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Setting off the 5G Advanced evolution

Our presenter

Juan Montojo

Vice President, Technical Standards
Qualcomm Technologies, Inc.

Today's agenda

1. Where are we now with 5G?
2. What will be included in 5G Advanced Release 18?
3. How do we see 5G evolving for the rest of this decade?
4. Questions?

5G

accelerating globally

200
Operators with 5G commercially deployed

285+
Additional operators investing in 5G

1250+
5G designs launched or in development

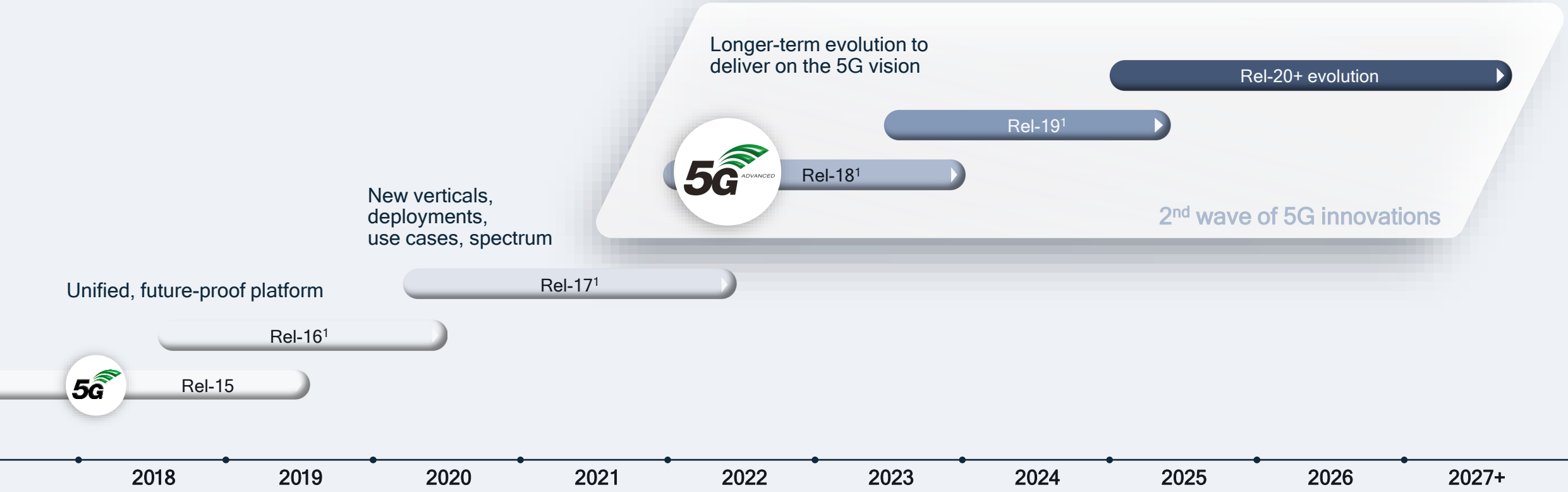
1B+
5G connections by 2023 – 2 years faster than 4G

750M+
5G smartphones to ship in 2022

3.8B+
5G smartphones to ship between 2020 and 2024

Sources – 5G commercial networks: operator public announcements. Operators investing in 5G: GSA, Oct 2020. 5G device shipment projections: Qualcomm internal estimates, Nov 2020. 2023 5G connections: avg of ABI (Jun 2020), Ericsson (Jun 2020) and GSMA Intelligence (Oct 2020). Cumulative 5G smartphone shipments - avg of CCS Insight (Sep 2020), CounterPoint Research (Sep 2020), IDC (Aug 2020), Strategy Analytics (Oct 2020).

Driving the 5G technology evolution in the new decade



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
- 5G V2X sidelink multicast
- In-band eMTC/NB-IoT
- Positioning

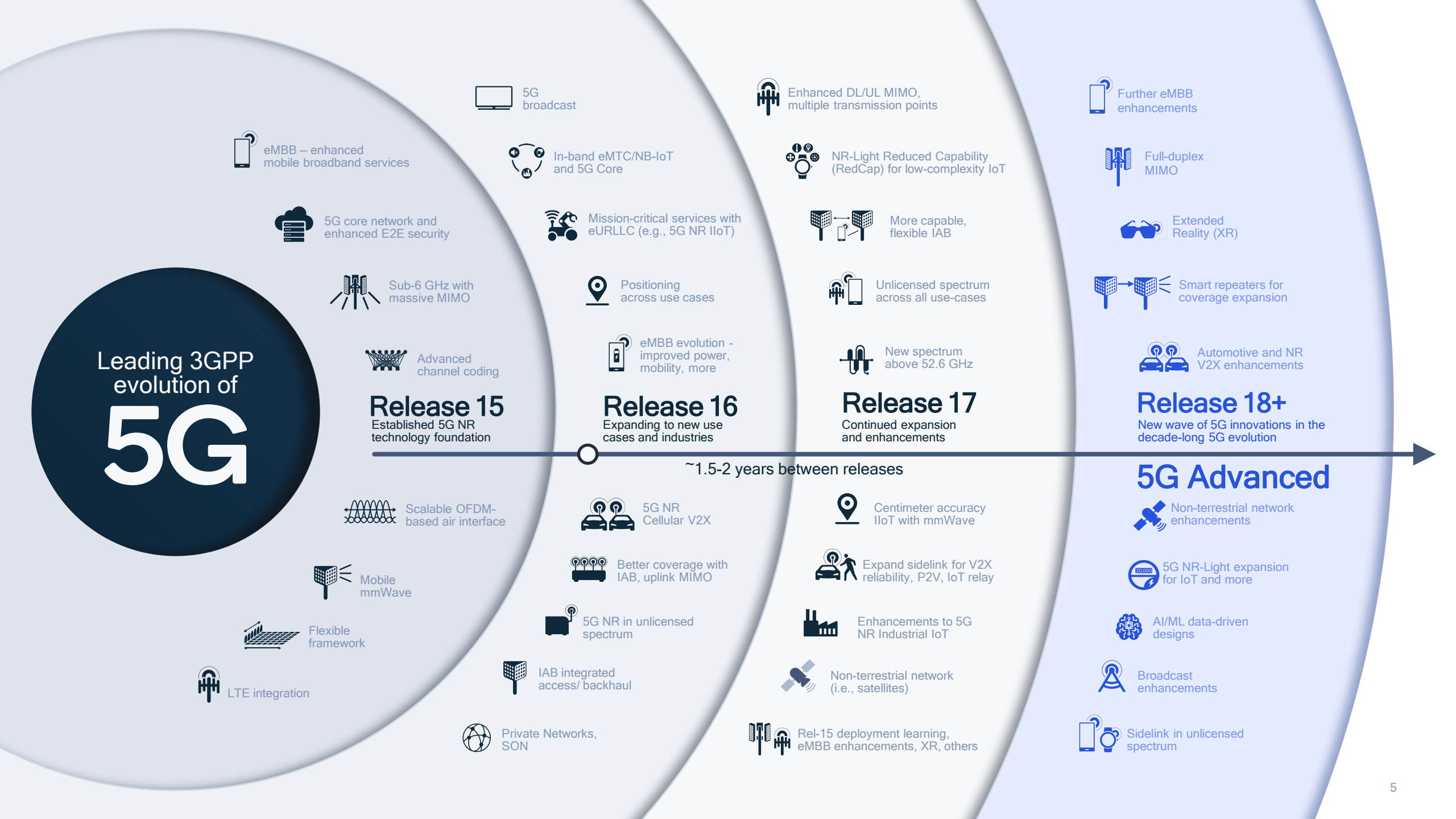
Rel-17 continued expansion

- Lower complexity NR-Light
- Non-terrestrial communication (satellites)
- Unlicensed/licensed spectrum in 60 GHz
- Improved IIoT, positioning V2X, IAB, …

Rel-18+ 5G-Advanced

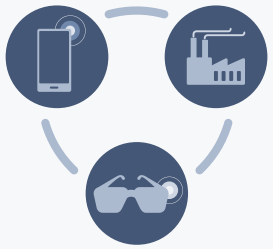
- Next set of 5G releases (i.e., 18, 19, 20, …)
- Rel-18 scope decided in Dec ’21
- Rel-18 study/work to start in Q2-2022

