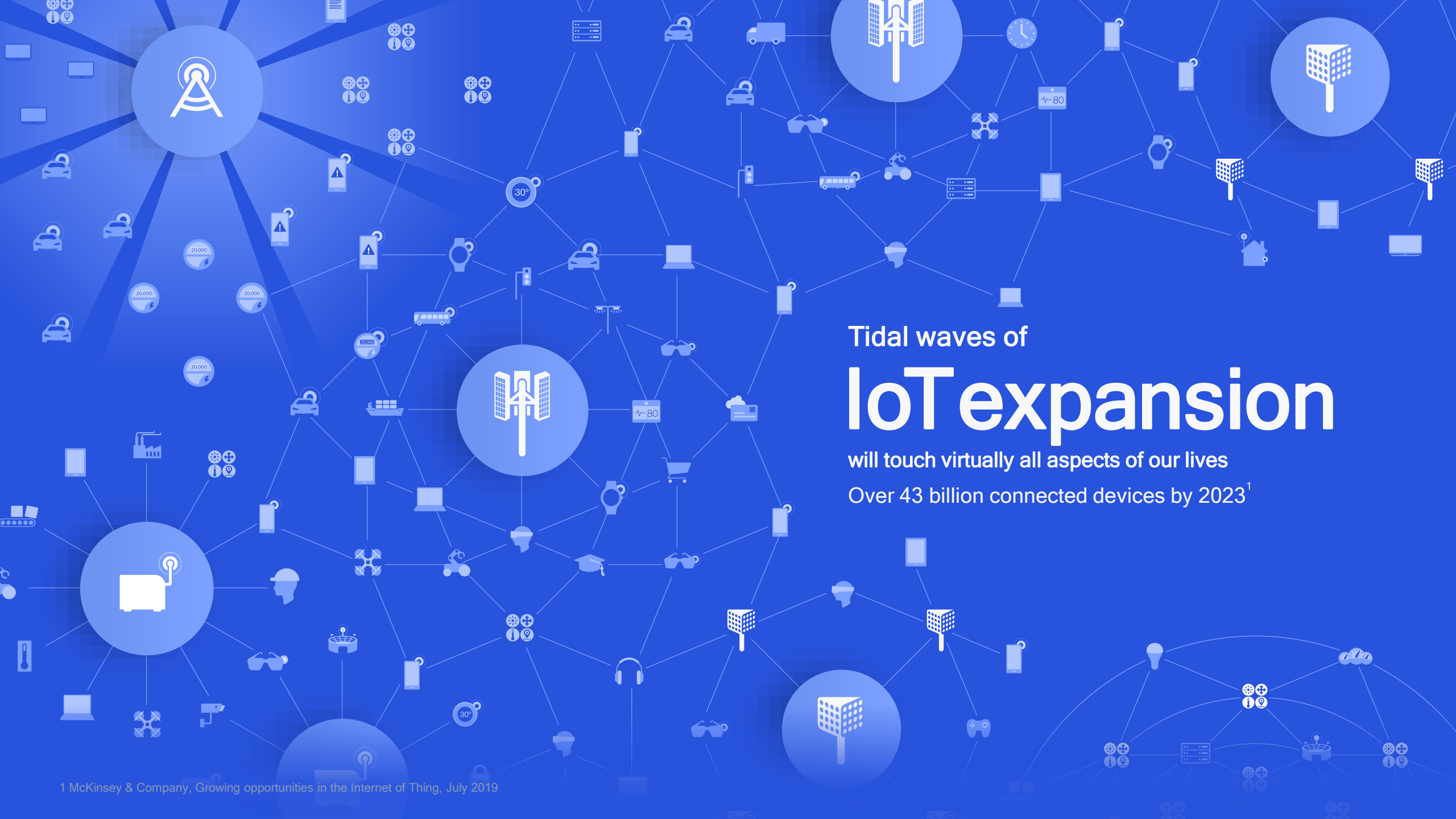
San Diego, CA May 11th, 2020 @qualcomm_tech Qualcomm

Intelligently connecting our world in the 5G era



Tidal waves of

IoT expansion

will touch virtually all aspects of our lives

Over 43 billion connected devices by 2023[1]

1 McKinsey & Company, Growing opportunities in the Internet of Thing, July 2019


Realize low latency
Privacy
Scalability
Immediacy
Customization
Efficiency
Robustness
Reliability
Content closer to user
Personalization
5G
Intelligent
Wireless Edge
is essential for the IoT expansion
Diverse system requirements
Scaling to more devices
New service values
Edge cloud
On-device

