Leading the world to 5G

February 2016
Qualcomm Technologies, Inc.
Our 5G vision: a unifying connectivity fabric

Enhanced mobile broadband
- Multi-Gbps data rates
- Extreme capacity
- Uniformity
- Deep awareness

Mission-critical services
- Ultra-low latency
- High reliability
- High availability
- Strong security

Massive Internet of Things
- Low cost
- Ultra-low energy
- Deep coverage
- High density

Unified design for all spectrum types and bands from below 1GHz to mmWave
Scalable to an extreme variation of requirements

- **Deep coverage**
  To reach challenging locations

- **Ultra-low energy**
  10+ years of battery life

- **Ultra-low complexity**
  10s of bits per second

- **Ultra-high density**
  1 million nodes per Km$^2$

- **Extreme capacity**
  10 Tbps per Km$^2$

- **Extreme data rates**
  Multi-Gigabits per second

- **Mission-critical control**

- **Enhanced mobile broadband**

- **Strong security**
  e.g. Health / government / financial trusted

- **Ultra-high reliability**
  <1 out of 100 million packets lost

- **Ultra-low latency**
  As low as 1 millisecond

- **Extreme user mobility**
  Or no mobility at all

- **Deep awareness**
  Discovery and optimization
Enhancing mobile broadband

Ushering in the next era of immersive experiences and hyper-connectivity

3D/UHD video telepresence
Tactile Internet
UHD video streaming
Demanding conditions, e.g. venues
Broadband ‘fiber’ to the home
Virtual reality

Extreme throughput
Ultra-low latency
Uniform experience

multi-gigabits per second
down to 1ms e2e latency
with much more capacity
Connecting the massive Internet of Things

Optimizing to connect anything, anywhere with efficient, low cost communications

- Smart cities
- Smart homes
- Utility metering
- Wearables / Fitness
- Remote sensors / Actuators
- Object tracking

Power efficient
- Multi-year battery life

Low complexity
- Low device and network cost

Long range
- Deep coverage
Enabling new mission-critical control services
With ultra-reliable, ultra-low latency communication links

High reliability
Extremely low loss rate

Ultra-low latency
Down to 1ms e2e latency

High availability
Multiple links for failure tolerance & mobility
A unified 5G design for all spectrum types/bands
Addressing a wide range of use cases and deployment scenarios

- **Licensed Spectrum**
  - Cleared spectrum
  - EXCLUSIVE USE

- **Shared Licensed Spectrum**
  - Complementary licensing
  - SHARED EXCLUSIVE USE

- **Unlicensed Spectrum**
  - Multiple technologies
  - SHARED USE

Below 1 GHz: longer range for massive Internet of Things

1 GHz to 6 GHz: wider bandwidths for enhanced mobile broadband and mission critical

Above 6 GHz, e.g. mmWave: extreme bandwidths, shorter range for extreme mobile broadband

From wide area macro to local hotspot deployments
Also support diverse network topologies (e.g. D2D, mesh)
Wireless/OFDM technology and chipset leadership

Pioneering 5G technologies to meet extreme requirements

End-to-end system approach with advanced prototypes

Driving 5G from standardization to commercialization

Leading global network experience and scale

Providing the experience and scale that 5G demands
Pioneering 5G technologies today with LTE

We are driving 4G and 5G in parallel to their fullest potential

- Advanced MIMO
- FDD-TDD CA
- Carrier aggregation
- CoMP
- SON+
- Unlicensed spectrum
- Internet of Things
- Massive/FD-MIMO
- Shared broadcast
- Dual connectivity
- Device-to-device
- V2X
- Low latency

Rel-10/11/12

LTE Advanced

Rel-13 and beyond

LTE Advanced Pro

Note: Estimated commercial dates. Not all features commercialized at the same time
Driving new LTE technologies to commercialization
Pushing LTE towards 5G with our unique end-to-end system approach

End-to-end prototype platforms
First LTE Unlicensed live demo at MWC 2014

Standards and research leadership
Pioneered LTE Unlicensed work in 3GPP

Industry-first trials with network operators
First LAA over-the-air trial in November 2015

Industry-first chipsets*
First modem and small cell solution to support LAA

Example: Driving LTE Unlicensed to commercialization

* Chipsets are products of Qualcomm Technologies, Inc.; firsts with respect to public announcement of a commercial LTE modem chipset
World’s first over-the-air LAA trial during November 2015
Joint effort by Qualcomm Technologies with Deutsche Telekom AG

LWA (Wi-Fi) test route*

LAA test route*

Coverages^ in unlicensed

<table>
<thead>
<tr>
<th>Mbps</th>
<th>Wi-Fi</th>
<th>LAA</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;10</td>
<td>24% of route</td>
<td>60% of route</td>
</tr>
<tr>
<td>&gt;1</td>
<td>39% of route</td>
<td>71% of route</td>
</tr>
<tr>
<td>&gt;0</td>
<td>47% of route</td>
<td>82% of route</td>
</tr>
</tbody>
</table>

