September 2018

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Qualcomm

Demystifying 3GPP

and the essential role of Qualcomm in leading the mobile ecosystem expansion

The revolutionary impact of mobile broadband

High-speed wireless Internet access–in the palm of your hand on-the-go

~5.1 B Mobile broadband connections[1] – surpassed fixed in 2010

675 4G LTE commercial networks in over 200 countries[2]

~49 Smartphones ship every second

Over 1.5 billion units in 2017[3]

2h 51m The average time a consumer spent on their smartphone per day[4]

~$3.3 T Global revenue generated by mobile value chain in 2014, directly responsible for 11 million jobs

1. GSMA Intelligence, Jun.'18; 2. GSA, May'18;
3. Gartner, Feb '18; 4. comScore, Dec. '16; 5. BCG, Jan '15

3GPP drives global cellular standards – 2G, 3G, 4G and 5G

19+
Years driving cellular tech evolution

13
Major releases

>1.2K
Tech specifications*

100,000's
Technical contributions

3rd Generation Partnership Project

560+
Member companies

16
Technical working groups

6-8
Working group meetings per year

2,000+
Man years in cumulative meeting time*

* Source: 3GPP Mobile Competence Centre (3GPP Support Team) Summary Report from RAN#79 (RP-180616)

Member-driven organization
Relies on R&D and tech inventions from members, e.g., 'contributions'

Collaborative engineering effort
Consensus-based, tech-driven effort across 100s of entities

Distributed work-flow
Scale/complexity requires division of work into smaller, specialized pieces

3GPP technologies have fueled mobile innovation

3GPP
A GLOBAL INITIATIVE

2G GSM/EDGE

3G UMTS /WCDMA HSPA / HSPA+

4G LTE | LTE Advanced | LTE Advanced Pro

5G NR 5G NR

1990s
Digital voice

2000s
Mobile data

2010s
Mobile internet

2020s
Mobile expansion

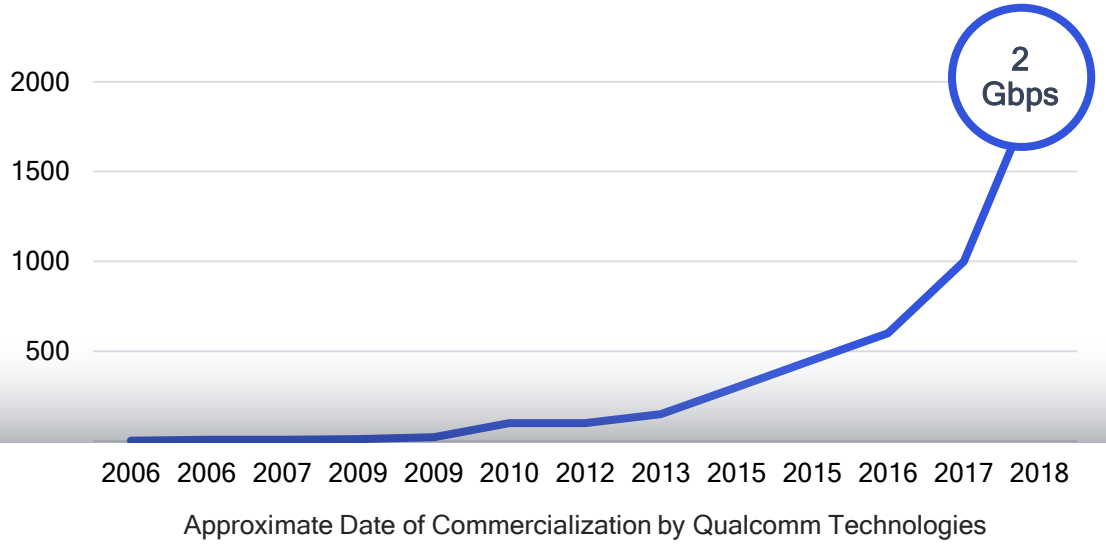
3GPP started 1998 after introduction of 2G, but has been responsible for GSM/EDGE evolution since 1998

Last 15+ years focused on faster, better mobile broadband

Delivering innovations to address the ever-increasing data demand

Wireless technology advances, …

Peak download speed supported in modem (Mbps)



Approximate Date of Commercialization by Qualcomm Technologies

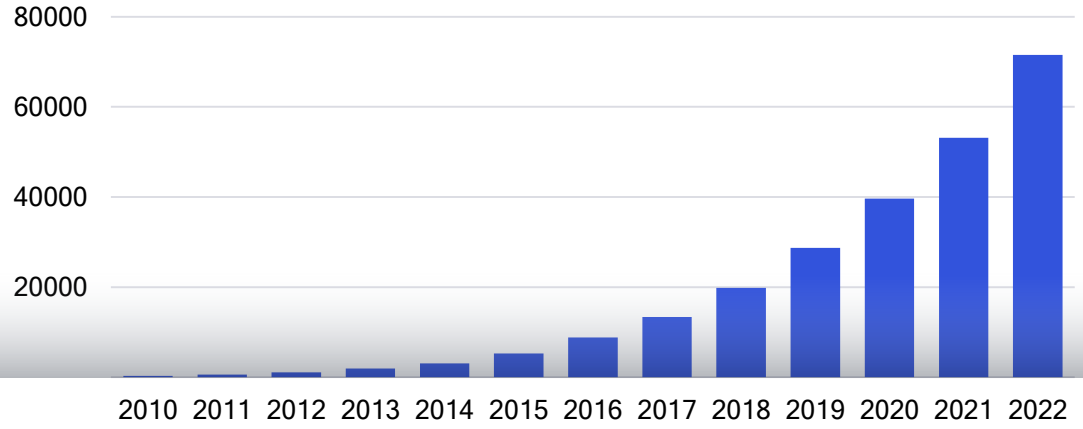
>1000x growth

in peak download speeds from early 3G devices

Source: Qualcomm Technologies, Inc.; subject to network availability

… to meet increasing demand

Global mobile data traffic (Petabytes per month)



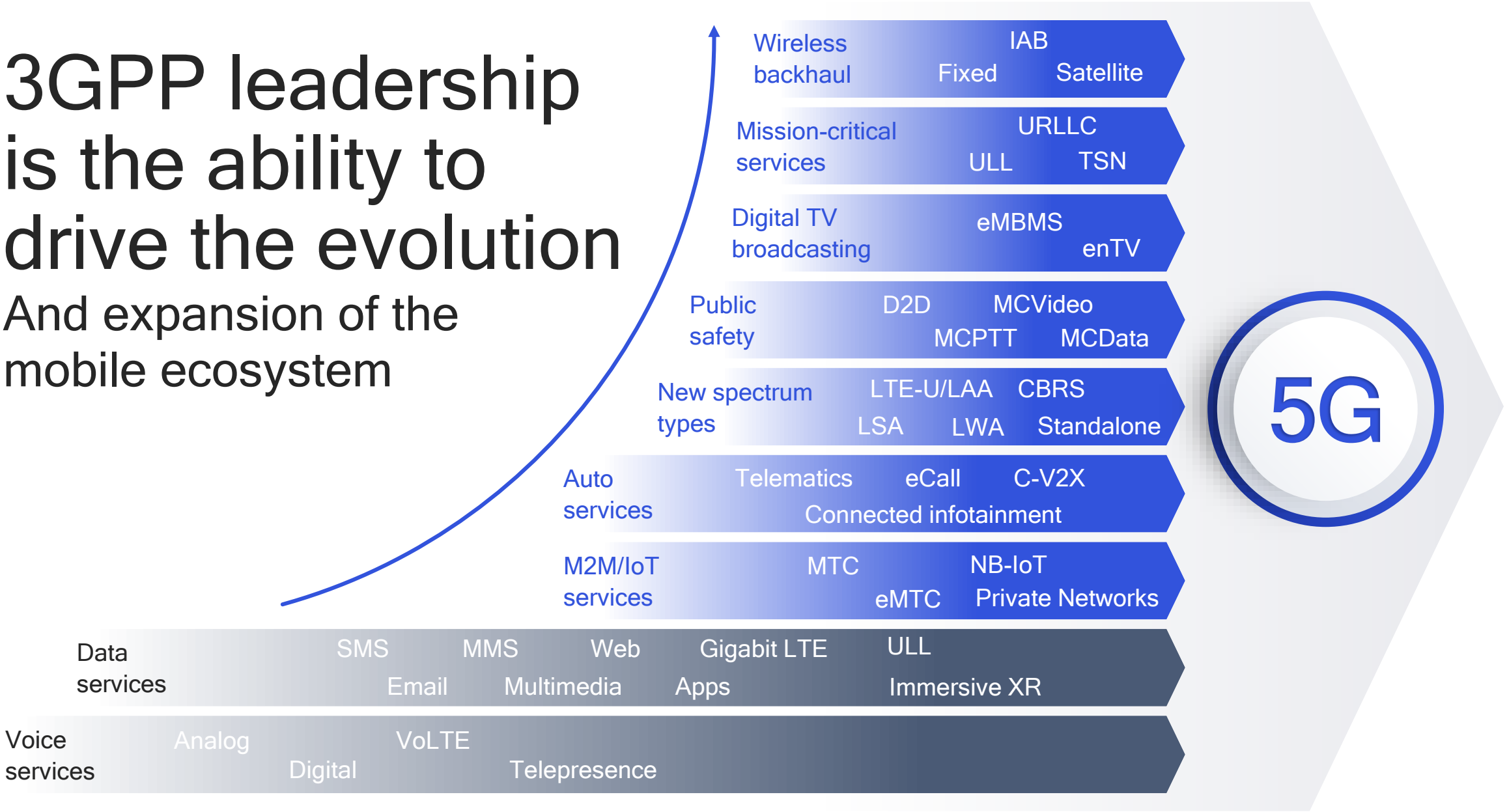
>250x growth

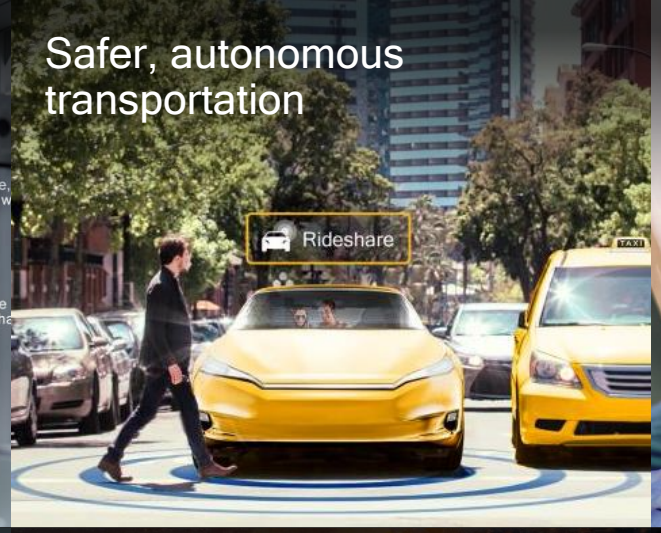
in data traffic between 2010 and 2022

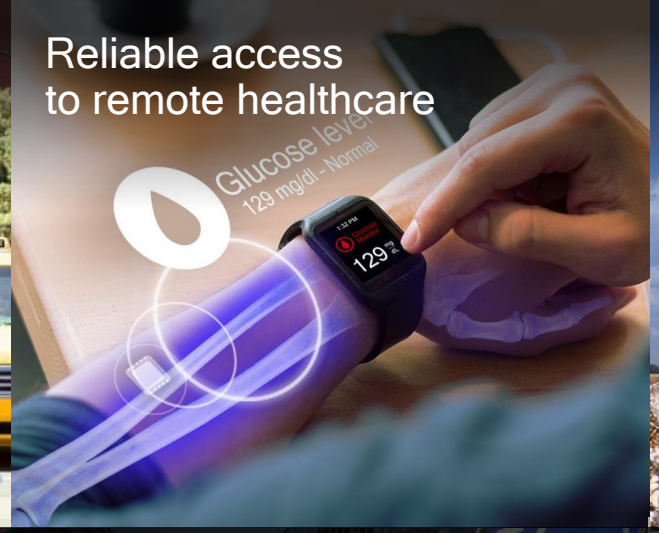
Source: Ericsson's Mobility Report 2017

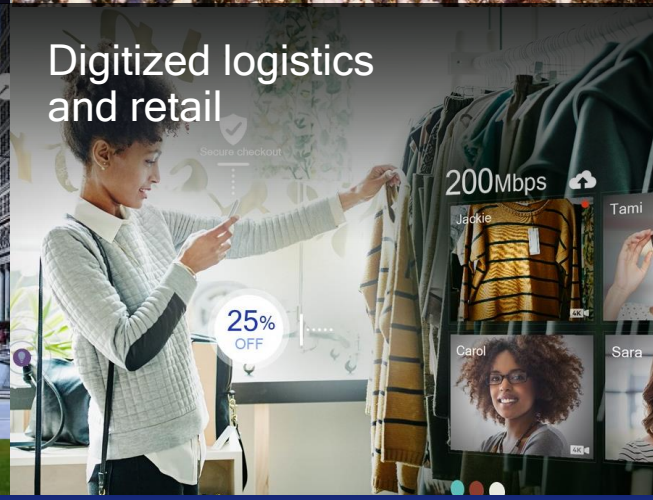
3GPP leadership is the ability to drive the evolution

