happen at the device-level (inside the camera), while post-processing would happen either in the far edge or in the studio directly.

Massive Wireless Sensor Networks

Particularly interesting in the smart city context is the ability to connect many devices over a 5G cellular network (1,000,000 devices/km^2 guaranteed by enhanced mMTC). This allows 5G connectivity to be applied to large scale smart city use cases that require a high number of connections because of the density of individual connections that need to be considered.

While the individual use case does not rely on performance indicators that would require 5G connectivity, it is the density of connections offered by 5G capabilities that enables the application of cellular connectivity to these environments. 5G connectivity can be used to increase citywide road traffic control, where a dense network is needed to connect a plethora of cars in an urban environment with roadside infrastructure and/or other cars to increase fuel efficiency and traffic flow, which would decrease the carbon footprint of individual traffic. Furthermore, cellular connectivity can be used for city-wide smart grid management. While smart grid management itself primarily relies on artificial intelligence, 5G connectivity will provide the network density that is needed to scale smart grid management applications to cover large urban areas.

3.4.2. Technology Aspects

In considering the requirements of network performance, one has to distinguish between 5G enabling new smart city use cases (such as the remote operation of drones) and 5G as a catalyst for enhancing technology to scale up use cases that on an individual level can already be supported with previous generations of cellular connectivity. While the newly enabled use cases by and large require high bandwidth that is standardized through enhanced mobile broadband capabilities (eMBB) in 3GPP’s Release 15, scaling up existing use cases requires 5G's ability to connect a large enough number of devices with each other and the network infrastructure.

From a network architecture point of view, the provision of mobile edge compute capabilities (MEC) will result in more decentralized processing of network traffic, as close to the origin of data as possible.

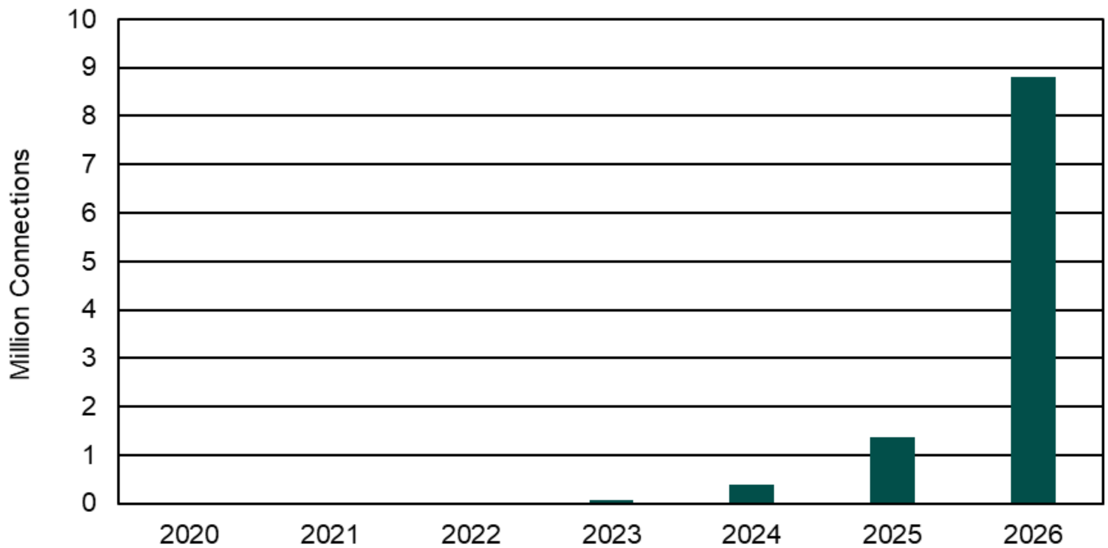
The deployment of cellular for smart city applications requires a much more rigid test and measurement system in place to ensure a constantly high level of quality of service, which is vitally important for automated traffic management. Resulting from this, the demand for test and measurement devices will increase drastically, which provides new revenue opportunities for electronics manufacturers. Furthermore, in response to the increased network traffic that will arise by 5G connectivity, more fiber will be needed to cope with the increased amount of backhaul.

3.4.3. Business Case Aspects

Benefits from 5G deployments in the smart city context are macroeconomic benefits that affect society as a whole: Enhancing citywide flow of traffic, for example, will lead to indirect productivity gains for the overall city population since it reduces the time that each individual will have to spend unproductively in traffic. Furthermore, it will decrease the number of exhaust gasses being emitted from cars in traffic jams, leading to a beneficial effect on society through two different channels. Firstly, it will reduce the negative impact on the environment and climate. Secondly, increasing air quality will result in fewer people requiring admittance to a hospital with respiratory problems. Similarly, the benefits of 5G enabled smart grid management must be considered for the whole population.

To quantify the revenue opportunity for 5G in the smart city environment, in Figure 10, ABI Research forecasts that more than 8 million smart city-wide area network (WAN) connections will utilize 5G connectivity by 2026.

Figure 10: Number of 5G City WAN Connections
2020 - 2026
(Source: ABI Research)



3.5. Transportation & Logistics

Completing the picture, 5G cellular connectivity will also have the capabilities to fundamentally impact the transportation and logistics sector. By enhancing device-to-device communication and enabling point-to-multipoint transmission (multicast mode), 5G will be an important enabler for connected vehicle (C-V2X) applications, such as vehicle-to-vehicle communication (V2V) and vehicle-to-infrastructure (V2I) and vehicle-to-network (V2N) connectivity. Furthermore, it will be a key enabler of smart warehousing applications and therefore enhance trends towards increased end-to-end supply chain visibility.

