5G Revolution

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Agenda

1. 5G vision, services and requirements
2. 5G NR design and technologies
3. 5G NR Commercialization
4. 5G NR evolution and expansion
Cellular has revolutionized the way we communicate
From voice only to a plethora of new services that our lives depend on today (e.g., smartphone)

Source: Ericsson Mobility Report, November, 2019
Mobile has made a leap every ~10 years
Continuous innovation between “G”

- **1G (1980s)**: Analog voice
  - AMPS, NMT, TACS

- **2G (1990s)**: Digital voice
  - D-AMPS, GSM, IS-95 (CDMA)

- **3G (2000s)**: Wireless Internet
  - CDMA2000/EV-DO, WCDMA/HSPA+

- **4G (2010s)**: Mobile broadband
  - LTE, LTE Advanced, Gigabit LTE

- **5G (2020s)**: Wireless Edge
  - 5G New Radio (NR)
5G will address the insatiable demand for mobile broadband
Over 60x growth in mobile data traffic from 2013 to 2024

~131B Gigabytes
Monthly global mobile data traffic in 2024

In 2024, ~75% of mobile data traffic from multi-media creation & consumption

In 2024, 25% of mobile data traffic will be carried by 5G networks – 1.3x more than 4G/3G/2G traffic today

Source: Ericsson Mobility Report June 2019
5G is essential for next generation mobile experiences

- Fiber-like data speeds
- Low latency for real-time interactivity
- More consistent performance
- Massive capacity for unlimited data

Mobilizing media and entertainment
Rich user-generated content
Congested environments
High-speed mobility
Connected cloud computing
Immersive experiences
Connected vehicle
Augmented reality
5G NR Services
To meet an extreme variation of 5G NR requirements

Mission-critical services
Enhanced mobile broadband
Massive Internet of Things

10x Decrease in end-to-end latency
10x Experienced throughput
3x Spectrum efficiency
100x Traffic capacity
100x Network efficiency
10x Connection density

Based on ITU vision for IMT-2020 compared to IMT-advanced; URLLC: Ultra Reliable Low Latency Communications;
5G NR Key Technologies
Release 15
Key Technologies driving Rel-15 specifications

- **Scalable OFDM-based air interface**
  - Scalable OFDM numerology
  - Address diverse services, spectrum, deployments

- **Flexible slot-based framework**
  - Self-contained slot structure
  - Low latency, URLLC, forward compatibility

- **Advanced channel coding**
  - Multi-Edge LDPC and CRC-Aided Polar
  - Support large data blocks, reliable control channel

- **Massive MIMO**
  - Reciprocity-based MU-MIMO
  - Large # of antennas to increase coverage/capacity

- **Mobile mmWave**
  - Beamforming and beam-tracking
  - For extreme capacity and throughput
Scalable 5G NR OFDM numerology—examples

Outdoor macro coverage
  e.g., FDD 700 MHz

Outdoor macro and small cell
  e.g., TDD 3-5 GHz

Indoor wideband
  e.g., unlicensed 6 GHz

mmWave
  e.g., TDD 28 GHz

Efficiently address 5G diverse spectrum, deployments and services
Scaling reduces FFT processing complexity for wider bandwidths with reusable hardware
Flexible slot-based 5G NR framework

Efficiently multiplex envisioned and future 5G services on the same frequency

- **Scalable slot duration**
  Efficient multiplexing of diverse latency and QoS requirements

- **Forward compatibility**
  Transmissions well-confined in time/frequency to simplify adding new features in future

- **Self-contained slot structure**
  Ability to independently decode slots and avoid static timing relationships across slots

- **Nominal traffic puncturing**
  To enable URLLC transmissions to occur at any time using mini-slots
Advanced ME-LDPC\(^1\) channel coding is more efficient than LTE Turbo code at higher data rates

- **High efficiency**
  - Significant gains over LTE Turbo—particularly for large block sizes suitable for MBB