And expansion of the mobile ecosystem









5G

5G will expand the mobile ecosystem to new industries

Powering the digital economy

>$12 Trillion

In goods and services by 2035*

* The 5G Economy, an independent study from IHS Markit, Penn Schoen Berland and Berkeley Research Group, commissioned by Qualcomm

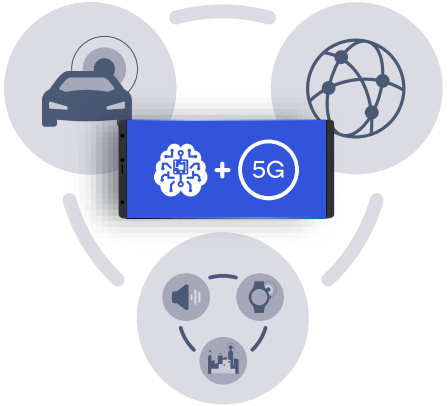
Leading mobile innovation for over 30 years

Digitized mobile communications

Analog
to digital

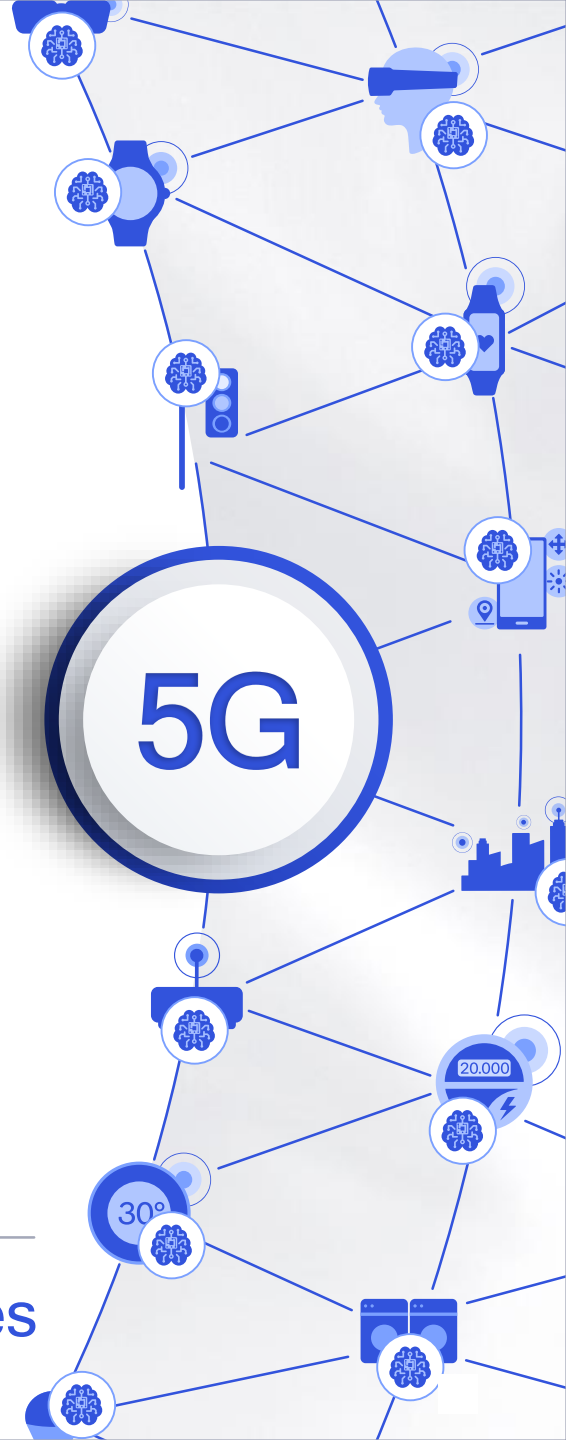
Redefined computing

Desktop to
smartphones



Transforming industries

Connecting virtually everything
at the wireless edge



Transforming how the world connects, computes and communicates

Solving system-level problems is in our DNA

Qualcomm's mission statement

"Qualcomm's objective is to apply our experience to **systems problems** that arise in the design, analysis, implementation and testing of digital communication processing systems and networks to bring reliable, functionally effective, user-friendly products to the marketplace."

Dr. Irwin Mark Jacobs
Dr. Andrew J. Viterbi
July 1, 1985

Qualcomm founders

CORPORATE OBJECTIVE

From the onset of our industrial careers, we have been dedicated to the "elegant solution"--the solution that provided the most cost effective, reliable answer to today's communication problems. As more sophisticated communication systems become feasible, particularly due to the advent of the microprocessor, it becomes especially important to use sound principles of information theory and computer science to analyze system performance and simulate system operation wherever feasible, to ensure that the resulting system as implemented performs its assigned tasks in a cost effective and efficient manner. Now more than ever before, the existing tools of our trade--microprocessors and VLSI, along with the emerging technology of artificial intelligence and expert systems--offer exciting new approaches to elegance and innovation in synthesizing practical solutions to real-world problems.

QUALCOMM's objective is to apply our experience to systems problems that arise in the design, analysis, implementation and testing of digital communication processing systems and networks to bring reliable, functionally effective, user-friendly products to the marketplace.

We have a proven record of accomplishment in the digital communication, software engineering and signal processing fields. We have put together an experienced team that has produced not only theoretical innovation, but real, working, quality products and systems to start QUALCOMM. This group of people has, for the most part, worked together for the last 15 years and is dedicated to building QUALCOMM into what its name implies--The Quality Communication Company of our time.

Dr. Irwin Mark Jacobs

Dr. Andrew J. Viterbi

Demystifying the organization and working procedures of 3GPP

The basics

3GPP is a global partnership of seven regional SSOs

Prepares, approves, enhances and maintains globally applicable specifications

Transpose 3GPP specs into standards[2]
also responsible for IPR[3] policy for 3GPP members[4]

1. Also Market Representation Partners that provide guidance on market dynamics and requirements, e.g. GSMA, NGMN; 2. Regional SDOs transpose 3GPP specs into national standards - ITU responsible for transposing 3GPP specs into international standards; 3. Intellectual Property Rights; 4. In order to participate in 3GPP, individual members must formally join one of SSOs

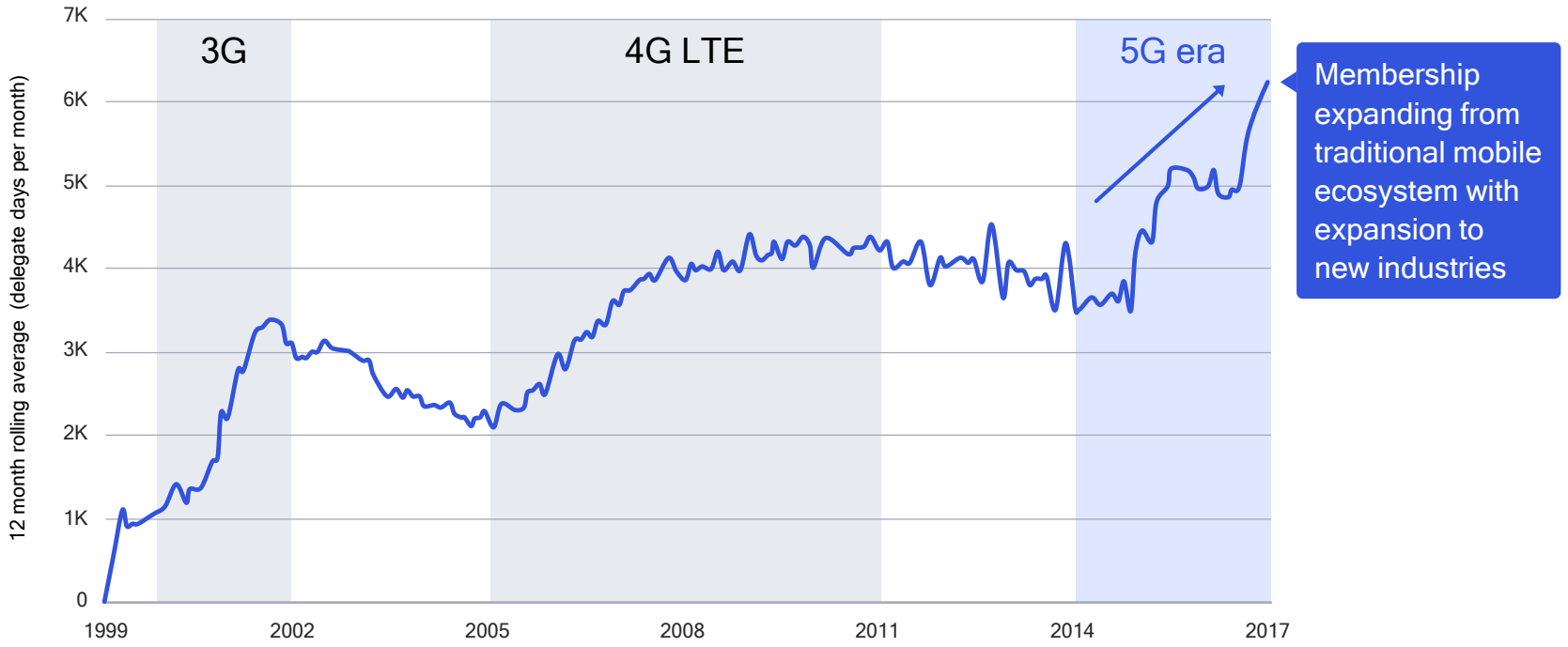
Ensures compliance with industry requirements

Seamless interoperability between vendors

Delivers global specifications and scale

3GPP is an expanding, member-driven organization

3GPP meeting attendance



* Source: 3GPP Mobile Competence Centre (3GPP Support Team) Summary Report from RAN#76 (RP-170872)

Collaboration among 500+ members across 40+ countries

- Network operators
- Device manufacturers
- Chipset manufacturers
- Infrastructure manufacturers
- Academia
- Research institutions
- Government agencies

Over 2,000+ delegate man years in cumulative meeting time since ’98

3GPP participants are engineers and discussions are technical in nature

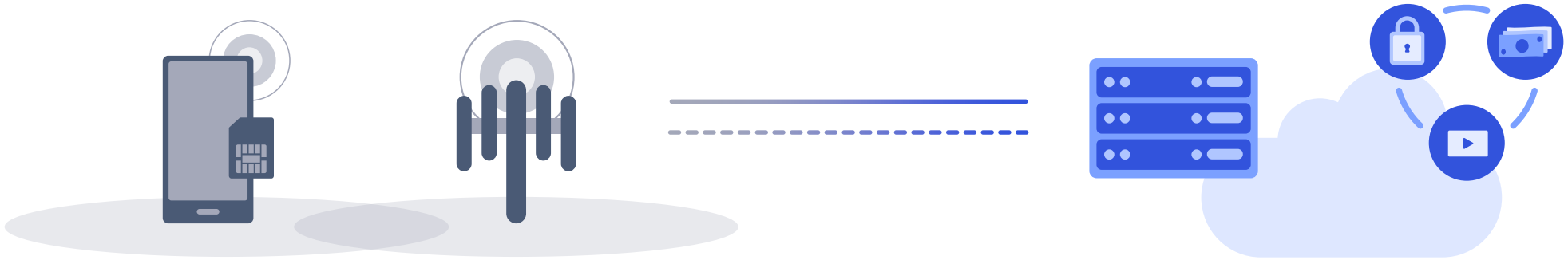
3GPP defines complete end-to-end system specifications

Radio Access Network (RAN)

Implements radio access technology, e.g., LTE, managing radio link to connect UEs to core network

Services

Framework for service architecture, capabilities, multimedia and charging



User Equipment (UEs)

Devices, e.g., smartphones, that connect to services via radio access technology

Core Network (CN)

Manages the RAN, e.g., mobility mgmt., and routes data to outside world, e.g., Internet

The scale and complexity requires division of work into smaller, specialized pieces in 3GPP

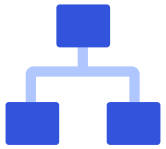
3GPP is a distributed, systems-engineering effort

Technical work occurs across 3 TSGs and 16 specialized WGs

Radio Access Network (RAN)

Defines the radio communications between UEs and core network

RAN WG1 Layer 1 (Physical) spec
RAN WG2 Layer 2 and 3 (RR) protocols
RAN WG3 Access network interfaces + O&M
RAN WG4 Performance requirements
RAN WG5 UE conformance testing
RAN WG6 Legacy RAN, e.g. GSM, HSPA



Service / System Aspects (SA)

Responsible for overall architecture and service capabilities

SA WG1 Service requirements
SA WG2 Architecture
SA WG3 Security
SA WG4 Codecs, multimedia system
SA WG5 Telecom management
SA WG6 Mission-critical services