3.5.1. Use Case Overview

Broadly speaking, uses cases in the transportation domain can be distinguished into two groups with different requirements. On the one hand, 5G cellular connectivity can be used to provide immersive onboard entertainment opportunities for passengers. On the other hand, 5G will be a critical enabler for cellular-connected car use cases, which will increase traffic efficiency and road safety.

Onboard Entertainment Opportunities

By guaranteeing a bandwidth of up to 20 Gbps in the downlink and 10 Gbps in the uplink, 5G has the potential to equip cars with particularly data-rich information and entertainment (in short, infotainment) opportunities, such as video streaming, enhanced gaming experiences, and augmented reality-enriched navigation opportunities.

The necessary capabilities for eMBB have already been standardized with 3GPP's Release 15 (deployed in three distinct drops in during the year 2019). Since chipset suppliers, as well as infrastructure vendors, have already had time to develop compatible components, this presents an immediate realizable revenue opportunity for 5G in the automotive domain.

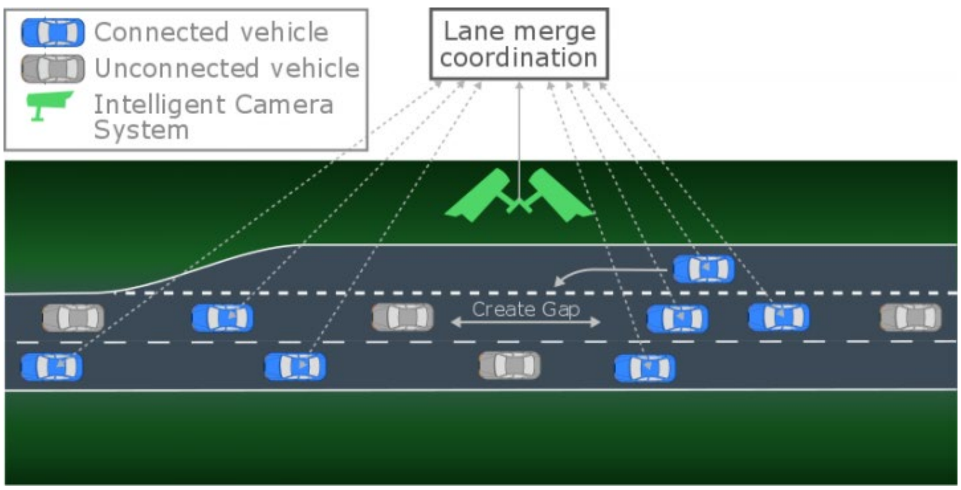
Cooperative Maneuvering & Driving

Based on the principle of sharing local awareness and driving intentions, the driving trajectory of a considered group of vehicles can be coordinated with the goal to improve overall traffic safety and efficiency. This will increase driving comfort (due to smoother maneuvering), as well as reduce emissions and fuel consumption.

Concise use cases include, for example, lane-merging scenarios. A vehicle seeking to merge from one lane into another ("main") lane shares its positioning as well as driving intention data to the cars in the "main" lane. A schematic description of a lane-merging scenario is illustrated in Figure 11 below.

Figure 11: Possible Lane-Merging Scenario

(Source: 5GCAR)



Another application scenario can be equipping emergency response vehicles (ambulances or fire brigades, for example) with C-V2X capabilities. This would enable emergency cars to communicate their presence to the vehicles in the immediate vicinity to ensure other road users clear the route to guarantee smooth navigation in case of an emergency. In a similar way, these capabilities can be used to communicate with roadside units (e.g., traffic lights) to ensure green lights for emergency vehicles to minimize disruptions to the overall traffic.

By sharing vehicle status data such as position, speed, engine output, and steering angle, connected vehicles can maneuver cooperatively, resulting in numerous advantages relating to safety and efficiency. Simultaneous acceleration and deceleration can enable safe, close following distances between connected vehicles. Within a fleet of trucks, for example, V2V connections can be used for automatic "platooning," automatically keeping a predefined distance to even out traffic movements. Widespread penetration of V2V communication could therefore have a significant impact on traffic flows, with ensuing environmental and fuel efficiency advantages.

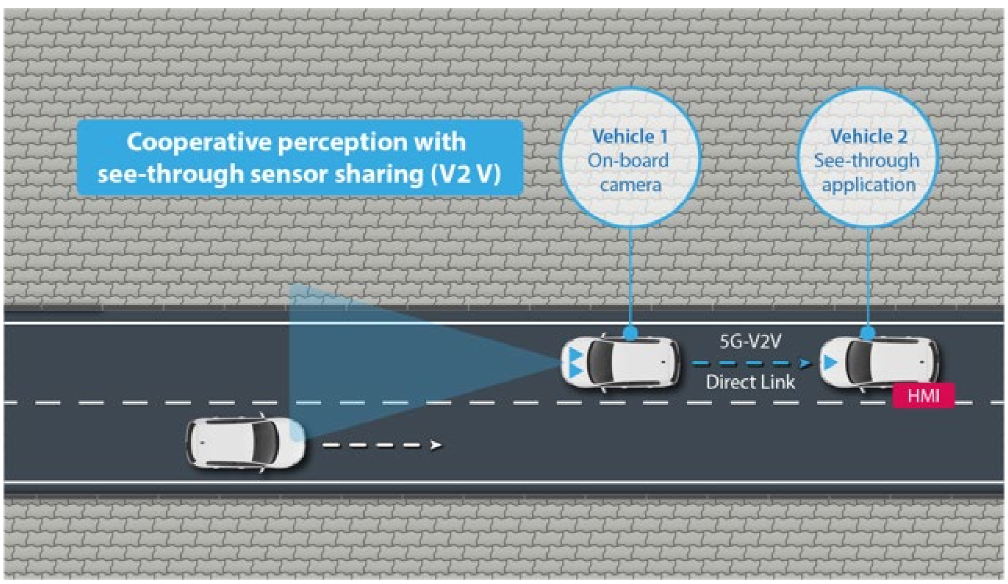
Cooperative Perception & Awareness

While cooperative maneuvering rests on the coordination of positioning data between different vehicles, cooperative perception considers exchanging data from a variety of other sources (such as sensors or cameras, for example), which is then shared among all vehicles in a given vicinity.

