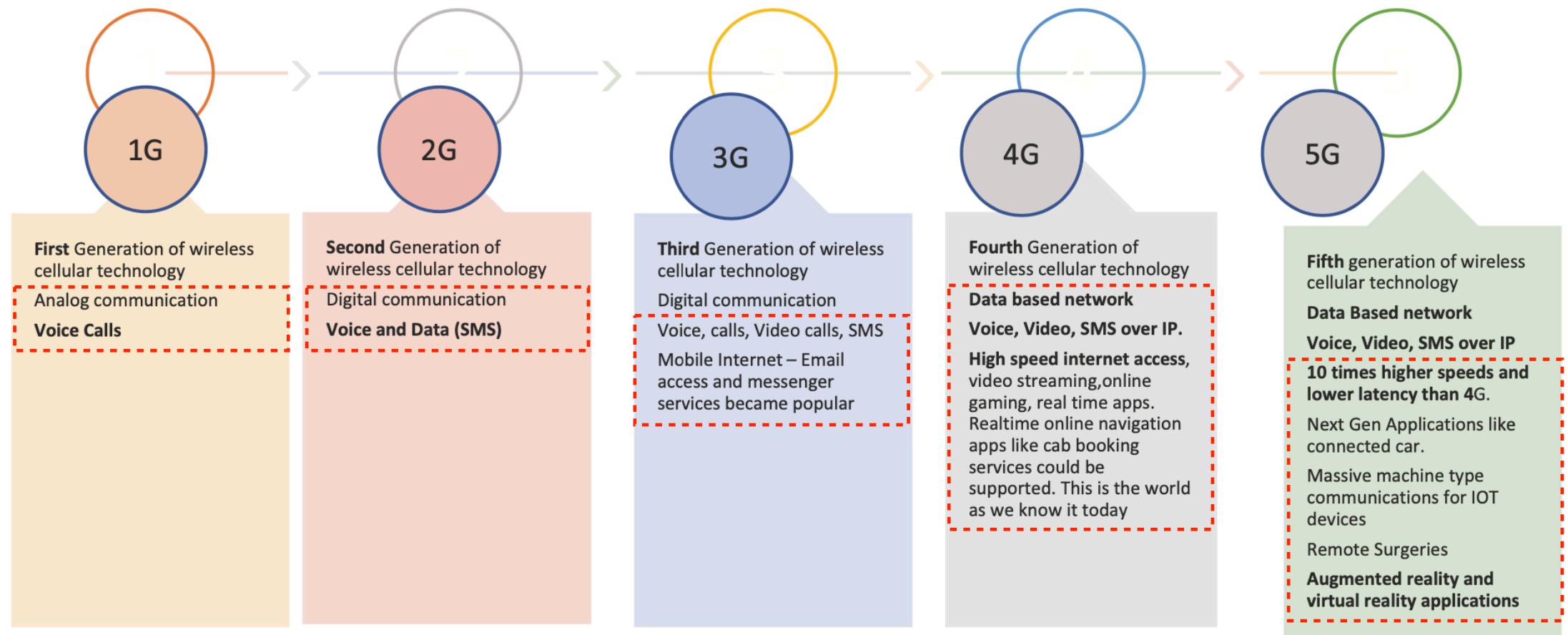


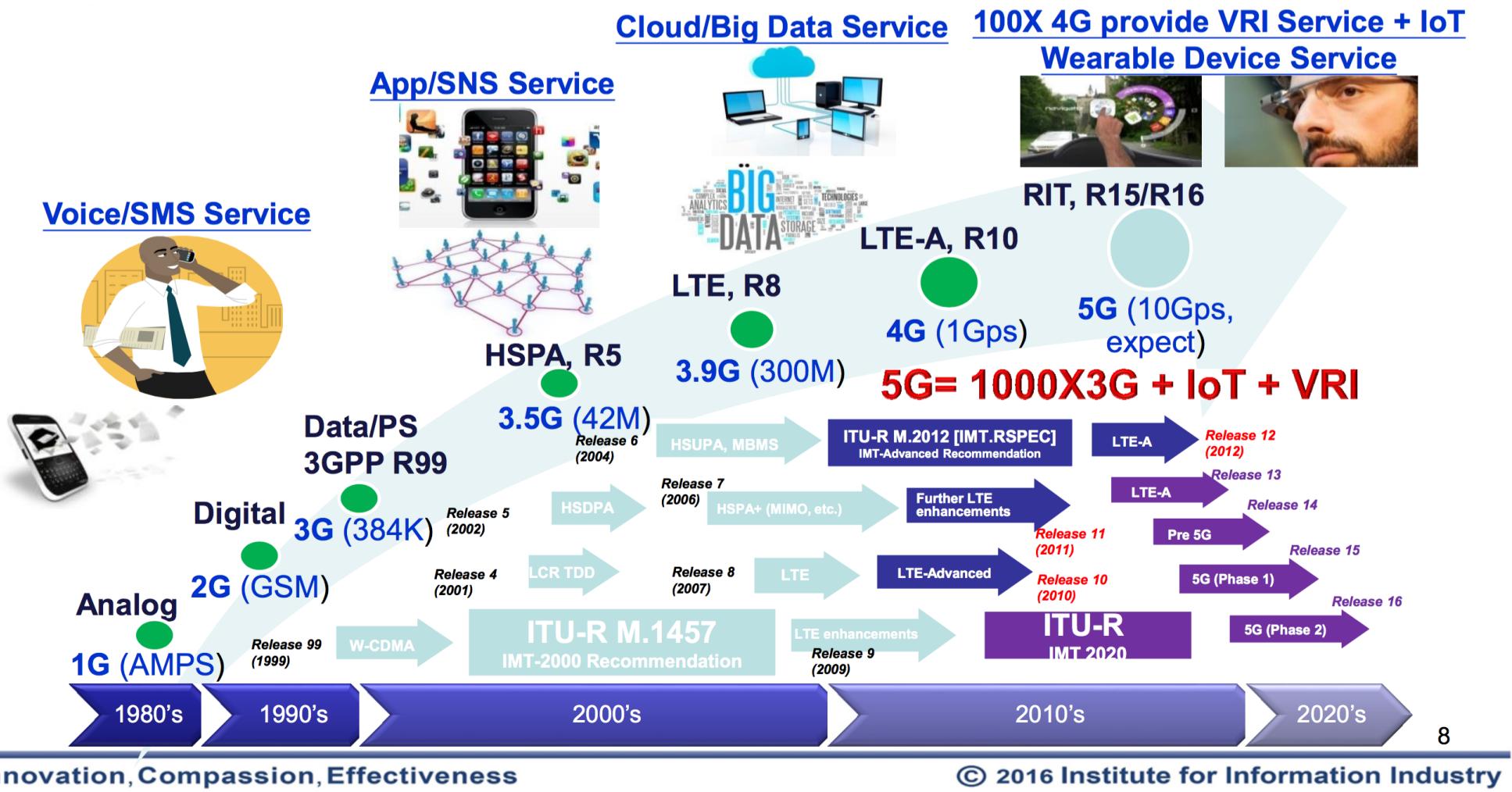
Overview of 5G and 6G Networks

- **Evolution of Mobile Communication**
- ITU/3GPP Standardization
- ITU 5G Service Scenarios
- 5G-New Radio
- 5G System Architecture
- SDN/NFV
- Network Slicing
- Mobile Edge Computing (MEC)
- The Road to the 6G Mobile Communication

Evolution of Mobile Communication



Evolution from 1G to 5G : Tech & Service



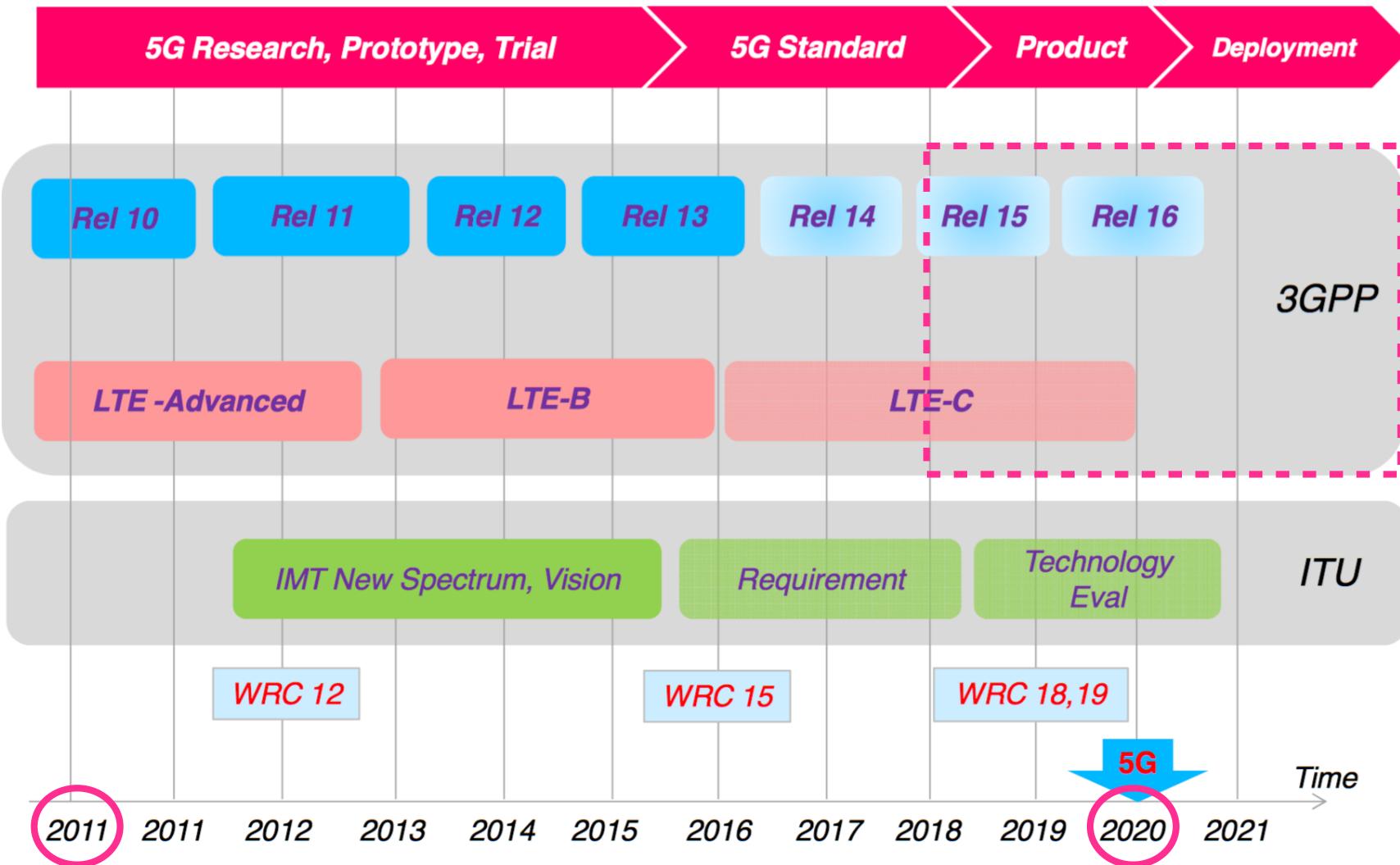
VRI : Virtual Reality Imaging

Parameters	4G	5G
Air Link User Plane Latency	10 ms	1 ms
Air Link Control Plane Latency	100 ms	50 ms
Simultaneous Connection Density per km ²	10^5	10^6
Mobility	300 km/h	500 km/h
Uplink Cell Spectral Efficiency	1.8 bps/Hz	5 bps/Hz
Downlink Cell Spectral Efficiency	2.6 bps/Hz	10 bps/Hz
Peak Throughput (Downlink) per Connection	100 Mbps to 1 Gbps	10 Gbps to 50 Gbps
Cell Edge Data Rate	1 Mbps	1 Gbps
Cost Efficiency	10 times	100 times
Packet Delay Budget without Quality Assurance	100 to 300 ms	Undetermined
Packet Delay Budget with Guaranteed Quality	50 to 300 ms	1 ms
Packet Loss Ratio for video broadcasting	10^{-8} (4k UHD)	10^{-9} (8k UHD)
Packet Loss Ratio for M2M Services (without quality assurance)	10^{-3}	10^{-4}
Packet Loss Ratio for M2M Services (without guaranteed quality)	10^{-6}	10^{-7}

QoS requirements for 4G and 5G networks

- Evolution of Mobile Communication
- **ITU/3GPP Standardization**
- ITU 5G Service Scenarios
- 5G-New Radio
- 5G System Architecture
- SDN/NFV
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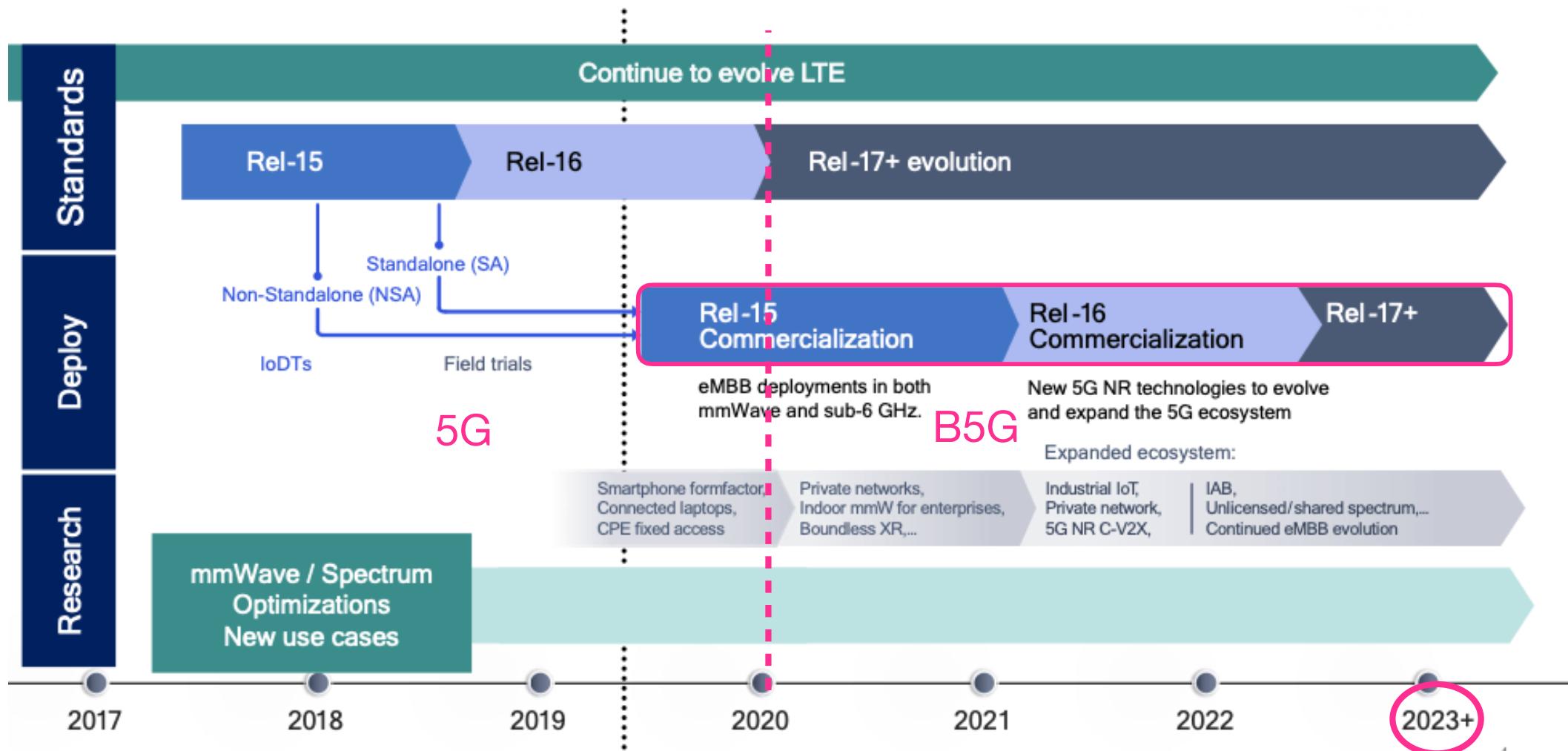
3GPP Standardization

