May 2015

Qualcomm Technologies, Inc.

Providing the Connectivity Fabric for Everything

The expanding role of LTE Advanced

QUALCOMM®

The evolution of wireless

Redefined Telephony
By mobilizing communications

2002

Mobile surpassed fixed voice

Redefined Computing
By mobilizing the Internet

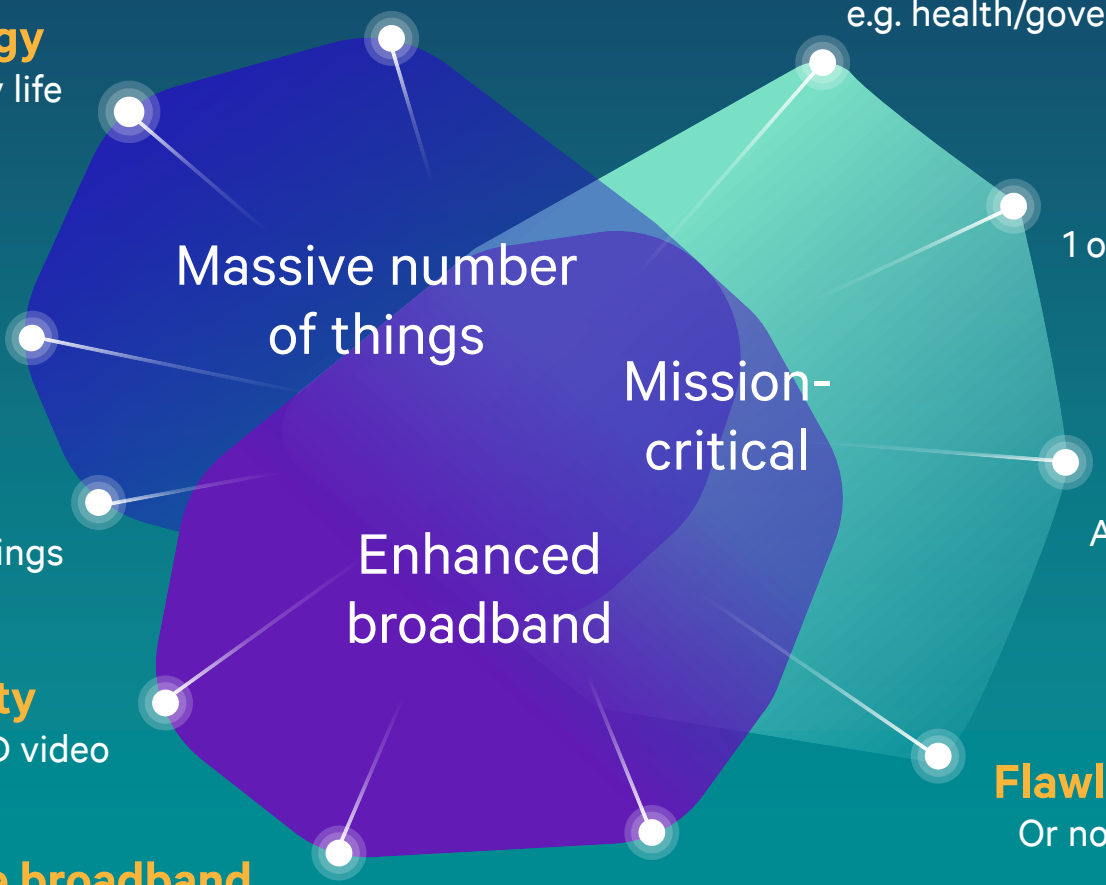
2010

Mobile surpassed fixed BB

Redefining Everything
By providing the connectivity fabric for everything

Fixed connections per ITU, mobile per GSMA. MBB per GSMA, Jul. '14; Fixed connections: BB per WBIS, Oct. '14

This new era brings e^x^ponential connectivity complexity



Deep coverage
To reach challenge locations

Strong security
e.g. health/government/financial trusted

Ultra low energy
10+ years of battery life

Ultra-high reliability
1 out of 100 million packets lost

Ultra low complexity
10s of bits per second

Ultra-low latency
As low as 1 millisecond of latency

Ultra high density
Tens of billions of devices/things

Flawless mobility
Or no mobility at all

Extreme capacity
1000x challenge, 4K UHD video

Deep awareness
Discover and optimize

Extreme broadband
Billions of bits per second (Multi-Gbps)

Providing the connectivity fabric for everything

Requires a new connectivity paradigm

Human communication	Scaling to connect virtually anything, anywhere
Devices as end-points	New and intelligent ways to connect & interact
Best effort data services	Also, new kinds of control & discovery services
Disparate networks	Convergence of access, spectrum types, services

The expanding role of LTE Advanced—a new paradigm

Scaling to connect the Internet of Everything

Carrier Aggregation

High performance

Ultra efficient

Cat-0, LTE-M

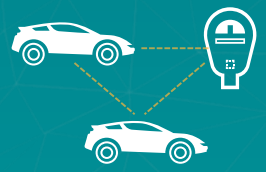
Bringing new ways to connect & interact

Evolving the LTE Direct Platform

Device-to-Device

Multi-hop

Vehicle-to-Vehicle / Infrastructure



Empowering new classes of services

Mission-critical control

LTE ULL

Broadcast

LTE Broadcast

Discovery

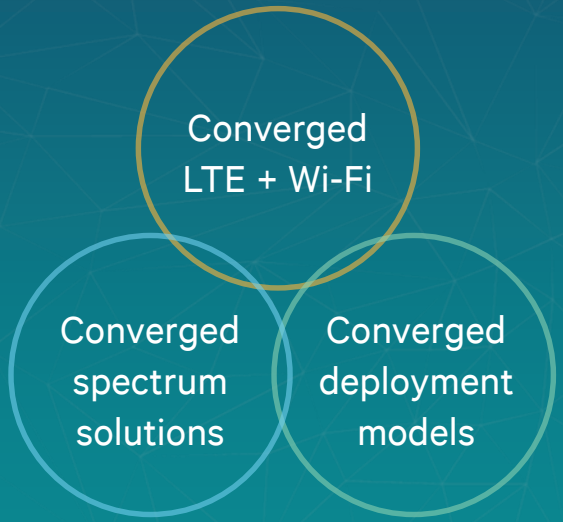
LTE Direct Proximity

Public Safety

LTE Direct MCPTT

Creating a converged connectivity platform

Link aggregation



LTE-U and LSA

Neighborhood small cell

Connecting everything requires different wireless solutions

To support the wide range of performance, cost, and energy requirements

Personal Area
Bluetooth

Short range communications, such as mobile/PC accessories

Local Area
Wi-Fi 802.11

The center of the connected home/enterprise

Wide Area
Mobile 3G & 4G LTE

For applications that demand ubiquitous coverage and high reliability

Bluetooth, Wi-Fi, and LTE all expanding to provide the connectivity fabric for everything