One of the most promising applications in this context is referred to as “invisible car.” Sharing sensor data will overcome the visibility limitations of a subject vehicle caused by another vehicle driving in front of the subject (as illustrated in Figure 12 below). Once the rear vehicle is ready to initiate a certain traffic maneuver (overtaking, for example), the front - driving car starts to transmit all its sensor and video data to the rear-moving vehicle, therefore become “invisible” (or rather “transparent”) to the subject vehicle.

Figure 12: Possible Scenario “Invisible Car”

(Source: 5GCAR)



Furthermore, sensor sharing can also be used to detect and therefore increase the safety of vulnerable road users. The detection mechanism could be based on sensors/cameras, a positioning system, or a cellular communication system (utilizing the other road user’s mobile phone signal). Other deployment scenarios consider the use of thermal imaging cameras (mounted onto either a vehicle or a roadside unit) for detection.

Autonomous Navigation

To provide the basis for optimal route selection for semi-/fully automated vehicles, a high-definition map, aggregated with real-time data (gathered through cooperative perception), can be provided to all vehicles in a predefined vicinity. Giving them this real-time traffic information would result in a more efficient way of organizing traffic (i.e., reducing time spent in traffic, as well as cutting emissions and fuel consumption). Furthermore, it would increase driving comfort for both vehicle drivers as well as passengers.

Smart Warehousing

Looking at the logistics aspect, 5G cellular connectivity will be an important enabler for smart warehousing concepts to materialize. While cellular connectivity is one important aspect in the understanding of smart warehousing, it is important to understand that it is not the only important aspect since smart warehousing refers to a number of different technologies that all find their application in the warehousing environment: the operation of automatically guided vehicles (AGVs) as well as autonomous mobile robots (AMRs), the application of augmented reality (AR) as well as different technologies for real-time location services (RTLS). All these examples are important components of smart warehousing and will be enabled by 5G connectivity.

3.5.2. Technology Aspects

Taking into consideration technology aspects, the use cases described in the previous section can be distinguished between consumer-oriented onboard entertainment use cases and mission-critical. While the former primarily require high enough throughput to transmit high-resolution video content to passengers (with eMBB capabilities that have been standardized with Release 16), C-V2X use cases like cooperative maneuvering, perception, and safety as well as autonomous navigation and remote driving require a combination of bandwidth network availability, reliability, and specifically low latency. Table 6 below summarizes the requirements that use cases in the automotive sector pose towards cellular connectivity.

Table 6: Automotive Use Case Requirements: Comparison
(Source: Huawei Research Center)

Use Case Class	End-to-End Latency	Reliability	Data Rate per Vehicle
Cooperative Maneuver	3 ms to 100 ms	99.999%	Up to 5 Mbps
Cooperative Perception	<1 s	99%	Up to 25 Mbps
Cooperative Safety	100 ms	99.99%	10 Kbps
Autonomous Navigation	1 s	95%	Up to 2 Mbps
Remote Driving	5 ms to 10 ms	99.999%	>25 Mbps

From a network architecture perspective, 5G-enabled NR-V2X will allow processing of non-real-time data to move out of the car into an edge cloud, while the processing of real-time data will remain inside the vehicle. Therefore, it will increase the overall amount of data that can be processed by different components within the cellular network without putting too much strain on either the core network, the device edge (i.e., the car in this case), or the network edge.

Furthermore, 5G offers critical improvements in sidelink communications (for device-to-device communication) as well as in the up- and downlink (for V2N connections) that will be beneficial for automotive use cases: while the sidelink communications in previous generations of cellular connectivity (i.e., 4G / LTE) is limited to transmission mode only, New Radio sidelink introduces unicast and groupcast modes, which enable direct communication between multiple devices simultaneously.

3.5.3. Business Case Aspects

When considering the business case around connected cars and intelligent transportation, a wide enough focus needs to be adopted to take into account that the benefits of these applications are to the overall society rather than clearly conceivable and easily monetizable benefits for a clearly defined economic group.

On the contrary, applications in the logistics sector have a clear beneficiary when considering the operator of a truck fleet or warehouse. By equipping a convoy of trucks with cellular connectivity and using it for *platooning*, fleet operators will be able to save up to 30% of fuel consumption. In addition to the clearly monetizable benefit to a fleet operator, this reduction in fuel consumption also decreases negative externalities to the environment, which needs to be factored into any kind of cost-benefit analysis.

When considering smart warehousing, the benefits of a wireless network above a wired connectivity solution, by and large, follow the business case aspects in the industrial manufacturing domain (discussed in Section 3.3). Particularly important in this context is the fact that warehouses are characterized by a high degree of mobile assets. Not only would cabling all these assets be expensive in the first place, but it would also require a high degree of maintenance and premature replacement, considering the high wear and tear of the cables. Similar to industrial manufacturing deployment considerations, other wireless connectivity technologies (such as Wi-Fi or Bluetooth) cannot offer the degree of network determinism required by warehoused operators. Other automated identification technologies like RFID (radio frequency identification) only allow for passive tracking of goods and assets along the supply chain but do not allow the sending of data (from sensors or other sources) back and forth.