Efficiently expanding the IoT requires a new distributed intelligence paradigm

Current

Cloud-centric intelligence

IoT services depends on the central cloud to extract value

Future

Distributed intelligence

Based on economic and performance tradeoffs for IoT use cases

Enriched user experiences, new use case, new verticals

Distributed functionality

5G

Longer latency
Big data/aggregated value
Content/storage/AI/processing

5G low latency
Customized/local value
Content/storage/AI/processing

Compute, vision, sensing
AI powered use cases
Internal AI optimizations

On-premise control for ultra-low latency

On-device intelligence assisted by cloud

Distributed processing, like boundless XR

New services

Cloud computing, storage, instant access

Low-latency gaming

Real time assisted services like voice UI

Delivering on the 5G vision

Where virtually everyone and everything is intelligently connected

5G will expand the mobile ecosystem to new industries

Powering the digital economy

$13.2 Trillion

in global economic value by 2035*

Precision agriculture
$389B

Construction and mining
$1,061B

Digitized education
$258B

Connected healthcare
$1,056B

Richer mobile experiences
$2,291B

Smart manufacturing
$4,687B

Intelligent retail
$1,198B

Smart city
$2,242B

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

5G is rapidly evolving to meet diverse IoT requirements

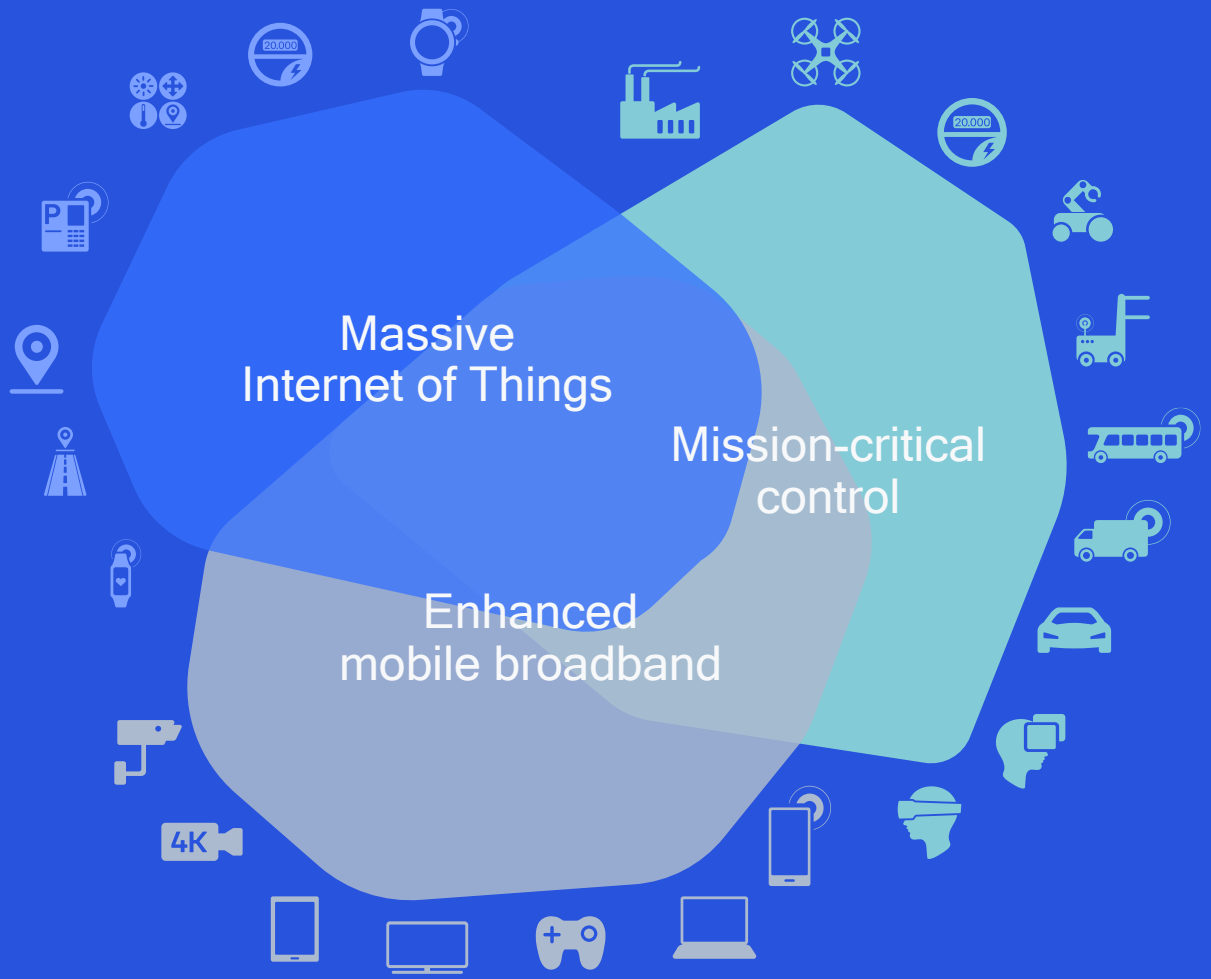
A unified innovation platform for this decade and beyond

Qualcomm 2020

5G is the common connectivity platform

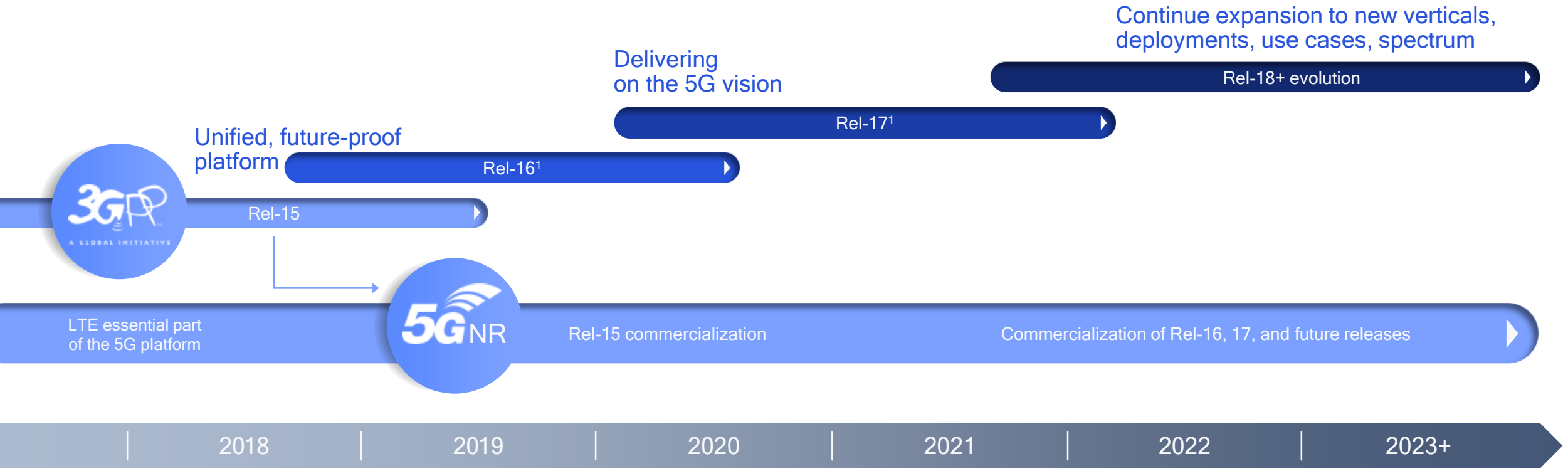
for the IoT

Broad set of devices and services
For all spectrum bands[1] and types[2]
Public and private networks