- **Low complexity**
  - Easily parallelizable decoder scales to achieve high throughput at low complexity

- **Low latency**
  - Efficient encoding/decoding enables shorter transmission time at high throughput

Selected as 5G NR eMBB data channel as part of 3GPP Release-15

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1. Multi-Edge Low-Density Parity-Check
5G NR optimized design for massive MIMO

Key enabler for using higher spectrum bands, e.g. 4 GHz, with existing LTE sites

- Exploit 3D beamforming with up to 256 antenna elements
- Accurate and timely channel knowledge essential to realizing full benefits
- Mitigate UL coverage with 5G NR massive MIMO + HPUE

Enabled through an advanced 5G NR end-to-end Massive MIMO design (network and device)

- Optimized design for TDD reciprocity procedures utilizing UL SRS
- Enhanced CSI-RS design and reporting mechanism
- Advanced, high-spatial resolution codebook supporting up to 256 antennas
- New features, such as distributed MIMO

5G NR massive MIMO increases coverage & capacity

Faster, more uniform data rates throughout cell

Assumptions: carrier frequency 4GHz; 200m ISD; 200MHz total bandwidth; base station: 256 antenna elements (x-pol), 48dBm Tx power; UE: 4 Tx/Rx antenna elements, 23dBm max. Tx power; full buffer traffic model, 80% indoor and 20% outdoor UEs.
New frontier of mobile broadband — mobilizing mmWave

Vast amount of bandwidth that is ~25x more than what’s being used for 3G/4G today

Sub-6 GHz (e.g., 3.5 GHz)

6 GHz

24 GHz

Millimeter wave (mmWave)
(e.g., 26, 28 GHz, 69 GHz)

100 GHz

Multi-Gbps data rates
With large bandwidths (100s of MHz)

Much more capacity
With dense spatial reuse

Lower latency
Bringing new opportunities
Overcoming the mobile mmWave challenge
Proving the skeptics wrong about mmWave can never be used for mobile

**Limited coverage and too costly**
Significant path loss means coverage limited to just a few hundred feet, thus requiring too many small cells.

**Significant coverage with co-siting**
Analog beamforming w/ narrow beam width to overcome path loss. Comprehensive system simulations reusing existing sites.

**Works only line-of-sight (LOS)**
Blockage from hand, body, walls, foliage, rain etc. severely limits signal propagation.

**Operating in LOS and NLOS**
Pioneered advanced beamforming, beam tracking leveraging path diversity and reflections.

**Only viable for fixed use**
As proven commercial mmWave deployments are for wireless backhauls and satellites.

**Supporting robust mobility**
Robustness and handoff with adaptive beam steering and switching to overcome blockage from hand, head, body, foliage.

**Requiring large formfactor**
mmWave is intrinsically more power hungry due to wider bandwidth with thermal challenges in small formfactor.

**Commercializing smartphone**
Announced modem, RF, and antenna products to meet formfactor and thermal constraints, plus device innovations.

1 LOS: Line of sight, NLOS: Non-line-of-sight
Mobilizing 5G mmWave in real-world environments
Demonstrating NLOS operation and robust mobility

Handheld and in-vehicle UEs with four selectable sub-arrays

Multiple gNodeBs with 128 antenna elements

Indoor mobility with penetration and dynamic blockage

Utilizing adaptive beamforming and beam tracking techniques

Outdoor vehicular mobility up to 30 mph with seamless handover
Showcasing enhanced mobile mmWave user experiences

Simulation assumes 5G NR mmWave co-siting at actual LTE DAS locations in Fira Gran Via Hall 3, uses 800 MHz spectrum in 28 GHz, and is based on Qualcomm engineering simulation tools.

