Leading the LTE IoT evolution to connect the massive Internet of Things

Qualcomm Technologies, Inc.
June, 2017
We are at the heart of the IoT ecosystem

Creating a connectivity fabric for everything

To support the wide range of IoT use cases with varying requirements
Cellular technologies enable a wide range of IoT services

Bringing significant value for LPWA use cases over non-3GPP solutions

- Smart cities
- Mobile health
- Smart utilities
- Environmental monitoring
- Connected building
- Connected industrial
- Connected retail
- Asset tracking

>5B
IoT connections by 2025

Always-available, ubiquitous connectivity
Mature, interoperable global ecosystem
Scalable performance
Seamless coexistence of different services
High reliability and proven security

1. Low-power, wide-area; 2. Including cellular and LPWA M2M connections, Machina Research, May, 2017
LTE today provides a scalable IoT connectivity platform

- **LTE Cat-1 and above**
  - Delivering scalable performance and seamless mobility for high-performance IoT use cases

- **eMTC\(^1\) Cat-M1**
  - Optimizing for the broadest range of IoT applications with high-reliability and lower latencies

- **NB-IoT\(^2\) Cat-NB1**
  - Providing extreme optimizations for low cost/power, low-throughput, delay-tolerant IoT use cases

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1. Enhanced machine-type communication; 2. Narrowband IoT
Evolving LTE IoT
for the massive Internet of Things

Ubiquitous connectivity
To reach challenging locations by achieving device link budget of 164 dB

Massive scale
To efficiently support dense connections of 1+ million devices/km²

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

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

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

1. Maximum Coupling Loss, assuming data rate of 160bps; 2. Assuming 2008 UL + 208 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

**5G NR (Rel-15)**
- Enhanced mobile broadband
- Mission-critical services with URLLC

**LTE IoT (Rel-13+)**
- Continued evolution for the massive IoT
- Migration to NB-IoT with re-farmed GSM spectrum

**2G/GPRS**

**Complementary use cases**
5G NR Rel-15 focuses on enhanced mobile broadband, also suitable for high-performance IoT, while LTE IoT address the massive IoT

**Leveraging LTE’s global footprint & coverage**
LTE IoT leverages existing LTE infrastructure & coexist with other services such as Gigabit LTE – the anchor to the 5G experience

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

- Multiple design wins across leading module OEMs & operators
- Announced support for Verizon ThingSpace Platform, Jan. 2017
- Demonstrated LTE IoT VoLTE call with Ericsson & AT&T, Feb. 2017
- Announced 1st multi-mode trial with Mobike & China Mobile, May 2017

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

- Global multi-mode solution—single SKU
- Cat-M1 modules commercially available today
- Over-the-air software upgrade to Cat-NB1 support
- Pre-certified for major global mobile operators
Broaden use cases and expand into unlicensed spectrum

LTE IoT evolving to meet tomorrow’s massive IoT needs - essential to 5G Platform

1. LTE IoT, part of LTE Advanced Pro, will be submitted with 5G NR to meet IMT-2020 requirements per defined in ITU Recommendation ITU-R M.2083-0, September, 2015; 2. Standardization in MulteFire Alliance
LTE IoT in unlicensed spectrum enables new use cases

Such as dedicated private networks for optimized IoT services

<table>
<thead>
<tr>
<th>Spectrum Range</th>
<th>IoT Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>400/800/900 MHz (Regional)</td>
<td>MulteFire™ 1.0: For mobile broadband and high-performance IoT</td>
</tr>
<tr>
<td>1.9 GHz (Regionally)</td>
<td>MulteFire 1.1 eMTC: For the broadest range of IoT use cases</td>
</tr>
<tr>
<td>2.4 GHz (Global)</td>
<td></td>
</tr>
<tr>
<td>3.5 GHz (USA)</td>
<td>MulteFire 1.1 NB-IoT: For low-power, wide-area (LPWA) IoT use cases</td>
</tr>
<tr>
<td>5 GHz (Global)</td>
<td></td>
</tr>
</tbody>
</table>