1. Low, mid, high bands; 2. Licensed, unlicensed, share licensed

Driving 5G expansion for IoT



Rel-15 eMBB focus

- 5G NR foundation
- Smartphones, FWA, PC
- Expanding to venues, enterprises

Rel-16 industry expansion

- eURLLC and TSN for IIoT
- NR in unlicensed (NR-U)
- Positioning
- 5G V2X sidelink multicast
- In-band eMTC/NB-IoT

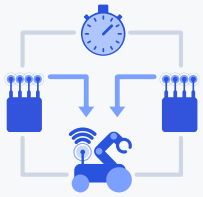
Rel-17+ long-term expansion

- Lower complexity NR-Light
- Boundless extended reality (XR)
- Higher precision positioning and more…

1. 3GPP start date indicates approval of study package (study item->work item->specifications), previous release continues beyond start of next release with functional freezes and ASN.1

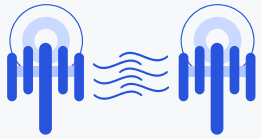
Building on the 5G NR foundation for expanding into the IoT

High-precision positioning
Accurate indoor and outdoor positioning



Mission-critical design
Ultra-high reliability of up to 99.9999%

Unlicensed spectrum
Improved capacity and new use cases



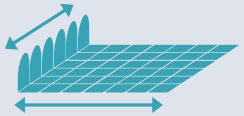
New deployment models
New deployments e.g., IIoT and enterprise

Advanced power saving and mobility
Better device performance and coverage

Expanded 5G foundation in Rel-16

Sidelink
Advanced safety use cases

5G NR Rel-15 technology foundation

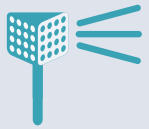


Flexible slot-based framework

Scalable numerology

Advanced channel coding

Massive MIMO



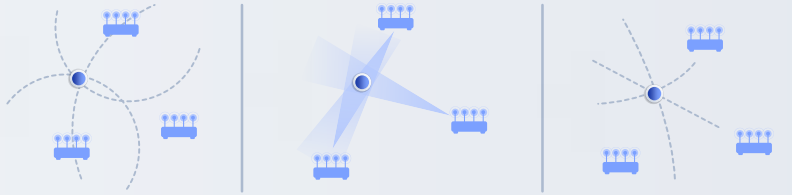
Mobile mmWave

5G positioning supports a wide range of IoT use cases

Release 16

Meeting initial accuracy requirements of 3m (indoor) to 10m (outdoors) for 80% of time

Multi-cell positioning

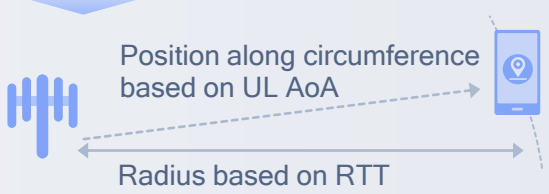


Roundtrip time (RTT)

Angle of arrival / departure (AoA/AoD)

Time difference of arrival (TDOA)

Single-cell positioning



New evaluation scenarios

Supporting new channel models for industrial IoT environment

Release 17

Enhancing capability and performance for a wide range of use cases

Centimeter level accuracy

Meeting absolute accuracy requirements[1] of down to 0.2m

Lower latency

Reducing positioning latency to as low as 10 ms

Higher capacity

Scaling to millions of simultaneous devices (e.g., IoT, automotive)

1 5G positioning requirements defined in TS 22.261; 2 Such as GNSS, beacons, sensors, Wi-Fi/Bluetooth

For indoor and outdoor applications

Targets various accuracy and latency requirements

Complements existing positioning technologies[2]

Optimizing 5G NR for Boundless XR experiences

Use cases in scope

Distributed computing | Split rendering | Cloud gaming
Viewpoint dependent streaming | Conversational XR

Edge processing framework

Defining a standardized system architecture / interface (e.g., APIs) for XR split processing over 5G NR

Traffic awareness

Optimizing XR traffic scheduling[1] in the network to improve user experience and network efficiency

System enhancements

Additional improvements tailoring to the XR use case and device limitations (e.g., formfactor, power)

1 For example, using File Error Rate (FER) and File Delay Budget (FDB) that are used by the app funcation vs. Packet Error Rate (PER) and Packet Delay Budget (PDB)

