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Industrial IoT Networks: How 5G is transforming industry verticals

Research and standardization perspectives on industrial IoT

White paper

Industry is increasingly looking to the Internet of Things (IoT) as the next big thing in the digitalization and automation of processes and operations. As well as improving efficiency, industrial IoT will transform businesses and organizations, greatly increasing flexibility and giving them the ability to customize their offerings for each customer.

As part of that transformation, 5G, with its raw capability and flexibility, bridges the gap between the physical and digital worlds. It unlocks business productivity and agility on a scale not seen in previous phases of mechanization and automation.

This paper explores how fundamental characteristics of 5G address the needs of two industry verticals, namely future factories and complex transportation and logistics hubs. The evolution of both the radio and core are outlined, on a path towards a 5G system that will be central to the next industrial revolution.

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Executive summary: How 5G will transform industry through IoT

Vision

Over the last hundred years, modern control and operational technologies (OT) have transformed industrial systems, vastly increasing efficiency and resilience. Looking forward, the incorporation of 5G wireless technology into OT solutions is triggering another transformative leap forward, through pervasive digitalization. This industrial transformation is again improving efficiency and resilience but is also bringing us to new levels of flexibility and personalization/customization.

Multiple studies have shown how industrial IoT (Internet of Things) can achieve huge value for end users, running into trillions of dollars/euros worldwide by 2025. While 5G wireless network and cloud infrastructure is just a part of the overall required investment, every €1 of investment in this area yields more than €4 of value for end-users.

For industrial IoT built on 5G, one can easily identify valuable benefits that are common across many sectors, such as manufacturing and transportation/logistics hubs:

- Increased efficiency with intelligent industrial automation, on a shared virtualized infrastructure
- Higher value outcomes arising from greater flexibility, adaptation, and personalization
- Reduced risk through resilient, scalable infrastructure

Challenges and solutions

Bringing 5G to industry sectors that use OT heavily results in technology requirements and business models that are new to the traditional cellular ecosystem. These include the need for highly reliable solutions, the requirement to keep business-critical data local and an infrastructure investment lifecycle that spans a decade or more. Therefore, the telecom and cloud infrastructure industries also need to evolve to deliver on these requirements. To enable this evolution, Nokia's Future X network architecture and 5G standards provide a four-part blueprint:

1. Cutting the wires, thanks to 5G wireless access with ultra-reliable, low-latency and time-synchronous protocols as a drop-in replacement for wired Ethernet.
2. Scalable, secure local computing supported by private edge clouds, often on-premises.
3. Supporting multiple stakeholders on a single infrastructure via deep slicing technology.
4. Effortless operations through machine-learning-based automation.

The pivotal role of 5G

Industrial IoT systems use a bewildering array of device types, with diverse combinations of radio requirements previously impossible to meet with any one radio technology. As 5G evolves from the initial consumer-centric and low-latency industrial use cases in 3GPP's Release 15, it will address a widening range of delivery mechanisms (e.g. satellite in Release 16) and use cases (e.g. low-complexity devices in Release 17). 5G New Radio (5G NR) is the only wireless technology that can simultaneously provide high reliability and low latency, as required by important use cases such as robotics and industrial automation.

Support for a diverse range of use cases also extends to the 5G core, with a wide range of features for both on-premises private networks and for wide-area networks with massive scalability. Deep network slicing then allows the organization of these features into virtual network infrastructures, highly customized for the various stakeholders in an industrial vertical.

The path of the 3GPP standards releases that will enable this full vision is rapidly unfolding. As already noted, Release 15 focused on consumer user cases and low-latency industrial applications, and it is in Release 16 that industrial IoT support improves further with multiple critical features:

- Enhancements for ultra-reliable, low latency communications
- Deterministic communications with time synchronous operation
- Private (so-called “non-public”) networking
- Access via unlicensed spectrum
- Improved device positioning systems
- 5G Core support for NB-IoT and LTE-M scalable radio access standards for low-complexity devices

Current work in Release 17 will continue its focus on critical topics like time-sensitive communications and private networking, but will also address a broader range of use cases with new features such as:

- Determining positions accurate to the centimetre
- “NR-Light” for medium-rate applications with limited complexity terminals (e.g. video monitoring)
- Multicast for V2X (i.e. vehicular) communications

These use cases will further increase 5G’s relevance within many industry verticals.

5G will meet the most stringent requirements of both business- and mission-critical use cases, while sharing a common, universal infrastructure.

Realizing Nokia’s vision for industrial IoT

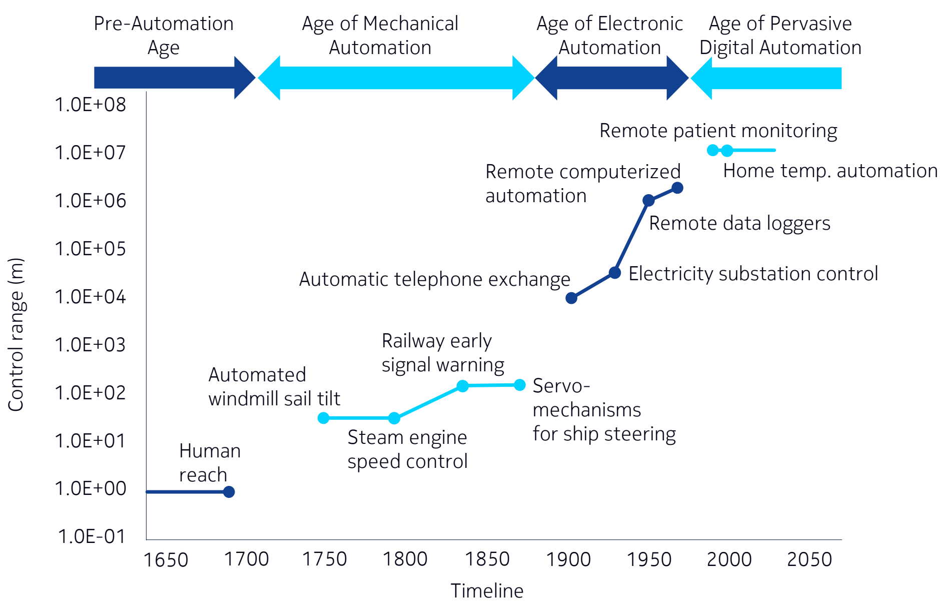
In closing the gap between the physical and digital world, 5G will enable business productivity and flexibility on a scale not seen in previous waves of mechanization and automation. This will run across multiple industry segments, from manufacturing to logistics, from automated vehicles to smart buildings.