Core Network and Terminals (CT)

Responsible for core network; defines terminal interfaces and capabilities

CT WG1 Mobility Mgmt, Call Ctrl, Session Mgmt
CT WG3 Policy, QoS and Interworking
CT WG4 Network protocols
CT WG6 Smart card application

* 3 Technical Service Groups (TSGs) and 16 Working Groups (WGs)

A system approach to standardize 5G NR Industrial IoT

Approved Rel-16 SI – requiring close collaboration & consensus across multiple WGs

Early system-level R&D

- Private networking
- Coordinated Multipoint (CoMP)
- Unlicensed spectrum
- Spectrum sharing
- Ultra high-reliability, low-latency
- Industrial ethernet

3GPP standardization

RAN WG1

NR URLLC[1]
L1 enh., UL pre-emption, grant-free, …

NR MIMO[2]
Multi-TRP (CoMP), Type II CSI, …

NR in unlicensed[3]
Sub-7 GHz, standalone, …

RAN WG2

NR industrial IoT[4]
Time sensitive network (TSN), …

Mobility enhancement[5]
Zero interruption, robustness booster, …

SA WG1

LAN support in 5G[6]
Industrial ethernet requirements, …

Automation in vertical domains[7]
99.9999% reliability, …

SA WG2

Vertical and LAN services[8]
Private networks, …

3GPP A GLOBAL INITIATIVE

1. RP-181477; 2. RP-181453; 3. RP-181339; 4. RP-181479; 5. RP-181433; 6. S1-172416, produced TR 22.821; 7. SP-170169, produced TR 22.804; 8. SP-180507

Each TSG/WG has elected Chair- and Vice Chairpersons

Elected from member companies – must be impartial and act on behalf of 3GPP

- Responsible for overall management/progress of technical work within their group
- Manage meeting agenda based on individual member contributions
- Ensure compliance with 3GPP working procedures and policies
- TSG elections are held every two years; serve a maximum of two terms

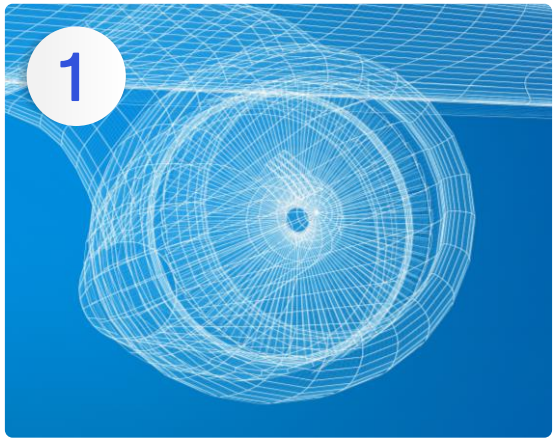
Dino Flore

Qualcomm Technologies, Inc.

Successfully served as RAN Chairman from 2013-2017; led the expansion the mobile ecosystem on path to 5G

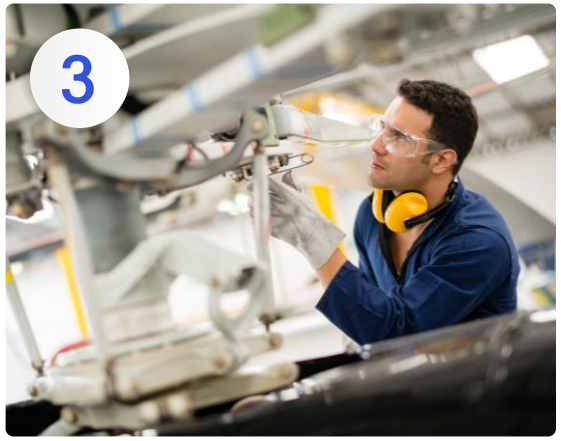
Dino Flore (right) passes 3GPP RAN Chairman bell to Balázs Bertényi of Nokia Corporation

3GPP is a collaborative, system-engineering effort



Early R&D and project proposal to management

Break project into specialized areas, e.g., jet engine



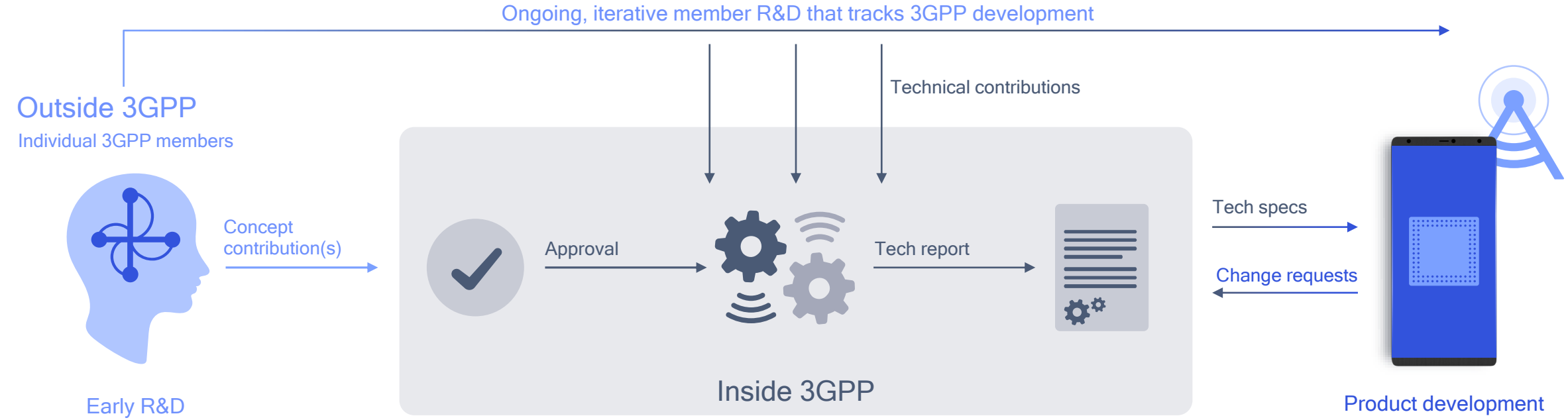
Feasibility study and explore different technical solutions

Develop solution(s) based on agreed work plan

3GPP™ A GLOBAL INITIATIVE

Managed like any other complex system-engineering effort, e.g., designing a jet plane. 3GPP develops technical specifications (vs. jet planes), is constrained by meeting time (vs. OPEX) and is a collaborative effort across 100s of different entities with diverse interests/incentives

Workflow and procedures for collaborative system-level effort



1 Vision and concept

2 Project proposal

3 Feasibility 'Study Item'

4 Development 'Work Item(s)'

5 Commercial deployments

Early member R&D fuels new innovations

Outside 3GPP

Individual 3GPP members

Vision → Early R&D → Partner

Concept contribution(s)

Inside 3GPP

Iteration and negotiation → Approval (TSG) → Approved Study Item(s)

Yes

No: Abandon, hold or reiterate

Vision and concept

1

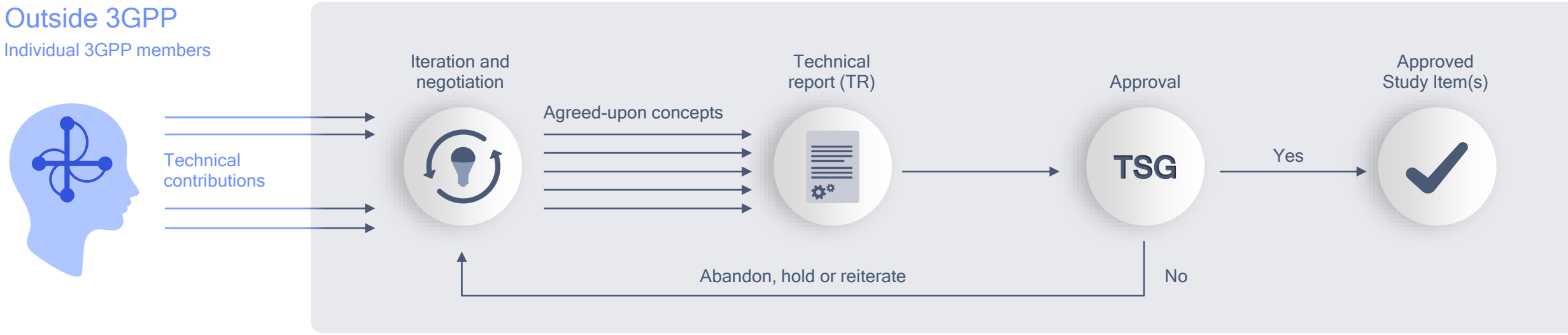
- Define need or problem solution
- Specify requirements and constraints
- Develop early design and technologies
- Garner support and test assumptions
- Submit 3GPP 'concept' tech contribution

Project proposal

2

- New feature may be initiated by any member
- Must have support of at least 4 members
- Usually iterate on concept over multiple meetings
- New work activity must be approved by TSG plenary
- Approval results in approved Study Item(s)

Feasibility study evaluates options/solutions – Study Item



3GPP Study Item

3

Members submit tech docs (contributions) to propose solutions and technologies

Contributions are made publicly available, discussed in 3GPP meetings (time permitting)

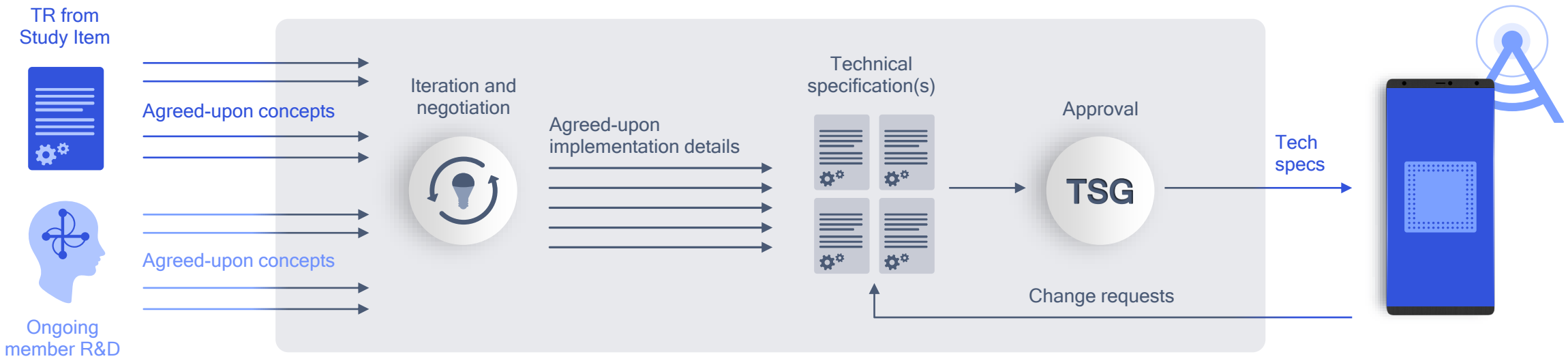
Decisions are tech-driven and result from consensus-based process open to all members

Process is iterative and non-linear–many discussions continue beyond 3GPP agenda

Agreed-upon concepts included in Tech Report–rarely untouched from initial contributions

Approved TR (by TSG) may result in corresponding Work Item(s)–may be less scope than Study

Work Item develops specification(s) based on Study Item[1]



3GPP Work Item

Commercial Deployments

4

5

Similar contribution-driven, iterative, consensus-based process to specify selected solutions

Complete list of active work-items make up 3GPP work-plan; available on 3GPP website

Each Work Item has supporting companies and rapporteur(s) - the WI manager(s)

Agreed-upon implementation details executed in Tech Specification(s) - either new or existing[2]

Once spec approved, changes can only be accomplished through formal 'change request'[3]

Released specs kick-off race to standards-compliant devices and infrastructure for deployments

1. Not all Work Items are the result of a Study Item - may start directly and have some study phase at the start of the Work Item; 2. Updates to existing specifications accomplished via Change Requests (type of contribution);
3. Change Requests are tracked rigorously since it can impact product development for manufacturers of chipset, infrastructure and User Equipment

Tech specs ultimate output of work completed in 3GPP

Over 1,200 active 3GPP technical specifications[1]

- 100s of technical contributions are submitted towards formation of single specification
- Each specification has a Rapporteur (editor and manager) following guidance of WGs
- Owned by a specific TSG–responsible for freezing specs when functionality is stable at quarterly plenary
- Tech specifications are used by downstream manufacturers for product development
- Identified by a 5 digit number that categorizes specs into meaningful tech categories[2]

25.bbb	Radio access aspects	25.1bb: UTRAN radio performance 25.2bb: UTRA layer 1 25.3bb: UTRA layers 2 & 3 25.4bb: UTRAN Iub, Iur & Iu interfaces

1. Source: www.3GPP.com/specifications as of June 2017 2. See TR 21.900

Technical spec example

RRC Protocol specification (TS 25.331)

3GPP TS 25.331 V13.6.0 (2017-03)

