Leading the LTE IoT evolution to connect the massive Internet of Things
At the heart of the IoT ecosystem

Delivering heterogeneous connectivity powered by global standards

Qualcomm

5G NR
4G LTE
Wi-Fi
Bluetooth

NFC
15.4
GNSS
Powerline

Trillions of connected things
Massive amount of data
Cellular technologies enable a wide range of IoT services
Bringing significant value for LPWA\(^1\) use cases over non-3GPP solutions

1. Low-power, wide-area; 2. Including cellular and LPWA M2M connections, Machina Research, June, 2018
LTE today provides a scalable IoT connectivity platform

1. Based on Release-13, Release 14 provides additional enhancements; 2. Full duplex mode, ~300 kbps in half-duplex mode; 3. Integrated PA possible

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<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>
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<tbody>
<tr>
<td><strong>For high-performance IoT and eMBB – scalable to Gigabit LTE</strong></td>
<td><strong>For the broadest range of low-complexity IoT use cases</strong></td>
<td><strong>For delay-tolerant, ultra-low complexity IoT use cases</strong></td>
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<td><strong>Deployment</strong></td>
<td>In-band</td>
<td>Standalone, in-band, guard band</td>
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1. Based on Release-13, Release 14 provides additional enhancements; 2. Full duplex mode, ~300 kbps in half-duplex mode; 3. Integrated PA possible
Massive scale
To efficiently support dense connections of 1+ million devices/km²

Power efficient
To realize 10+ year device battery life and 100x network energy efficiency

Long range
To reach challenging locations by achieving device link budget of 164 dB

Extreme simplicity
To allow scaling to the lowest-end use cases with e.g., single Rx antenna

Scaling for the massive Internet of Things

Addressing growing needs of low-power, wide-area IoT use cases

1. Maximum Coupling Loss, assuming data rate of 160bps
2. Assuming 200B UL + 20B DL per day at 164 MCL with 5Wh battery
3. Compared to IMT-Advanced
LTE IoT starts to connect the massive IoT today
Complemented with early 5G NR eMBB deployments starting in 2019

1. Enhanced Mobile Broadband; 2. Ultra-reliable, low-latency communications; 3. 3GPP also defining new 5G core network that will support continued eMTC and NB-IoT evolution

Complementary use cases
5G NR Rel-15 focuses on eMBB and high-performance IoT; LTE IoT addresses the massive IoT with in-band 5G NR deployment in Rel-16

Leveraging LTE’s global footprint
LTE IoT leverages existing LTE infrastructure & coexist with other services such as Gigabit LTE – the anchor to the 5G experience
LTE IoT starts to connect the massive IoT today
50+ commercial Cat-M1 and/or Cat-NB1 networks in over 30 countries

- Wearables
- City infrastructure
- Energy management
- Cat-M1 (eMTC)
  - Higher throughput, mobility, VoLTE
- Cat-NB1 (NB-IoT)
  - Lower cost, larger coverage, 2G migration
- Utility metering
- Environment monitoring
- Object tracking
- Smart buildings
- Connected health care
- Voice (VoLTE)

MDM9206
Flexible LTE IoT chipset platform for Cat-M1 / Cat-NB1 / E-GPRS

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

Qualcomm MDM9206 is a product of Qualcomm Technologies, Inc. and/or its subsidiaries
Sources: GSA NB-IoT and LTE-M: Global Market Status, March, 2018
Continued evolution to meet tomorrow’s massive IoT needs

Essential to 5G – LTE IoT to be submitted to meet IMT-2020\textsuperscript{1} 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

Flexible framework designed to support future evolution addressing even broader IoT use cases such as latency sensitive applications

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

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
Pioneering tomorrow’s massive IoT technologies
Applies to LTE IoT and 5G massive 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
Expanding into new areas requires system leadership
The ability to drive an end-to-end design across multiple 3GPP Working Groups

Each new area requires creating a new sub-system built on top of “baseline”
Adjusting, optimizing, and redesigning procedures across all layers to address the new requirements
Leading the LTE IoT evolution to connect the massive IoT

LTE IoT starts to connect the massive IoT today
Complemented with initial 5G NR eMBB deployments

