Accelerating the mobile ecosystem expansion in the 5G Era with LTE Advanced Pro

Qualcomm Technologies, Inc.
Mobile is the largest technology platform in human history

1980s
Analog voice
AMPS, NMT, TACS

1990s
Digital voice
D-AMPS, GSM, IS-95 (CDMA)

2000s
Mobile data
WCDMA/HSPA+, CDMA2000/EV-DO

2010s
Mobile broadband
LTE, LTE Advanced, Gigabit LTE

1. Source: GSMA Intelligence, January 2018
5G will expand the mobile ecosystem to new industries

More autonomous manufacturing
Safer, more autonomous transportation
Reliable access to remote healthcare
Smarter agriculture

More efficient use of energy and utilities
Improved public safety and security
Sustainable cities and infrastructure
Digitized logistics and retail

5G will power the digital economy to over $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
LTE Advanced Pro accelerates the 5G mobile expansion
Providing ubiquitous coverage and essential services that complement 5G NR

Gigabit LTE is here now and delivers a seamless 5G mobile experience

LTE IoT, private LTE network, C-V2X are enabling new mobile use cases today

LTE Advanced Pro leadership is essential to success in the 5G Era
Providing essential services to 5G from Day 1
Also digital TV, public safety, drone communication, and more...

LTE Advanced Pro

- **Gigabit LTE with LAA**
  Enables ubiquitous Gigabit-class mobile experiences globally; LAA co-siting benefits 5G NR mmWave coverage

- **Voice (VoLTE)**
  Delivers essential voice services for a wide variety of 5G use cases leveraging ubiquitous LTE networks

- **LTE IoT (eMTC + NB-IoT)**
  Starts to connect the massive IoT today; deployable in-band with 5G NR to enable new 5G NR IoT deployments

- **Cellular V2X (C-V2X)**
  Establishes the foundation for safety use cases; continued 5G NR C-V2X evolution for future autonomous cars

- **Private LTE Network**
  Deploys optimized, dedicated, on-premise network for industrial IoT use cases; paving the path to private 5G NR networks

1. ITU Recommendation ITU-R M.2083-0, September 2015

**LTE-A Pro** will be submitted with 5G NR to meet IMT-2020\(^1\) requirements
A rich and continued roadmap of LTE Advanced Pro advancements is foundational to the 5G evolution.
Gigabit LTE delivers 2 Gbps now and is essential to 5G

LAA enables global deployments
Utilizing unlicensed spectrum for carrier aggregation

% of operators capable of achieving Gigabit LTE

- 16% Using licensed only* (60 MHz)
- 64% Using 20 MHz licensed + LAA
- 90% Using 10 MHz licensed + LAA

LTE infrastructure benefits 5G NR deployment
Co-siting with LAA small cells to achieve significant mmWave coverage

5G NR mmWave enables differentiating extreme mobile broadband services

5G NR mid-band further augments wide-area Gigabit-class capacity

Ubiquitous Gigabit LTE coverage

Qualcomm Snapdragon is a product of Qualcomm Technologies, Inc. and/or its subsidiaries 1. Based on the use of 4x4 MIMO and 256-QAM; 2. Based on mmWave coverage study, more details at https://www.qualcomm.com/documents/white-paper-5g-nr-millimeter-wave-network-coverage-simulation

Over 20 commercial devices, including smartphones, always connected PCs, and more...
Learn more at: https://www.qualcomm.com/gigabit-lte

Operators in 26 countries with Gigabit LTE planned or trialed

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LTE IoT will be the massive IoT solution in the 5G Era

Starting to connect the massive IoT today
With global commercial Cat-M1/NB1 network deployments

5G NR IoT fully leverages LTE IoT
Deploying eMTC and NB-IoT in-band with 5G NR

Flexible LTE IoT chipset platform for
Cat-M1 / Cat-NB1 / E-GPRS

Learn more at: https://www.qualcomm.com/lte-iot

- Global dual-mode solution — single SKU
- Pre-certified modules commercially available today
- Multiple design wins across industry-leading OEMs