5G NR Technology Foundation

Lower device complexity

- Narrower bandwidths
- Fewer receive antennas
- Half duplex

Coverage optimization

- Repetition and bundling
- Lower order modulation
- Sidelink or relays

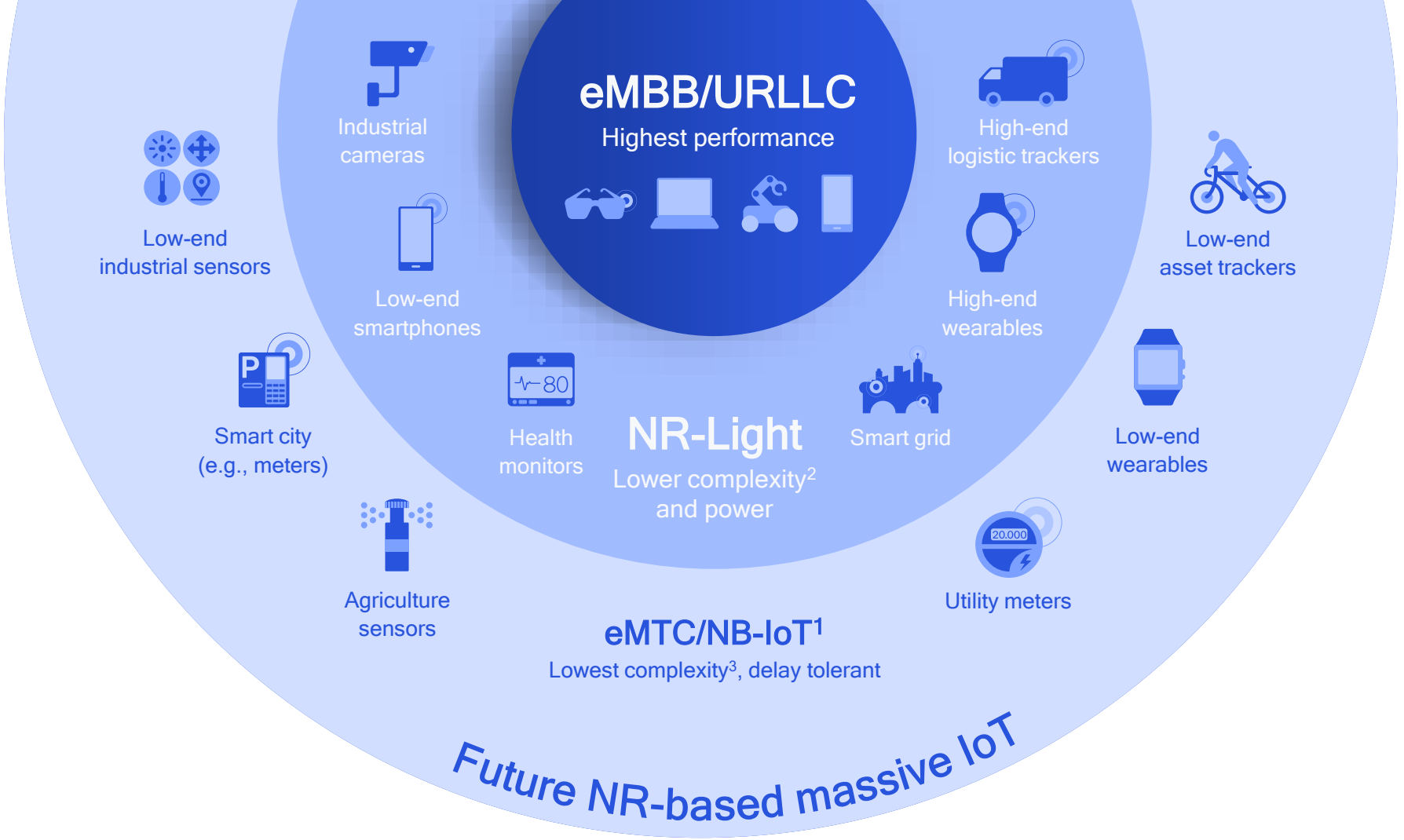
Reduced power consumption

- Lower transmit power
- Enhanced power saving modes
- Limited mobility and handovers

Increased network efficiency

- Reduced signaling overhead
- Simplified core network
- Better resource management

Scaling down 5G NR for lower complexity IoT devices



5G NR: A unified, scalable air interface allowing coexistence of a wide range of 5G device classes

1 Also including satellite access; 2 Data rate of 150 Mbps DL / 50 Mbps UL, latency of 10-30 ms, 10-3 to 10-5 reliability, coverage MCL of 143 dB; 3 Data rate of 1Mbps, MCL of 155.7 dB (eMTC) and 164 dB (NB-IoT)

5G NR-Light brings new efficiencies for the IoT

Lower device complexity

Narrowband operation (down to 10 MHz), single/dual receiver antenna, half-duplex operation

Optimized power consumption

Enhanced low-power modes (PSM and eDRX), lower output power (e.g., 23/20 dBm)

Network enhancements

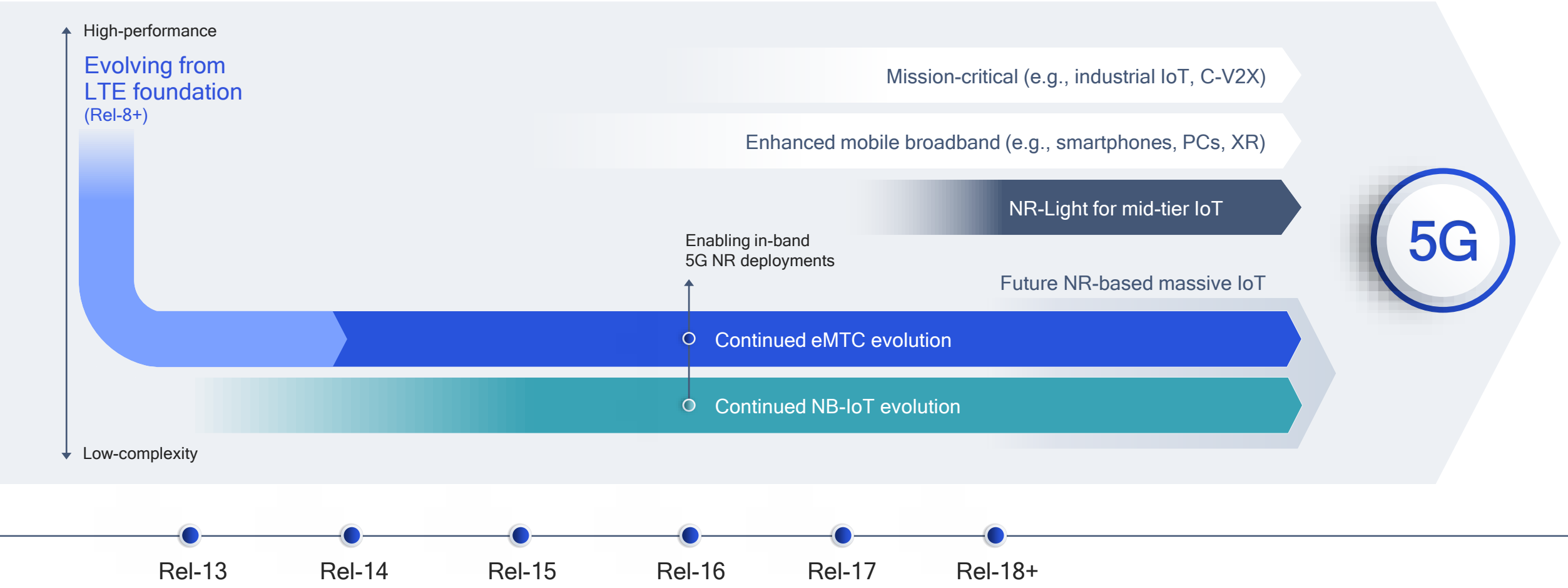
Coexistence of half- and full-duplex devices, reduced control signaling, small data transmissions