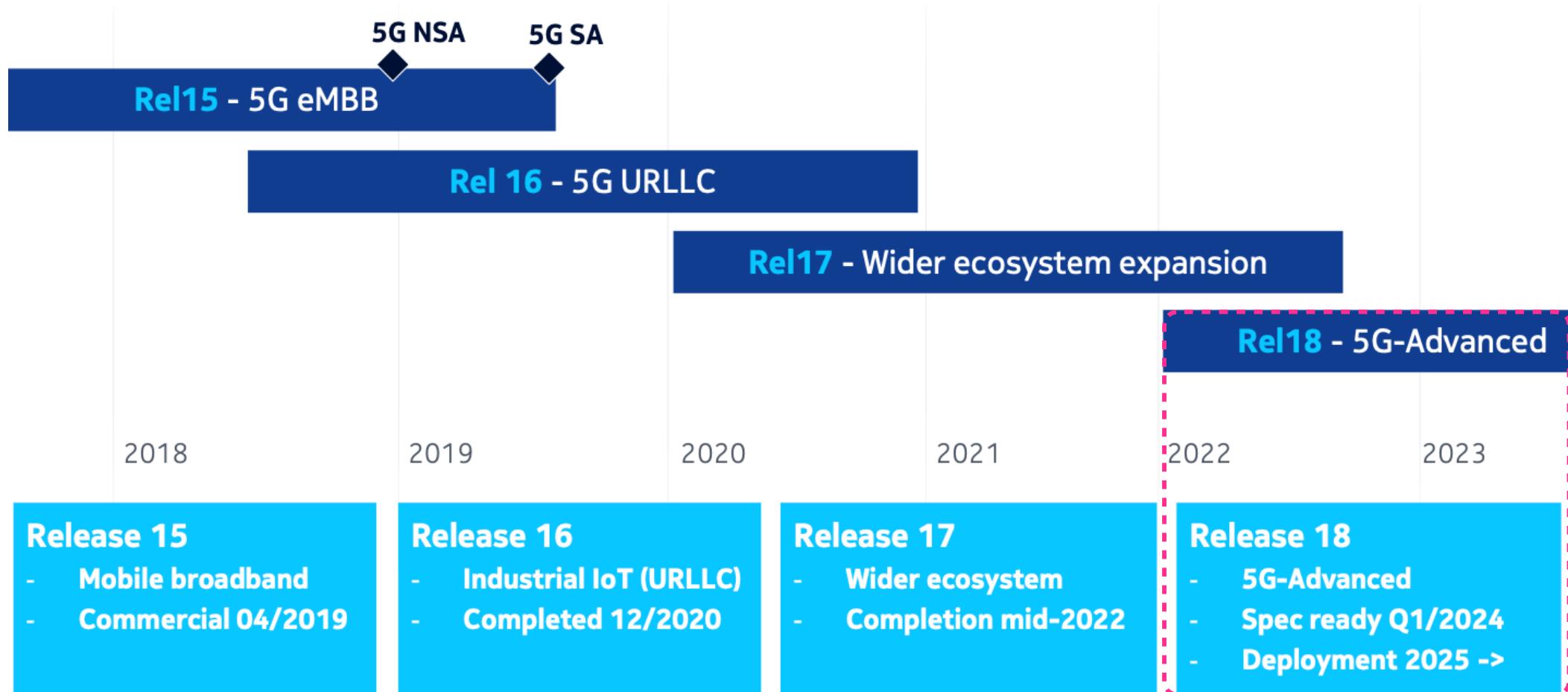


- 3.9G (LTE) : 3GPP Rel. 8-9
- 4G (LTE-Advanced) : 3GPP Rel. 10-11
- 4.5G (LTE-Advanced Pro) : 3GPP Rel. 12-14
- 5G (IMT-2020) : 3GPP Rel. 15-16
- IMT** : International Mobile Telecommunications
- WRC** : World Radiocommunication Conference

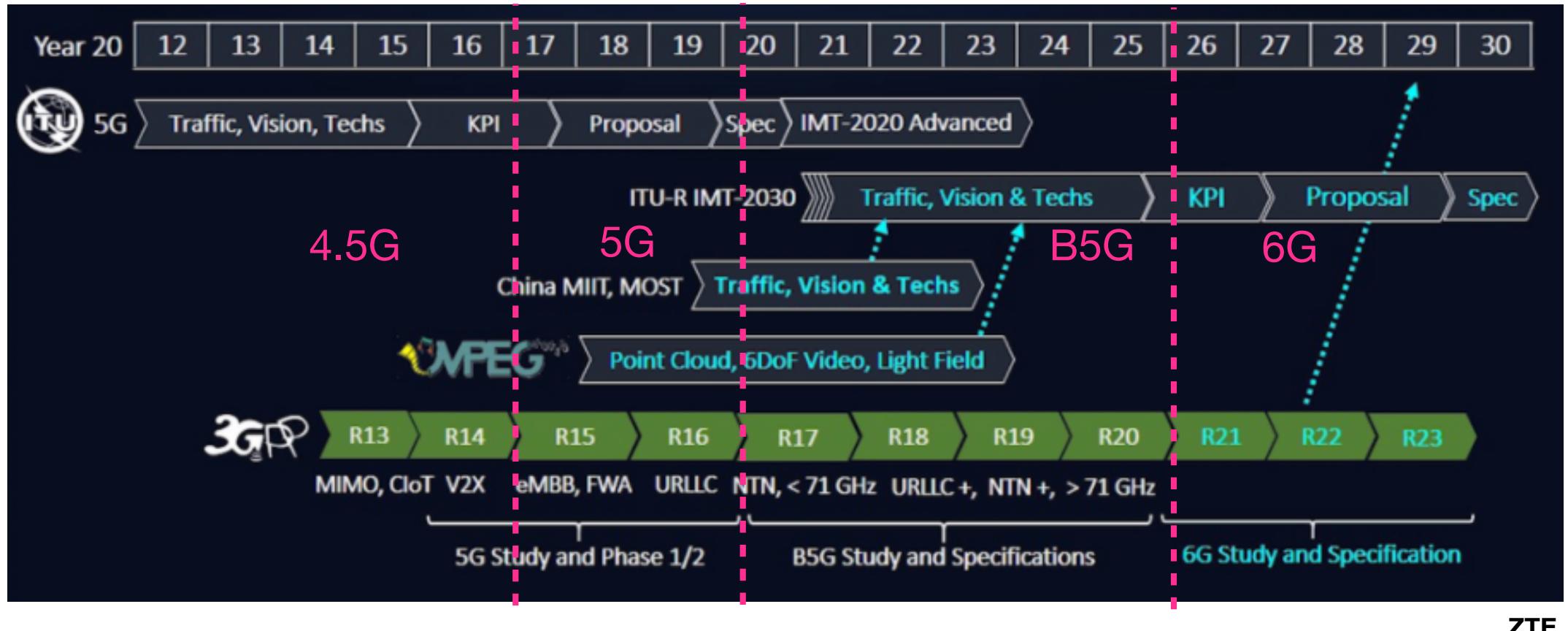
	Release	End date	New features
3.9G	Rel-99	December 1999	UMTS, WCDMA
	Rel-4	June 2001	TD-SCDMA
	Rel-5	September 2002	HSDPA, IP multimedia subsystem
	Rel-6	September 2005	HSUPA
	Rel-7	March 2008	Enhancements to HSPA
4G	Rel-8	March 2009	LTE
	Rel-9	March 2010	LTE Location services for LTE
5G	Rel-10	June 2011	LTE-Advanced, carrier aggregation
	Rel-11	March 2013	Co-ordinated multi-point transmission
	Rel-12	March 2015	LTE Advanced Dual connectivity, LTE sidelink
	Rel-13	March 2016	LTE-Advanced Pro, eMTC, NB-IoT
	Rel-14	June 2017	V2X services for LTE
	Rel-15	June 2019	NR 5G phase 1
	Rel-16	June 2020	NR 5G phase 2
	Rel-17	December 2021	Enhancements to 5G

3GPP 5G Timeline





Tentative Timeline from 5G to B5G and 4G

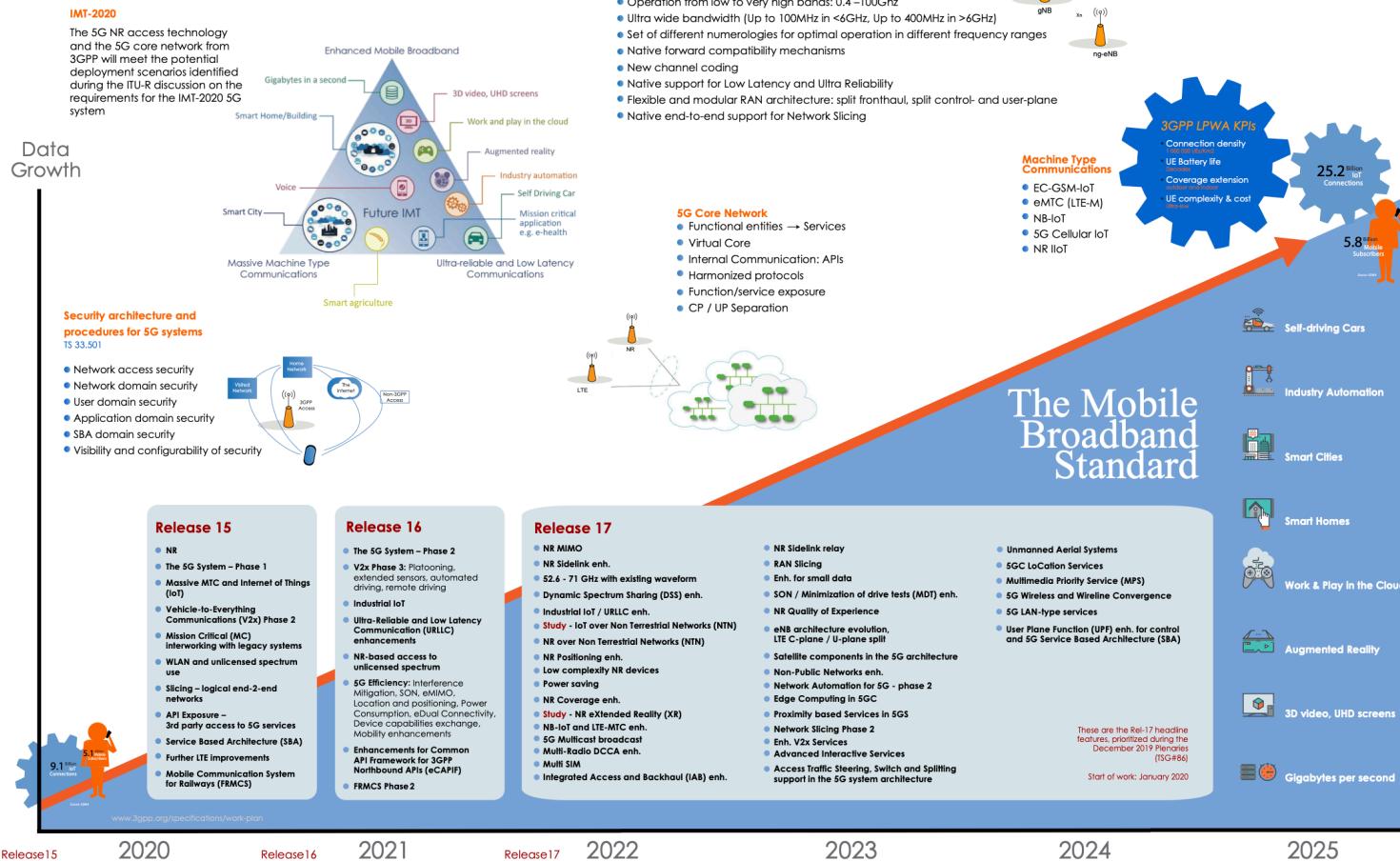


4.5G (LTE-Advanced Pro) : 3GPP Rel. 12-14 5G (IMT-2020) : 3GPP Rel. 15-16 B5G : 3GPP Rel. 17-20 6G : 3GPP Rel. 21-23

5G Evolution Major Releases (Real. 15-17)



Evolution across three major Releases



- Release 15
 - NR
 - The 5G System - Phase 1
 - Massive MIC and Internet of Things (IoT)
 - Vehicle-to-Everything Communications (V2x) Phase 2
 - Mission Critical (MC) interworking with legacy systems
 - WLAN and unlicensed spectrum use
 - Slicing - logical end-2-end networks
 - API Exposure - 3rd party access to 5G services
 - Service Based Architecture (SBA)
 - Further LTE improvements
 - Mobile Communication System for Railways (FRMCS)

- Release 16

- The 5G System - Phase 2
- V2x Phase 3: Platooning, extended sensors, automated driving, remote driving
- Industrial IoT
- Ultra-Reliable and Low Latency Communication (URLLC) enhancements
- NR-based access to unlicensed spectrum
- 5G Efficiency: Interference Mitigation, SON, eMIMO, Location and positioning, Power Consumption, eDual Connectivity. Device capabilities exchange. Mobility enhancements
- Enhancements for Common API Framework for 3GPP Northbound APIs (eCAPIF)
- FRMCS Phase2

- Release 17

- NR MIMO
- NR sidelink enh.
- 52.6 - 71 GHz with existing waveform
- Dynamic Spectrum Sharing (DSS) enh.
- Industrial IoT / URLLC enh.
- Study- IoT over Non Terrestrial Networks (NTN)
- NR over Non Terrestrial Networks (NTN)
- NR positioning enh.
- Low complexity NR devices
- Power saving
- NR coverage enh.

- Study - NR eXtended Reality (XR)
- NB-IoT and LTE-MTC enh.
- 5G multicast broadcast
- Multi-Radio DCCA enh.
- Multi SIM
- Integrated Access and Backhaul (IAB) enh.
- NR sidelink relay
- RAN slicing
- Enh. for small data
- SON / Minimization of Drive Tests (MDT) enh.
- NR Quality of Experience

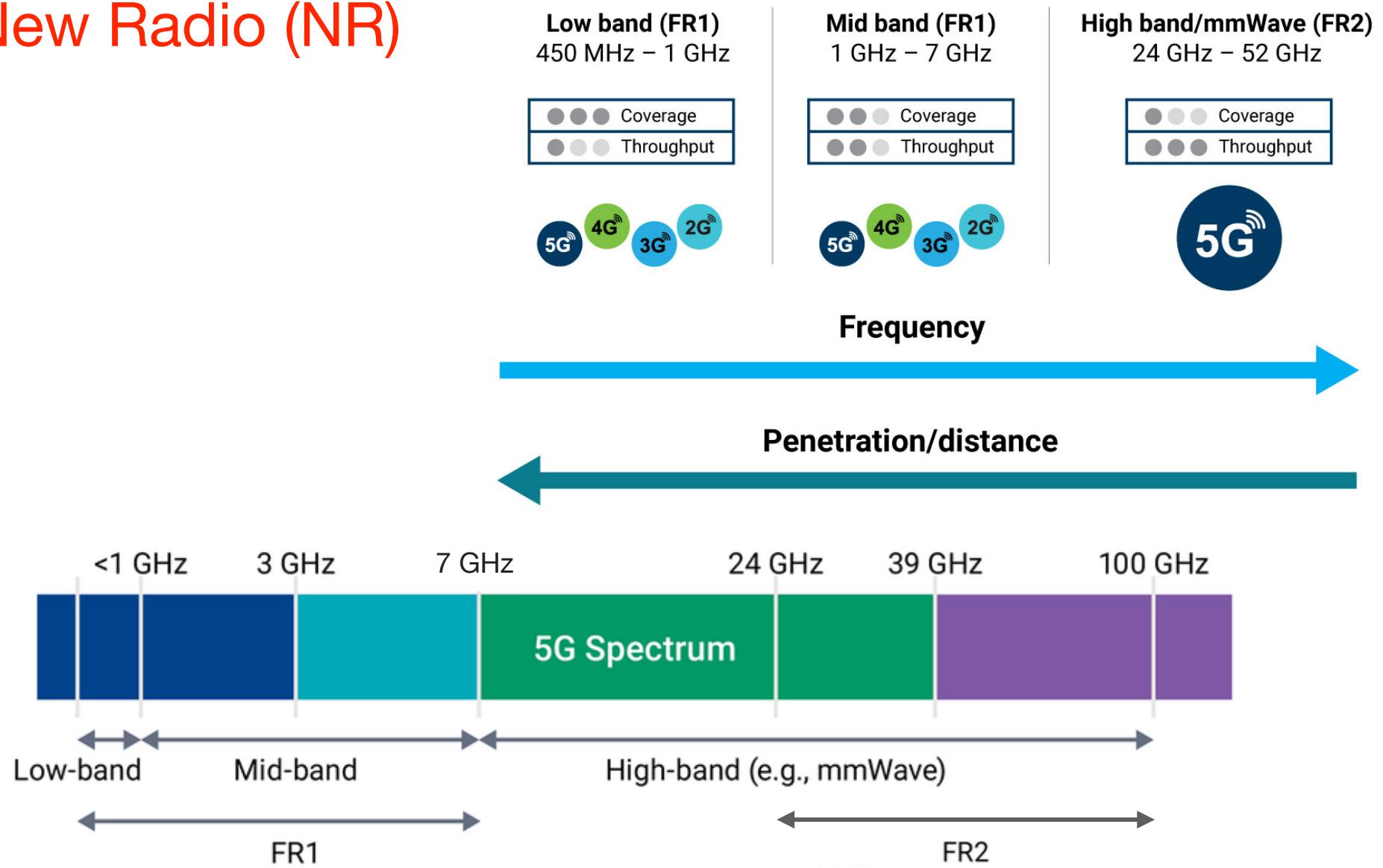
- eNB architecture evolution, LTE C-plane / U-plane split
- Satellite components in the 5G architecture
- Non-Public Networks enh.
- Network automation for 5G - phase 2
- Edge computing in 5GC
- Proximity based services in 5GS
- Network slicing phase 2
- Enh. V2x services
- Advanced interactive services