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


Leading 3GPP evolution of 5G
eMBB – enhanced mobile broadband services
5G core network and enhanced E2E security
Sub-6 GHz with massive MIMO
Advanced channel coding
Scalable OFDM-based air interface
Mobile mmWave
Flexible framework
LTE integration
Release 15
Established 5G NR technology foundation
5G broadcast
In-band eMTC/NB-IoT and 5G Core
Mission-critical services with eURLLC (e.g., 5G NR IIoT)
Positioning across use cases
eMBB evolution - improved power, mobility, more
5G NR Cellular V2X
Better coverage with IAB, uplink MIMO
5G NR in unlicensed spectrum
IAB integrated access/ backhaul
Private Networks, SON
Release 16
Expanding to new use cases and industries
Enhanced DL/UL MIMO, multiple transmission points
NR-Light Reduced Capability (RedCap) for low-complexity IoT
More capable, flexible IAB
Unlicensed spectrum across all use-cases
New spectrum above 52.6 GHz
Centimeter accuracy IIoT with mmWave
Expand sidelink for V2X reliability, P2V, IoT relay
Enhancements to 5G NR Industrial IoT
Non-terrestrial network (i.e., satellites)
Rel-15 deployment learning, eMBB enhancements, XR, others
Release 17
Continued expansion and enhancements
~1.5-2 years between releases
Further eMBB enhancements
Full-duplex MIMO
Extended Reality (XR)
Smart repeaters for coverage expansion
Automotive and NR V2X enhancements
Release 18+
New wave of 5G innovations in the decade-long 5G evolution
5G Advanced
Non-terrestrial network enhancements
5G NR-Light expansion for IoT and more
AI/ML data-driven designs
Broadcast enhancements
Sidelink in unlicensed spectrum

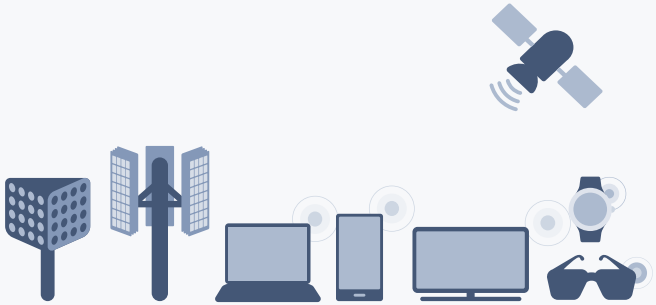
Driving a balanced 5G evolution across key technology areas

Mobile broadband evolution vs. further vertical expansion



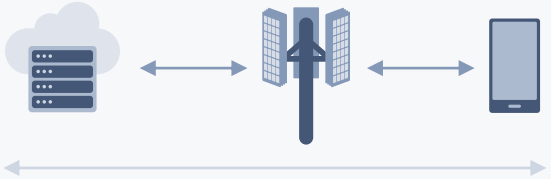
Deliver enhanced mobile broadband experiences and extend 5G's reach into new use cases

Immediate commercial needs vs. longer-term 5G vision



Drive new value in commercialization efforts and fully realize 5G's potential with future deployments

New and enhanced devices vs. network evolution

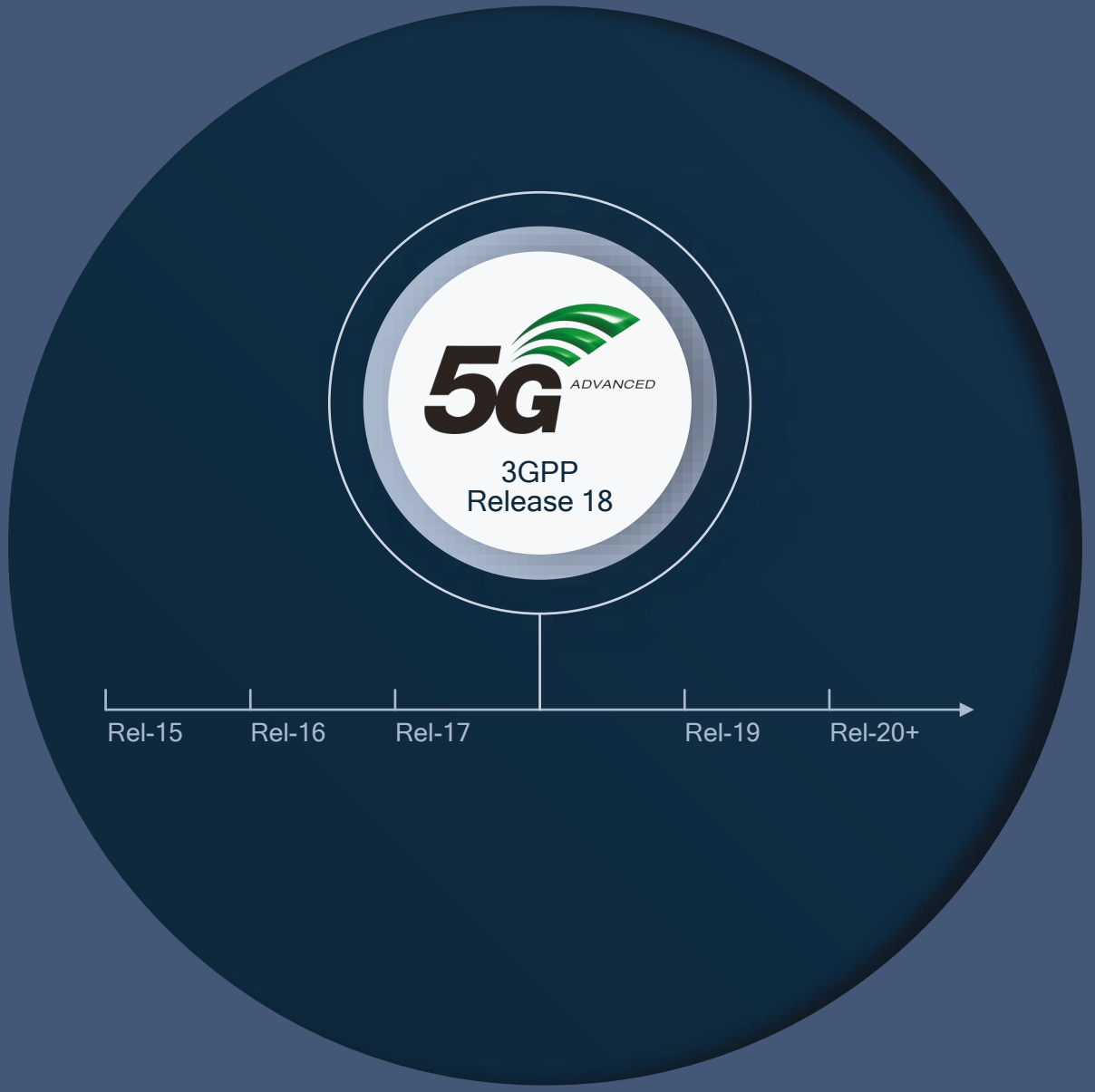


Focus on the end-to-end technology evolution of the 5G system to bring new levels of performance

Release 18 scope takes into consideration of the 5G Advanced evolution in Release 18, 19, and beyond (i.e., many Study Items defined to set up for Work Items in later releases)

What will be included in Release 18?

The first 3GPP release in 5G Advanced evolution

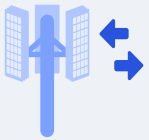


Release 18

3GPP Release 18 sets off the 5G Advanced Evolution

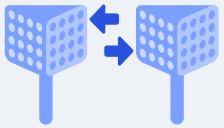
Approved package has a wide range of projects – nominal work to start in Q2 2022