Personalized Retail

Entertainment on-the-go

Smart Digital Homes

Intelligent Energy

Redefining Everything

Connecting new industries

Empowering new experiences

Transforming society

Continuous Healthcare

Transportation Redefined

Sustainable Cities

Education Anywhere

Scaling LTE Advanced for the Internet of Everything (IoE)

Mobile technologies enable valuable IoE services

Ubiquitous coverage
Established networks serving ~7.1 Billion connections worldwide[1]

High reliability
Provides redundant network design for high availability, plus managed QoS

Robust security
Features built-in; trusted in government and finance sectors

High performance
Broadband data rates and real-time responsiveness

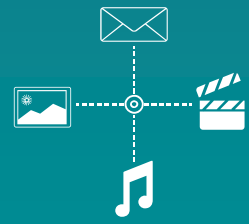
Mature ecosystem
Backed by global standards with seamless interoperability

Sample services

Remote monitoring and management

Real-time control and automation

Secure data services, e.g. financial, medical



Broadband services

1 Source: GSMA Intelligence, Jan. '15;

4G LTE provides a solid foundation for IoE growth

Common global standard

with a vibrant global ecosystem

390+ Networks
in 135+ countries

2,500+ Devices
from 250+ vendors

Network longevity

LTE has become one of the fastest growing wireless technologies providing a solid foundation for many years to come

Network efficiency

Increased spectral efficiency, simplified network infrastructure, and more efficient signaling

Superior performance

LTE and LTE Advanced provides the fastest and best broadband experiences for applicable wide area IoE use cases

Source: GSA (www.gsacom.com) – April 2015 for networks and Feb 2015 for devices

Scaling LTE Advanced to connect a wider range of device/things

Scaling up in performance and mobility

Scaling down in complexity and power

LTE Advanced
>10 Mbps
n x 20 MHz
Today+

LTE Cat-0
Up to 1 Mbps
20 MHz
Release 12

LTE-M (Machine-Type Communications)
10s of kbps up to 1 Mbps
~1 MHz narrowband
Release 13 & beyond

Clean-slate design[1]
Up to 100s of bps
~200 kHz narrowband

Sample use cases

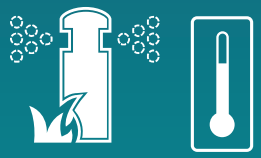

Mobile


Video security


Wearables


Object Tracking


Utility metering


Environment monitoring


Connected car

Energy Management


Connected healthcare


City infrastructure

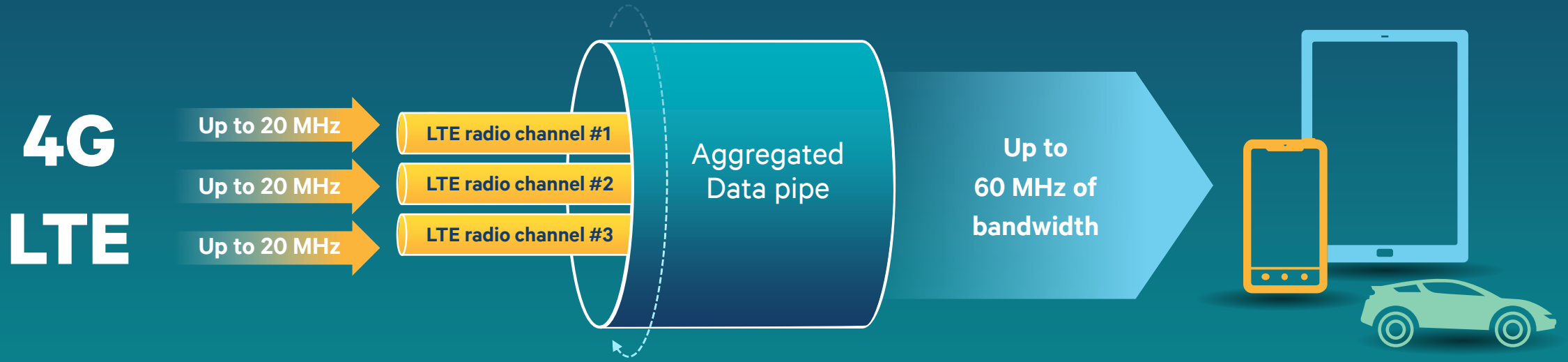

Smart buildings

Significantly widening the range of enterprise and consumer use cases

[1] New clean-slate radio design in 3GPP – proposed for Release 13 to scale to lower data rates and power; proposed to leverage LTE RAN; 3GPP study ongoing

Carrier Aggregation - Defining feature of LTE Advanced today

Scaling up for a superior mobile broadband user experience



Higher peak data rate and lower latency

Better experience for all users

More capacity and better network efficiency[1]

Maximizes use of radio spectrum

For more information: www.qualcomm.com/ca

1The 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

LTE Advanced Carrier Aggregation—strong global momentum

116 Operators investing

55 Countries

64 Commercial launches

2011–2012	2013	2014	Beyond
Up to 100 Mbps*	**Up to 150 Mbps***	**Up to 300 Mbps**	**Up to 450 Mbps***
LTE CAT3	LTE Advanced CAT4	LTE Advanced CAT6	LTE Advanced CAT10

Source: GSA Apr'15

* Maximum download rate

Progressively scaling down for machine-type communications

With critical optimizations realized with R13

For more information:
www.qualcomm.com/lte-mtc

RELEASE 11

Overload Control
Such as the ability to restrict access to delay-tolerant devices during overload[1]

RELEASE 12

PSM state
Power savings for some use cases

UE Category 0
Some cost/complexity reductions

RELEASE 13

LTE-M

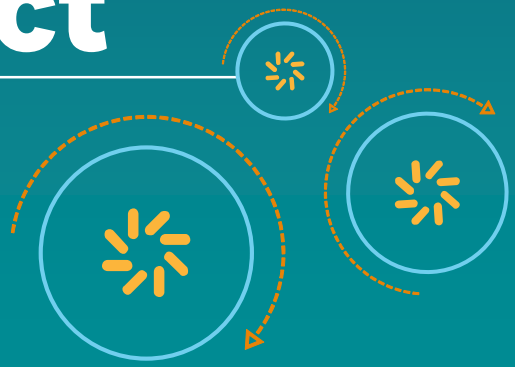
Significant power savings
New enhanced power save modes and efficient signaling

New, simpler device
Narrowband[2] operation reduces overall device complexity/cost