Coverage recovery

Repetition and bundling of small payloads, frequency hopping, also use of relay and/or sidelink

Continue to drive IoT expansion as part of 3GPP Release 17

Continued 5G evolution to meet all future IoT needs



1 Low-power, wide-area; 2 Unlicensed spectrum is supported in Rel-17+; 3 Relays can be either network (Uu) or sidelink (PC5) based; 4 NB-IoT to support higher-order modulation such as 64-QAM and carrier aggregation

We are driving a rich roadmap of system innovations for the IoT expansion

Our system approach to bring cutting-edge inventions to the world

Source: Company data as of Q2 FY'20. Cumulative expenditures to date since 1985.

Foundation to 5G leadership is technology leadership

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

Invention

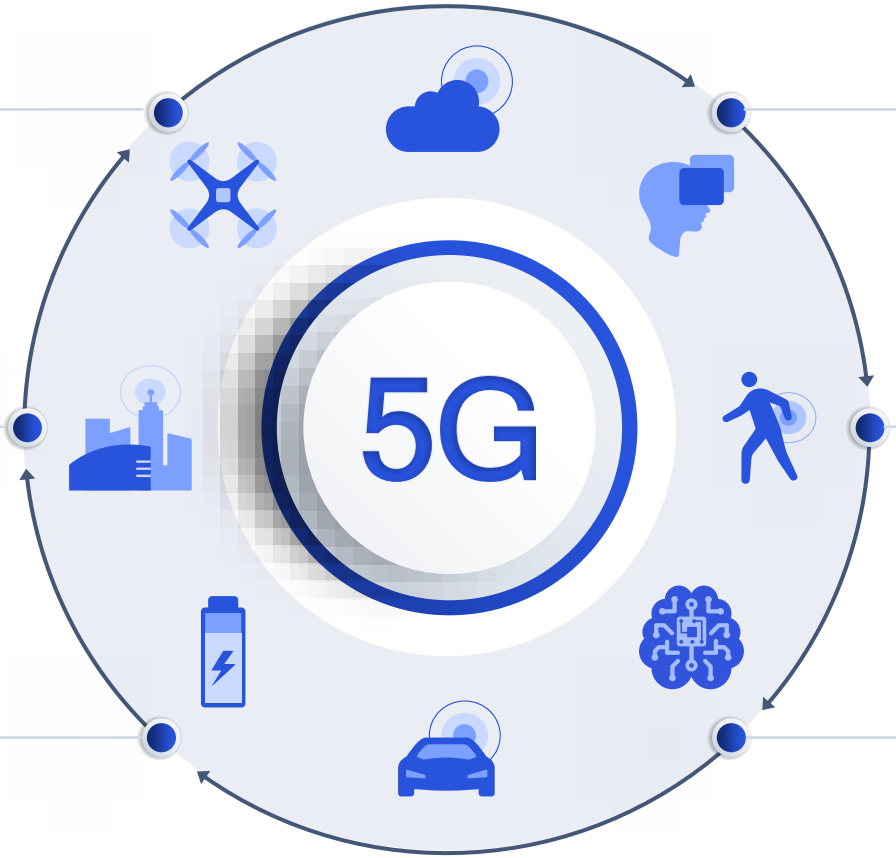
Invent new technologies and e2e system architecture

Vision

Identify a problem or need; establish requirements

Commercialization

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



Proof-of-concept

Deliver end-to-end prototypes and impactful demonstrations

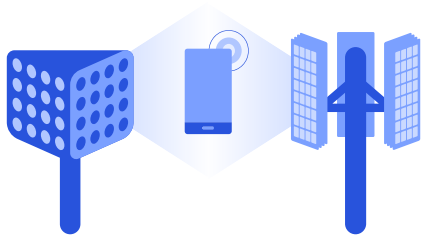
Standardization

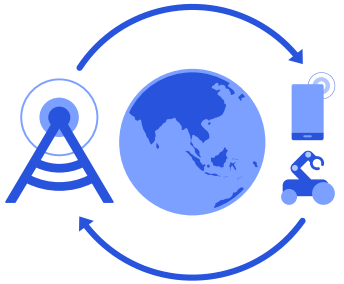
Drive e2e design with ecosystem and through standards process

Trials

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

A system approach to inventions – the Qualcomm way





1 2 3 4 5

Qualcomm Snapdragon, Qualcomm wireless edge services and Qualcomm FSM are products of Qualcomm Technologies, Inc. and/or its subsidiaries.