Technical Specification

3rd Generation Partnership Project;
Technical Specification Group Radio Access Network;
Radio Resource Control (RRC);
Protocol specification
(Release 13)

>2,000 pages

New features are introduced via 3GPP Releases

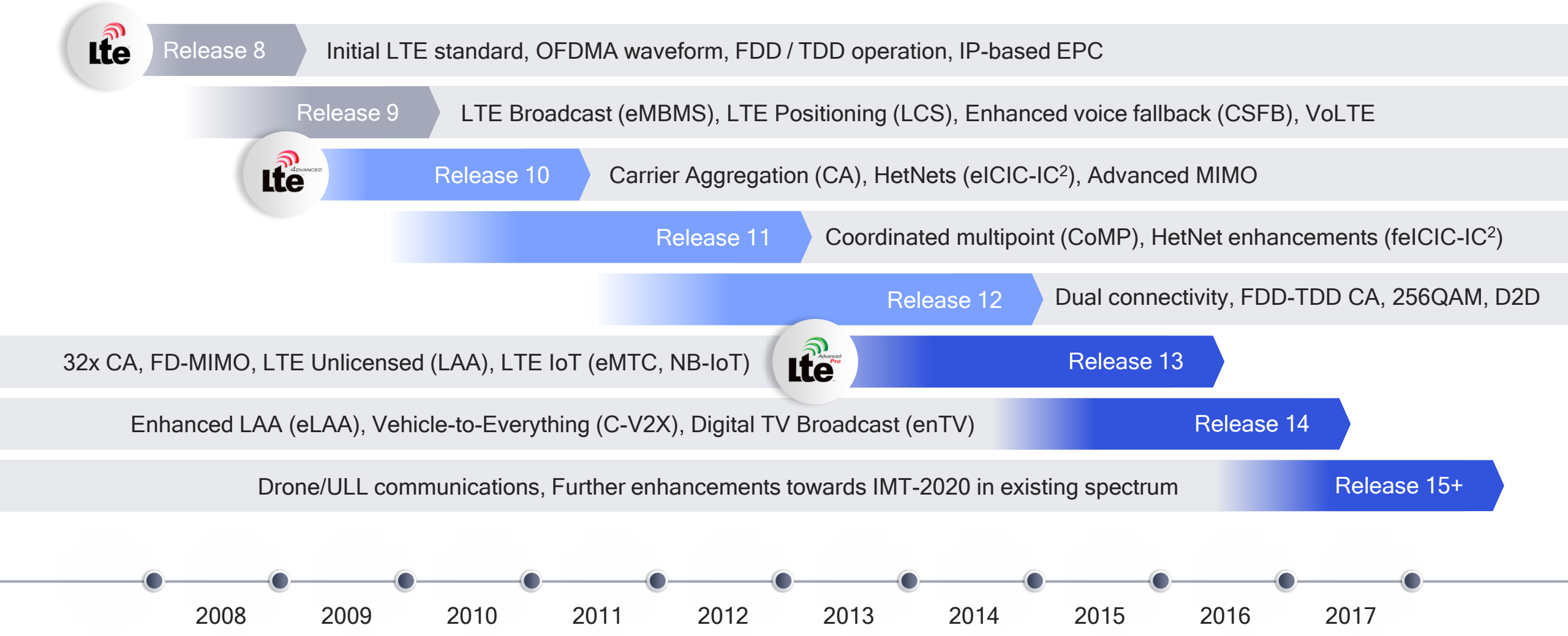
Staggered–3GPP works on a number of Releases in parallel at different stages

Very similar to major Releases of Operating Systems

Self-contained–can build system based on the set of frozen specs in a Release

Measure of real progress–new features are functionally frozen, ready for implementation

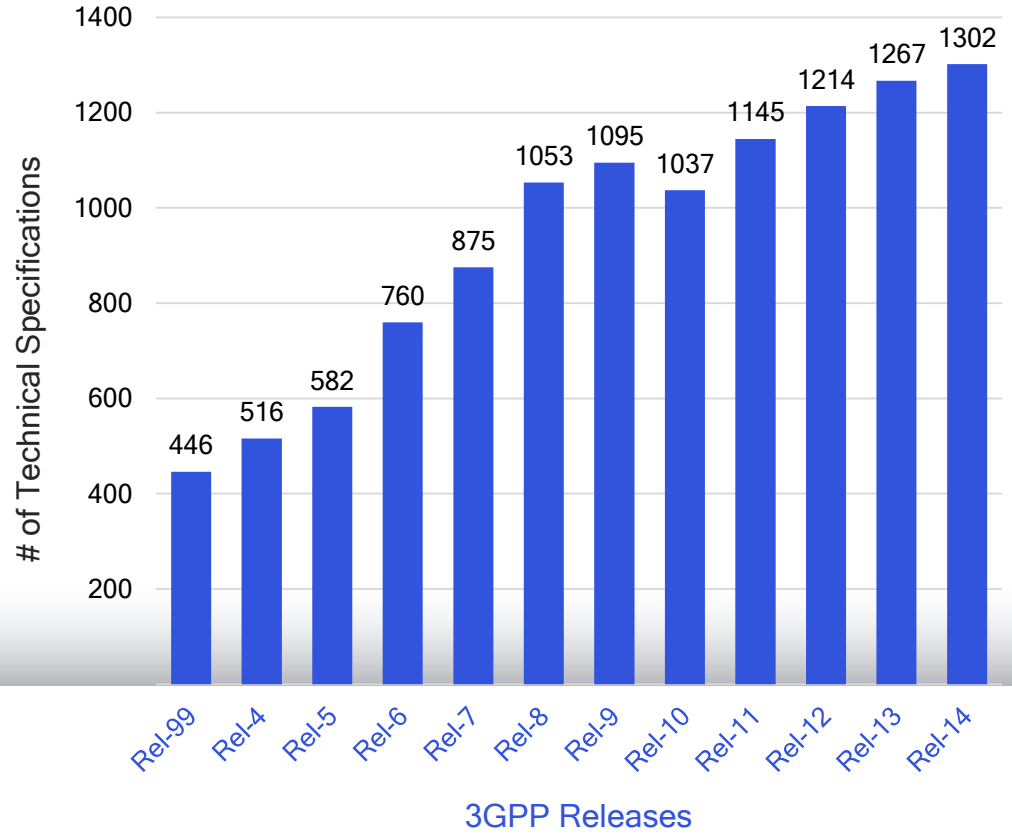
The feature-rich evolution of 4G LTE over 8+ Releases



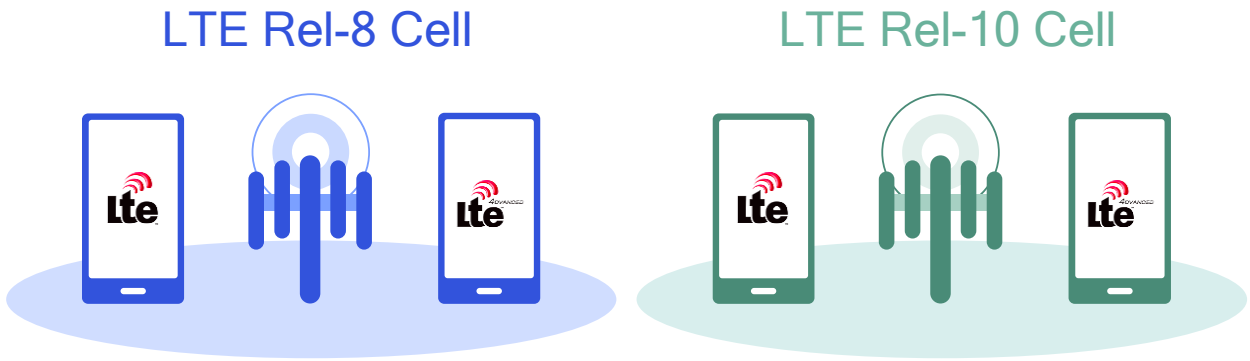
Dates represent Start and End dates for 3GPP Releases; Features shown are representative and do not reflect full-set of features

3GPP specifications evolve in highly iterative manner

Building on top of each other to enable backward compatibility



Example of backward compatibility



An LTE Rel-10 UE can work in a LTE Rel-8 cell

An LTE Rel-8 UE can work in a LTE Rel-10 cell

3GPP standards leadership

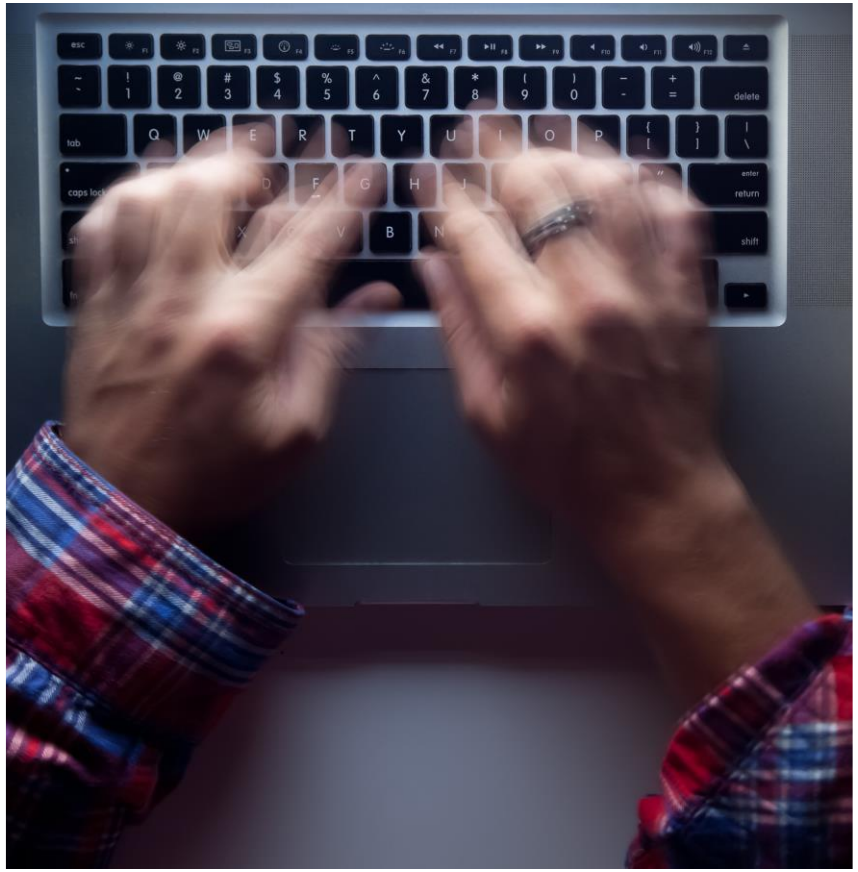
Driving end-to-end expansion of the mobile ecosystem

Some assert 3GPP leadership based on # of contributions

Analogous to asserting leadership in sports on the basis of time-of-possession

Some assert 3GPP leadership based on # of contributions

Analogous to asserting leadership in sports on the basis of time-of-possession



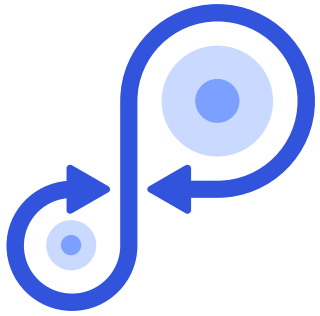
Analogous to assessing the impact of an author by counting the # pages written

Analogous to assessing the quality of an artist by counting the # paintings completed

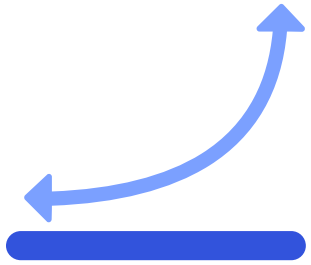
Contribution counting does not gauge 3GPP leadership

Quality is harder to measure, but far more important than quantity

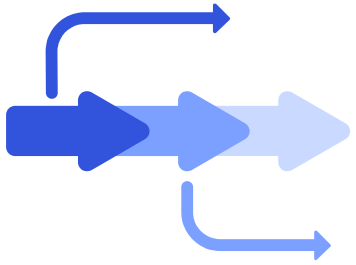
Contributions are not created equal – many do not contain new technology inventions



3GPP specs are not made via a direct mechanism of acceptance or rejection of contributions



Companies can game the counting system by incentivize representative to maximize contributions



Cellular technologies build upon previous work done both in and outside of 3GPP

Leading the evolution and expansion of the mobile ecosystem is a true measure of 3GPP standards leadership

Contributions are not created equal. Quality matters.