To quantify the return on investment that warehousing operators can expect from deploying 5G connectivity within their premises, a recent ABI Research study suggests that a tier 1 warehouse operator in Germany (with a floorspace of 50,000 square meters) could realize potential cost savings in the region of US$ 355 million over a 5-year period. ABI Research estimates that the cost of inaction for a warehouse operator would result in approximately US$ 348 million per warehouse over a 5-year period.

4. 5G Ecosystem

The industrial manufacturing vertical is much more fragmented than the consumer market. The diversity of use cases and the respective technology requirements will force operators and vendors to offer more flexible, customizable 5G connectivity solutions, rather than a “one-size-fits-all” model. Furthermore, addressing the needs of enterprise verticals will fundamentally change the shape of the 5G value chain, requiring a change in behavior from all relevant actors and an emergence of new players such as system integrators or webscale providers. 5G enterprise would need tighter collaboration between all parties to address the unique connectivity needs of each vertical.

4.1. Communication Service Providers

Communication Service Providers (CSPs) have an enormous opportunity to manage the diverse use cases of enterprise verticals due to their ownership and experience in deploying network infrastructure. There is no doubt that CSPs can contribute significantly with their legacy assets (software, equipment, spectrum, etc.) and expertise. Initial 5G enterprise deployments would, therefore, most likely go through service providers.

4.1.1. Spectrum Leasing

To be able to offer a deterministic network that can support data-intensive use cases, enterprises must have adequate spectrum resources. On a global level, 99% of the spectrum belongs to CSPs; they are in an excellent position to lease or share spectrum to enterprise verticals. For example, Swedish provider, Three arranged a spectrum leasing arrangement with Finnish “micro-network” provider Edzcom (previously Ukkoverkot). Edzcom reserves this leased spectrum to build private industrial cellular networks for its customers.

4.1.2. Network Slicing

CSPs are increasingly seeking to create services that are more differentiated in a bid to generate new revenue sources and be more attractive to their enterprise clientele. As mentioned in Section 2, a promising development that can add value to enterprises is network slicing. From the provider’s perspective, network slicing affords the opportunity to be agile, therefore enabling the ability to capture new revenue streams from personalized Service-Level Agreement (SLAs), personalized billing, and customization of networks.

From the vantage point of enterprises, network slicing can establish an optimized environment that serves as a stepping stone to launch, update, and bundle services much more rapidly than with traditional WAN or cellular connectivity. Industry verticals can have appropriate allocation and flexible, quick customization of network resources (a network slice) to a unique use case that requires specific latency, security, or availability levels, thereby reducing operational costs. This rapid customization also allows industry verticals to deploy new services with little or no disruption to existing services, leading to new revenue streams and customer segments without the need to reconfigure the network when new features in current networks are introduced.

4.1.3. Platforms

Additionally, CSPs can bundle together multiple technologies and applications from different partners into one network platform to provide efficient, automated, and integrated service. A platform’s utility and appeal rests in its ability to enable operators to act as facilitators of transactions between end-users, enterprise, and other third-party suppliers. Industrial engineering firms, for example, can establish their own marketplace platforms to directly engage with end-users' shared data on their products. This real-time aggregation of user data would then inform otherwise disparate internal processes such as optimizing set-up times, preempting maintenance orders, or anticipating purchase orders (wherein third-party suppliers are already in the loop).

For example, TELUS and an insurance company (Emergis) have built a health exchange platform. Through building partnerships with health institutions and enabling a shared database, TELUS has been able to introduce value-added offerings such as electronic medical records (EMRs), digital prescriptions, secure messaging, and home health monitoring. The revenue opportunity for TELUS, in this case, would be the percentage of the fees and charges associated with every new user of the platform.

4.2. Infrastructure Vendors

In the past, infrastructure vendors were the sole providers of solutions that presented telco interfaces in the broader global interconnectivity ecosystem. But increasingly, vendors are viewed as the focal point for the continued digitalization of enterprise verticals. There is potential growth, but realizing it requires a new mindset from a product and technology perspective and from the commercial aspect. Vendors will play a vital role in guiding industrial verticals to successful digital transformations. Building up new expertise outside of merely providing connectivity will differentiate vendors moving forward.

Vendors have already understood the value of tailoring to vertical-specific solutions and have begun offering customized solutions. Automotive manufacturer Scania used a 5G proof-of-concept test network devoted to controlling a bus remotely from a vehicle operations center at its headquarters in Södertälje, Sweden. Total system response time for remote monitoring and control and the automated tools required to provision prioritized network services were the key applications analyzed. Data from the bus, including high-resolution video, was streamed to the remote operations center over LTE radio access with an evolved 5G core network. The testbed had automated service ordering and provisioning, allowing for the prioritization of network resources, which was essential for remote monitoring and operation. The test showed that network latency improved significantly with 5G radio access, lowering network RTT to less than 4 ms.

Enterprises implementing non-public networks would need a firm understanding of the connectivity needs of their network. Having a clear understanding would help reduce CAPEX in infrastructure equipment investment (especially for 5G NR equipment). Non-public networks require purchasing the appropriate type and number of small cells, sensors, and accompanying equipment for deployment. Other considerations such as indoor (requiring shorter bandwidth range) or outdoor (such as airports, oil rigs that need non-overlapping wider area coverage) deployments; standalone or working in conjunction with public networks also play a sizable role in determining the overall financial commitment from the implementing enterprise.