Industry-leading R&D

Breaking technology boundary to bring new capabilities and efficiencies for new devices, services, deployments

Prototyping while driving standards

Validating new designs by building real systems – networks and devices, driving standards with learning

Advanced system simulations

Using real models to accurately predict system performance in a wide range of scenarios

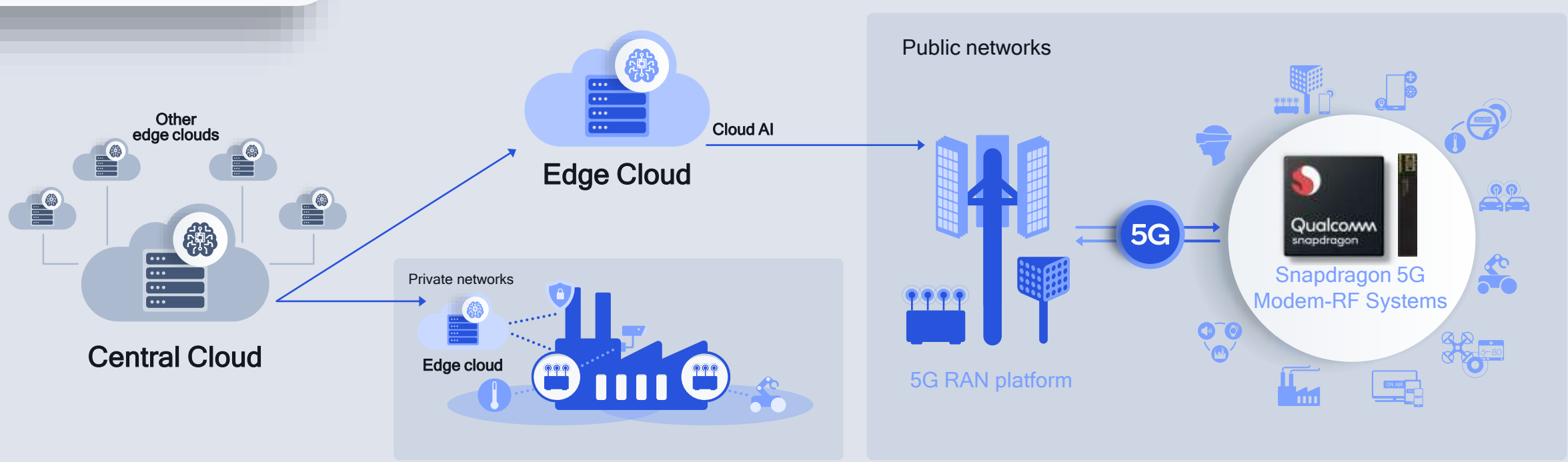
Broad industry collaboration and trials

Working closely with the ecosystem to prototype new solutions, fully utilizing our global experience

Cutting-edge system solutions

Delivering not just device chipsets but system solutions, such as small cells, device and data management

Expanding the IoT requires an end-to-end system solution

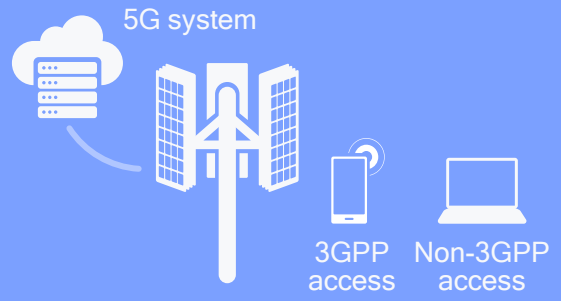


QWES

System security | Device management | Data management

5G system brings enhanced security and privacy

Building on the proven, solid security foundation of 4G LTE



Flexible framework

To support new devices, use cases, and deployments

Unified authentication for 3GPP/non-3GPP devices

Security anchor function

Network slicing

Tighter security

To expand protection and increase flexibility

User-plane integrity protection

Lower trust in serving networks

Subscription credentials in secure HW element

Enhanced privacy

To eliminate communication of unprotected device-specific info

Ciphered user and device specific information

Data ownership

Establish ownership structure for devices and associated data

Local/remote management of devices

Proof of data ownership by device

Data provenance

Establish a single version of the facts

Immutable record of the data origin and authenticity

Data governance

Control the management and access of data

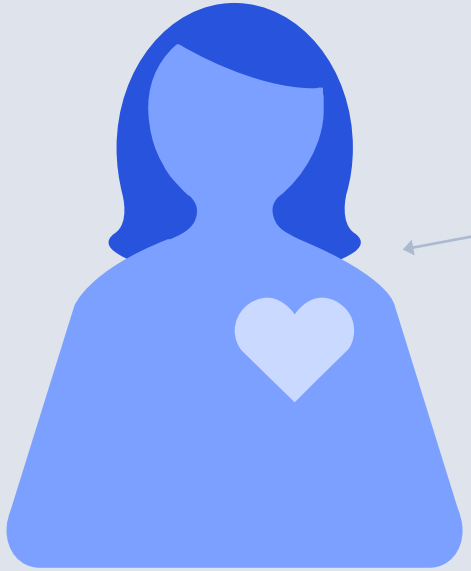
Policy control and enforcement

Audit trail of transactions on the data

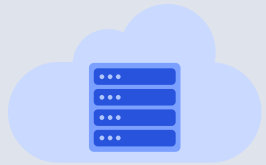
End-to-end data management for 5G use cases

Establishing an audit chain of control and access to private data on top of 5G security