Enhanced Coverage
Advanced techniques to reach challenging locations

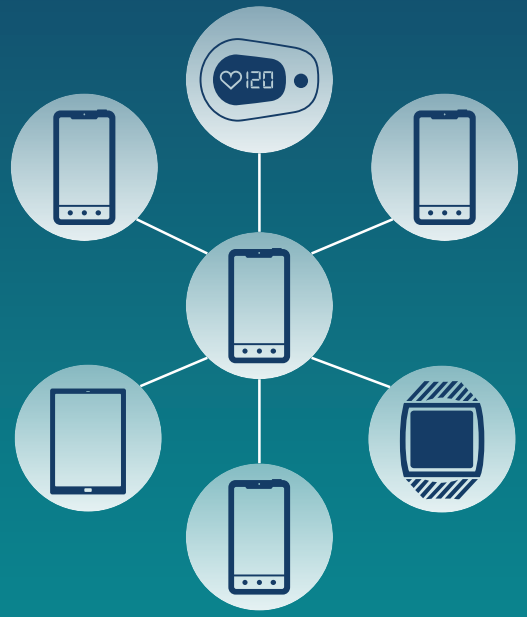
[1] By utilizing EAB Extended Access Barring; [2] ~1 MHz

Bringing new ways to connect and interact with LTE Direct

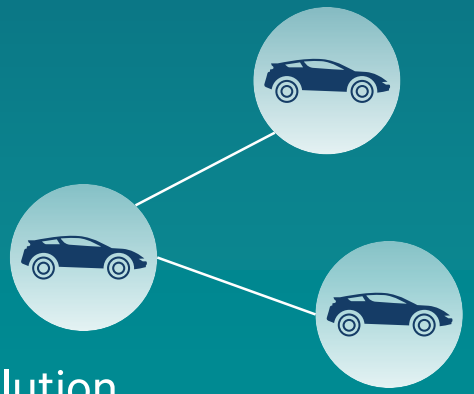


Bringing new ways to intelligently connect and interact

Device-to-device discovery and communications

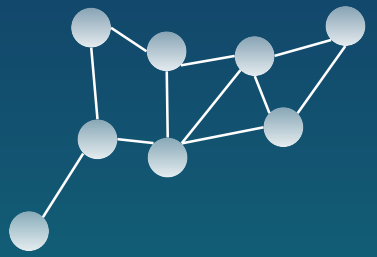


LTE Direct
Bluetooth Smart
Wi-Fi Direct/Aware



DSRC/802.11p
LTE Direct Evolution

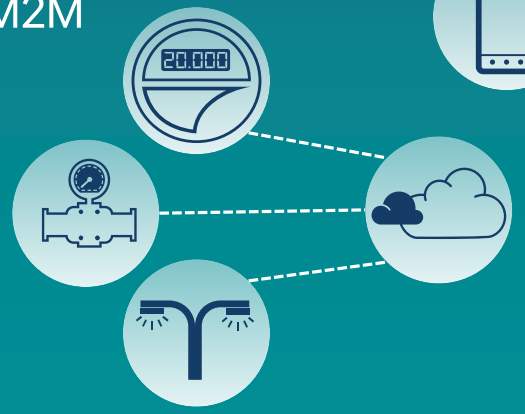
Relays and multi-hop to extend coverage



LTE Direct Evolution
11ah Mesh

Interoperable connectivity frameworks

oneM2M

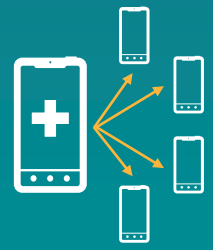


AllJoyn is a collaborative open source project of the AllSeen Alliance

Expanding the LTE Direct device-to-device (D2D) platform

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 and beyond
Multi-hop communication and more use cases

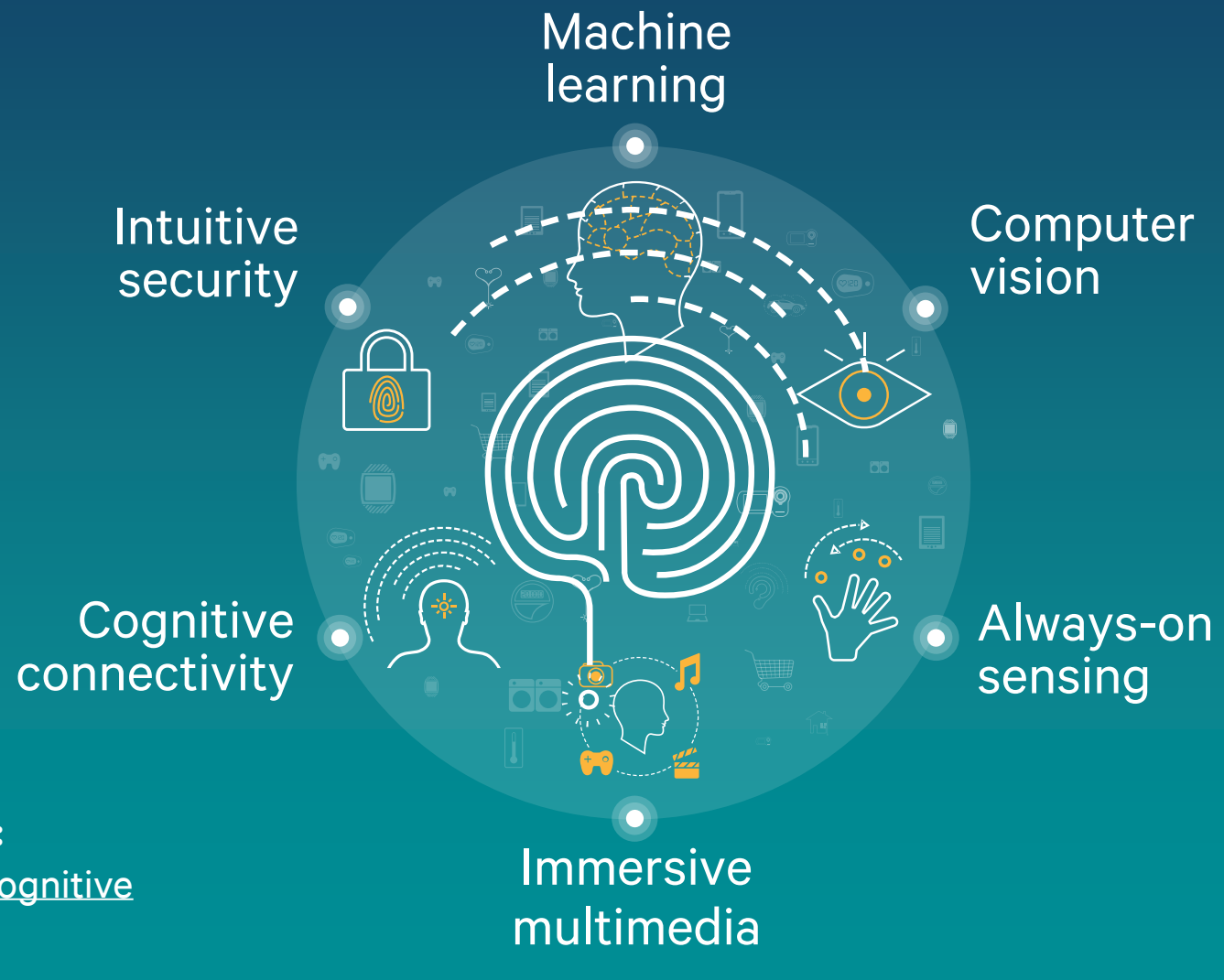
Additional D2D communication capabilities

