Making 5G NR a reality
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Designing a unified, more capable 5G air interface for the next decade & beyond

- Scalability to address diverse services & devices
- Unified design across diverse spectrum bands & types
- Adaptable to diverse deployments & topologies

- Coordinated spatial techniques
- Integrated access and backhaul
- Hyper dense deployments
- Multi-connectivity
- Mobilizing mmWave
- Beam forming
- Redundant links
- Multicast
- Advanced receivers
- New shared spectrum paradigms

- Ultra-reliable links
- Narrowband Internet of Things
- V2N
- Multi-hop
- Wide bandwidths
- Advanced MIMO
- Dynamic, low-latency TDD/FDD
- Device-centric mobility
- V2V

- Massively MIMO
- Advanced channel coding, e.g. LDPC
- Grant-free uplink transmissions, e.g. RSMA

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5G NR R15 is establishing the 5G foundation
For enhanced mobile broadband and beyond

- **Optimized OFDM-based waveforms**
  - With scalable numerology and TTI, plus optimized multiple access for different use cases

- **A flexible, forward compatible framework**
  - To efficiently multiplex services and features with a dynamic, low-latency TDD/FDD design

- **Advanced wireless technologies**
  - Such as massive MIMO, robust mmWave, advanced channel coding, and device-centric mobility

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Unified design across spectrum types and bands

For licensed and shared/unlicensed spectrum bands both below 6 GHz and above 6 GHz

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1 Able to aggregate multiple Component Carriers to achieve bandwidths of 800+ MHz; 2 Multi-Edge Low-Density Parity-Check
5G NR Massive MIMO to increase coverage and capacity

Allows reuse of existing sites and same transmit power at e.g. 4 GHz

Exploit 3D beamforming with up to 256 antenna elements

200m inter-site distance
48 dBm transmit power

Median user perceived throughput

Cell edge user perceived throughput

<table>
<thead>
<tr>
<th>System</th>
<th>Median User Throughput</th>
<th>Cell Edge User Throughput</th>
</tr>
</thead>
<tbody>
<tr>
<td>4x4 MIMO</td>
<td>52 Mbps</td>
<td>27 Mbps</td>
</tr>
<tr>
<td>5G NR Massive MIMO</td>
<td>195 Mbps</td>
<td>79 Mbps</td>
</tr>
</tbody>
</table>

Assumptions: carrier frequency 4GHz; total bandwidth: 200MHz; base station: 256 antenna elements (x-pol), 48dBm Tx power over 200MHz; UE: 4 Tx/Rx antenna elements, 23dBm max. Tx power; full buffer traffic model, 80% indoor and 20% outdoor UEs.
Qualcomm Research 5G NR Sub-6 GHz Demonstration
Showcasing 5G NR technologies to achieve multi-Gbps at ultra-low latency

- Wide area coverage at 3.3-3.8 GHz band with multiple simultaneous users
- High data rates (up to multi-Gbps) utilizing multi-user Massive MIMO
- Live connection with sub-2 ms latencies
- Faster, more uniform data rates both outdoor and indoor
- Self-contained TDD operation
Mobilizing mmWave with 5G NR technologies

Key properties for robust mmWave operation in a NLOS mobile environment

Directional antennas with adaptable 3D beamforming and beam tracking

Very dense network topology and spatial reuse (~150-200m ISD)

Fast beam steering and switching within an access point

Architecture that allows for fast beam switching across access points

Tight integration with sub-6 GHz (LTE or NR)
Qualcomm Research 5G mmWave OTA testing
Showcasing robust mobile communications in real-world environments

Handheld and in-vehicle UEs with hand-blocking

Multiple gNodeBs with seamless handovers

Indoor mobility with wall penetration and dynamic blocking

Utilizing adaptive beamforming and beam tracking techniques

Outdoor vehicular mobility up to 30 mph
Working with global network operators to simulate 5G NR mmWave network coverage

Showcases significant outdoor coverage possible utilizing existing LTE sites (10+ global cities)

Outdoor coverage only; frees up sub-6 GHz resources for out-to-indoor capacity

San Francisco simulation demoed at MWC Americas 2017

Outdoor coverage can be complemented with targeted indoor deployments – stay tuned for upcoming study
5G NR mmWave continuing to evolve beyond R15

Bringing new capabilities, new spectrum bands and new deployment opportunities

Integrated Access & Backhaul
Rel-15 Study Item on enabling easy/low-cost deployment of small cells using mmWave spectrum for access and backhaul

Unlicensed Spectrum
Rel-15 Study Item for both LAA and standalone operation (aka 5G MulteFire™) in sub-6 GHz and mmWave spectrum bands

Higher spectrum bands
Exploring the use of spectrum bands above ~40 GHz, including unlicensed spectrum in the 57 GHz to 71 GHz band
5G NR evolution and expansion beyond eMBB
URLLC part of Rel-15 Work Item; also new Rel-15 5G NR Study Items approved

- **Work on 5G NR Ultra-Reliable Low Latency Communications**
  For mission-critical control services like industrial automation, incl. efficient multiplexing with mobile broadband

- **Study on 5G NR operation in unlicensed spectrum**
  For both licensed-assisted access (aka LAA) and standalone operation (aka MulteFire™) in sub-6 GHz and mmWave spectrum bands

- **Study on 5G NR non-orthogonal multiple access, e.g. RSMA**
  For grant-free uplink transmissions that can be utilized e.g. for small data exchanges in IoT communications

- **Evaluation of 5G NR for C-V2X communications**
  For augmenting today’s C-V2X technology with use of high-frequency ITS bands

- **Study on 5G NR Integrated Access & Backhaul**
  For enabling easy/low-cost deployment of small cells with integrated access and backhaul

- **Study on 5G NR for non-terrestrial networks**
  Explore deployment scenarios and channel models for utilizing 5G NR for satellite operation

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1 Part of 5G NR Rel-15 Work Item with identification of necessary techniques starting in Q3’17 and normative work 1H’18; 2 Resource Spread Multiple Access
Making 5G NR a commercial reality in 2019

Best-in-class 5G prototype systems and testbeds

5G standards, technology and research leadership

Interoperability testing and trials with network operators

Modem and RFFE leadership to solve 5G complexity

To test, demonstrate & verify our innovative 5G NR designs

Our technology inventions are driving the 5G NR standard

Leading the way on 5G NR IoDTs and trials starting 2H-17

Announced world’s first 5G NR multimode modems for 2019

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