This industrial transformation will require the active participation of an entire ecosystem. Nokia works with all the critical stakeholders, through targeted pilot trials with key industry players, through taking a leading role in industry organizations such as 5G ACIA, and through acting as a trusted advisor to government agencies. Nokia is playing a lead role in this 5G-enabled transformation.

Past to present: industrial automation

Until recently, industrial automation has focused on achieving cost-effective productivity and efficiency gains. As a result, the range of control capabilities and variety of devices controlled have grown dramatically since the start of the Industrial Revolution in the mid-eighteenth century.

Figure 1. Industrial automation has evolved at an ever-increasing pace with exponential growth in control capabilities



In parallel, control technologies have evolved from the mechanical, to the pneumatic, electrical and ultimately to the electronic, enabling more resilient, sophisticated and cost-effective solutions. The final stage, introducing electronic control, also opened up a new dimension, namely flexibility. An early example here includes the introduction of PLC (progammable logic control) to replace hard-wired relay systems.

Present state-of-the-art

In the field of industrial control and automation, operational technologies (OT) provide solutions for:

1. real-time control
2. day-to-day operations and enterprise resource planning
3. month-by-month maintenance and supply chain management.

Despite very different timescales, all have loops with measurement and sensing, analytics and optimization, decisions and actions.

Figure 2. Operational technologies in a factory setting

			Cycle Times
Value Chain	Cross-company collaboration	Level 5 Systems (SCM/PLM)	Days- weeks
Company	Business, Engineering & Logistics Planning	Level 4 Systems (PLM/ERP)	Days- weeks
Factory	Manufacturing Operations & Control	Level 3 Systems (MES)	Min. - hrs
Cell/Line	Indoor Traffic Control Logic Control	Level 2 Systems (SCADA)	10ms-10 sec
Field Equipment	Indoor Mobility Control Logic Control Motion Control	Level 1 Systems (PLC, field bus)	1-10 ms 1 ms

Most applications of OT focus on efficiency and resiliency, leading to customized solutions building on SCADA, industrial control protocols, wired industrial Ethernet connectivity, embedded controllers, and more.

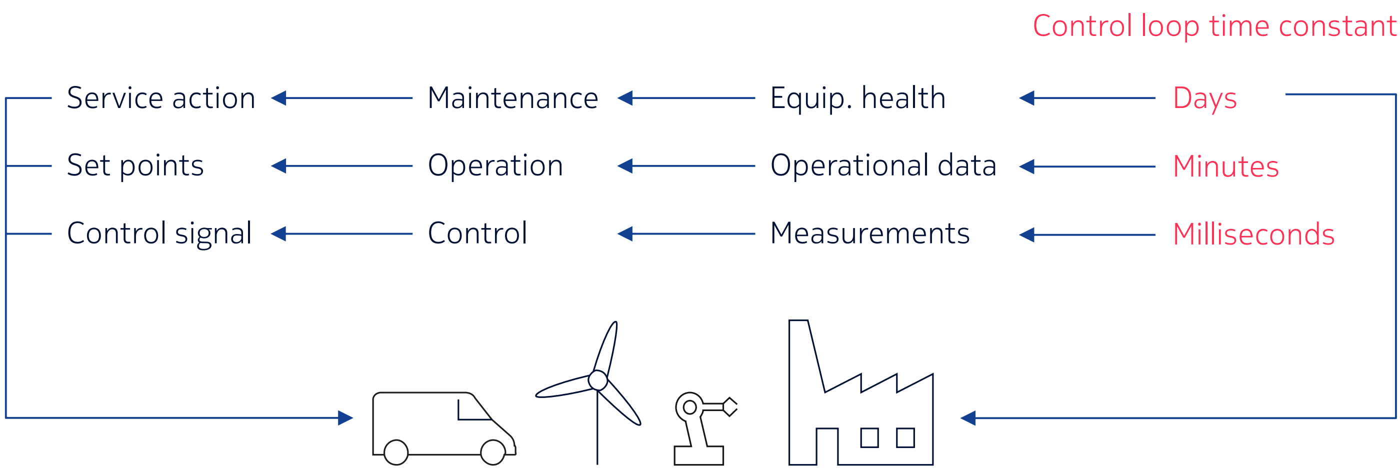
The next big leaps forward will address a third aspect - flexibility and personalization as discussed in the next sections. This calls for pervasive digital automation and the industrial Internet of Things (IoT).

Future transformation of industrial automation

Industrial Internet of Things converges IT and OT

Industrial IoT combines information and operational technologies to create cyber-physical systems with intelligent automation of feedback loops. As well as enabling autonomous operation, the IoT helps to simplify human interactions with these increasingly complex systems.

Figure 3. Industrial IoT is marked by the convergence of IT and OT, closing feedback loops in cyber-physical systems.