"Stacking the deck" resulted in multiple WGs instituting a policy of "one contribution per company per agenda item"

Databases built for engineers – not high-level analysis – open to interpretation and manipulation

Difficult to assess impact of any single contribution – most focused on one part of one feature or studies that do not get standardized

Qualcomm

Example contributions

Introducing LTE in unlicensed spectrum
RP-131635 - Concept Contribution[1]

Way Forward on the 5G NR workplan
RP-170741 - Way Forward Contribution[2]

Physical layer options for LAA
RP-150477 - Seminal technical contribution

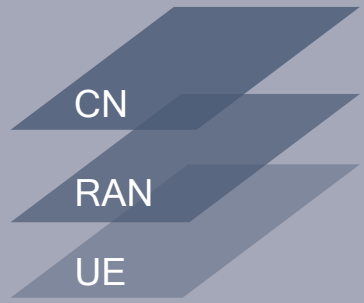
Introduction of new DL category
RP-171037 - Intro new UE category for 1.6 Gbps

FeMBMS/unicast-mixed carrier flag in measurement object
RP-171169 - Change Request

1 Submitted with Ericsson; 2 Submitted with 40+ other members – led by Qualcomm

3GPP leadership is the ability to drive the evolution

The proven desire and ability to build broad consensus across the ecosystem towards new directions

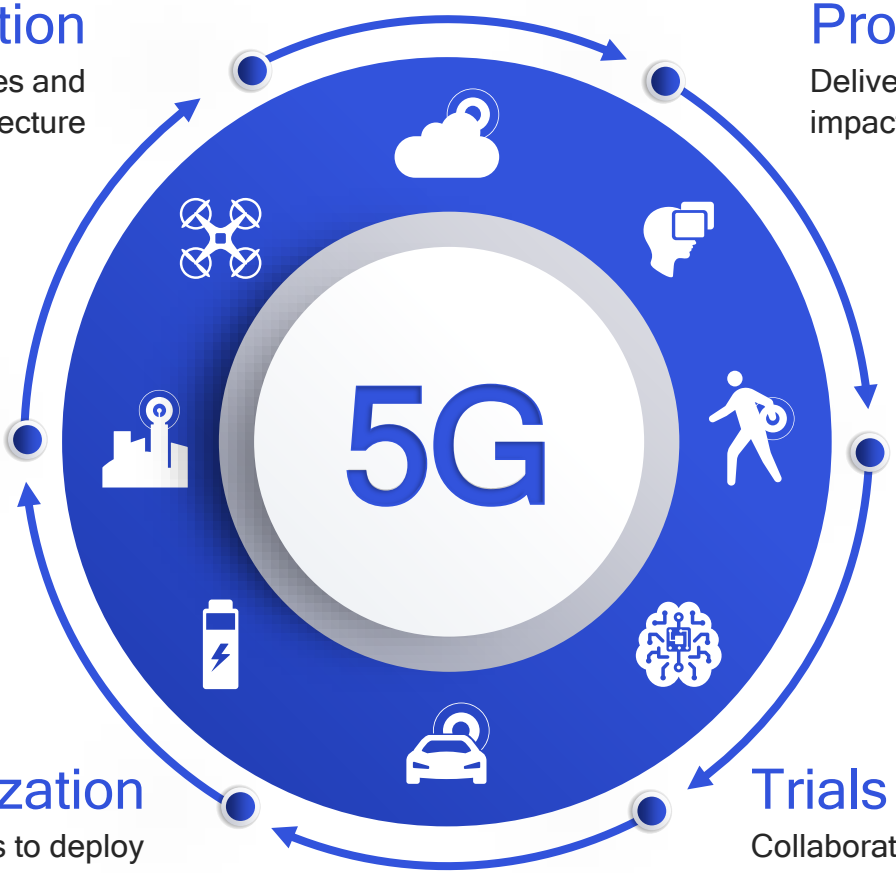


The proven expertise and ability to drive an end-to-end design through 3GPP

The foundation is end-to-end technology and R&D leadership

Foundation to 5G leadership is technology leadership

Early R&D and technology inventions essential to leading ecosystem forward



Invention

Invent new technologies and e2e system architecture

Proof-of-concept

Deliver end-to-end prototypes and impactful demonstrations

Vision

Identify a problem or need; establish requirements

Standardization

Drive e2e design with ecosystem and through standards process

Commercialization

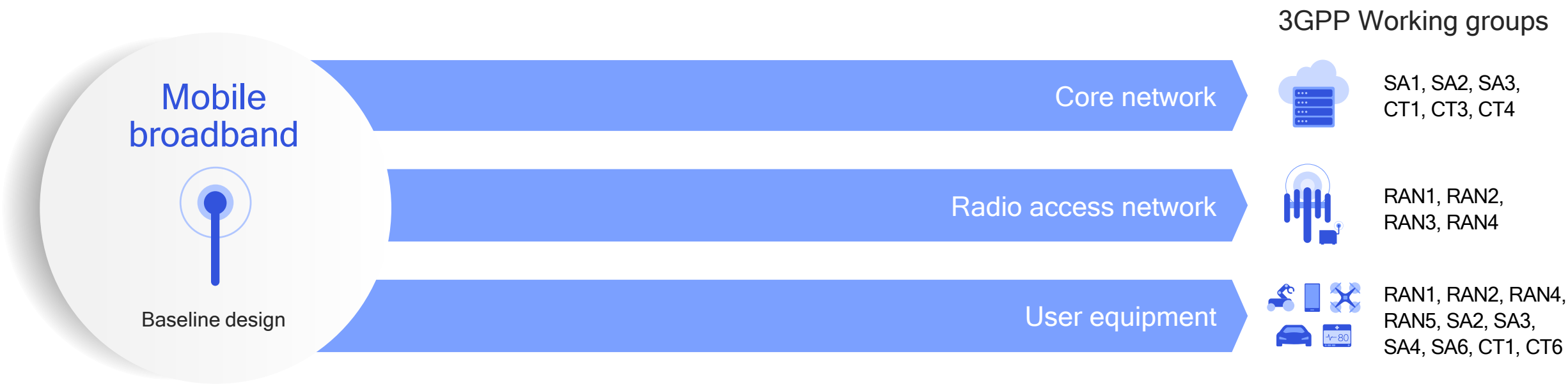
Engage with global network operators to deploy new features with standards-compliant infrastructure and devices

Trials

Collaborate on OTA field trials that track 3GPP standardization and drive ecosystem towards rapid commercialization

In 3GPP, system design is done in piecemeal fashion

Block-by-block decision process across 3GPP WGs with limited e2e supervision

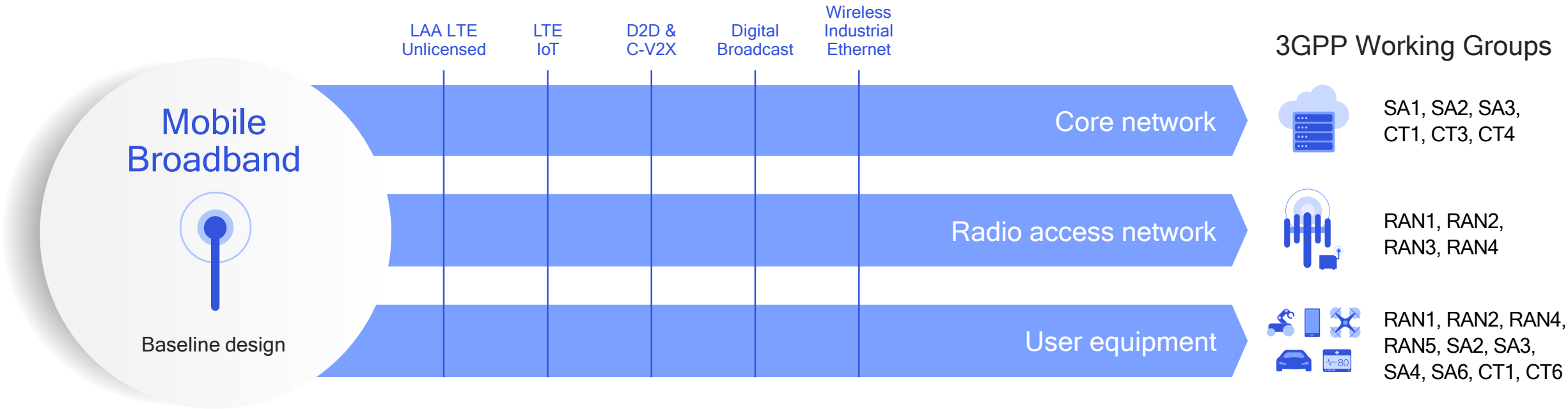


* For 4G LTE and 5G NR; 2G and 3G systems started from voice

3GPP starts with defining cellular systems for mobile broadband*

Expanding into new areas requires system leadership

The ability to drive an end-to-end design across multiple 3GPP Working Groups



Each new area requires creating a new sub-system built on top of “baseline”

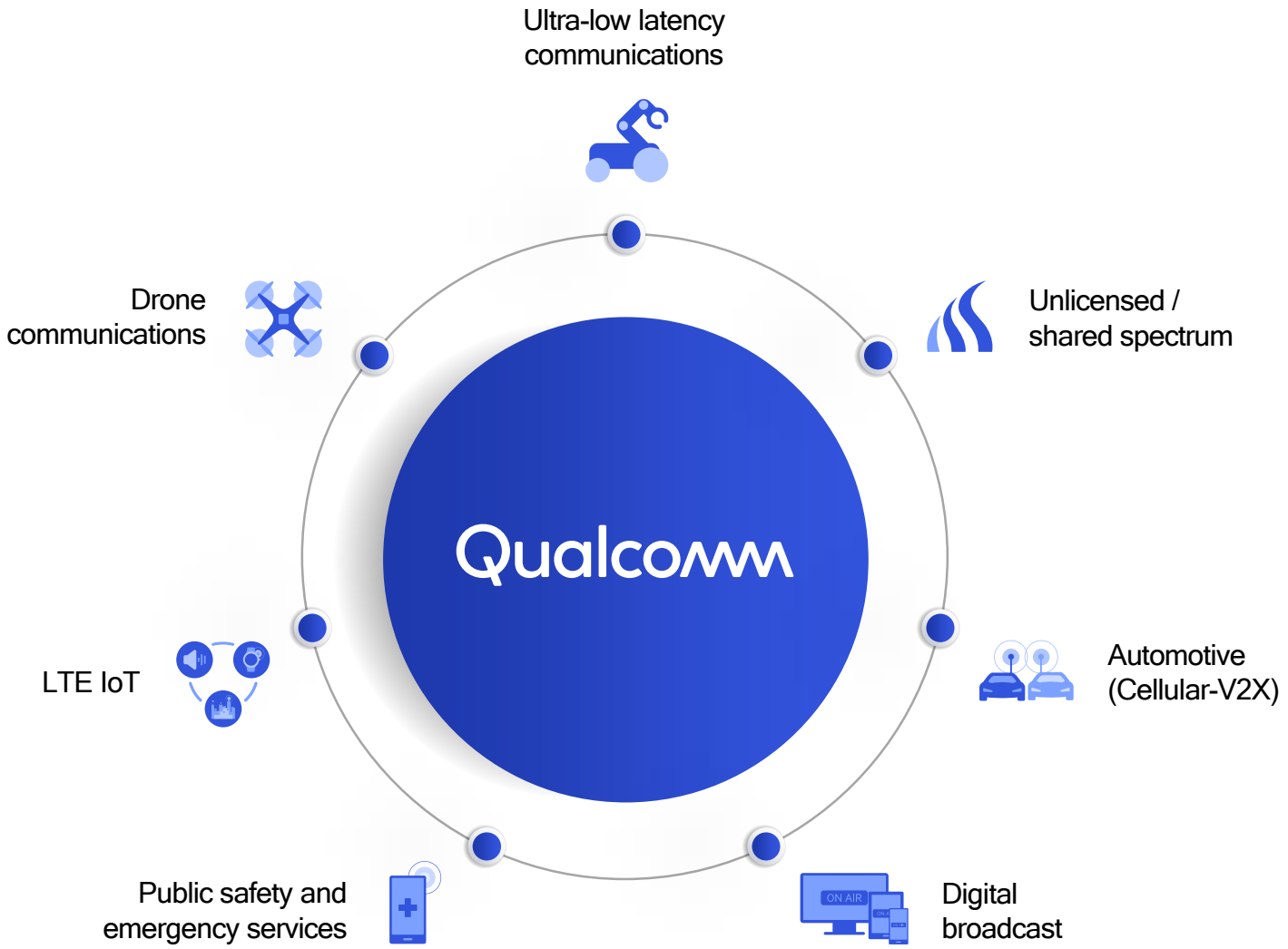
Adjusting, optimizing, and redesigning procedures across all layers to address the new requirements

Our system-level inventions fuel the mobile industry

*Cumulative expenditures to date since 1985. Taking significant risks to start early with an end-to-end design

Our LTE advancements are expanding the mobile ecosystem

Essential to leading in 5G



Qualcomm has led the evolution and expansion of LTE

Delivering fundamental systems-level inventions that are essential to 5G

Leading the expansion of LTE to unlicensed spectrum

Licensed Assisted Access (LAA)

Technology and R&D leadership

MWC 2014: First demo (Wi-Fi coexistence)
MWC 2015: First live LAA demo
MWC 2016: First live eLAA demo