Continued LTE IoT evolution is broadening use cases
A rich technology roadmap for tomorrow’s massive IoT and expansion into unlicensed spectrum

We are driving broad ecosystem adoption of LTE IoT
Strong global momentum with our multi-mode commercial solution
Continued LTE IoT evolution is broadening use cases

A rich technology roadmap for tomorrow’s massive IoT and expansion into unlicensed spectrum
LTE IoT evolution builds on a shared foundation
Also expanding into unlicensed spectrum for new use cases

Operation in licensed spectrum only

Release 13

- eMTC
- Shared foundation
  - Such as single Rx, half-duplex, PSM, eDRx, TTI bundling, overload control, overhead optimization

Release 14

- More shared improvements
  - Such as multicast, positioning, larger transport block, more HARQ's

Release 15+

- Further shared enhancements
  - Such as wake-up radio and early data transmission

Operation in unlicensed spectrum

MulteFire Alliance standardization
Adapts LTE IoT for unlicensed spectrum to broaden IoT capabilities, e.g., for private networks

Additional MulteFire capabilities
Leverages further LTE IoT enhancements standardized by 3GPP

5G
Delivering new efficiencies for the massive IoT

**Extreme simplicity**
- Reducing complexity
  - Narrowband operation (down to 180 kHz) plus further device and core network complexity reductions

**Ultra energy efficiency**
- Lowering power consumption
  - Enhanced power save modes (PSM) and more efficient signaling, e.g., extended DRX (eDRx) sleep cycles

**Ubiquitous coverage**
- Deepening coverage
  - Up to 20 dB link budget increase for hard-to-reach locations via redundant transmissions and more

**Massive scale**
- Increasing device density
  - Signaling & network optimizations, e.g., overload control, to support a large number of devices per cell

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Shared eMTC and NB-IoT foundation
Such as single Rx antenna, half-duplex, PSM, eDRx, TTI bundling, overload control, overhead optimizations, etc.
Reducing complexity: start supporting narrowband operation
To enable low-cost modules optimized for small, infrequent data transmissions

<table>
<thead>
<tr>
<th></th>
<th>LTE Cat-1 (Rel-8)</th>
<th>eMTC Cat-M1 (Rel-13)</th>
<th>NB-IoT Cat-NB1 (Rel-13)</th>
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1. Single Rx added in Rel-14; 2. Full duplex mode, ~300 kbps in half-duplex mode; 3. Integrated PA possible

Reduces baseband/RF complexity and decreases memory
Lowering power: achieve 10+ year device battery life
For eMTC and NB-IoT, allowing devices wake up on a per-need basis

Power save mode (PSM)
Eliminates page monitoring between data transmissions for device-originated or scheduled applications, e.g., smart metering, environmental monitoring

Extended discontinuous receive (eDRx)
Extends time between monitoring for network messages for device-terminated applications, e.g., object tracking, smart grid

Also features such as reduced complexity and overhead optimizations extend battery life

Note: PSM and eDRx applicable to both eMTC & NB-IoT, may also be applied to LTE Cat-1 and above
1. Rel-13 includes less channel measurements, Rel-15 includes semi-persistent scheduling, data transmission during random access, faster RRC release, relaxed monitoring for cell reselection, and more
Deepening coverage: provide ubiquitous IoT connectivity
To reach the most challenging locations, e.g., penetrating more walls and floors

1. Link budget; 2. At least for standalone operation mode; 3. Transmission Time Interval; 4. Quadrature Phase Shift Keying

NB-IoT enhancements
• Further relaxed timing requirements
• Lower-order modulation, e.g., QPSK
• Single-tone UL transmissions

eMTC and NB-IoT enhancements
• Repetitive transmissions
• TTI bundling

LTE Cat-1 and above
Baseline 140.7 dB

eMTC Cat-M1
>155.7 dB

NB-IoT Cat-NB1
164 dB or better

Trading off spectral efficiency and latency

1. Link budget; 2. At least for standalone operation mode; 3. Transmission Time Interval; 4. Quadrature Phase Shift Keying
Increasing density: optimize for better network efficiency

**More efficient signaling**
To support a larger number of devices per cell with new features such as group-based paging, messaging, and improved load management.

**Simplified core network (EPC-lite)**
Reduced functionality, e.g., no/optional voice, limited mobility, optional optimizations that integrate network functions into a single entity.