Strengthen the end-to-end 5G system foundation



Advanced DL/UL MIMO

Enhanced mobility



Mobile IAB, smart repeater

Evolved duplexing

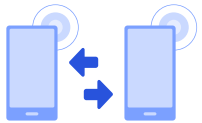
AI/ML data-driven designs

Green networks

Proliferate 5G to virtually all devices and use cases

Boundless extended reality

NR-Light (RedCap) evolution



Expanded sidelink

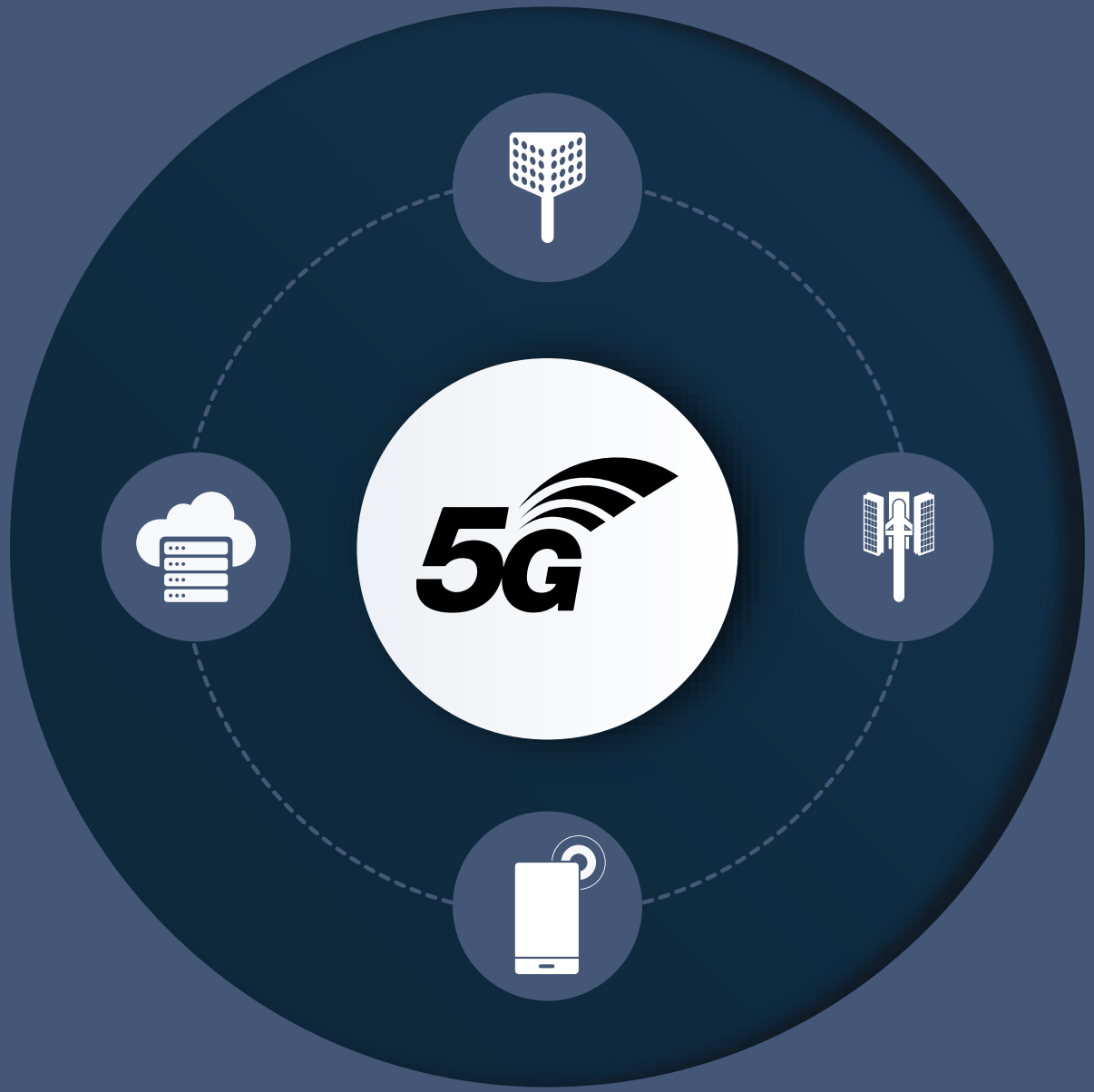
Expanded positioning

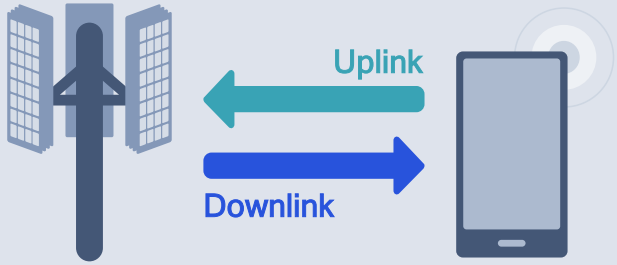
Drones & expanded satellites comm.

Multicast & other enhancements

Strengthen the end-to-end 5G system foundation

Further enhancing
5G mobile broadband
and expanded use cases





Continuing to evolve 5G MIMO performance and efficiency

Focus areas for Release 18

CSI[1] and CSI-RS[2] enhancements in high or medium velocities to exploit time-domain correlation or Doppler-domain information

Extending Rel-17 unified TCI[3] framework for multiple downlink/uplink TCI states

Supporting larger number of orthogonal DMRS[4] ports for downlink or uplink multi-user MIMO

Enhanced CSI acquisition for coherent-JT[5] targeting 4 TRPs for both FDD[6] and TDD[7] bands in sub-7 GHz

Supporting uplink DMRS, SRS[8] for 6/8 Tx uplink to support 4+ layers per device targeting CPE[9], FWA[10], vehicle, industrial devices

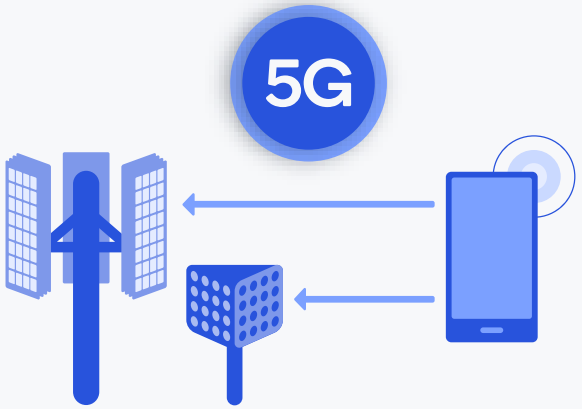
Facilitating simultaneous multi-panel uplink for higher throughput and reliability

Specifying panel-specific timing/ power control for uplink multi-TRP[11] or multi-panel setup

Source: RP-213598 (MIMO Evolution)

1 Channel State Information; 2 CSI Reference Signal; Transmission Configuration Indicator; 4 Demodulation Reference Signal; 5 Joint Transmission; 6 Frequency Division Duplexing; 7 Time Division Duplexing; 8 Sounding Reference Signal; 9 Customer Premises Equipment; 10 Fixed Wireless Access;11 Transmission Reception Points;

Driving higher 5G uplink performance and efficiency



Uplink enhancements
3GPP Release 18

- **Coverage enhancements** targeting multiple PRACH[1] transmissions with same beam as well as with different beams (for mmWave) targeting 4-step RACH
- **Power domain enhancements**, such as dynamic power aggregation for CA/DC and enhanced transmit power efficiency (e.g., via spectrum shaping, tone reservation)
- **Improved support of UL-MIMO** via dynamic waveform switching between CP-OFDM[3] and DFTS-OFDM[2]

9 (UL coverage enhancements)
ccess Channel; 2 Discrete Fourier Transform Spread Orthogonal Frequency Division Multiplexing;
gonal Frequency Division Multiplexing.

Further optimizing 5G device mobility management

Work Item targeting operations in both sub-7 GHz and mmWave bands

5G NR Release 18 project is proposed to address different deployment configurations

Layer 1 / 2 based inter-cell mobility

Configuration and maintenance of multiple candidate cells, dynamic switching among those, and other L1 enhancements (e.g., L1 measurement reporting / mobility command)

NR-DC[1] with selective activation of cell groups via L3 enh.

Conditional PSCell[2] Addition and Change among multiple candidate SCGs. One SCG[3] active at a time.

Conditional Handover enhancements

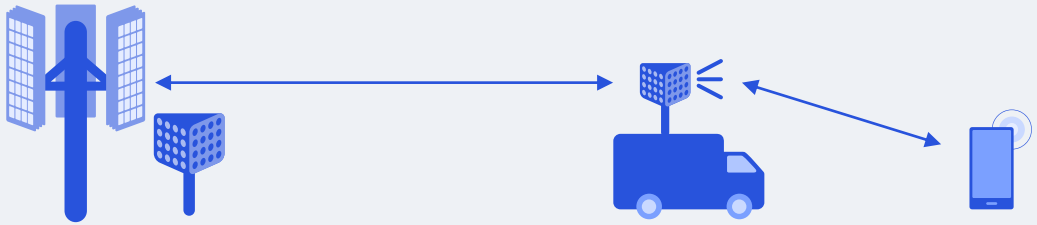
Conditional configuration including target MCG and target SCG or target MCG[4] and target SCGs for Conditional PSCell Addition and Change.

FR2 enhancements

SCell[5]/SCG setup delay improvement. New early UE measurements procedure.

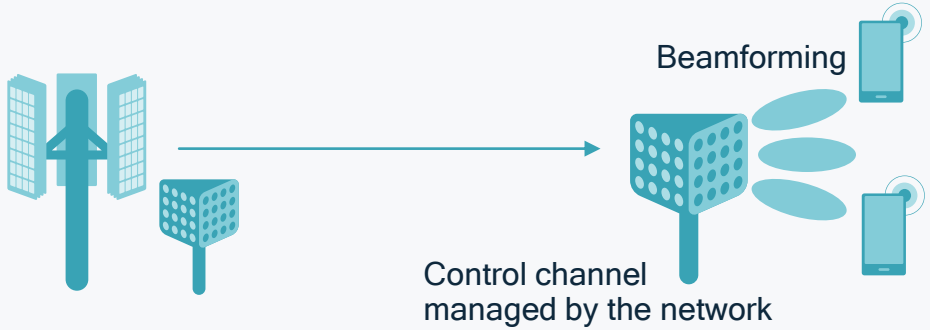
ource: RP-213565 (Mobility enhancements)
Dual Connectivity; 2 Primary Cell of Secondary Cell Group (SCG); 3 Secondary Cell Group;
Master Cell Group; 5 Secondary Cell.