Proposed for vehicle-to-vehicle (V2V)

* Designed for Public Safety use cases

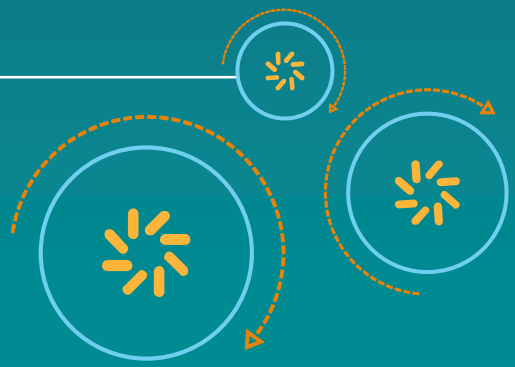
Also requires new levels of on-device intelligence & integration

Bringing cognitive technologies to life



For more information:
www.qualcomm.com/cognitive

Empowering new classes of services—such as broadcast, discovery, and control

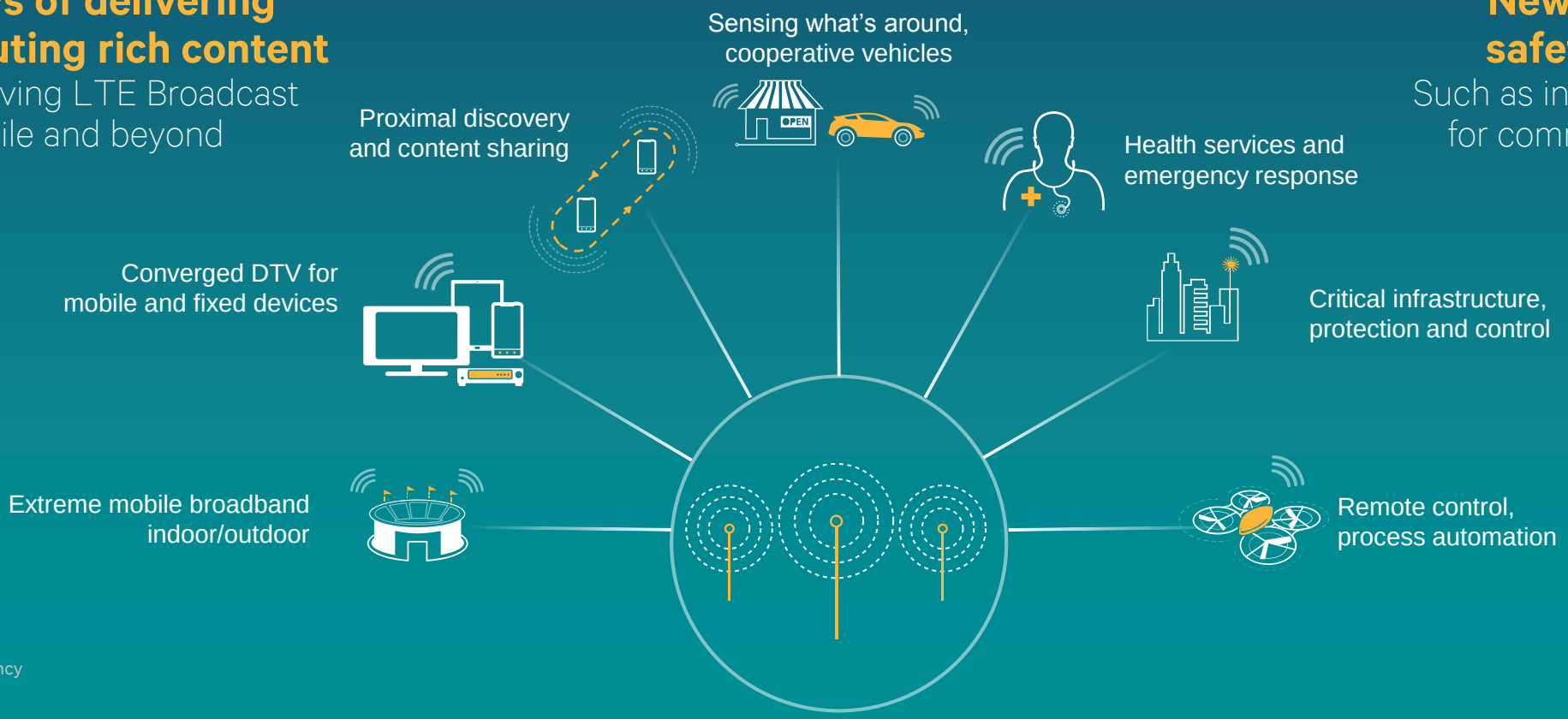


Empowering new classes of wireless services

New ways of interacting with the world
Such as LTE Direct proximal awareness and discovery services

New ways of delivering and distributing rich content
Such as evolving LTE Broadcast for mobile and beyond

New control and safety use cases
Such as introducing LTE ULL[1] for command-and-control

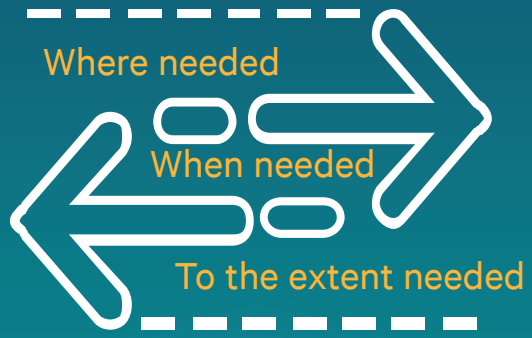


[1] ULL = Ultra Low Latency

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

Small Cell Optimizations

Including using bandwidth-rich 5 GHz unlicensed spectrum

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

Converged TV services

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

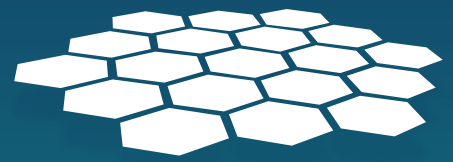
Longer range up to 15 km[3], flexibility to dedicate full carrier, higher capacity[4], ability to insert customized ads, and support for shared broadcast[5]

For more information: 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.