Source: Dr. Dirk Schulz, ABB

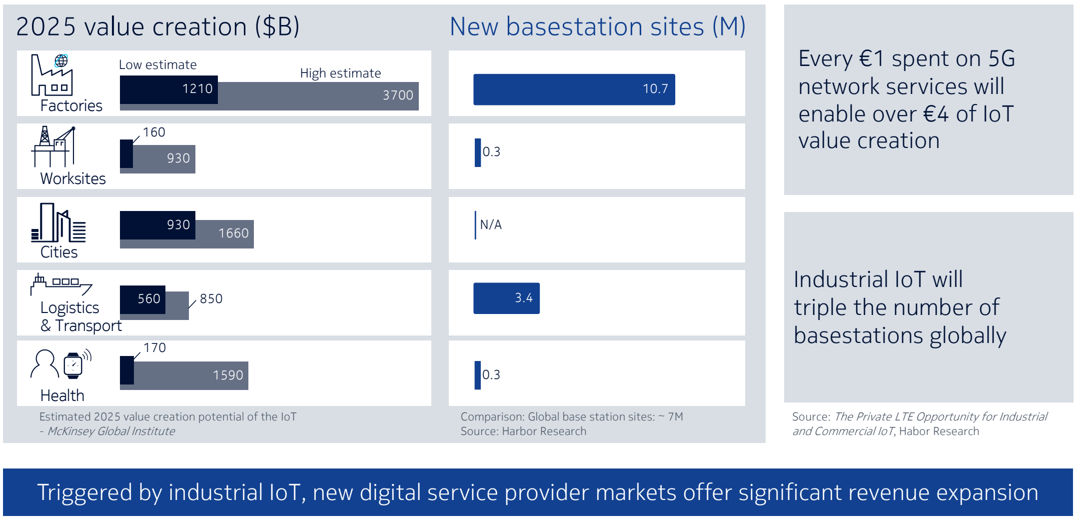
Universal value proposition for industrial IoT

Many industries are rebuilding their business models, which has become known as the 4th Industrial Revolution in manufacturing industry or digital enterprise transformation in other commercial segments. Either way, industrial IoT will be the key enabler.

Multiple estimates of the potential market point to similar conclusions: the value creation for end users is significant, running into trillions of dollars/euros worldwide by 2025. Much of that value sits at the end of the supply chain, that is with application developers and system integrators.

Even so, there remains significant new business even for connectivity and compute infrastructure, as the potential number of new small cell and macrocell base station sites shows. This will be very affordable because every €1 of investment in network and cloud infrastructure yields more than €4 of end-user value creation.

Figure 4. Industrial IoT and the quest for new economic value



Where does this end-user value arise? Running across multiple segments, from future factories to transport hubs to eHealth, there are three universal value propositions:

1. Increased efficiency in existing operations through:

- the extensive application of automation informed by massive instrumentation of internal systems
- seamless integration with key external stakeholders, such as clients, customers, collaborators and suppliers.

Automation is no longer simply a fixed on-machine PID[1] control loop, but an evolving adaptive algorithm that continually adjusts its short-term objectives based on the multiple inputs from the world around it. The costs of delivering that automation are capped by the extensive reuse of a single, unified communications and compute infrastructure that is shared across many applications and end-users together with shared sensor data fused from multiple diverse sensors.

2. Higher value outcomes

Since the automation is adaptive, the systems that are automated are themselves more flexible, more responsive to the short-term needs of end users. Personalization and customization allow providers to address smaller markets and smaller groups of stakeholders whose needs have yet to be economically addressed. A good example is e-health solutions that provide both supervised and semi-autonomous real-time, patient-specific adjustment of treatments for chronic-condition sufferers at home. Previously, these could only be delivered in the monitored environment of a hospital.

3. Reduced risk

Prediction, detection and response to system failures is greatly enhanced by a pervasive IoT monitoring for detecting and correcting anomalies. Also, we can create an IoT infrastructure that is itself resistant to failure. All this allows for a more secure business/operational model and more consistent outcomes and returns.

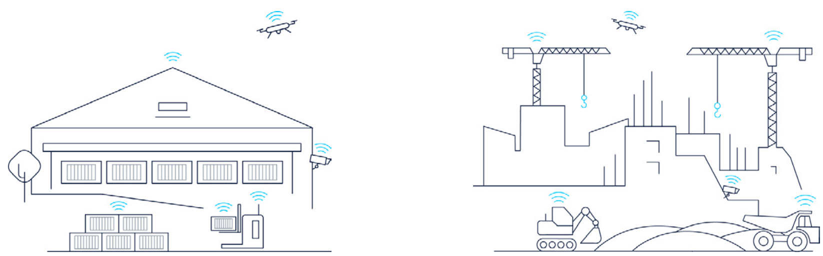
1. PID control: “proportional--integral--derviativel” control – a classical control loop used widely in control applications.

Figure 5. The combination of IT and OT technologies is triggering a radical transformation in many industry segments

Increase efficiency with intelligent industrial automation on a shared virtualized infrastructure

Higher value outcomes from greater flexibility, adaptation, and personalization

Reduced risk through resilient, scalable infrastructure



Radical transformation in multiple industries, triggered by the convergence of IT and OT*

Challenges for traditional architectures and business models

Machines are less forgiving, less adaptable than humans. This forces OT providers to impose system requirements not typical in the telco world. These include:

- A resilient distributed data and compute architecture with no dependency on centralized, cloud-based resources, keeping data local to where it is generated and used.
- A security architecture under full control of end-users and with minimal or zero exposed attack surface: IT/webscale level of external attacks is simply not acceptable in these environments.
- A business model that does not depend on a few critical, irreplaceable vendors nor providers or requires government license (such as for spectrum).
- Clearly established liability for failures.
- An investment lifecycle that is much longer than that of traditional telecommunications gear, with much longer equipment and support lifetimes.

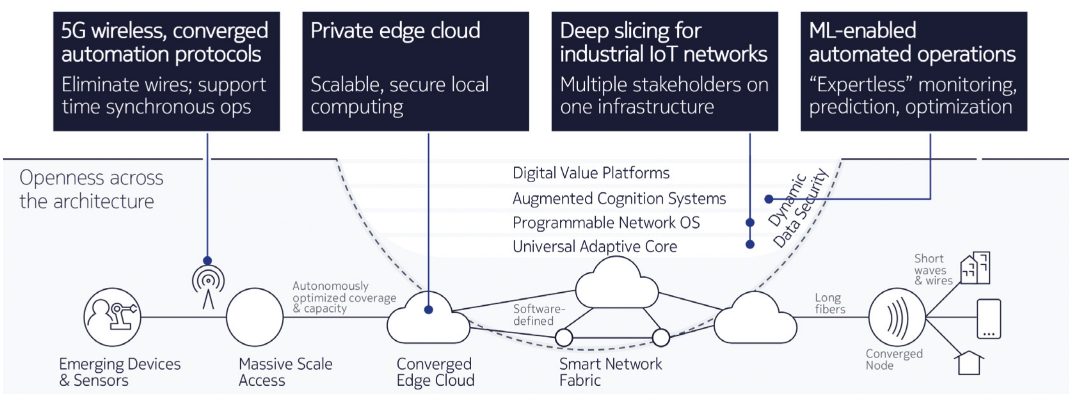
5G as the technology enabler for an industrial IoT revolution