3GPP standards leadership

3GPP™
A GLOBAL INITIATIVE

Introduced concept Dec 2013 and pioneered work in 3GPP across multiple working groups

Impactful trials with operators and customers

First over-the-air trials, LAA with DT Nov 2015 and eLAA with SK Telecom Sep. 2016

Industry-first chipsets

Qualcomm snapdragon

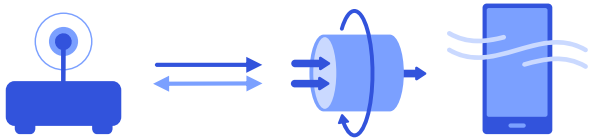
Qualcomm® Snapdragon™ X16 LTE modem

Announced industry's first modem to support LAA in Feb '16; Commercial devices have since launched

Our technology inventions drove the LAA standard

- Floating frame structure and signaling
- Dynamic UL-DL sub-frames per TxOP
- LBT self-deferral for synchronization
- Multi-carrier LBT
- UL-interlaced waveform
- Dynamic TX power per TxOP
- Multi-TTI UL grants
- Cross-TxOP triggered UL grants
- Self-schedule DL & cross-carrier UL scheduling

3GPP™ A GLOBAL INITIATIVE



LAA part of Release 13

Boosts downlink data rates and capacity–key aspect for Gigabit LTE

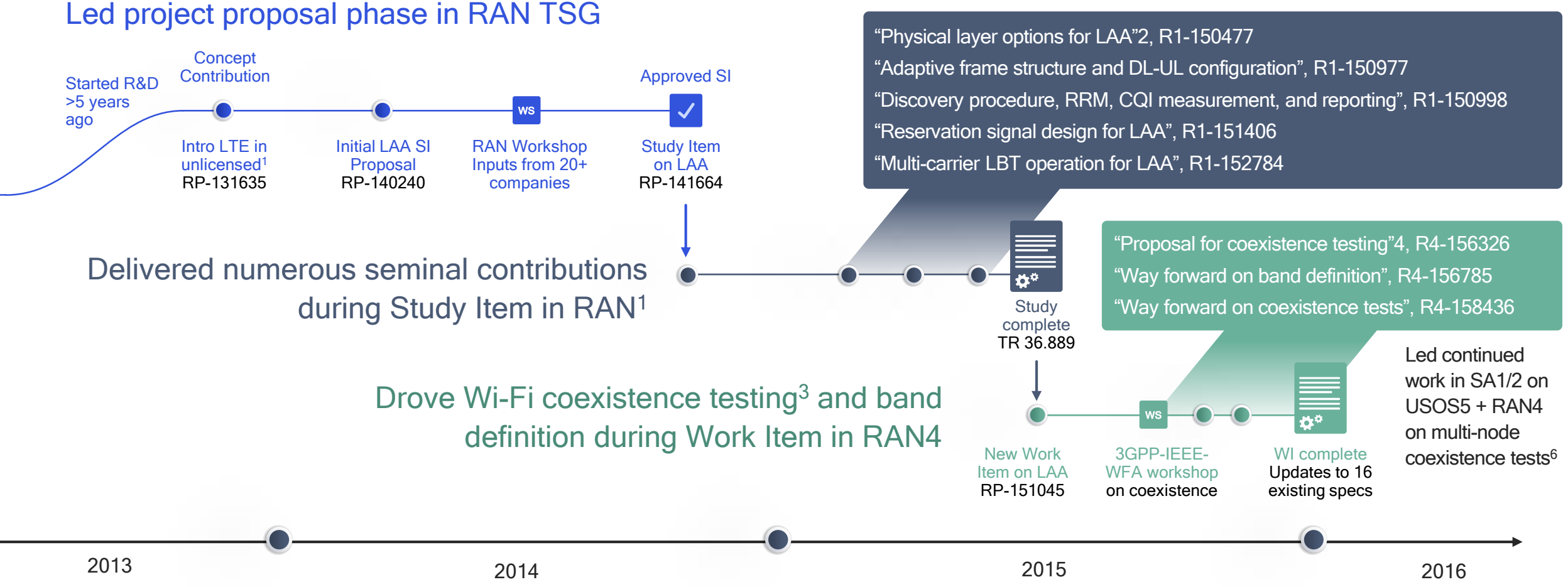
5G NR

Broadening to new areas

- Enhancing LAA, e.g., UL (eLAA, feLAA)
- Standalone operation with MulteFire™
- New deployment types, e.g. Private IoT
- New capabilities/efficiencies with 5G NR

Pioneered and led work on LAA in 3GPP – part of Rel-13

Led project proposal phase in RAN TSG



Delivered numerous seminal contributions during Study Item in RAN[1]

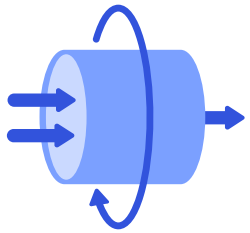
Drove Wi-Fi coexistence testing[3] and band definition during Work Item in RAN4

Led continued work in SA1/2 on USOS5 + RAN4 on multi-node coexistence tests[6]

[1] Made in collaboration with Ericsson; [2] Such as Load Based Equipment channel access protocol, DRS-based RRM procedure, Reservation signal; [3] Led engagements with IEEE and WFA; [4] Also R4-156327;
[5] Unlicensed Spectrum Offloading System-enhancements – design work related to identification of traffic carried over unlicensed spectrum (reporting from RAN to CN) to be used for charging, etc. and for regulatory reasons;
[6] R4-1706224 – "Way Forward on Multi-node tests" – Introduces ability to have coexistence tests among LTE base stations and Wi-Fi Access Points for LAA

Initial work on LAA broadening to new technology areas

Evolving LAA with new functionality and enhancements



E.g., UL and DL aggregation

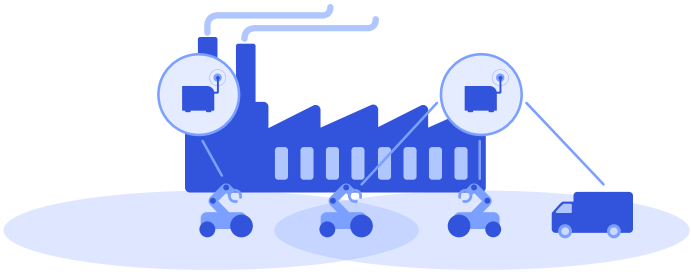
Drove key technologies in 3GPP[1]; first OTA demo at MWC 2016; first OTA field trial with SKT Sep 2016

Opening up new opportunities with MulteFire™

LTE operation solely in unlicensed spectrum

Introduced concept[1] in June 2015; founding member of MulteFire alliance; first OTA demo at MWC 2017

Extending to new deployment types, e.g., Private IoT



Factories, ports, mines, warehouses smart buildings, …

First demo[3] in CBRS shared spectrum Feb 2017 (venues, enterprise); Industrial IoT demo[4] at MWC 2017

3GPP is studying NR in unlicensed spectrum

Licensed-assisted and standalone operation

Drove new Release 15 Study Item that was approved in March 2017 RAN plenary with Qualcomm as rapporteur

[1] E.g., "New interleaved UL waveform: to satisfy bandwidth and PSD constraints" R1-150477;
[2] OnQ Blog: "Introducing MulteFire: LTE-like performance with Wi-Fi-like simplicity"; [3] with Nokia and Alphabet's Access Group; 4 with Nokia and GE

Leading the expansion of LTE to the Internet of Things

Starting in Rel-13 – Narrowband LTE IoT includes both eMTC and NB-IoT

Technology and R&D leadership

Prototyped LTE IoT low-power modes (PSM and eDRX) and demonstrated simulations and system tests at MWC 2016

3GPP standards leadership

3GPP™
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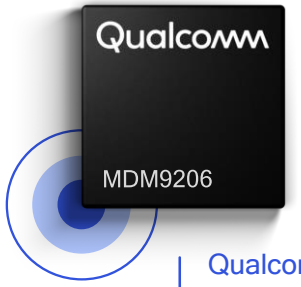
Proposed architecture enhancements[1] and led the harmonization of NB-IoT across multiple 3GPP working groups

Impactful trials with operators and customers

First LTE IoT multimode trial in China with CMCC and Mobike; multiple commercial deployments

Industry-first chipsets



Qualcomm® MDM9206 multimode LTE modem

Announced industry's first multimode modem in Oct '15; commercial devices have since launched

1. SP-150167 that identified the impacts of introducing IoT in overall system architecture

Our technology inventions drove the LTE IoT standard

- Narrowband random access channel design
- Efficient resource allocation for narrowband UE
- Narrowband synchronization
- UL power control in coverage extension mode
- Multi-PRB narrowband operation
- MBMS and location services support
- Raster design for narrowband operation
- Uplink DM-RS design
- Interference randomization

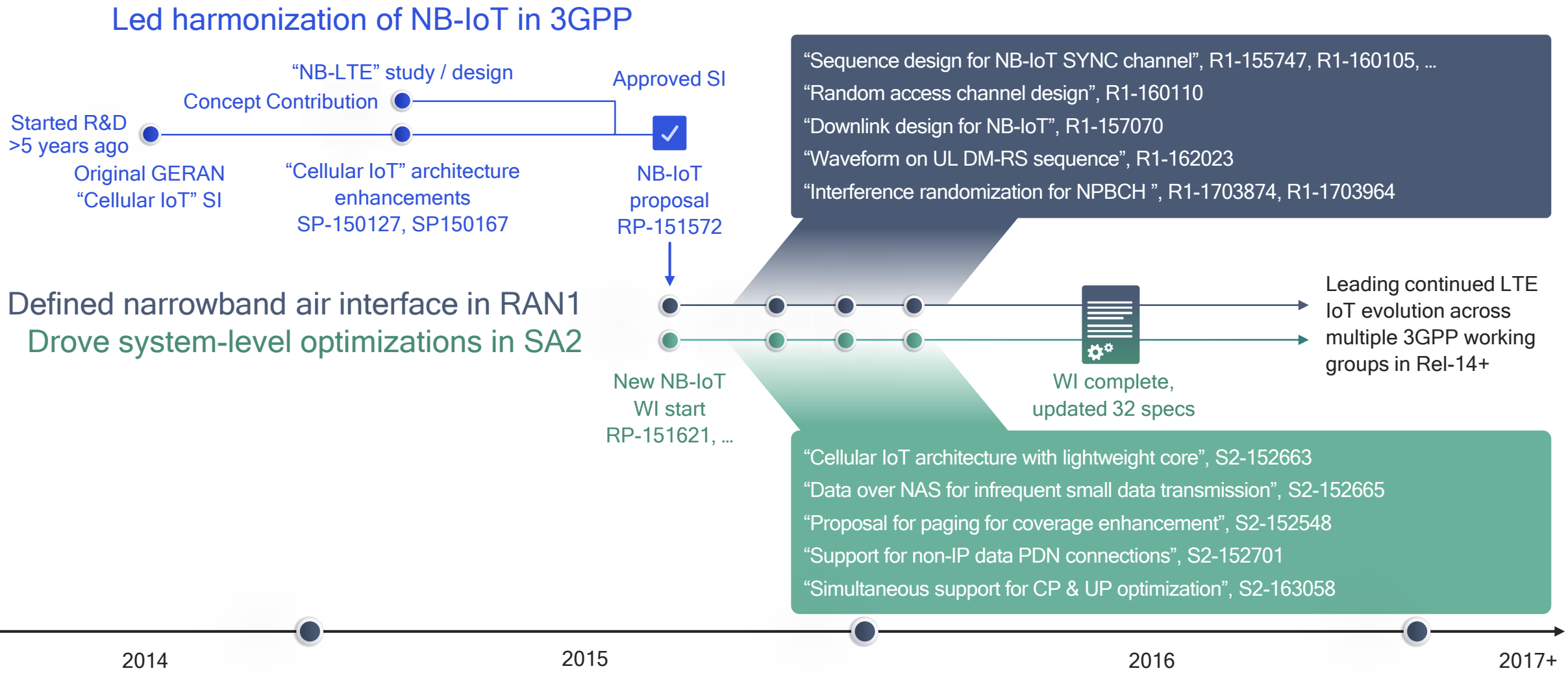
eMTC and NB-IoT part of Release 13

Reduces complexity, extends battery life, deepens coverage, and increases density–key aspects for connecting the massive IoT