**Enhanced resource management**
Such as optimizations to allow a large set of devices to share the same subscription, e.g., all the water meters in a city.
Coexist with today’s mobile broadband services
Flexible deployments in FDD & TDD\(^1\); leveraging existing infrastructure & spectrum

**In-band**
- eMTC
- NB-IoT
- Regular LTE Data

- eMTC reuses LTE sync.
- NB-IoT utilizes 1 RB (180 kHz) within a normal LTE carrier

**Guard-band**
- NB-IoT
- Regular LTE Data
- Utilizing unused resource blocks within a LTE carrier’s guard-band

**Standalone**
- NB-IoT
- 2G/GPRS
- Utilizing standalone 200 kHz carrier, e.g., re-farming spectrum currently used by 2G/GPRS

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1. NB-IoT support in TDD proposed in Rel-15; 2. Center 6 Resource Blocks; 3. Resource Block
### A rich roadmap of enhancements in 3GPP Rel-14 & 15

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
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</table>
| **eMTC** | **Enhancing VoLTE**<sup>1</sup>  
Providing location services  
Supporting wider bandwidth, e.g., 5 MHz, and more<sup>1</sup>  
| **Better mobility** | Full support for inter-frequency measurements<sup>1</sup> and higher velocity in extended coverage<sup>1</sup> |
| **eMTC and NB-IoT** | **Single-cell multicast**<sup>1</sup>  
Efficient OTA firmware update for large number of devices  
**Device positioning**<sup>1</sup>  
Providing location services for e.g., asset tracking and eCall  
**Higher data rate**<sup>1</sup>  
Supporting wider bandwidth, e.g., 5 MHz, and more<sup>1</sup> |
| | **Lower latency**  
More HARQ processes<sup>1</sup>, faster system acquisition<sup>1</sup>, early data transmission<sup>1</sup> |
| | **Energy reduction**  
Wake-up radio for low-power channel monitoring<sup>1</sup> and lower transmit power classes<sup>1</sup> |
| | **Higher density support**<sup>1</sup>  
Improved load control with level-based access class barring |
| **NB-IoT** | **Cell size extension**<sup>2</sup>  
Additional cyclic prefixes to support cell radius of at least 100km  
| **TDD support**<sup>2</sup> | For deployment in higher TDD bands, also further optimizing for small cells |

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1. Rel-14 feature; 2. Rel-15 feature; 3. eMTC adds support for 5 MHz, larger TBS, more HARQ processes, eNB-IoT increases TBS and HARQ process; 4. Also relaxed monitoring for cell reselection, semi-persistent scheduling, quicker RRC release in Rel-15; 5. eNB-IoT adds 14 dBm in Rel-14, lower transmit power proposed for eFeMTC in Rel-15.
New device categories to address broader IoT use cases
Evolving to deliver faster peak rates, new capabilities, and efficiency optimizations

Rel-13
- eMTC evolution
  - Cat-M1
    - 1.4 MHz carrier bandwidth
    - Peak rate: DL ~300 kbps; UL ~375 kbps
    - Supporting limited-to-full mobility, VoLTE
  - Cat-NB1
    - 200 kHz carrier bandwidth
    - Peak rate: DL ~20 kbps; UL ~60 kbps
    - Supporting cell re-selection only

Rel-14
- eMTC evolution
  - Cat-M2
    - 5 MHz carrier bandwidth
    - Peak rate: DL ~2.4 Mbps; UL ~2.6 Mbps
    - Enhanced mobility and half-duplex voice
    - Supporting positioning and single-cell multicast
  - Cat-NB2
    - Peak rate: DL ~120 kbps; UL ~160 kbps
    - Supporting positioning and single-cell multicast
    - Energy/latency optimizations

Cat-M1
- 1.4 MHz carrier bandwidth
- Peak rate: DL ~300 kbps; UL ~375 kbps
- Supporting limited-to-full mobility, VoLTE

Cat-M2
- 5 MHz carrier bandwidth
- Peak rate: DL ~2.4 Mbps; UL ~2.6 Mbps
- Enhanced mobility and half-duplex voice
- Supporting positioning and single-cell multicast

