Qualcomm

September 2020

San Diego, CA

The essential role of technology standards

Driving interoperability, ecosystem development, and future innovation

The virtuous circle of technology innovation

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

Vision
Identify a problem or need; establish requirements

Invention
Invent new technologies and end-to-end system architecture

Proof-of-concept
Deliver end-to-end prototypes and impactful demonstrations

Commercialization
Engage with global ecosystems to deploy new features with standards-compliant infrastructure and devices

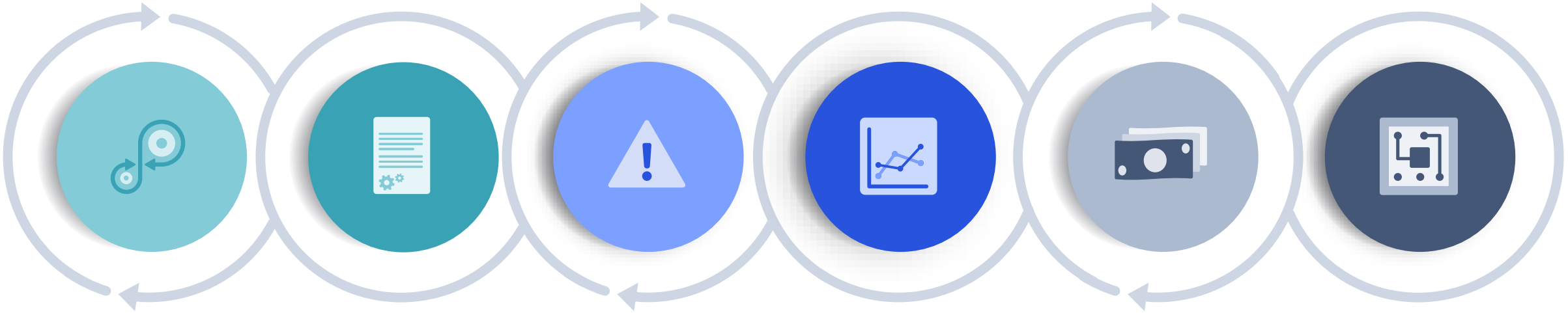
Trials
Collaborate on field trials that track standards development and drive ecosystem towards rapid commercialization

Standardization
Lead ecosystem towards new projects and drive system design through technology standardization process

The value of standards

Why leadership in standards is important

Communications industry is based on technology standards



Ensuring system interoperability
while enabling product differentiation and spurring transparent industry competition

Meeting regulatory requirements
test and certification procedures are developed to aid in meeting obligations

Reducing market risk
especially in areas of large investments (e.g., 5G infra)

Creating new markets
and expanding addressable markets of existing products and technology

Lowering cost
through economies of scale and multi-vendor sourcing

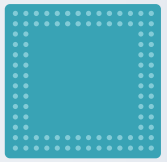
Improving technology
multiple companies participate, collaborate, compete – best prevails

Standards create significant value for the wireless ecosystem

Industry leaders contribute to technology standards

Better, quicker-to-market products

Communications standards are very complex in nature; thus, leadership in designing technology standards goes hand in hand with leadership in product development



Standards leadership

Valuable intellectual property (IP)

When inventions are contributed to standards, they become available to everyone in the ecosystem; therefore, it is important to have a solid IP framework that adequately incentivizes inventors to contribute their innovation to standards bodies

Driving technology forward with new functionalities and efficiencies, fostering healthy market growth that benefits the broader ecosystem

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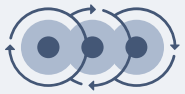
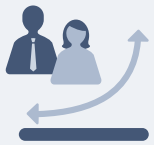
Allows a wide ecosystem to address attractive business opportunities

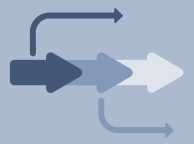


Garners broad ecosystem adoption and implementation

Defines great technologies with superior performance and efficiency



Drives marketing and regulation guiding activities



Exceptional leadership in the standards process

We have the deep technical expertise, broad ecosystem reach, and decades of global experience to drive successful standards

Addresses the global market need of solving vital technology problems

Provides the proper tools (e.g., testing, certification) for mass market productization

What are the ingredients of a successful standard?

We participate in

~200 global

standards and industry organizations

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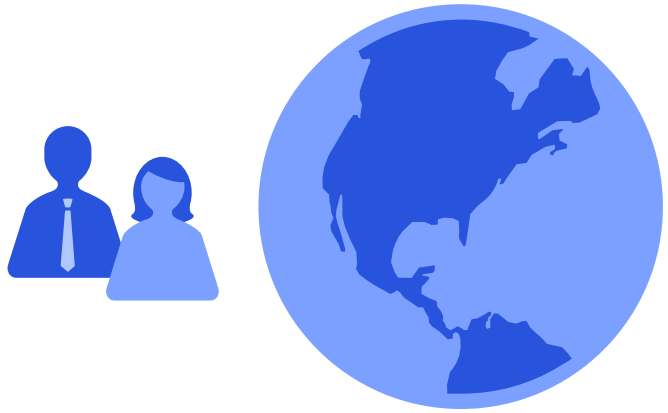
Recent events leading to new standardization challenges

COVID-19 preventing in-person meetings in the foreseeable future

Virtual meetings can be harder to manage and less efficient for consensus driven work

Global trade tension[1] preventing participation of key standards members



Interim Final Rule in June 2020 partially solved some issues but needs to be further enhanced

1 For example, companies put on the U.S. Bureau of Industry and Security (BIS) Entity List

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We're doing what's right to move standards forward

Standards in mobile devices

Complex systems that require global interoperability

Also broadly applicable across device categories and industries

Cellular connectivity

3GPP, ATIS, TIA, ETSI, TTA, TTC, ETRI, ARIB, CCSA, TSDSI, GCF, PTCRB, FCC, GSMA, GSA, CCF, RED, Future Forum, 5G Forum, CTIA

WLAN & WPAN connectivity

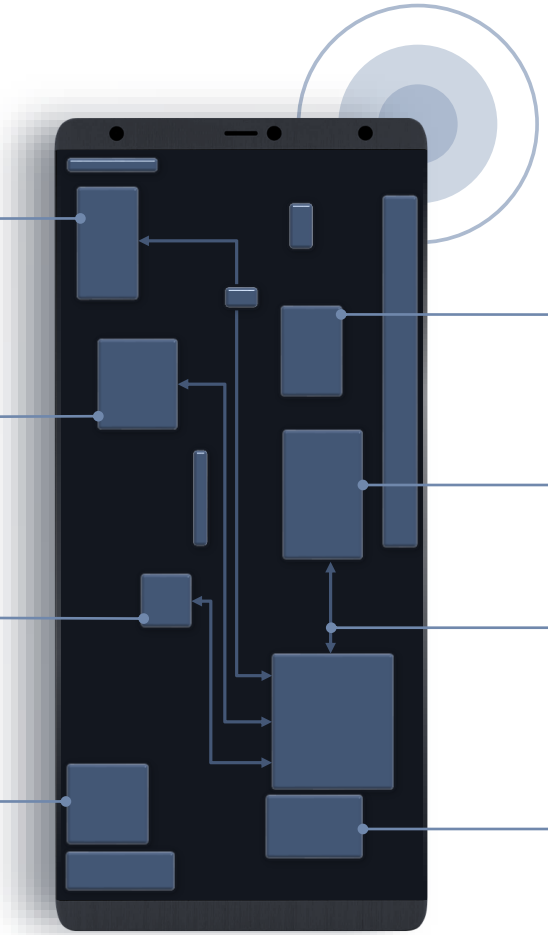
IEEE, WFA, WBA, WAPI Alliance, Bluetooth SIG, NFC forum

Emergency & location services

Galileo, 3GPP, ATIS, CCSA, CEN CENELEC, CSRIC, ETSI, GUTMA, OMA

Security and local content protection

ETSI-SCP, GlobalPlatform, Eurosmart, JHAS-SOGIS, TCA, GSMA, JEDEC, EMVCo, TCG



And many others...

Multimedia services

MPEG, 3GPP, Khronos Group, INCITS, DASH-IF, DVB, CTA WAVE, ATSC, SMPTE, AIS, IVAS

Semiconductor manufacturing

Si2, Accellera, UEFI, GSA, FlexTech, LTAB, CSIA

Wired connectivity

MIPI Alliance, JEDEC, NVMe, PCI-SIG, USB-IF, DMTF, VESA, UHD Alliance, HDMI, RISC-V, xHCI

AI processor

MLPerf/ML-Commons, FIDO, SAE, Khronos, MPEG, NIST, ORAN-AI, ISO/IEC SC42

Many standardized components and interfaces in a smartphone

ITS/V2X

5GAA, 3GPP, SAE International V2X SC, ETSI TC ITS, IEEE 1609 WG, CAICV, OmniAir Consortium, CAMP, CCSA, C-SAE, NTCAS, ITS America, ERTICO, C-ITS, ITS Forum, ISO TC 204, NEMA

ADAS/Automated Driving

ISO TC 22, SAE International ORAD Committee, ISO TC 204 WG 14, IEEE 2846 WG, IEEE 2851 WG, Accellera Functional Safety WG, Khronos Group Safety Critical WG, 5G ADA

Telematics/Infotainment

CCC, WFA Automotive Market Segment TG, AGL, AEC, AESIN, AEIA

Vehicle Security

SAE International Vehicle Electrical System Security and Vehicle Cybersecurity Systems Engineering Committees, Auto-ISAC

And many others…

Standardized technology across components and interfaces in automotive

Cellular standards

The heart of the mobile ecosystem – leading standards development and the ecosystem expansion

Cellular has revolutionized the way we communicate

From voice only to a plethora of new services that our lives depend on today (e.g., smartphone)

< Then

Now >

8.9B
mobile subscriptions
by 2025

Source: Ericsson Mobility Report, November, 2019

3GPP drives global cellular standards

2G, 3G, 4G and 5G

22
Years driving cellular tech evolution

14
Major releases

>1.4K
Tech specifications*

100,000's
Technical contributions

3rd Generation Partnership Project

700+
Member companies

~20
Technical 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#86 (RP-192371); Including 3G/4G/5G Release 99/4/5/6/7/8/9/10/11/12/13/14/15/16