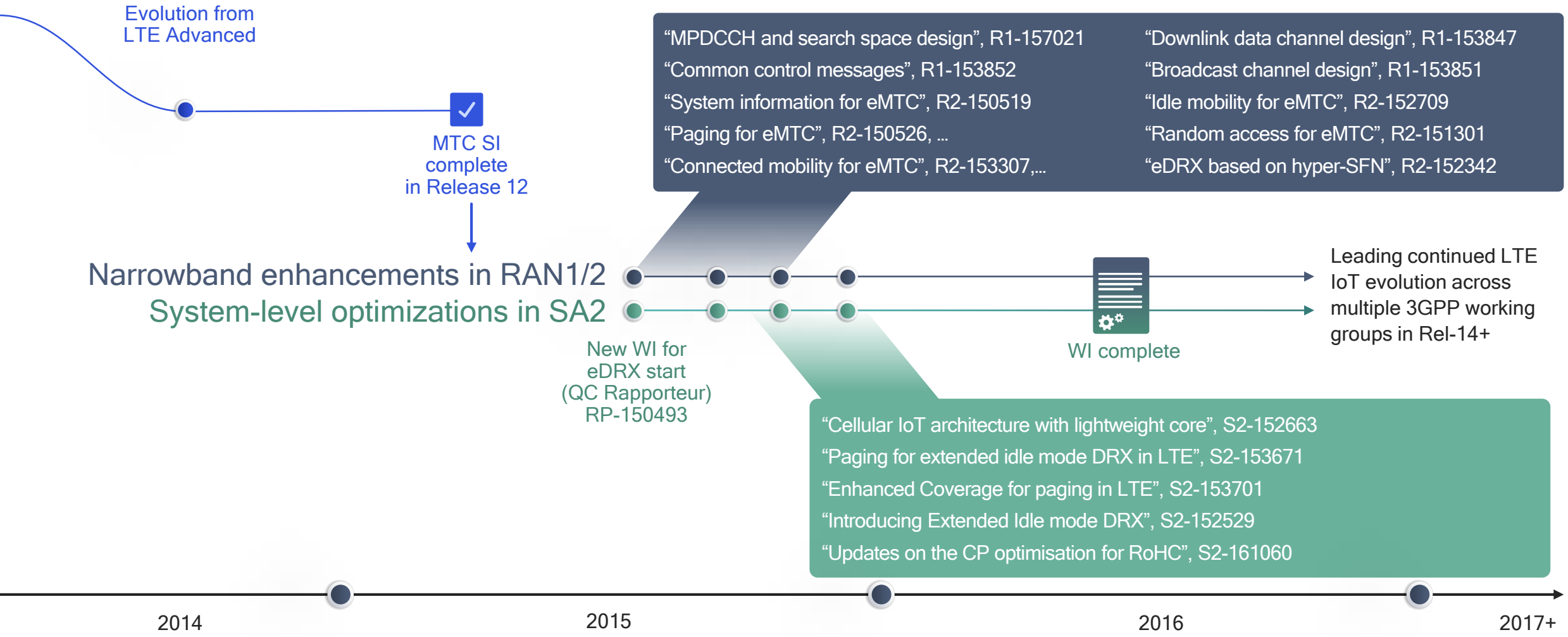
Strong evolution path towards 5G

- New capabilities, e.g., multicast, positioning
- Further efficiency enhancements, e.g., wakeup radio
- Future advanced designs e.g, multi-hop mesh
- In-band operation with 5G NR

Pioneered and led work on NB-IoT in 3GPP – Part of Rel-13

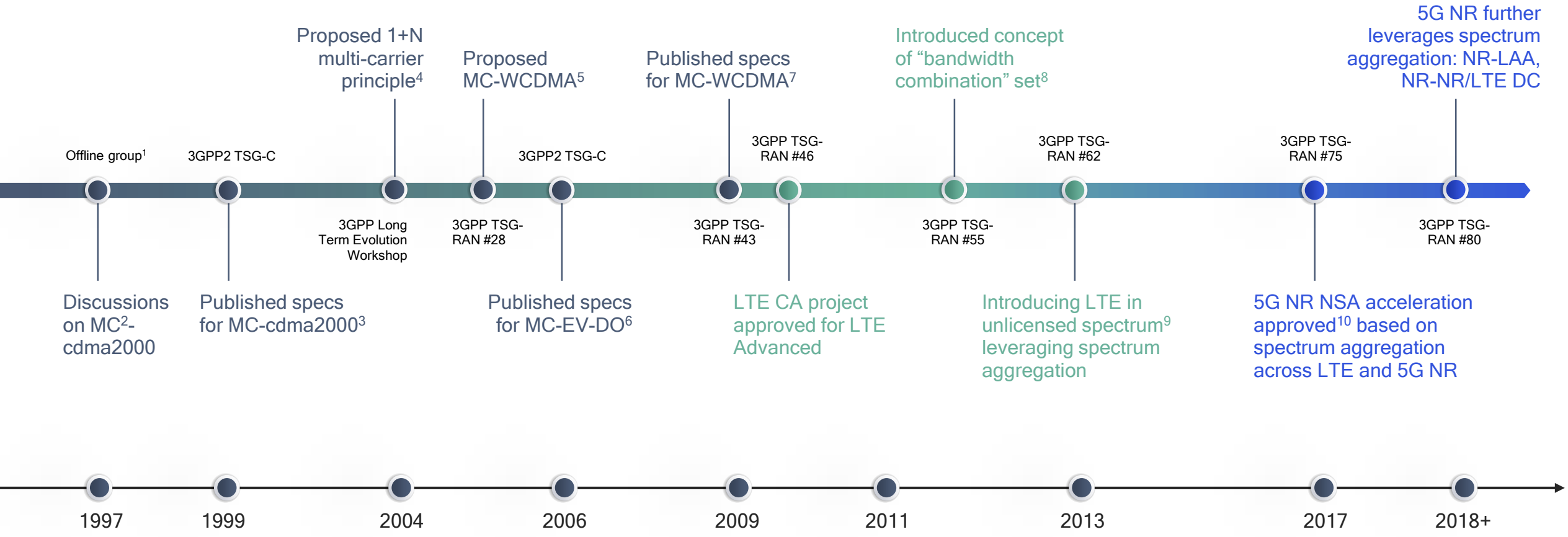


Pioneered and led work on eMTC in 3GPP – part of Rel-13



Pioneered and led work on spectrum aggregation

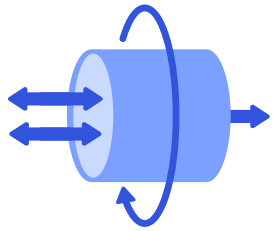
Work started in late 90's with 3G and later for LTE Advanced and 5G NR



1. Included Qualcomm, Lucent, Motorola, and Nortel; 2. Multi-carrier; 3. Part of Release 0 of C.S0002 (TIA IS-2000); 4. REV-WS037; 5. Multiple contributions including R1-050262, R1-050498, R1-050908, TR 814; 6. Part of C.S0024-B; 7. Multiple contributions including RP-080148, R1-081358, R1-081359, R1-081360, R1-081361, RP-080490, TR-25.825, RP-080490, R1-091082, RP-090014, RP-090015, RP-09332; 8. RP-120213; 9. RP-131635; 10. RP-170741

Spectrum aggregation is fueling mobile innovations

Extending into unlicensed spectrum

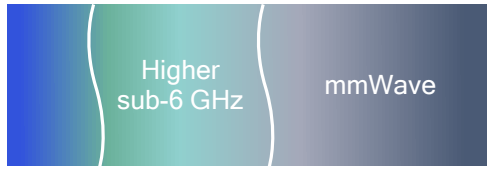


Making more spectrum available by aggregating licensed with unlicensed (e.g., 5 GHz)

Enabling Gigabit LTE

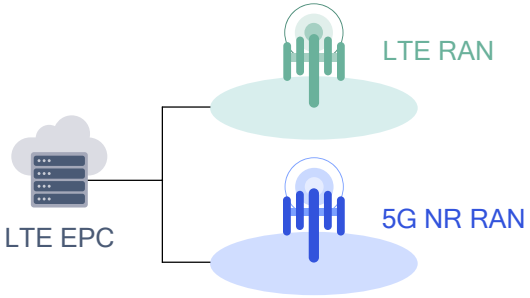
Achieving higher throughput and capacity; LAA also makes global deployments possible

Expanding to higher spectrum bands



Balancing capacity gain from using higher bands with wider coverage of lower bands

Enabling 5G NR deployments in 2019



Leveraging existing LTE networks to anchor new 5G NR deployments in NSA mode

Qualcomm Snapdragon is a product of Qualcomm Technologies, Inc. and/or its subsidiaries.

Building on solid spectrum aggregation technology foundation

3G (3GPP2/3GPP)
Multi-carrier CDMA2000-1x, EV-DO, WCDMA

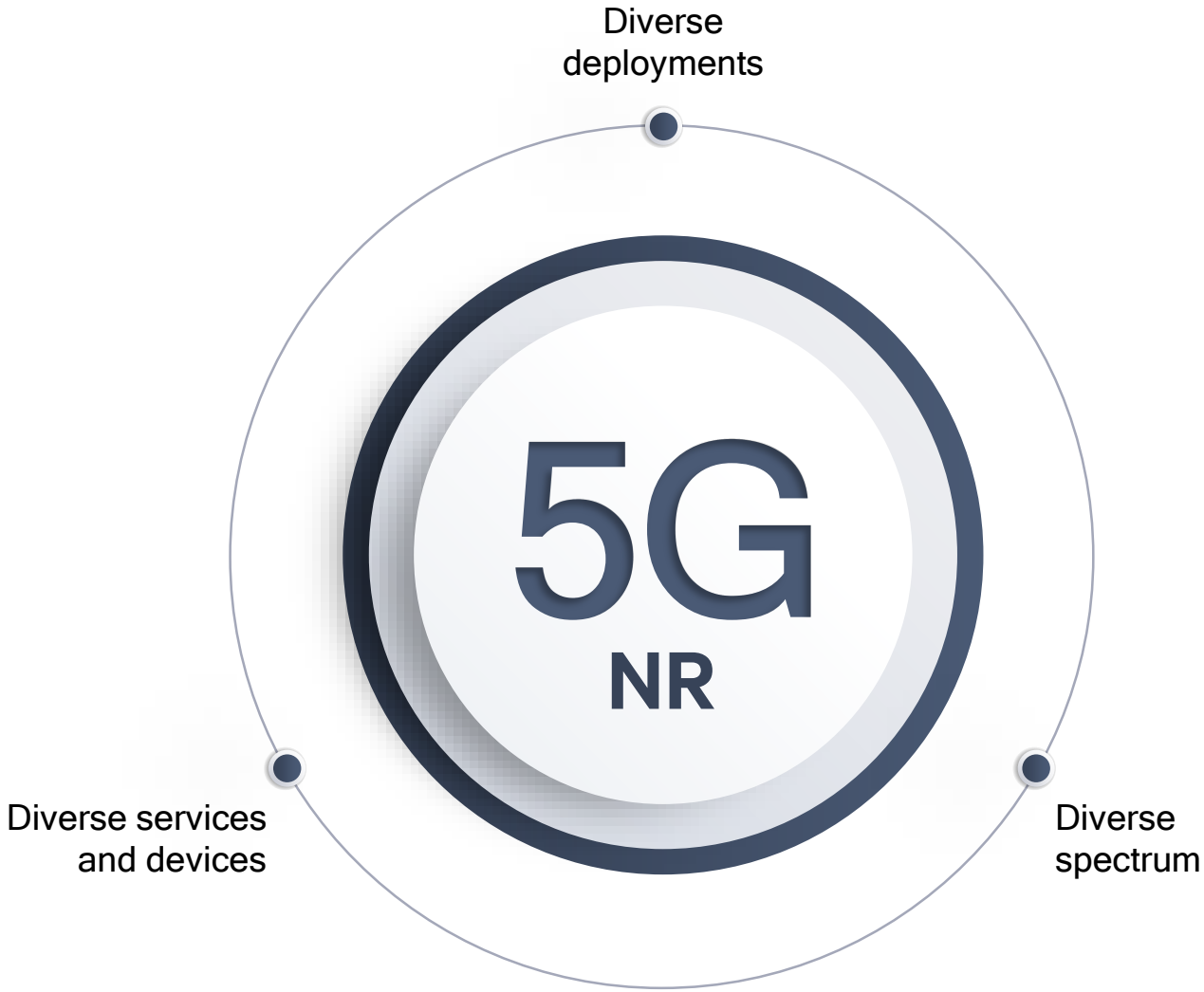
4G LTE (Rel-10+)
Supplemental DL
FDD/TDD CA
LAA CA
Dual Connectivity

5G NR (Rel-15+)
LTE/5G NR NSA
Supplemental UL
Supplemental DL
FDD/TDD CA
NR LAA CA
Dual Connectivity

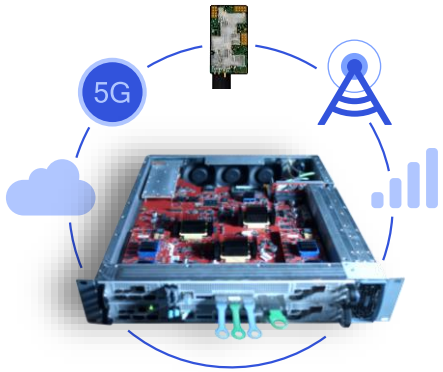
Qualcomm

Making 5G NR a reality

Leading the technology inventions to meet an extreme variation of requirements



Making 5G NR a commercial reality for 2019



Best-in-class 5G prototype systems

Designing and testing 5G technologies for many years

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5G NR standards and technology leadership