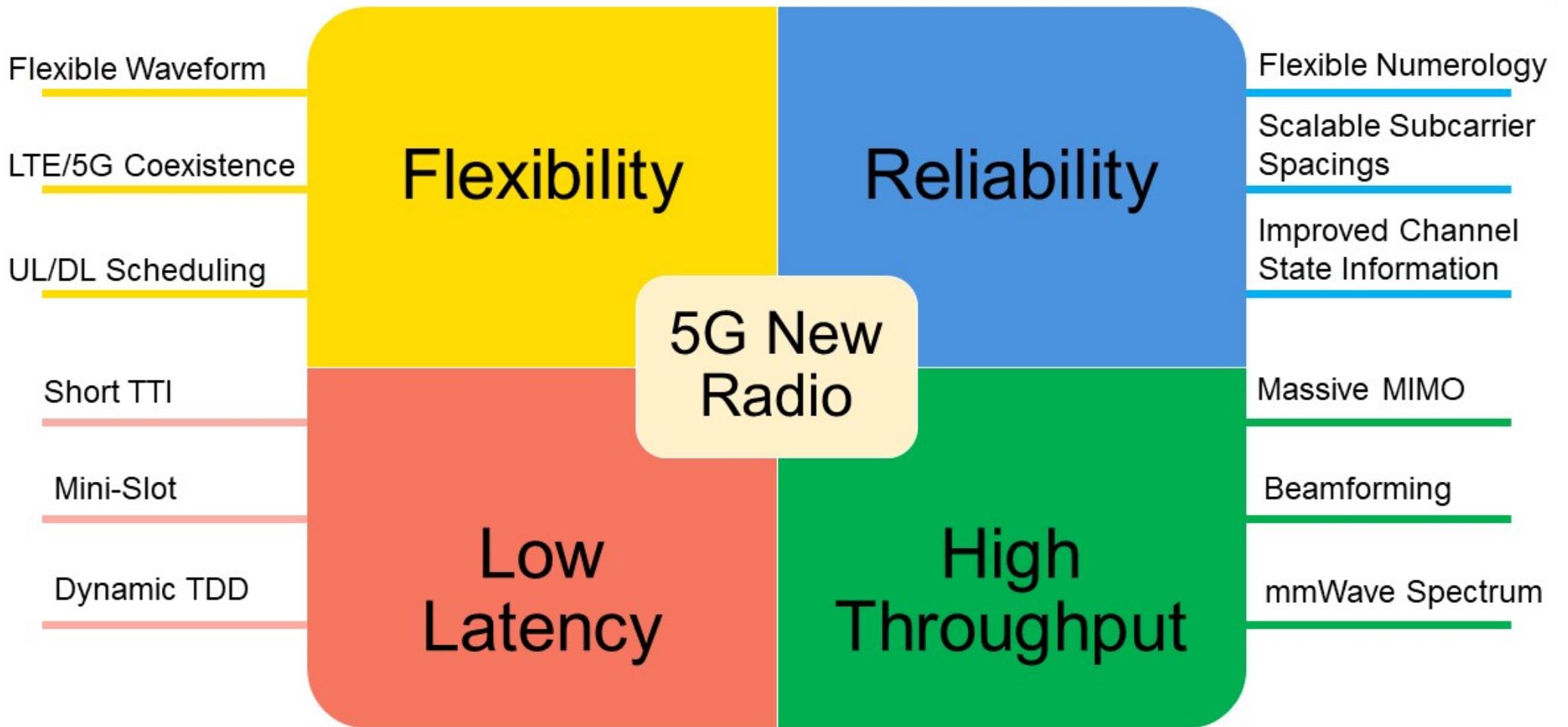
- Access traffic steering, switch and splitting support in the 5G system architecture Unmanned Aerial Systems (UAS)
- 5GC LoCation Services (LCS)
- Multimedia Priority Service (MPS)
- 5G Wireless and Wireline Convergence
- 5G LAN-type services
- User Plane Function (UPF) enh. for control and 5G Service Based Architecture (SBA)

- **Release 15**

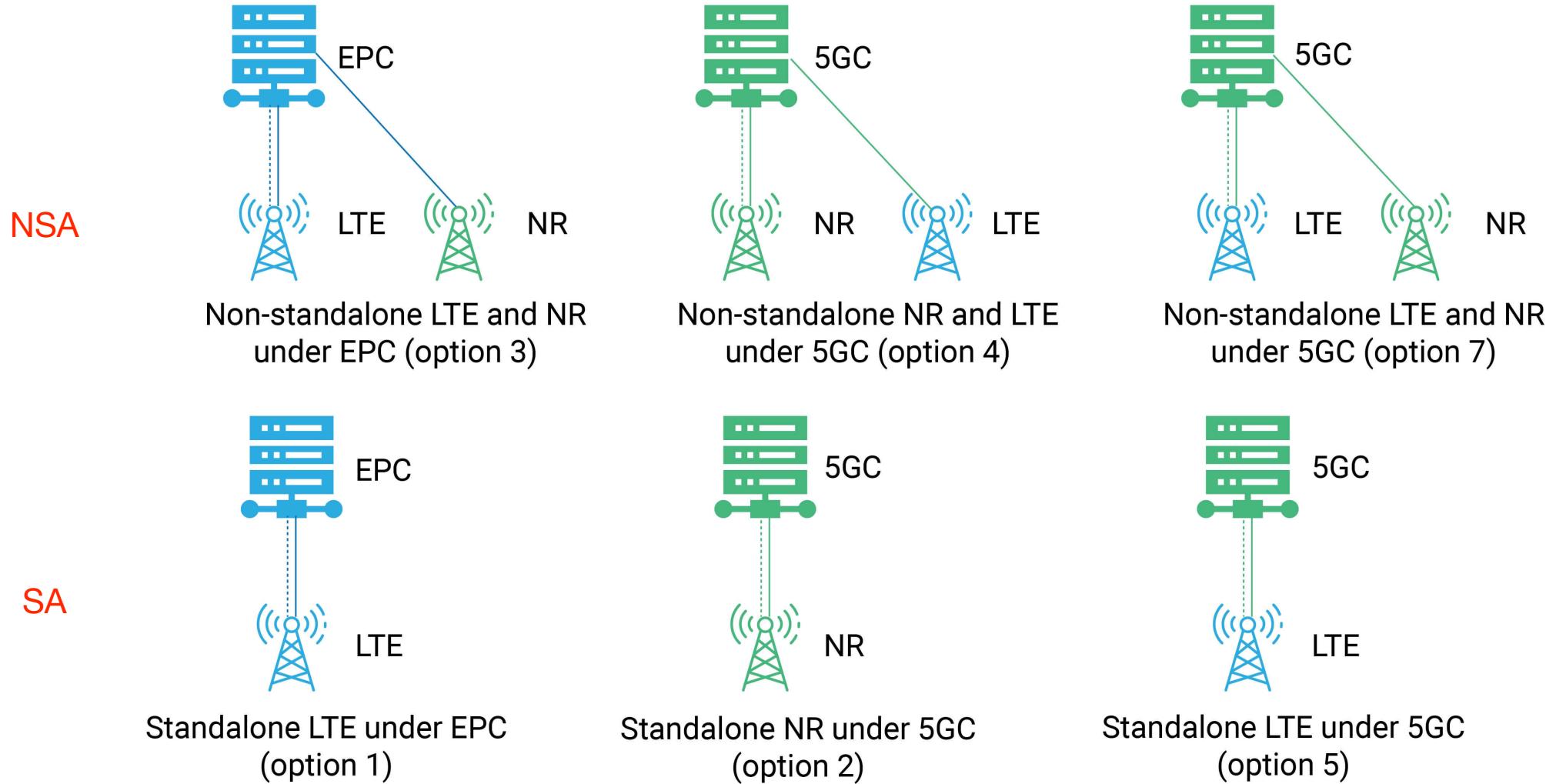
- NR-New Radio (NR)
 - NR **NSA** ,5G radio to work with LTE core
 - NR **SA**, 5G radio to work with 5G core
- **Massive MTC** and Internet of things
- Vehicle to everything communication (**V2X**)
- Mission critical (**MC**) internetworking with legacy systems

NR-New Radio (NR)





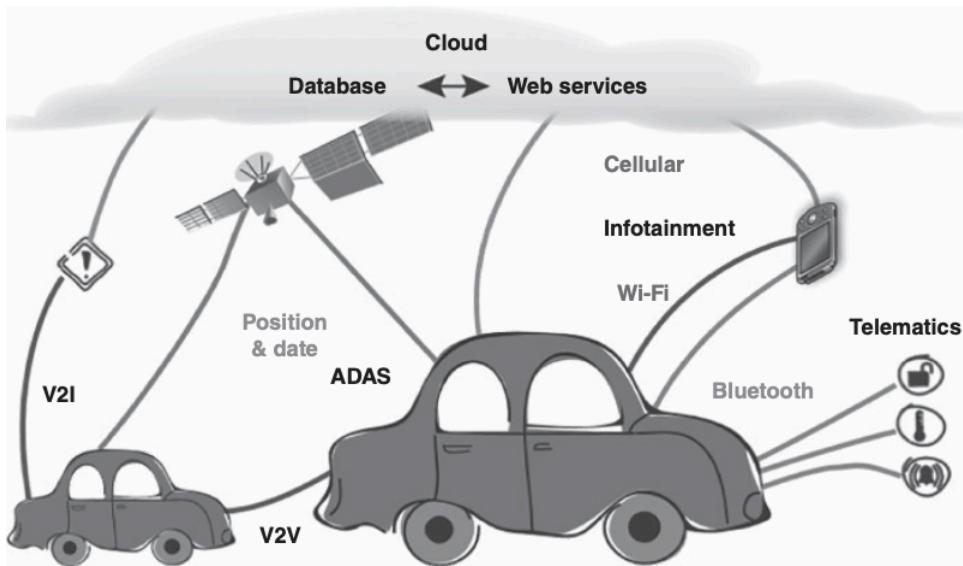
NSA vs. SA



Massive MTC (mMTC)

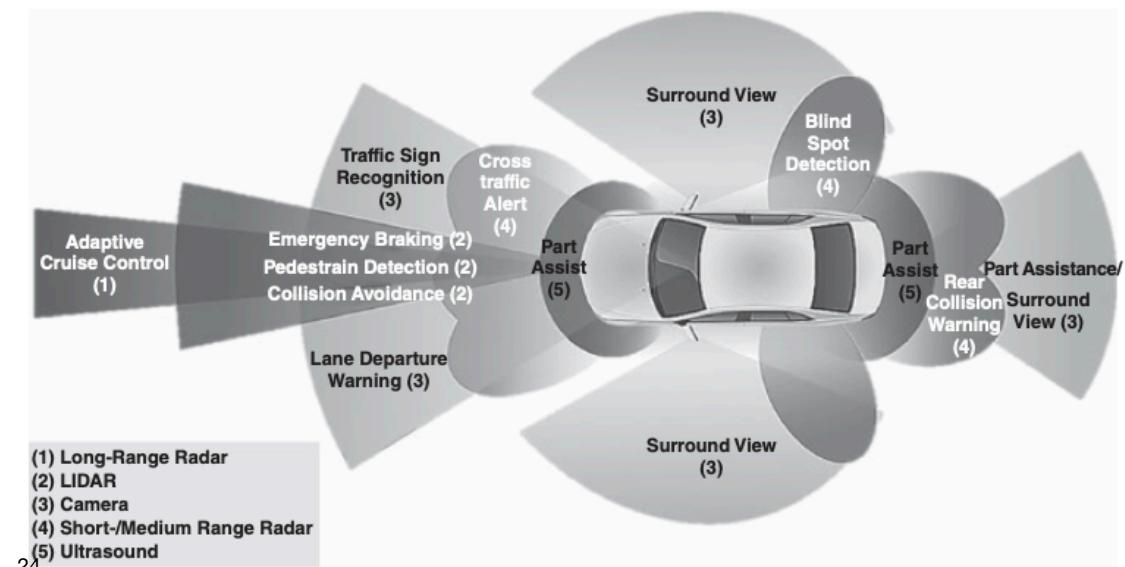
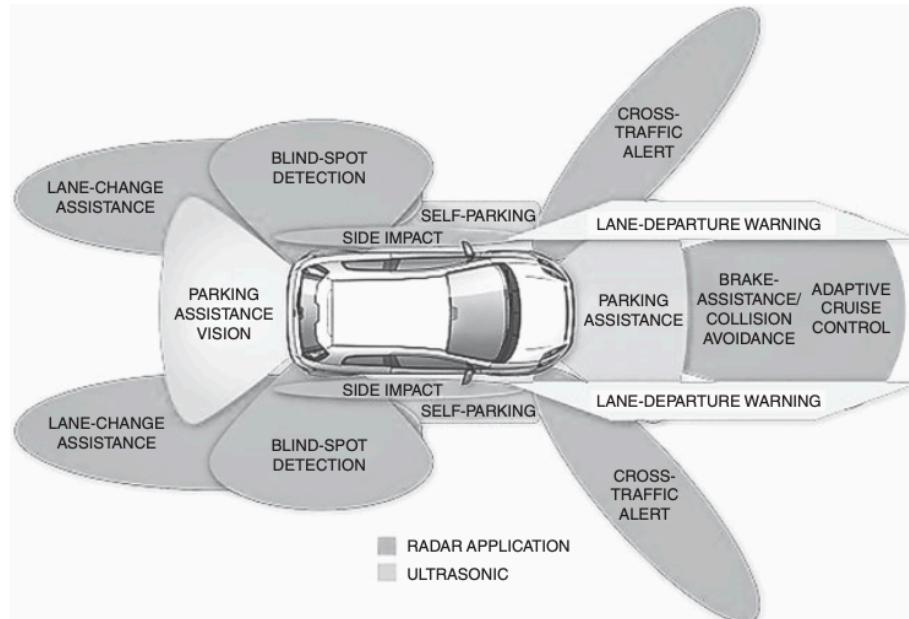