Using LTE Broadcast for converged digital TV services

Candidate in Europe—a single broadcast network for mobile and fixed devices



Overlay broadcast on existing LTE network—with opportunity for shared broadcast[2]

Unpaired Spectrum

Offering TV service on dedicated spectrum

Exploiting LTE devices with inherent LTE Broadcast support

Adding LTE Broadcast capability to other devices, such as regular TV

2x more efficient than today's DVB-T/ATSC[1]

Allows broadcasters to reach lucrative mobile market

Converged broadcast-unicast, e.g. on-demand, interactivity

1 Current broadcast technology operates in Multi Frequency Network (MFN) mode with a frequency reuse of at least 4 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 LTE-B operates in SFN over the entire coverage area with a spectrum efficiency of up to 2bps/Hz. 2 Proposed for 3GPP R14; delivery of broadcast via several providers using a common SFN timing on a shared broadcast carrier

Empowering new proximal awareness services

New ways to passively discover and interact with the hyper-connected world

Based on the user's interests/affinities

Scaling up proximity services for mass consumer adoption

Location-based

Centralized Geo-fencing

Poor adoption due to poor battery life, privacy barriers, and mobile app silos

Bluetooth Beacons

Distributed Geo-fencing

Gaining traction across limited use cases due to Bluetooth range and capacity, plus mobile app silos continue

LTE Direct Proximity Services

Device-to-Device Discovery

The path to mass adoption across a wide range of use cases with discovery that is:

- Battery efficient and privacy sensitive
- ~10x the range of Bluetooth
- Scalable to 1000s of devices/service
- Interoperable across mobile apps

Implementation of the LTE Direct ecosystem well underway

Standardization

by 3GPP as a feature in Release 12

- System Architecture and RAN specification complete
- RF performance and conformance forecasted to be complete by June 2015[1]

Operators Trials

launching across multiple regions

- Trials announced with Deutsche Telekom (Germany) & KT Corp. (Korea)
- Additional trials planned in Korea, US, and Europe
- Trials supported by multiple infrastructure vendors and device OEMs

App Developers

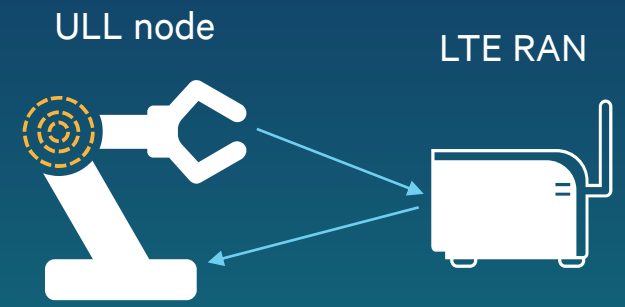
engaging on use case development

- Developing use cases leveraging trial SDK by Qualcomm Technologies
- Early developers include Facebook, Yahoo, Control Group, R/GA, Sacramento Kings, M-87, Compass.To, and more

For more information: www.qualcomm.com/lte-direct

1 Estimated completion date

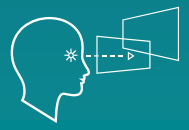
Enabling new low-latency use cases with LTE Ultra Low Latency



Potential use cases

Industrial process automation

Cooperative vehicles



Industrial HMI (e.g., augmented reality)

UAS command & control

Millisecond latency—targeting end-to-end (e2e) latency of ~1 millisecond[1]

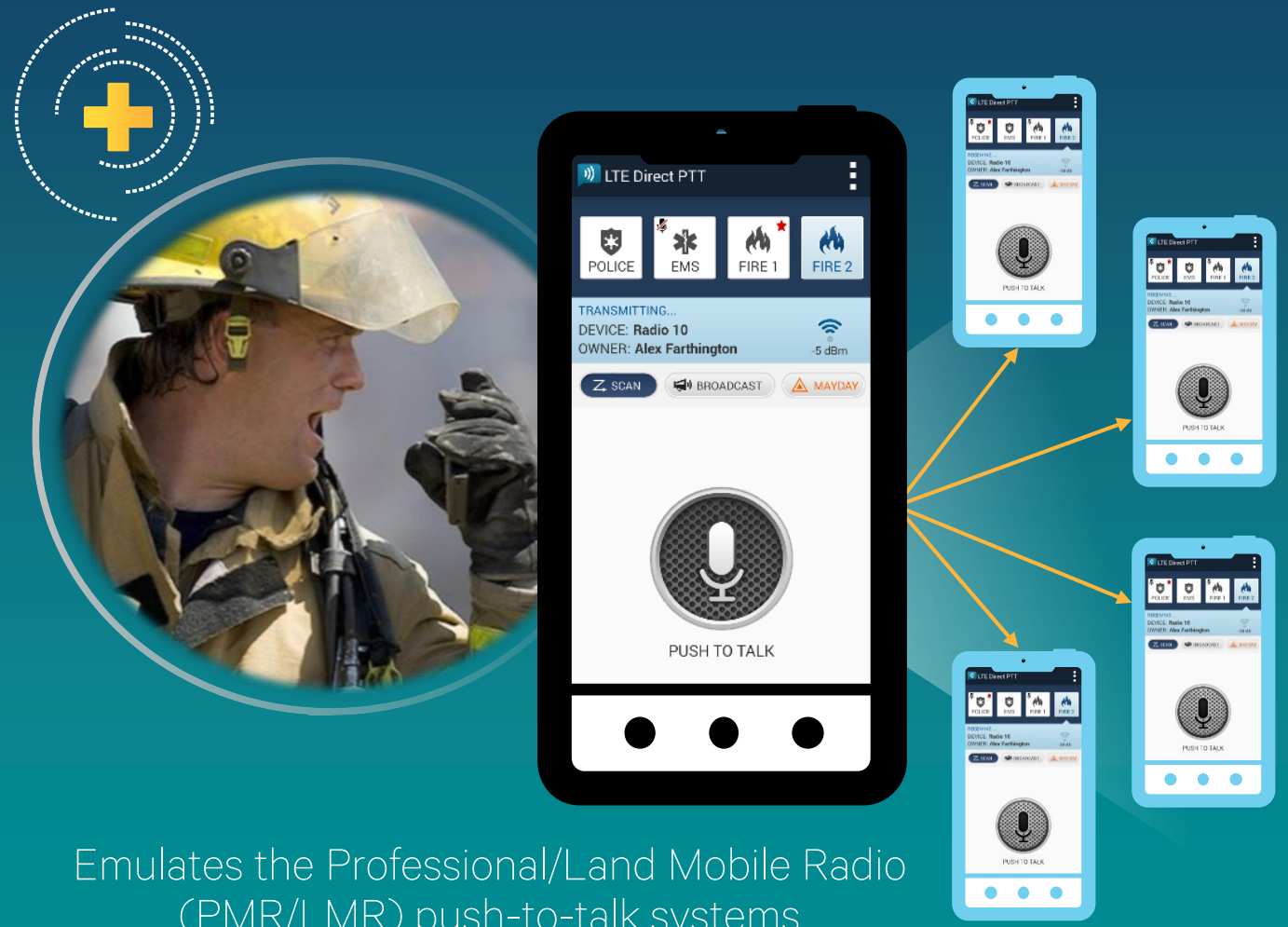
Co-existence between regular LTE and LTE ULL nodes

Standardization by 3GPP as a work study in Release 13

Also, delivers faster speeds for general TCP transactions

[1] Round Trip Time (RTT) at edge of RAN with edge caching

Enabling mission-critical Public Safety services with LTE Direct



Emulates the Professional/Land Mobile Radio (PMR/LMR) push-to-talk systems

Robust device-to-device communications
(both in-coverage and out-of-coverage)