Establishing ownership structure for device and data



Device ownership

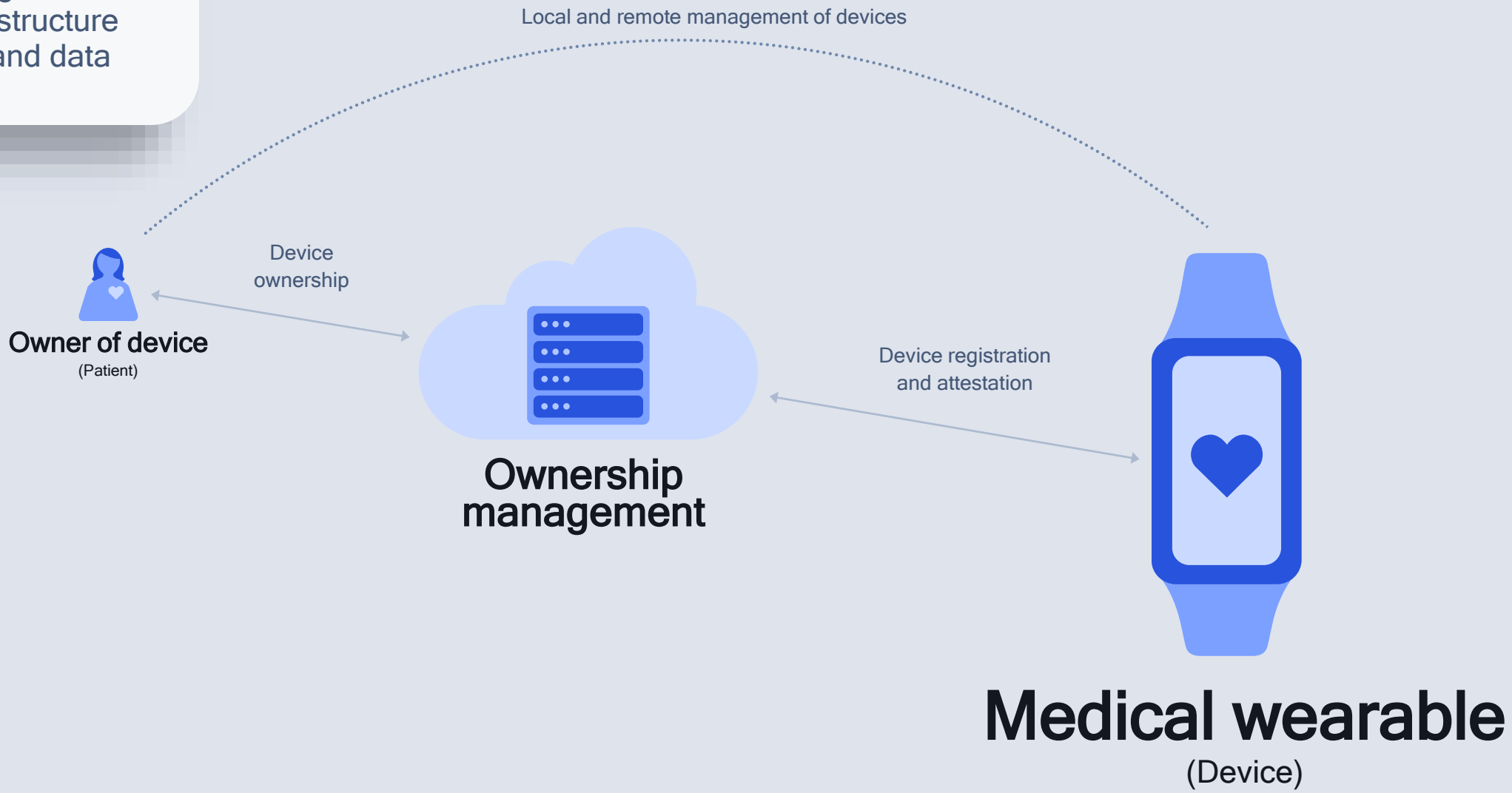


Ownership management

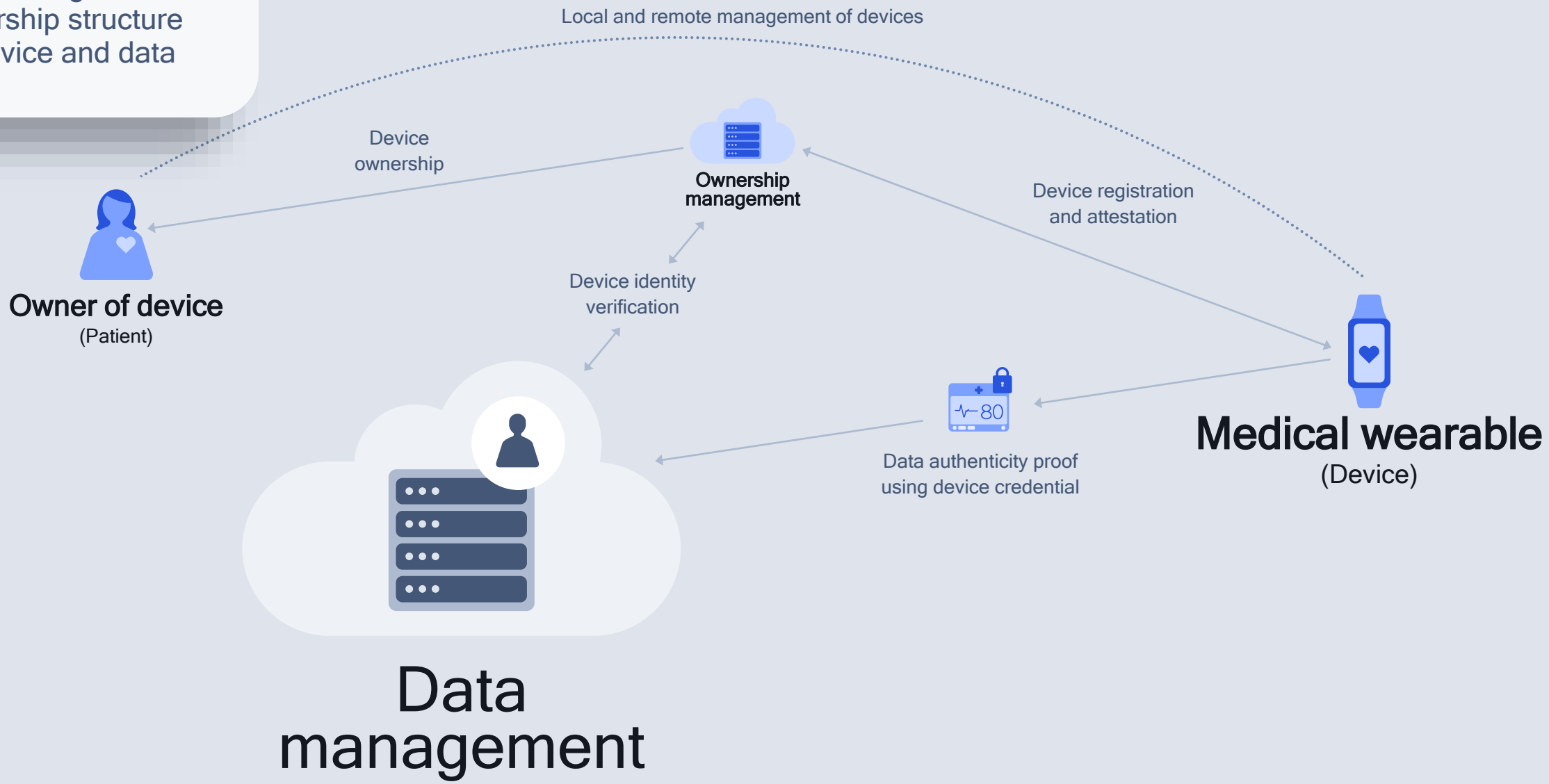
Owner of device

(Patient)