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

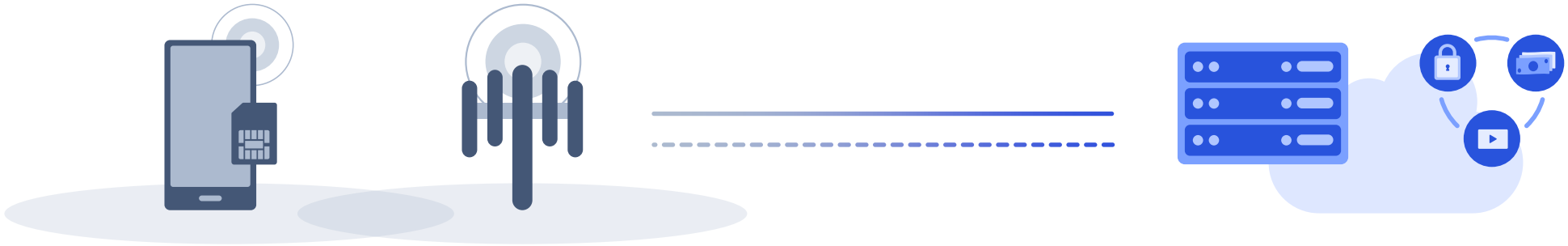
3GPP defines complete end-to-end system specifications

Radio Access Network (RAN)

Implements radio access technology, e.g., 5G NR, LTE, managing radio link to connect UEs to networks

Core Network (CN)

Manages macro-mobility, sessions, quality of service, policies, security, and routes traffic to outside world, e.g., Internet, or local intranet



User Equipment (UEs)

Devices, e.g., smartphones and all types of IoT devices that connect to services via radio access technology

Services

Framework for service delivery architecture, multimedia, billing, charging, etc.

Test Requirements

Defines performance and conformance test procedures to ensure interoperability used for certification (e.g., GCF)

This large scope requires division of work into smaller, specialized working groups in 3GPP

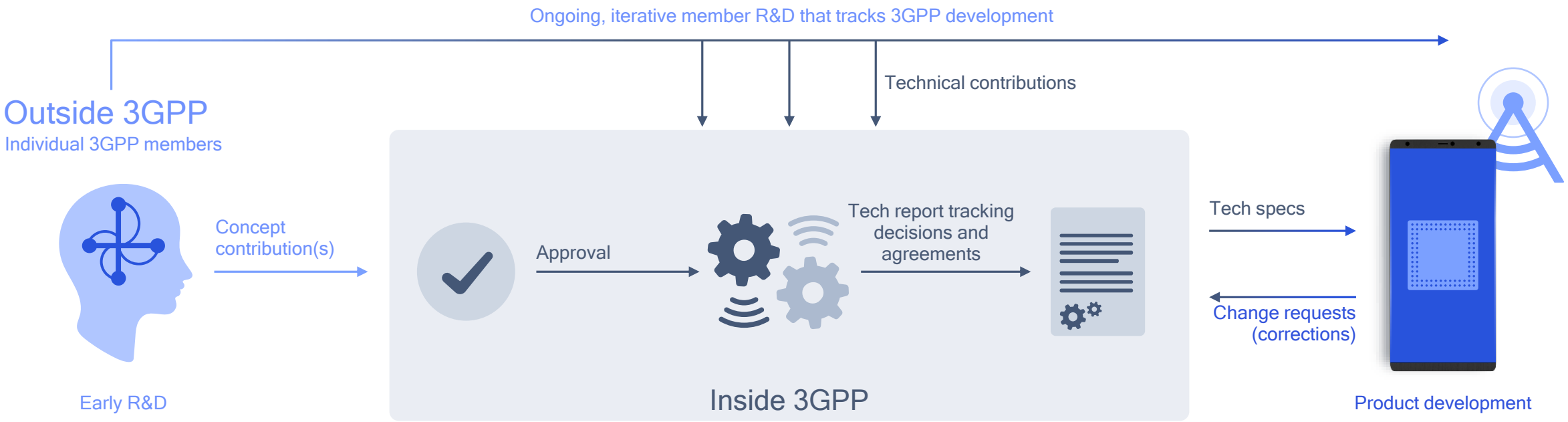
3GPP is a collaborative, system-engineering effort

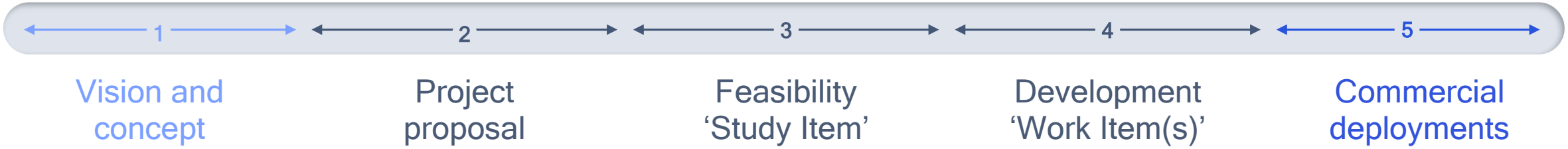
Analogous to other large-scale engineering efforts

3GPP projects are similar to other complex system-engineering effort, e.g., designing an airplane.

3GPP develops technical specifications for different parts of the system (vs. jet engines, wings, …), is constrained by meeting time (vs. OPEX) and is a collaborative, consensus-based effort across 100s of different entities with diverse interests/incentives (vs. collaboration of teams and suppliers in a single company).

