Delivering on the LTE Advanced promise

Faster, better mobile broadband experience

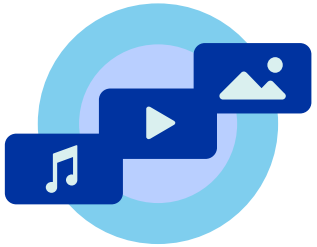
Qualcomm Technologies, Inc.

March, 2016

The insatiable demand for faster, better mobile broadband

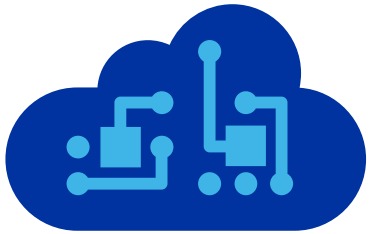
To enhance today's user experiences and pave the way for new ones

Higher resolution photos / videos with more ways to share

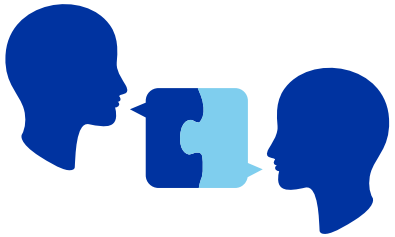


Near instant access to entertainment

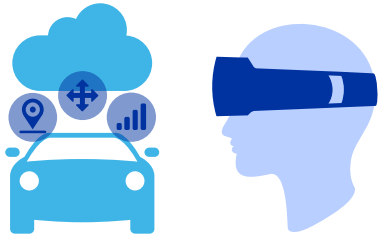
Always-on cloud services including "infinite storage"



Increasing complexity of mobile webpages



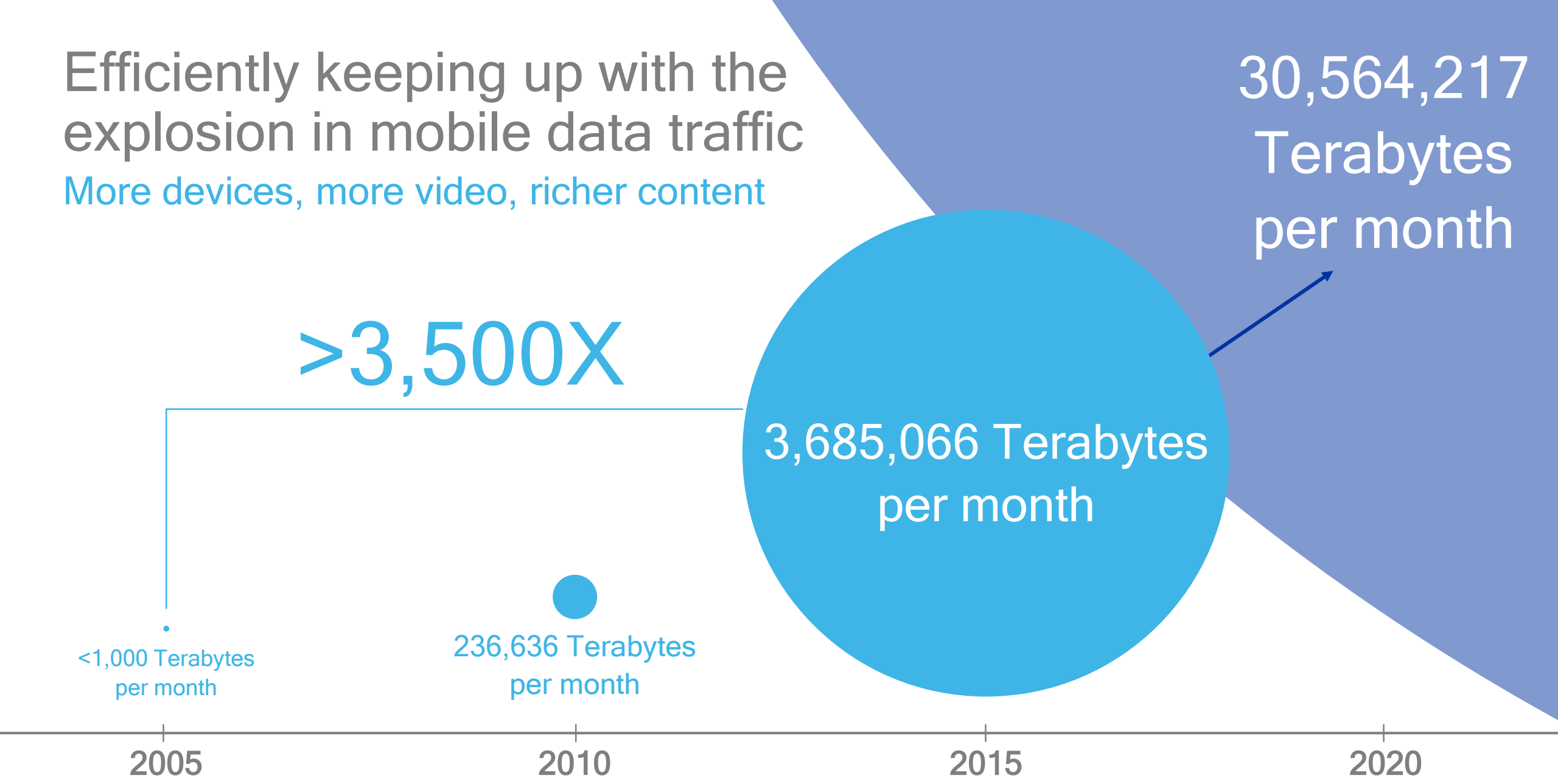
Higher frame-rate video communication



New types of use cases, e.g. connected car, virtual reality

Efficiently keeping up with the explosion in mobile data traffic

More devices, more video, richer content



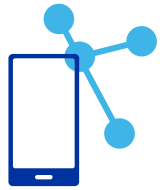
Source: Cisco Visual Network Index: Global Mobile Data Traffic Forecast Update, 2015 - 2020

Delivering on the LTE Advanced promise

Rising up to deliver a better, faster mobile broadband experience

1.  **Achieving** Gigabit Class LTE by evolving Carrier Aggregation and beyond

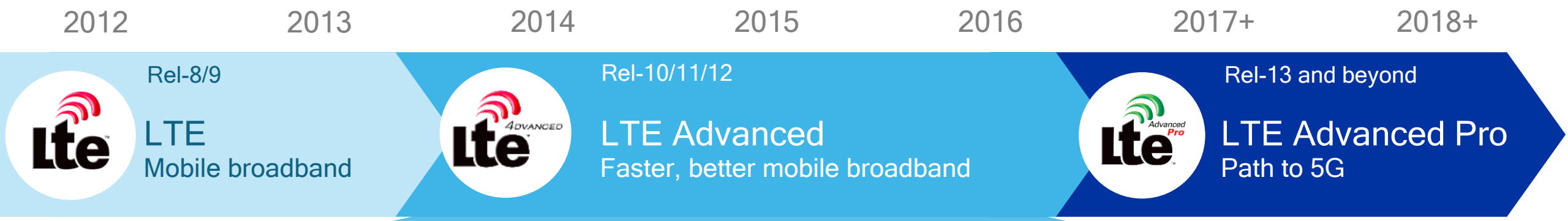
2.  **Providing** solutions to efficiently increase capacity by enhancing HetNets

3.  **Bringing** new ways to efficiently connect with LTE Broadcast & LTE Direct

4. QUALCOMM Why Wait **Leading** the LTE Advanced evolution – a history of technology firsts

Learn more at www.qualcomm.com/lte-advanced

LTE Advanced: part of a rich roadmap of LTE technologies



Achieving
Gigabit Class LTE

Carrier Aggregation (CA)

FDD/TDD CA

LTE-U / LAA

256-QAM

Advanced MIMO

Providing
enhanced HetNets

Interference management

Best use of all spectrum

Dual connectivity

Coordinated multipoint

SON+

Bringing
new ways to connect

LTE Broadcast

LTE Direct (D2D)

Note: Estimated commercial dates. Not all features commercialized at the same time.

LTE Advanced is being rapidly deployed globally

~100 | LTE Cat6+ commercial network launches in 50+ countries

2,000+ | Commercial devices across 100s of vendors

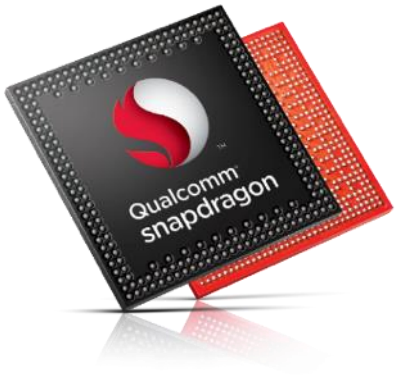
1B+ | LTE / LTE Advanced subscriptions worldwide

Source: GSA (www.gsacom.com) – Jan 2016 on network launches, Feb 2016 on commercial devices, Dec 2015 on subscriptions (estimated based on >900M subscriptions at the end of Q3'2015)

Achieving Gigabit Class LTE

Leading the way to Gigabit Class LTE

A significant milestone for the entire mobile industry



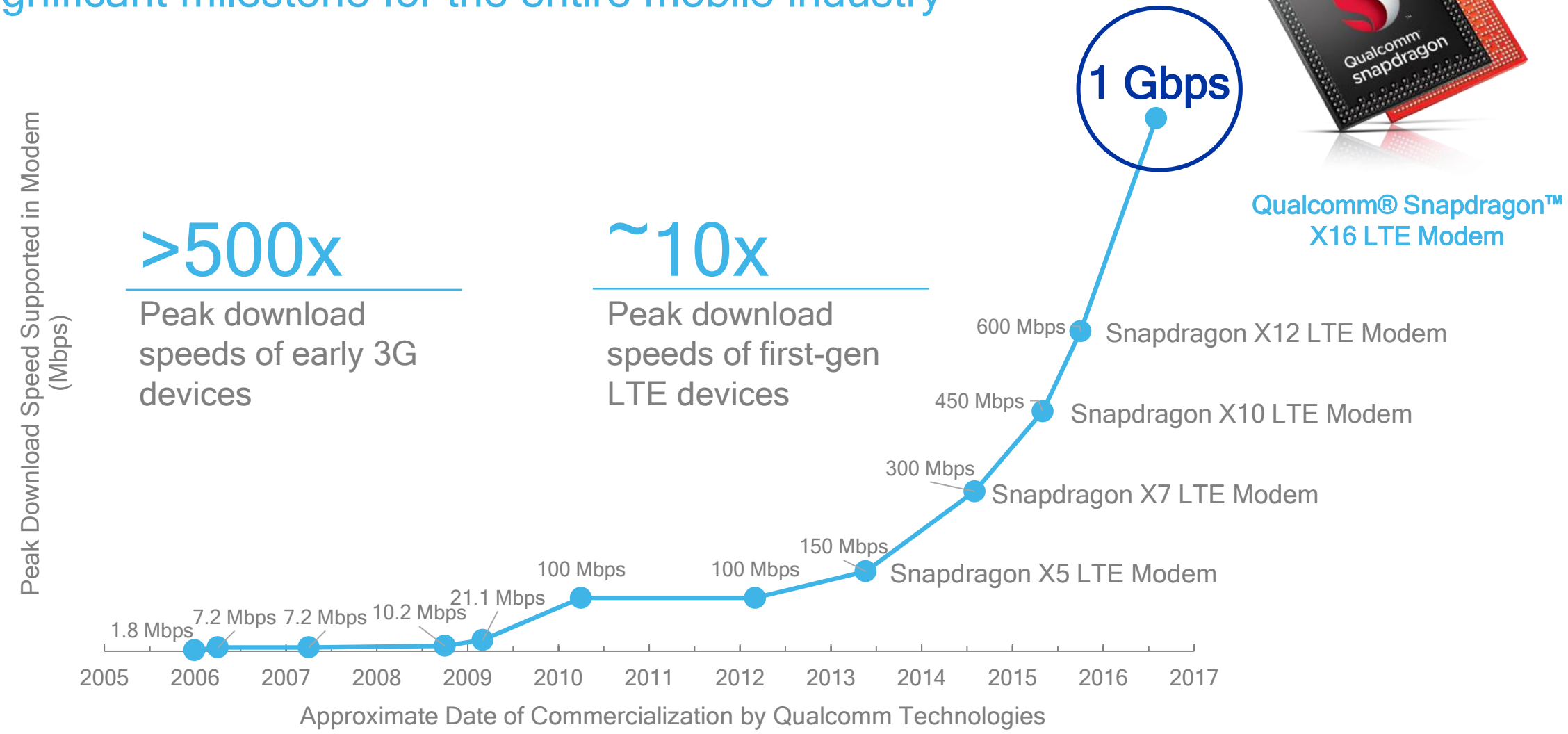
Qualcomm® Snapdragon™ X16 LTE Modem

>500x

Peak download speeds of early 3G devices

~10x

Peak download speeds of first-gen LTE devices



Qualcomm Snapdragon is a product of Qualcomm Technologies, Inc.
Subject to network availability