There is clearly a gap to bridge. 5G and the Nokia Future X architecture unify the telco and the industrial automation worlds:

- Today, industrial control is often wired and inflexible. Wired access needs to be replaced with wireless technologies to achieve maximum adaptability. 3GPP is creating 5G solutions for common industrial control protocols (e.g. Profinet) as a drop-in replacement for older wired Ethernet. Critical features include support for multi-access convergence (for high reliability via multi-connectivity), time synchronous communications and ultra-low latency.
- Private edge cloud, as supported by 3GPP and ETSI MEC, is a natural solution to keep data and computation local and secure.
- Deep slicing enables multiple applications and stakeholders to be supported on a common infrastructure, minimizing CAPEX and OPEX outlays. Deep slicing is the fine-grain network and service composition enabled by decomposition of network functions, intelligent placement algorithms and secure personal slices.
- Support for machine learning and general analytics for effortless network operations and intelligent applications. This allows automated optimization and the mitigation of failures.

The result is a communications and compute infrastructure that enables intelligent converged OT solutions for industrial IoT.

Figure 6. The technological enablers of industrial IoT



Use case: Future factories

One of the most exciting emerging industry segments for the marriage of IT and OT is that of advanced manufacturing. Manufacturers constantly strive to increase efficiency, reduce downtime and increase production flexibility. Safety and energy efficiency have also become increasingly important.

While 5G (and industrial IoT) is a transformative agent, it is just one of a number of large-scale digital technology trends that are leading to a manufacturing transformation.

These include:

- 3D printing and additive manufacturing, advanced robotics and nanotechnology for lighter, smarter, more adaptive products

- Autonomous vehicles to transform logistics
- Augmented and virtual reality, IoT instrumentation and artificial intelligence to dramatically reduce operational costs
- Blockchain technology to simplify business-to-business relationships.

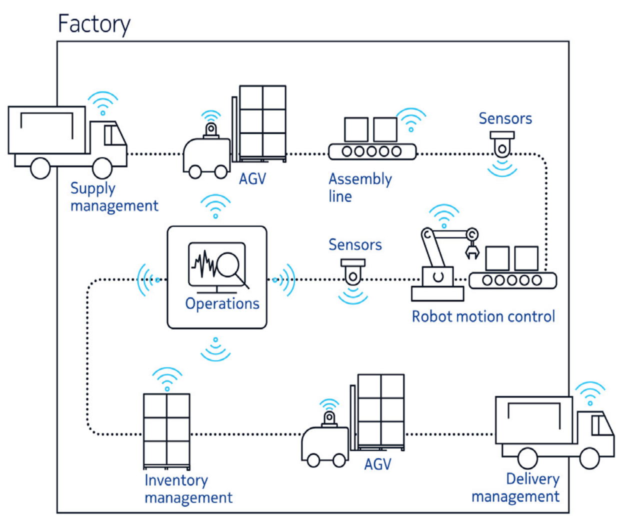
These trends, united by 5G/Future X infrastructure as the nervous system, are driving the coming Fourth Industrial Revolution.

Manufacturing, particularly high-value manufacturing, will look dramatically different a decade from now:

- Agile, easily reconfigured manufacturing lines will efficiently accommodate short production runs
- Despite reduced job lot sizes, fast, automated scaling of overall factory throughput will be underpinned by intelligent, self-organizing real-time logistics.
- Enhanced enterprise platforms for B2B and Enterprise Resource Planning (ERP) will aid rapid reconfiguration of supply chains
- Factory downtime and defect rates will be reduced by predictive maintenance and early interventions driven by extensive instrumentation an analytics.
- All this will be underpinned by pervasive digital automation, driving up productivity.

Figure 7. The factory of the future

- "Job-lot size of one" – **mass personalization** of products
- Real-time logistics for dynamic planning and **automated capacity scaling**
- Digital value platforms for **fast reconfiguration of supply chains**
- AI-backed, automated testing, monitoring, and analytics, for **production resiliency**
- Digital automation for **productivity**



5G technology is a key enabler of this vision of the future factory.

A flexible factory floor requires wireless connectivity. This will be based on 5G, the only technology that can meet the stringent timing and reliability requirements of legacy wired networking.

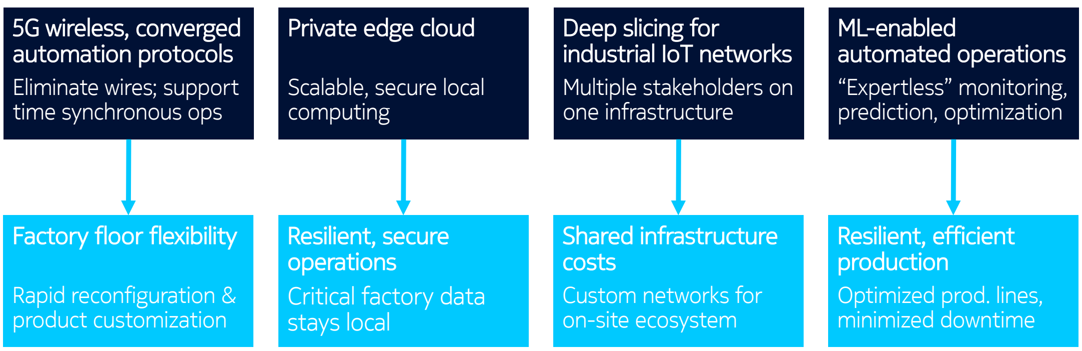
Unlike previous generations of cellular technology, 5G provides native support for private networks, combined with edge cloud computing. This meets the demand to keep factory operational data on-site to ensure resilience and security.

Yet, 5G also recognises that factories are more than a building with machinery and logistics. They are complex ecosystems with multiple stakeholders from different business entities, all of which need access to communications infrastructure. 5G's flexible, deep network slicing supports all of these, with virtual networks customised for individual needs, all running on a single common physical infrastructure.