As such, manufacturers should collaborate with infrastructure vendors that offer end-to-end yet flexible deployment models that can efficiently maximize the network and spectrum assets to the needs of their specific business. The chosen infrastructure vendor must prioritize the manufacturer's needs and must create an ecosystem that enhances operational efficiencies and achieve tangible business outcomes and return on investment (ROI).

4.3. Webscale Companies

Webscale providers are leading the market when it comes to selling cloud Software-as-a-Service (SaaS) offerings, a divergence from the conventional CAPEX-intensive business models of infrastructure vendors.

This is a trend that is now picking up pace in industry verticals. The commercial imperative, from a technology supplier's perspective, is stark: depart from a finite supply of physical equipment, enhanced by feature differentiation and characterized by scarcity, to a monetization model where the supply is essentially relegated to an OPEX item. The former promotes differentiability and avoids product surplus, whereas the latter offers convenience and scale at commodity-like economics, the chief appealing factor among consumers.

Benefits that web-scale providers can bring to enterprises include:

- **Bypassing Installing Physical Sata Centers On-premise.** Cloud-computing can alleviate the exponential increase of data from an extensively connected 5G enterprise setting. Outsourcing the data centers would also place the responsibility of operations, maintenance, and security on the web-scale provider.

- **Flexibility in Application Development.** Enterprise customers can develop their own cloud-computing applications that can address the different needs across their organization.

- **Utilizing Artificial Intelligence (AI) and Machine Learning (ML).** These provide more real-time processing and executing automated context-based actions.

- **Establishing Data Lakes.** Having a single, central repository of data available would introduce new avenues for enterprises to improve plant productivity. Operational efficiencies can be attained by data-driven oversight and management of resource consumption, fleet management, and machine uptime. Having the access and capabilities in processing data can also help inform the basis of the development of new customer propositions. Services and hardware can be tailor-made based on the insights gleaned from data analytics.

The likes of Amazon, Microsoft, and IBM have positioned themselves accordingly to cater to the vertical industry market. With telco-specific solutions like Amazon Web Services (AWS) Wavelength, Microsoft Azure Edge Zones, and IBM Telco Network Cloud, respectively, these companies can complement an operator's connectivity offerings to bring vertical industry solutions to market. These players view themselves as components and service builders that range from scalable cloud infrastructure to high-level platform services with sophisticated data analytics and applications.

4.4. System Integrators

5G deployments in enterprises will likely involve four distinct players: 1) the network infrastructure vendor who will provide the equipment and software, 2) CSPs who own the network assets, 3) the application vendor who builds and provides applications, and 4) the enterprise vertical itself. The multiple stakeholders involved in the 5G deployments of enterprises will need an orchestrator to effectively interweave the diverse roles that each stakeholder fills.

Furthermore, some industry verticals will almost certainly need some level of customization to suit their needs. The integration of 5G cellular technologies and the imperative of expansive automation in enterprise have created a new category of system integrators that have capabilities in not just IT but also telecommunications and Operational Technology (OT). The transition to modernized and more integrated processes within the enterprise requires assistance from the advisory and consultancy arms of system integrators. More permeability amongst hitherto siloed processes and business units need proper change management strategies. Properly inculcating and assimilating existing staff is crucial to maximizing the productivity and capabilities of a digitalized industrial environment.

ABI Research projects that by 2026, spending on system integrators and professional services will reach US$ 65 billion, with US$ 35.5 billion going to system integrators and US$ 29.4 billion spent on professional services.

Expenditure on system integrators and professional services is driven by the following needs:

- **The Need to Future-proof the Business**: Commission professional services to help the firm shore up the balance sheet in the short term and devise the best strategy going forward regarding products and operations. System integrators will be required to help IT, and OT teams recalibrate operations for the new environment, be that inside the facility, or enabling remote operations.

- **The Need for Quality Expertise:** While internal IT and OT teams are often focused on day-to-day operations, system integrators (SI) can provide project staff who have been trained in the latest iterations of technology providers' offerings or Original Equipment Manufacturers' (OEMs) initiatives and have the certificates to prove it. Manufacturers do not have to spend money on training their staff or have them away from the plant, instead using an SI to tap into that expertise.

4.4.1. System Integrator Consulting Example

Bain worked with Bosch Industry Consulting to digitize an automotive plant, from the factory floor to the back office. The client was interested in introducing Industry 4.0 technologies for both mechanical processing and assembly. Bain and Bosch Connected Industry helped compile, structure, and evaluate where to apply such technologies. In addition, the scope encompassed the IT infrastructure and key back-office functions, including Human Resources (HR), facility management, and security. The project involved two phases. Phase I addressed production, energy management, and HR issues, while in Phase II, the companies focused on quality management, facility management, and security. The project delivered efficiency gains of 15% to 20% through digitalization, higher output, and increased flexibility regarding the client's ability to offer product variants and improved product quality, thanks to faster error detection rates through new camera systems and advanced data analytics applications.

5. Overview of 5G Related Regulations

The high connectivity, high capacity, and low latency of 5G will impact a broad number of stakeholders spanning multiple industries. Governments need to balance an enabling regulatory environment to expedite 5G network rollouts with prudent measures that ensure the privacy, safety, and security of both enterprises and end-users.

5.1. 5G Related Regulations in the United States

5.1.1. Regulations Concerning Infrastructure

Ubiquitous, nation-wide connectivity of 5G requires an upgrade and proliferation of 5G infrastructures such as macro or small cell sites. The need for network densification is due to the low propagation distances of millimeter waves – more cell sites are needed to overcome the propagation limitations of these higher frequencies.