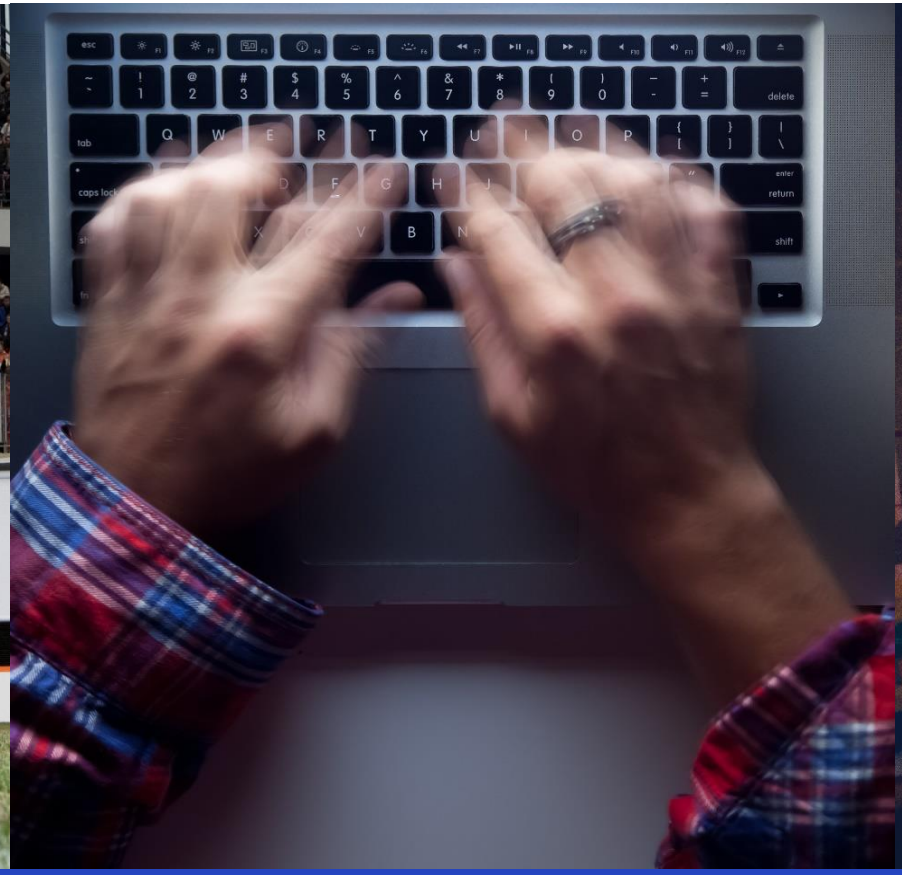
A typical workflow in 3GPP





Some assert 3GPP leadership based on # of contributions

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

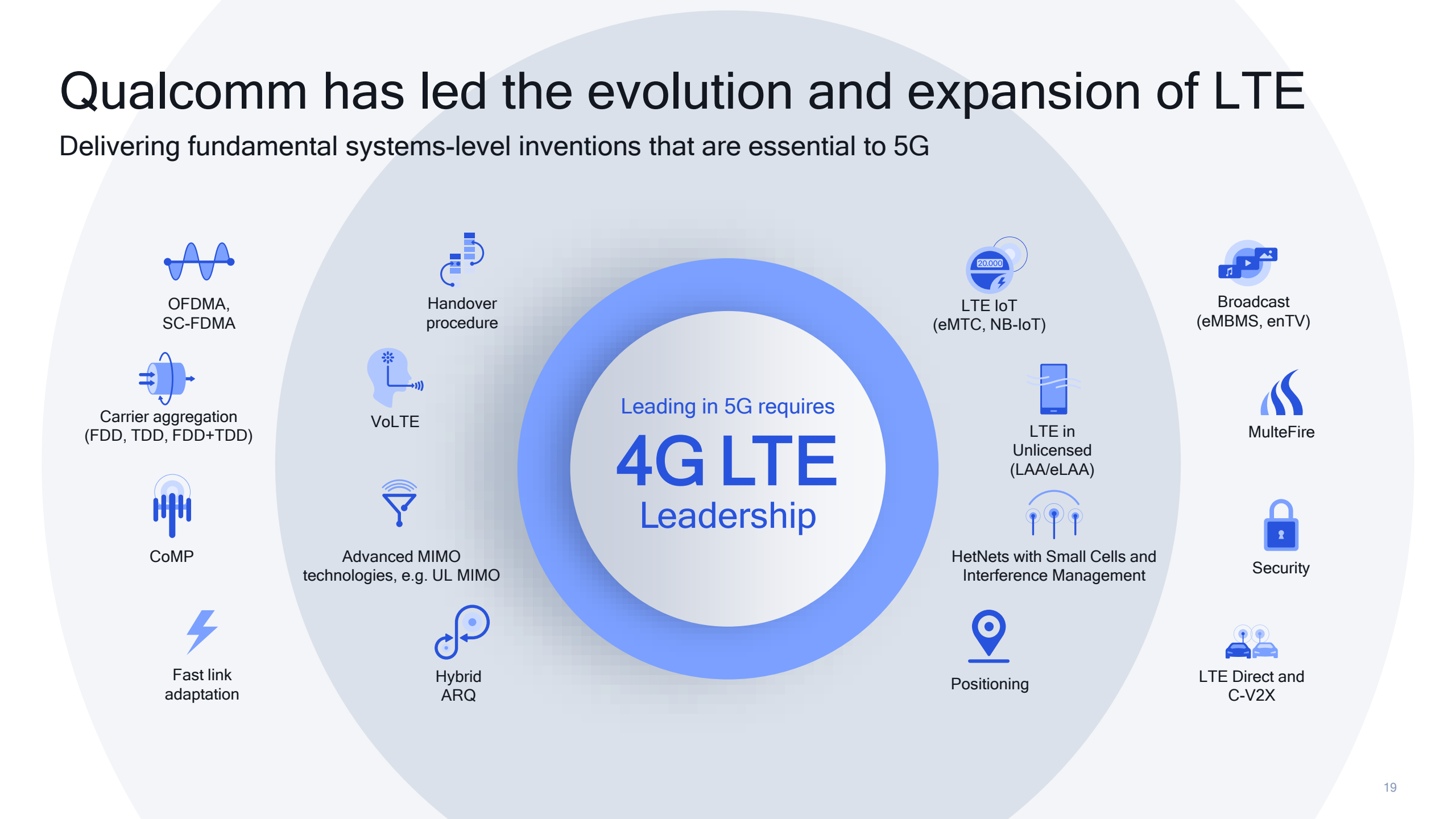


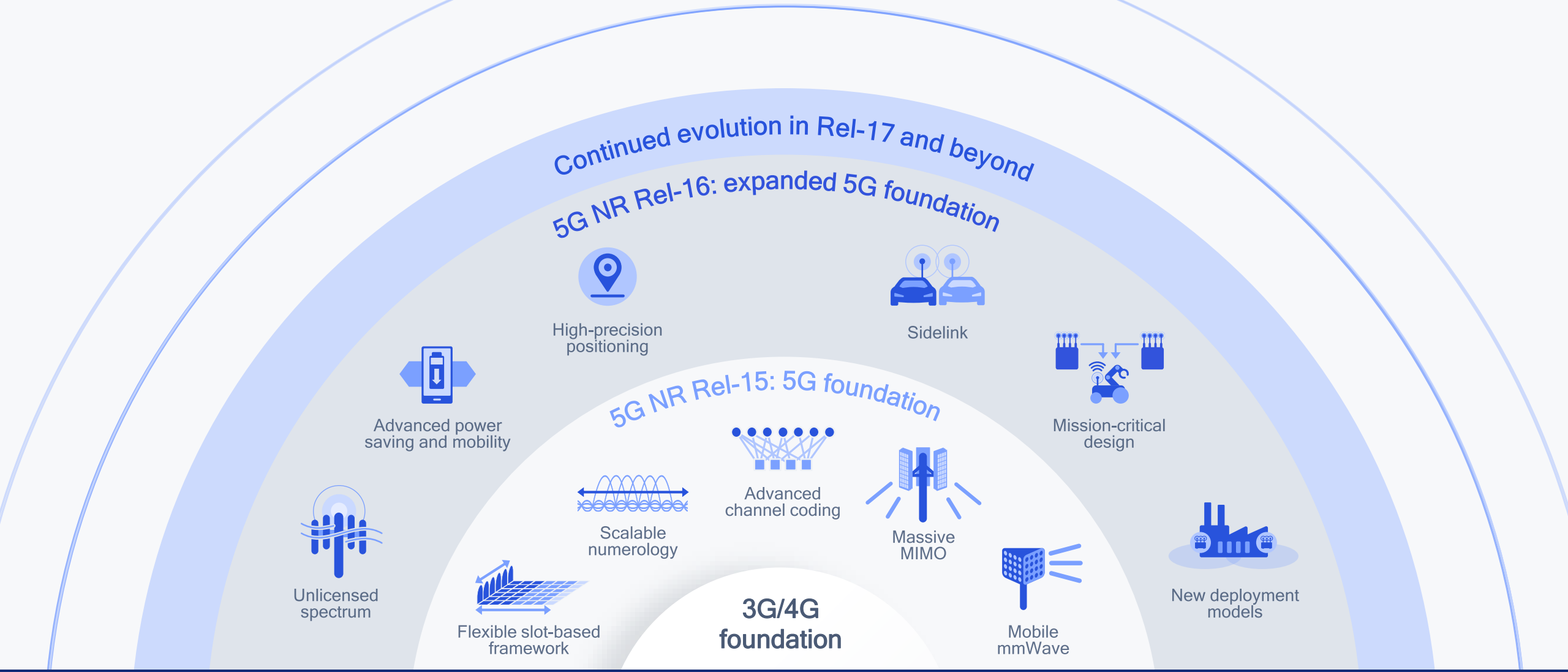
Analogous to assessing the impact of an author by counting the # pages written

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

Qualcomm has led the evolution and expansion of LTE

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





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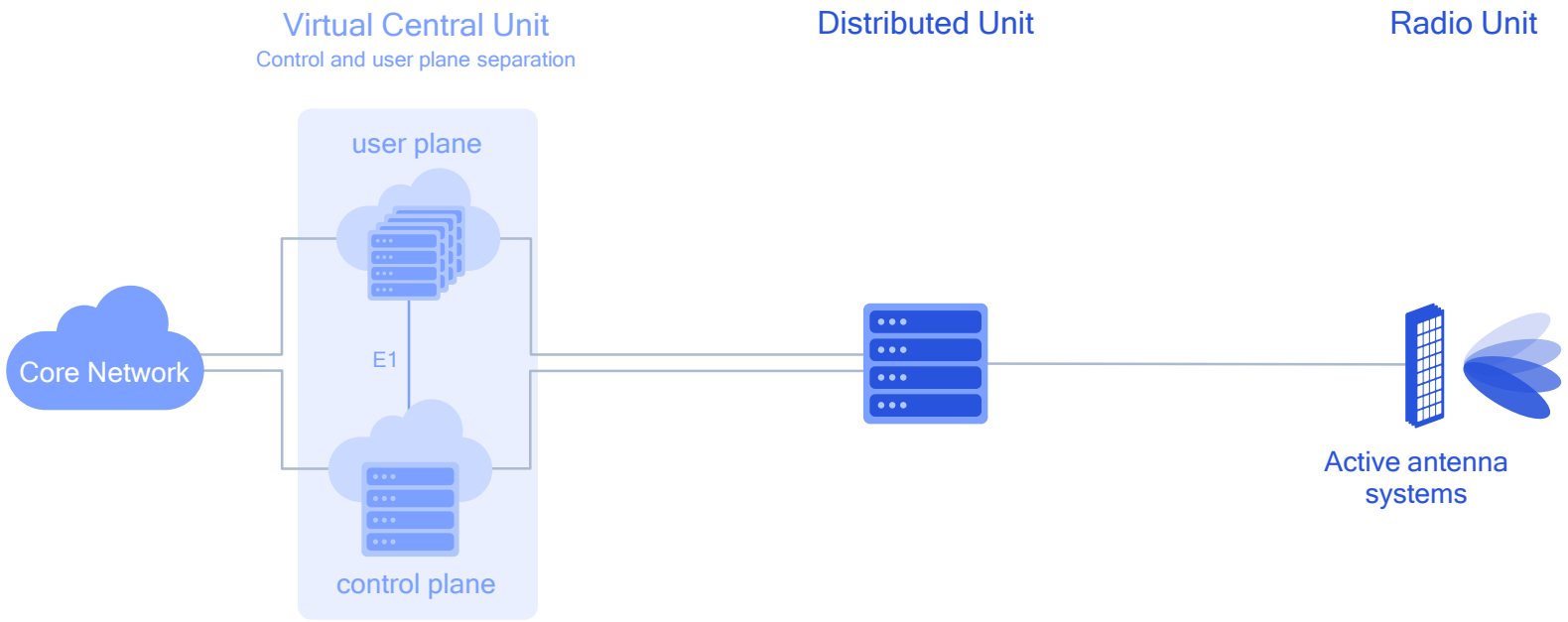
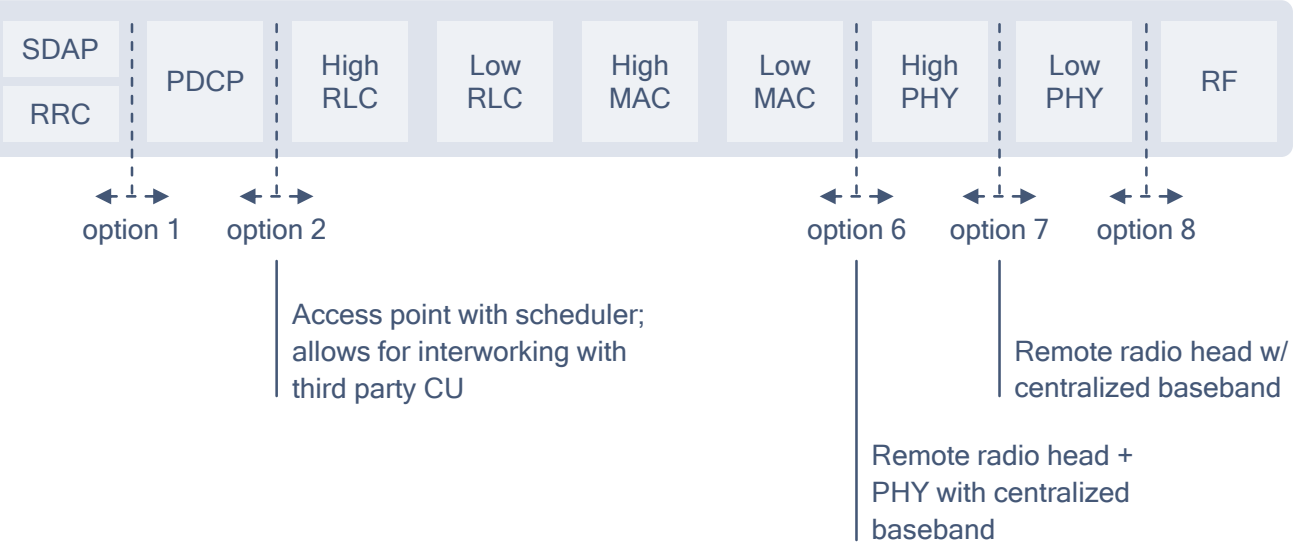
Our wireless inventions are leading the 5G evolution