Private LTE network addresses industrial IoT needs today

Optimizing LTE for the industrial IoT
Scalable from Gigabit LTE to LTE IoT

Paving the path to private 5G NR networks
Advanced capabilities in 3GPP Release 15 Study Items

- Ultra-reliable low-latency
- Time-sensitive networking
- mmWave for extreme eMBB
- Wireless industrial ethernet

Optimized
Tailored for industrial applications, e.g., QoS, latency, security
Learn more at: https://www.qualcomm.com/private-lte

Dedicated
Easy to deploy small-cells, hosted or self-contained core network

On-premise
Locally managed, sensitive data stays local
Learn more at: https://www.qualcomm.com/private-lte
Enhanced range and reliability for direct communication without network assistance

C-V2X
Establishes the foundation for safety use cases and a continued 5G NR C-V2X evolution for future autonomous vehicles

- V2V: Vehicle-to-vehicle
  e.g., collision avoidance safety systems

- V2I: Vehicle-to-infrastructure
  e.g., traffic signal timing/priority

- V2P: Vehicle-to-pedestrian
  e.g., safety alerts to pedestrians, bicyclists

- V2N: Vehicle-to-network
  e.g., real-time traffic/routing, cloud services

Learn more at: https://www.qualcomm.com/c-v2x
LTE Advanced Pro accelerates the 5G mobile expansion

Providing ubiquitous coverage and essential services that complement 5G NR
LTE IoT starts to connect the massive IoT and will be the 5G NR IoT solution

- Low complexity and power
- Long range
- Large scale
- In-band 5G NR deployment
LTE today provides a scalable IoT connectivity platform

<table>
<thead>
<tr>
<th>IoT gateways</th>
<th>Cameras</th>
<th>Industrial handhelds</th>
<th>Wearables</th>
<th>Vending machines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smartphones</td>
<td>Connected cars</td>
<td>Asset trackers</td>
<td>Health monitors</td>
<td>Security systems</td>
</tr>
</tbody>
</table>

LTE IoT: complementary narrowband technologies scaling down in complexity/power

<table>
<thead>
<tr>
<th>LTE Cat-1 and above</th>
<th>eMTC Cat-M1&lt;sup&gt;1&lt;/sup&gt;</th>
<th>NB-IoT Cat-NB1&lt;sup&gt;1&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>For high-performance IoT and eMBB – scalable to Gigabit LTE</td>
<td>For the broadest range of low-complexity IoT use cases</td>
<td>For delay-tolerant, ultra-low complexity IoT use cases</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Feature</th>
<th>eMTC Cat-M1&lt;sup&gt;1&lt;/sup&gt;</th>
<th>NB-IoT Cat-NB1&lt;sup&gt;1&lt;/sup&gt;</th>
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</thead>
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<tr>
<td>Peak data rate</td>
<td>Up to 1 Mbps&lt;sup&gt;2&lt;/sup&gt;</td>
<td>&lt;100 kbps</td>
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<tr>
<td>Bandwidth</td>
<td>1.4 MHz</td>
<td>200 kHz</td>
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<td>Rx antenna</td>
<td>Single Rx</td>
<td>Single Rx</td>
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<tr>
<td>Duplex mode</td>
<td>Full or half duplex FDD/TDD</td>
<td>Half duplex FDD</td>
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<tr>
<td>Mobility</td>
<td>Limited-to-full mobility</td>
<td>Cell reselection only</td>
</tr>
<tr>
<td>Voice</td>
<td>VoLTE</td>
<td>No voice support</td>
</tr>
<tr>
<td>Transmit power</td>
<td>23, 20 dBm&lt;sup&gt;3&lt;/sup&gt;</td>
<td>23, 20 dBm&lt;sup&gt;3&lt;/sup&gt;</td>
</tr>
<tr>
<td>Deployment</td>
<td>In-band</td>
<td>Standalone, in-band, guard band</td>
</tr>
</tbody>
</table>

1. Based on Release-13, Release 14 provides additional enhancements; 2. Full duplex mode, -300 kbps in half-duplex mode; 3. Integrated PA possible.
Strong global momentum for LTE IoT—May 2018 status
50+ commercial Cat-M1 and/or Cat-NB1 networks in over 30 countries