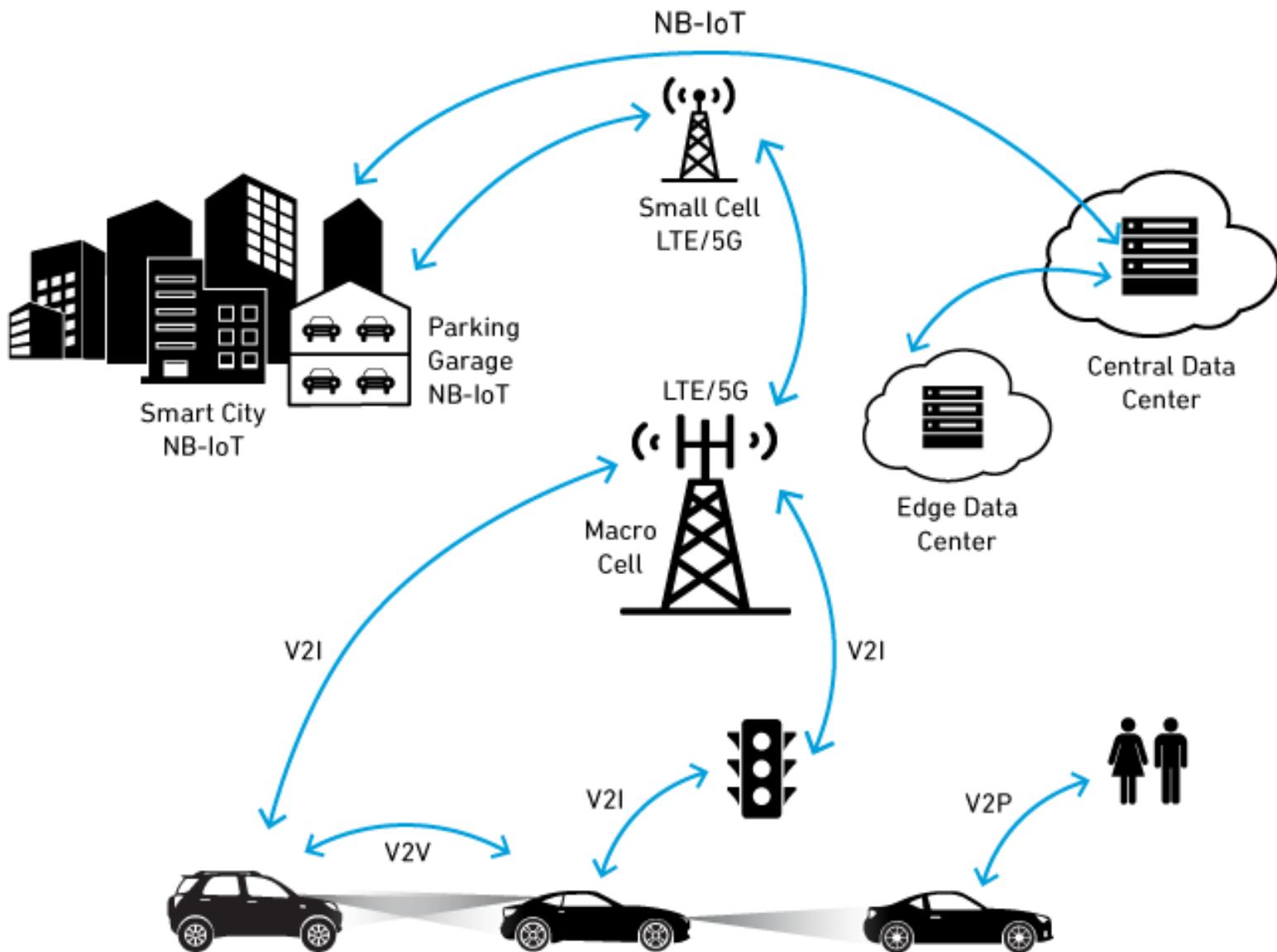
Vehicle to Everything (V2X)



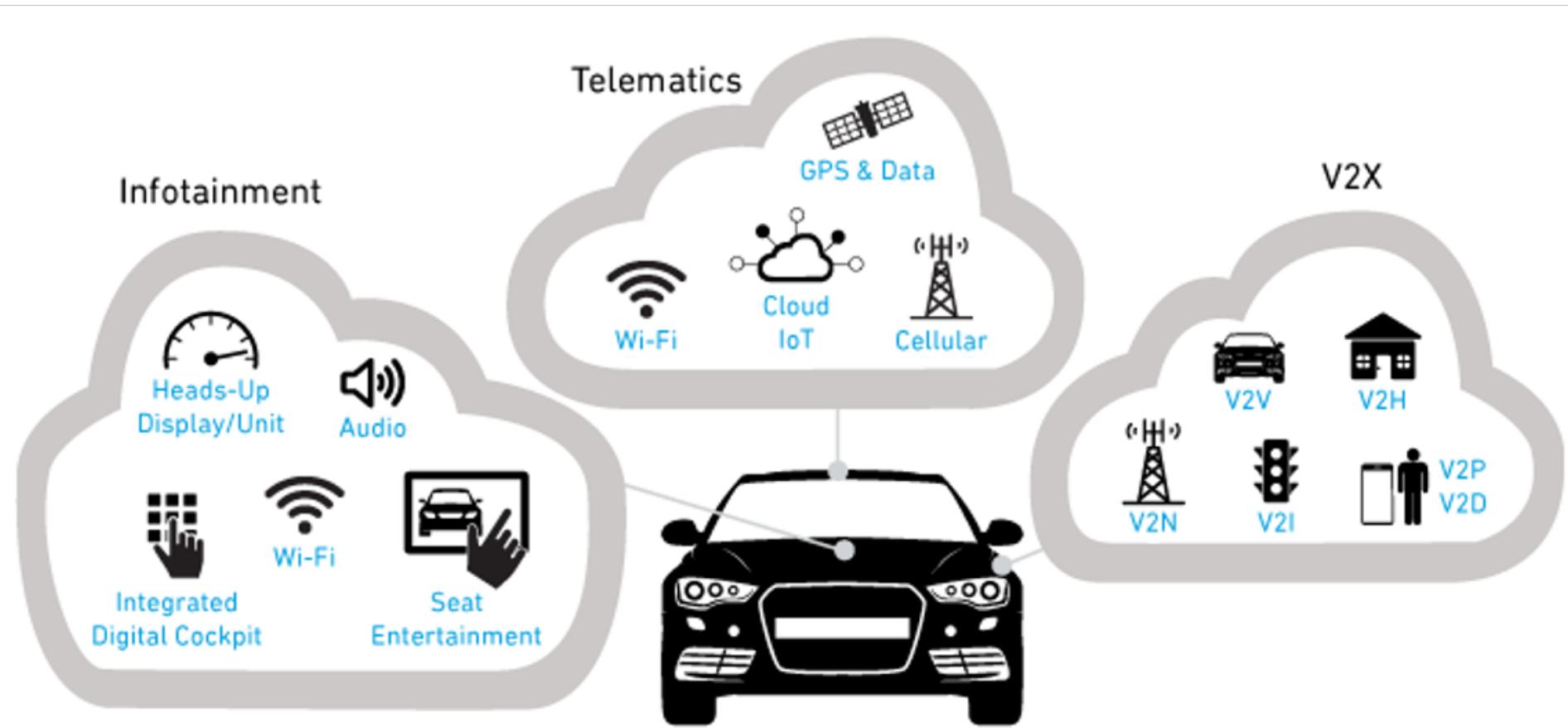
ADAS : Advanced Driver Assistance Systems

LiDAR : Light Detection and Ranging





V2X: Connecting to the Environment



Mission Critical (MC)

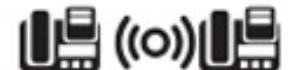
Very critical applications,
things that can't fail – reliability
is VITAL



Human to Human



Human to Machine



Machine to Machine

eMBB

Extreme Mobile Broadband



Virtual Reality / Augmented Reality



Video Calling
Virtual Meeting



Fixed Wireless



UHD Video

Video Monitoring



Video Cloud Computing



mMTC

Massive Scale Communication

Wearables



Social Networking



Smart Homes/ Smart Cities



URLLC

Ultra-Reliable Low Latency Service

Health Care Monitoring



Vehicle to Infrastructure



Industrial Automation



Public Safety



Remote Surgery



Vehicle to Pedestrian



Vehicle to Vehicle



Traffic per cell = Users per cell * traffic per subscriber (Data rate)

Required Spectrum = Traffic per cell / Spectral Efficiency

Spectral Efficiency = 1.5bps/Hz/Cell

MC PTT

Users Per Cell ~50
DL/UL Spectral Efficiency
= 1.5bps/Hz/Cell

MC Data

Users Per Cell ~10
DL/UL Spectral Efficiency
= 1.5bps/Hz/Cell

MC Video

Users Per Cell ~10
DL/UL Spectral Efficiency
= 1.5bps/Hz/Cell

MC AR

Users Per Cell ~5
DL/UL Spectral Efficiency
= 1.5bps/Hz/Cell

~0.7 MHz – 3 MHz

~0.06 MHz – 7 MHz

~ 1 MHz – 35 MHz

~ 4 MHz – 170 MHz

UL/DL Bandwidth Requirement

Spectrum requirements for different **Mission Critical (MC)** services for a spectrum efficiency of **1.5 bps/Hz**

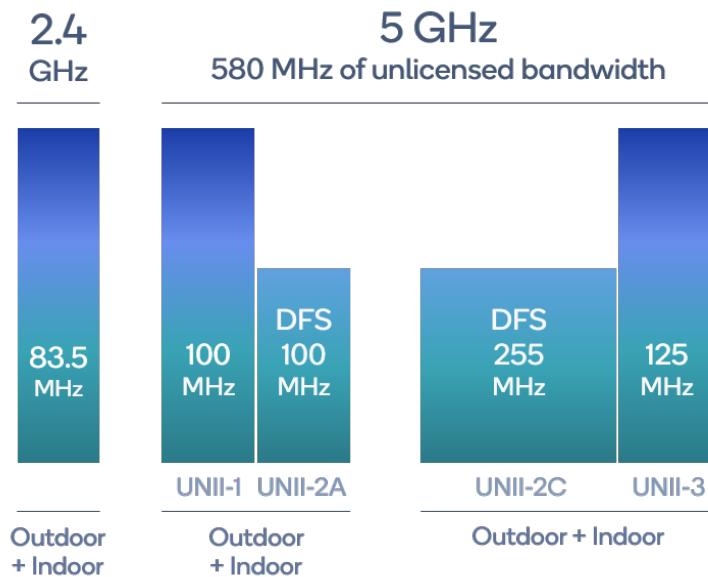
- WLAN unlicensed spectrum use
- Slicing- logical and end to end networks
- API Exposure – 3rd Party access to 5G services
- Service Based Architecture (SBA)
- Further LTE improvements
- Mobile communication system for railways
(5G Railway)
- Mobile Edge Computing (MEC)

WLAN Unlicensed Spectrum Use

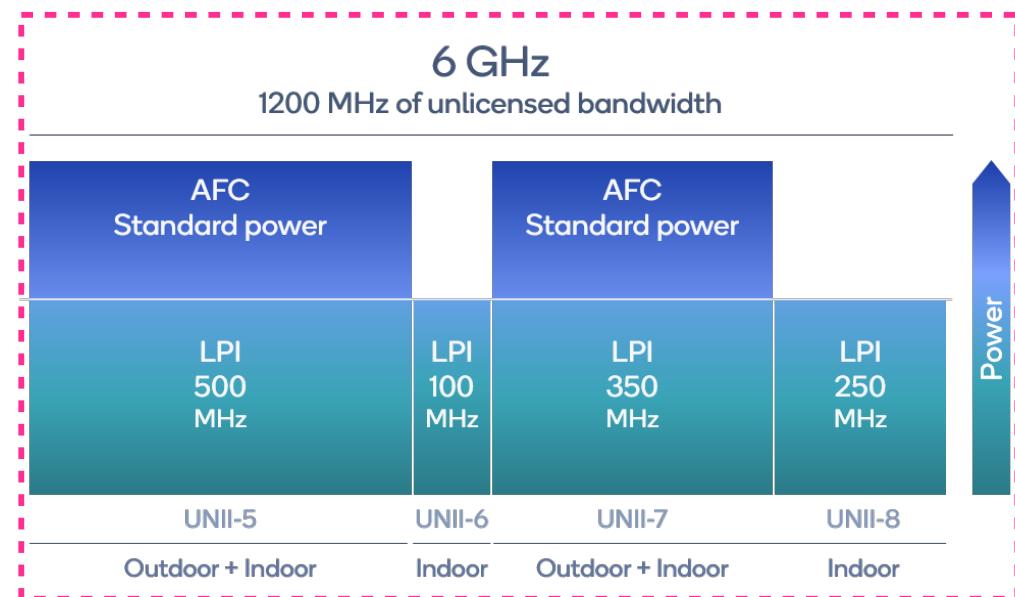
WiFi 6E: WiFi 6 Extended to 6GHz

6 GHz brings new unlicensed bandwidth for Wi-Fi and 5G

United States



WLAN unlicensed



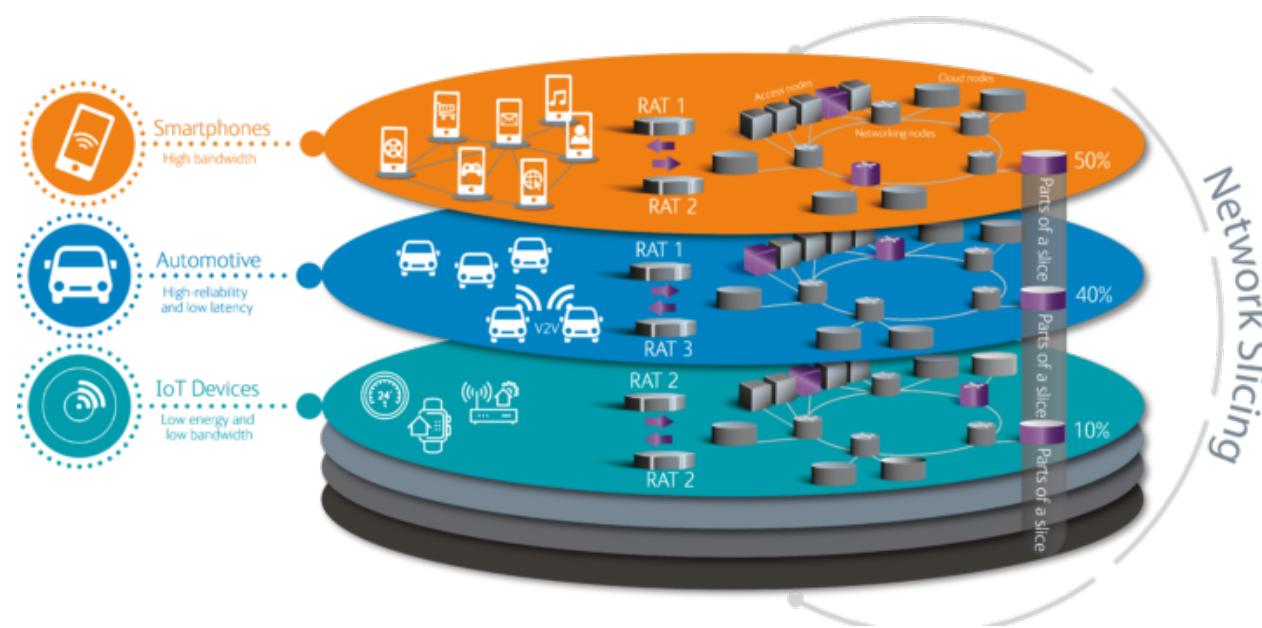
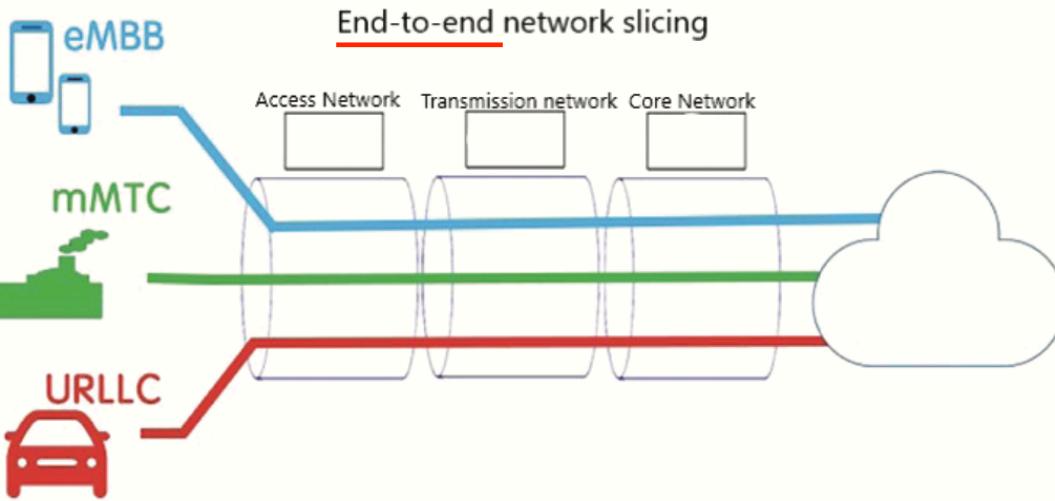
1200 MHz