5G vRAN

Designed for unprecedented flexibility and cost-effective network deployments





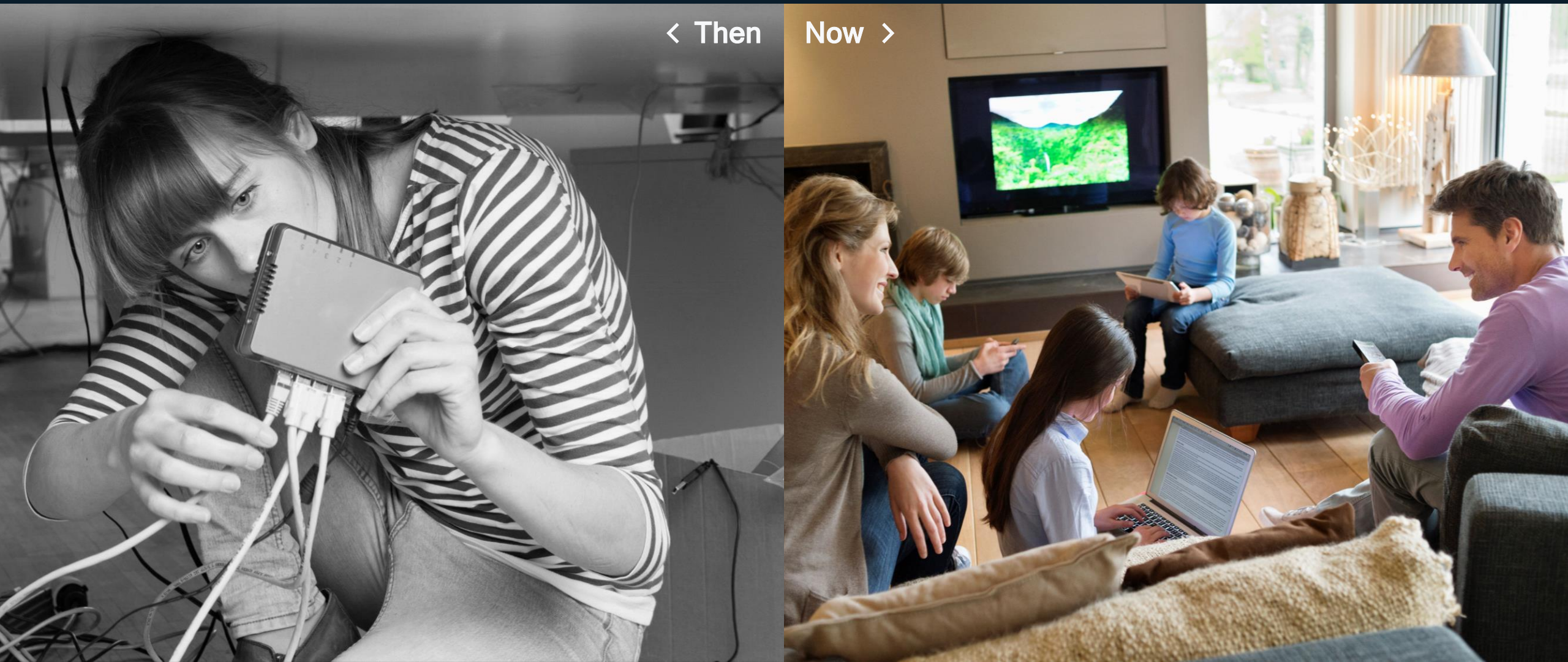
CU: Central unit; DU: Distributed unit; MAC: Medium access control; PDCP: Packet data convergence protocol; PHY: Physical layer; RF: Radio frequency; RLC: Radio link control; RRC: Radio resource control; SDAP: Service data adaptation protocol

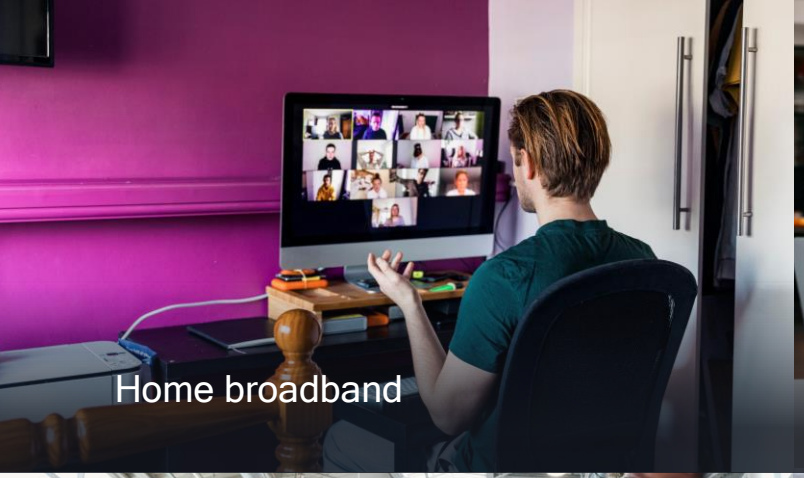
Wi-Fi Standards

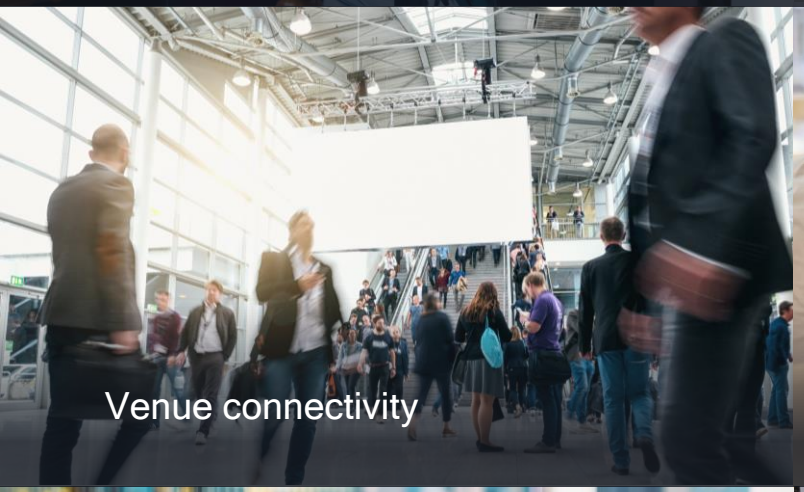
Driving the technology evolution of wireless local area networking

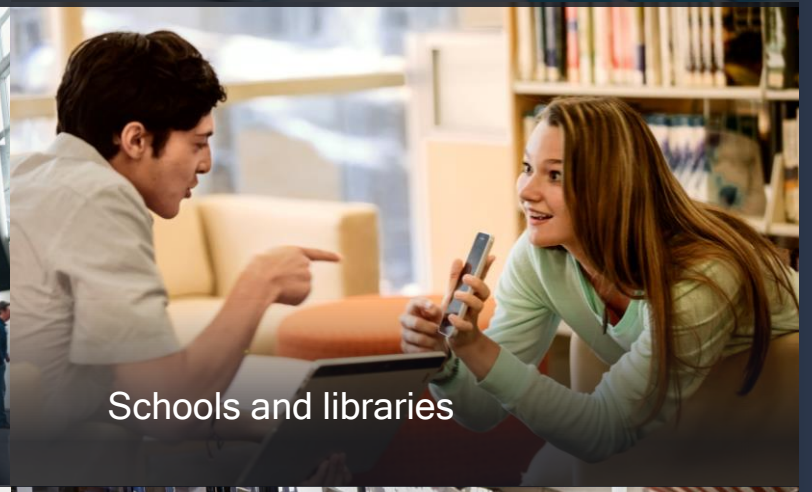
Wi-Fi has revolutionized the way we access the internet

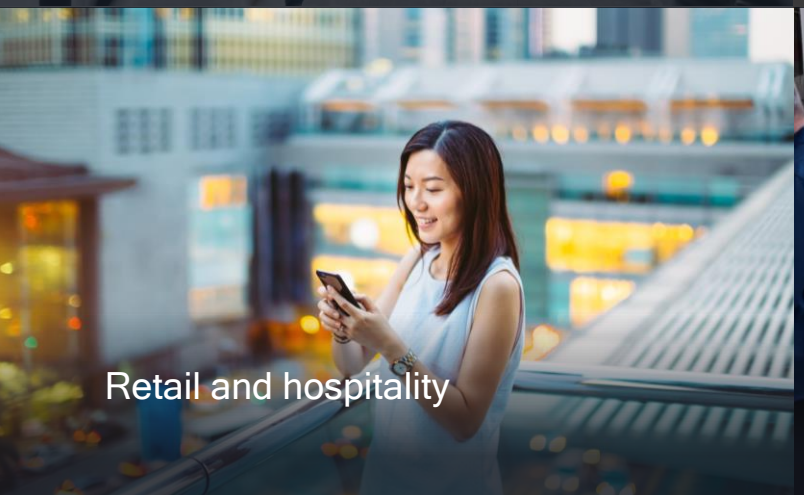
Cutting-the-wire for a wide range of devices – PCs, tablets, TVs, smartphones, etc…

