How will 5G transform Industrial IoT?

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Leading mobile innovation for over 30 years

Digitized mobile communications
Analog to digital

Redefined computing
Desktop to smartphones

Transforming industries
Connecting virtually everything @ Wireless Edge

Transforming how the world connects, computes and communicates
Today, intelligence is primarily associated with the cloud
To scale, intelligence must be distributed to the wireless edge.

Trillions of connected things
Massive amount of data
On-device capabilities complemented with edge cloud at wireless edge

**Edge cloud**
- Distributed/virtualized core
- Mobile edge compute
- Cloud RAN, ...

**On-device**
- Sensing, processing, security, intelligence

**Central cloud**

**Synergistic balance**
- Ultra-low latency—key to 5G use cases
- Processing to augment on-device
- Local content, analytics, management
- Opportunity to provide tailored value
- Privacy as data stays on device
- Immediacy—tasks on device
- Efficient use of bandwidth
- Personalization with privacy

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1. Such as distributed packet gateway functionality for low latency
2. Also related MEC Multi Access Edge Computing as defined by ETSI
Global economic output in 2035 enabled by 5G in the following five categories:

- **Manufacturing**: $3,364B
- **Transport**: $659B
- **Construction**: $742B
- **Utilities**: $273B
- **Mining**: $249B

1. "The 5G economy: How 5G technology will contribute to the global economy" by IHS Economics / IHS Technology
Industry 4.0
The next industrial revolution is on its way

5G takes Industry 4.0 to the next level

- Reconfigurable factories
- Mobile robots and AGV
- Connecting moving parts
- Easy retrofitting
- Single network
- Scale to more devices
- Lower maintenance costs
- Inherent security
Designing a unified, more capable 5G air interface

Diverse services
Scalability to address an extreme variation of requirements

Diverse spectrum
Getting the most out of a wide array of spectrum bands/types

Diverse deployments
From macro to indoors, with support for diverse topologies such as private networks

A unifying connectivity fabric for future innovation
A platform for existing, emerging, and unforeseen connected services
Making 5G a reality in 2019

- Phase 1: Commercial launches
  - Accelerate eMBB deployments, plus establish foundation for future 5G innovations

- Phase 2: Commercial launches
  - Deliver new fundamental 5G NR technologies that expand and evolve the 5G ecosystem

NSA

- Continue to evolve LTE in parallel as essential part of the 5G Platform
Combination of 5G and compute is essential for Industry 4.0

**Compute**

- **Powerful processing**
  On-device CPU / DSP / GPU, computer vision, audio, sensing, ...

- **Artificial intelligence**
  Efficient machine learning, on-device intelligence

- **Edge services/cloud**
  Data privacy, low latency, local services, device management

**Security**

**Connectivity**

- **5G NR**

  - Gigabit LTE
  - LTE IoT

- **Low power**

- **Industry 4.0 + 5G**

- **BLE**

- **Wi-Fi**

- **Mesh**
Cloud analytics and virtualized core network functions

Sensitive data stays on site
Quick turnaround for ultra low latency

Local network at edge
RAN, core network and analytics functions

Industrial IoT devices
Sensing, processing, security, intelligence

Cloud services
Enhanced mobile broadband

Head mounted display
- Augmented Reality
  - Latency: <10 ms
  - Availability: 99.9%
  - Rate: Gbps-Mbps

Handheld terminal
- Safety functions
  - Latency: <10 ms
  - Availability: 99.9999%
  - Rate: Gbps-Mbps

Industrial robot
- Motion control
  - Latency: <1 ms
  - Availability: 99.9999%
  - Rate: Mbps-kbps

Automated guided vehicle (AGV)

Security camera

Massive IoT

Sensors
- Process Monitoring
  - Latency: ~100 ms
  - Availability: 99.99%
  - Rate: kbps

Ultra-reliable low latency
Designing 5G to meet industrial IoT requirements

- Private 5G network for all services
- Ultra Reliable Low Latency Communication (URLLC)
- Time Sensitive Networking (TSN)
- Dedicated licensed or shared/unlicensed spectrum

- Unifying connectivity, dedicated network, optimized services
- High reliability with low latency in challenging RF environments
- Replace wireline industrial ethernet for reconfigurable factories
- Spectrum to deploy private 5G network
Private 5G networks for Industrial IoT use cases

Optimizing LTE for the Industrial IoT today

New opportunities with 5G NR capabilities

Scalable from Gigabit LTE to LTE IoT

Optimized
Tailored for industrial applications, e.g., QoS, latency

Dedicated
Local network, easy to deploy, independently managed

Secure
Cellular grade security and keeping sensitive data local

1. Time Sensitive Networks (TSN); 2. Mobile Broadband (MBB); 3. Extended Reality (XR)—umbrella term for Augmented Reality (AR), Virtual Reality (VR), mixed reality (MR), etc.
Spatial diversity is essential

- Coordinated multi-point (CoMP) provides spatial diversity with high capacity
- CoMP enabled with dense deployment of small cells with high bandwidth backhaul

Other diversity limited

- Frequency diversity does not address RF blockage/shadowing
- Time diversity limited as ultra low latency dictates timing