Mobile integrated access/backhaul (IAB) and vehicle mounted relay (VMR)



Focus on the mobile IAB mounted on vehicles providing 5G coverage/capacity enhancement supporting single hop in-band, out-of-band backhauling, device handover and dual connectivity

Smart repeaters with side control information



Focus on single-hop operation that is transparent to the device, supporting identification/authorization of smart repeaters, with side control information including max Tx power, beamforming, timing, TDD configurations, and on/off

Cost-efficient expansion of 5G coverage and capacity

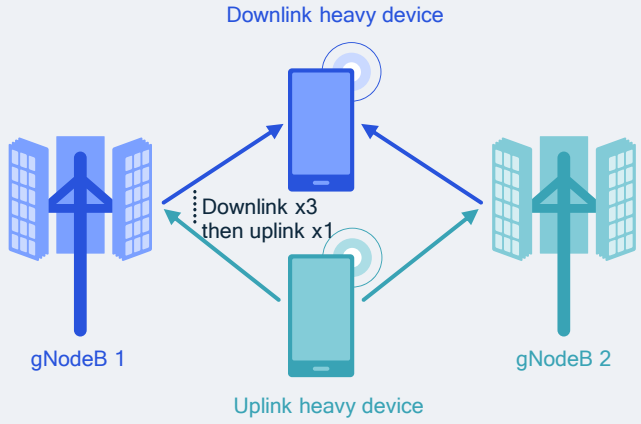
New Release 18 project focuses on new 5G deployment topologies

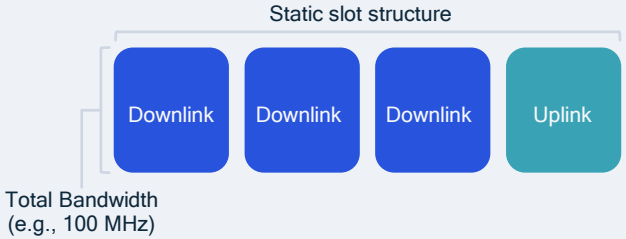
Source: RP-213601 (Mobile IAB); RP-213700 (Network Controlled Repeaters)

Static TDD

Time aligned to avoid inter-site interference

Time separation to avoid self-interference



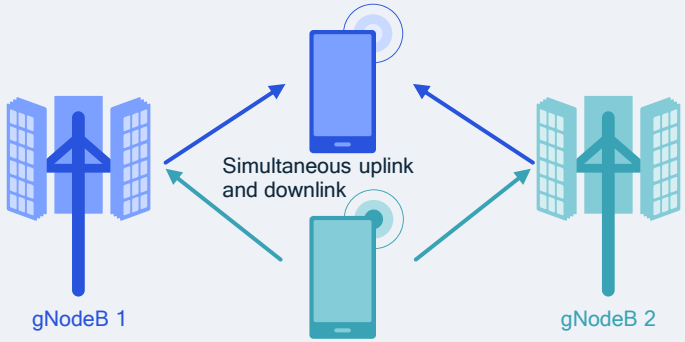


Sub-band Full Duplex (SBFD)

Frequency aligned to avoid inter-site interference

Frequency separation and interference cancellation to avoid self-interference

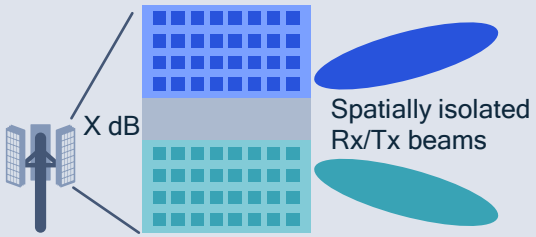
gNodeBs are full-duplex capable, devices are half-duplex



Evolving towards a full duplex wireless system

Improving perceived user throughput, latency, uplink coverage – path to single-frequency full duplex (SFFD)

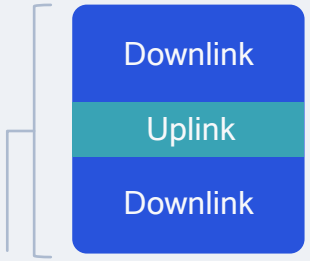
Spatial/beam isolation/duplexer



Two separate antenna panels for simultaneous Tx/Rx

80 to 90 dB isolation between 2 panels based on lab measurement in mmWave

Frequency isolation (for SBFD)

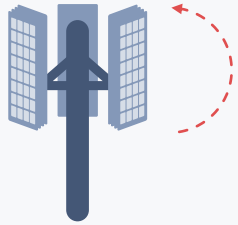


Total Bandwidth
(e.g., 40 MHz x2 DL, 20 MHz UL)

Subband “frequency” multiplexing uplink and downlink (FDM)

Y dB isolation (Y > 40 dB)

Digital/analog self-interference mitigation



Tx/Rx processing including potential nulling

Z dB from mitigation technique

Key enablers for a full duplex air interface

Working to define suitable parameter values for X,Y and Z to enable full duplex operations

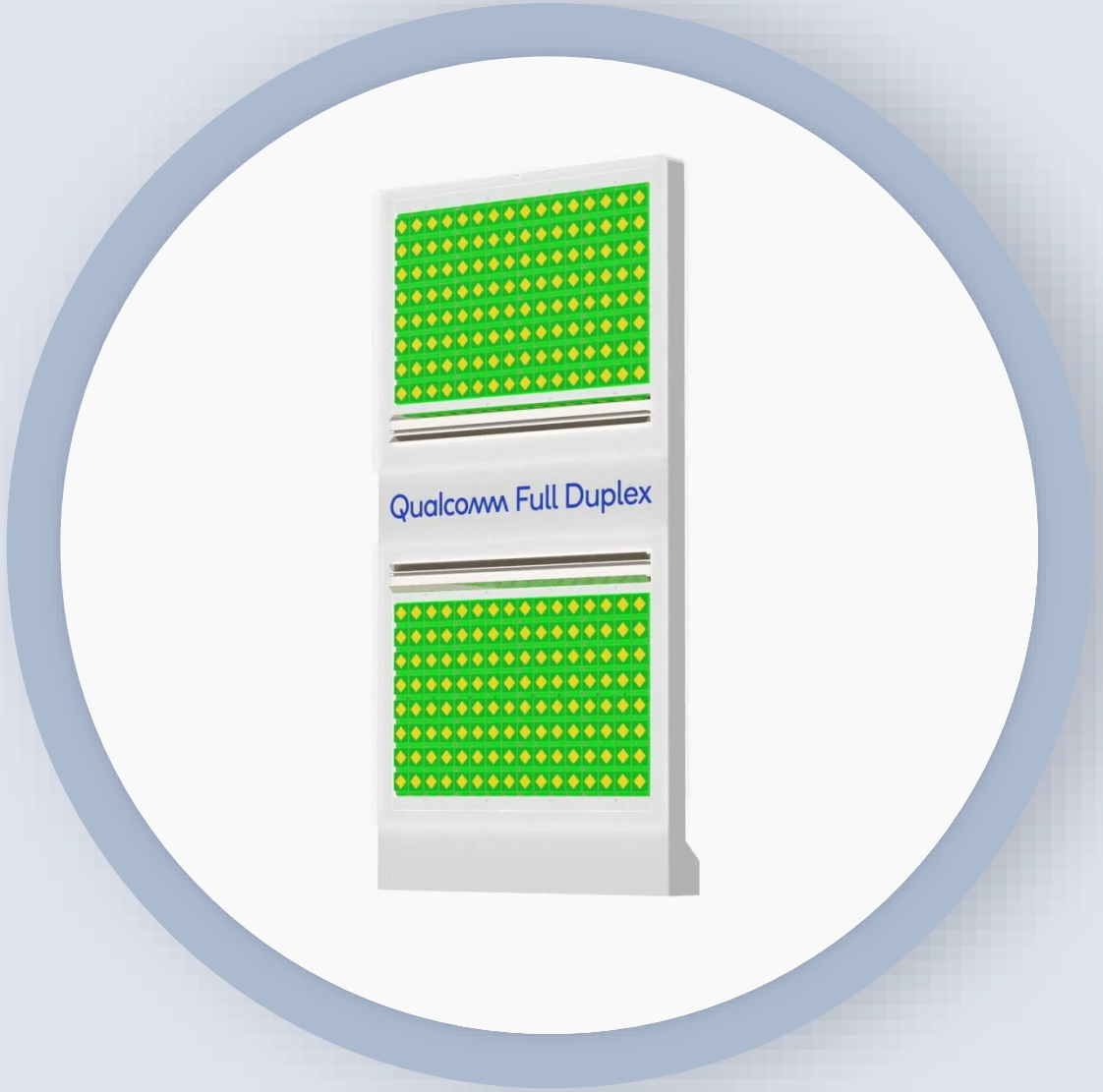
Release 18 lays the foundation for the future of full duplex

Identify and evaluate potential enhancements to support duplex evolution for 5G NR TDD spectrum

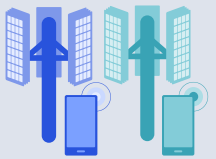
Identify applicable and relevant deployment scenarios and use cases

Study subband non-overlapping full duplex and potential enhancements on dynamic TDD

Future study may include partial overlapping and full overlapping subband



Develop evaluation methodology for duplex enhancement



Study inter-gNodeB, inter-device CLI[1] management and impact on RF requirements considering adjacent-channel coexistence with legacy operation

Source: RP-213591 (Evolution of duplex operation)

1 Cross-link Interference

Network architecture enhancements

Allowing for machine learning to run over different HW/SW and future RAN function split to improve flexibility and efficiency

AI/ML procedure enhancements

Optimizing system for model management, training (e.g., federated and reinforced learning), and inference