Sources: GSA NB-IoT/LTE-M: Global Market Status, Mar’18; AT&T, NTT DoCoMo, KDDI, KPN, Orange, TELUS, Telstra, Telefonica, Verizon, Feb.’17, Sprint May ‘17, Bell June ’17; SKT, Softbank, SFR from GSA 4G Market & Technology Update, Jan. ’17
Continued evolution to meet tomorrow’s massive IoT needs

Essential to 5G – LTE IoT to be submitted to meet IMT-2020 requirements

1. Defined in ITU Recommendation ITU-R M.2083-0, September, 2015; 2. Standardization in MulteFire Alliance
5G NR IoT to fully leverage the LTE IoT evolution

Enabled by in-band deployment of LTE IoT in 5G NR spectrum

**In-band eMTC / NB-IoT support in Rel-16**
5G NR 2ⁿ scaling of 15 kHz subcarrier spacing is natively compatible with eMTC and NB-IoT numerologies

**Agnostic to core networks**
Both 5G NR deployment options – NSA with LTE EPC and SA with 5G core – support eMTC and NB-IoT evolution

**Advanced features coming in Rel-16+**
Non-orthogonal access, grant-free uplink, and multi-hop mesh will deliver even better performance and efficiency

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1. Cat-M1 uses 6 Resource Blocks (RBs) with 12 tones per RB at 15 kHz SCS; 2. Cat-NB1 uses 1 Resource Block (RB) with 12 tones with 12 tones per RB at 15 kHz SCS, single-tone option also available

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**5G NR**
Flexible framework designed to support future evolution addressing even broader IoT use cases such as latency sensitive applications
Pioneering tomorrow’s massive IoT technologies
Applies to LTE IoT and 5G NR IoT evolution – potential for 3GPP Rel-16+

Non-orthogonal multiple access
Even higher connection density
- NOMA is part of 5G NR Rel-15 Study Item
- Can be either scheduled or grant-free
- Increases device density and network efficiency

Grant-free uplink
Autonomous mode transmission
- Contention-based access for IoT devices
- For sporadic uplink of small data bursts
- Also key enabler of mission-critical communication

Mesh networking
Multi-hop mesh with WAN management
- For low-power devices with challenging placements
- Especially uplink data relayed via nearby devices
- Expands on LTE Device-to-Device (D2D)

1. Greater range and efficiency when using licensed spectrum, e.g. protected reference signals. Network time synchronization improves peer-to-peer efficiency
Private LTE network enables optimized industrial IoT use cases

- Dedicated local network
- Customized services
- Ready for deployment
- Path to private 5G NR network
Providing a scalable platform for diverse IIoT use cases

Private LTE network
Optimized, dedicated, and locally managed network that scales from Gigabit LTE to LTE IoT

Low-complexity IoT
Mobility and VoLTE support based on eMTC Cat-M1; Ex: industrial wearables

Ultra-low complexity IoT
Deep coverage and long battery life
Based on NB-IoT Cat-NB1
Ex: environmental sensors

High-performance IoT and eMBB
Higher throughput, lower latency based on LTE Cat-1+
Ex: industrial AR goggles

Wide-area fallback
Public carrier LTE network
For wide-area coverage beyond areas served by private networks

Scalable from Gigabit LTE to LTE IoT
Private LTE Networks—an opportunity for mobile operators

**Licensed spectrum assets**
- Dedicate a portion for private LTE networks
- Provides predictable performance
- Spectrum often under-utilized in industrial areas

**Expertise in mobile networks**
- Expertise in deploying and operating mobile networks
- Existing relationships with vendors
- Leverage existing mobile network assets

**Existing sales channels**
- Already provide services to many industrial customers
- Extend with private LTE network
- Multiple options, including selling private LTE network as a service
Private 5G NR network enables the next Industrial Revolution

New capabilities
• URLLC – ultra-reliable, low-latency
• Time sensitive networking

