Mobilizing mmWave to realize the full 5G potential

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Agenda

• Qualcomm & QGOV Introduction
• 5G Overview & Current State
• Overcoming mmWave Challenges
• Conclusion/Q&A
A global leader in wireless innovation

35+ years of sustained innovation
$64B+ in cumulative R&D
140,000+ patents/patent applications

Key business segments
QTL: technology licensing
QCT: semiconductors
- Mobile
- RF front end
- Auto
- IoT
- Networking
- Voice and music
- Computing
- Extended reality
- Cloud AI
QGOV: government mission impact

Source: Company data as of Q1 FY20; R&D is cumulative expenditure since 1985
Leading mobile innovation for over 35 years

Digitized mobile communications
Analog to digital

Redefined computing
Desktop to smartphones

Transforming industries
Connecting virtually everything at the wireless edge

Transforming how the world connects, computes and communicates
A trusted partner to the Government

Mission:
Employ our wireless expertise, innovative technologies and vast industry reach to provide intelligent systems solutions and services that enable our government partners to realize significant technology gains and excellence in mission performance.
5G Overview & Current State
Delivering on the 5G vision

Continue expansion to new verticals, deployments, use cases, spectrum

Future-proof platform

Rel-17

Rel-16

Rel-15

LTE essential part of the 5G 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
5G delivers a unified, more capable platform for innovation

Diverse services

Enhanced mobile broadband
Mission-critical services
Massive Internet of Things

Diverse spectrum

High-bands
Above 24 GHz (mmWave)
Mid-bands
1 GHz to 6 GHz
Low-bands
Below 1 GHz
Licensed/shared/unlicensed

Diverse deployments

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; IAB: Integrated Access & Backhaul
5G commercialization moving into the mainstream

**5G Sub-6**

**5G Sub-6 + mmWave**
(launched or scheduled)

**EU**
36 Operators in 17 Countries

**NA**
9 Operators in 2 Countries

**LATAM**
2 Operators in 2 Countries

**MEA**
17 Operators in 8 Countries

**Asia**
16 Operators in 5 Countries

**SEA**
8 Operators in 4 Countries

**40+**
Countries with 5G commercially deployed

**90+**
Mobile operators with commercial live 5G networks

**200M**
5G handsets expected to ship in 2020

Sources - GSA: 5G Market Snapshot Member Report - June 2020; Qualcomm estimates (2020 projection is at mid-point of guidance range), Nov. '19
Building on the technology foundation for the 5G expansion

- **High-precision positioning**: Accurate indoor and outdoor positioning
- **Mission-critical design**: Ultra-high reliability of up to 99.9999%
- **Unlicensed spectrum**: Improved capacity and new use cases
- **New deployment models**: New deployments e.g., IIoT and enterprise
- **Advanced power saving and mobility**: Better device performance and coverage
- **Sidelink**: Advanced safety use cases

**Expanded 5G foundation in Release 16**

**5G NR Release 15 technology foundation**

- **Flexible slot-based framework**
- **Scalable numerology**
- **Advanced channel coding**
- **Massive MIMO**
- **Mobile mmWave**
5G NR mmWave IAB\(^1\) for cost-efficient dense deployments

Improves coverage and capacity, while limiting backhaul cost

Traditional fiber backhaul can be expensive for mmWave cell sites

- mmWave access inherently requires small cell deployment
- Running fiber to each cell site may not be feasible and can be cost prohibitive
- mmWave backhaul can have longer range compared to access
- mmWave access and backhaul can flexibly share common resources

\(1\) Integrated Access and Backhaul
5G Coordinated Multipoint (CoMP) - different variants

Coord. Sched./Beamforming
- Data via one base station
- Coordinated beamforming between base stations to improve overall signal quality
- Coordinated scheduling to maximize resource utilization

Dynamic Point Selection
- Data via multiple base stations
- Transmission from a single base station at each time instance
- Which base station is transmitting is dynamically changing on a subframe basis

Joint Transmission (JT)
- Data via multiple base stations
- Multiple base stations transmit same data with beamforming
- Coherent JT enables nulling; requires channel knowledge and antenna calibration

1) For example maximize the minimum signal to noise plus interference ratio. 2) This is referring to downlink. For uplink Joint Reception (JR) can be used.
Overcoming mmWave Challenges
We overcame 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)¹
Blockage from hand, body, walls, foliage, rain etc. severely limits signal propagation

Operating in LOS and NLOS¹
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
mmWave RF complexities in designing 5G handsets

Implementing 5G mmWave in smartphone form factors presents difficult but solvable challenges.

**Link budget**
Achieve target radiated power with high bandwidths at mmWave frequencies.

**Power consumption**
Support multi-Gigabit throughputs with high power efficiency.

**Mobility**
Maintain reliable mmWave connectivity in a changing, mobile environment.

**Stringent size constraints**
Achieve high antenna efficiency and multi-band support in challenging smartphone form factors.

**Thermal performance**
Support high transmit power while maintaining thermal stability and avoiding localized hot spots.