Cat-NB2
- Peak rate: DL ~120 kbps; UL ~160 kbps
- Supporting positioning and single-cell multicast
- Energy/latency optimizations

Cat-NB1
- 200 kHz carrier bandwidth
- Peak rate: DL ~20 kbps; UL ~60 kbps
- Supporting cell re-selection only

5G
- 5 MHz carrier bandwidth
- Peak rate: DL ~2.4 Mbps; UL ~2.6 Mbps
- Enhanced mobility and half-duplex voice
- Supporting positioning and single-cell multicast

1. Based on 4008b UL/DL TBS, 10 HARQ’s & ACK bundling; 2. Half-duplex; 3. Half-duplex, increase UL TBS to 2984b from 1000b, HARQ’s from 8 to 10, & ACK bundling; 4. Increase DL/UL TBS from 600/1000b to 2536b, HARQ’s from 1 to 2.
Enabling IoT device positioning with OTDOA\textsuperscript{1}
First introduced in Rel-9 for LTE; adapted for LTE IoT in Rel-14

Key enabler for new use cases
Such as asset tracking and eCall services that require always-available device locations

Complements satellite positioning
To provide location services in challenging NLOS\textsuperscript{2} settings, such dense urban or inside buildings

Optimized for LTE IoT\textsuperscript{3}
Utilizing a narrower bandwidth PRS\textsuperscript{4} with higher repetition factors that extends range

Download Qualcomm Technologies whitepaper for more information: https://www.qualcomm.com/documents/otdoa-positioning-3gpp-lte

Efficiently communicating with IoT devices using multicast
Extending SC-PTM\(^1\) defined in Rel-13 to LTE IoT in Rel-14

- **eMTC**
  - Single-cell multicast (e.g., group messaging)

- **NB-IoT**
  - Single-cell multicast (e.g., firmware upgrade)

Coexisting with LTE unicast services

**Easy firmware upgrades**
Eliminates expensive truck roll maintenance of deployed devices (e.g., environmental sensors)

**Longer battery life**
Simplified control protocol that reduces amount of time devices need to be awake

**More capacity**
Efficient use of network resources by serving a group of devices simultaneously
Small cells bring many benefits for the IoT
Supported by LTE IoT today with further enhancements proposed in Rel-151

- Improved coverage: Bringing the network closer for deeper reach indoors and more reliable connectivity
- Longer battery life: Allowing devices to reduce uplink transmit power, minimizing overall power consumption
- More deployment options: Leveraging neutral hosts to provide IoT connectivity in shared/unlicensed spectrum (e.g., MulteFire)

Venues | Industrial | Residential | Enterprise/Buildings | Cities

1. With new eNB classes and support for CSG (Closed Subscribers Group)
Private LTE network addresses industrial IoT needs today

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

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

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

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

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

Optimized
Tailored for industrial applications, e.g., QoS, latency

Dedicated
Local network, easy to deploy independently managed

Secure
Industrial grade security with LTE and 5G NR

Learn more at: https://www.qualcomm.com/private-lte
Support for multi-hop mesh with WAN management
Advanced massive IoT design for 3GPP Rel-16+

1. Greater range and efficiency when using licensed spectrum, e.g. protected reference signals. Network time synchronization improves peer-to-peer efficiency

Problem: Uplink coverage
Due to low power devices and challenging placements, in e.g. basement

Solution: Managed uplink mesh
Uplink data relayed via nearby devices – uplink mesh but direct downlink.
NOMA\(^1\) for efficient IoT communications

Characterized by small data bursts in uplink where signaling overhead is a key issue

**Grant-free transmission of small data exchanges**

- Eliminates signaling overhead for assigning dedicated resources
- Allows devices to transmit data asynchronously
- Capable of supporting full mobility
- Technically feasible for LTE IoT, but requires spec. formalization

**Increased battery life**

**Scalability to even higher device density**

**Better link budget**

1. Non-orthogonal multiple access
We are driving broad ecosystem adoption of LTE IoT

Strong global momentum with our multi-mode commercial solution - MDM9206
Mobile technology drives the IoT

Building on our leadership in mobile inventions
We have an end-to-end platform approach to the IoT
For massive scale deployment and quicker time-to-market

- **Simplified device development**
  Reference platforms that include hardware & software; pre-certified modules & devices