Data management enhancements

Standardizing ML data storage/access, data registration/discovery, and data request/subscription

New and expanded use cases

Supporting traffic/mobility prediction, coverage/capacity optimization, massive MIMO, SON, CSI feedback, beam management, and other PHY/MAC and upper layer improvements

5G ADVANCED

5G Advanced (Rel-18+) targets to expand wireless machine learning to the end-to-end system across RAN, device, and air interface

5G ADVANCED

Wireless ML
Rel-18

3GPP Release 18

Scope for wireless ML projects

AI/ML-enabled air interface design

Use cases
Including enhanced channel state information (CSI) feedback, beam management, and positioning accuracy (including heavy non-line-of-sight conditions)

AI/ML models
Identifying collaboration models, from no collaboration to cross-node ML, life cycle management of models, characterizing model generation/inference algorithms

Evaluation methodology
Utilizing existing 3GPP framework for evaluations and field data to assess performance in real-world environments, as well as identifying common KPIs

Impact assessment
Evaluating specification changes needed to support identified use cases, covering PHY layer, protocol, interoperability and testability aspects

AI/ML framework for next-generation radio access network

Network optimization
Specify enhanced data collection and signaling support for AI/ML-based network energy saving, load balancing and mobility optimization

Future study
Study new use cases (e.g., AI/ML for slicing, QoE[1]), as well as network functionality and interface procedures (e.g., multi-vendor interoperability)

Source: RP-213599 (AI/ML for NR Air Interface), RP-213602 (AI/ML for NG-RAN)

1 Quality of Experience

Driving towards greener 5G networks

Release 18 project scope

Define a base station energy consumption model

Define an evaluation methodology and KPIs

Study techniques on the base station and device side to improve network energy savings

Target system-level studies with various scenarios:

- Urban micro in sub-7 GHz, including TDD massive MIMO
- mmWave beam-based deployments
- Urban/rural macro in sub-6 GHz with/without DSS[1]
- Dual connected macro with FDD anchor and TDD on higher sub-7 GHz
- Other scenarios, e.g., small cell deployment

Source: RP-213554 (Network energy savings)

1 Dynamic Spectrum Sharing

Proliferate 5G to virtually all devices and use cases

Continued expansion to new device types and tiers – fulfilling the 5G vision

Purpose-built system enhancements for XR over 5G

Release 18 focuses on capacity considerations as well as power savings for XR use cases

KPIs[1] and QoS[2]

Enhancing RAN[3] support for enhanced granularity for QoS and XR-specific parameters

Application awareness

Optimizing DL/UL XR traffic in the network to improve user experience and network efficiency

Power optimization

Specifying XR-specific power saving techniques such as enhanced C-DRX[4] and control channel monitoring

Capacity enhancement

Supporting resource allocation and scheduling specifically for XR traffic profile, such as enhanced SPS[5] and dynamic grants

Source: RP-213587 (Enhancements for XR)

1 Quality of Service; 2 Key Performance Indicators; 3 Radio Access Network; 4 Connected Discontinued Reception; 5 Semi-Persistent Scheduling

Sidelink enhancements

Coexistence of LTE and 5G NR sidelink

Reusing the in-device coexistence framework defined in Rel-16 as much as possible

Multi-beam operation

Supporting sidelink beam management by reusing and enhancing existing framework and concepts

Unlicensed spectrum

Supporting optimized sidelink operations in unlicensed 5 and 6 GHz bands

Sidelink carrier aggregation

Prioritizing backward compatible 5G NR design based on LTE for sub-7 licensed and ITS bands

Sidelink relay enhancements

Device-to-device relay

Allowing single-hop operation for unicast with forward compatibility for more hops

Service continuity enhancements for UE-to-NW relay

Supporting inter-gNodeB mobility and intra-gNodeB indirect-to-indirect path switching

Multipath relay & UE Aggregation/Switching

Enhancing reliability and throughput for 1 direct (Uu) + 1 indirect (PC5 or ideal link) path within the same cell

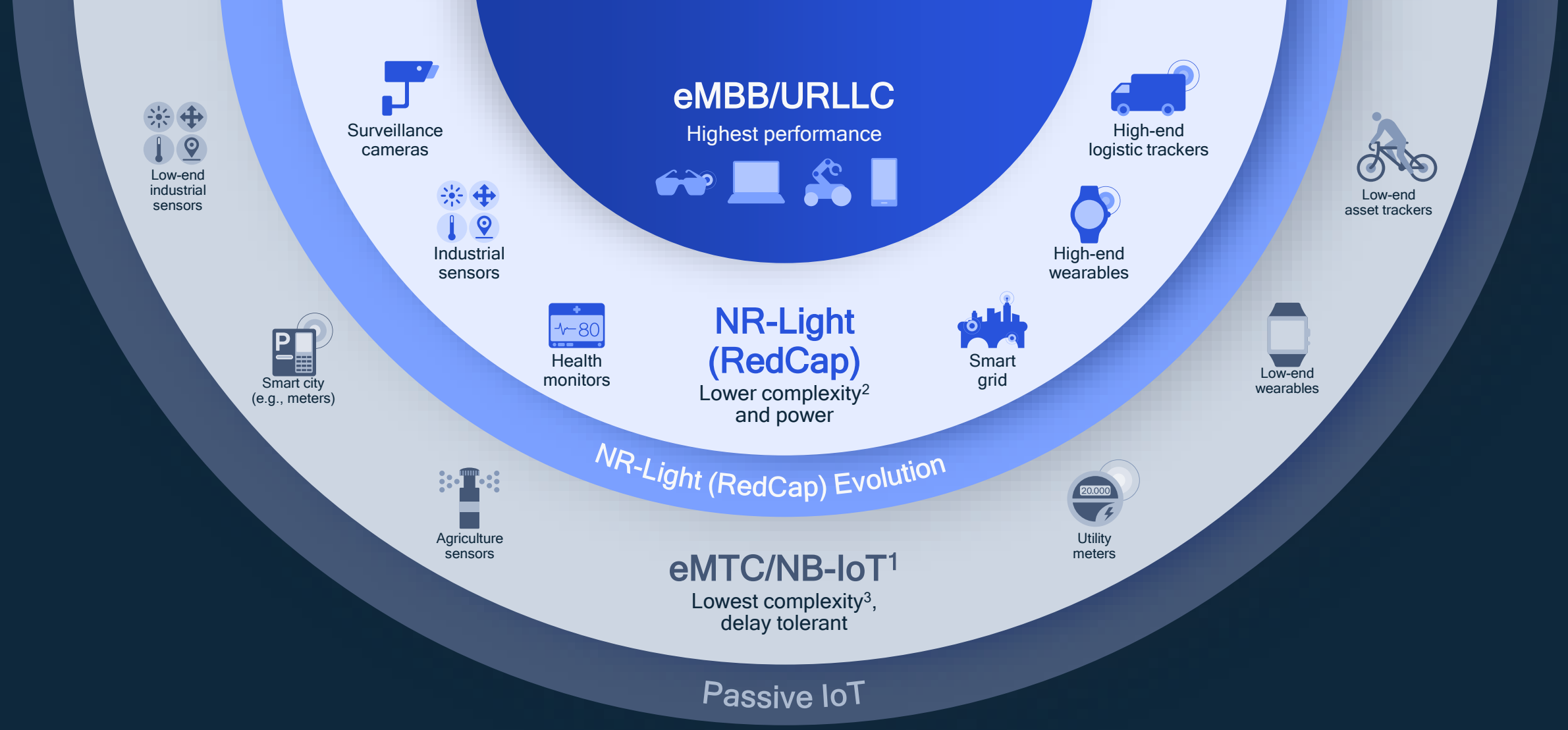
Remaining Rel-17 work

Completing features such as discontinued reception (DRX) for sidelink relay operations

Expanding 5G Sidelink capabilities in Release 18

For V2X, public safety, commercial use cases – Study and Work Item project scope

Source: RP-213678 (Sidelink enhancements); RP-213585 (Sidelink Relay Enhancements)



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 eMBB/URLLC

Highest performance

Rel-15+

Surveillance cameras

Industrial sensors

Lower-tier mobile devices

High-end wearables

Health monitors

Smart grid

5G NR-Light (RedCap)

Lower complexity and power

Rel-17

Lower device complexity

Reduced bandwidth (e.g., 5 MHz), peak data rate, and relaxed device processing timeline

Power savings

Enhanced DRX[1] in inactive mode (>10.24s) and lower device power class

Device coexistence

With Rel-17 NR-Light reduced capability and eMBB/URLLC devices

Low-power WUS[2]/WUR[3]

Enhanced low-power operations targeting IoT use cases

Further scaling down 5G NR-Light

for reduced capability devices

Release 18

Source: RP-213661 (RedCap evolution); RP-213645 (Low-Power WUS)

1 Discontinued Reception; 2 Wakeup Signal; 3 Wakeup Receiver

Supporting 5G NR devices with 5 MHz or lower bandwidth

3 to 5 MHz bandwidth in dedicated FDD sub-7 GHz spectrum

15 kHz SCS[1] with normal CP[2]