Network densification for small cells is a complex issue that calls for CSPs to confront disjointed zoning application processes across different counties. CSPs must have to satisfy administrative perquisites, residents' aesthetic preferences; while also striving to achieve optimal technical Standards that successful small cell deployments require.

In orders FCC-18-30 and FCC-18-133, the Federal Communications Commission (FCC) has enacted several policies to address the inefficiencies of securing site permits needed to deploy 5G. The 5G FAST Plan streamlines deployment of 5G and wireless broadband infrastructure by excluding non-essential requirements that would cause siting delays. The FCC has also reformed short-sighted municipal roadblocks that have the effect of prohibiting deployment of 5G and provides states and localities a reasonable deadline to approve or disapprove small-cell siting applications.

In FCC-18-111, the federal framework governing pole attachments has also been improved by adopting a process in which the party attaching new equipment moves existing attachments and performs all other work required to prepare the pole new equipment. Called "one-touch, make ready," this process speeds and reduces the cost of broadband deployment by allowing the party with the strongest incentive to prepare the pole quickly, rather than spreading the work across multiple parties.

Through FCC-17-154, the FCC has also revised its regulations to make an investment in next-generation network technologies more convenient for implementors. This ruling reduces pole costs by preventing pole owners from charging costs in which they have already recovered; implements a mandated time-window to resolve pole attachment disputes, and allows local providers equal access to each other's poles. The order also ameliorates companies' efforts in adopting Internet Protocol (IP) technologies. This includes reforms that speed up the timeframe for upgrading fixed-line connections from copper to fiber and expedite applications by carriers that are requesting to phase out growingly outdated network services.

5.1.2. Regulations Concerning Equipment and Devices

The FCC will be regulating the evolving 5G equipment and device ecosystem. Equipment and devices must be below specified radio frequency (RF) radiation thresholds to protect the safety of end-users. Regulations involving RF radiation must be incorporated during the manufacturing phase of equipment and devices. The FCC is currently seeking consultation on Proposed Rule FCC 19-226, which may expand the non-ionizing RF human exposure safety limits for new wireless telecommunications equipment that will emit RF frequencies above 6 GHz and that do not penetrate the body beyond the skin.

5.1.3. Regulations Concerning Spectrum

The FCC is also prioritizing opening High-, Mid- and Low-band spectrum for 5G. FCC also recognizes the importance of unlicensed spectrum in the 6 GHz and above 95 GHz band. The FCC has conducted spectrum auctions in the 24 GHz, 28 GHz bands, as well as the higher frequencies of 37 GHz, 39 GHz, and 47 GHz bands. Mid-band spectrum in the 2.5 GHz, 3.5 GHz, and 3.7–4.2 GHz are also being positioned for 5G. The CBRS Priority Access License (PAL) auction for 22 631 spectrum licenses in the frequency range between 3550 MHz and 3700 MHz has drawn significant interest from diverse industries. Aside from communication service providers, the auction has attracted participants from the energy, education, healthcare industries, just to name a few.

5.2. Trade & Business Relations

The FCC has also emphasized the preservation of the security and safety of the supply chain of network equipment. Section 889 of the John S. McCain National Defense Authorization Act (NDAA) for Fiscal Year 2019, Prohibition of Certain Telecommunications and Video Surveillance Services or Equipment, has prohibited U.S. government agencies from procuring or obtaining telecommunications equipment and services from certain Chinese technology companies.

Furthermore, Section 889 prevents agencies from dealing with any entity that uses prohibited technology as a "substantial or essential component" or "critical technology." This sweeping prohibition also applies to systems that are not used in the performance of a government contract.

5.2.1. OpenRAN Initiative

The current geopolitical climate and the competition between China and the United States have distorted the network infrastructure market. The exclusion of Chinese infrastructure vendors with high manpower resources and proven technical expertise is forcing many companies and regulators to look for other solutions in constructing their 5G networks. On the other hand, 5G is positioned to actuate the next industrial revolution and will represent the backbone infrastructure for any country's prosperity in the future. From a security point of view, compromising or mishandling the 5G infrastructure supply by one or two big vendors could put an entire country at serious security risks.

The OpenRAN (ORAN) initiative is a favored alternative to vendors that provide end-to-end network equipment. ORAN networks open the interface between the different baseband processing functions and radio units in a base station, allowing CSPs to theoretically mix and match between these units. Conventional equipment vendors rely on proprietary end-to-end equipment such as base stations and core networks operating through specific interfaces. Excluding the 2 Chinese major infrastructure vendors would exacerbate market inefficiencies of the vendor ecosystem. The already limited pricing negotiation of CSPs (due to end-to-end offerings) is compounded by the remaining vendors who have attained more pricing power due to the reduced supplier diversity.

By desegregating software and hardware, modularizing network functions, and opening transport interfaces, the ORAN approach of open networks can help create a best-of-breed multi-vendor interoperable network architecture, accelerate time to innovation, and lower the overall CAPEX and OPEX of a communication service provider while also allowing new types of companies to deploy agile and flexible networks using the shared spectrum.

ORAN's flexibility in the customization of wireless networks through intelligent software-defined networking and automation in a cost-efficient manner is also suitable for NPNs in enterprise environments that have diverse connectivity demands. By enabling flexible RAN functional splits, system integrators can meet specific requirements in terms of latency and reliability to customize fronthaul investment and ultimately save CAPEX for implementing clients. In addition, ORAN can help automatically manage heterogeneous networks efficiently by reducing manual human interventions. Unlike legacy RAN architectures, in which new feature development takes time, ORAN allows management to be performed remotely and expediently.