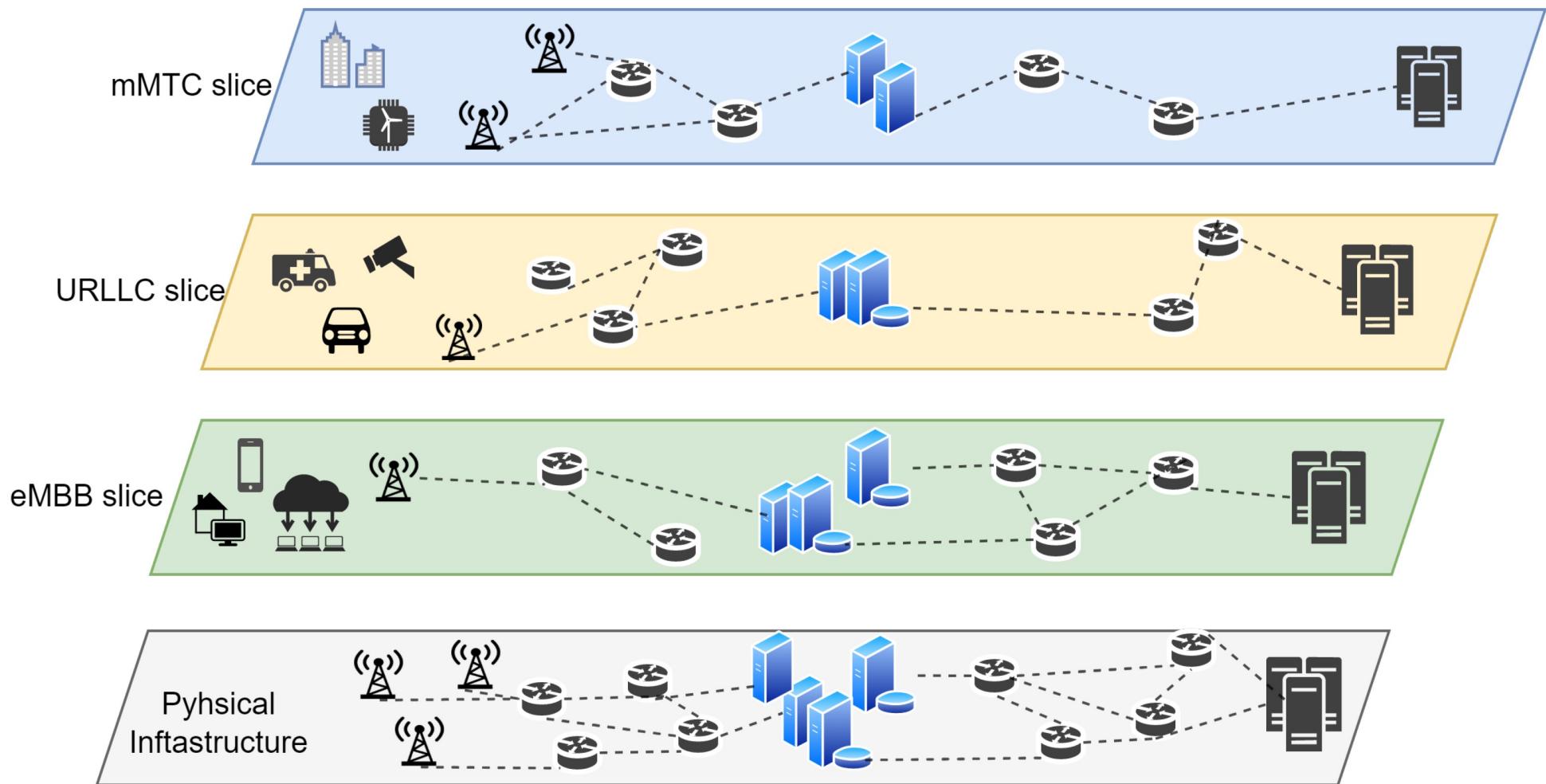


A massive amount of new unlicensed spectrum
is now available in the U.S. for Wi-Fi 6E and 5G

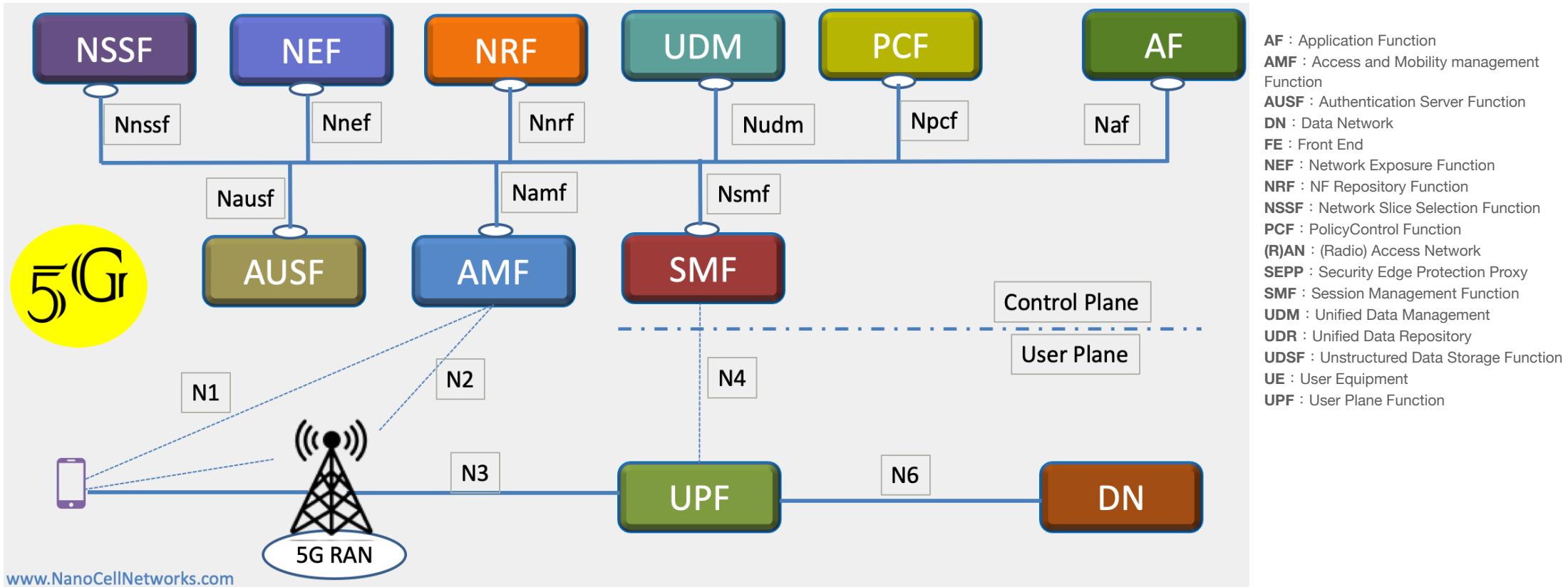
AFC= Automated frequency control, DFS= Dynamic Frequency Selection, LPI= Low power indoor

Slicing





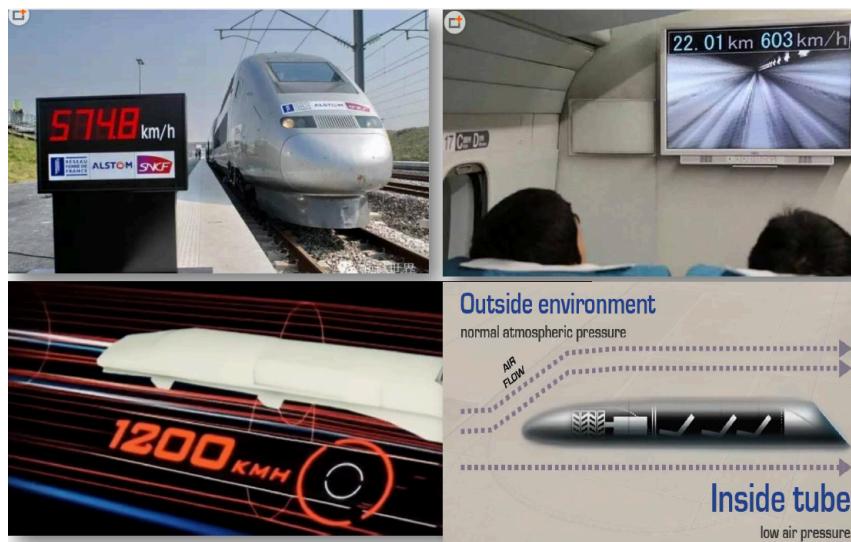
Service Based Architecture (SBA)



5G Railway



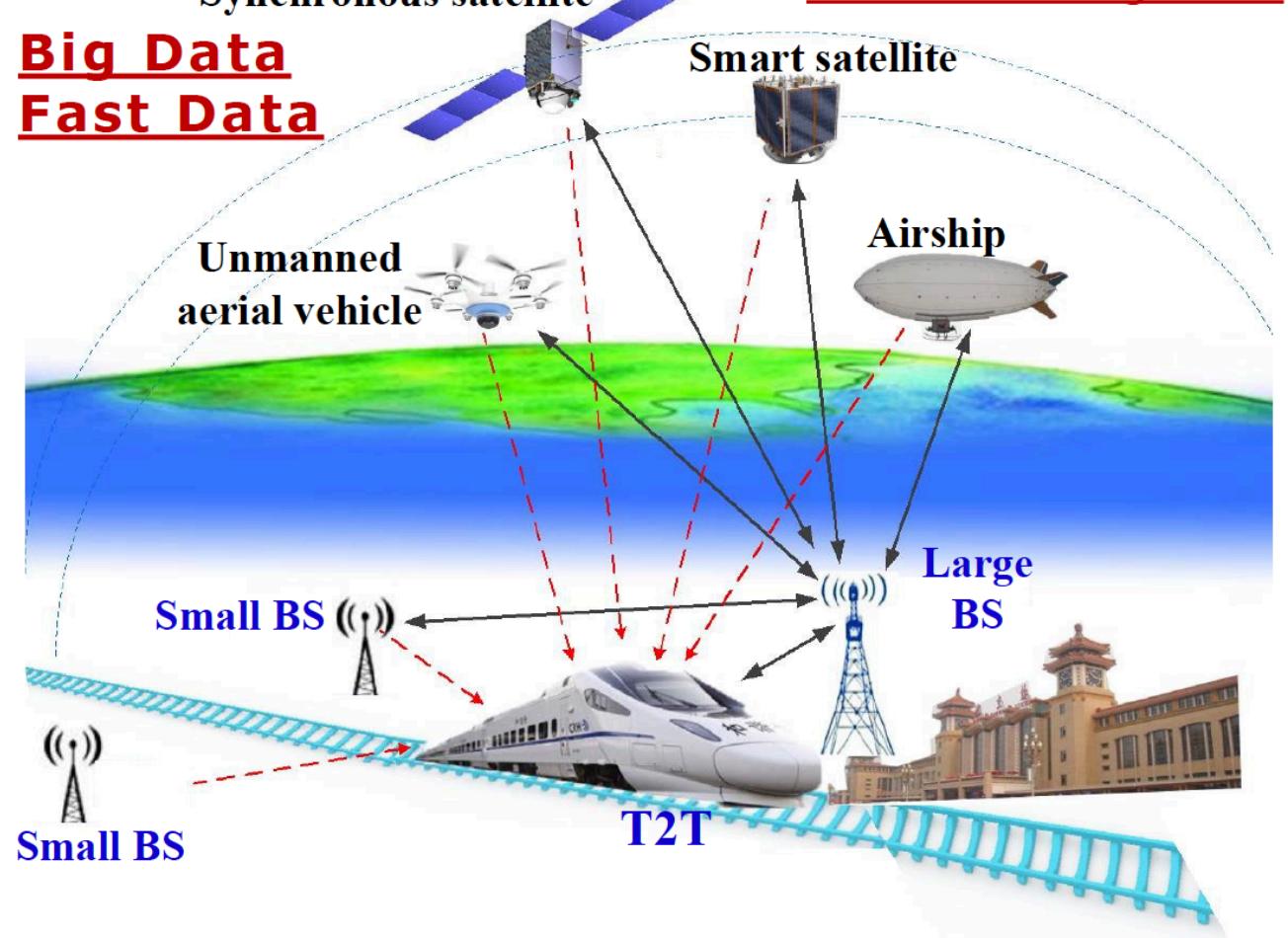
Services Category	Services Attribution	Use Case Category
Railway Safety-Critical Services	Train Control and Operation Services	Intelligent Transportation and Control System
		Onboard and Wayside HD Video Surveillance
		Distributed Emergency Communication
		Remote Monitoring and Diagnosis System
Railway Non-Safety Services	Train Comprehensive Services	Train Information Distribution System
		Customized Passenger Supplementary Business
		Train Multimedia Entertainment System
Passenger-Oriented Services	Onboard Broadband Communication	Onboard Cloud Office
		Onboard HD Multimedia Entertainment System
		Onboard Instant Messaging
		Onboard Online Game
		Social Network Services for Passengers
		Remote Medical Assistance System
		Intelligent Train Marshalling System
Internet of Things for Railways	Internet of Things for Railways	Dynamic Crew Scheduling System
		Railway Mobile Ticketing Dynamic
		Passenger Luggage Safeguarding System
		Freight Management Information System
		Intermodal Container Management System