The Nokia Future X vision of machine-learning/AI embedded within the future cloud and communications infrastructure, facilitates automation, optimization, and predictive maintenance.

5G and Future X will be at the heart of the next IoT-driven industrial revolution in manufacturing.

Figure 8. Technology enablers for the future factory



Putting the theory into practice

Nokia is working with key industrial automation players such as Bosch and OMRON Corporation to make the future factory vision a reality. In addition, Nokia is also deploying Industry 4.0 solutions in its own factories. At its Oulu factory in Finland, Nokia is trialing automated quality assurance, based on high-definition (wireless) video feeds coupled with advanced analytics.

Use case: Transport and logistics hubs

Transport and logistics hubs, ports, public transport hubs and airports, are prime targets for 5G-enabled industrial IoT and digital automation. In five to ten years, the most advanced hubs will have the following characteristics:

- Maximized efficiency for overall throughput, with reliable, short transit times for individual consignments and people, all enabled by AI-based optimization and management.
- A single underlying infrastructure providing resilient, secure control, for the complex mix of stakeholders working in and/or using such hubs.
- Minimized environmental footprint through monitoring, predictive maintenance and route optimization.

Figure 9. The future of transport and logistics hubs

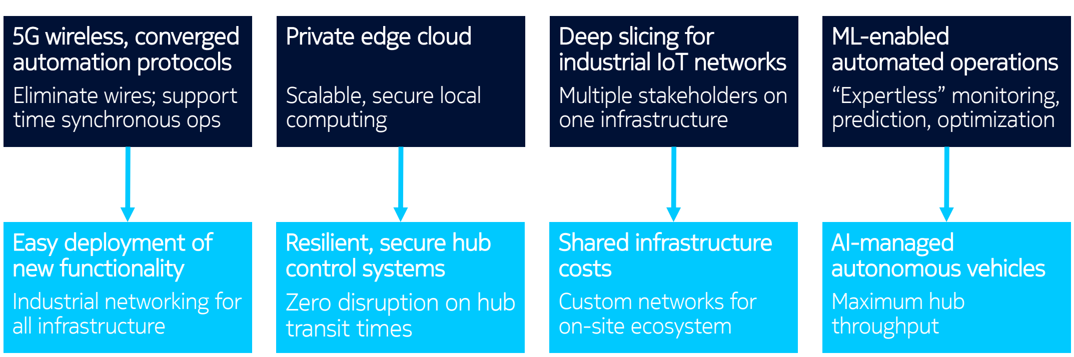
- AI-managed, automated vehicles for **maximum throughput** through multi-modal transport and logistics hubs
- **Resilient, secure control systems**
- Highly dependable, short transit times for **just-in-time supply chains**
- One coms/compute infrastructure to support an **increasingly complex ecosystem** of modalities & stakeholders
- Massive instrumentation to ensure **minimal carbon footprint and particulate pollution**

Again, 5G and Nokia's Future X architecture provide key technology solutions:

- Ultra-reliable, low-latency or time-synchronous communications of 5G NR (New Radio) for ubiquitous wireless connectivity of new and legacy infrastructure, all while meeting the stringent requirements of industrial-grade control.
- Private edge cloud coupled with deep network slicing allows for a common communications and compute infrastructure shared by all stakeholders, while simultaneously meeting strict resilience and privacy requirements.
- An analytics-friendly, open architecture will allow the deployment of advanced AI/machine-learning techniques. This will enable intelligent optimization of the often-competing objectives of maximum traffic throughput, minimized transit time and minimized carbon footprint.

5G will transform these critical nodes that form the heart of the world's transport connections.

Figure 10. Technology enablers for future transport and logistics hubs



Private networking proof of concept at Hamburg Port

Nokia and Nokia Bell Labs are creating innovative solutions to address the challenges of major ports in a critical collaborative project with the Hamburg Port Authority and Deutsche Telekom:

Hamburg is a critical node in European logistics networks. A major failure of its ICT infrastructure could affect goods transport right across central Europe. In addition, increased cyber threats need to be countered.

Use cases considered include:

- Sharing data between shippers & their companies, trucks, port operators (guiding vehicles, dock gates/crane control)
- Emission measurement
- Connecting tourists coming in "batches"
- Cargo maintenance: Real-time information on container location, temperature, or humidity

This 5G Smart Sea Port demonstrator is a multi-year project culminating in a proof of concept for ITS World Congress in 2021.

The pivotal role of 5G

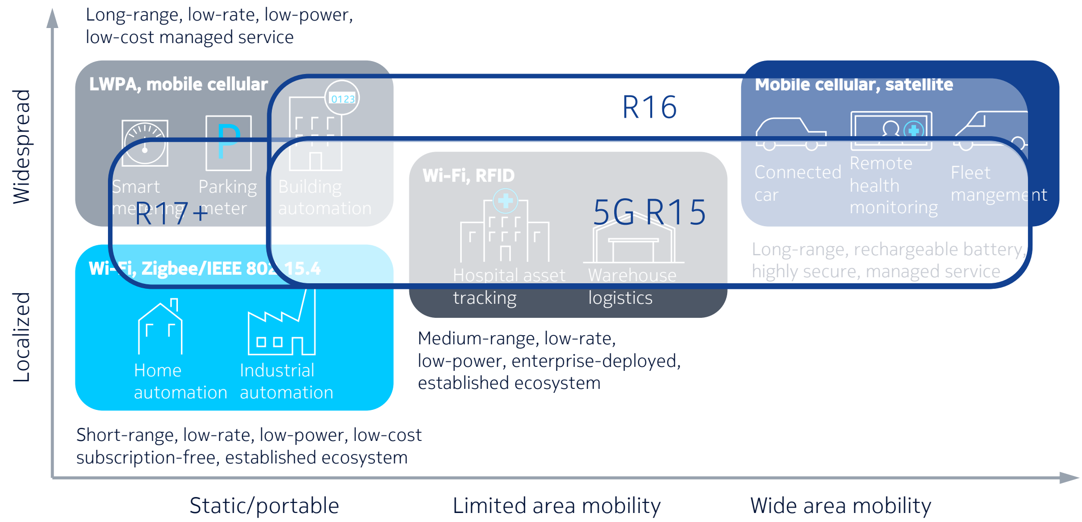
5G is not the only air interface technology suitable for industrial IoT. For low-mobility, localized applications, the 802.15.4 family of standards (e.g. Zigbee), Wi-Fi and RFID can be suitable. For a low-mobility application used over a much wider area, recent low power wide area (LWPA) solutions such as Lora and 4G's NB-IoT are useful. If greater mobility is needed, more familiar 2G, 3G and 4G solutions are used.