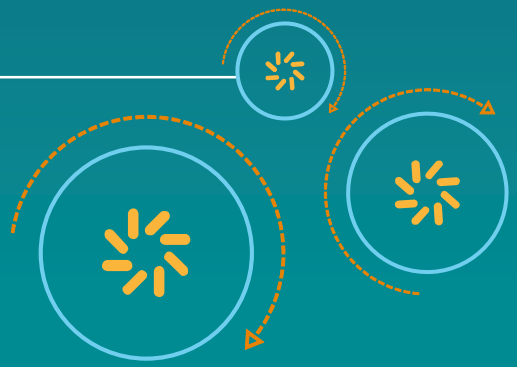
Vast ecosystem of devices leveraging global LTE standard

Standardization by 3GPP as a features in:

- Release 12: one-to-many communications
- Release 13: UE-network relays, MCPTT[1] service layer

[1] MCPTT = Mission-Critical Push-to-Talk

Driving convergence of spectrum types, networks, and deployment models



Creating a converged connectivity platform

LTE and Wi-Fi convergence

Going beyond complexities of multimode, multiband and interworking—such as LTE – Wi-Fi link aggregation

Converged business models

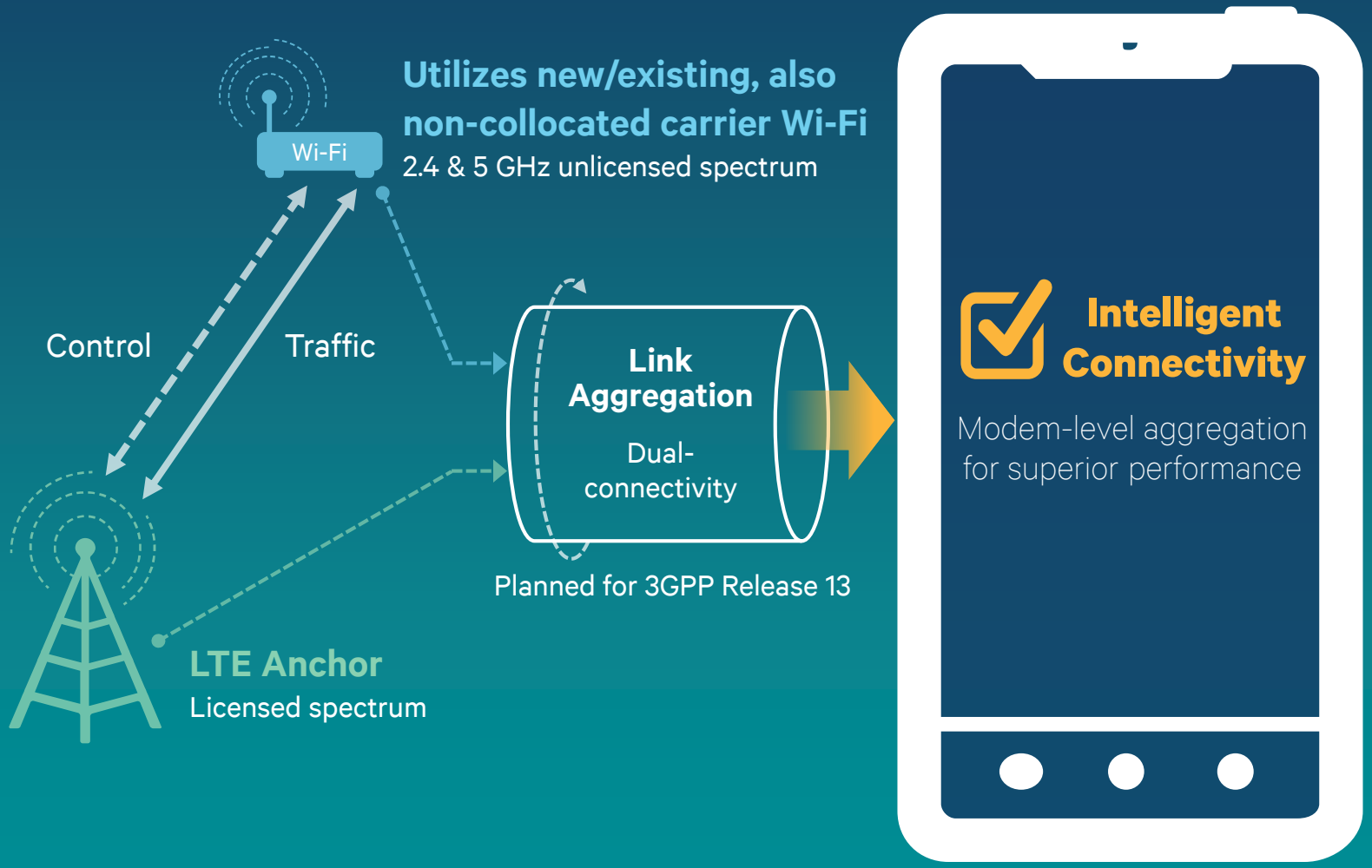
Providing more scalable solutions, e.g. Neighborhood Small Cells (NSC) to drive fixed/mobile convergence

Converged spectrum solutions

Unifying spectrum types with LTE-U, new spectrum sharing models—such as Licensed Shared Access (LSA)

With new levels of distributed intelligence in access nodes, devices, and things

LTE - Wi-Fi link aggregation for a converged network



Converged network
LTE network (eNB) in control of Wi-Fi resources

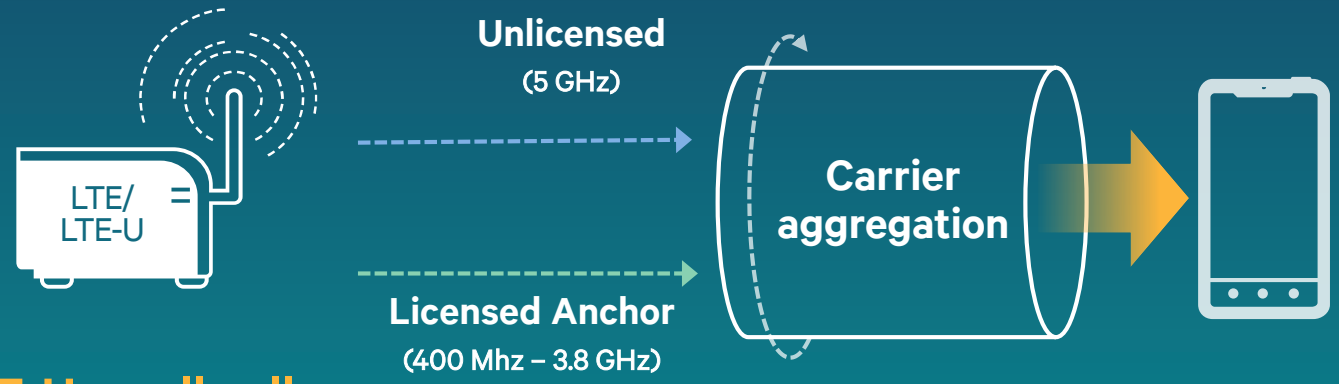
Better performance
Simultaneously using both LTE & Wi-Fi links

