5G: From Concept to Commercialization, and What’s Next

Dr. Durga Malladi
SVP & GM, 4G/5G
Qualcomm Technologies, Inc.
Leading mobile innovation for over 30 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 unifying connectivity fabric for future innovations

- Scalable to extreme simplicity
- On-device intelligence
- Multi-gigabit speed
- Extreme reliability
- Ultra-low latency
- Virtually unlimited capacity
Efficient use of energy and utilities

Safer, autonomous transportation

Reliable access to remote healthcare

Precision agriculture

Private networks for logistics, enterprises, industrial,…

Sustainable smart cities and infrastructure

Digitized logistics and retail

Enabler to the factory of the future

5G will expand the mobile ecosystem to new industries

Powering the digital economy

>$12 Trillion

In goods and services by 2035*

* The 5G Economy, an independent study from IHS Markit, Penn Schoen Berland and Berkeley Research Group, commissioned by Qualcomm
Designing a unified, more capable 5G air interface

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

Existing, emerging, and unforeseen services - a platform for future innovation
Commercializing 5G and expanding the mobile ecosystem

Rel-15
- Non-Standalone (NSA)
- Standalone (SA)
- IoDTs
- Field trials

Rel-16
- Rel-15 Commercialization
  - eMBB deployments in both mmWave and sub-6 GHz.

Rel-17+ evolution
- New 5G NR technologies to evolve and expand the 5G ecosystem
- Expanded ecosystem:
  - Smartphone formfactor, Connected laptops, CPE fixed access
  - Private networks, Indoor mmW for enterprises, Boundless XR,...
  - Industrial IoT, Private network, 5G NR C-V2X,
  - Integrated Access and Backhaul, Unlicensed/shared spectrum,...
  - Continued eMBB evolution

Continue to evolve LTE in parallel as essential part of the 5G Platform

Our technology inventions drove Release 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

Early R&D investments | Cutting-edge prototypes | Fundamental contributions to 3GPP
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

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

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

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

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

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

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

- **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
Making 5G NR a commercial reality in 2019

Industry-leading R&D
Interoperable global standards
End-to-end system prototypes
Network and system simulations
Interoperability testing and field trials
Qualcomm® Snapdragon™ X50 5G modem & Snapdragon 855 Mobile Platform
Commercial 5G NR mmWave networks and products

Qualcomm Snapdragon is a product of Qualcomm Technologies, Inc. and/or its subsidiaries.
2019 is the year of 5G

Deployments happening in regions across the globe
5G rollout happening faster than 4G

- 4 Operators launched (4G)
- 3 OEMs launched (4G)
- 20+ Operators announced (5G)
- 20+ OEMs announced (5G)

Source: IHS Report Jan '19, Qualcomm Technologies data

Year 1 announcements underscore tremendous momentum with 5G
5G is Here
30+ devices scheduled to launch in 2019
The 5G opportunity will be massive

We are uniquely positioned to be a leader in the 5G era

5G R&D, system prototypes, test beds

5G modems

5G RF solutions (Sub-6 GHz, mmWave)

5G platforms and reference designs

Qualcomm RF IC is a product of Qualcomm Technologies, Inc. and/or its subsidiaries.
Qualcomm®
QTM052 mmWave antenna modules

Pairs with Snapdragon X50 5G modem to deliver modem-to-antenna capabilities across spectrum bands

Smartphone form factor
Suitable for compact smartphone industrial designs with four mmWave modules

Fully-integrated mmWave RF
Including transceiver, PMIC, RF front-end components, and a phased antenna array

Supported mmWave bands
Support for up to 800 MHz of bandwidth in n257, n260, and n261 5G NR mmWave bands

Advanced mobility features
Supporting beamforming, beam steering, and beam tracking for bi-directional mmWave communications

1 3GPP band definition are n257 (26.5-29.5 GHz); n260 (37-40 GHz); n261 (27.5-28.35 GHz)
5G will significantly enhance the app experience versus 4G

- **Download latency**
  - 20x improvement
  - up to a 3x improvement
  - (across sub-6 GHz and mmWave)