Technology enablers for achieving Gigabit Class LTE

More bandwidth

Better spectral efficiency

Best use of all spectrum assets

Carrier Aggregation

Combines multiples LTE carriers for wider bandwidth, e.g. fatter pipe

Aggregation across diverse spectrum types

Makes the best use of spectrum, e.g. FDD/TDD, licensed/unlicensed spectrum

Advanced MIMO

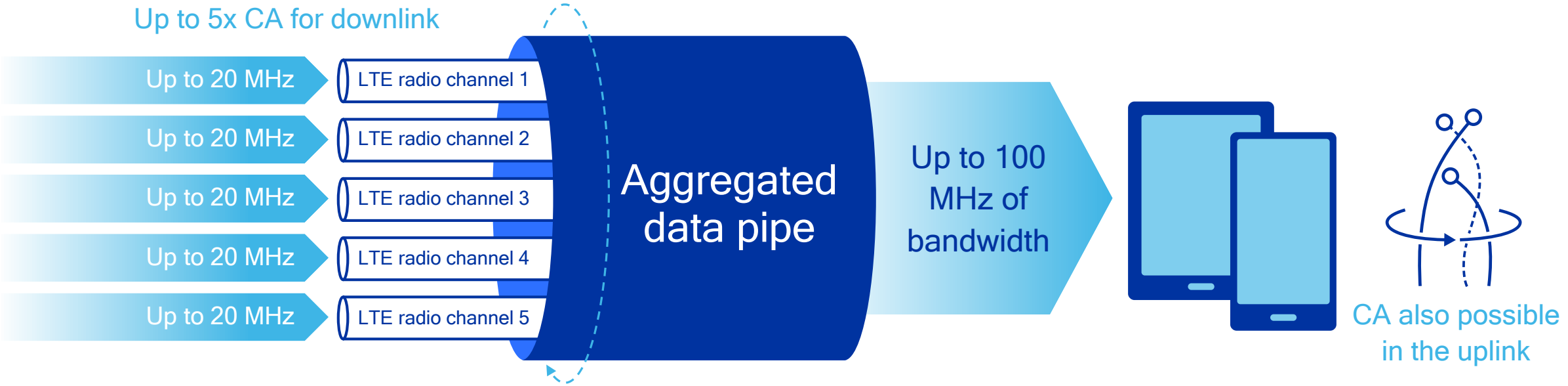
Leverages more antennas to increase spectral efficiency

Higher-order modulation (256-QAM)

Transmits more bits per symbol to increase spectral efficiency

Carrier Aggregation (CA) for a fatter pipe

Combine multiple LTE carrier data streams



Higher peak data rate and lower latency

Better experience for all users

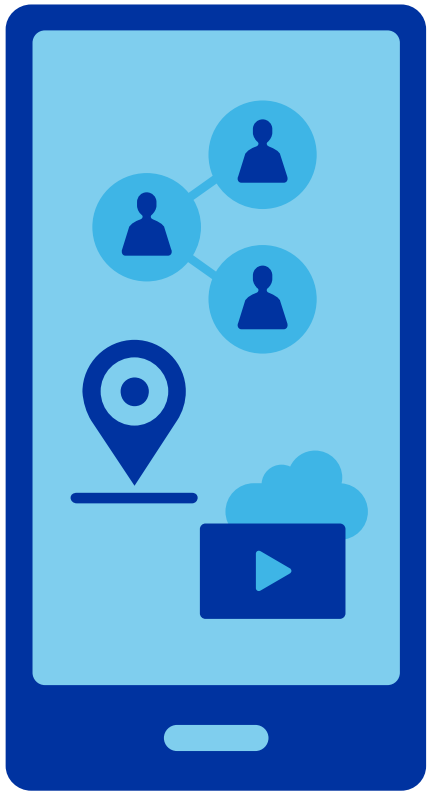
More capacity and better network efficiency[1]

Maximize use of spectrum assets

1 The typical bursty nature of usage, such as web browsing, means that aggregated carriers can support more users at the same response (user experience) compared to two individual carriers, given that the for carriers are partially loaded which is typical in real networks. The gain depends on the load and can exceed 100% for fewer users (less loaded carrier) but less for many users. For completely loaded carrier, there is limited capacity gain between individual carriers and aggregated carriers

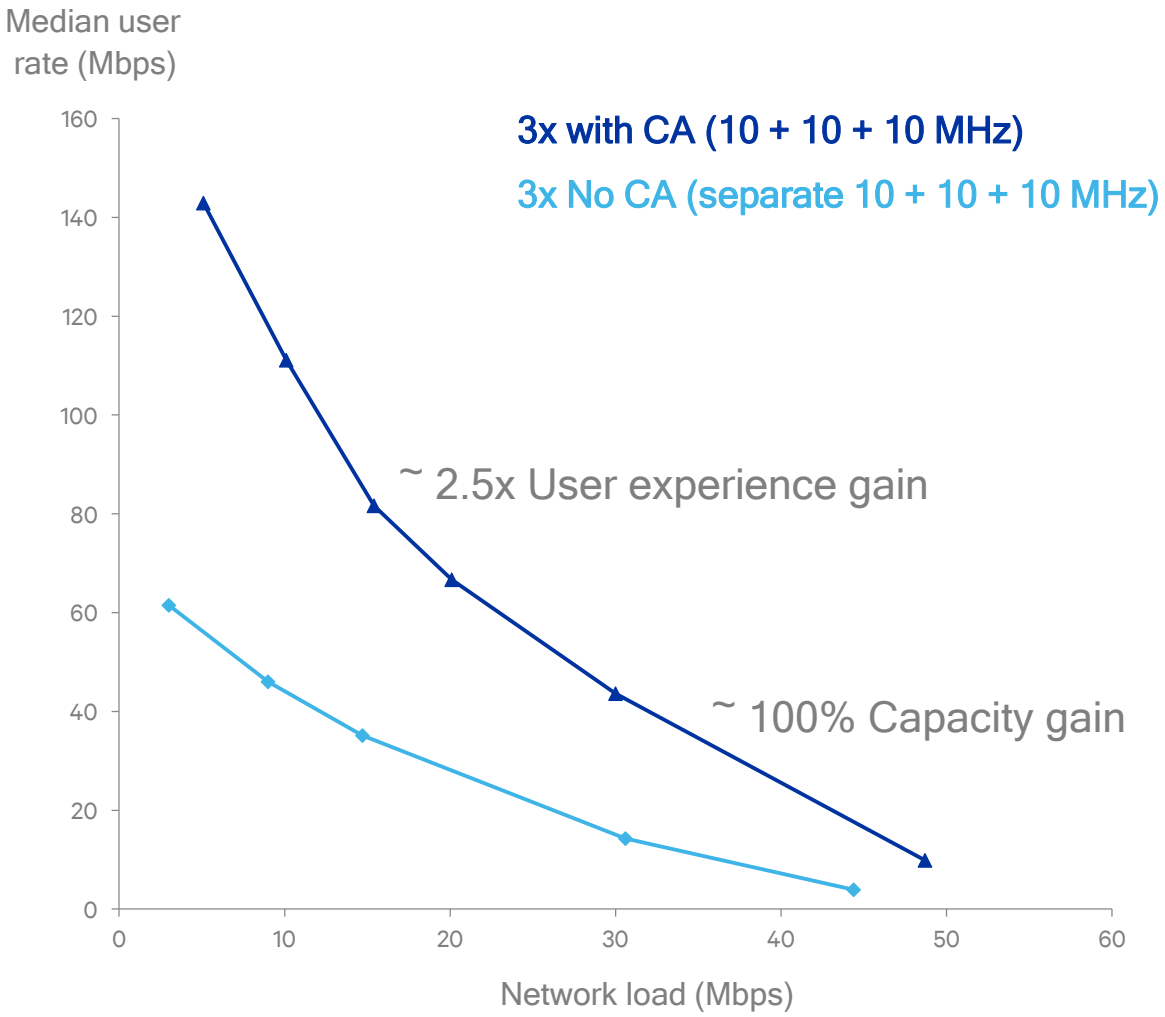
Delivering higher capacity for bursty applications

Mobile operators can trade off increased data rates for higher capacity



Typical bursty applications

- Web browsing
- Video streaming
- Social media
- Navigation
- Media downloads

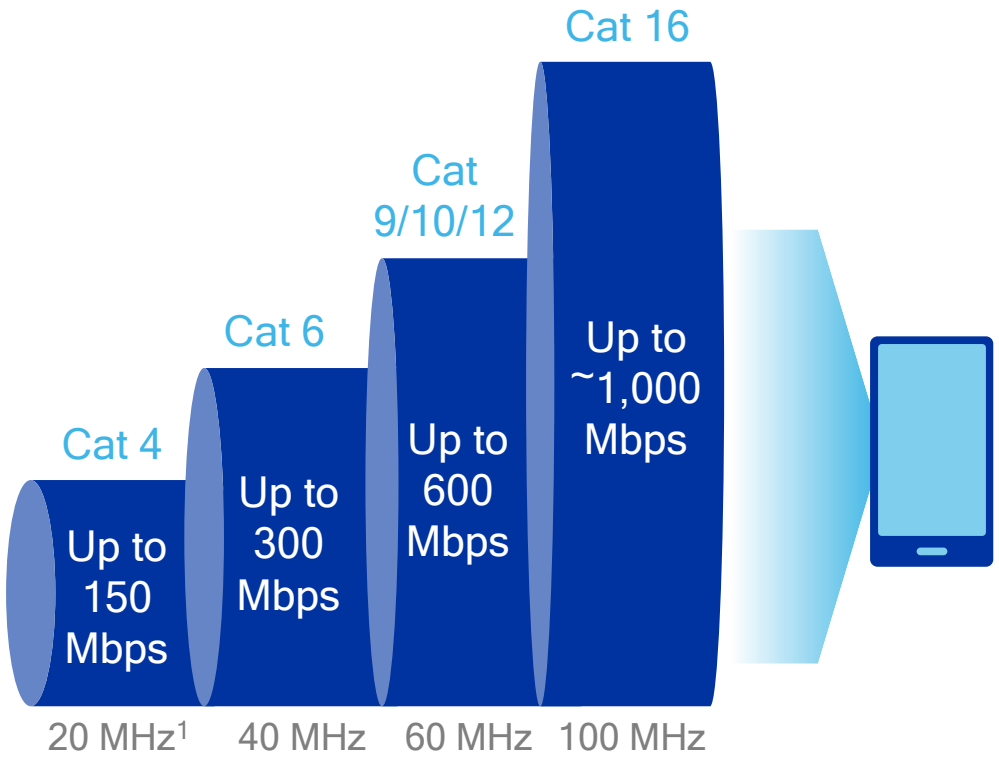


Based on 3GPP simulation framework, 1st carrier is 10MHz in 700MHz band, 2nd and 3rd carriers are 10MHz each in 2GHz band, FTP traffic model with 0.5MB file size, 57 macro cells wrap-around, 500m ISD (D1), 2x2 MIMO, TU3, NLOS, 10 degree antenna down tilt, bursty user rate is calculated from the downloading time of the file.