Enhanced user experience
Licensed anchor for control and mobility

Notes: Aggregation on modem level (PDCP level), also leveraging dual connectivity defined inR12; Control over X2-like interface needs to be supported by Wi-Fi AP. No change to LTE & WiFi PHY/MAC. No change to core network

LTE-U: A unified solution for licensed & unlicensed spectrum

LTE-U R10/11/12 for most regional markets[1]; LTE-U R13 (LAA) for markets that require LBT[2]



LTE-U small cell

- Supplemental Downlink (SDL) to boost downlink [3]
- Carrier aggregation to boost both downlink and uplink [4]

~2x capacity and range
Compared to Wi-Fi[3]

Enhanced user experience
Licensed anchor for control and mobility

Unified LTE network
Common management

A good Wi-Fi neighbor
In many cases, better neighbor to Wi-Fi than Wi-Fi itself

For more information: www.qualcomm.com/convergence

[1]Regional markets that do not require modified waveform for LBT including USA, China, Korea, India, and more; With dynamic channel selection and Carrier Sensing Adaptive Transmission (CSAT) required in small cell for fair coexistence with Wi-Fi.

[2]LTE-U in 3GPP Rel 13 is referred to as Licensed Assisted Access (LAA); includes modified waveform for Listen Before Talk (LBT); for Europe, Japan, and beyond

[3]Main option for LTE FDD, but the specific band for SDL need to be defined. Either TDD or FDD aggregation is possible with SDL; [2]Using TDD + TDD aggregation, or FDD + TDD aggregation with TDD used for unlicensed spectrum

[4]Assumptions: Two operators. 48 Pico+108 Femto cells per operator. 300 users per operator with 70% indoor. 3GPP Bursty model. 12x40MHz @ 5GHz for unlicensed spectrum; LTE 10 MHz channel at 2 GHz;. 2x2 MIMO, Rank 1 transmission, eICIC enabled; LTE-U – LAA R13, 2x2 MIMO (no MU-MIMO).; Wi-Fi - 802.11ac 2x2 MIMO (no MU-MIMO), LDPC codes and 256QAM)

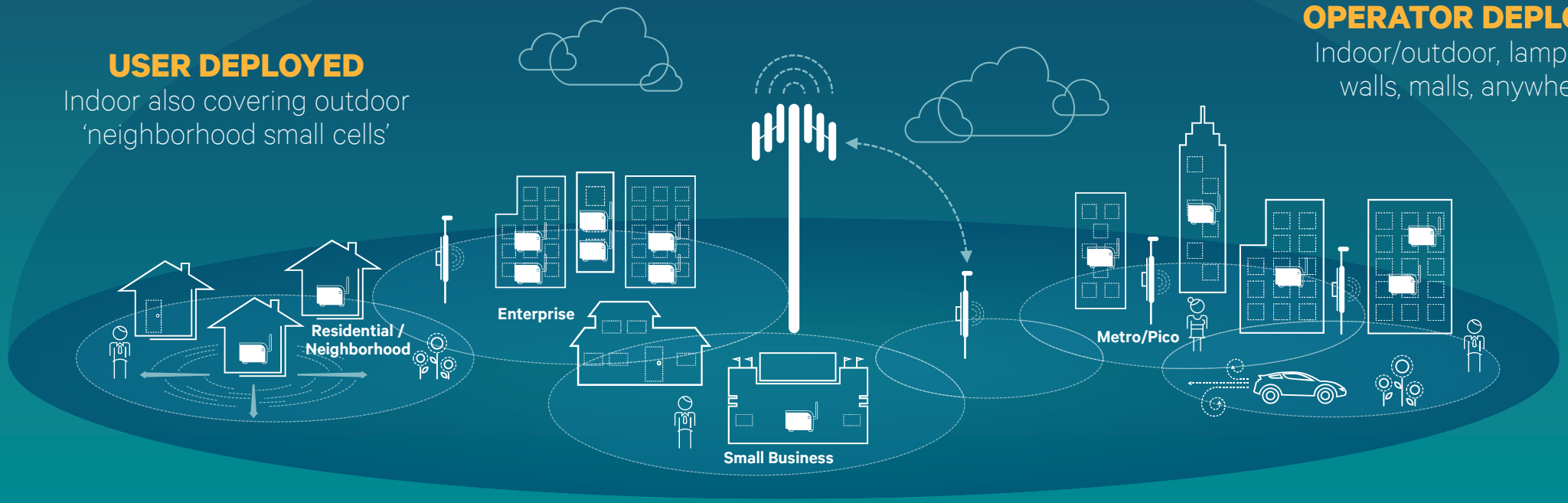
Enabling more scalable deployment solutions

Convergence of fixed/mobile with unplanned, ad-hoc deployments of small cells

PARTNER DEPLOYED
Such as utility provider, contractor or enterprise IT department

USER DEPLOYED
Indoor also covering outdoor 'neighborhood small cells'

OPERATOR DEPLOYED
Indoor/outdoor, lampposts, walls, malls, anywhere...



Viral, ad-hoc, 'unplanned', e.g. where backhaul exists—more like Wi-Fi

Plug & play, self organizing, coordinated small cells

Managed by operator in licensed spectrum

LTE Advanced is expanding—new, transformative technologies

2009 • • •	2016	2017	2018+

Providing the connectivity fabric for everything

- LTE Broadcast
- LTE Direct discovery & broadcast comm.[4], Cat-0[5], new PSM[6], LTE Broadcast evolution (e.g. MooD[7])
- **Optimize for efficient machine-type communications**, e.g. LTE-M[8]
- **Bring new ways to connect** by expanding LTE Direct D2D capabilities (e.g. UE-network relays[4]) and use cases (e.g. vehicle-to-vehicle)
- **Empower new classes of low-latency services**, e.g., command-and-control, with the introduction of LTE Ultra Low Latency
- **Extend to new vertical markets**, e.g. evolving LTE Broadcast for converged digital TV, MCPTT[9] for Public Safety

Rel-8 | Rel-9 | Rel-10 | Rel-11 | Rel-12 | Rel-13 and Beyond

LTE

LTE Advanced
Driving beyond Gbps peak rates[1] and better efficiency

A new connectivity paradigm
Expanding to new usage models, while enhancing the foundation—faster, more efficient mobile broadband