PSS/SSS[3] without puncturing, PBCH[4] based on current design

For 5G NR deployments for specific applications

Source: RP-213603 (<5 MHz NR in dedicated spectrum)

1 Subcarrier Spacing; 2 Cyclic Prefix; 3 Primary/Secondary Synchronization Signals; 4 Physical Broadcast Channel

Precise device class definition

Supporting ultra-low power consumption and energy-harvesting capabilities

Potential use cases

Such as identification, tracking, monitoring, sensing for logistics, transportation, healthcare

Deployment scenarios

Such as public/private, indoor/outdoor, macro/small cells, direct/relay, traffic models, spectrum

Existing solutions

Competing technologies such as RFID or other proprietary connectivity platforms

Design targets

Such as link budget, data rate, power, energy harvesting techniques, positioning accuracy

Coexistence

With existing 3GPP devices, infrastructure, and spectrum

Further scaling down 5G NR IoT support

Continued 3GPP discussions focusing on key interest areas to refine future project scope

Source: RP-212688 (Passive IoT)

5G positioning evolution

Release 16
Establishing foundation

Achieving accuracy of 3m/10m (indoor/outdoor) for 80% of time

Supporting RTT[1], AoA/AoD[2], TDOA[3], single-cell positioning

Including new evaluation scenarios, i.e., industrial IoT

Release 17
Enhancing performance

Meeting centimeter-level absolute accuracy requirement of down to 0.3m

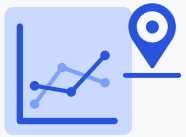
Reducing positioning latency to as low as 10 ms

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

5G Advanced in Release 18
Improving performance, expanding to new devices and deployments

Sidelink positioning and ranging

Defining methodologies, reference signals, measurements, procedures for absolute and relative (e.g., ranging) sidelink positioning in licensed and ITS[4] spectrum



Improved positioning performance

Specifying higher layer solutions for RAT[5] dependent positioning techniques, accuracy improvement based on PRS/SRS[6] bandwidth aggregation, and carrier phase measurements

NR-Light[7] positioning

Setting performance requirements, evaluating performance for R17 positioning procedures, and identifying potential enhancements

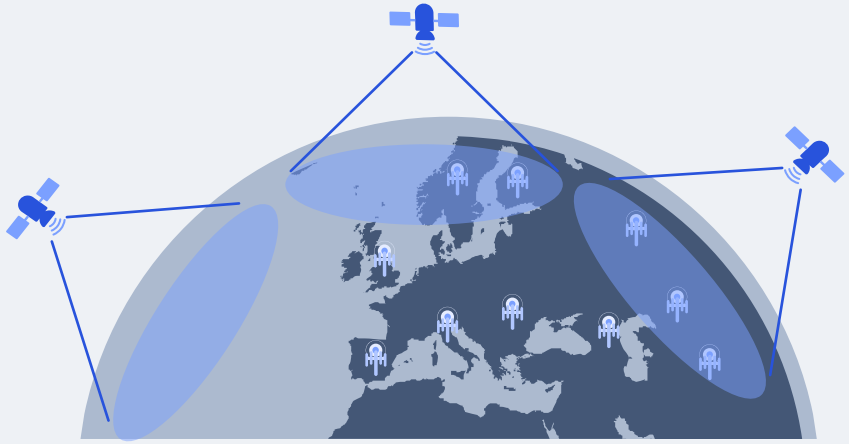
Pushing forward with the 5G positioning technologies

Source: RP-213588 (Expanded and improved Positioning)

1 Roundtrip Time; 2 Angle of Arrival, Angle of Departure; 3 Time Difference of Arrival; 4 Intelligent Transport System; 5 Radio Access Technology; 6 Positioning Reference Signal, Sounding Reference Signal; 7 aka. RedCap

5G NR for NTN

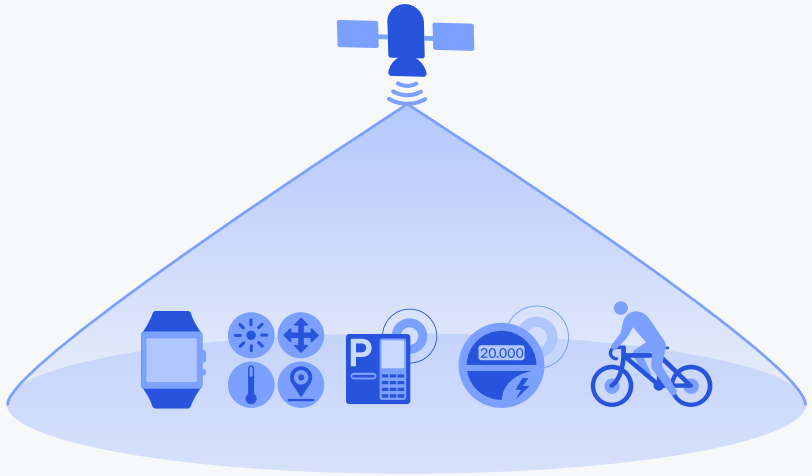
Complementing terrestrial networks in underserved areas



- Network verified device location based on satellites network
- Coverage enhancements for voice and low-data rate services
- Mobility enhancements for satellite and terrestrial networks
- Deployment in 10+ GHz bands and support for VSAT[1]/ESIM[2]

5G IoT for NTN

Expanding addressable market for the 5G massive IoT



- Addressing remaining Rel-17 issues (e.g., disabling HARQ[3] feedback to mitigate impact of HARQ device data rate stalling)
- Enhanced mobility such as neighbor cell measurements and extending to eMTC
- Enhanced GNSS operation for longer connections and reduced power consumption
- Study possible enhancements to Rel-17 for discontinuous coverage

Expanding the 5G NR support for satellites communication

5G Advanced will further enhance the non-terrestrial networks (NTN) foundation

Source: RP-213690 (NTN Enhancements); RP-213596 (IoT NTN Enhancements)

1 Very Small Aperture Termina; 2 Earth Station In Motion; 3 Hybrid Automatic Repeat Request;

5G drones are getting ready to take off

Release 18 leverages the cellular drones work in Rel-15 LTE-A Pro

Measurement reports

- Device-triggered measurement report (height, location, speed)
- Flight path reporting
- Based on a configured number of cells fulfilling the triggering criteria simultaneously

Signaling to support subscription-based aerial device identification

Support for broadcast/groupcast of drone identification

Beam management enhancements (e.g., device directional antenna)

Source: RP-213600 (5G NR Support for UAV)

Improved DSS[1]
Enabling NR-PDCCH[2] reception in symbols with LTE CRS. Allow two overlapping CRS rate matching patterns regardless of support of multiple TRPs.

Low-power WUS[3]
Study the feasibility of a very low-power WUS design not necessarily using existing signals and aiming at substantial gains compared to R15/R16/R17 mechanisms.

Multi-SIM[4]
Enhance support for simultaneous network connections (i.e., 2) and more seamless switching

In-device coexistence
Improve interference management of 5G and other technologies focusing on enhanced FDM[5] and TDM[5] solution

Small data transmission
Support mobile terminated triggered transmissions in inactive state for e.g., enhanced paging

SON/MDT[6] enhancements
Add IRAT[7] handover voice fallback, enhanced random access procedure, and expanded use cases (e.g., NPN)

Improved QoE[8]
Support new service types (e.g., AR, broadcast), QoE in NR-DC (e.g., reporting via Secondary Node)

gNodeB CU[9] resiliency
Study and agree possible failure scenarios associated with the Control Plane of the gNB-CU

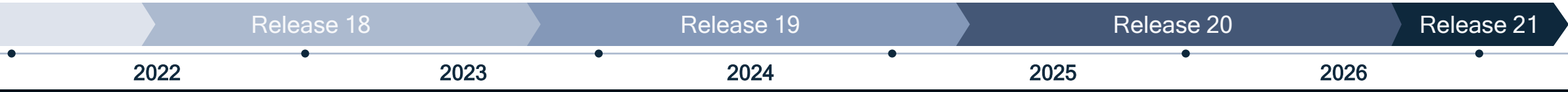
Multicast enhancements
Support reception in inactive mode, UE indication/signaling for "shared processing", enhanced RAN sharing

CA[10] enhancements
Support multi-cell scheduling and improve multi-carrier uplink focusing on Tx switching for 3 or more bands

Source: RP-213575 (DSS enhancements); RP-213645 (Low-Power WUS); RP-213584 (MUSIM Enhancements); RP-213589 (IDC Enhancements); RP-213583 (Small data transmission); RP-213553 (SON/MDT enhancements); RP-213594 (QoE Enhancements); RP-213677 (gNodeB CU resiliency); RP-213568 (MBS enhancements); RP-213577 (CA enhancements);

1 Dynamic Spectrum Sharing; 2 5G NR Physical Downlink Control Channel; 3 Wakeup Signal; 4 Subscriber Identity Module; 5 Frequency Division Multiplexing, Time Division Multiplexing; 6 Self Organizing Network/Minimization of Drive Test; 7 Inter Radio Access Technology; 8 Quality of Experience; 9 Central Unit; 10 Carrier Aggregation