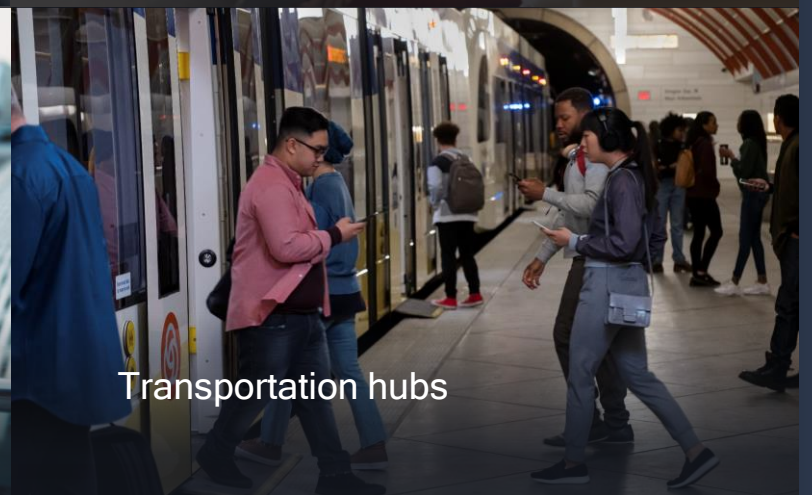












Wi-Fi complements cellular connectivity for local broadband access

- Utilizes unlicensed spectrum (e.g., 2.4/5/6/60 GHz)
- Focuses on indoor use cases
- For human and machine communications (i.e., IoT)
- Supports fixed and mobile devices

Evolving networks from speed to capacity

Core technology evolution and Qualcomm Technologies leadership

IEEE 802.11 Working Groups

Develops and maintains backward compatible global MAC and PHY standards

Defines spectrum use for Wi-Fi: 2.4 GHz, 5 GHz, 6 GHz, 60 GHz, and sub-1 GHz unlicensed bands

Releases key MAC and PHY performance upgrades with 4-6 year cadence

Industry standards

Symbiotic relationship since 1999

Feedback on standards and market requirements

Wi-Fi Alliance (WFA)

Develops test plans, manage interoperability test programs, and organizes industry plug fests

Develops industry specifications complementary to IEEE standards

Conducts regulatory advocacy for Wi-Fi technologies

Drives Wi-Fi technology marketing activities

IEEE 802.11 Working Groups

Actively drives Wi-Fi technology standardization process

Holds key leadership positions in working/task groups, e.g., 802.11 Vice Chair, 802.11be Chair, etc.

Leads in quality contributions to Wi-Fi standards (e.g., 802.11ax)

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Wi-Fi Alliance (WFA)

Consistently selected to be part of industry interoperability testbeds

Holds key leadership positions on the Board of Directors (since 2008) and WFA task groups

Received “Wi-Fi Alliance 2020 Industry Impact Award” and “Outstanding Leadership and Contribution” awards for sponsor members in multiple years

We are committed in pushing standardized Wi-Fi technology forward

A rich history of leading key Wi-Fi innovations

Advanced R&D | Standardization | Successful commercialization

802.11g

Drove OFDM into the 802.11g standard

Implemented OFDM in 1st commercial CMOS 5GHz product[1], then rapidly ported to 2.4 GHz

Enabled successful proliferation of 802.11g that greatly expanded the Wi-Fi ecosystem

Wi-Fi Mesh

Pioneered multi access point (AP) technology

Led contributions to the Wi-Fi EasyMesh industry specification

Wi-Fi 5: 802.11ac

Drove MU-MIMO – the foundational technology – into the 802.11ac standard

Proved to the ecosystem on the viability and value of MU-MIMO for Wi-Fi systems

Wi-Fi 6: 802.11ax

Drove key UL OFDMA and UL MU-MIMO designs into the 802.11ax standards

Developed synchronized AP scheduling, trigger-based OFDMA and MU-MIMO

Continued leadership in IEEE and WFA

Wi-Fi 4: 802.11n

MIMO-OFDM (spatial multiplexing) and transmit beamforming

Implemented MIMO-OFDM system architecture for mass market products[2] (e.g., PCs, routers)

Drove the success of “pre-standard” MIMO products

802.11ad / ay

Pioneered mmWave beam forming & antenna designs

Delivered the highest performing mmWave implementation, proving the viability of mmWave

Drove mmWave into the 802.11ad and brought wider bandwidths via channel bonding in 802.11ay

802.11ah

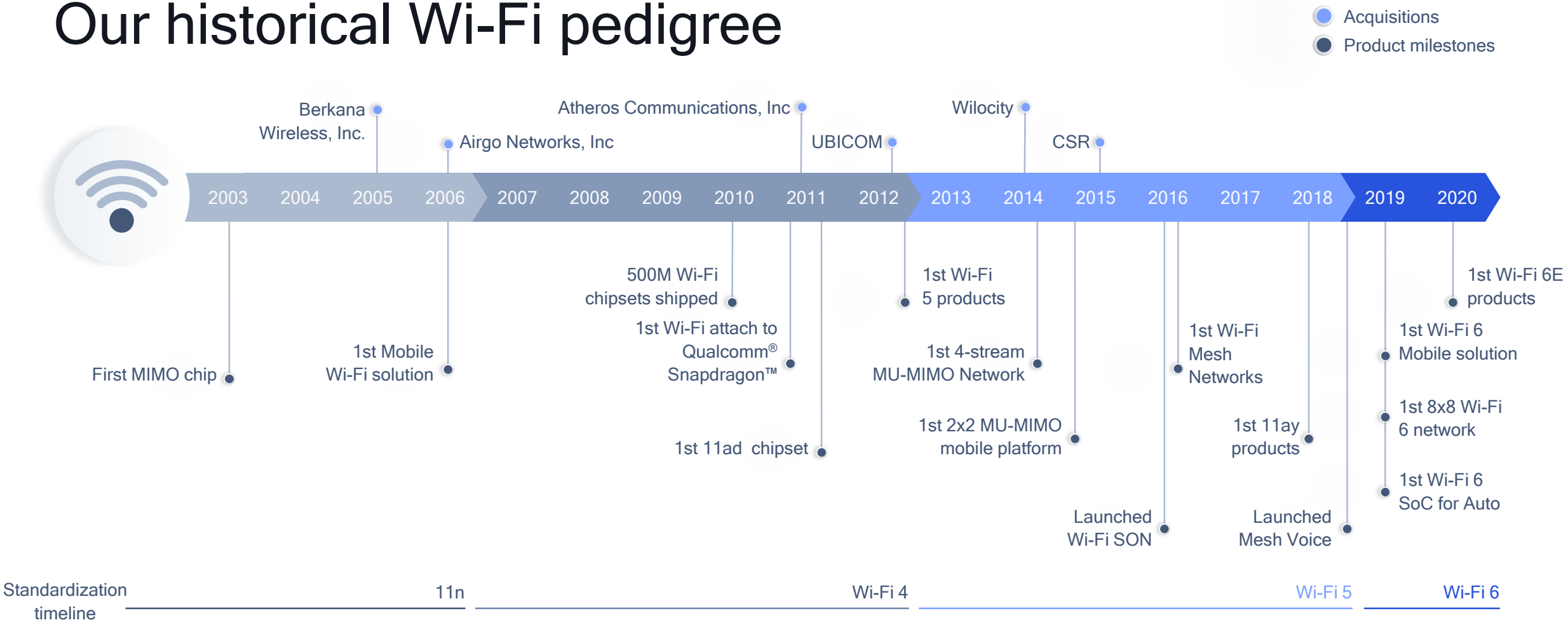
Drove key technologies enabling extended range, small battery operation and low-power for Wi-Fi operating in sub-1 GHz

Facilitated opening of spectrum for 802.11ah sensors in Europe

Nominal work on Wi-Fi 7 / 802.11be is just starting

1 Based on 802.11a; 2 Including Airgo, Atheros, and Wilocity

Our historical Wi-Fi pedigree



4B+ Wi-Fi chips shipped since 2015

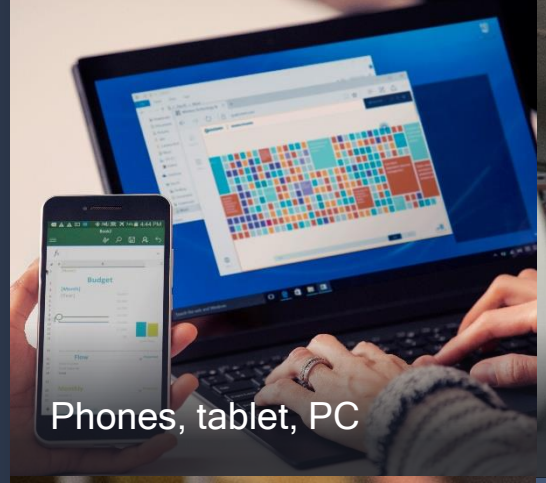
Qualcomm Snapdragon is a product of Qualcomm Technologies, Inc. and/or its subsidiaries.