However, 5G has the unique ability to serve multiple use case types, from enhanced mobile broadband (eMBB) to massive machine communications (mMTC) and ultra-reliable low-latency communications (URLLC):

- With its coverage of URLLC and mMTC use case groups, 5G NR in 3GPP Release 15 extends the applicability of cellular wireless standards to many new enterprise and campus-area scenarios.
- With the continuing work in Release 16 on non-terrestrial wireless access (e.g. satellite), this release will further increase 5G's ability to serve applications with even wider coverage.
- In Release 17 and beyond, there will be further features to improve support for a wider range of terminal capabilities, especially for simpler devices with tighter power requirements and hence shorter range.

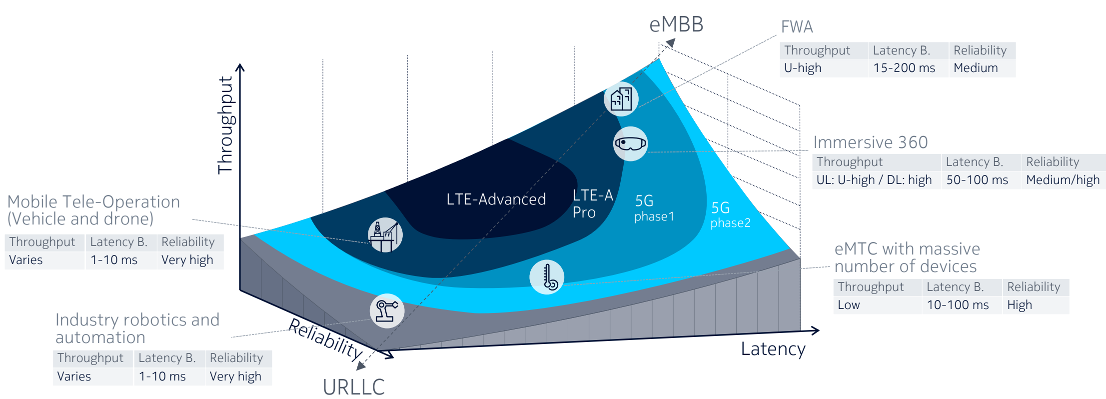
When it comes to its sheer range of applicability, 5G NR is streets ahead of any other wireless technology.

Figure 11. IoT connectivity technologies: 5G NR is ideally positioned to support diverse geographic requirements



As well as hugely diverse application needs, some individual industry IoT applications have extreme reliability and low latency requirements. Existing technologies such as LTE Advanced cannot deliver for all such applications. Important use cases such as robotics and automation need both high reliability and low latency, demands that can only be met, particularly at scale, by 5G.

Figure 12. Requirements for IoT connectivity



5G NR: the only radio technology to simultaneously provide high reliability & low latency

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Nokia Bell Labs PoC for future factory use cases

Factories of the future will be highly integrated, cyber-physical systems. Radars, lidars, cameras, magnetometers, acoustic, thermal and vibration sensors will be part of fixed infrastructure as well as being attached to workers, machines, robots and ground and aerial vehicles. These sensors will share information, including controllers that will decide on actions to be taken by a variety of factory-wide actuators. Such a factory will be hyper-automated, implementing control loops between the sensors, controller and actuators.

The safety and efficiency of in-factory automated systems is defined by the data-rate, capacity, latency and reliability of communication links. This is particularly challenging as the elements can be both widely distributed and mobile, as well as possibly experiencing high levels of electro-magnetic interference.

To test concepts and investigate performance, Nokia Bell Labs designed and developed an experimental 5G testbed. It was used to implement a factory-floor safety function which detected events such as a worker entering a restricted zone around a group of high-velocity assembly robots. When an intrusion is detected, the sensor generates an alarm to the controller, which then issues a command to the robots instructing them to take action to avoid collisions with the intruding worker.

Our experimental evaluations demonstrated a better than 2 ms latency between alarm detection and the controller delivering the command. Furthermore, reliability of the first message transmission being successfully received was better than 99.999 percent, significantly better than both LTE and Wi-Fi.

This proof of concept used the Nokia Bell Labs experimental radio-access equipment, and an off-the-shelf Rexroth-Bosch industrial controller and assembly robots supporting the Profinet protocol.

As well as the critical role it plays at the edge, 5G NR is only part of an end-to-end infrastructure for industrial IoT applications. The new 5G Core and distributed edge cloud computing, are also critical. The 5G Core is an early example of Nokia's Future X Universal Adaptive Core concept to support the rapid design and deployment of new industrial IoT solutions.

Both wide-area and local deployment scenarios are being supported by the 5G Core, with features for:

- **Compact LAN IoT core**
  Lightweight, compact, zero-touch core for non-CSP use, e.g. dedicated networks for industry vertical players.
- **Massively scalable WAN IoT core**
  Scaling to billions of IoT devices by offloading UE/session state to low-cost storage
- **Deep & Dynamic Network Slicing**
  Fine-granular network & service composition enabled by decomposition of network functions, intelligent placement algorithms and secure personal slices.

This means that one core, one edge cloud architecture can support diverse industry IoT applications and stakeholders, on one flexible, adaptive infrastructure.