Evolving Carrier Aggregation for faster data rates

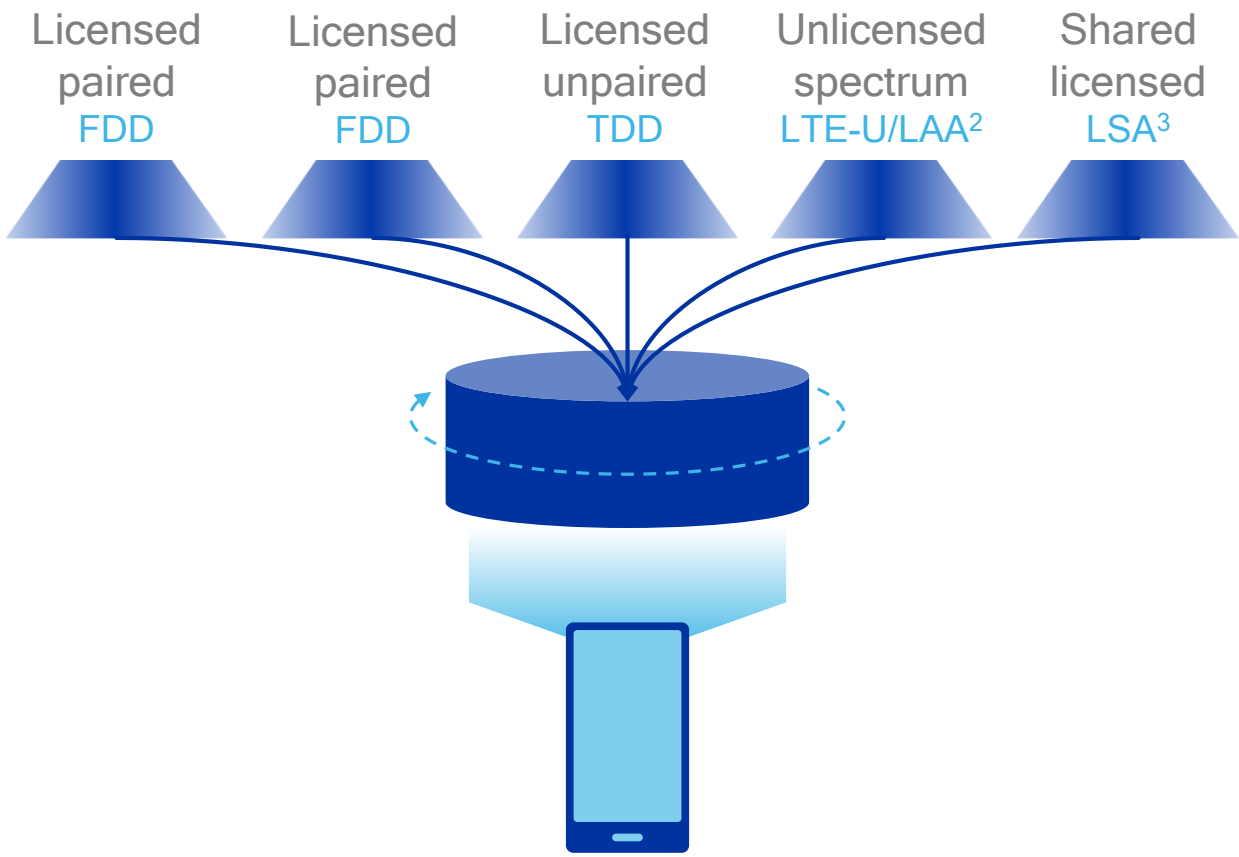
Enable mobile operators to maximize use of spectrum assets

Across more carriers



Note: UE category bandwidth shown are for 2x2 MIMO implementation; 256-QAM for Cat 11 and above

Across diverse spectrum types



[1] 10 + 10 CA; [2] LTE-U extends LTE to unlicensed spectrum, based on 3GPP Rel. 12 and supports migration to 3GPP Rel. 13 Licensed Assisted Access (LAA); [3] Licensed Shared Access

Leveraging more antennas for higher spectral efficiency

Advanced MIMO (Multiple Input, Multiple Output)

Relative spectral efficiency

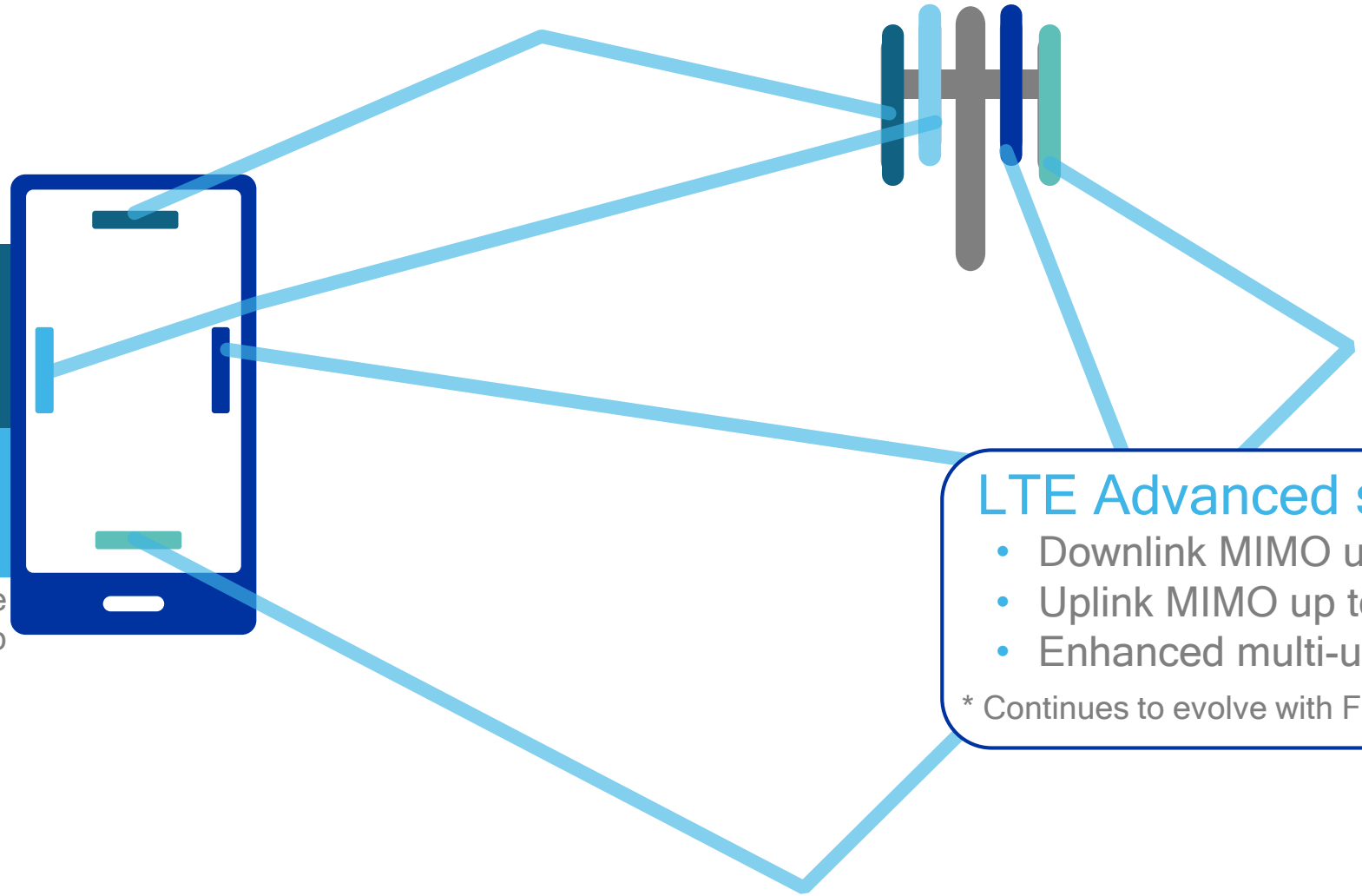
4x4 MIMO

1.8x

2x2 MIMO

1x

4 antennas also support receive diversity in 2x2 & 4x2 MIMO setup



LTE Advanced supports:

- Downlink MIMO up to 8x8
- Uplink MIMO up to 4x4
- Enhanced multi-user MIMO

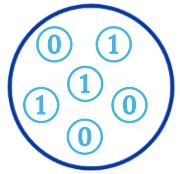
* Continues to evolve with FD-MIMO in Rel-13+

Simulations: 3GPP framework, 21 macro cells wrap-around, 500m ISD (D1), 10MHz FDD, carrier frequency 2GHz, 25 UEs per cell, TU 3km/h, full-buffer traffic, no imbalance or correlation among antennas. 2x4 MIMO used for receive diversity gain of 1.7x compared to 2x2 MIMO, similarly 2x3 diversity provides a 1.3x gain over 2x2 MIMO

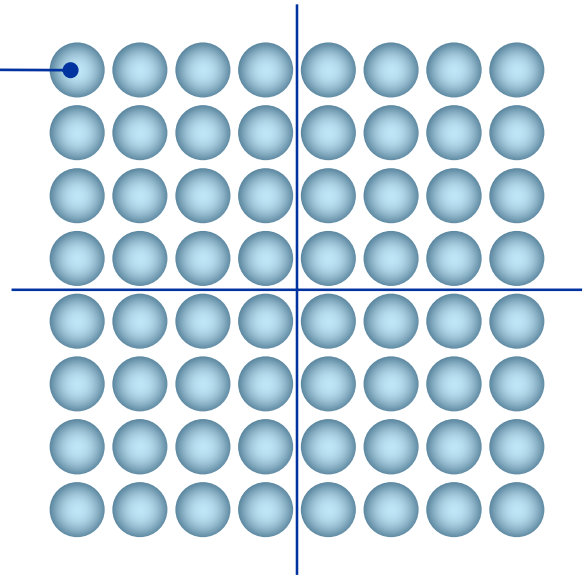
Using higher-order modulation (256-QAM)

Increases spectral efficiency for faster downlink throughput

64-QAM

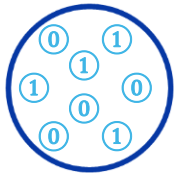


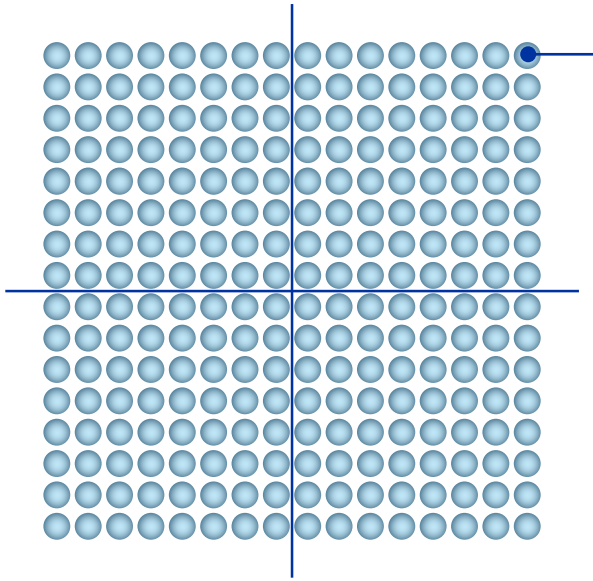
Each symbol represents 6 bits



33% more bit per transmission

256-QAM

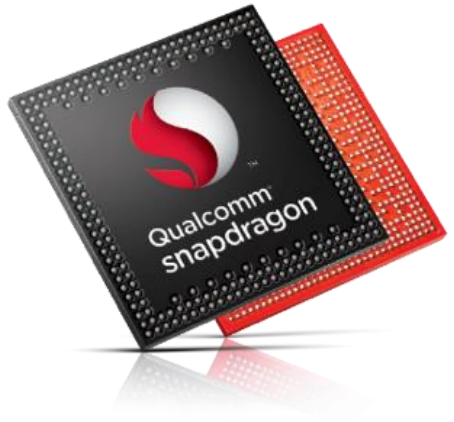




Each symbol represents 8 bits

The world's first Gigabit Class LTE modem

Qualcomm® Snapdragon™ X16 LTE Modem



X16
LTE Modem

Quick Facts

Learn more at: www.qualcomm.com/X16

Up to ~1 Gbps – Cat 16 DL
3x CA, 4x4 MIMO on 2x CA, 256-QAM; Up to 4x20 MHz CA supported with 2x2 MIMO