- **Simplified application development**
  Standardized communication protocols for interoperability & security; e.g., oneM2M

- **Simplified deployment/management**
  Full-stack IoT solution that provides data analytics, device management, and more; e.g., Verizon ThingSpace
MDM9206 delivers a **Global narrowband solution for the IoT**

**One hardware design**
Supporting multi-mode for Cat-M1, Cat-NB1, E-GPRS with integrated GNSS and VoLTE

**One software image**
Supporting dynamic mode selection with flexible configuration, e.g., Cat-M1 only/preferred, or Cat-NB1 only/preferred

**One RF**
15 LTE bands that cover virtually all of the world (B1-5, B8, B12-13, B17-20, B26, B28, B39)

Single SKU for diverse deployment needs of carriers/end-users worldwide

MDM9206 is a product of Qualcomm Technologies, Inc.

**Highly cost-effective**

**Fast commercialization**

**Futureproof with OTA upgrade**
Global multi-mode Cat-M1/NB1 most optimal approach
Combining the benefits of both technologies to address full range of use cases
Improved OEM profitability with global SKU

Global multimode offers superior overall device economics

**Total cost of ownership**
- Lower R&D and engineering costs
- Lower manufacturing overhead
- Simpler supply chain
- Lower inventory management costs

**Time to global launch**
- Potentially larger market share
- Potentially higher ASPs for longer

**De-risk EOL inventory**
- Higher forecasting accuracy
- Cost-effective SW-based repurposing of unsold inventory

**Higher return on R&D**
- Reduce R&D bottleneck from variant support
- Shift development resources to next-gen innovation
Driving broad ecosystem adoption of LTE IoT
Enabling global deployments today

MDM9206
Flexible LTE IoT chipset platform for Cat-M1, Cat-NB1, E-GPRS

- Multiple design wins across leading module OEMs and operators
- Announced support for Verizon ThingSpace Platform with modules from Quectel and Telit in Jan. 2017
- Jointly demonstrated the performance of a successful IoT VoLTE call with Ericsson and AT&T in Feb. 2017
- Announced 1st multi-mode trial with Mobike and China Mobile, May 2017
- Pre-certified for major global mobile operators that shortens time-to-market

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Strong global momentum for LTE IoT—July 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
Bringing new levels of HW-based security to IoT devices

MDM9206 security foundations

**Qualcomm Trusted Execution Environment**
- Isolates secure and non-secure software operations
- Small code base, rigorously reviewed
- Based on ARM’s TrustZone architecture

**Secure Boot**
- Deters unauthorized code execution
- Tamper resistant root of trust in ROM or e-fuses

**Wireless Protocol Security**
- WAN security and TLS to protect data-in-transit

**Hardware Crypto**
- FIPS certifiable cryptographic engines
- HW Keys for more robust and fast encrypt/decrypt operations

**Secure Storage**
- OTP eFuse memory for storage of keys and configurations
- Encrypted storage capable

**Secure and Key Provisioning**
- Provisioning of Keys

**Secure Debug**
- Prevents JTAG debugger connection in commercial products and reverse engineering
- Set by e-fuse, with support for secure RMA

DISCLAIMER: Reference to “secure” features and functions do not imply total impenetrability.
Delivering a scalable roadmap across all tiers and segments
LTE from gigabit to micro-amp

Scaling up in performance and mobility

Core

IoT-optimized modems

Cat-18
Next-gen Gigabit LTE

Cat-16
Fiber-like experience

Cat-12
Redefining mainstream

Cat-6
Entry-level MBB

Cat-4
High-end IoT

Cat-1
Cost-efficient, low power, scalable for IoT

Cat-M1/NB1
Ultra-low power, long battery life, extended coverage

Scaling down in complexity and power

Note: Showing DL UE categories. Qualcomm Snapdragon is a product of Qualcomm Technologies, Inc.
Leading the LTE IoT evolution to connect the massive IoT

- LTE IoT starts to connect the massive IoT today
- Continued LTE IoT evolution is broadening use cases
- We are driving broad ecosystem adoption of LTE IoT

Learn more at:
https://www.qualcomm.com/invention/5g/internet-of-things
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world.qualcomm.com & world.qualcomm.com/blog

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