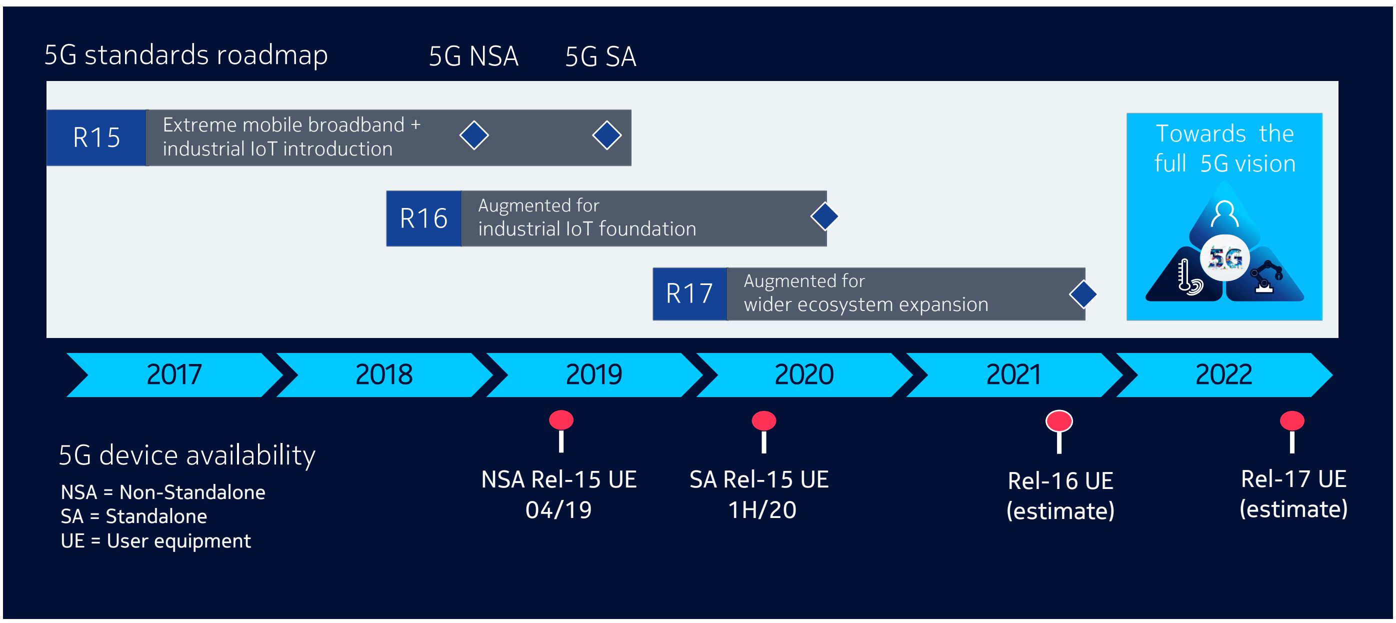
Combining 5G NR with the 5G Core, 5G can work in a wide range of deployments, as well as offering vastly improved reliability and service resiliency. These allow 5G to be used in new ways, generally in industrial automation, with ever increasing strictness in terms of service assurance:

- Business-critical communications are those where service downtimes interrupt important business processes. A good example would be that of industrial automation on a manufacturing line.
- Mission-critical communications require the highest level of service assurance to avoid the risk of injury or even loss of life. Examples include control of critical control systems for trains and power plants.

Only limited communication services are currently provided for these sectors, using specialized standards with dedicated, and therefore expensive, infrastructure and terminals.

5G changes this, meeting the most stringent requirements of both business- and mission-critical use cases, while sharing a common, universal infrastructure with much larger numbers of consumer and enterprise users.

Figure 13. 3GPP 5G standards releases timeline. IIoT capabilities emerging from Release 16 onwards



Evolution of 3GPP for IoT

Sequential 3GPP releases are introduced many industrial IoT features with particular emphasis on certain class of use cases in each Release.

Release 13 was an LTE release, but introduced NB-IoT and LTE-M to support low-power, wide-area use cases such as environment monitoring. These radio technologies are being co-opted into the 5G system, with support for them being built into the 5G core in release 16.

Release 15, the first completed 5G release, had enhanced mobile broadband services as its primary target, mainly for the traditional consumer markets. However, it also introduced URLLC with its simultaneous low latency and high reliability, a key requirement for applications in many industrial contexts.

Release 16 concentrates on URLLC. Further support for standalone networks is aligned with private network deployments for industrial vertical customers.

Release 17 will provide more complete support both for time-sensitive communications and for a wider range of device types for applications such as video monitoring and V2X.

As already noted, Release 16 is a major step forward for 5G in supporting industrial IoT use cases. Relevant study and work items in Release 16 can be broadly grouped into five themes:

(a) Enhancements for URLLC meeting the stringent requirements of the most demanding industrial automation use cases. For example, while Release 15 can deliver with five nines reliability within 2ms, Release 16 is expected to deliver eight nines with the same latency.

(b) Deterministic communications for industrial IoT: Maximum latency is not the only latency metric - in many applications, such as industrial ethernet, latency jitter is even more important. Release 16 is working towards capping jitter levels to less than two microseconds.

(c) Increased control: Many industrial end-users want more control over their network than allowed for by legacy cellular systems. 3GPP is working to address this through access to unlicensed bands (for example MuLTEFire) and additional support for closed user groups and private networks.

(d) Location determination: A fourth group of work/study items is looking at techniques for improved positioning solutions, enabled by 5G network measurements.

(e) Enhancements for massive machine communications: Finally, the 5G Core will support NB-IoT and eMTC for massive machine communications. There are also moves to extend device categories to higher throughput use cases beyond the more traditional low-throughput massive machine communications. One example is surveillance cameras.

Release 17 will build on the baseline industrial IoT solution from Release 16 in several dimensions:

a) Additional features for time-sensitive communications, by providing strict synchronization between devices over a wider area.

b) Extended support for private 5G networks, including neutral host models where the network infrastructure supports multiple service providers.

c) Improved pinpointing of location, down to the centimetre, important for manufacturing facilities and logistics hubs.

d) “NR-Light” – extra radio support for medium-capability applications (e.g. video monitoring) with limited complexity terminals.

e) Multicast communication features, particularly supporting use cases in critical communications/public safety and V2X.

Release 17’s support for a broader range of terminal capabilities and use cases will further enhance the applicability of 5G to the full range of industrial verticals and their ecosystems of devices.

Dedicated 5G enterprise spectrum for private local networks: 3.7 GHz band in Germany

Access to reliably "clean" spectrum is an important concern for many vertical enterprises relying on wireless networks for business-critical processes.