Up to 150 Mbps – Cat 13 UL
via 2x20MHz CA and 64-QAM

LTE-U and LAA – Convergence with unlicensed
Globalizing access to LTE in unlicensed spectrum

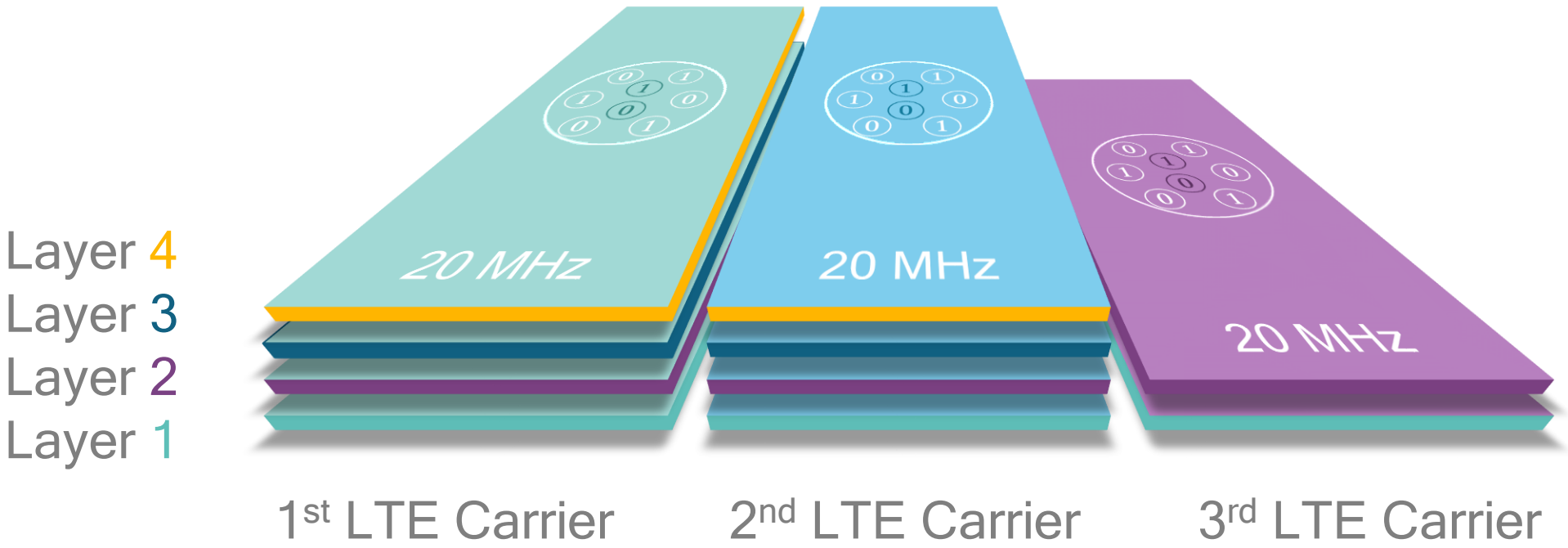
3.5 GHz band support – New 3GPP bands
Additional licensed LTE spectrum access

Qualcomm Snapdragon is a product of Qualcomm Technologies, Inc.
* The Snapdragon X16 LTE modem achieves peak Gigabit Class LTE speeds of 0.98 Gbps.

Achieving Gigabit Class LTE with 60 MHz of spectrum

Snapdragon X16 LTE Modem supports 10 data streams of ~100 Mbps

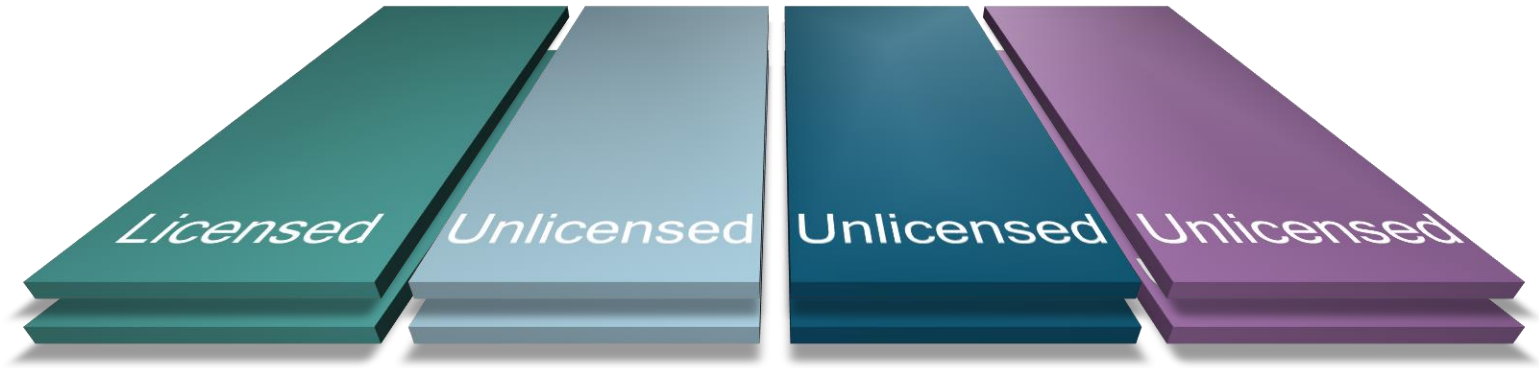
A combination of 3x Carrier Aggregation, 4x4 MIMO, and 256-QAM



Example configuration. Other RF configurations possible.

Globalizing the possibility of Gigabit Class LTE

For operators with as little as one block of 20 MHz licensed spectrum



Support for LTE in unlicensed spectrum
with LTE-U and LAA

Learn more at: www.qualcomm.com/invention/technologies/lte/unlicensed

Providing solutions to efficiently increase capacity by enhancing HetNets

Small Cells Everywhere

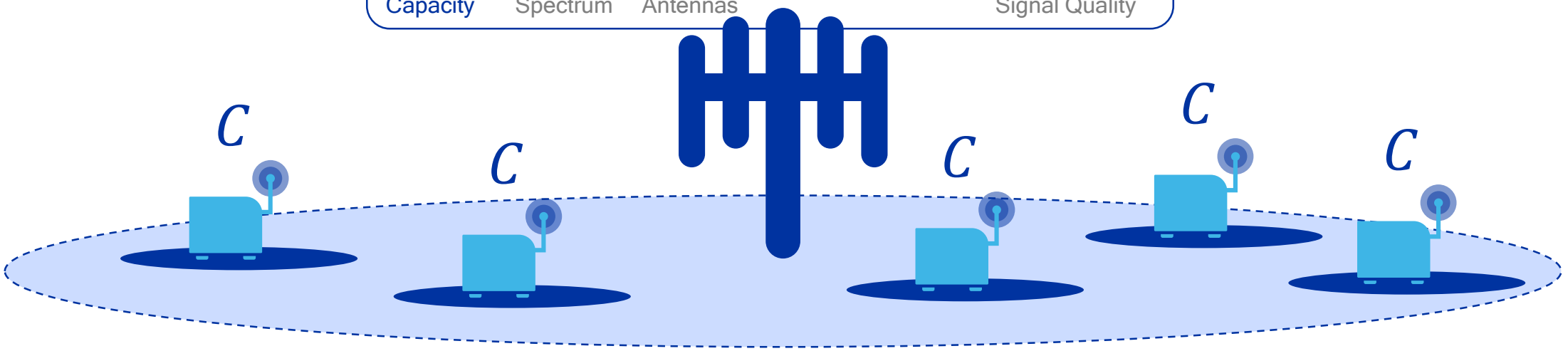
Small cells: the foundation to efficiently increasing capacity

Bringing the network closer to the user with Heterogeneous Networks (HetNets)

Shannon's Law

$$C \approx W \cdot n \cdot \log_2(1 + SNR)$$

Capacity · Spectrum · Antennas · Signal Quality



Reuse spectrum assets

Effectively repeating Shannon's Law everywhere

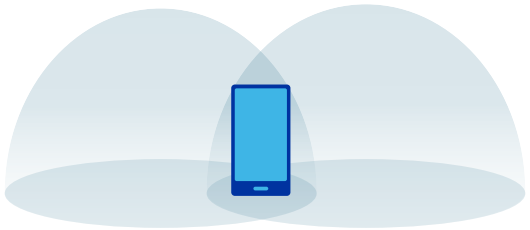
Provide localized capacity

For better signal quality, especially indoors

Use unlicensed spectrum

Opportunistically while maintaining anchor in licensed spectrum

LTE Advanced solutions for enhancing HetNets

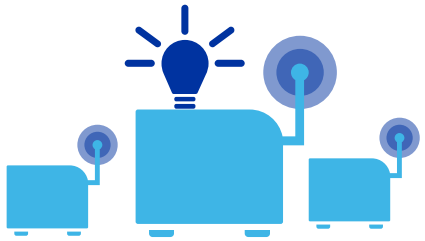


Interference Management

So that capacity scales with small cells added, e.g. FeICIC/IC

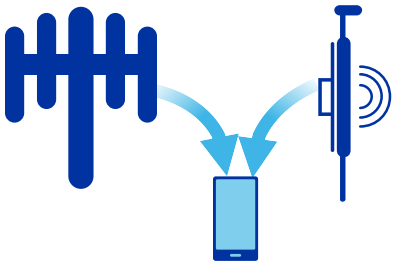
Best use of all spectrum

E.g. unlicensed spectrum; also shared licensed & higher bands



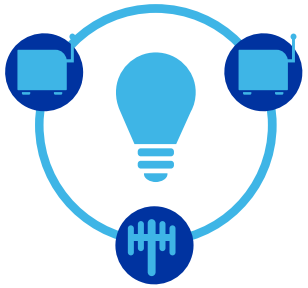
Self-Organizing Networks

Enhanced SON features to take plug & play to the next level



Dual Connectivity

Simultaneous connectivity across cells; maintain robust anchor to macro

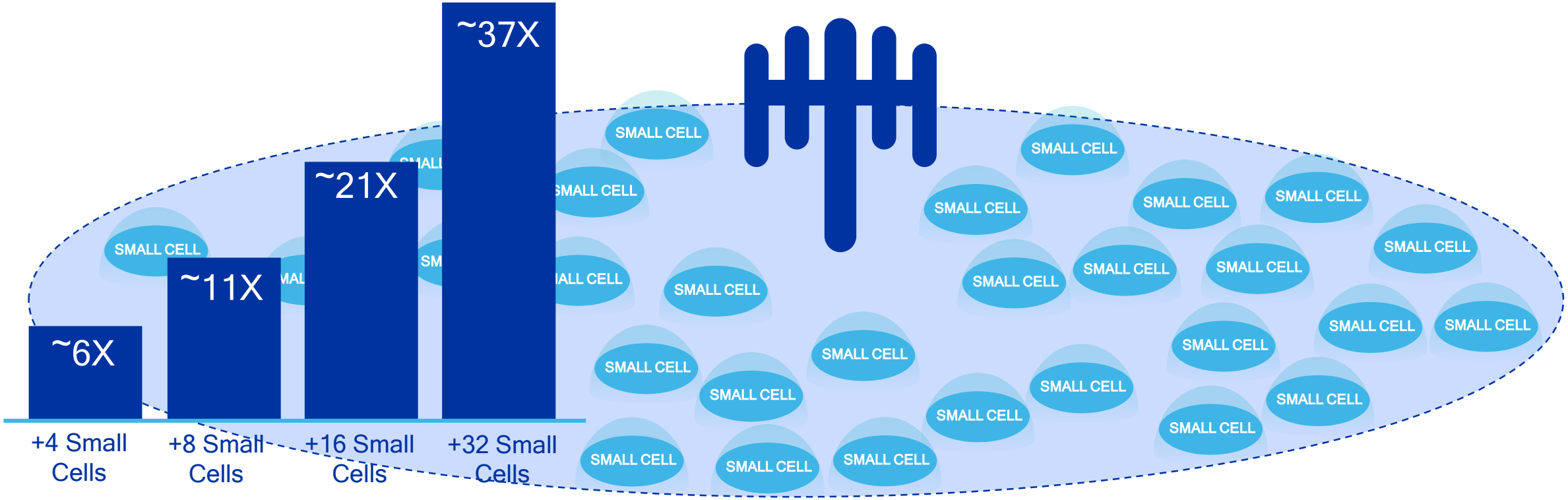


Coordinated Multipoint (CoMP)