**Regulatory compliance**
Optimize transmit power and throughput while meeting regulatory requirements.
Mobilizing mmWave with 5G NR technologies
Deploying a dense mmWave network with spatial reuse – ~150 - 200m ISD

- Tight integration with sub-6 macro network (LTE or 5G NR)
- Directional antennas with adaptable 3D beamforming and beam tracking
- Fast beam steering and switching within and across access points
- Device antenna diversity and dual connectivity
- Multipath signal propagation with reflections
- Delivering robust NLOS connectivity
- Supporting seamless mobility
- Complementing macro area coverage
Addressing mobility challenges with multi-beam techniques
Improves coverage, robustness, and non-line of sight operations

High-gain directional antenna arrays
Analog beamforming with narrow beamwidth to overcome significant path loss in bands above 24 GHz
Required in both base station (~128 to 256+ elements) and mobile device (~4 to 32 elements) for 3D beamforming

Beam switching
Switches between candidate beams to adapt to changing environment

Beam steering
Changes direction of uplink beams to match the that of incoming beams from gNodeB

Beam tracking
Distinguishes between beams arriving from gNodeB

Smart, closed-loop algorithms determine most promising signal paths with fast switching within and across access points
Improving reliability utilizing device antenna diversity

Front Antenna Module (+X, +Y, +Z direction)

Back Antenna Module (-X, -Y, -Z direction)

Provides nearly spherical coverage in free space

Total Gain (dBi)
Total Power Max=8.8 dBi

Qualcomm Research Simulations
Mitigates hand-blocking and reduces impact of random user orientation
Results drove commercial products – Qualcomm® QTM052 5G NR mmWave antenna module
UE antenna module design for coverage

Three-antenna configuration provides more robust spherical coverage than single antenna

Source: Qualcomm Technologies, Inc.
Achieving required transmit power for mobile mmWave

Required transmit power (EIRP\(^1\))

Beamforming and directional architectures allow more gain

# of antennas in array determines max EIRP

Physics dictates antenna size and spacing

\(\lambda = 10.5\) mm at 28 GHz

\(\lambda/4\)

Element gain

Power combining

Beamforming gain

Single polarization

PA output

PA

Element gain

Power combining

Beamforming gain

Single polarization

\(\lambda = 10.5\) mm at 28 GHz

\(\lambda/4\)

1 EIRP = Equivalent Isotropic Radiated Power. Represents peak directional power transmitted from the antenna array relative to an isotropic transmission.
Showcasing robust mobile communication in real-world OTA testing using Qualcomm Research 5G mmWave prototype
Showcasing reflections provide alternative paths when LOS is blocked — based on our outdoor channel measurements.

Channel response from omni-directional antennas (Example measurement)

- Operating at sub-6 GHz
- Operating above 24 GHz

*Alternative paths in mmWave can have very large receive signal*

*Small objects affect mmWave propagation more than sub-6 GHz (e.g., tree branches)*
Outdoor OTA example test results

Demonstrating sustained mobile communications outdoors, with NLOS and device mobility

Qualcomm Research over-the-air outdoor testbed

Source: Qualcomm Technologies Inc.
Indoor Office OTA example test results

with dimensions of 75m x 40m with seamless handovers between two gNodeBs

Demonstrating sustained mobile communications indoors, with wall penetration and hand/body-blocking

Two gNBs provides adequate coverage for large, walled indoor office

Cell-boundaries not well-defined – function of the environment

Coverage holes, e.g. area near elevators, can be addressed with more gNBs

Source: Qualcomm Technologies Inc.
5G mmWave offers massive capacity

Average 5G download speeds powered by Snapdragon™ Modem-RF Systems are 5x faster than LTE

Recent analysis by Ookla
Extended-Range mmWave delivers significant coverage improvement

Field trial collaboration with U.S Cellular operator and Ericsson in United States

Field trial collaboration with Casa Systems operator and Ericsson in Australia

Test Setup

Extended-range CPE

+5 km long distances
+200 Mbps

mmWave base station

+2.1 Gbps

<1 km short distances

Extended-range CPE

Line of sight
5G mmWave home broadband for rural American city

Significant extended range with 24 GHz outdoor CPE compared to a smartphone

<table>
<thead>
<tr>
<th>Outdoor Downlink Throughput</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 Mbps</td>
</tr>
<tr>
<td>50 Mbps</td>
</tr>
<tr>
<td>100 Mbps</td>
</tr>
<tr>
<td>300 Mbps</td>
</tr>
<tr>
<td>1000 Mbps</td>
</tr>
</tbody>
</table>

Deployment Detail

<table>
<thead>
<tr>
<th>Rural cluster type</th>
<th>12,100 population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cluster area</td>
<td>78.5 mi²</td>
</tr>
<tr>
<td>mmWave sites</td>
<td>3</td>
</tr>
</tbody>
</table>
Deploying IAB to expand mmWave coverage

End-to-end system simulations using 5G NR mmWave at 28 GHz

Frankfurt, Germany

Total simulation area: ~1 km^2
Total number of gNodeBs: 7
Total number of IAB nodes: 28
Total number of devices: 300

Link to full demonstration video

mmWave coverage simulation results

Network throughput improvement

Average downlink signal improvement
Commercial mmWave Devices

Hotspots, CPEs, and 5G Modules

Oppo 5G CPE Omni
Netgear Nighthawk 5G
Inseego 5G MiFi M1000
Askey RTL0300
Lenovo Yoga Flex 5G
Engagements
- Studies
- Prototyping / Demos
- Technical Explorations
- Support for Licensing, Tools and Chipset Sales
- User Trials

Analysis
- Landscape Analysis
- Product / Capability Analysis
- Market Intelligence
- Analyses of Threats and Opportunities
- Application to USG Use Cases
- Recommendations

Education
- Wireless Industry Information
- Commercial Use Cases
- Formal Training
- Product / Capability Roadmaps
- Ecosystem Education

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