- **Content download speed**
  - 10x improvement
  - up to a 3x improvement
  - (across sub-6 GHz and mmWave)

- **Streaming video performance**
  - 95% playback at max bitrate
  - vs
  - 4% playback at max bitrate
  - (across sub-6 GHz and mmWave)

Comparison of 5G in mmWave and sub-6 GHz vs LTE Category 12
5G NR is expanding to new use cases and verticals.
Bringing multi-Gigabit, low-latency, and virtually unlimited capacity

Supporting devices beyond smartphones — tablets, always-connected laptops, XR

Leveraging existing infrastructure — Wi-Fi or cellular — by co-siting small cells

5G NR indoor mmWave private network for new and enhanced experiences

Complementing Wi-Fi deployments

Venues
Conventions, event halls, concerts, stadiums, etc.

Enterprises
Offices, shop floors, meeting rooms, auditoriums, etc.
5G NR mmWave boosts performance in enterprise networks

- Downlink/uplink coverage comparable to Wi-Fi with 1:1 or partial co-site
- Realize multi-Gigabit burst rate with wider bandwidths (e.g., 800 MHz)
- Complement indoor Wi-Fi deployments

Complete coverage at 28 GHz at Qualcomm headquarters
- ~98% Downlink coverage with 1:1 co-siting
- ~99% Uplink coverage with 1:1 co-siting
- 5 Gbps downlink median burst rate

Coverage simulation based on MAPL (maximum allowable path loss) analysis with ray tracer propagation model and measured material and propagation loss; minimum 0.4/0.1 bps/Hz for downlink/uplink data and control. 2 Maximum Allowable Path Loss; DL 115 dB, UL 117 dB; 3 Using 800 MHz DL bandwidth and 100 MHz uplink bandwidth with 7:1 DL/UL TDD.
Enhanced network communication
Faster access to cloud for in-vehicle experiences and car OEM services and telematics

New direct communication
V2V, V2I, and V2P are independent of cellular network or cellular subscription for latency-sensitive use-cases, e.g. collision avoidance

Massive Internet of Things
Deeper coverage to connect road infrastructure (e.g. sensors and traffic cameras)

5G automotive private network for transportation use cases

Road safety
Car OEM services
In-vehicle experiences
Transportation efficiency
Connected road sensors
Smart city
Utilities
Sensors
Emergence of new automotive and transportation use cases
Requiring a more flexible and efficient direct communication design

- New autonomous driving use cases
  Perception and intention sharing for coordinated driving

- New smart transportation use cases
  Vehicles and infrastructure need to exchange new kinds of information, such as, real time 3D HD map updates.

- More sensor data needs to be shared
  Vehicles have new and more sensors, generating more information that needs to be shared

Automotive industry is undergoing a significant transformation
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 new benefits

- **Advanced safety**: Real-time situation awareness and sharing of new kinds of sensor data take safety to the next level
- **Faster travel/energy efficiency**: More coordinated driving for faster travel and lower energy usage
- **Accelerated network effect**: Sensor sharing and infrastructure deployment bring benefits, even during initial deployment rollouts

- Increased situational awareness
- Sensor sharing
- Coordinated driving / intention sharing
- Real-time infrastructure updates
5G NR Industrial IoT private network for dedicated and optimized services

- Container ports
- Oil refineries
- Manufacturing
- Hospitals
- Mines
- Enterprises
- Government
- Warehouse

Private LTE/5G networks available with 3GPP’s roadmap for the future

Next 5G release includes enhanced ultra-reliable low latency (eURLLC)

Optimized to meet requirements for wireless industrial Ethernet
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

Massive IoT

Security camera

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

Sensors

Automated guided vehicle (AGV)

Latency:
Availability: 99.9999%
Rate: Mbps-kbps

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

Handheld terminal

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

Edge computing and analytics

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
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
Private 5G NR networks can use different spectrum types
Providing a wide range of new services including URLLC

- **Licensed spectrum**
  - Operators can allocate a portion of their spectrum in a specific area, e.g., at an industrial plant.