Large cellular ecosystem
• Global solutions
• Certified interoperability

More spectrum
• Licensed, shared, unlicensed
• Low, mid, mmWave spectrum

Single network for the entire factory
• Multimode network supporting LTE & 5G NR
• Scalable to all connectivity needs

Cutting the cord
Wireless industrial ethernet enables reconfigurable factories

Leveraging big data analytics
Edge analytics of massive real-time data collection increases productivity

Enabling new use cases
Such as operators using Augmented Reality (AR) glasses

Enabling smart industry
C-V2X establishes the safety foundation for future autonomous vehicles

- Enhanced safety
- Low-latency and high-reliability
- Network-independent
- Forward compatible to 5G NR C-V2X
C-V2X enables network independent communication

Direct safety communication independent of cellular network
Low latency Vehicle to Vehicle (V2V), Vehicle to Infrastructure (V2I), and Vehicle to Person (V2P) operating in ITS bands (e.g. 5.9 GHz)

Direct PC5 interface
e.g. location, speed, local hazards

Network communications for complementary services
Vehicle to Network (V2N) operates in a mobile operator's licensed spectrum

Network Uu interface
e.g. accident 2 kilometer ahead

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1. PC5 operates on 5.9GHz; whereas, Uu operates on commercial cellular licensed spectrum. 2. RSU stands for roadside unit. 3. 3GPP also defines a mode, where eNodeB helps coordinate C-V2X Direct Communication; 4. GNSS is required for V2X technologies, including 802.11p, for positioning. Timing is calculated as part of the position calculations and it requires smaller number of satellites than those needed for positioning.
C-V2X has a strong evolution path towards 5G NR
While maintaining backward capabilities

Basic and enhanced safety
C-V2X Rel-14/Rel-15 with enhanced range and reliability

Basic safety
IEEE 802.11p

Evolution to 5G NR, while being backward compatible
C-V2X Rel-14 is necessary and operates with Rel-16

Autonomous driving use cases
5G NR C-V2X Rel-16
Backward compatible with Rel-14/Rel-15 enabled vehicles

Higher throughput
Higher reliability
Wideband ranging/positioning
Lower latency
5G NR C-V2X complements Rel-14 with new capabilities
Targeting new use cases for autonomous driving

Rel-14 C-V2X
Automotive safety

- Do not pass warning (DNPW)
- Intersection movement assist (IMA) at a blind intersection
- Blind curve / Local hazard warning

Rel-16 5G NR C-V2X
Autonomous driving

- Local high definition maps / “Bird’s eye view”
- Intention / Trajectory sharing
- High throughput sensor sharing
- Wideband ranging and positioning
LTE eMBMS/enTV is the 5G Broadcast solution

- High spectrum efficiency
- Scalable capacity
- For next-gen digital TV delivery
- Meets 5G broadcast requirements
LTE broadcast addresses a wide range of services

Two paths—mixed and standalone broadcasting

- **Mixed-mode broadcast**
  Dynamic mode switching between unicast and broadcast to more efficiently deliver identical content (e.g., OTA firmware update) over the network

- **Terrestrial broadcast**
  Dedicated broadcasting network that provides a common delivery platform for different contents and services (e.g., for next-gen digital TV)

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**LTE Broadcast evolution**
(Rel-14+)

Broadcast

Unicast

Broadcast only
Mixed-mode broadcast is essential to new mobile services
Enabling new capabilities and efficiencies for a wide variety of use cases

**LTE IoT**
3GPP Rel-14+

- Single-cell multicast to eMTC and NB-IoT devices
- Coexisting with LTE unicast services
- Enhancing SC-PTM\(^1\) to enable efficient firmware upgrade and group messaging

**C-V2X**
3GPP Rel-14+

- V2N communications for vehicles
- Also communicating directly via D2D in broadcast mode
- V2N builds upon eMBMS to deliver real-time information (e.g., traffic) to vehicles

**Public safety**
3GPP Rel-12+

- Broadcast to a wide variety of devices
- Also communicating directly via D2D broadcast
- Leveraging eMBMS to efficiently deliver real-time emergency notifications

**Venue broadcast**
3GPP Rel-9+

- Delivering shared content (e.g., instant replay)
- Dynamic broadcast can offload mass media traffic in high-density deployments