AI/ML	Air interface (cross-node channel state feedback, beam management, positioning) Study Item in **Rel-18** and Work Item in **Rel-19+**	
Full Duplex	Full Duplex in TDD bands, sub-6/mmWave, enhanced crosslink interference, coexistence with legacy and other operators Study Item in **Rel-18** and Work Item in **Rel-19+**	
Network Power Savings	**Rel-18:** Techniques on the gNodeB and device side to improve network energy savings in terms of both transmission and reception	**Rel-19+:** Further enhancements for system power saving
XR	**Rel-18:** Application-aware RAN (frame-level QoS, multi-streams), power enhancements, capacity enhancements	**Rel-19+:** Further enhancements for capacity and power
Enhanced RedCap/IoT	**Rel-18:** Reduced complexity/cost (5MHz devices), power savings, sidelink support, enhancements for narrow band positioning	**Rel-19+:** Low-power Wake Up Signal, passive IoT (energy harvesting)
Enhanced Non-terrestrial network	**Rel-18:** Coverage enhancements, deployment above 10 GHz bands, mobility and service continuity enhancements, enhancements for IoT-NTN	**Rel-19+:** Possible further enhancements
Sidelink/V2X	**Rel-18:** Enhancements for unlicensed, mmWave enhancements, device-to-device relay, coexistence of LTE/NR V2X, enhanced CA	**Rel-19+:** Enhancements for sidelink MIMO, enhancements for power savings, etc.
eMBB enhancement	**Rel-18:** Rel-18: MIMO enhancements, enhanced uplink coverage, smart repeater, enhanced mobility, network energy savings	**Rel-19+:** MIMO enhancements (CSF time domain compression, etc.), enhancements for network energy savings



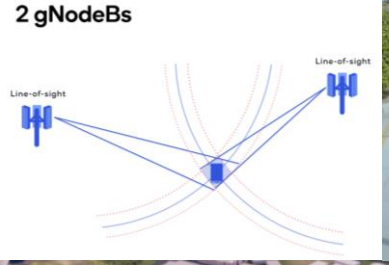
Release 18 is just the start of the 5G Advanced evolution

Further 5G NR enhancements in R19, R20, and beyond

How will 5G evolve in the new decade?

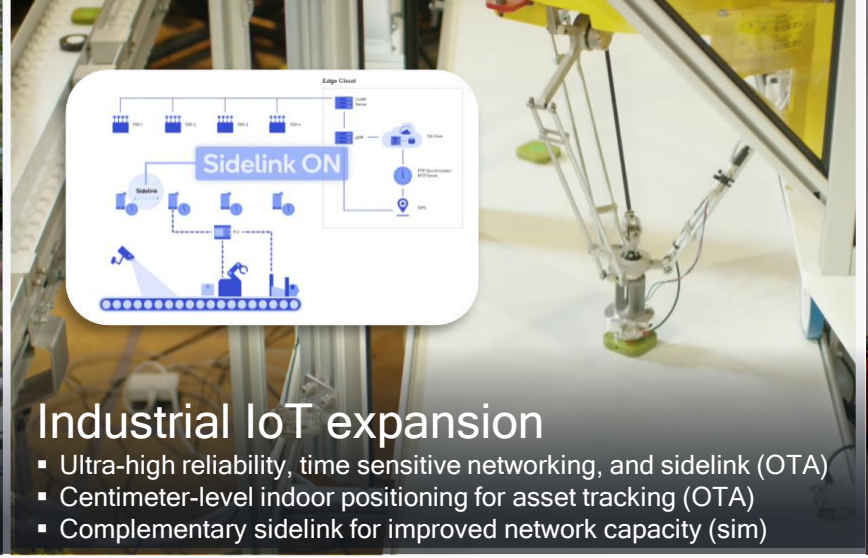
Advancing 5G to fulfill its full promise

Enhanced mobile experiences, new capabilities,
and expansion to diverse verticals



Wide-area 5G evolution

- Subband half duplex flexible service multiplexing (OTA)
- Precise positioning based on multi-RTT+AoA (OTA w/ ZTE/CMCC)
- Cross-node ML for CSF to improve uplink capacity (sim)
- NR-Light evolution with sidelink for lower-complexity IoT (sim)
- Device stack disaggregation for enhanced performance (msg)

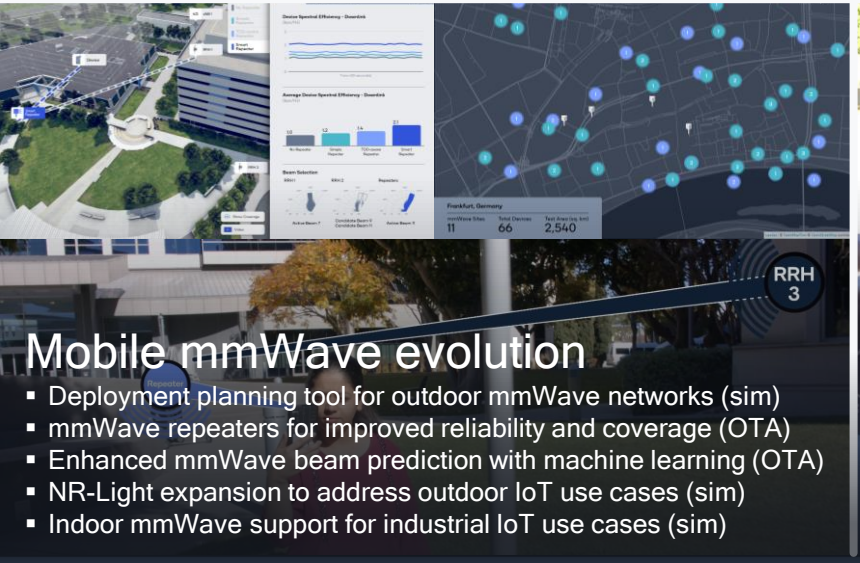


Industrial IoT expansion

- Ultra-high reliability, time sensitive networking, and sidelink (OTA)
- Centimeter-level indoor positioning for asset tracking (OTA)
- Complementary sidelink for improved network capacity (sim)

Boundless XR over 5G mmWave

- Multi-user, immersive boundless VR experience enabled and improved through end-to-end optimizations over mmWave (OTA)

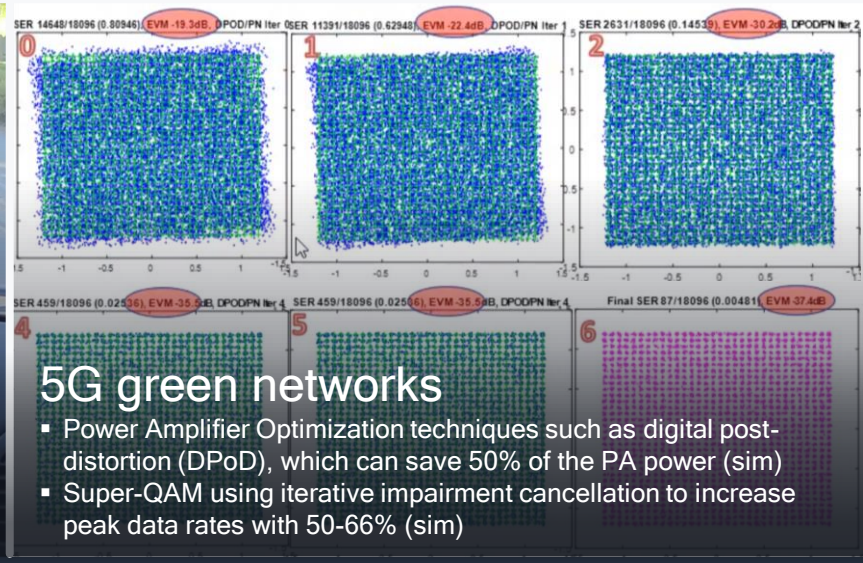


Mobile mmWave evolution

- Deployment planning tool for outdoor mmWave networks (sim)
- mmWave repeaters for improved reliability and coverage (OTA)
- Enhanced mmWave beam prediction with machine learning (OTA)
- NR-Light expansion to address outdoor IoT use cases (sim)
- Indoor mmWave support for industrial IoT use cases (sim)

Enhanced 5G V2X sidelink

- Complementing 5G networks with a local RSU to offload high bandwidth applications, e.g., 3D HD maps (OTA)
- Robust sidelink communication without GNSS coverage (OTA)