Dynamic coordination between neighboring cells

FeICIC/IC enables capacity to scale with more small cells

Advanced interference management for hyper-dense small cell deployments



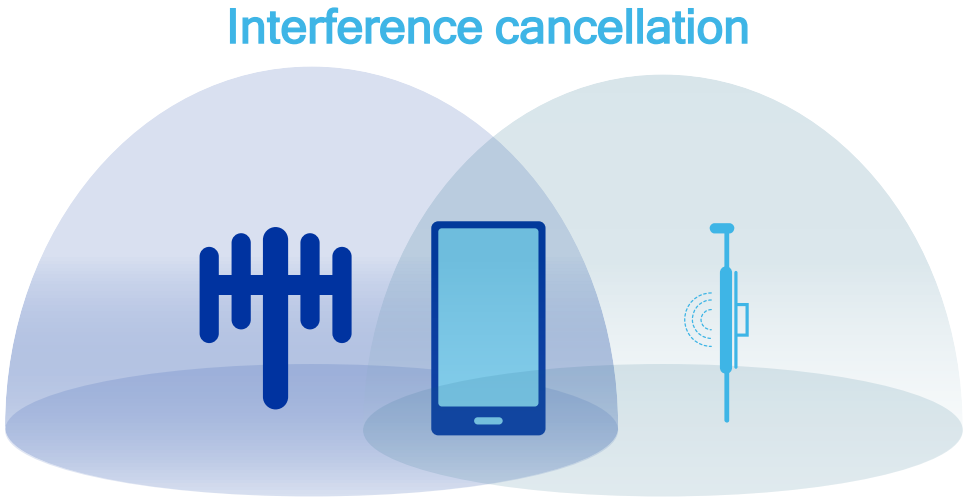
Capacity scales with small cells added[1]

LTE Advanced with 2x Spectrum added

[1] Assumptions: Pico type of small cell, 10MHz@2GHz + 10MHz@3.6GHz,D1 scenario macro 500m ISD, uniform user distribution scenario. Gain is median throughput improvement, from baseline with macro only on 10MHz@2GH, part of gain is addition of 10MHz spectrum. Users uniformly distributed–a hotspot scenario could provide higher gains. Macro and outdoor small cells sharing spectrum (co-channel)

Enhanced receivers further improve HetNets performance

Interference cancellation in both common and data channels



Interference Cancellation	Rel. 10/11	Rel. 12
Sync ref. signal	✓	✓
Common ref. signal	✓	✓
Primary broadcast channel	✓	✓
Data channel		✓

Better user experience

Higher data rates especially at cell-edges

Higher network capacity

Increased users data rate boosts overall network capacity

Enhanced performance

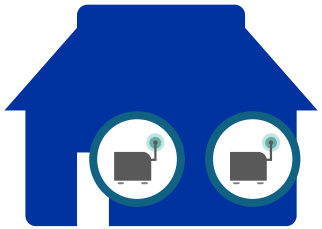
For hyper-dense HetNets; effectively minimizing inter-cell interference

Making best use of 5 GHz unlicensed spectrum

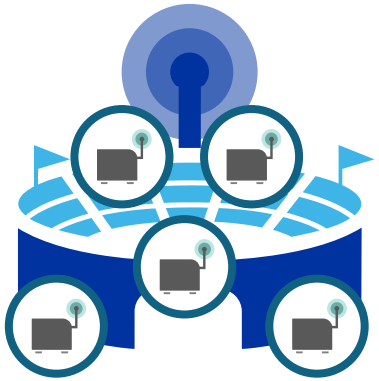
Ideal for small cells thanks to lower mandated transmit power

Pico/ Enterprises

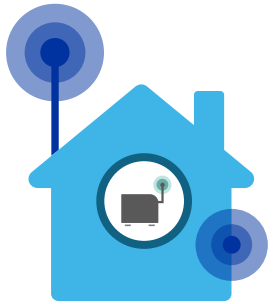
Small Businesses



Venues



Residential/ Neighborhood



Large amounts of spectrum available at 5 GHz (~500 MHz[1])

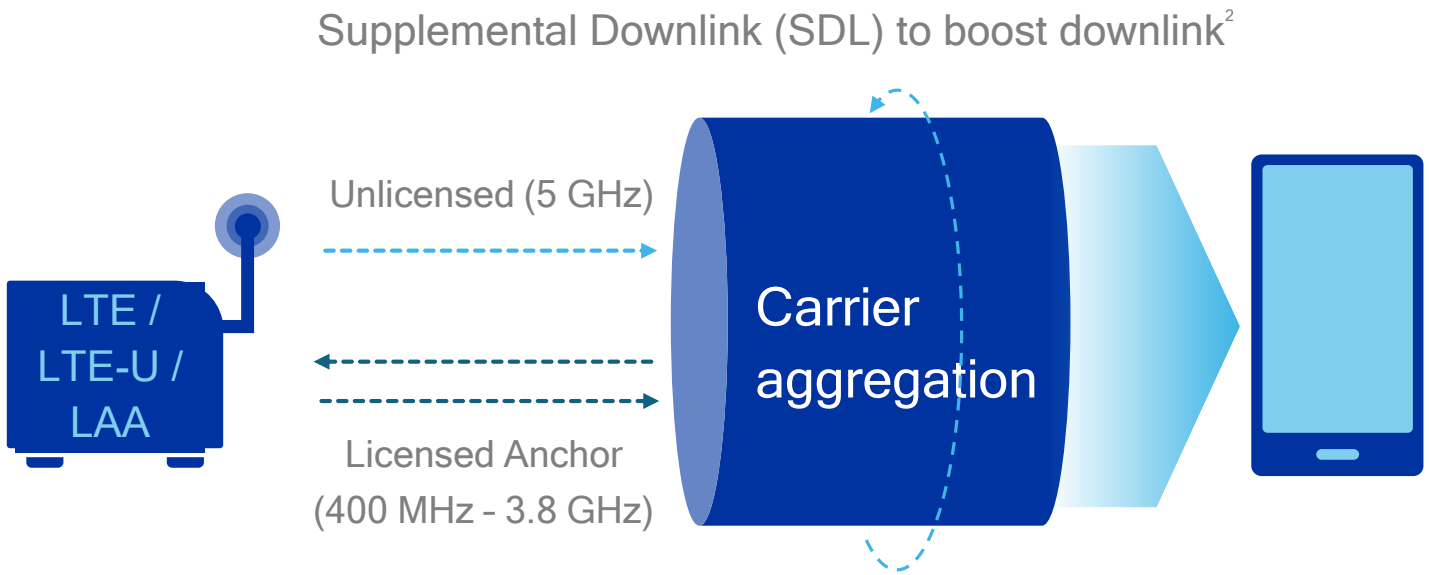
Aggregation with licensed spectrum for best performance

Multiple technologies will co-exist– LTE-U, LAA/eLAA, Wi-Fi/LWA[2], MulteFire™

[1] Regionally dependent [2]LTE - Wi-Fi Link Aggregation

Extending LTE to unlicensed spectrum

LTE-U based on 3GPP Rel-12 with migration path to LTE LAA[1] in Rel-13+



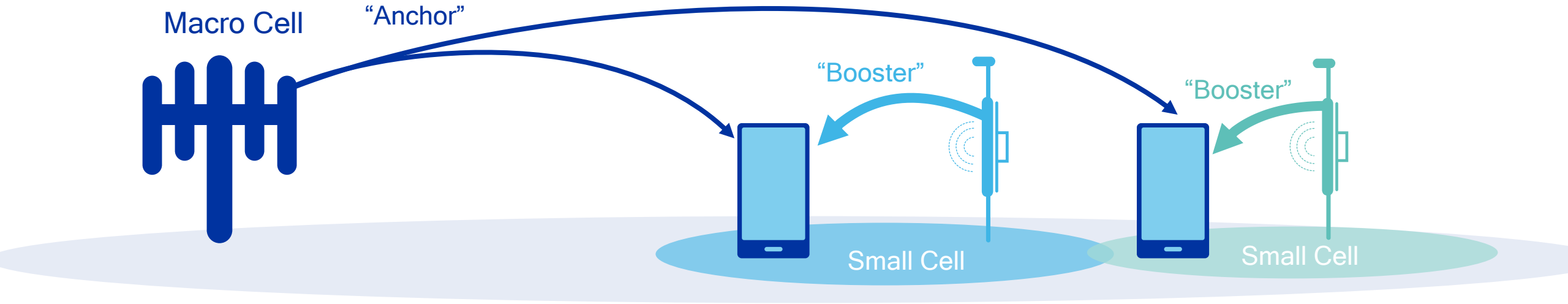
Learn more at:
www.qualcomm.com/invention/technologies/lte/unlicensed

- **Path to Gbps speeds**
  By aggregating as little as 20 MHz licensed spectrum with unlicensed
- **Robust user experience**
  With reliable licensed spectrum anchor
- **2x capacity and range**
  Over Wi-Fi capacity in dense deployments[3]
- **Single unified LTE network**
  Common management
- **Fair Wi-Fi coexistence**
  Fundamental design principle

[1] Licensed Assisted Access; [2] Accessing with either licensed TDD or licensed FDD is possible with SDL; [3] Assumptions: 3GPP LAA evaluation model based on TR 36.889, two operators, 4 small-cells per operator per macro cell, outdoor, 40 users on same 20 MHz channel in 5 GHz, both uplink and downlink in 5 GHz, 3GPP Bursty traffic model 3 with 1MB file, LWA using 802.11ac, DL 2x2 MIMO (no MU-MIMO), 24dBm + 3dBi Tx power in 5 GHz for LAA eNB or Wi-Fi AP.

Dual connectivity to both Macro and small cell

Simultaneous connection delivers better user experience and robust mobility



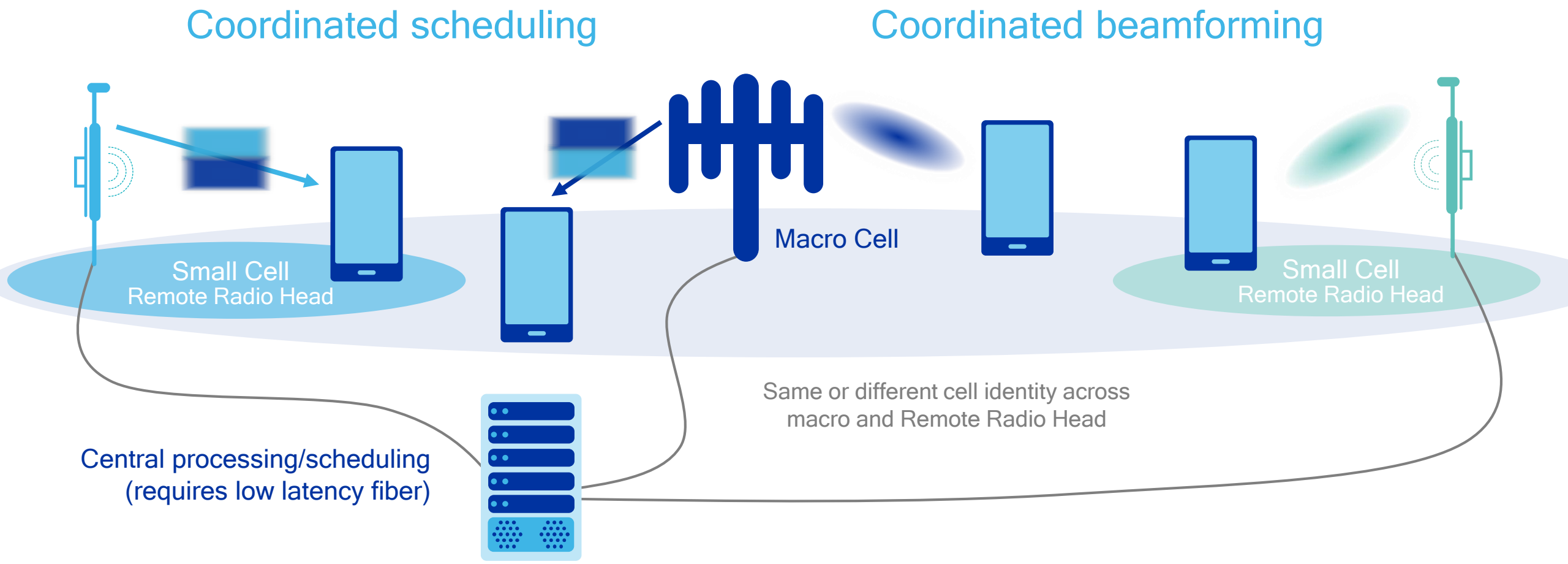
Improved offload to small cells
Better offloading coordination between Macro and small cells