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1. Single cell point to multipoint defined in 3GPP Rel-13
Terrestrial broadcast for next-gen digital TV delivery

enTV\(^1\) – part of 3GPP Rel-14 – meets terrestrial TV broadcast requirements

### Radio access enhancements

- **Longer range**
  New 1-symbol numerology with longer 200us CP\(^2\) to support 15 km ISD\(^3\)

- **More broadcast capacity**
  Supports dedicated broadcast network with 100% eMBMS carrier allocation

- **More deployment flexibility**
  Single network for mobile and fixed devices with enhanced support for rooftop reception

- **Better efficiency**
  New subframe design reduces overhead in dedicated broadcast transmissions

### System layer enhancements

- **Receive only mode**
  Delivery of free-to-air content to devices without SIM/service subscription

- **Transport only service**
  TV broadcasters can deliver content in native format without transcoding

- **Standardized interface**
  Content providers can deliver media over LTE with a unified framework

- **Shared broadcast**
  Multiple operators can serve users on a common broadcast carrier

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1. Enhanced TV; 2. Cyclic Prefix; 3. Inter-site distance
enTV—a strong candidate for next-gen digital TV in Europe

Targeting deployments in re-farmed 700 MHz

Meeting all EU digital TV broadcast requirements

Regulation compliant
Allows frequency reuse and adheres to ITU-GE-06 to protect existing DTT services

Wide-area coverage
Provides at least 50% edge coverage for fixed TV and 95% area coverage for mobile TV

Diverse services
Supports free-to-air content delivery, paid media streaming, as well as applications

Diverse deployments
Supports fixed (e.g., rooftop) and mobile (e.g., smartphone) receptions in a common spectrum allocation

1. ~2x more efficient than DVB-T/ATSC and provides longer range up to 15km (with further extended CP of 200 us and features such as 2x2 MIMO, 256 QAM, increased subframe limit); Assumptions: current broadcast technology operates in MFN mode with a frequency reuse of at least four with a spectrum efficiency of up to 4 bps/Hz inside each cell. This corresponds to an overall spectrum efficiency of approx. 1bps/Hz. Whereas eMBMS operates in SFN over the entire coverage area with a spectrum efficiency of up to 2bps/Hz; 2. Digital Terrestrial TV; 3. With margin for 1% time co-channel interference; 4. Can be video, audio, text, etc.
LTE eMBMS/enTV is the 5G broadcast solution
Building upon a strong 3GPP technology foundation

- eMBMS defined for LTE starting in Rel-8, improving coverage and efficiency
- eMBMS enhancements in Rel-12 include MOOD$^2$ and expansion to MCPTT$^3$
- Enabling terrestrial broadcast and expanding to new services; Meeting 7/10
- 5G Broadcast requirements$^4$ in Rel-14
- Further enhancements$^5$ to fully satisfy 5G broadcast requirements

1. 3GPP Rel-8 defined physical layer aspects, Rel-9 defined higher layer and network related aspects; 2. Multicast operation on Demand in Rel-12, evolving for per cell basis in Rel-13; 3. Mission-critical Push to Talk is part of Rel-12; 4. 5G broadcast requirements defined in 3GPP TS 38.913; 5. Such as wider area coverage up to 100 km cell radius, more efficient multiplexing with unicast, and utilizing MIMO.
Accelerating cellular drone communications technology

Completed OTA testing over commercial LTE networks and 3GPP Study Item in 2017

Optimize LTE for drones in Rel-15
Better mobility and interference management for high-altitude operation

Guide cellular drone regulations development
For command and control, subscription verification, certification, and more

Accelerate 5G development
Specifically for massive deployments of mission-critical drone use cases

Learn more at: http://www.qualcomm.com/cellular-drones
Gigabit LTE is here now and delivers a seamless 5G mobile experience

Global deployments today
Enabling next-gen mobile broadband
Evolving to 2Gbps
Essential to 5G NR eMBB
Gigabit LTE provides the coverage foundation for 5G
Spectrum aggregation with 5G NR to fully leverage LTE investments