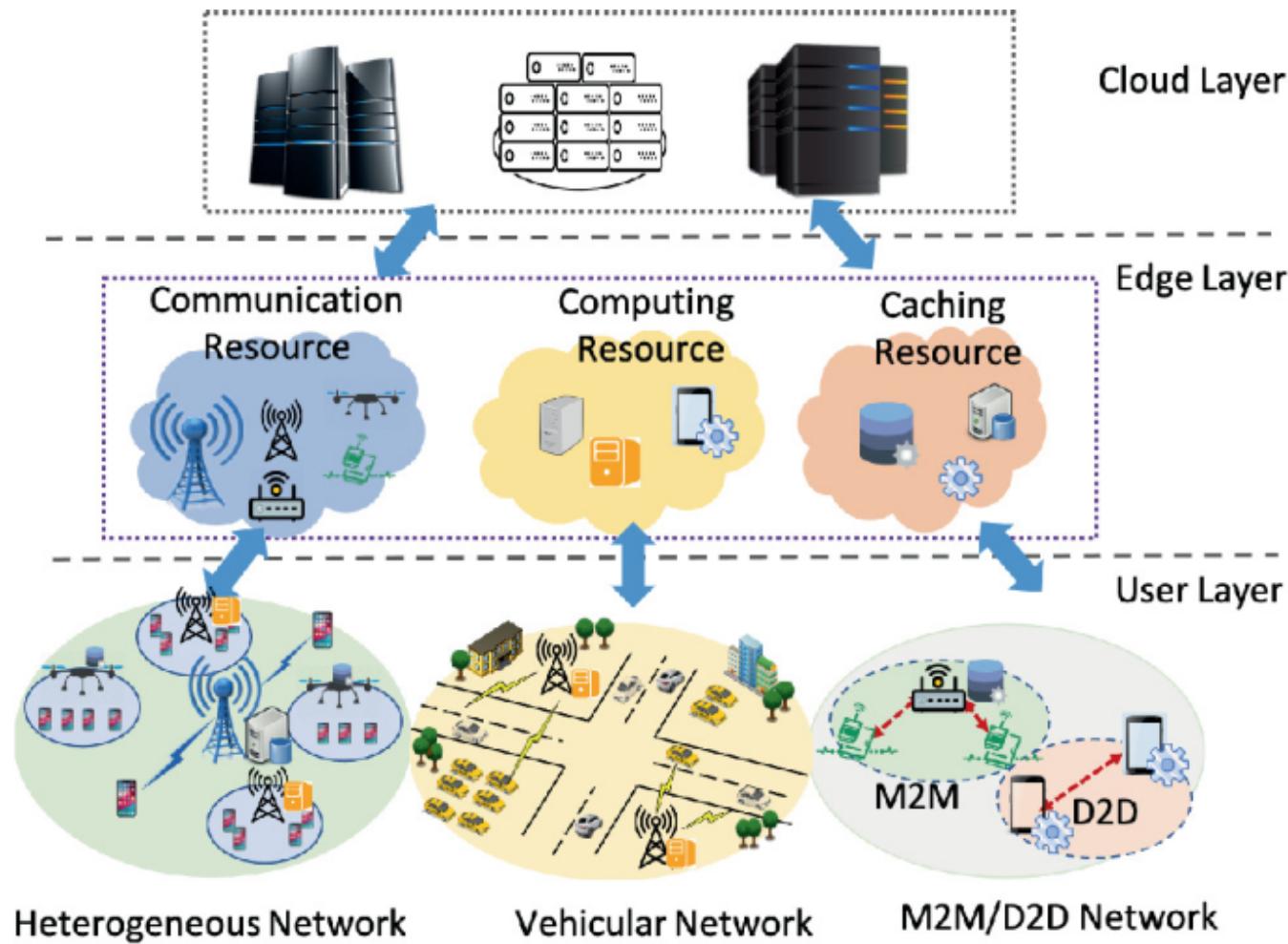
Big Data
Fast Data

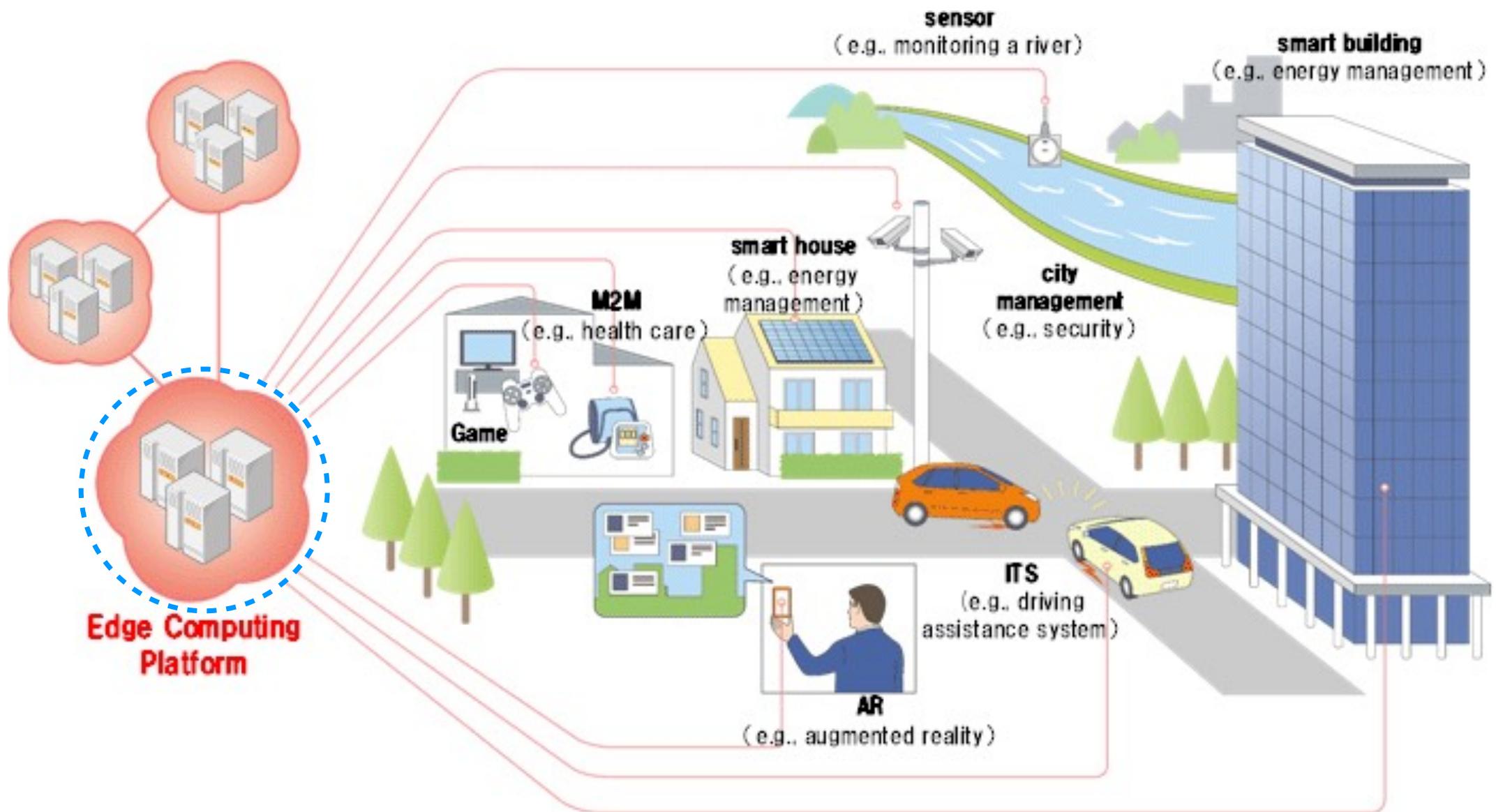
Synchronous satellite

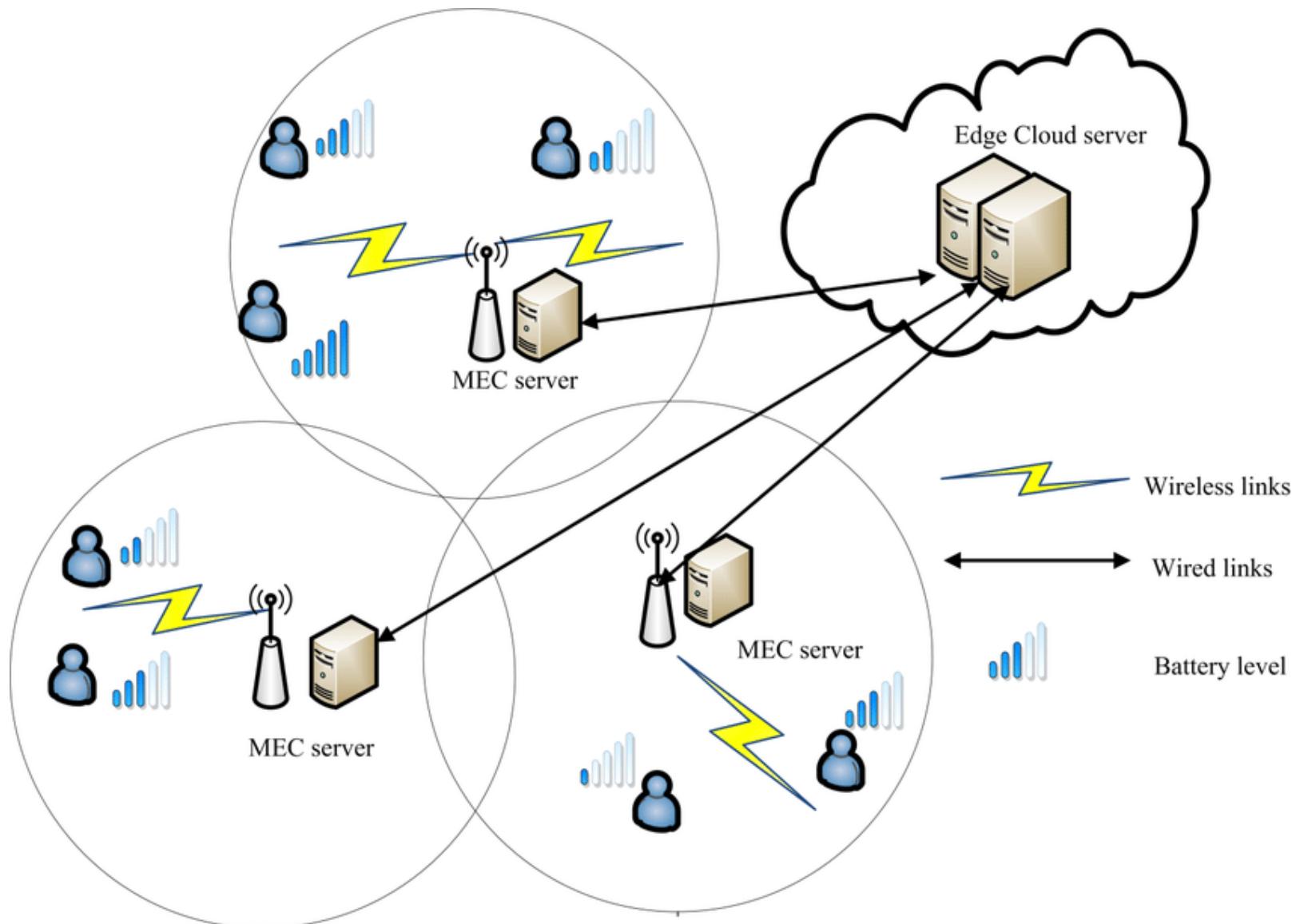
Air World Integration



Mobile Edge Computing (MEC)





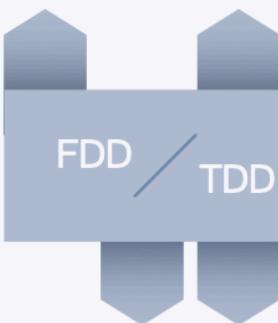


- **Release 16**
 - Radio
 - NR in unlicensed band (NR-U)
 - Industrial IOT
 - Accurate NR positioning
 - NR for Integrated Access and Backhaul (NR-IAB)

NR in Unlicensed Band (NR-U)

Anchored NR-U

Unlicensed spectrum is combined with other licensed or shared spectrum as anchor



Licensed or shared anchor spectrum



Unlicensed NR-U spectrum*

Standalone NR-U

Only unlicensed spectrum is used



Unlicensed NR-U spectrum*

NR-U Async. Vs. Synch.

Asynchronized sharing

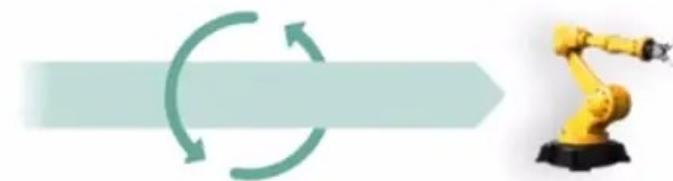
Evolutionary path: existing coexistence rules in unlicensed spectrum



Synchronized sharing

Revolutionary path: new rules for time synchronized sharing in unlicensed and shared spectrum

Time synchronization

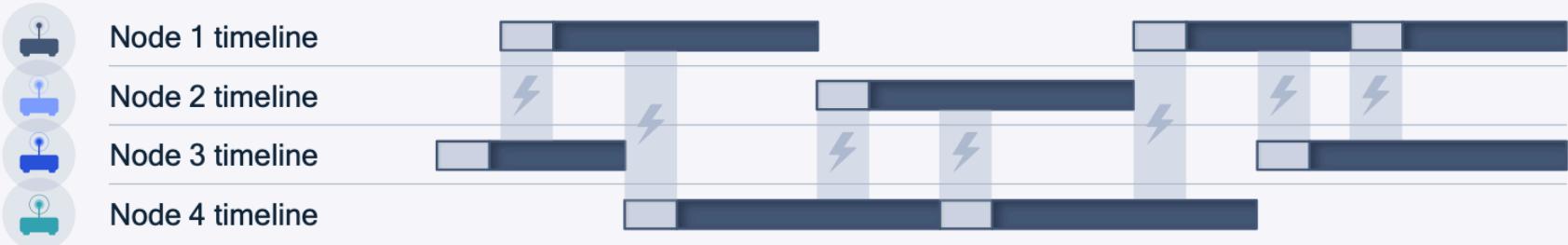


- URLLC w/ CoMP
- Predictable sharing
- Spatial sharing

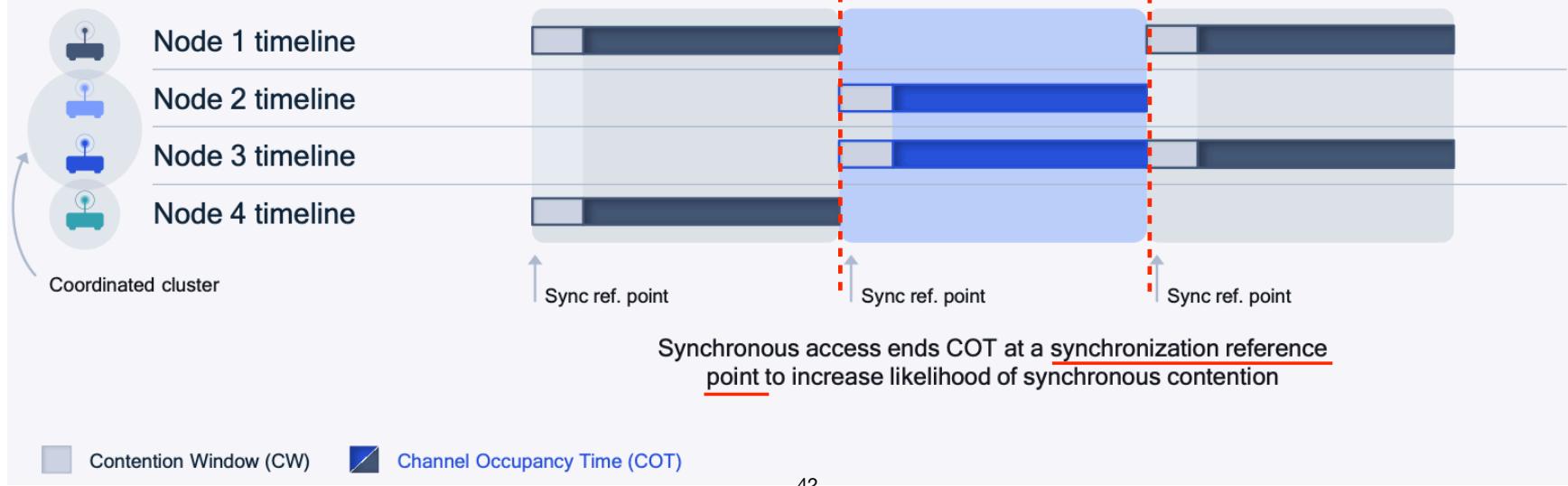
LAA : License-Assisted Access

NR-U Synchronized Sharing brings Higher Performance

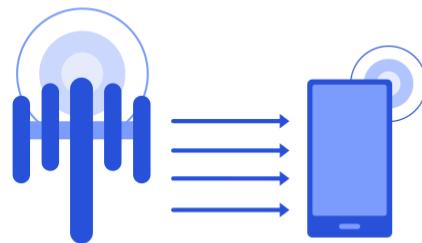
Asynchronized sharing



Synchronized sharing



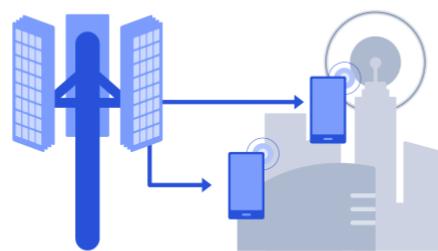
Coordinated Multi-Point (CoMP)



LTE MIMO

2 Gbps peak-rates with 4x4 MIMO¹, carrier aggregation and higher order modulation

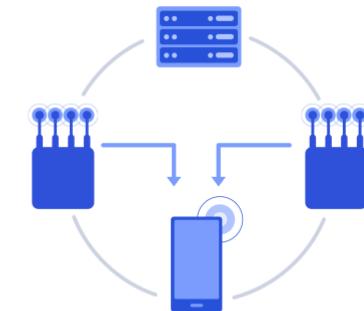
Example: 2 or 4 antennas for transmit and receive