Higher data rates
Booster cell provides higher bandwidth even at the cell-edge

Robust mobility
Macro anchor ensures uninterrupted connectivity during small cell hand-offs

CoMP[1] leverages backhaul to better coordinate HetNets

Dynamically coordinate scheduling and beamforming with neighboring cells



1 Coordinated Multipoint

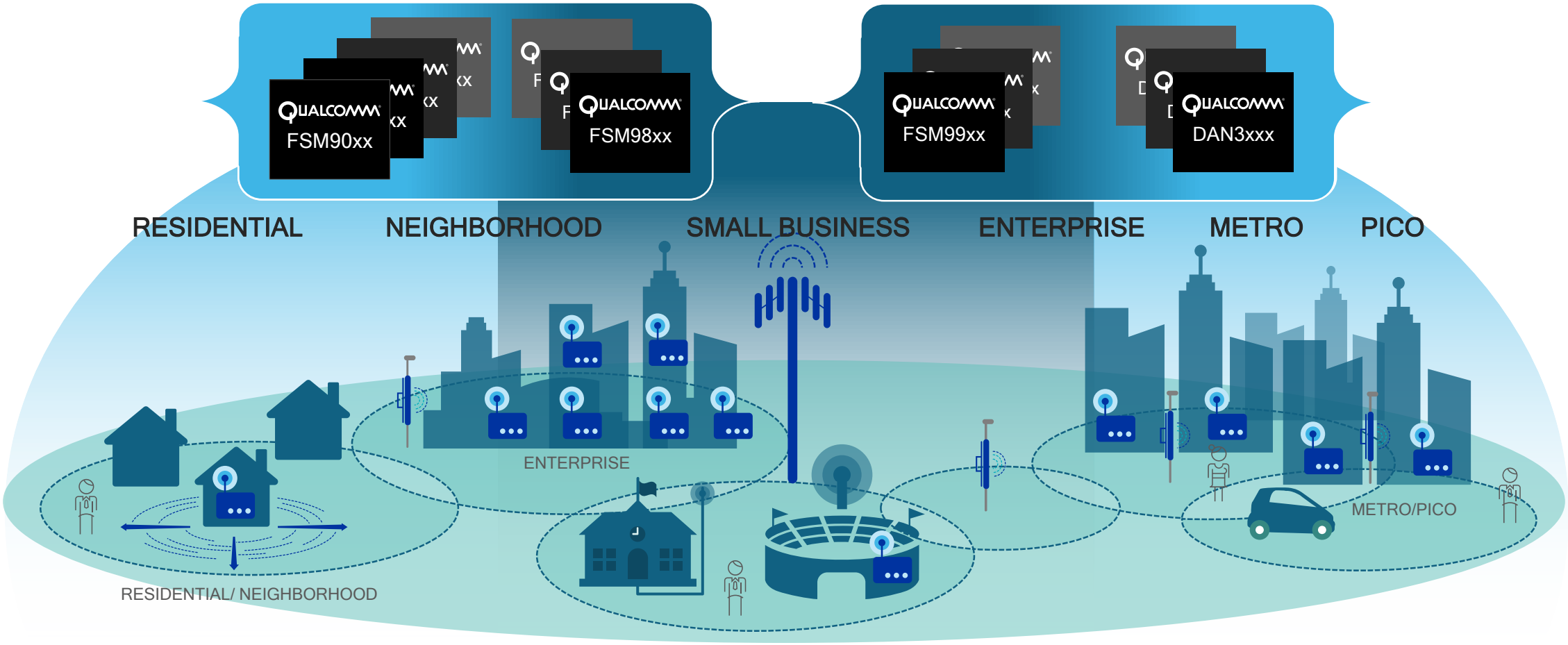
Note: CoMP enabled by TM10 transmission modes in the device and network. Graphic focuses on downlink CoMP techniques; CoMP can also apply to uplink.

Qualcomm Technologies' small cell solutions for all venues

- Complete 3G/4G chipsets (multimode baseband, RF, power)
- Wi-Fi hosting

- Software solutions enabling UltraSON™, eICIC and HotSpot 2.0

- Wireless backhaul
- HomePlug PLC,PON, Ethernet backhaul



eICIC=enhanced Inter Cell Interference Coordination PLC=Power-line communications, PON=Passive Optical Networks. UltraSON, FSM and DAN are products of Qualcomm Technologies, Inc.

Hyper-dense deployments with UltraSON™ technology

Reliable coverage

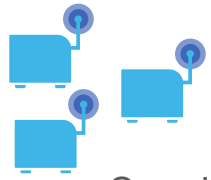
Mobility

Qualcomm Technologies' UltraSON

Enables 'unplanned' deployments, robust mobility and reliable user experience

By providing solutions for self-configuration, mobility management, resource and transmit power management, backhaul aware operation

Self-configuration



Coordination

Includes 3GPP defined SON

Implements algorithms for 3GPP features such as ANR, MLB, MRO[1]

Unplanned

Backhaul aware

Supports a wide range of deployment scenarios

Neighborhood, SMB, Enterprise, Metro, Pico

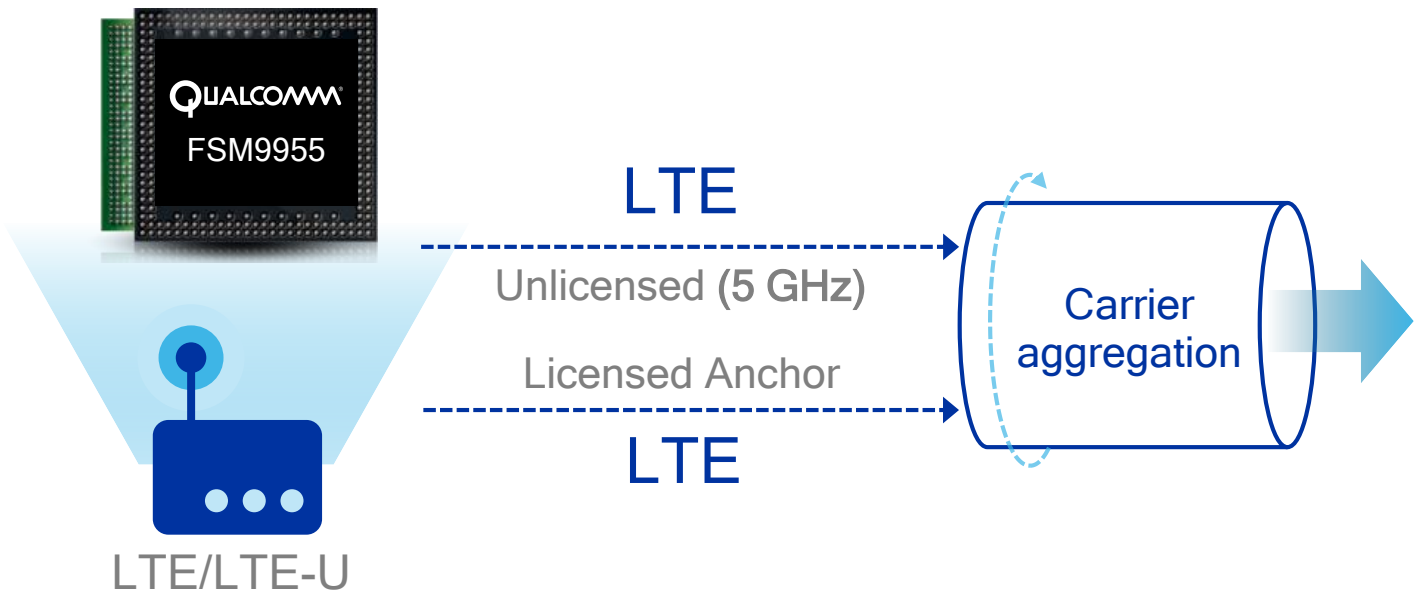
Distributed/hybrid SON

Co-channel with macro or dedicated spectrum

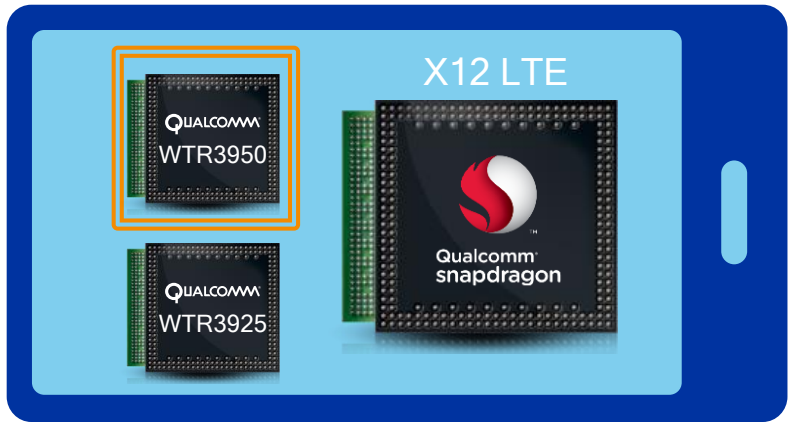
[1] ANR - Automatic Neighbor Relations, MLB - Mobility Load Balancing, MRO - Mobility Robustness Optimization

Spearheading LTE-U commercialization

Industry's first LTE-U small cell SoC



Industry's first UE solution for LTE-U



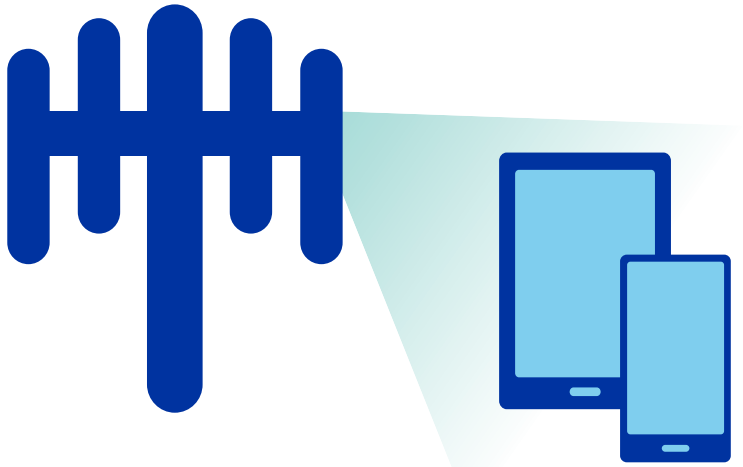
Converged SoC
with CSAT for LTE/Wi-Fi fair coexistence