**Existing deployments**
- Ubiquitous LTE coverage
  - 640+ Commercial networks
  - 9,500+ Commercial devices
  - 2.3B+ LTE/LTE-A subscriptions

**Seamless mobility**
- Simultaneous dual-connectivity across 5G NR and 4G LTE

**5G augmented deployments**
- Gigabit LTE, VoLTE
  - 5G NR below 10 GHz
  - 5G NR above 10 GHz

- 5G NR mmWave

Enabling gigabit experiences everywhere
Providing VoLTE leveraging LTE’s ubiquitous coverage
Supplementing 5G NR mid-band and mmWave

Gigabit LTE enables a more consistent 5G experience

Optimizing existing LTE networks to deliver faster throughput and more capacity

Faster experienced user throughput\(^1\)

- +164%
  - 108 Mbps
  - 285 Mbps

More capacity with fewer licensed resources\(^2\)

- -76%
  - Licensed carriers
  - Unlicensed carrier 1
  - Unlicensed carrier 2
  - Unlicensed carrier 3

Higher spectral efficiency\(^3\)

- +32%
  - Near cell: 117 Mbps
  - Mid cell: 154 Mbps
  - Far cell: 117 Mbps

Based on real-world Gigabit LTE network testing by Signals Research Group


1. Based on Google Play download; 2. Using 20 MHz licensed carrier and 60 MHz unlicensed carriers, 4x4 MIMO, 256-QAM; 3. RB normalized data rates, RSRP assumptions: far cell - > -85 dBm; mid cell - < -85 dBm & > -100 dBm; far cell - < -100 dBm
Gigabit LTE continues to evolve in multiple dimensions

- **Carrier aggregation (CA) evolution**
  Aggregating more carriers across diverse spectrum
  - Higher peak rate up to 2 Gbps

- **Higher-order modulation**
  Introducing 1024-QAM in downlink and 256-QAM in uplink
  - More capacity and higher peak rate

- **Enhanced LAA (eLAA)**
  Even better use of spectrum and foundational to 5G NR SS
  - More capacity

- **Evolving to massive MIMO**
  3D beamforming and a testbed for 5G NR massive MIMO
  - More capacity and better uniformity

- **Ultra-low latency**
  New FDD/TDD design to reduce round trip time (RTT)
  - Improved throughput and real-time performance
Achieving peak throughputs up to 2 Gbps

Higher peak rates by adding more, higher-efficiency ~100 Mbps streams\(^1,2\)

Utilizing higher-order modulation (e.g., 256-QAM and beyond)

Adding up to 4 MIMO layers

Aggregating more carriers across licensed and unlicensed with LAA\(^3\)

New Gigabit LTE device categories

- Category 20 (2.0 Gbps)
- Category 19 (1.6 Gbps)
- Category 18 (1.2 Gbps)
- Category 16 (1 Gbps)

1. Example configuration per 3GPP specification; 2. Each data stream ~100 Mbps per 20 MHz stream with 256-QAM; 3. Licensed Assisted Access
Which Chipsets support Gigabit LTE?

Portfolio of Gigabit LTE Products

1\textsuperscript{st} Gigabit LTE Generation

1. Qualcomm Snapdragon X16 LTE modem
   - 4xCA
   - 1.0 Gbps
   - 10 streams

2\textsuperscript{nd} Gigabit LTE Generation

1. Qualcomm Snapdragon X20 LTE modem
   - 5xCA
   - 1.2 Gbps
   - 12 streams

3\textsuperscript{rd} Gigabit LTE Generation

1. Qualcomm Snapdragon X24 LTE modem
   - 7xCA
   - 2.0 Gbps
   - 20 streams

Qualcomm Snapdragon is a product of Qualcomm Technologies, Inc. and/or its subsidiaries
Our best LTE modem yet - unprecedented user throughput enabling breakthrough mobile performance

World’s first announced 2 Gbps LTE modem
Breakthrough mobile user experience

World’s first announced 7nm Chip
Lower power, smaller footprint*

World’s first announced 14nm RF Chip
Better power efficiency*

World’s first announced 7x Carrier Aggregation
Expanded Gigabit footprint

*Compared to larger feature-size fabrication processes.
Snapdragon X24: Full utilization of operator spectrum