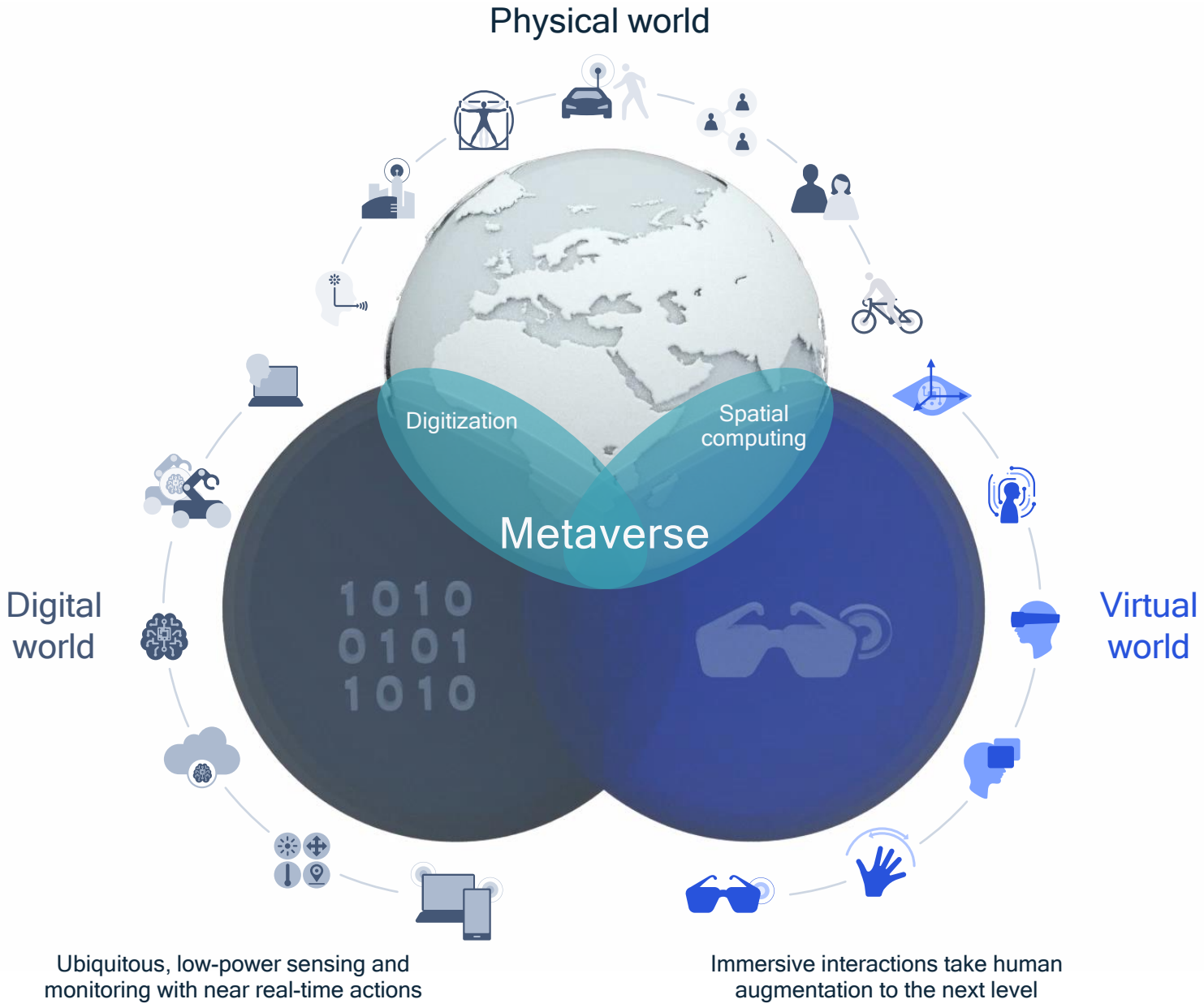
5G green networks

- Power Amplifier Optimization techniques such as digital post-distortion (DPoD), which can save 50% of the PA power (sim)
- Super-QAM using iterative impairment cancellation to increase peak data rates with 50-66% (sim)

Accelerating the 5G expansion and paving the path to 6G

A heavyweight lineup of advanced wireless R&D demonstrations for MWC Barcelona 2021

YouTube Playlist



New interface opportunities through

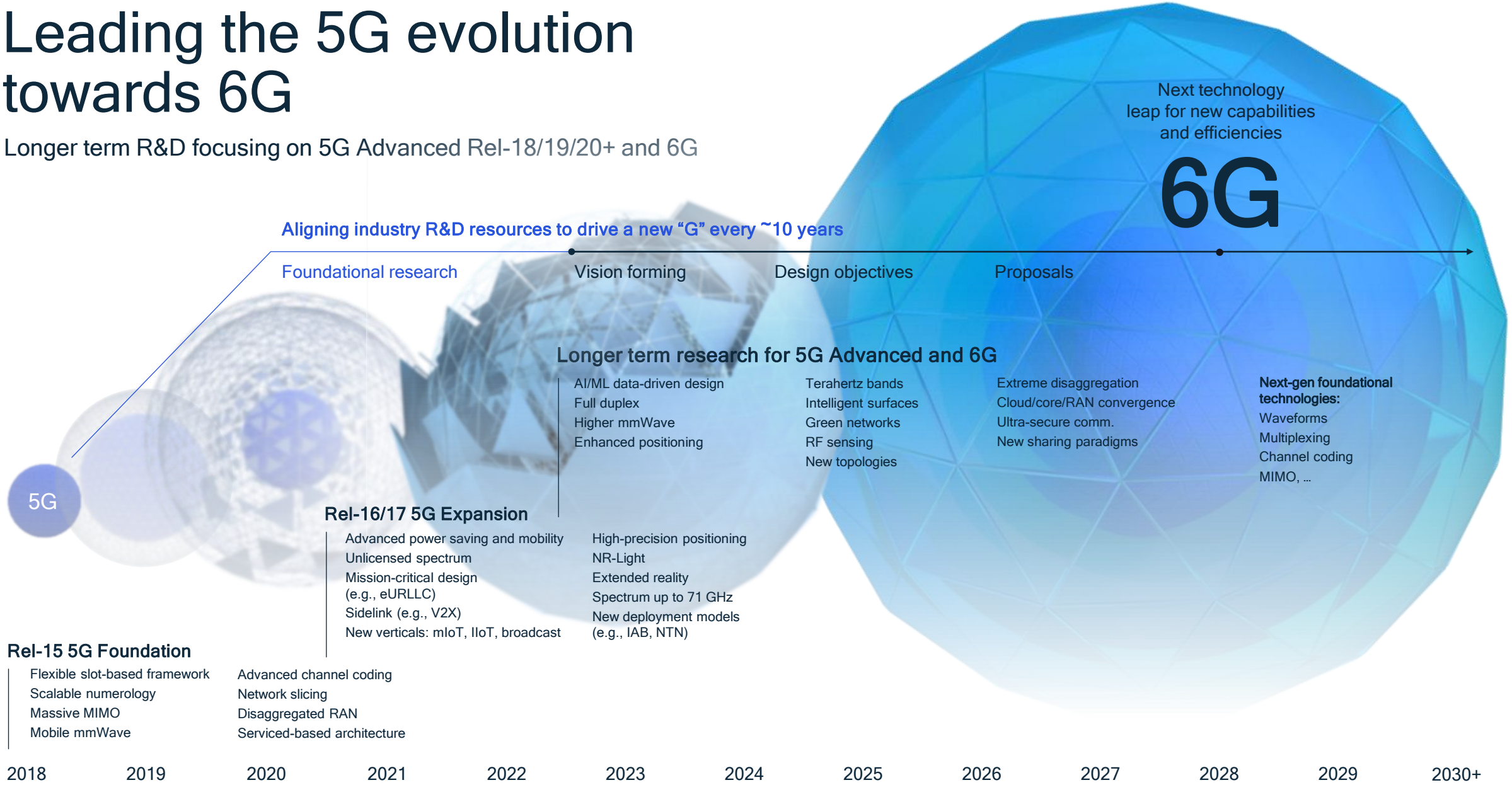
Merging worlds

The

New human interface

Leading the 5G evolution towards 6G

Longer term R&D focusing on 5G Advanced Rel-18/19/20+ and 6G



Key research vectors enabling the path towards 6G

AI/ML powered E2E communications

Data-driven communication and network design, with joint training, model sharing and distributed inference across networks and devices

Spectrum expansion & sharing

Expanding to THz, wide-area expansion to higher bands, new spectrum sharing paradigm, dynamic coordination with environmental awareness

New radio designs

Evolution of duplexing schemes, large-scale MIMO, mmWave evolution, reconfigurable intelligent surfaces, non-terrestrial communications, waveform/coding for MHz to THz, system energy efficiency

Merging of worlds

Physical, digital, virtual, immersive interactions taking human augmentation to next level via ubiquitous, low-power joint communication and sensing

Scalable network architecture

Disaggregation and virtualization at the Connected Intelligent Edge, use of advanced topologies to address growing demand

Communications resiliency

Multifaceted trust and configurable security, post quantum security, robust networks tolerant to failures and attacks

6G

Design goals & performance vectors

Capacity | Latency | Spectral efficiency | User experience | Ease of onboarding

Data rate | Reliability | Mobility | Security | Scalability | Intelligence | Cost efficiency

Coverage | Energy efficiency | Connection density | Positioning capability | And others...

Innovating to pave the path to 6G

A unified connectivity fabric for this decade

Next technology leap for new capabilities and efficiencies

Historically 10 years between generations

Strong 5G momentum sets stage for global expansion

Qualcomm

Thank you

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