- Carrier Aggregation, HetNets (eICIC-IC[2]), Advanced MIMO
- Realizes full benefits of HetNets (feICIC-IC[2]), CoMP[3]
- Dual connectivity, Enhanced receivers, FDD-TDD CA, 256QAM
- **Make better use of unlicensed spectrum**, e.g. LTE-U (LAA[10]), LTE/Wi-Fi link aggregation, LTE-U enhancements (dual connectivity, wider BW)
- **Further enhancing HetNets**, e.g. enhance dual connectivity
- **Evolve carrier aggregation**, e.g. more carriers
- **More advanced antenna features**, e.g. 3D-FD MIMO
- **Advanced receivers**, e.g. Non-Orthogonal Multiple Access (NOMA)

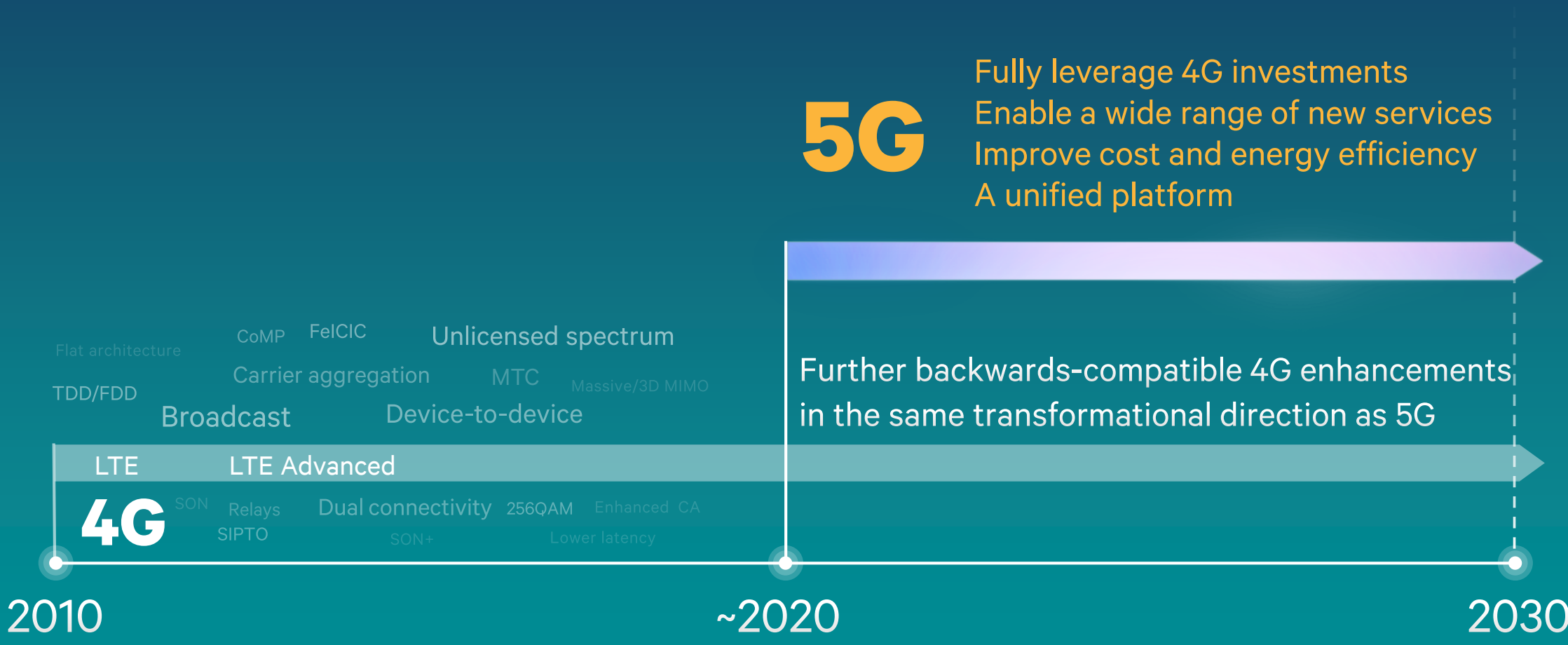
Continuing to solve the 1000x challenge

Commercial Releases

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

[1] Based on standard capable of up to 3 Gbps DL and 1.5 Gbps UL; [2] (further) enhanced Inter-Cell Interference Coordination and advanced terminal receivers with Interference Cancellation; [3] Coordinated Multipoint; [4] Designed for Public Safety in R12, R13; [5] UE category, peak rates of 1 Mbps; [6] Power Save Mode; [7] Multicast operation on demand; [8] Machine-type Communications; [9] Mission-Critical Push-to-Talk; [10] License Assisted Access

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



For more information: www.qualcomm.com/5G

We are inventing new, transformative technologies for;

Solving the 1000x data challenge

Innovative small cells and spectrum solutions

More Capacity

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

Providing the connectivity fabric for everything

Intelligently connect everything, empower new classes of services, drive convergence

A new connectivity paradigm

- LTE-M (Machine-Type Communications), Clean-slate IoT
- LTE Direct device-to-device
- LTE Broadcast
- LTE Ultra-low Latency (ULL)
- LTE – Wi-Fi Convergence
- Wi-Fi – 11ah, 11ad, Wi-Fi Aware, Wi-Fi Direct, DSRC
- Bluetooth Smart
- 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

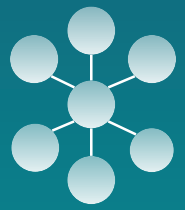
The expanding role of LTE Advanced—a new paradigm

Connecting new industries, enabling new use cases

1

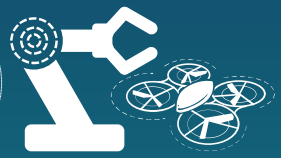
Scaling to connect a wider variation of devices/things—such as LTE-M optimizations

2



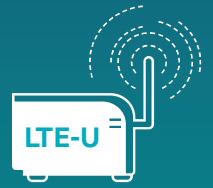
Bringing new, intelligent ways to connect & interact by expanding the LTE Direct platform

3



Empowering new classes of services such as ultra low latency command-and-control

4

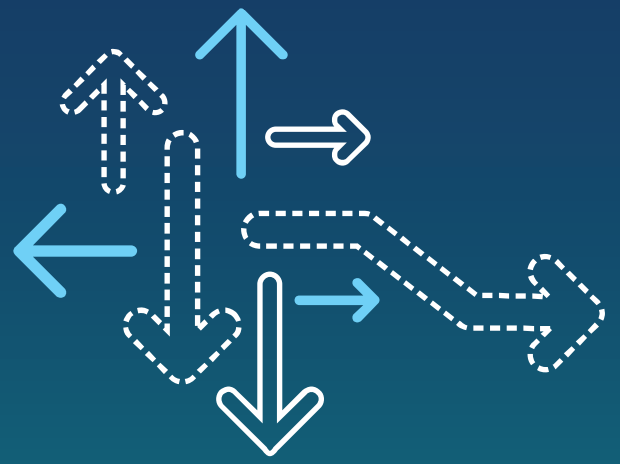


Driving convergence of spectrum types, networks, and deployment models—such as LTE-U

5

Also, continuing to deliver key enablers to solve the 1000x data challenge

Questions? - Connect with Us



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