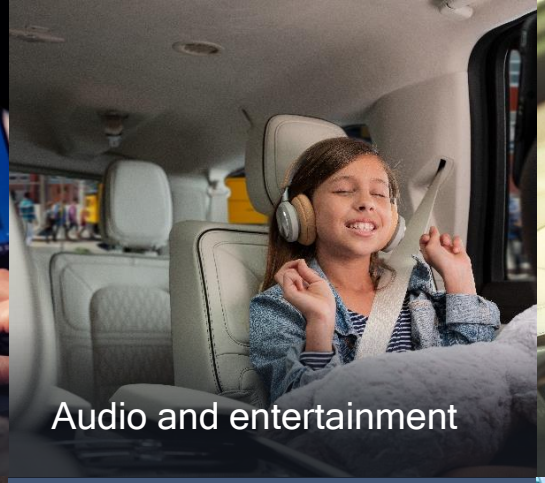
Bluetooth Standards

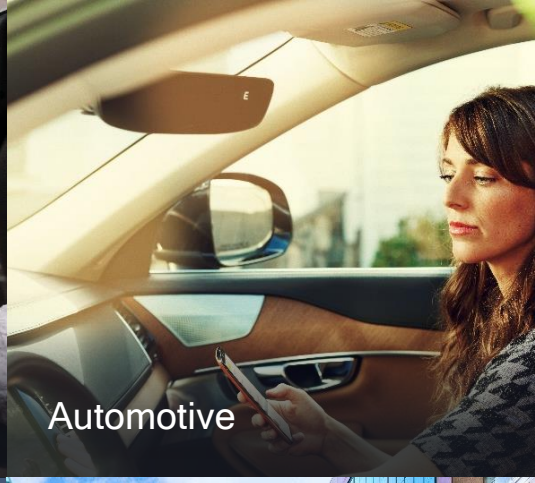
Connecting wireless
personal area networks

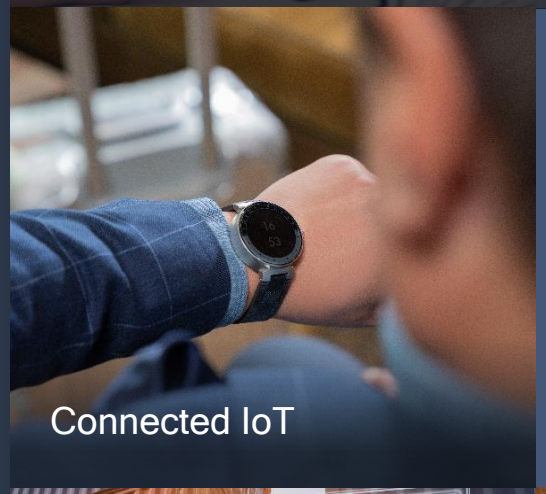
Bluetooth supports broad use cases across a wide range of industries

- Audio streaming
- Data transfer
- Location services
- Device network





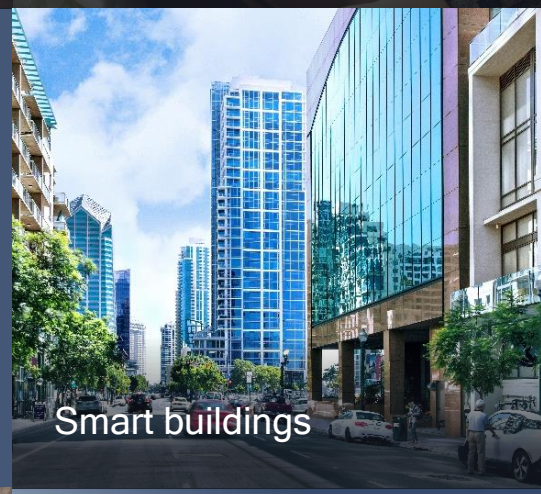


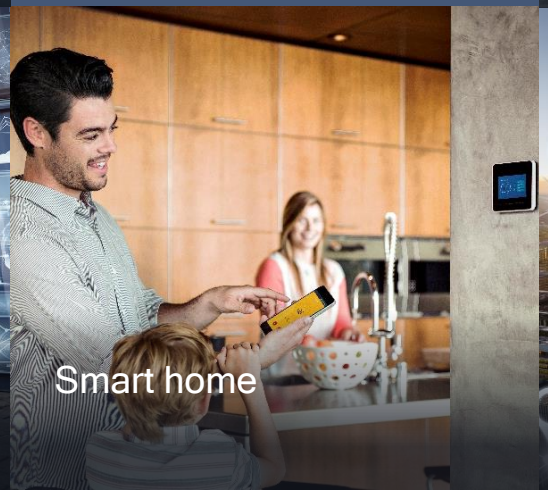


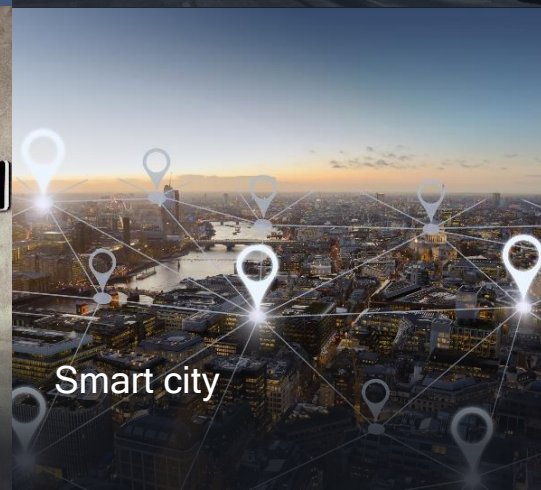
Bluetooth®

6.2B

annual device shipment by 2024







Source: Bluetooth SIG Market Update 2020

Founded in 1998

Bluetooth

Special Interest Group (SIG)

14
Working Groups (WG)[1]

80
Active specification projects

Driving the technology evolution and commercial success

Technology standardization

~15 promoter/associate members actively contributing to Core WG meetings to evolve Bluetooth specifications[2]

Product qualification

World-class programs that drive product interoperability, and give access to technology and trademark licensing

Brand promotion

Campaigns to increase the awareness, understanding, and adoption of Bluetooth technology

Source: Bluetooth SIG Market Update 2020;
1 Audio/Telephony/Auto, Automation, Core Specification, Direction Finding, Discovery of Things, Easy Pairing, Generic Audio, Hearing Aid, HID, Internet, Medical Devices, Mesh, PUID, Sports and Fitness
2 Based on 6 months attendance records, analysis done in June 2020

Leading the way in Bluetooth SIG

Working Group/committee leadership and participation

Current working groups

Core Specification (CSWG) – **Chair**

Generic Audio (GAWG) – **Chair**

Bluetooth Test and Interoperability (BTI) – **Chair**

Automotive, Telephony, Audio (ATA)

Mesh

Current committees

Bluetooth Architecture Review Board (BARB)

Bluetooth Qualification Review Board (BQRB)

Bluetooth (Qualification) Technical Advisory Board (BTAB)

Past leadership positions

Board member: 2012-2014 (CSR), 2014-2016 (Qualcomm)

Chairs or vice chairs: BARB, BQRB, Regulatory, ATA, Automation, Mesh, Internet, HID, HCI, Radio Improvements

Contributing member: Regulatory, Automation, Direction Finding, HID, Internet, Medical Devices, PUID, Sports and Fitness, HCI, Radio Improvements

Key recognitions for our leadership role

- Awarded “Outstanding Technical Contributor” in 2011, 2012, 2014, 2015 (x2), 2016, 2017 (x3)
- Awarded “Working Group and Committee Chair of the Year” in 2010, 2018, 2019
- Awarded “Bluetooth Core Specification Team Award” in 2014, 2016
- Inducted to “Bluetooth Hall of Fame” in 2017 (x2), 2010, 2011

A rich history of leading key Bluetooth innovations

Advanced R&D | Standardization | Successful commercialization

Joined BT SIG as associate member since 2000

Bluetooth 1.2

Adaptive frequency hopping

Bluetooth 2.0

Enhanced data rate design (EDR)

Bluetooth 2.1

Secure pairing/ connection

Bluetooth 4.0

Low energy (LE) design

Attribute protocol (ATT)

Generic attribute profile (GATT)

Bluetooth 4.1

Dual mode devices

Bluetooth 5.0

Long range PHY

Advertising extensions

Mesh networking

Mesh design[1]

Bluetooth 5.1

Location services (AoA/AoD[2])

Bluetooth 5.2

Enhanced Attribute Protocol

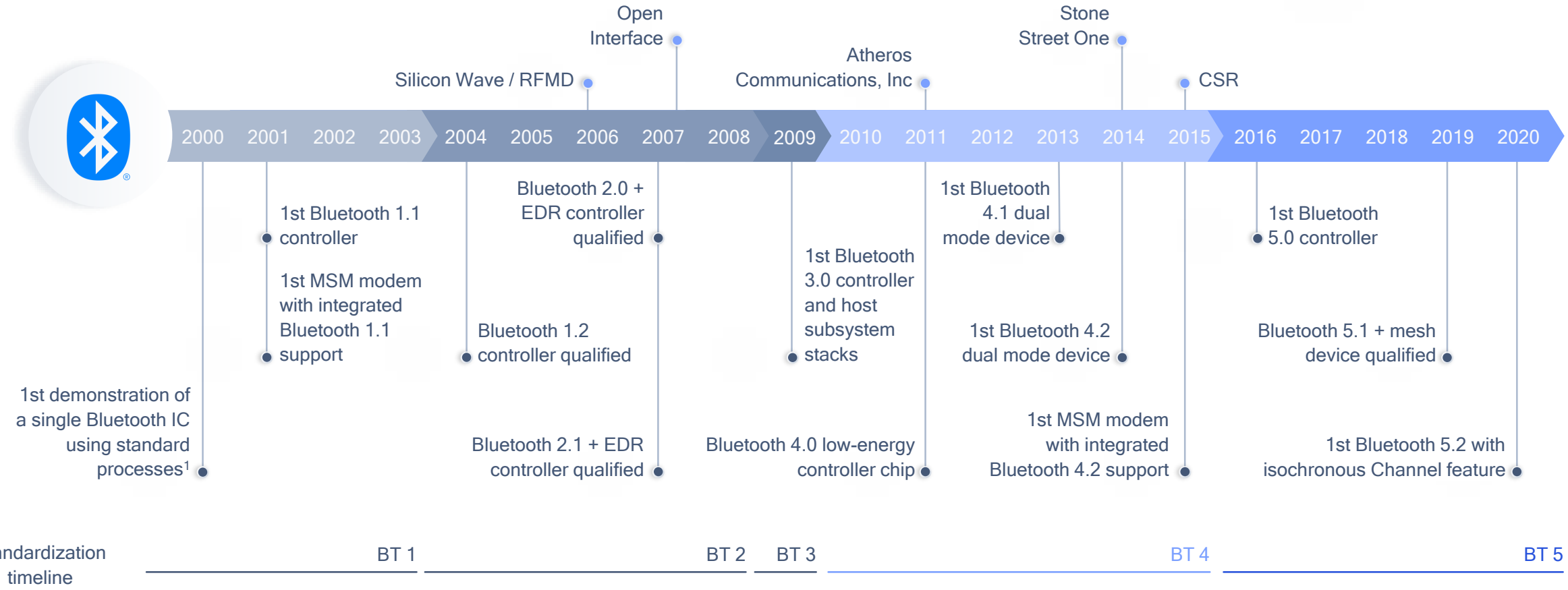
Continued leadership in Bluetooth SIG

Also actively involved in creation/revisions of various Bluetooth SIG processes

(e.g., Bluetooth Specification Development Process, Qualification Process)