X12 LTE supporting LTE-U
with WTR 3950

Bringing new efficient ways to connect

LTE Broadcast for efficient delivery of mass media content

First introduced as part of 3GPP Release 9—evolving for mobile and beyond



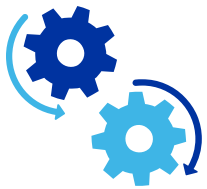
Integral part of LTE

Uses LTE spectrum, infrastructure, and devices

Media Delivery

Live Event Broadcasts

Breaking News



Over-the-Air OS/App Updates

Public Safety Alerts

Venue Casting

Traffic offload from unicast – live TV, software updates, and more

Scalable capacity – virtually unlimited number of users accessing same content

Increase network capacity even with just a few users per cell

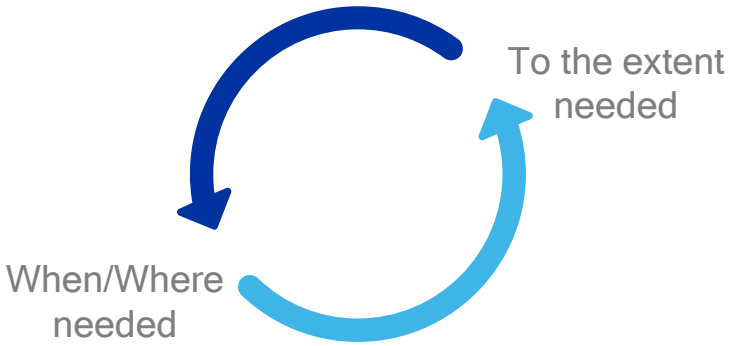
Leading operators are embracing LTE Broadcast

Including commercial launches, launch plans, trials, demos, and commitments

Evolving LTE Broadcast for mobile and beyond

Broadcast on Demand

Dynamic switching[1] between unicast and broadcast, even on a per cell basis



Provides scalability for demand or event driven broadcast, e.g. sports event

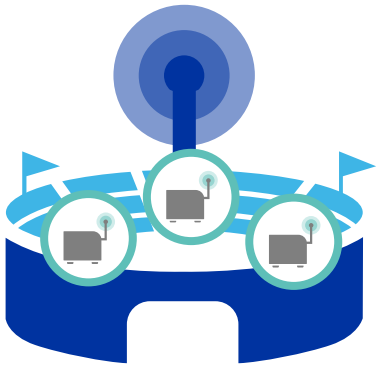
Converged TV services

Performance enhancements to enable a single network for mobile/fixed devices

Longer range up to 15 km[3], flexibility to dedicate full carrier, higher capacity[4], ability to insert customized ads, and support for shared broadcast[5]

Small Cell Optimizations

Including using bandwidth-rich 5 GHz unlicensed spectrum



Enhancing venue casting and beyond; such as leveraging LAA for better user experience than Wi-Fi[2]

Learn more at: www.qualcomm.com/broadcast

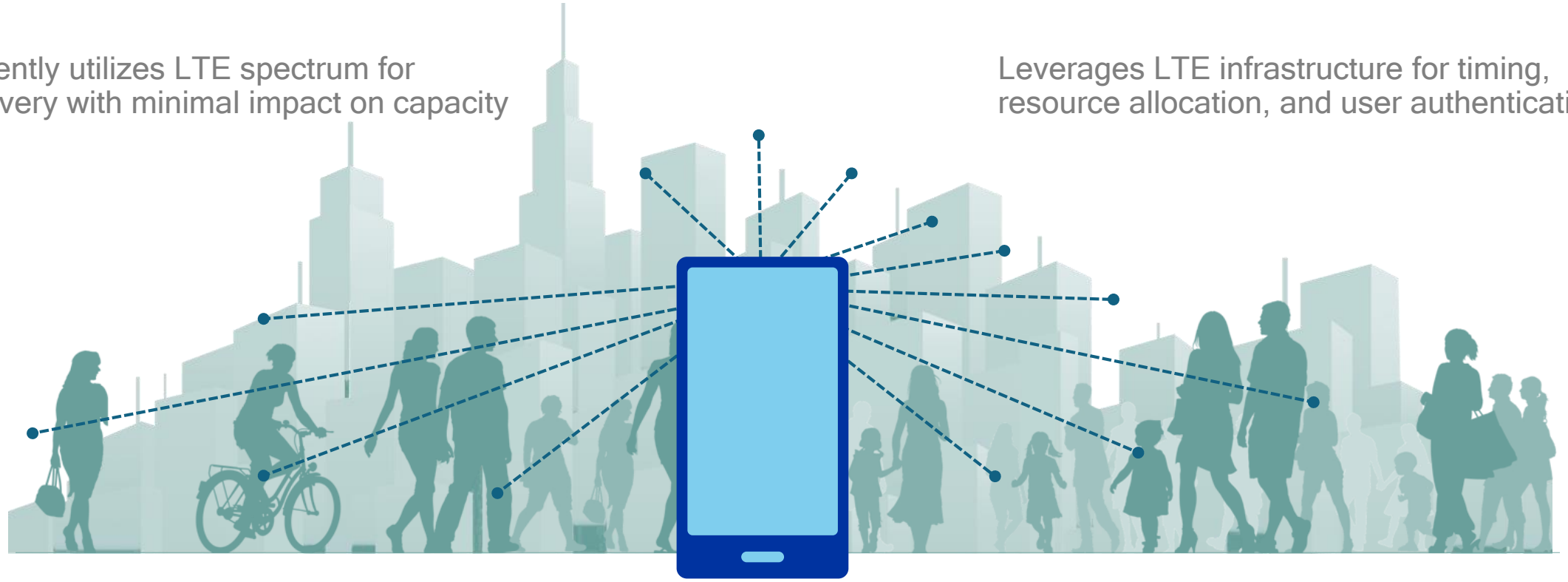
1 This feature is called Mood (Multicast operation on Demand) introduced in Rel. 12, evolving for per cell basis in Rel. 13; 2 Based on SFN gain and mandatory anchor in licensed spectrum; 3 with cyclic prefix of 200 us; 4 features such as 2x2 MIMO and 256 QAM part of Rel. 13 of 3GPP. 5 Proposed for 3GPP R14; delivery of broadcast via several providers using a common SFN timing on a shared broadcast carrier.

LTE Direct device-to-device proximity services

Part of 3GPP Rel. 12 – evolving in Rel. 13 and beyond

Efficiently utilizes LTE spectrum for discovery with minimal impact on capacity

Leverages LTE infrastructure for timing, resource allocation, and user authentication



Discovery at scale

Discovery of 1000s of devices / services in the proximity of ~500m

Always-on awareness

Privacy sensitive and battery efficient discovery

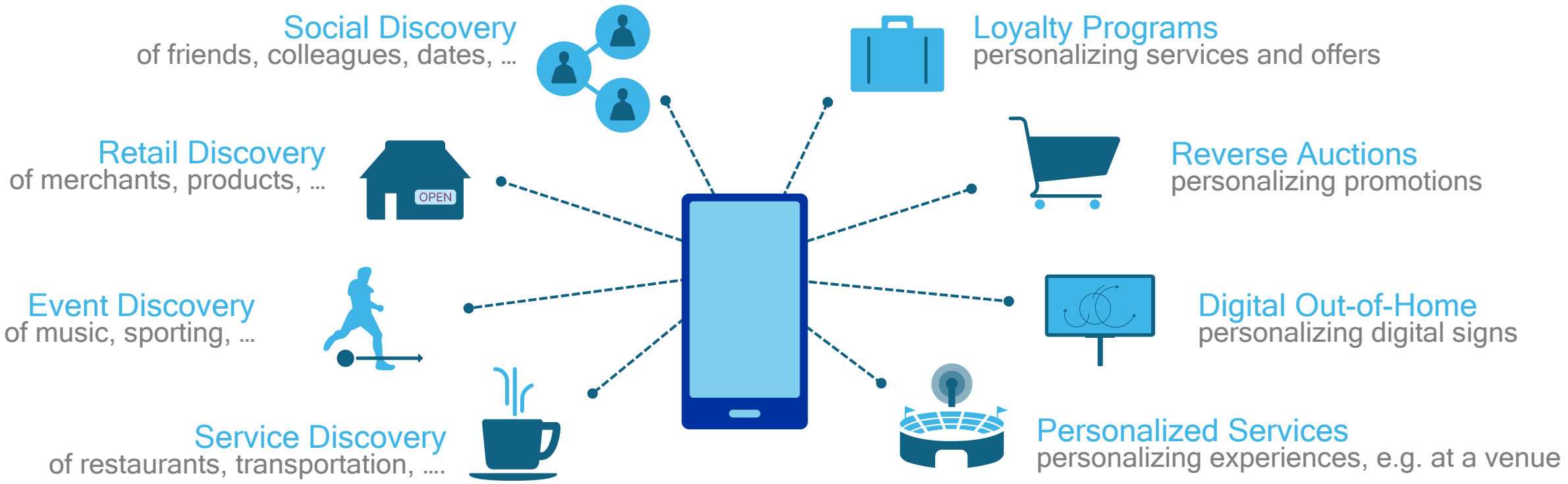
Interoperable discovery

Universal framework for discovery across apps/devices/operators

Enabling new LTE Direct proximal awareness services

Continuous Discovery
of relevant people, products, services, events

Personalized Interactions
with the user's surroundings and environment

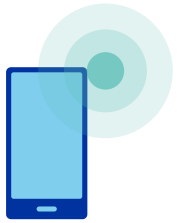


Based on the users interests/affinities

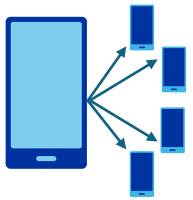
Expanding the LTE Direct device-to-device platform

Continuing to evolve in Release 13 and beyond

Release 12
D2D platform for consumer and public safety use cases



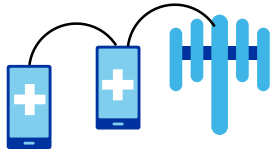
Discovery of 1000s of devices/services in ~500m



Reliable one-to-many communications (in- and out-of-coverage)*

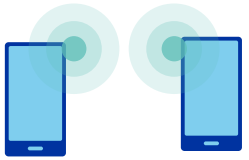
Release 13
Expanded D2D discovery and D2D communications

More flexible discovery such as out-of-coverage and multi-carrier



Device-to-network relays*

Release 14 & beyond
Multi-hop communication and more use cases



Additional D2D communication capabilities

Proposed for vehicle-to-vehicle (V2V)