Wide range of indoor and outdoor test cases

Demonstrated coverage and capacity benefits of LAA

Demonstrated fair co-existence with Wi-Fi

* Single small cell, LAA based on 3GPP release 13; LWA using 802.11ac; LTE on 10 MHz channel in 2600 MHz licensed spectrum with 4W transmit power; the following conditions are identical for LAA and Wi-Fi: 2x2 downlink MIMO, same 20 MHz channel in 5 GHz unlicensed spectrum with 1W transmit power, terminal transmit power 0.2W, mobility speed 6-8 mph; ^ Based on geo-binned measurements over test route
Multi-mode/multi-connectivity essential to 5G success

5G/4G/3G/Wi-Fi
Multi-mode device

Simultaneous connectivity across
5G, 4G and Wi-Fi
Leading the world to 5G
From standardization to commercialization

Qualcomm 5G activities

- Designing 5G, e.g. OFDM-based unified air interface
- Contributing to 3GPP, e.g. massive MIMO simulations, new LDPC code designs
- Delivering advanced prototypes, e.g. 5G mmWave demo at MWC’16
- Participating in impactful trials with major operators

5G study items

3GPP 5G standardization

- R15 5G work items
- R16 5G work items
- R17+ 5G evolution
- 5G commercial launches

Note: Estimated commercial dates;
Designing a unified, more capable 5G air interface

Building on our strong OFDM/wireless foundation

Optimized OFDM-based waveforms
OFDM adapted to extremes

A common, flexible framework
Designed for forward compatibility

Advanced wireless technologies
Such as massive MIMO, mmWave
Massive MIMO at 4 GHz allows reuse of existing sites

Leverage higher spectrum band using same sites and same transmit power

Average Cell Throughput = 808 Mbps @ 80 MHz

Macro site
1.7km inter-site distance
46 dBm transmit power

Source: Qualcomm Technologies, Inc. simulations; Macro-cell with 1.7km inter-site distance, 10 users per cell, 46 dBm Tx power at base station, 20MHz@2GHz and 80MHz@4GHz BW TDD, 2x4 Massive MIMO
Realizing the mmWave opportunity for mobile broadband

The extreme mobile broadband opportunity

- Large bandwidths, e.g. 100s of MHz
- Multi-Gbps data rates
- Flexible deployments (integrated access/backhaul)
- High capacity with dense spatial reuse

The challenge—‘mobilizing’ mmWave

- Robustness due to high path loss and susceptibility to blockage
- Device cost/power and RF challenges at mmWave frequencies

5G Solutions

Intelligent directional beam forming & beam tracking
Increase coverage & provide continuous connectivity

Tight interworking with sub 6 GHz
Increase robustness and faster system acquisition

Optimized mmWave design for mobile
To meet cost, power & thermal constraints
Making mmWave a reality for mobile
Qualcomm is driving 5G mmWave

60 GHz chipset commercial today for mobile devices

Developing robust 5G mmWave for extreme mobile broadband

Qualcomm® VIVE™ 802.11ad technology with a 32-antenna array element

Manhattan 3D map
Results from ray-tracing

28 GHz outdoor example with ~150m dense urban LOS and NLOS coverage using directional beamforming

Qualcomm VIVE is a product of Qualcomm Atheros, Inc.;
^ Based on Qualcomm Technologies Inc. simulations
Modem and RFFE leadership critical

Roadmap to 5G is significantly more complex and faster moving

Source: Qualcomm Technologies Inc.

2012 LTE Multimode

Today—LTE evolution

Tomorrow—5G and LTE evolution

Radio frequency bands

21 22 33 35 36 19 23 24 26 27 28 37 38 7 10 11 12

Connectivity

WI-FI  BT  GPS

EV-DO  GERAN  CDMA 1x  UMTS  TD-SCDMA  LTE TDD  LTE FDD

Handover combinations (hypothetical examples)

Source: Qualcomm Technologies Inc.
Modem and RFFE leadership critical

Roadmap to 5G is significantly more complex and faster moving

Wi-Fi, 3G, 2G technologies

50+ spectrum bands 450 MHz-5.8 GHz (licensed and unlicensed)

-200 Carrier Aggregation combinations

4G LTE OFDM-based waveforms, transmission modes, and UE categories

New LTE services, e.g. LTE Broadcast, VoLTE

2000+ modem features to-date and counting

Source: Qualcomm Technologies Inc.

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Tomorrow—5G and LTE evolution
Modem and RFFE leadership critical

Roadmap to 5G is significantly more complex and faster moving

Source: Qualcomm Technologies Inc.

Many more spectrum bands/types

More diverse deployment scenarios

Advanced wireless technologies

A much wider variation of use cases

2012 LTE Multimode

Today—LTE evolution

Tomorrow—5G and LTE evolution

Source: Qualcomm Technologies Inc.
Leading the world to 5G

A unifying connectivity fabric for the next decade and beyond

Connecting new industries and devices

Empowering new user experiences

Enabling new services

Delivering new levels of efficiency
Thank you

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