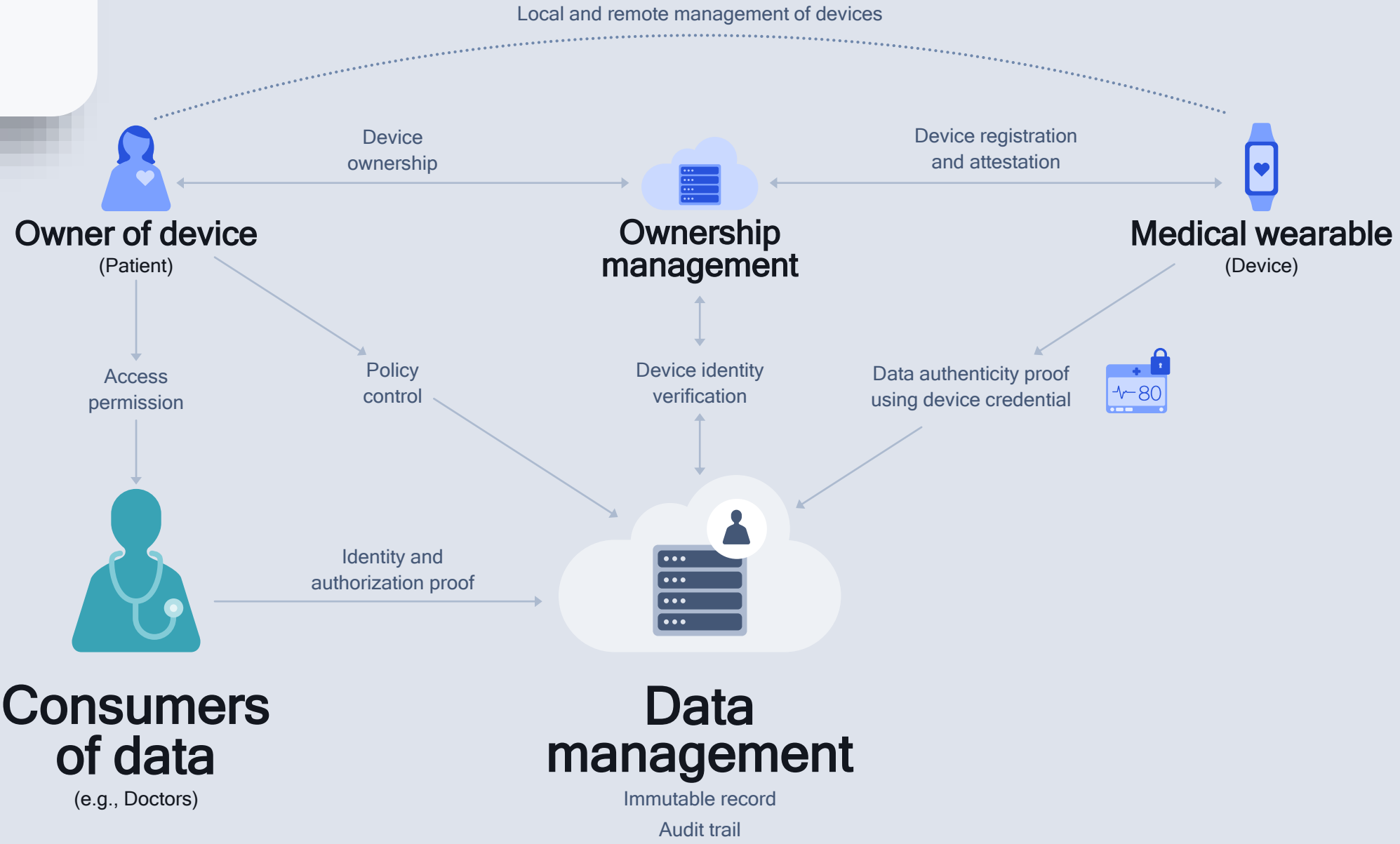
Establishing ownership structure for device and data



Establishing ownership structure for device and data



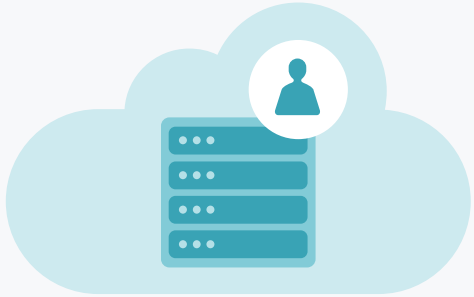
Controlling the management and access of data



Our research focus in 5G data management

Ownership management

- Security hardening
- Remote device attestation
- Single device with multiple owners
- Group management of devices with a single owner



Data management

- Identity privacy
- Zero-knowledge proof
- Homomorphic encryption
- Secure multiparty computation
- Proof of data processing at its origin for MPC

Intelligently connecting

our world in the 5G era

A unified connectivity fabric for the IoT

5G

Next technology leap for new capabilities and efficiencies

Continued evolution

Rel-15
eMBB focus

Rel-16 and 17
Expanding to new industries

Rel-18, 19. 20 and beyond
Continued 5G proliferation

6G

Historically 10 years between generations

Strong 5G momentum sets the stage for the global IoT expansion

Qualcomm

Thank you

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