URLLC
Ultra Reliable Low Latency Communication

99.9999% reliability

Ultra reliability using CoMP

1. One of the performance requirements for "Discrete automation, motion control" in 3GPP TS 22.261 V16.3.0 Table 7.2.2-1
Tradeoffs between different physical layer (PHY) splits

3GPP describes multiple options for splitting RAN functionality

- **Option 6 (Centralized PHY)**
  - Benefits:
    - Can support coherent joint-transmission CoMP resulting in higher capacity
    - More resource pooling
    - Requires high-performance backhaul, e.g., fiber

- **Option 7 (Decentralized PHY)**
  - Benefits:
    - Can support non-coherent CoMP
    - Less stringent backhaul requirements, e.g., GbE

1. 3GPP TR38.801
Achieving ultra-low latency with flexible slot structure

Flexible slot structure allows efficient multiplexing of long and short transmissions

With 2, 4, or 7 symbols – optimized for shorter transmissions suitable for URLLC
Industrial Ethernet using Time Sensitive Networking

1) Time Sensitive Networking (TSN) is a collection of IEEE 802.1Q standards

- Enables time synchronization of machines
- Deterministic packet delivery
- Reserved time slots allow co-existence with best effort traffic

\[
\begin{align*}
\text{Cycle } n & : \quad t_n \quad t'_n \\
\text{Reservation interval} & : \quad t_n \quad t'_n \\
\text{Cycle } n+1 & : \quad t_{(n+1)} \quad t'_{(n+1)} \\
\text{Cycle } n+2 & : \quad t_{(n+2)} \quad t'_{(n+2)}
\end{align*}
\]

\[t'_{(n+2)} = (t_{(n+2)} - t'_{(n+1)} + t'_{(n+1)} - t'_{(n+2)}) + t_{(n+2)}\]
Upgrading existing industrial networks with wireless 5G

Industrial Ethernet, e.g., PROFINET

5G / Ethernet adaptation

Core network

Small cells

UE

5G / Ethernet adaptation
Adapting 5G to support Time Sensitive Networking (TSN)

**Quality of Service (QoS)**
- Interface between 5G control plane and TSN for QoS management
- Define new 5G QoS identifier for industrial Ethernet
- Admission control & interaction with TSN QoS framework

**Time synchronization**
- Time synchronization architecture
- Microsecond synchronization for all nodes
- Broadcasting precise time by gNB

**Ethernet over 5G**
- Transport Ethernet frames over 5G
- Efficient transport of broadcast packets, including loop prevention
- Automatic address discovery
Private network spectrum options for both mobile operators and new entrants

Licensed spectrum

Operators can dedicate a portion in a specific geographical area, e.g., at an industrial plant
Regional regulators can allocate spectrum, e.g., 3.7 GHz under consideration in Germany

Unlicensed/shared spectrum

Unlicensed spectrum behaves like dedicated spectrum in a confined environment controlled by property owner
New sharing paradigms provide enhanced performance with guaranteed performance
Regional shared spectrum for private industrial networks, e.g., CBRS in the USA
5G NR – opportunity for new spectrum sharing paradigms
Building on spectrum sharing technologies that we are pioneering today for LTE

Evolution path
NR unlicensed (NR-U)
- LTE-U / LAA
- LWA
- MulteFire
- CBRS / LSA

Revolution path
NR spectrum sharing (NR-SS)
- Flexible NR framework
- Time synch. and coordination
- Guaranteed QoS
- Spatial sharing with CoMP
- Vertical and horizontal sharing

1. Coordinated Multi-Point (CoMP)
Key industrial IoT functionality targeted for 3GPP rel. 16

Requirements

- Multiple verticals including industrial IoT

URLLC

- Sub-ms latency and 99.9999% reliability

Time Sensitive Networks (TSN)

- Handling of Ethernet switch functions
- Enhanced Quality of Service (QoS)
- Microsecond time synchronization

Spectrum

- 5G NR in unlicensed or shared spectrum

5G NR is being designed to meet Industrial IoT requirements
MWC 2018

Industry-first demo of wireless PROFINET Industrial Ethernet over 5G NR

Showcases precise command-and-control of high-demand factory apps

Previews new use cases for 5G NR URLLC with sub-millisecond latencies

Highlights factory automation use case with 5G NR Private Networks

Enables wireline replacement and reconfigurable factories: a key concept of Industry 4.0

Demo video available on YouTube, search for “5G NR Industrial IoT”
Trusted services to securely connect and manage devices

- Unique device key embedded in chipset at factory
  - Secure boot, debug
  - Hardware Root-of-trust
  - Secure execution environment
  - Runtime integrity checks

- Secure and trusted lifecycle management
  - Device attestation and connection integrity
  - Device provisioning with plug-n-play on-boarding
  - On-demand chipset upgrades and feature activation

Qualcomm wireless edge services is a product of Qualcomm Technologies, Inc. and/or its subsidiaries.
Multiple spectrum options
Private 5G NR networks can be deployed in licensed spectrum or in shared/unlicensed spectrum with NR-U or NR-SS

Extending 5G to industrial IoT
URLLC with TSN support demanding industrial IoT applications such as replacing wired industrial Ethernet

Using CoMP to extend 5G
Coordinated Multi-Point (CoMP) can be used for both increased reliability and efficient spectrum sharing

Wireless edge
To scale industrial IoT, the center of gravity shifts to the wireless edge with distributed intelligence