7xCA and 20 spatial streams allow wider variety of ways to deploy Gigabit LTE

More advanced modem allows operator to tap into all existing spectrum resources, and add more capacity via LAA.
Snapdragon X24: Full utilization of operator spectrum

7xCA and 20 spatial streams allow wider variety of ways to deploy Gigabit LTE

More advanced modem allows operator to tap into all existing spectrum resources, and add more capacity via LAA.
Snapdragon X24: Full utilization of operator spectrum

7xCA and 20 spatial streams allow wider variety of ways to deploy Gigabit LTE

More advanced modem allows operator to tap into all existing spectrum resources, and add more capacity via LAA.

Operator A with Snapdragon X24
Boosting the speed through unlicensed spectrum

20 Layers | 7 Carriers | 2.0 Gbps

Unlicensed Spectrum
Delivering new levels of performance and efficiency
Also enabling a more consistent 5G experience when 5G NR rolls out

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**Frankfurt**
Gigabit LTE vs. Cat-12
Macro + small cells

- ~3x increase in burst rate
- ~2.8x faster responsiveness
- ~2x higher spectral efficiency

**San Francisco**
Gigabit LTE vs. Cat-12
Macro + small cells

- ~3.2x increase in burst rate
- ~4x faster responsiveness
- ~2.2x higher spectral efficiency

Source: Company data and internal analysis
Frankfurt: B3 (4x4), B7 (4x4), B20, B28, B32; San Fran: B2 (4x4), 2xB66 (4x4), B12, B71, 4xB46 LAA
5G NR Rel-15\textsuperscript{1} eMBB expands to new spectrum bands

5G spectrum – low, mid, and high

Scalable numerology to support a wider range of spectrum bands

![Diagram of 5G spectrum bands]

- **Low bands**: Re-farmed for mobile, e.g., 600 GHz in US and 700 MHz in EU
- **Higher mid-bands**: New bands opening for eMBB, e.g., 3.5 GHz in US/EU
- **Rel-15 mmWave bands**: Enabling extreme mobile broadband, e.g., 28/39 GHz
- **Rel-16+ mmWave bands**: Even more mmWave bandwidth up to ~100 GHz

**New mid-band spectrum**

Expanding to new frequency bands leveraging existing cell sites

**mmWave spectrum**

LTE/5G NR in existing low/mid bands provides the anchor

**Excels in wider bandwidths**

Improved performance, efficiency, and ability to leverage even more antennas

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\textsuperscript{1} 3GPP Rel-16+ will bring continued eMBB evolution, plus new features for massive IoT and mission-critical
Significant 5G NR mmWave coverage via co-siting
Simulations based on extensive over-the-air testing and channel measurements

28 GHz downlink coverage %
Co-siting with LTE

<table>
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<tr>
<th>Site density (per km²)</th>
<th>Total</th>
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<th>Korea City 2</th>
<th>Hong Kong</th>
<th>Japan City 1</th>
<th>LVCC Venue</th>
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<tbody>
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<td>28 GHz coverage %</td>
<td>81%</td>
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<td>49%</td>
<td>49%</td>
<td>41%</td>
<td>81%</td>
<td>74%</td>
<td>76%</td>
<td>66%</td>
<td>85%</td>
</tr>
</tbody>
</table>

Co-siting with LTE
Leveraging LAA small cells used for Gigabit LTE to deliver significant 5G NR mmWave coverage

LAA vs. 28 GHz coverage

Source: Qualcomm Technologies, Inc. 5G NR mmWave Network Coverage Simulation;
1. Link budget based on assumptions; additional variations possible due to temporary blockage—field measurements to follow; 2. Target spectral efficiency of 0.4 bps / Hz
Industry-first simulation of real world performance reveals immense 5G user experience gains over 4G

Frankfurt
5G NR multi-mode
3.5GHz (sub-6GHz)

5x increase in capacity
>490 Mbps median browsing speed
~7x faster responsiveness