1 As part of Mesh Networking specifications v1.0 first adopted on July 13, 2017; 2 Angle of Arrival/Departure

Our legacy of Bluetooth leadership



Key product milestones

First single-chip Bluetooth controller[1]

First Bluetooth controllers qualified for new releases

First Bluetooth mesh product[2]

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

CMOS from CSR, BiCMOS from Silicon Wave: https://www.eetimes.com/cambridge-silicon-radio-demonstrates-single-chip-bluetooth-radio-ic/; https://www.eetimes.com/silicon-wave-radio-modem-ic-gets-bluetooth-qualification/# 3. CSRMesh

Video Coding Standards

Powering the creation and consumption of rich digital media experiences

Video technology revolutionized how we create and consume media

Enhanced video quality with less bits lead to broad adoption across a wide range of devices and services

1. Cisco Annual Internet Report, 2018-2023

Founded in 1988 as part of ISO/IEC JTC 1

SC 29 (MPEG)

Motion Picture Experts Group

Developing international standards for compression, decompression, processing, and coded representation of moving pictures, audio, and their combination, in order to satisfy a wide variety of applications

Generic coding of moving pictures and associated audio information	H.262
Advanced video coding (AVC)	H.264

Collaborative video standard development

High efficiency video coding (HEVC)	H.265
Versatile Video Coding (VVC)	H.266*

Developed first spec in1984 as part of ITU-T

VCEG

Video Coding Experts Group

A long and rich history in visual compression coding work focusing on video and still image, with three ITU standards before working jointly with MPEG

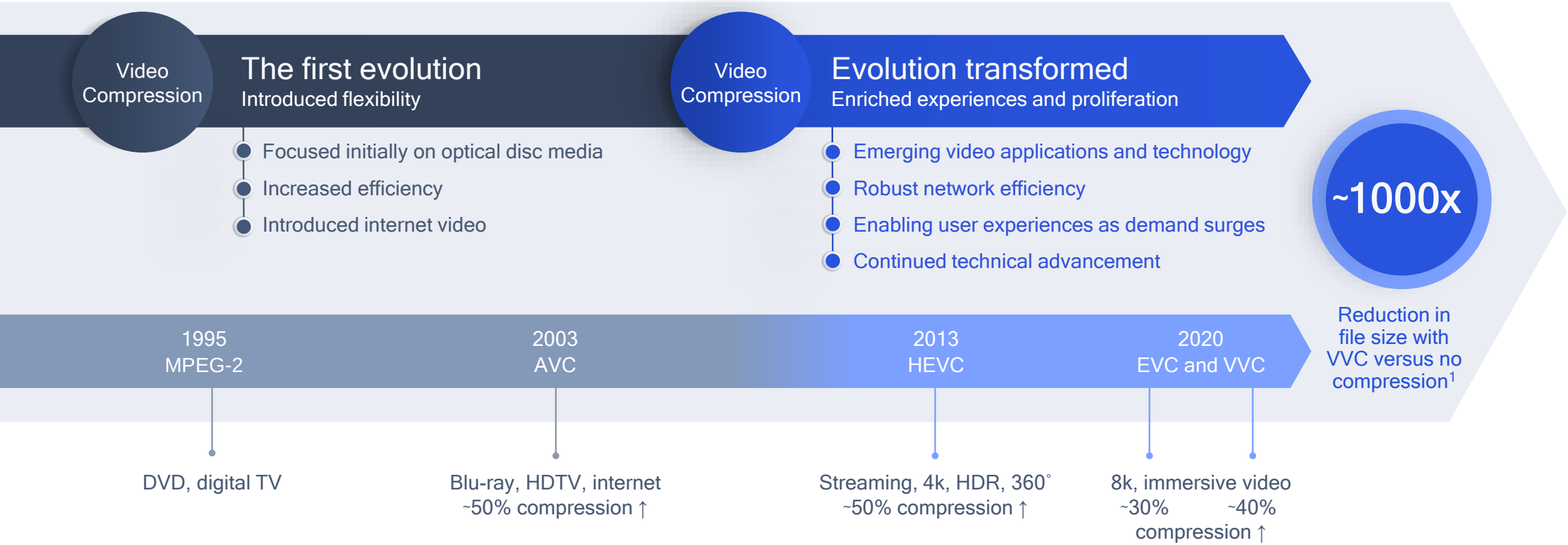
Driving the technology evolution and commercial success

Expert working groups | Technology standardization | Product interoperability

*not the official name yet

Technical innovation drives video evolution

A regular cadence of technical advancement in video codecs has led to massive reduction in file size



1. On a 1080p video at 30 frames per second; EVC = Essential Video Coding, VVC = Versatile Video Coding,

Key contributions across video technologies

Standard video codecs

H.265/HEVC

In addition to being a key contributor to HEVC initiation, our innovations provide broad impact across coding features

Next generation video codecs

VVC and EVC

Continued industry leadership in contributing fundamental innovations in next generation high performance video codec standards

A rich heritage of leading video innovation

Coding performance and efficiency

Implementation

Contributions facilitate coding efficiency and low computational complexity at reduced power consumption for video codec implementors

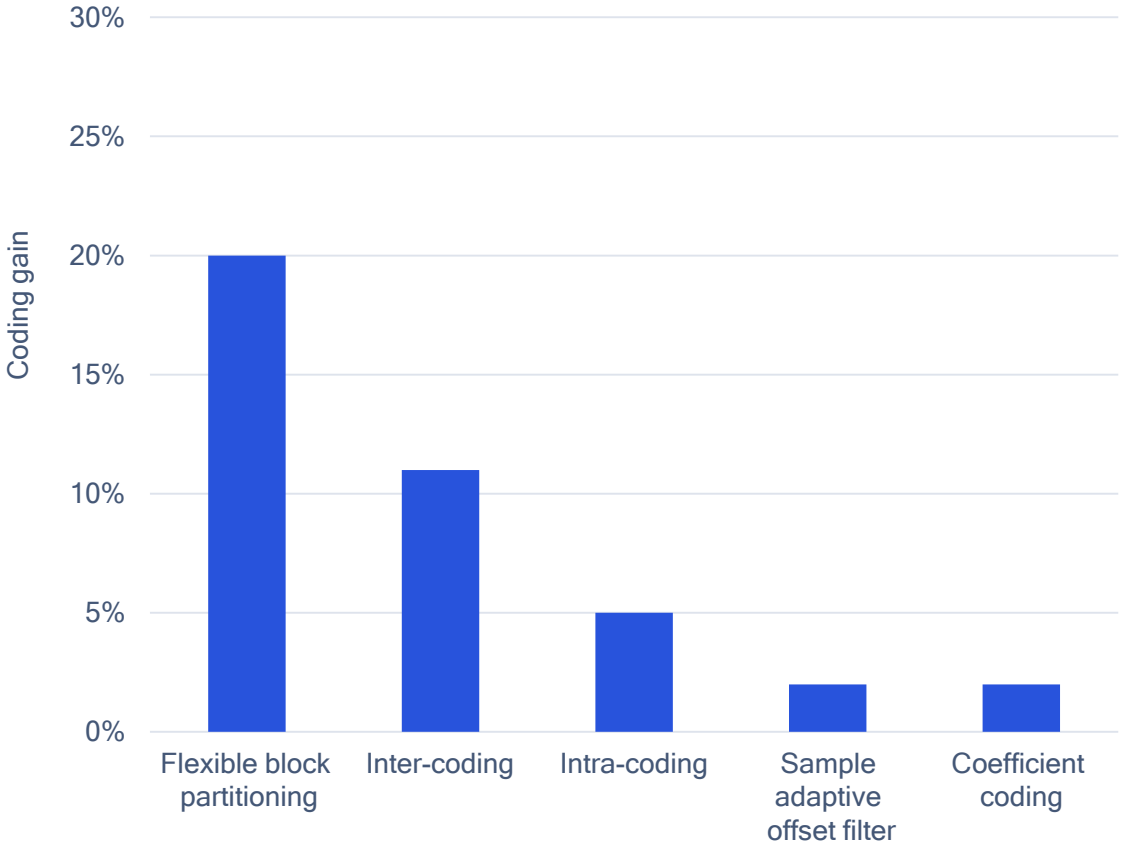
Video delivery

DASH and file format

Innovations, such as adaptive streaming and extensible file formats

HEVC coding gain leadership

Our innovations contributed to coding tools that provide significant gain



Key contributor to HEVC's seed ideas

HEVC complexity reduction leadership

Our innovations contributed to tools that provide more efficient processing

Parallel processing

Real-time encoding and decoding of UHD signals through coarse and fine granularity parallel processing provisions.

Entropy coding (CABAC)

Reduced number of context coded bins, context sharing, grouping bypass bins, and grouping bins with the same context.

Deblocking filter

Selection of filtered block boundaries, and hierarchical filtering decisions efficiently avoiding filtering in unwarranted situations.