6. Conclusion: NEMA Implications & Suggested Future Activities

6.1. Implications on NEMA Markets

Due to 5G's provision of multi-dimensional connectivity scenarios, it expands high data applications from consumer-driven use cases to cater to a diverse set of industry verticals. In particular, mMTC and URLLC spearhead this paradigm shift. mMTC enables enterprise networks to support an exponentially larger number of devices and sensors within industrial environments. URLLC allows wireless networks to ensure high-reliability (of up to 5 nines) and low-latency (below 10 ms). These stringent Standards propel enterprises toward meaningful digitalization as they form the foundation in supporting mission-critical use cases across multiple industries.

The extension of cellular connectivity to new use cases and verticals has important implications on existing networking technology as well as the sale of auxiliary products. The implications of 5G on the 7 major U.S. markets that NEMA serves are summarized in Table 7.

Table 7: 5G Implications on NEMA Markets

(Source: ABI Research)

NEMA Markets	5G Implications
Building Infrastructure	To address backhaul considerations resulting from the high data throughput, cable trays, busses as well as ties need to be designed to accommodate additional fiber deployments.
Building Systems	In-building systems will be upgraded to 5G, driving demand for new components, including cables, connectors and other peripherals.
Industrial Products & Systems	TSN, CoMP, mMTC and URLLC transmissions will increase reliability and efficiency in manufacturing through integration IT, OT & CT domains.
Lighting Systems	Integration of sensors, networks and LED infrastructure in 5G Smart Grid applications will increase demand for connected lighting controls, light sources and emergency lighting.
Medical Imaging and Technology	Anticipating a lifecycle of >10 years for medical equipment, the deployment of cellular connectivity will require retrofitting of medical equipment & devices, increasing demand for chipsets and processors. Furthermore, existing patient data management Standards (e.g., FHIR, HL 7) might need to be adjusted to guarantee full functionality when being applied to a cellular network.
Utility Products & Systems	Smart 5G connected microgrids require the combination of intelligence (AI) with conventional utility products & systems: The demand for smart meters and intelligent capacitor solutions will rise. The powering of necessary infrastructure for cellular network deployments will increase demand for electrical connectors.
Transportation Systems	5G enabled Intelligent Transportation Systems (ITS) will increase the demand for data processing capabilities in the car & the network infrastructure, requiring more powerful chipsets and processors. To guarantee full interoperability between LTE-V2X and NR-V2X, dual chipsets will be required, supporting both 4G LTE and 5G NR.

In the short term, enterprises deploying 5G will ensure that 5G will provide full interoperability with existing connectivity technologies (either fixed line or wireless) since production assets have a lifecycle of 15 to 20 years; replacing equipment is costly and increases the risk of workflow disturbances. Therefore, for 5G to be useful to enterprises, a 5G network needs to be fully interoperable with existing automation protocols (such as PROFINET in Industrial Manufacturing or HL7 and FHIR in Healthcare). Once 5G is deployed and legacy technology is replaced, enterprises must carefully consider whether 5G connectivity can be extended to replace this legacy technology.

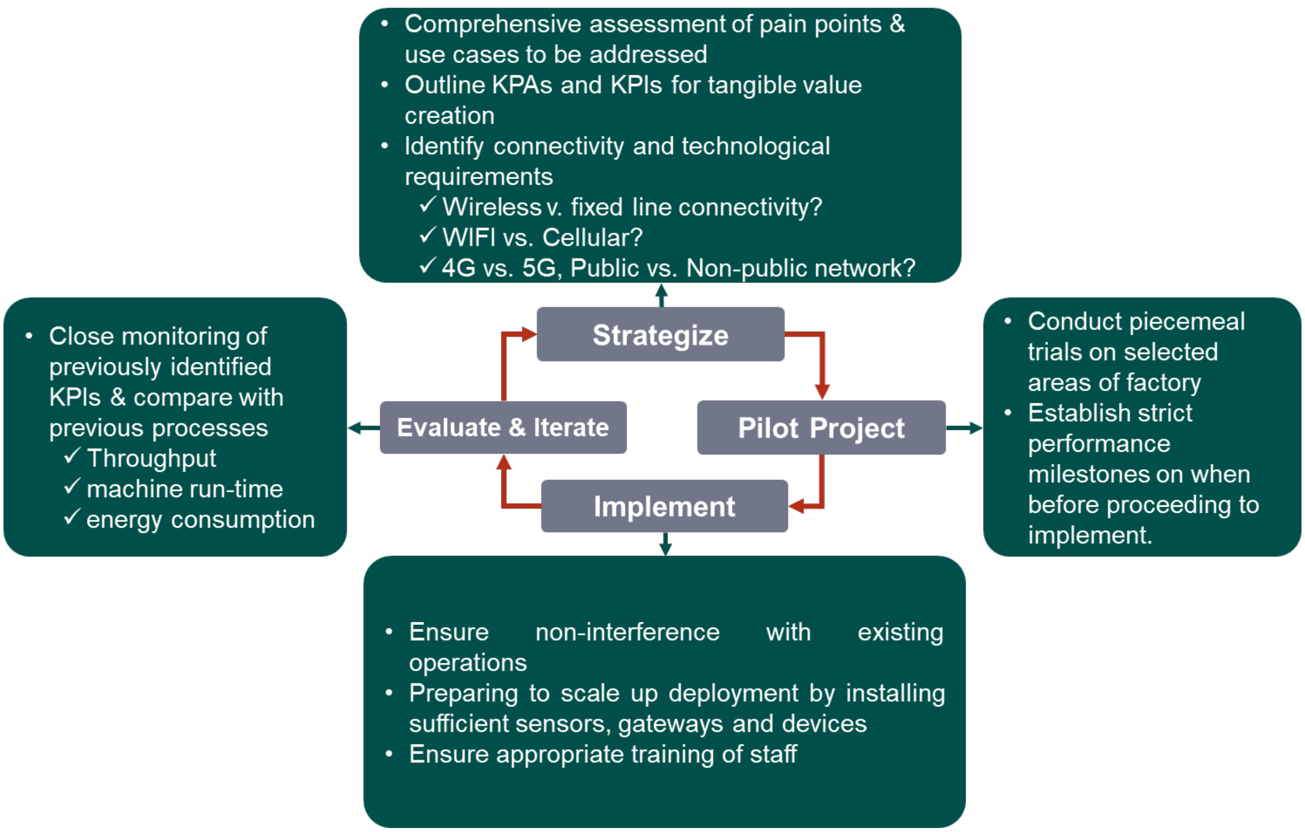
From an infrastructure point of view, the deployment of 5G in enterprise verticals will result in an increased demand for fiber to cope with the increasing amount of backhaul that 5G generates. Electronic manufacturers need to be prepared for this surge to address this revenue opportunity generated by market demand.