San Francisco
5G NR multi-mode
28GHz mmWave

5x increase in capacity
1.4 Gbps median browsing speed
~23x faster responsiveness

Source: Company data and internal analysis
Frankfurt: 3.5 GHz 5G NR + Gigabit LTE multimode vs. Gigabit LTE
San Francisco: 28 GHz 5G NR + Gigabit LTE multimode vs. Gigabit LTE
Anyone can talk about 5G. We are making it a reality.
Learn more at www.qualcomm.com/5G

Qualcomm

5G NR

Enhanced Mobile Broadband
Mission-critical services
Massive Internet of Things
We have led the evolution and expansion of LTE
Our fundamental systems-level inventions are leading the world to 5G

Leading in 5G requires

4G LTE Leadership

- Carrier aggregation
- Hybrid ARQ
- CoMP
- CSFB
- LTE Broadcast (eMBMS)
- Handover procedure
- Lower power consumption technologies, e.g. DTX/DRX
- Small cell self-configuration techniques
- Fast link adaptation
- LTE-U/LAA/eLAA
- Small cells interference management
- Advanced MIMO technologies, e.g. UL MIMO
- OFDMA, SC-FDMA waveforms
- MulteFire
- LWA
- LTE Direct and C-V2X
LTE is essential in enabling early NSA 5G NR deployments

Non-Standalone (NSA) leverages LTE RAN and EPC for coverage and mobility, while introducing 5G NR to enhance the user plane performance and efficiency.
Accelerating 5G NR to meet the ever-increasing global demand for mobile broadband

- **R14 study items**
- **R15 5G NR study items**
- **R16+ 5G NR study items**
- **R15 5G work items**
- **R16 5G work items**
- **R17+5G evolution**

**5G NR Standalone (SA) mode**

**5G NR Non-Standalone (NSA) mode**

**We are here**

Enabling eMBB deployments starting in 2019

- **Gigabit LTE and eMTC / NB-IoT deployments**
- **Continue to evolve LTE in parallel to become a critical part of the 5G Platform**

**Timeline:**
- 2016
- 2017
- 2018
- 2019
- 2020
- 2021
- 2022

1. Forward compatibility with R16 and beyond
3GPP Rel-15 establishes a solid foundation for 5G NR

For enhanced mobile broadband and beyond

Scalable OFDM-based air interface
Flexible slot-based framework
Advanced channel coding
Massive MIMO
Mobile mmWave

Scalable OFDM numerology
Self-contained slot structure
ME-LDPC and CA-Polar
Reciprocity-based MU-MIMO
Beamforming and beam-tracking

Efficiently address diverse spectrum, deployments and services
Key enabler to low latency, URLLC and forward compatibility
Efficiently support large data blocks and a reliable control channel
Efficiently utilize a large # of antennas to increase coverage / capacity
Enables wide mmWave bandwidths for extreme capacity and throughput

Our technology inventions are driving Rel-15 specifications

Early R&D investments | Best-in-class prototypes | Fundamental contributions to 3GPP
Learn more at: https://www.qualcomm.com/5gnr

1. Multi-Edge Low-Density Parity-Check and CRC-Aided Polar
Making 5G NR a commercial reality for 2019
For standard-compliant networks and devices

Best-in-class 5G prototype systems
Designing and testing 5G technologies for many years

5G NR standards and technology leadership
Our technology inventions are driving the 5G NR standard

5G NR interoperability testing and trials
Leveraging prototype systems and our leading global network experience

Modem and RFFE leadership
Announced the Qualcomm Snapdragon X50 5G modem family

LTE foundational technologies
LTE Advanced Pro accelerates the 5G mobile expansion

- Gigabit LTE
- Unlicensed/Shared spectrum
- Private LTE networks
- LTE IoT
- Automotive (Cellular-V2X)
- Digital broadcast
- Public safety and emergency services

LTE IoT, private LTE network, C-V2X are enabling new mobile use cases today

Gigabit LTE is here now and delivers a seamless 5G mobile experience

LTE will be submitted with 5G NR to meet IMT-2020 requirements

5G NR will fully leverage LTE investments and enable a phased roll-out
Thank you!

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