Our technology inventions are driving the 5G NR standard

AT&T · BT · 中国移动 China Mobile · SAMSUNG · ERICSSON · China Unicom · KDDI · 中国电信 China Telecom · LG U+ · orange · SK telecom · Deutsche Telekom · NOKIA · docomo · TIM · kt · HUAWEI · Sprint · verizon · Singtel · Vodafone Group · ZTE中兴 · WIND · 3

5G NR interoperability testing and trials

Leveraging prototype systems and our leading global network experience

Qualcomm® snapdragon™ X50 5G modem

Modem and RFFE leadership

Announced the Qualcomm Snapdragon X50 5G modem family

Qualcomm Snapdragon is a product of Qualcomm Technologies, Inc. and/or its subsidiaries

LTE foundational technologies

Our technology inventions are driving the 5G NR standard

- Scalable OFDM-based air interface
- Flexible slot-based framework
- Advanced channel coding
- Massive MIMO
- Mobile mmWave

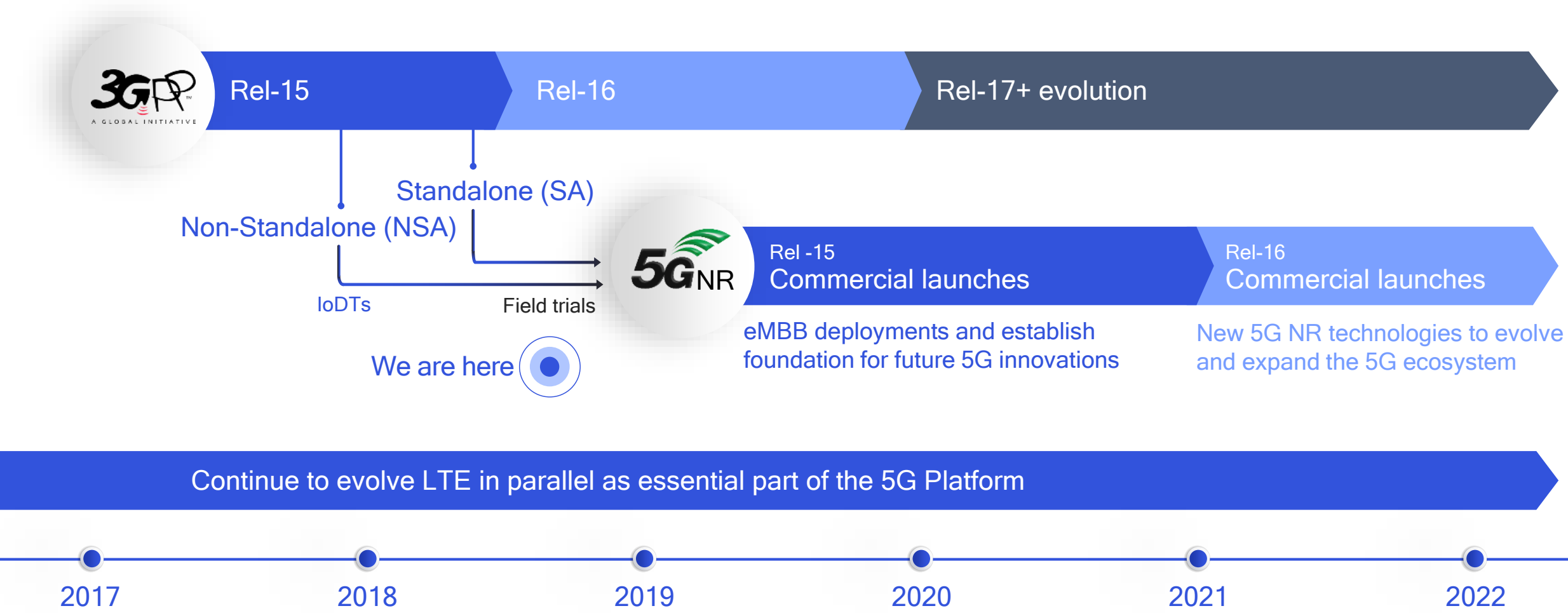
Early R&D investments and best-in-class prototypes

First successful 5G NR interoperable connection

Fundamental contributions to 3GPP standardization

Technologies part of 5G NR Release-15

Driving the 5G roadmap and ecosystem expansion



Qualcomm led way forward on 5G NR eMBB workplan

Stage 3 completion for 5G NR NSA
by December 2017 (RAN#78)[1]

Stage 3 completion for 5G NR SA
by June 2018 (RAN #80)[2]

RP-170741 agreed upon at 3GPP RAN #75 in March 2017
Broad support to meet increasing mobile broadband needs with global 5G NR standard

AT&T NTT DOCOMO SK Telecom Vodafone Ericsson Nokia Qualcomm

Alcatel-Lucent Shanghai-Bell Alibaba Apple Broadcom CATT China Telecom China Unicom China Mobile Cisco

Convida Wireless Deutsche Telekom Etisalat Fujitsu Huawei Intel Interdigital KDDI Korea Telecom LG Electronics

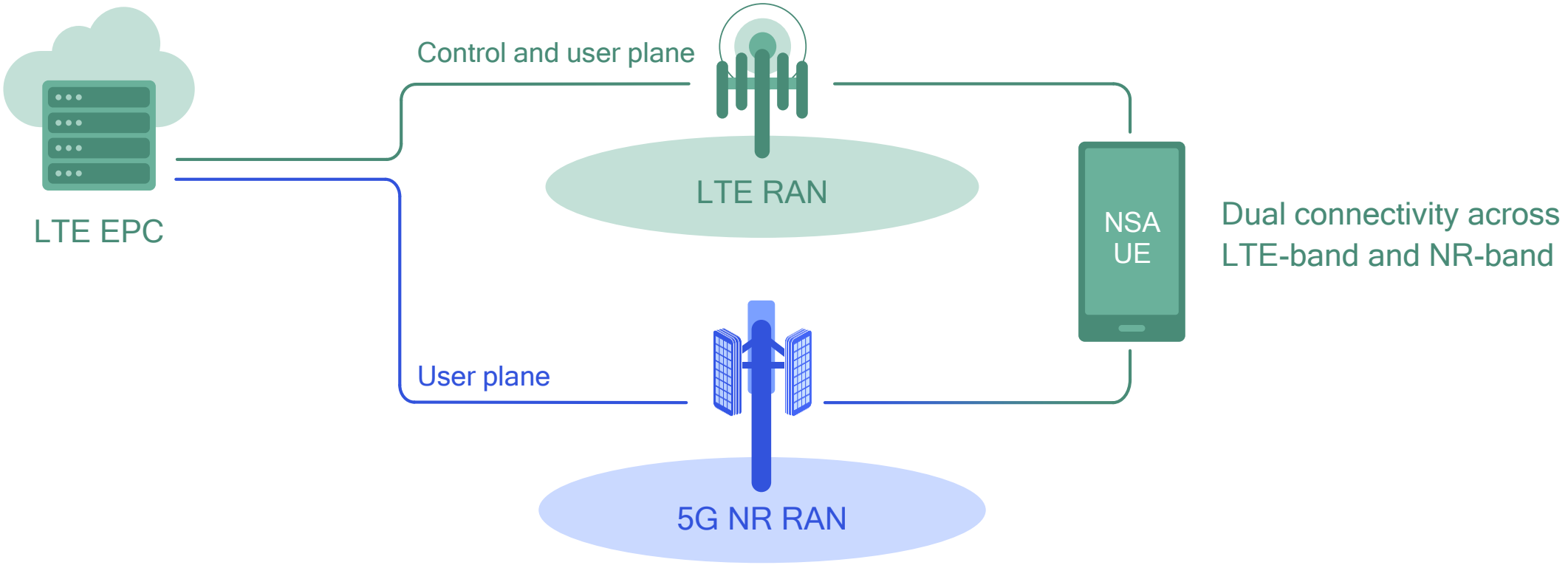
LGU+ MediaTek NEC Ooredoo OPPO Samsung Sierra Wireless Sony Sprint Swisscom TCL ZTE

Telecom Italia Telefonica TeliaSonera British Telecom Telstra T-Mobile USA Verizon vivo Xiaomi

1. NSA Option 3 family ASN.1 by March 2018; 2. Release-15 ASN.1 for 5G NR NSA and SA by September 2018

NSA 5G NR accelerated to support 2019 deployments

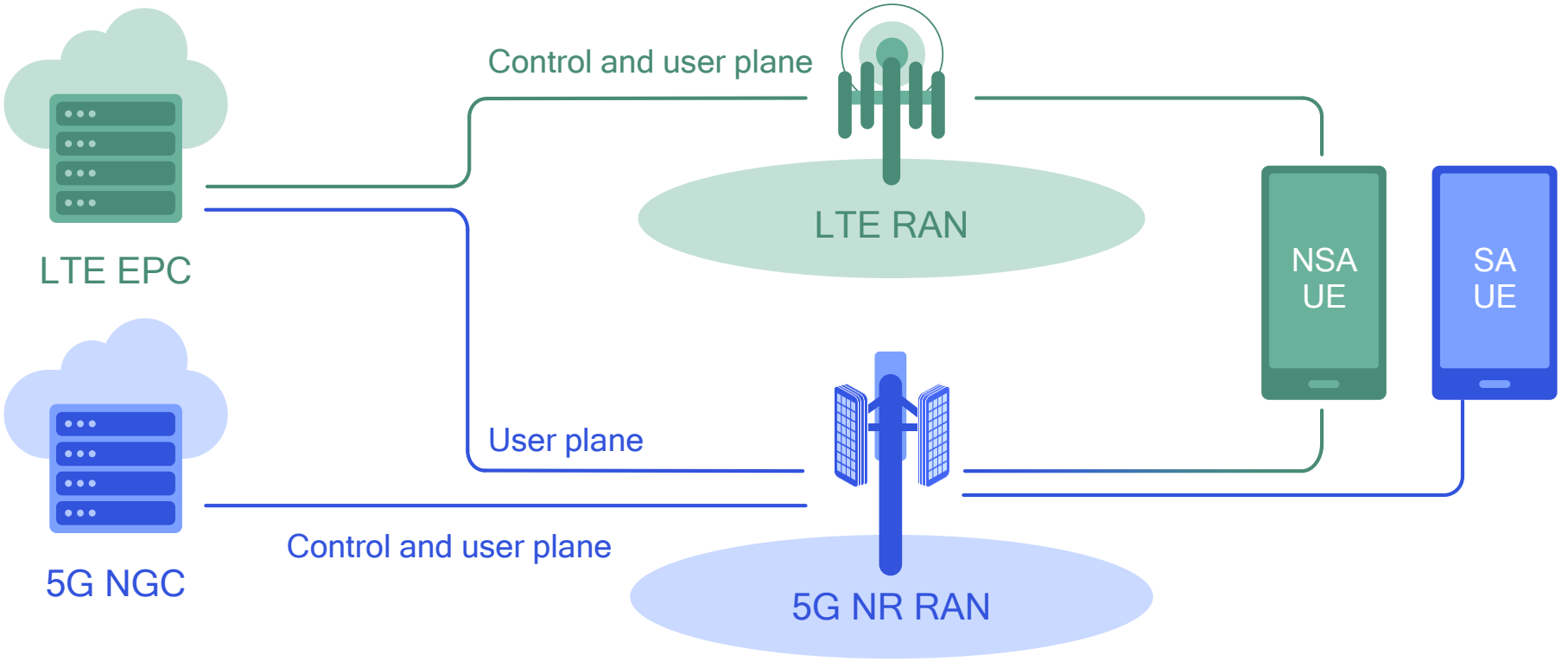
Specifications completed in December 2017



Non-Standalone (NSA) leverages LTE RAN and EPC for coverage and mobility

While introducing 5G NR to enhance the user plane performance and efficiency

SA 5G NR specifications completed in June Plenary



Standalone (NSA) utilizes 5G NextGen Core Network (NGC)

Leveraging SDN/NFV technologies to create optimized network slices and deliver on 5G's full potential

3GPP approved Release 16 projects

Fueling the 5G evolution and the expansion to new industries

1. New Rel-16 SI;
2. Rel-15 SI converting to Rel-16 WI;
3. Including enhancements to UE power consumption, network interference management, mobility, and NOMA;
4. Rel-16 WI to enable LTE IoT in-band with 5G NR;
5. Enhancing LTE enTV in Rel-14 to meet 5G requirements;
6. Non-terrestrial networks, 5G NR SON/MDT and more…

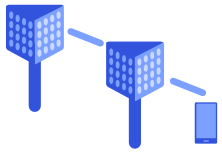
Release 16 projects

Including continuation of Release 15 projects

5G NR IIoT / eURLLC[1]

5G NR Cellular V2X[1]

5G NR in unlicensed spectrum[2] and spectrum sharing



Integrated access/backhaul[2]

MIMO, dual connectivity, and other eMBB enhancements[3]

5G massive IoT[4]

5G broadcast[5]

Positioning[1]

Others[6]

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