Inter-coding

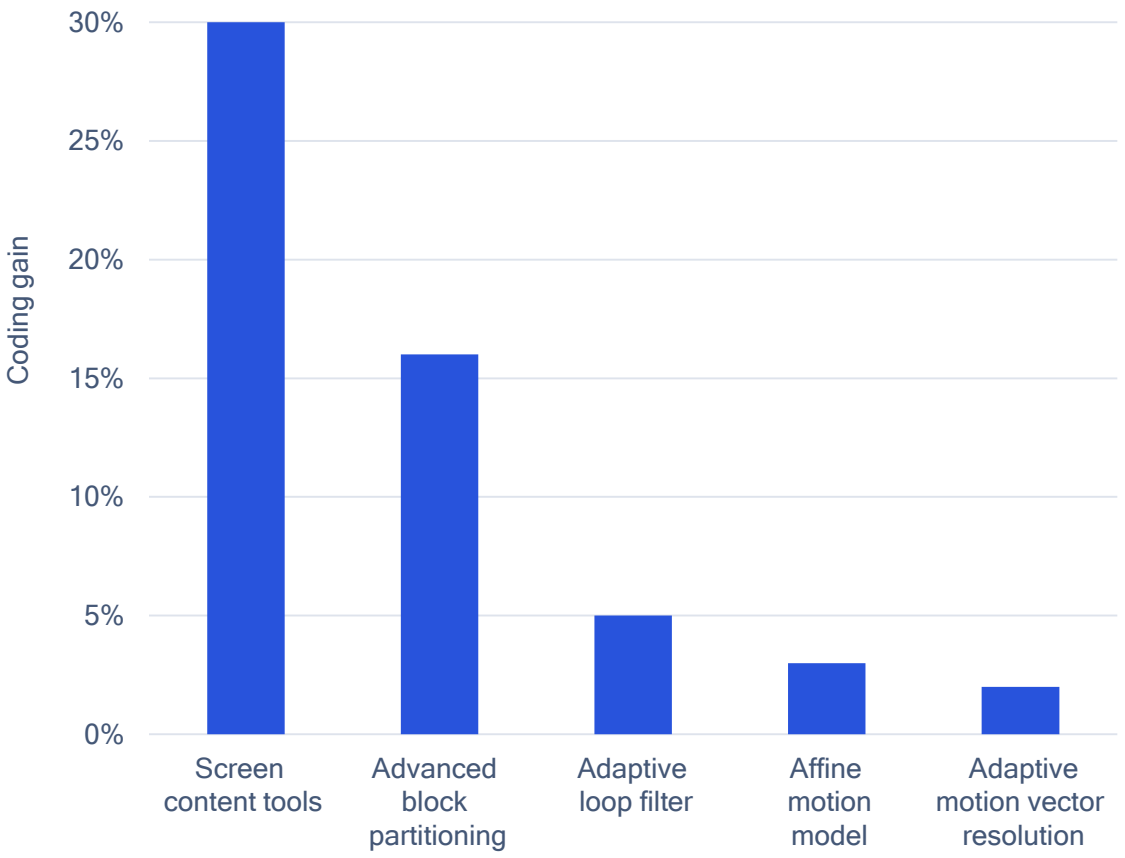
Higher level of parallelism for merge mode processing of neighboring blocks through the use of configurable merge mode motion estimation region.

Coefficient coding

Coefficient grouping into 4x4 sized subblocks harmonizing transform block processing design and enabling use of a common scan pattern.

VVC coding gain leadership

Initial or a main contributor to tools that provide 80% of VVC's rate reduction



Key contributor to VVC

VVC complexity reduction leadership

Our innovations contributed to tools that provide more efficient processing

Parallel processing

Parallel processing within a picture through the use of tile partitioning and/or wavefront parallel processing (WPP), as well as virtual pipeline data units (VPDU) at an even finer granularity.

Intra-coding

Simplified calculation of position-dependent intra prediction sample combining (PDPC) weights through the use of position dependent integer shift operations.

Transforms

Low Frequency Non-Separable Transform (LFNST) use through zeroing out the transform coefficients outside LFNST support region.

Entropy coding (CABAC)

Efficient multi-hypothesis weighted probability estimation through the use of estimator functions incorporating integer shift operations rather than division operations.

Viewport-dependent 360° video coding

Efficient tiled streaming of 360˚ video content through the use of subpictures (independent coded regions) and scalability features, enabling simple extraction and merging.

A prominent contributor to 3GPP DASH and MPEG DASH

Enabled streaming at scale

Created Internet video delivery service in 2007

Best technology for quality, latency, stall rates, but not scalable due to cloud compute

Re-design based on deployment experience

In 2010, the 3GPP solution backed by 20+ companies was accepted as baseline for MPEG DASH

3GPP and MPEG collaborated to create the first and only global streaming standard–DASH

We were the main contributor and spec editor

First published in 2012, 4th edition in 2019

Standard globally adopted and deployed

In 2017, CMAF project launched to support convergence towards DASH content formats for remaining two streaming solutions, DASH and HLS

In 2019, the second edition published with co-editing by Apple, Netflix, and us

We are driving the interop through CTA WAVE and DASH-IF

Continued leadership in MPEG and 3GPP

In 2009, we were the main contributor to the first Adaptive HTTP Streaming standard

Specification designed for streaming at scale and varying mobile network conditions

In 2013, we were the initiator and founder of DASH-IF to catalyze the adoption of MPEG-DASH

80 charter members with a focus on interop, test, reference and promotion - we have lead interop group since 2012

Our key contributions

Reach

Flexibility to create a variety of encoded media and use a common protocol to serve any device, under virtually any network condition

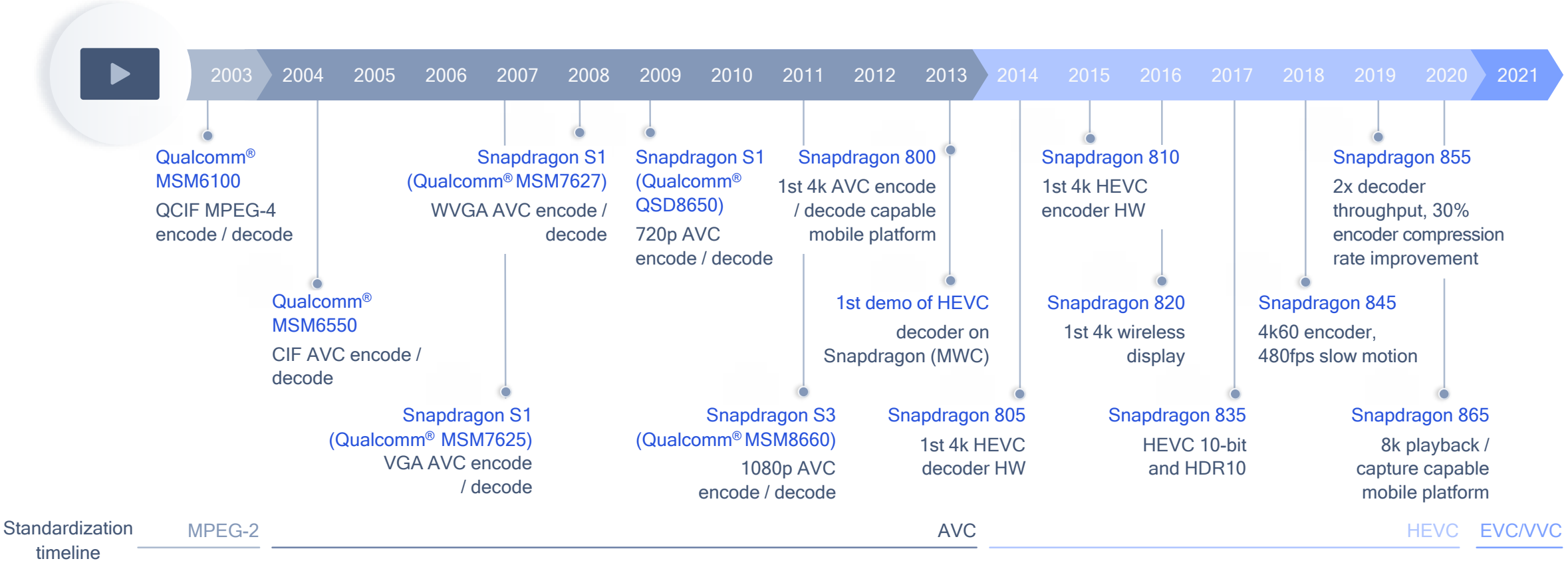
Quality

Decreased start-up time, faster seeking, and quicker buffer fills to reduce video freeze while maintaining the highest video quality

Scalability

Adaptive bit-rate to serve many clients in a scalable and cost-efficient manner without network architecture changes - smart and power clients

Our legacy of video product leadership



Key product milestones

First 4K AVC encode and decode

First 4K HEVC encode and decode

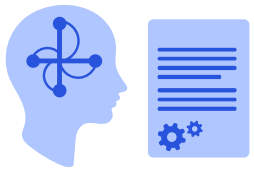
First HEVC 10-bit and HDR10

Qualcomm MSM6100, Qualcomm MSM6500, Qualcomm MSM7625, Qualcomm MSM7627, Qualcomm QSD8650 and Qualcomm MSM8660 are products of Qualcomm Technologies, Inc. and/or its subsidiaries.

Our contributions to standards drive the future for industries

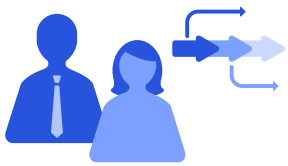
Leading technology standardization in a complex global ecosystem – key for future innovations

Qualcomm



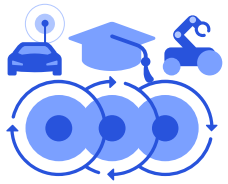
Technology leadership

Driving cutting-edge R&D and taking bold bets to address fundamental challenges and deliver industry-changing breakthroughs



Standards leadership

Taking leadership positions in standards and industry organizations to set guiding directions and do what's right to move the industry forward



Ecosystem support

Supporting ecosystem development through higher membership levels and close collaboration with 80+ leading universities on future research

Qualcomm

Thank you

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