5G Massive MIMO

Multi-user MIMO and 3D beamforming for better capacity and cell edge performance

Example: 128 or 256 antenna elements for macro deployments

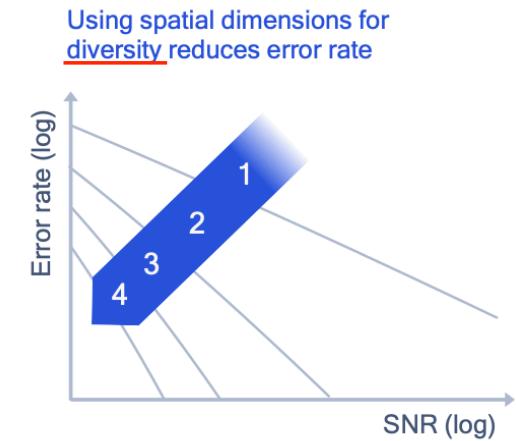
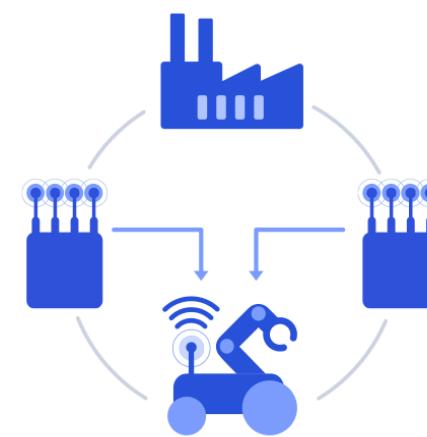
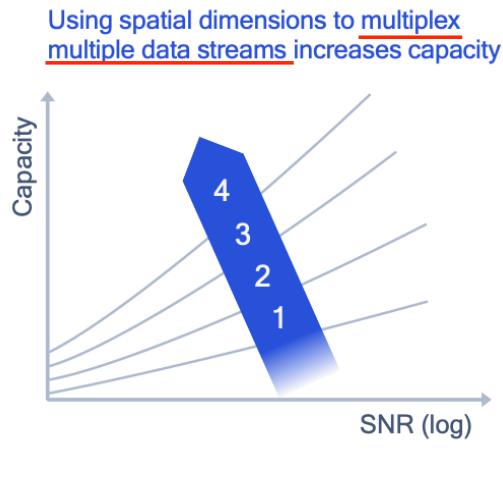
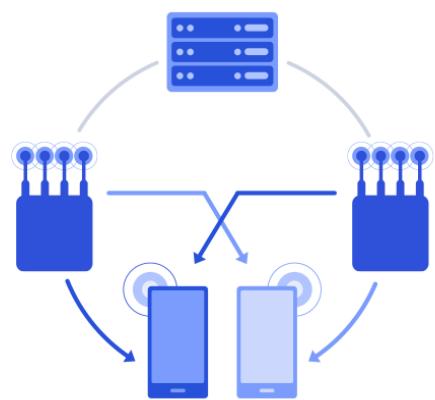


5G CoMP

Leveraging CoMP² diversity and multiplexing to extend 5G to new use cases and verticals

Example: Multiple small-cells with 4 antennas

CoMP Expands 5G: Capacity or Ultra-reliability Tradeoff



Capacity from spatial multiplexing increase capacity

Allows multiple transmissions at the same time to multiple location without interfering

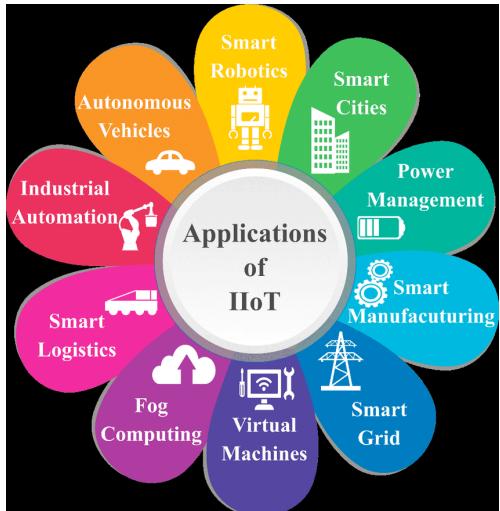
Can also be used to by multiple operators to share spectrum more efficiently

Reliability from spatial diversity reduce error rate

Spatial diversity can overcome radio shadowing in challenging radio environments

Key for URLLC to meet 99.9999% reliability and challenging industrial IoT applications

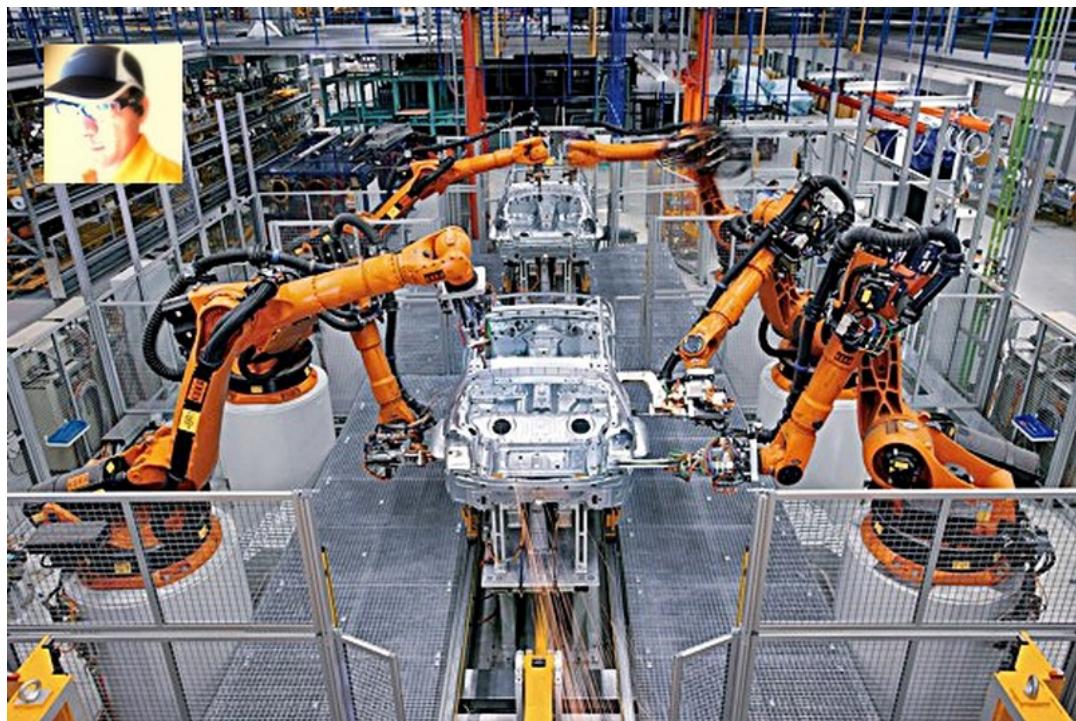
Industrial IOT



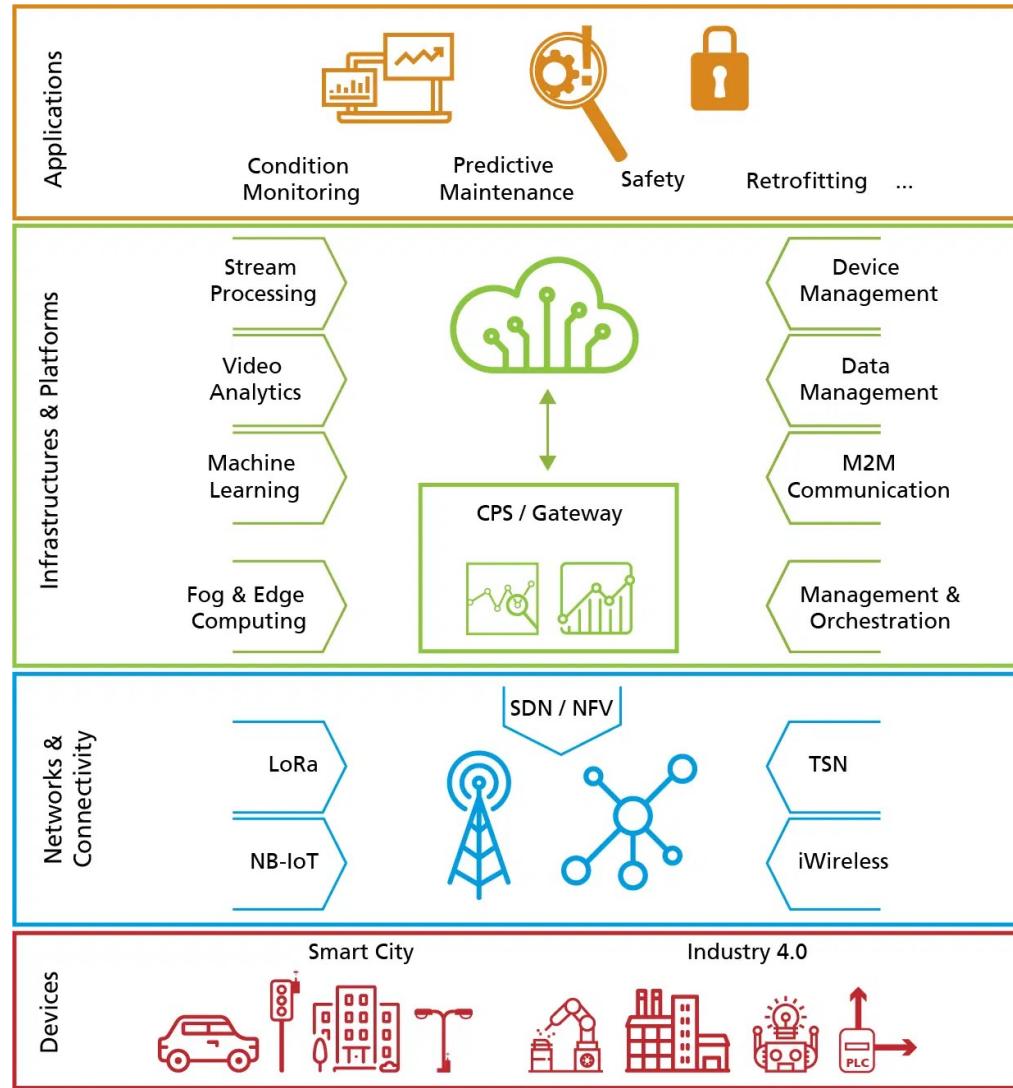
IIoT applications



IIoT is able to do ...