Advanced Network Simulations
Deploying 28 GHz 5G NR mobile mmWave at Mobile World Congress venue

Ubiquitous coverage via co-siting
Virtually unlimited capacity
Multi-Gbps speed & low latency
More uniform user experience

For a wide range of mobile devices:
Non-Stand-alone (NSA) stepping stone to new core

- 4G Evolved Packet Core
- 4G Radio Network
- Data + control over 4G LTE link
- 5G mmWave and/or sub-6GHz
- Data only over 5G NR link
- Dual connectivity

Fast-to-launch

Stand-alone (SA) for new core benefits

- New 5G Next Gen Core
- 5G sub-6GHz
- 5G mmWave
- Data and control over 5G NR link
- Carrier Aggregation
- Built on 5G Core Network
5G NR
Commercialization
Comparison of Year 1 announcements

4G
4 Operators launched
3 OEMs launched

5G
80+ Operators in 35+ countries
5G momentum accelerating globally

- 80+ Operators with 5G commercial deployed
- 380+ Operators investing in 5G globally
- 200M 5G smartphones to ship in 2020
- 750M+ 5G smartphones to ship in 2022
- 1B+ 5G connections by 2023 - 2 years faster than 4G
- 2.8B 5G connections by 2025

Sources - 5G commercial networks and operators investing in 5G: GSA and operator announcements, Apr. ‘19; 5G device shipment projections: Qualcomm estimates (2020 projection is at mid-point of guidance range), Nov. ‘19; 5G connection projections: 2023 - GSMA Intelligence (Dec. ‘19); ABI (Nov. ‘19); 2025 - ABI (Oct. ‘19), CCS Insight (Oct. ‘19), Ericsson (Nov. ‘19)
Driving 5G NR evolution and expansion

3GPP Release-16 and beyond
Driving the 5G technology evolution

Unified, future-proof platform

Rel-15 eMBB focus
• 5G NR foundation
• Smartphones, FWA, PC
• Expanding to venues, enterprises

Rel-16 industry expansion
• eURLLC and TSN for IIoT
• NR in unlicensed (NR-U)
• Positioning
• 5G V2X sidelink multicast
• In-band eMTC/NB-IoT

Rel-17+ long-term expansion
• Lower complexity NR-Light
• Boundless extended reality (XR)
• Higher precision positioning and more...

1. 3GPP start date indicates approval of study package (study item->work item->specifications), previous release continues beyond start of next release with functional freezes and ASN.1
Global economic output in 2035 enabled by 5G in the following five categories:

1. **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: Mbps-kbps

2. **Massive IoT**
   - **Security camera**
     - Latency: 50 ms
     - Availability: 99.9%
     - Rate: Mbps
   - **Automated guided vehicle (AGV)**
     - Latency: 20 ms
     - Availability: 99.9999%
     - Rate: Mbps

3. **Ultra reliable low latency**
   - **Industrial robot**
     - **Motion control**
       - Latency: 1 ms
       - Availability: 99.9999%
       - Rate: Mbps-kbps
   - **Edge computing and analytics**

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**1. “The 5G economy: How 5G technology will contribute to the global economy” by IHS Economics / IHS Technology**

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

**Sensors**
- Latency: 10 ms
- Availability: 99.9999%
- Rate: Mbps-kbps

**Safety functions**
- Latency: 10 ms
- Availability: 99.9999%
- Rate: Gbps-Mbps

**Augmented Reality**
- Latency: 10 ms
- Availability: 99.9%
- Rate: Mbps-kbps

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**Latency**
- Process Monitoring: 100 ms
- Sensors: 10 ms
- Security camera: 50 ms
- Enhanced mobile broadband: 10 ms
- Massive IoT: 20 ms
- Ultra reliable low latency: 1 ms

**Availability**
- Process Monitoring: 99.99%
- Sensors: 99.9999%
- Security camera: 99.9%
- Enhanced mobile broadband: 99.9%
- Massive IoT: 99.9999%
- Ultra reliable low latency: 99.9999%