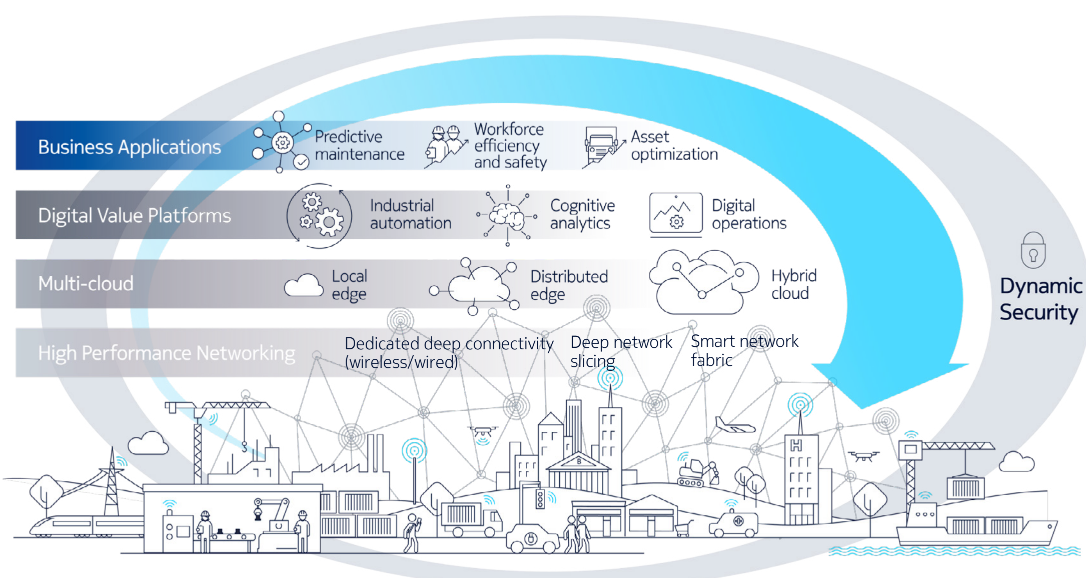
In March 2019, the German regulator, BNetzA, announced that it would license 100 MHz of spectrum (3.7–3.8 GHz) directly to enterprises for 5G use at a specific location. While the fees involved are not very high, the spectrum comes with a "use-it-or-lose-it" principle after one year. The band is assigned in blocks that are multiples of 10 MHz, up to the full 100 MHz. Where there is interference between neighbours, either a bilateral arrangement is agreed or else both parties fall back on strict emissions limits.

BNetzA President Jochen Homann said: "We want to make frequencies available for companies to build local networks that exactly meet their needs." Clearly this scheme is designed to encourage innovative use of 5G spectrum and solutions by industrial verticals, with several major automotive and industrial firms expressing interest.

Realizing Nokia's vision for industrial IoT

5G will be a key component in the realization of Bell Lab's Future X vision, which reaches beyond access and networking to digital value platforms, analytics, and applications. Closing the various digital control and management loops will unite the digital and physical worlds.

Figure 14. Nokia's Future X architecture will help transform industry



However, this industrial transformation will take an entire ecosystem, from government agencies to industry associations, from end-users to automation solution providers and infrastructure vendors.

Nokia works with all the critical stakeholders, always playing a key role in realizing 5G's transformation potential. This includes being:

- A lead vendor in key industrial associations such as 5G ACIA and the Industrial Internet Consortium, defining the requirements for standardization bodies such as 3GPP and the IETF.
- The solution provider for pilot deployments in selected verticals, always in collaboration with key industry players from those verticals.
- A trusted advisor and advocate for industrial IoT with government agencies for regulation and spectrum allocations.

Nokia Digital Automation Cloud - industrial internet everywhere

The Nokia Digital Automation Cloud (Nokia DAC) is an easy to use plug-and-play platform combining a dedicated wireless broadband solution (Private LTE / 4G) and local data processing (with an ultra-scalable edge computing solution or via a local breakout function).

This 5G-ready solution provides wireless tailored, pervasive indoor and outdoor high capacity and low latency connectivity, built on top of unlicensed (MulteFire), shared (CBRS) or licensed spectrum. It forms an end-to-end solution as it comes with digital automation building blocks such as asset/object tracking, video processing, VR/AR, analytics, and Nokia Drone Networks, as well as open APIs for third party integration.

Nokia DAC allows enterprises and industrial companies to take the next step in their digitalization journey. It allows instant creation of a private wireless network and edge cloud computing. With its high capacity, extreme scalability, business critical wireless attributes, ability to create network slices for different types of traffic and strong security, it is suited for the demanding needs and requirements of factories, logistics hubs, and other verticals.

Nokia DAC supports both small and large deployments and suits both local and international needs through its set of regional clouds. The solution uses secure and reliable standardized mobile technology for wireless connectivity and the latest webscale technologies.

In closing the gap between the physical and digital world, 5G will enable business productivity and flexibility on a scale not seen in previous mechanization and automation stages. This will run across multiple industry segments, from manufacturing to logistics, from automated vehicles to smart buildings.

Nokia is playing a lead role in that transformation.

Abbreviations

5G	Fifth Generation Mobile Technology
5GC	5G Core
5G-NR	5G New Radio
AI	Artificial Intelligence
CBRS	Citizens Broadband Radio Service
CSP	Communication Service Provider
eMBB	Enhanced Mobile Broadband
ERP	Enterprise Resource Planning
ETSI	European Telecommunications Standards Institute
ICT	Information and Communications Technology
IoT	Internet of Things
LAN	Local Area Network
LTE	Long Term Evolution
LTE-M	LTE-Machine Type Communication
LPWA	Low Power Wide Area
MEC	Mobile Edge Computing
mMTC	Massive Machine Communications
NB-IoT	Narrow Band IoT
OT	Operational Technologies
RFID	Radio Frequency Identification
SCADA	Supervisory Control and Data Acquisition
UE	User Equipment
URLLC	Ultra-Reliable Low-Latency Communications
WAN	Wide Area Network

Nokia Oyj
Karakaari 7
FI-02610 Espoo, Finland
Tel. +358 (0) 10 44 88 000

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