1. CBR 3.5 GHz is a shared spectrum band, also for LTE-TDD. 2. Available bandwidth is regionally dependent, e.g., ~80 MHz in 2.4 GHz & ~500 MHz in 5 GHz for the US
Pioneering tomorrow’s massive IoT technologies
Applies to LTE IoT and 5G NR-based IoT evolution – potential for 3GPP Rel-16

Grant-free uplink
Resource Spread Multiple Access (RSMA)

- Asynchronous, non-orthogonal, contention-based access
- For sporadic uplink of small data bursts common for IoT
- Further increases device density and network efficiency

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
Extending the mobile ecosystem requires system leadership

Driving system-level inventions into multiple 3GPP working groups

LTE IoT
Led the harmonization of NB-IoT & drove upper layer enhancements, e.g., eDRx, lightweight core, CP optimization, positioning, multicast

Unlicensed spectrum
First introduced concept & drove standardization of LTE-U, LAA, eLAA; leading study of standalone unlicensed for e.g., private IoT networks

3GPP Working Groups
SA1, SA2, SA3, CT1, CT3, CT4
RAN1, RAN2, RAN3, RAN4
RAN1, RAN2, RAN4, RAN5, SA2, SA3, SA4, SA6, CT1, CT6
Leading the LTE IoT evolution to connect the massive IoT

LTE IoT starts to connect the massive IoT today
Complemented with early 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

- LTE Cat-1 and above (Rel-8+)
- eMTC (Rel-13+)
- NB-IoT (Rel-13+)
- eMTC/NB-IoT in unlicensed spectrum (MulteFire)
- 5G NR-based IoT (Rel-16+)

Migration to NB-IoT with re-farmed GSM spectrum
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 15+**
  - Further shared enhancements
  - Such as wake-up radio and early data transmission

- **Release 14**
  - More shared improvements
  - Such as multicast, positioning, larger transport block, more HARQ’s

- **Release 13**
  - eMTC
  - Shared foundation
    - Such as single Rx, half-duplex, PSM, eDRx, TTI bundling, overload control, overhead optimization
  - NB-IoT

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

Operation in unlicensed spectrum
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

**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>
</tr>
</thead>
<tbody>
<tr>
<td>Peak data rate</td>
<td>Up to 10 Mbps</td>
<td>Up to 1 Mbps(^2)</td>
<td>&lt;100 kbps</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>Up to 20 MHz</td>
<td>1.4 MHz</td>
<td>200 kHz</td>
</tr>
<tr>
<td>Rx antenna</td>
<td>Dual Rx(^1)</td>
<td>Single Rx</td>
<td>Single Rx</td>
</tr>
<tr>
<td>Duplex mode</td>
<td>Full duplex FDD/TDD</td>
<td>Full or Half duplex FDD/TDD</td>
<td>Half duplex FDD</td>
</tr>
<tr>
<td>Mobility</td>
<td>Full mobility</td>
<td>Limited-to-full mobility</td>
<td>Cell reselection only</td>
</tr>
<tr>
<td>Voice</td>
<td>VoLTE</td>
<td>VoLTE</td>
<td>No voice support</td>
</tr>
<tr>
<td>Transmit power</td>
<td>23 dBm</td>
<td>23, 20 dBm(^3)</td>
<td>23, 20 dBm(^3)</td>
</tr>
</tbody>
</table>

Reduces baseband/RF complexity and decreases memory

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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
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

**LTE Cat-1 and above**
Baseline 140.7 dB

**eMTC Cat-M1**
>155.7 dB

**NB-IoT Cat-NB1**
164 dB or better

**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

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; leveraging existing infrastructure and spectrum

- In-band
  - eMTC
  - NB-IoT
  - Regular LTE Data
  - eMTC reuses LTE sync. data channel operates across entire LTE band
  - NB-IoT utilizes 1 RB (180 kHz) within a normal LTE carrier