**Rate**
- Process Monitoring: kbps
- Sensors: Mbps-kbps
- Security camera: Mbps
- Enhanced mobile broadband: Gbps-Mbps
- Massive IoT: Mbps
- Ultra reliable low latency: Mbps-kbps

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**Global economic output in 2035 enabled by 5G in the following five categories**

1. Enhanced mobile broadband
2. Massive IoT
3. Ultra reliable low latency
4. Process Monitoring
5. Sensors

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**Economic Output by Industry**

- **Utilities**: $273B
- **Mining**: $742B
- **Construction**: $659B
- **Transport**: $3,364B
- **Manufacturing**: $5 Trillion
Scalable wireless connectivity
on a future proof platform

Dedicated and reliable networks
optimized for local services

Capabilities for new use cases
e.g. wireless Industrial Ethernet

Private 5G network

Licensed, shared and
unlicensed Spectrum

Ultra Reliable Low Latency
Communication (URLLC)

Time Sensitive
Networking (TSN)

Positioning

Designing 5G to meet industrial IoT requirements
Evolving C-V2X direct communications towards 5G NR
Rel-16 5G NR C-V2X vehicles will also support Rel-14/Rel-15 for safety

5G NR C-V2X brings about complementary capabilities while being backwards compatible

R14/R15 C-V2X for automotive safety
5G NR C-V2X enables advanced use cases

- **Increased situational awareness**: Sharing of vehicle-specific info with other vehicles and road infrastructure (e.g., door open warning)
- **Sensor sharing**: Sharing of sensor data, e.g., vehicle’s perception, including road world model
- **Coordinated driving/intention sharing**: Exchanging intention and sensor data for more predictable, coordinated autonomous driving
- **Real-time infrastructure updates**: Real-time sharing of 3D HD map and other information between vehicles and infrastructure

**Higher throughput**

**Lower latency**

**Higher reliability**

**Application aware**
5G NR enhancements for mmWave

**Completed Release 16 Projects**

- **Integrated access and backhaul (IAB)**
  Enabling flexible deployment of small cells reusing spectrum and equipment for access and backhaul

- **Enhanced beam management**
  Improving latency, robustness and performance with full beam refinement and multi-antenna-panel beam support

- **Power saving features**
  Maximizing device sleep duration to improve power consumption as well as allowing faster link feedback

- **Dual connectivity optimization**
  Reducing device initial access latency and improving coverage when connected to multiple nodes

- **Positioning**
  Meeting initial accuracy requirements of 3m (indoor) to 10m (outdoors) for 80% of time

**Release 17+ Projects**

- **Improved IAB for distributed deployment**
  Introducing full duplex operations and mobile relays for improved capability, coverage, and QoS

- **Optimized coverage & beam management**
  Reducing overhead, enhancing performance (e.g., beam selection), improving coverage

- **Expanded spectrum support**
  Supporting licensed and unlicensed spectrum in frequencies ranging from 52.6 GHz to 71 GHz

- **New use cases beyond eMBB**
  Expanding mmWave support for sidelink, URLLC, and industrial IoT use cases (e.g., NR-Light)

- **Enhanced positioning**
  Enhancing capability for a wide range of use cases — cm-level accuracy, lower latency, higher capacity
Strong Alignment between 5G and AI

Past
Cloud-centric AI
AI training and AI inference in the central cloud

Today
Partially-distributed AI
Power-efficient on-device AI inference

Future
Fully-distributed AI
With lifelong on-device learning
Intelligently connecting our world in the 5G era

A unified connectivity fabric this decade

5G

Strong 5G momentum sets the stage for the global expansion

Rel-15 eMBB focus

Rel-16 and 17 Expanding to new industries

Rel-18, 19, 20 and beyond Continued 5G proliferation

6G

Next technology leap for new capabilities and efficiencies

Historically 10 years between generations

Continued evolution

Strong 5G momentum sets the stage for the global expansion
Questions?

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