Learn more at: www.qualcomm.com/lte-direct

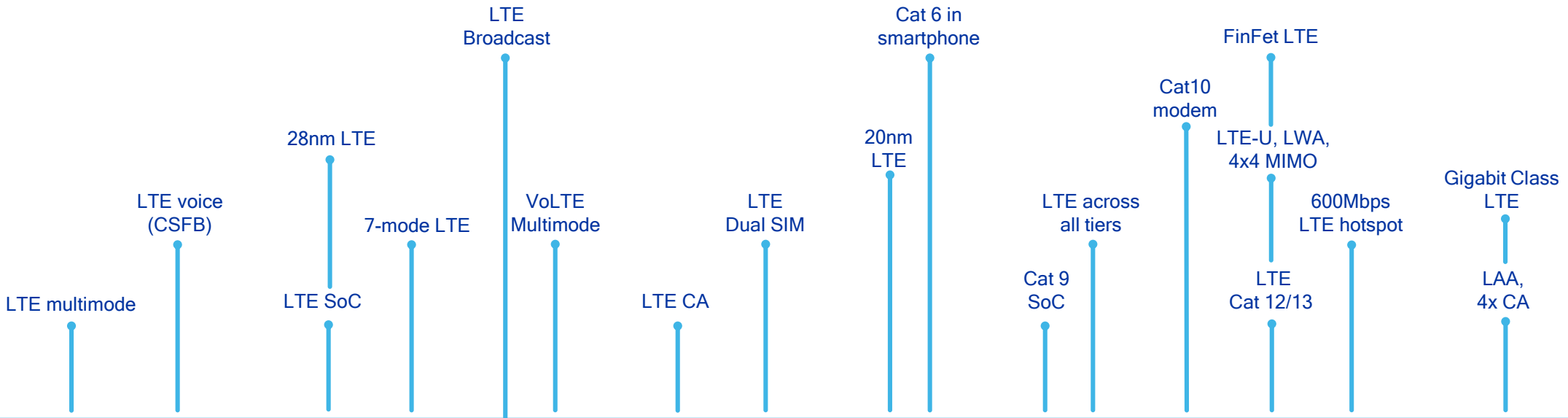
* Designed for Public Safety use cases

Leading the LTE Advanced evolution

A history of technology firsts

LTE platform leadership – a history of technology firsts

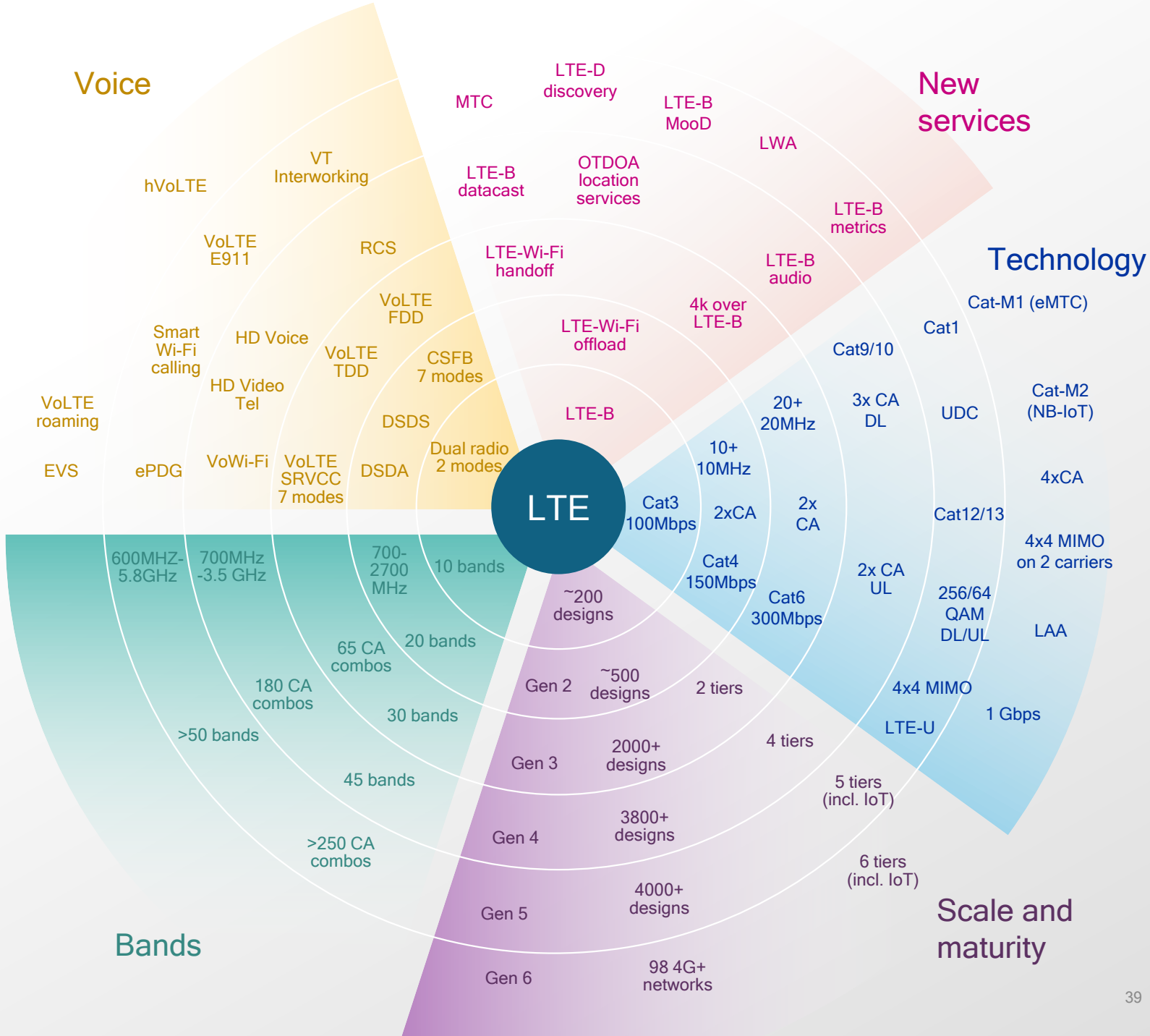
Qualcomm Snapdragon LTE modem leadership



Qualcomm inventions have fueled the evolution of mobile for over 30 years

Modem and RFFE technology leadership

Roadmap is significantly more complex and faster moving



Scale and maturity section includes cumulative LTE designs launched or in the pipeline by operational timeframe. Source: Qualcomm Technologies, Inc.

Driving new LTE technologies to commercialization

Example: Driving LTE Unlicensed to commercialization

Other industry-first demos include Carrier Aggregation, enhanced receivers, LTE Direct

Main contributor to LTE, LTE Advanced, and LTE Advanced Pro features

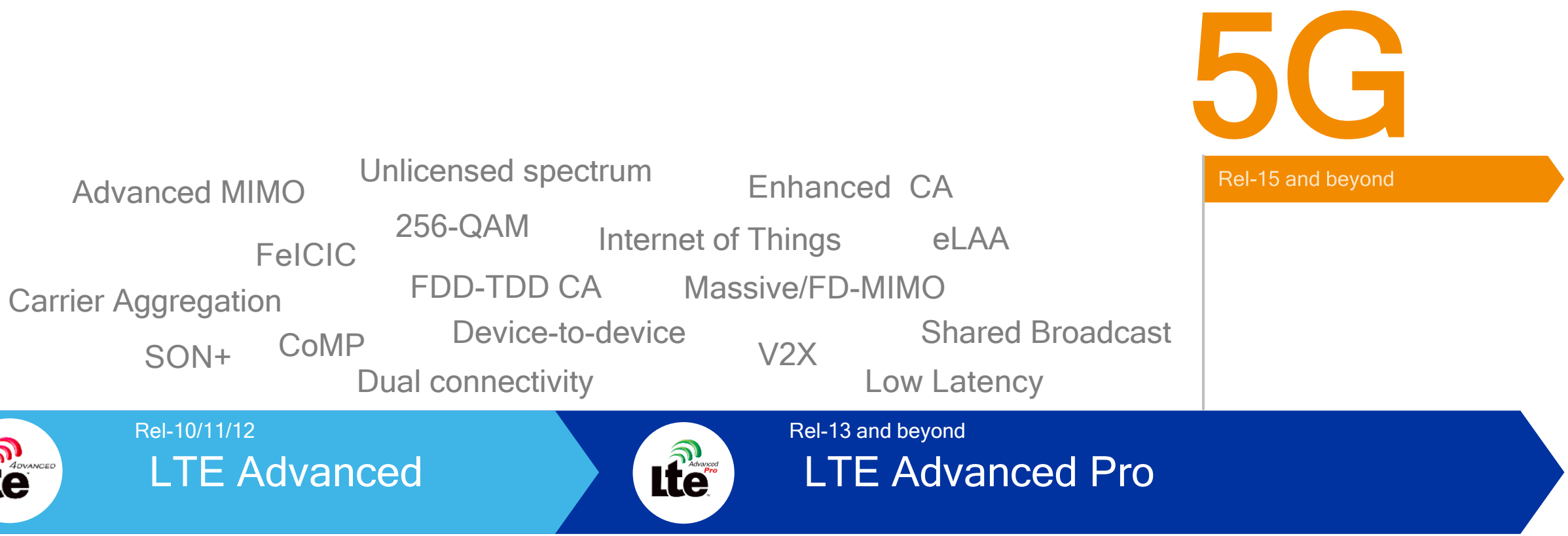
Other industry-first trials include LTE Broadcast, LTE Direct, FDD/TDD Carrier Aggregation

Other industry-first chipsets include LTE Multimode, LTE Carrier Aggregation, LTE SoC

* Chipsets are products of Qualcomm Technologies, Inc.; firsts with respect to public announcement of a commercial LTE modem chipset

Progressing LTE capabilities towards 5G

In parallel driving 4G and 5G to their fullest potential



Note: Estimated commercial dates. Not all features commercialized at the same time

Introducing LTE Advanced Pro

Rising up to meet the significant expanding connectivity needs of tomorrow

3GPP Release 13+

Propel mobile broadband even further

Enhance the mobile broadband experience and continue to deliver solutions to efficiently grow capacity

Progress LTE capabilities towards a unified, more capable 5G platform

Proliferate LTE to new use cases

Connecting new industries, enabling new services and empowering new user experiences

Learn more at www.qualcomm.com/lte-advanced-pro

Our 5G vision: a unifying connectivity fabric

5G

Enhanced mobile broadband

- Multi-Gbps data rates
- Extreme capacity
- Uniformity
- Deep awareness

Mobile devices

Networking

Mission-critical services

- Ultra-low latency
- High reliability
- High availability
- Strong security

Automotive

Robotics

Health

Massive Internet of Things

- Low cost
- Ultra-low energy
- Deep coverage
- High density

Wearables

Smart cities

Smart homes

Unified design for all spectrum types and bands from below 1GHz to mmWave

Qualcomm, leading the world to 5G

Investing in 5G for many years—building upon our leadership foundation

Wireless/OFDM technology and chipset[1] 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

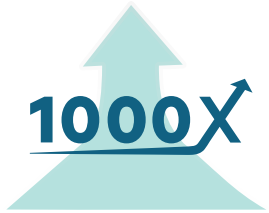
Providing the experience and scale that 5G demands

1 Chipsets are products of Qualcomm Technologies, Inc.

An essential innovator and accelerator of mobile and beyond

Delivering solutions for the 1000x data challenge

Innovative small cells and spectrum solutions



More capacity

- Small cells and self organizing technology
- LTE in unlicensed spectrum, MuLTEfire™
- LTE Advanced Carrier Aggregation, dual connectivity
- Advanced receivers and interference management
- Spectrum innovations like LSA
- Wi-Fi - 11ac, 11ad, MU-MIMO, OCE, 11ax
- 3G

Creating the connectivity fabric for everything

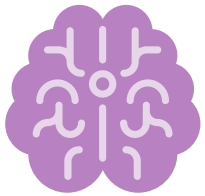
Connect new industries,
Enable new services,
Empower new user experiences

A new connectivity paradigm

- LTE-M (Machine-Type Communications), NB-IOT
- LTE Direct device-to-device
- LTE Broadcast
- LTE - Wi-Fi Convergence
- Wi-Fi - 11ah, 11ad, Wi-Fi Aware, Wi-Fi Direct, DSRC
- Bluetooth Smart
- OneWeb
- 5G

Bringing cognitive technologies to life

Devices and things that perceive, reason, and act intuitively



Next level of intelligence

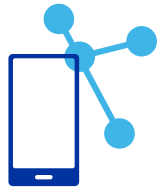
- Machine learning
- Computer vision
- Always-on sensing
- Immersive multimedia
- Cognitive connectivity
- Intuitive security
- Heterogeneous computing

Delivering on the LTE Advanced promise

Rising up to deliver a better, faster mobile broadband experience

1.  **Achieving** Gigabit Class LTE by evolving Carrier Aggregation and beyond

2.  **Providing** solutions to efficiently increase capacity by enhancing HetNets

3.  **Bringing** new ways to efficiently connect with LTE Broadcast & LTE Direct

4. QUALCOMM Why Wait **Leading** the LTE Advanced evolution – a history of technology firsts

Learn more at www.qualcomm.com/lte-advanced

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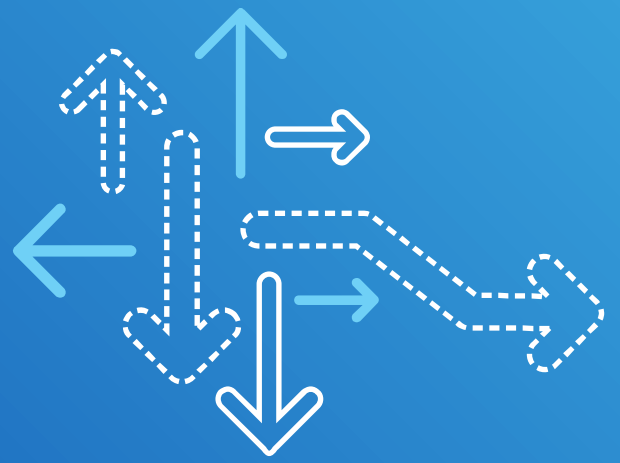
http://www.slideshare.net/qualcommwirelessevolution



Thank you

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