- **Dedicated spectrum**
  - In some regions, spectrum is dedicated for specific use such as 3.7 GHz in Germany for industrial.

- **Unlicensed/shared spectrum**
  - 3GPP Rel-16 adds support for unlicensed spectrum (5G NR-U) including standalone operation; can support URLLC services in non-public locations controlled by tenant/owner.

- **New sharing paradigms**
  - CoMP with spatial sharing can provide significant capacity gains, predictable QoS and URLLC services.
5G NR in unlicensed spectrum (NR-U) part of 3GPP R16
For wide range of deployments – also opportunity for new sharing paradigms

Evolutionary path
NR unlicensed (NR-U)—existing coexistence rules

Revolutionary path
NR spectrum sharing (NR-SS)—potential for new rules

Time synchronization provides great potential to share spectrum more efficiently

Predictable resources
5G CoMP
Spatial sharing
Flexible sharing
What is possible when not constrained by existing rules?

Revolutionary path

NR spectrum sharing (NR-SS)–potential for new spectrum sharing rules
For green-field unlicensed spectrum bands such as 6 GHz

Predictable resources
- Prioritized resources for each operator → predictable service
- Opportunistic sharing of unused resources

5G CoMP
- Exploiting the spatial domain with 5G CoMP
- Significantly increased capacity and reliability

Spatial sharing
- Spatial sharing between multiple operators
- Allows for simultaneous use of same spectrum in same location

Flexible sharing
- Native support for sharing with different priority levels
- Flexible framework to support various regional sharing needs
New 6 GHz band, an opportunity to share more efficiently

Define rules for greenfield unlicensed spectrum to be more future-proof

Proposal: allocate a portion of the band where time synchronized operation has precedence

In locations where no networks are using time sync. the entire band is shared as usual

In locations where some networks want to use time sync. this mode takes precedence in the allocated portion
Qualcomm Technologies, together with Nokia, were selected as the technology provider by the Hannover Messe to provide the 5G over-the-air connectivity for the demonstrations in the 5G Arena.
The wireless edge transformation realizes the full potential of 5G

- New experiences with new levels of immersion, immediacy, personalization and privacy
- Creating new industries and transforming existing industries in the new era of distributed autonomy
- Essential on-device capabilities augmented with processing/compute, content, control,… at edge cloud
Enhancing services, creating new services, new deployment models with our end-to-end expertise

Cloud

- Big data, AI training, less delay
- Sensitive content, storage,...

Augmented by edge cloud

- Compute/processing, content, control, storage,.. closer to user

Driving the best possible on-device capabilities

- Sensing, processing, security, intelligence

Latency could be over 100s ms today

Latency as low as 1 ms

Cooperation between operators, infra vendors, OEMs, content providers, cloud providers,...

1. Such as distributed/virtualized core, distributed packet gateway functionality for low latency, mobile edge compute, related to MEC Multi Access Edge Computing as defined by ETSI
Augment on-device processing for boundless photorealistic mobile XR

Cloud
Less latency sensitive content (e.g. recorded streaming video)

Edge Cloud
Deeper in network with rendering
On-premise, e.g. venue

5G
XR headset
with on-device processing
6-DoF head pose
Encoded data

On-device adjustment to latest pose

Cloud
Today’s latency is unpredictable

Edge Cloud
Partial rendering offload possible with 5G’s low latency, capacity and quality of service

5G
Power-efficient, latency sensitive on-device rendering and tracking

1. Asynchronous time warp reduces Motion to Photon (MTP) latency by using on-device processing based on the latest available pose. MTP below 20 ms generally avoids discomfort – has to be processed on the device.
A new era in distributed processing

Essential on-device processing
- Optimized under strict power, thermal, size constraints
- Premium experiences today that continuously improve

Split rendering

Augment by edge cloud processing
- Significant higher power envelope—beyond PC class
- Augment on-device rendering with edge cloud rendering

5G
- Low latency
- High capacity
- Reliable link
Thank you!

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5G rollout happening much faster than 4G

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