- Guard-band
  - 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

Easy migration to NB-IoT with re-farmed 2G/GPRS spectrum

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

- **eMTC**
  - Enhancing VoLTE\(^1\): For wearables to more efficiently handle voice in half-duplex mode
  - Better mobility
    - Full support for inter-frequency measurements\(^2\) and higher velocity in extended coverage\(^2\)

- **eMTC and NB-IoT**
  - Single-cell multicast\(^1\): Efficient OTA firmware update for a large number of devices
  - Device positioning\(^1\): Providing location services for e.g., asset tracking and eCall
  - Higher data rate\(^1\): Supporting wider bandwidth, e.g., 5 MHz, and more\(^1\)
  - Lower latency
    - More HARQ processes\(^1\), faster system acquisition\(^1\), early data transmission\(^1\)
  - Energy reduction
    - Wake-up radio for low-power channel monitoring\(^1\) and lower transmit power classes\(^1\)
  - Higher density support\(^2\): Improved load control with level-based access class barring

- **NB-IoT**
  - Cell size extension\(^2\): Additional cyclic prefixes to support cell radius of at least 100 km
  - TDD support\(^2\): For deployment in higher TDD bands, also further optimizing for small cells

Release 14 and 15 enhancements

1. Rel-14 feature; 2. Rel-15 feature; 3. FeMTC 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

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

**NB-IoT evolution**

- **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
  - Supporting positioning and single-cell multicast
  - Energy/latency optimizations

Potential for additional LTE IoT device categories

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

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 settings, such dense urban or inside buildings

Optimized for LTE IoT
Utilizing a narrower bandwidth PRS with higher repetition factors that extends range

Efficiently communicating with IoT devices using multicast

Extending SC-PTM 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-15

Venues  Industrial  Residential  Enterprise/Buildings  Cities

**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)

1. With new eNB classes and support for CSG (Closed Subscribers Group)
Private LTE networks offers key benefits for Industrial IoT

Leveraging readily available unlicensed spectrum (or part of licensed spectrum)

- **Local**
  Dedicated radio equipment, independent network, sensitive data stays local

- **Optimized**
  Network tailored for industrial applications, e.g., quality-of-service, latency

- **Scalable performance**
  From high with wideband LTE Cat-1 and above to low with narrowband LTE IoT
Support for multi-hop mesh with WAN management

Advanced massive IoT design for 3GPP Rel-16+

Direct access on licensed spectrum

Mesh on unlicensed or partitioned with uplink licensed spectrum

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.

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

Downlink remains OFDM-based for coexistence with other services

Increased battery life
Scalability to even higher device density
Better link budget
We are driving broad ecosystem adoption of LTE IoT

Strong global momentum with our multi-mode commercial solution - MDM9206

MDM9206 is a product of Qualcomm Technologies, Inc.
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

- Highly cost-effective
- Fast commercialization
- Futureproof with OTA upgrade

MDM9206 is a product of Qualcomm Technologies, Inc.
Global multi-mode Cat-M1/NB1 most optimal approach
Combining the benefits of both technologies to address full range of use cases

Single-mode
Cat-M1 vs. Cat-NB1

Multi-mode
vs. Single-mode

Global multi-mode
vs. Multi-mode

Cost optimization
Power efficiency
Mobility
Coverage
Data rate
Deployment flexibility

Cost optimization
Power efficiency
Mobility
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Data rate
Deployment flexibility

Cost optimization
Power efficiency
Mobility
Coverage
Data rate
Deployment flexibility

Cat-M1  Cat-NB1  Multi-mode
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
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 - June 2017 status

Over 20 mobile operators committed to deploy Cat-M1 and/or Cat-NB1 networks

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 and HW Keys for more robust and fast encrypt/decrypt operations

Secure Storage and Key Provisioning
- OTP e-fuse memory for storage of keys and configurations
- Encrypted storage capable
- Provisioning of Keys

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

Secure Storage
- Secure Storage and Key Provisioning
- Secure Debug
- Hardware Crypto

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
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: 
http://www.qualcomm.com/LTE-IoT
Thank you

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