6.2. Recommendations for Manufacturers & Future NEMA Activities

Since monetizing 5G enterprise deployments is a marathon rather than a sprint, realizing this immense opportunity requires close collaboration between the telco industry (network operators and infrastructure vendors) and manufacturers. From a NEMA-specific perspective, this opens the field for future activities to strengthen

the ecosystem around enterprise 5G. NEMA Members looking into the deployment need to understand that 5G deployment is a conceptual process requiring different activities from the implementing enterprise at each stage. These are described in figure 13.

Figure 13: Step-by-Step guidance for 5G deployments
(Source: ABI Research)



6.2.1. Utilize Existing Organizations

One of the key aspects of this is to thoroughly analyze the amount as well as the influence of existing interest groups around 5G. In this context, 5G-ACIA is an association to connect to while they concentrate manufacturing requirements and have the necessary influence into the 3GPP, building up the same capabilities would be an avoidable duplication of efforts. Rather, an association like NEMA should utilize the network and influence of 5G-ACIA to promote industrial applications and use cases of 5G. In doing so, NEMA should focus their efforts on how to extend the reach of already existing associations within the North American market.

6.2.2. Deriving Tangible Value from Proper Network Planning

Network deployment scenarios come in varying forms depending on specific network requirements, security considerations, and accessibility of user plane gateways and control plane functions. Flexible deployment models provide more autonomy to enterprises in implementing the specific network requirements of their business. Digital transformation projects would need to be oriented towards concrete, quantifiable commercial targets. Besides ROI, manufacturers should assess the impact of NPN on metrics such as production volume over time, inventory turnover, production downtime instances, or maintenance costs.

Furthermore, introducing low-risk and cost-effective industrial automation projects in the earlier stages of 5G development can be accomplished by leveraging existing wireless technologies like DECT in the overall network strategy. Instead of jumping into a drastic overhaul of their network, manufacturers can leverage DECT's maturity in voice and data capabilities, supplier maturity, and open interface to expediently integrate DECT-5G enabled devices onto the factory floor and to upgrade mMTC/URLLC processes sooner. Acquiring spectrum for DECT-5G devices would also be quicker and more convenient as the technology already has dedicated spectrum resources, enabling manufacturers to bypass the leasing spectrum from operators or regulators.

6.2.3. Build up Expertise and Experience in Managing Complex Ecosystems

Industry 4.0-enabled manufacturers must also establish robust strategies in the oversight of the evolutionary roadmap of their organization. The complex integration of 5G in enterprise requires capabilities in not just IT but also telecommunications and OT. Manufacturers can leverage system integrators (such as Amdocs, Accenture, or Capegemini) to help orchestrate the specific roles of the network operator, network infrastructure vendors, and webscale companies in optimizing their processes and obtaining tangible business value.

6.2.4. Establishing an Ecosystem of Device Classes

The introduction of NR-Light has given manufacturers more options in addressing the wide range of use cases and connectivity requirements across an Industry 4.0 factory floor.

Manufacturers should complement their existing LTE-M/NB-IoT sensors with NR-Light to address the varying data rate, latency, coverage, and power consumption requirements across increasingly sophisticated use cases and applications. Release 17's NR-Light devices are situated in the middle ground between the lower complexity, eMTC/NB-IoT devices, and higher-end eMBB/URLLC devices. Introduction of NR-Light devices on a factory floor will provide implementors more options in addressing varied use case requirements with appropriate connectivity specifications.

The fragmentation of device classes requires manufacturers to discern the connectivity needs and intended outcomes of each use case they desire to adopt. Successful navigation of these diverse device classes is, therefore, dependent on identifying accurate connectivity requirements of each manufacturing process and prescribing the appropriate wireless technology to address them.

6.3. Final Considerations

Modern life functions seamlessly because of NEMA Members’ products. They are used to run the data centers that provide connectivity. They protect people and sensitive electronics from being harmed. These technologies and products are in place to make people’s lives comfortable, efficient, and safe both at work and at home. 5G technology has the power to transform the way manufacturers create those products.

Manufacturing efficiency levels and process monitoring will reach levels once thought of as unattainable, but before new technologies are implemented, it is important to understand the term “5G” encompasses a wide range of technologies and systems. Manufacturers should be methodical as they begin to consider and install new systems and processes in their facilities. The setup for one factory or building will not be the same for another, and the technology needs to be tailored to each specific application and situation.

5G will undoubtedly become a lynchpin of manufacturing going forward. Correctly specified, it will boost productivity and knowledge generation for all sectors.

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