IIoT Techs and Apps for Industry 4.0 and Smart Cities

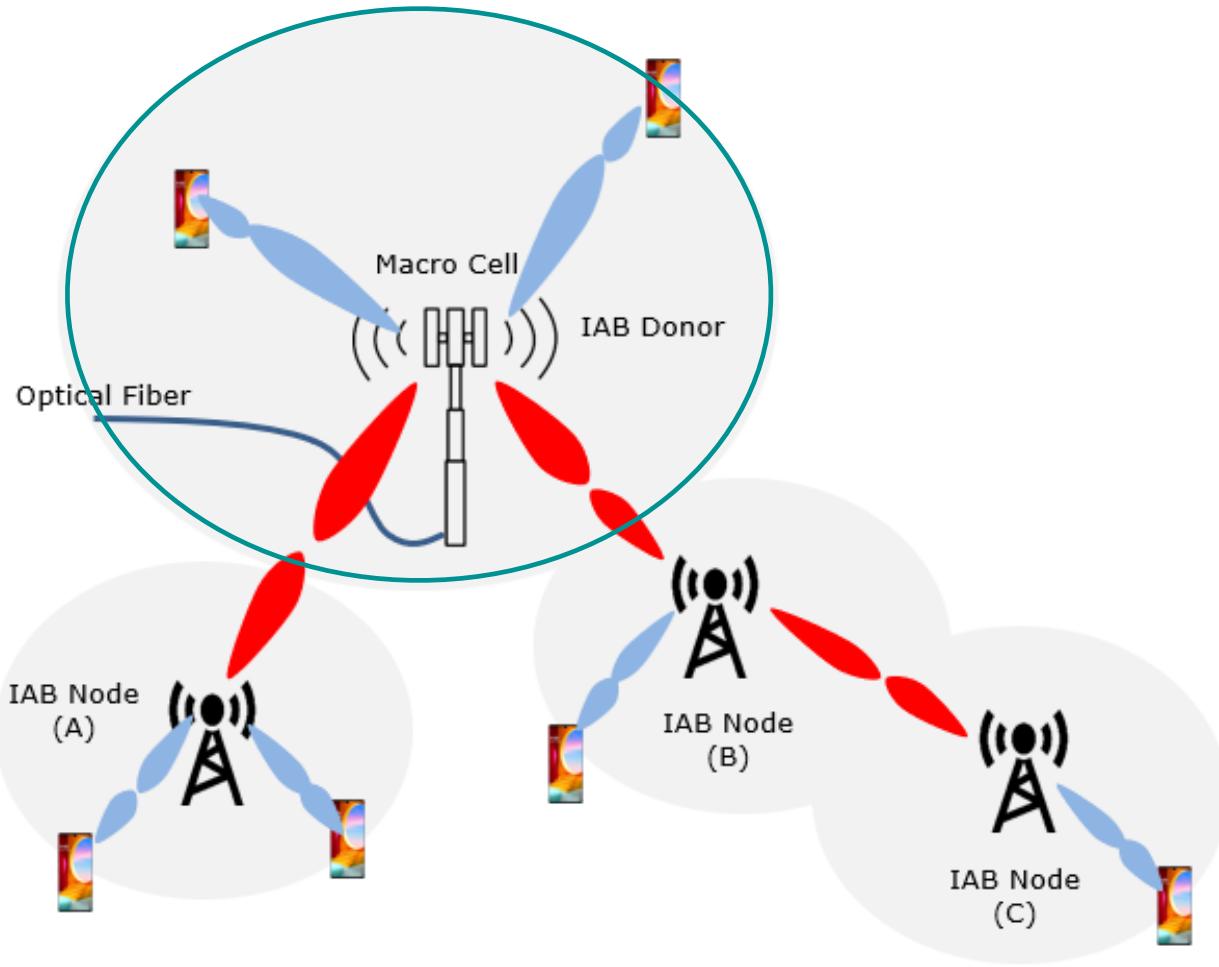


CPS : Cyber-Physical Systems

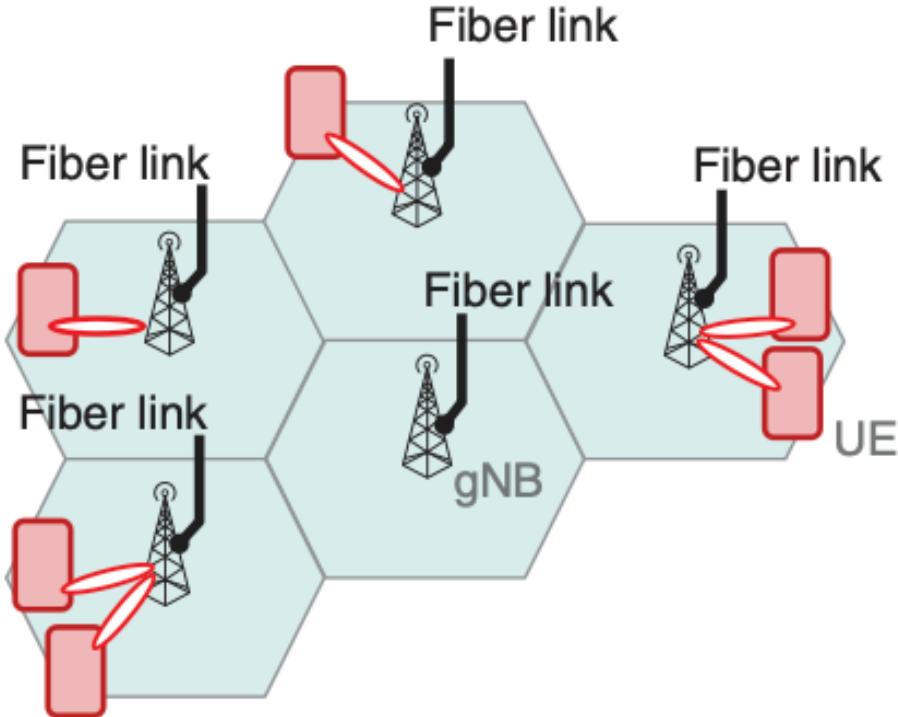
LoRa : Long Range

TSN : Time Sensitive Network

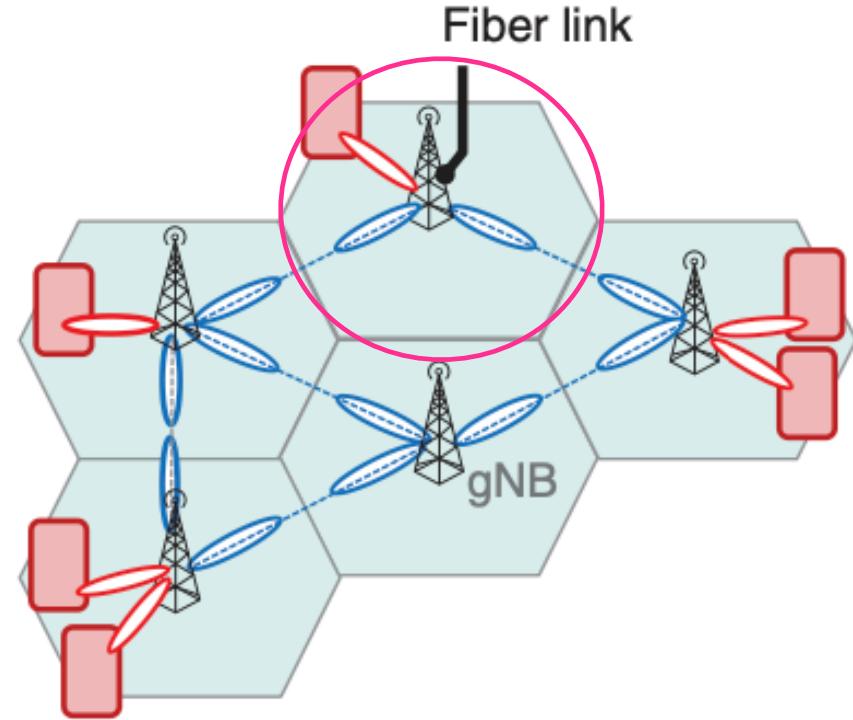
NR-IAB



NR-IAB : NR for Integrated Access and Backhaul



Without IAB: Separate fiber link needed
for each cell

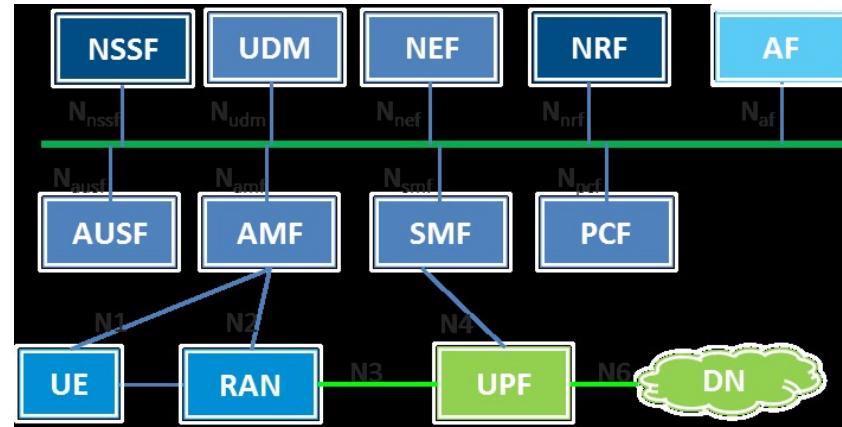


With IAB: One fiber link shared among
multiple cells

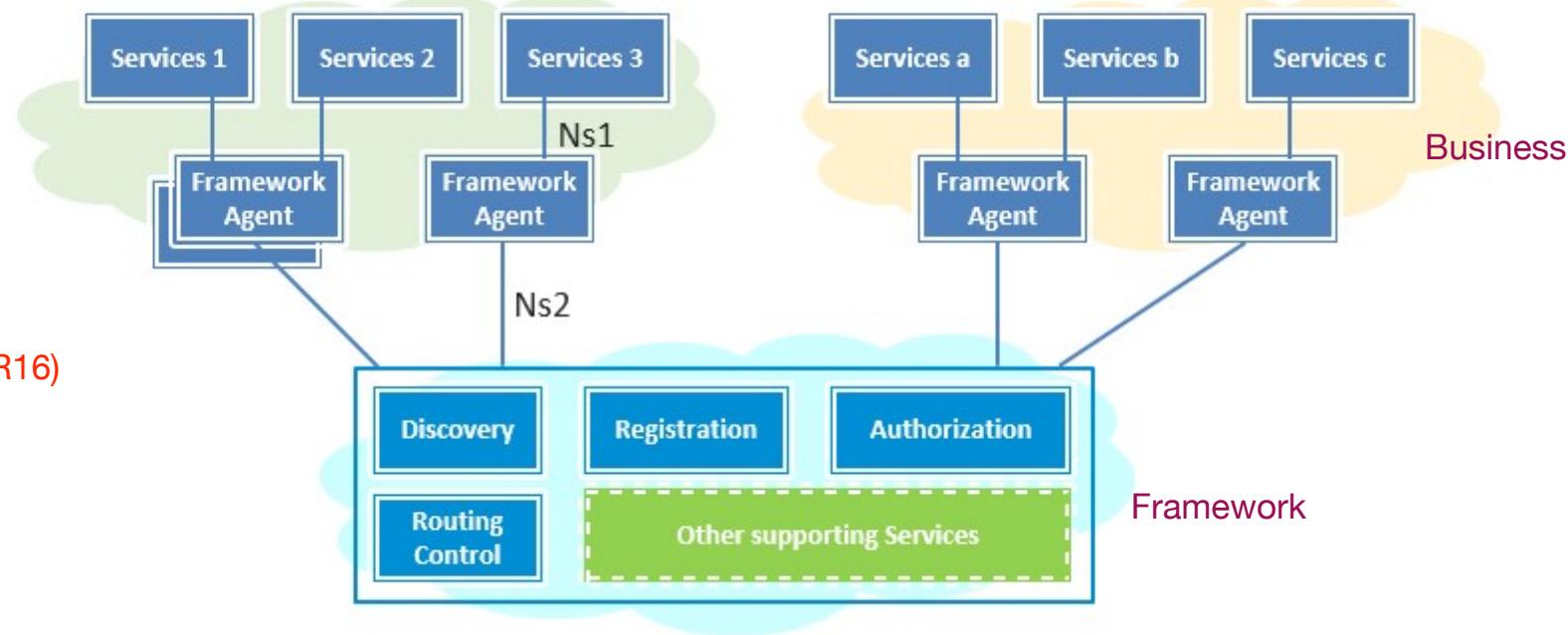
- 5G Core
 - Enhanced SBA (eSBA)
 - Private networks
 - Wireless/Wireline (Cable/BNG) convergence + access steering
 - Time Sensitive Network (TSN)
 - Cellular IoT (NB-IOT, CatM)
 - Slice management
 - Network analytics

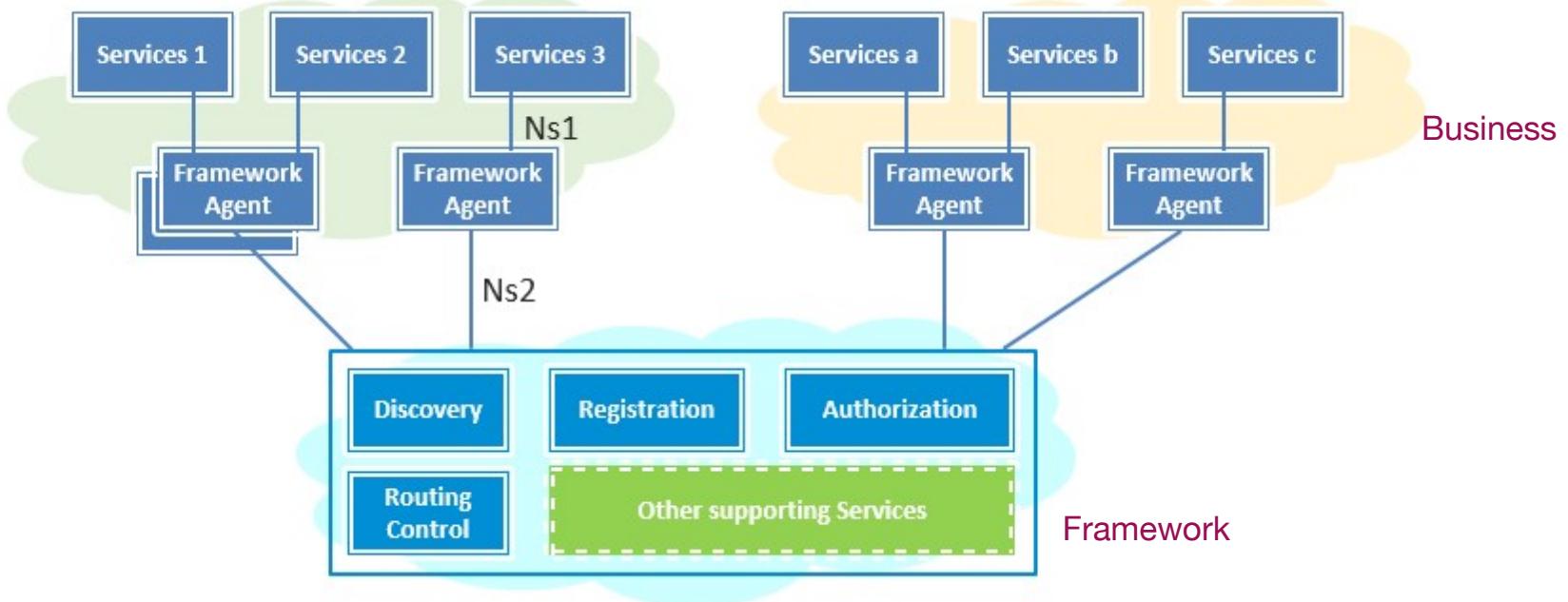
Enhanced SBA (eSBA)

3GPP SBA (R15)



3GPP eSBA (R16)





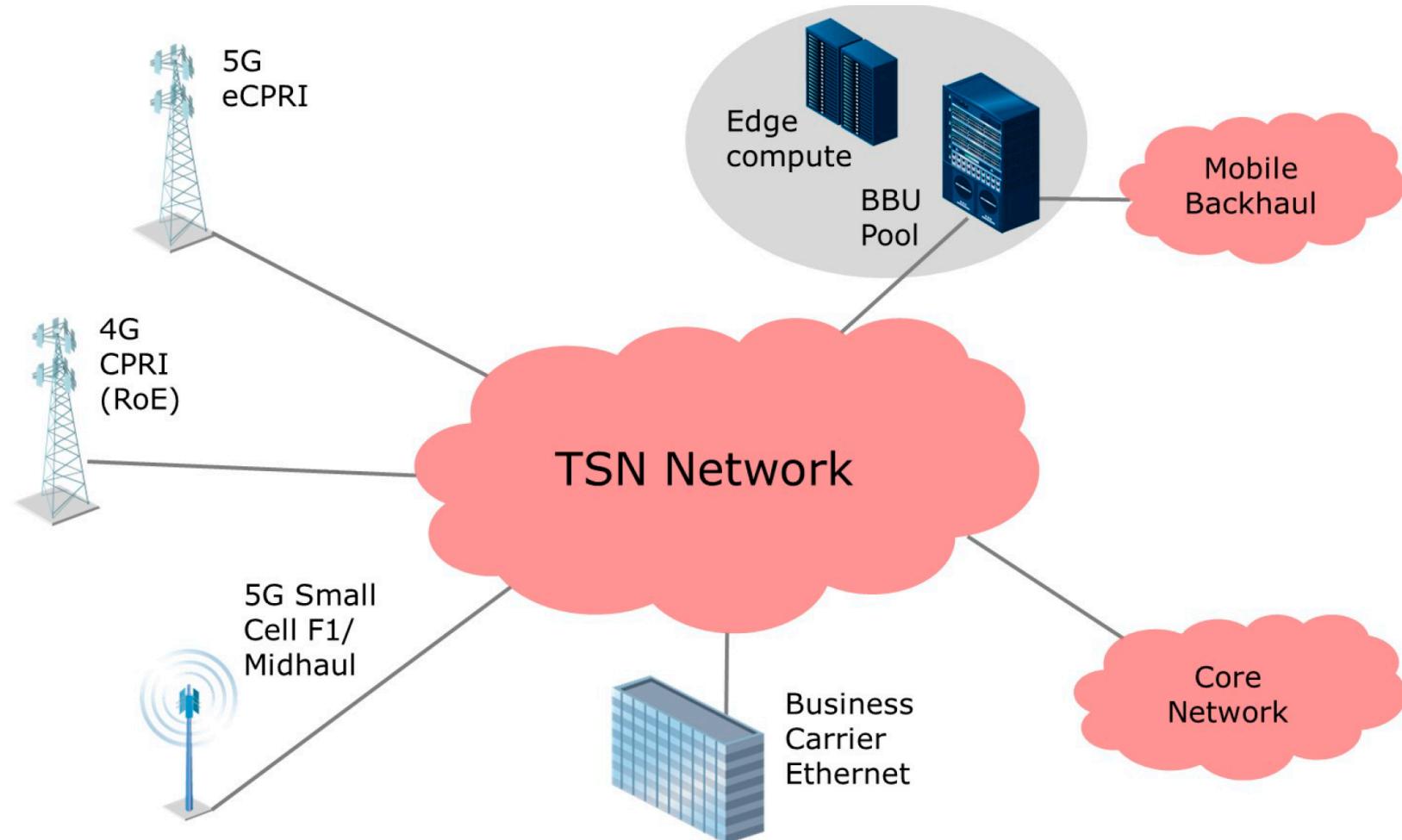
- The **business** (business logic) and **framework** (framework proxies) are decoupled
- The framework performs function reconstruction
 - Basic functions: service discovery, registration, authentication, and routing control
 - Serve all businesses through the framework proxies

Time Sensitive Network (TSN)

CPRI : Common Public Radio Interface

RoE : Radio over Ethernet

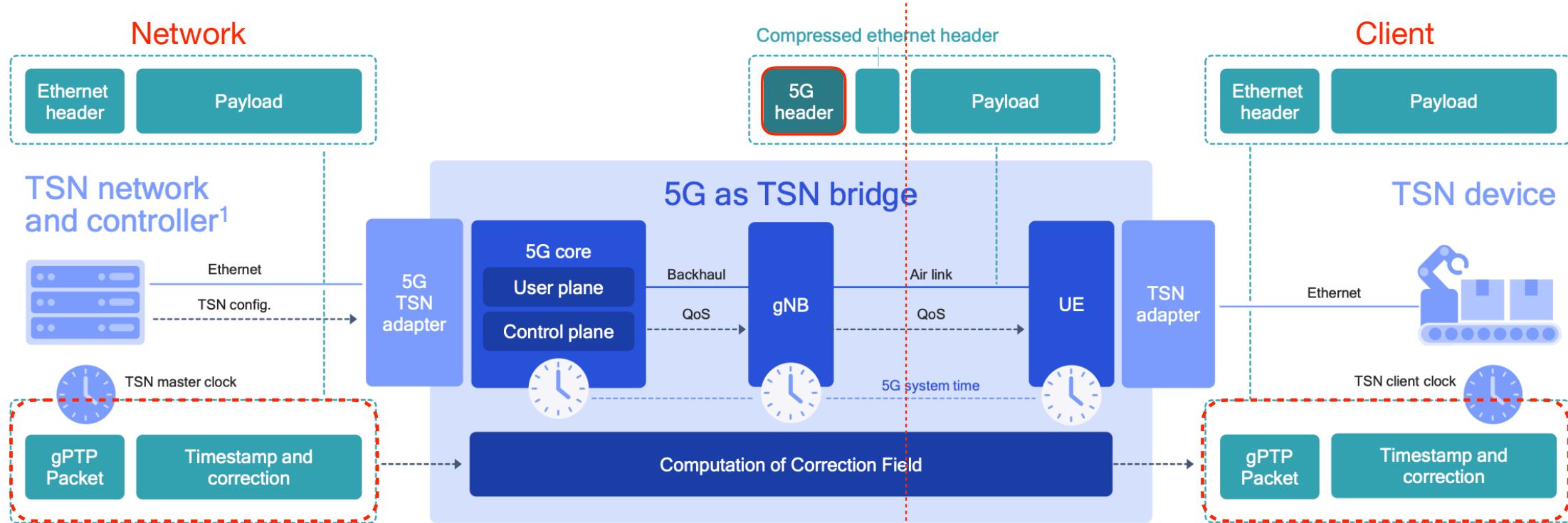
eCPRI : evolved Common Public Radio Interface



- **Time-Sensitive Networking (TSN)**

- Define mechanisms for the time-sensitive transmission of data over deterministic Ethernet networks
- Three basic components
 - **Time synchronization:** all devices that are participating in real-time communication need to have a common understanding of time
 - **Scheduling and traffic shaping:** all devices that are participating in real-time communication adhere to the same rules in processing and forwarding communication packets
 - **Selection of communication paths, path reservations and fault-tolerance:** all devices that are participating in real-time communication adhere to the same rules in selecting communication paths and in reserving bandwidth and time slots, possibly utilizing more than one simultaneous path to achieve fault-tolerance

5G supports TSN



gPTP : general Precise Time Protocol

Cellular IoT (NB-IOT, CatM)

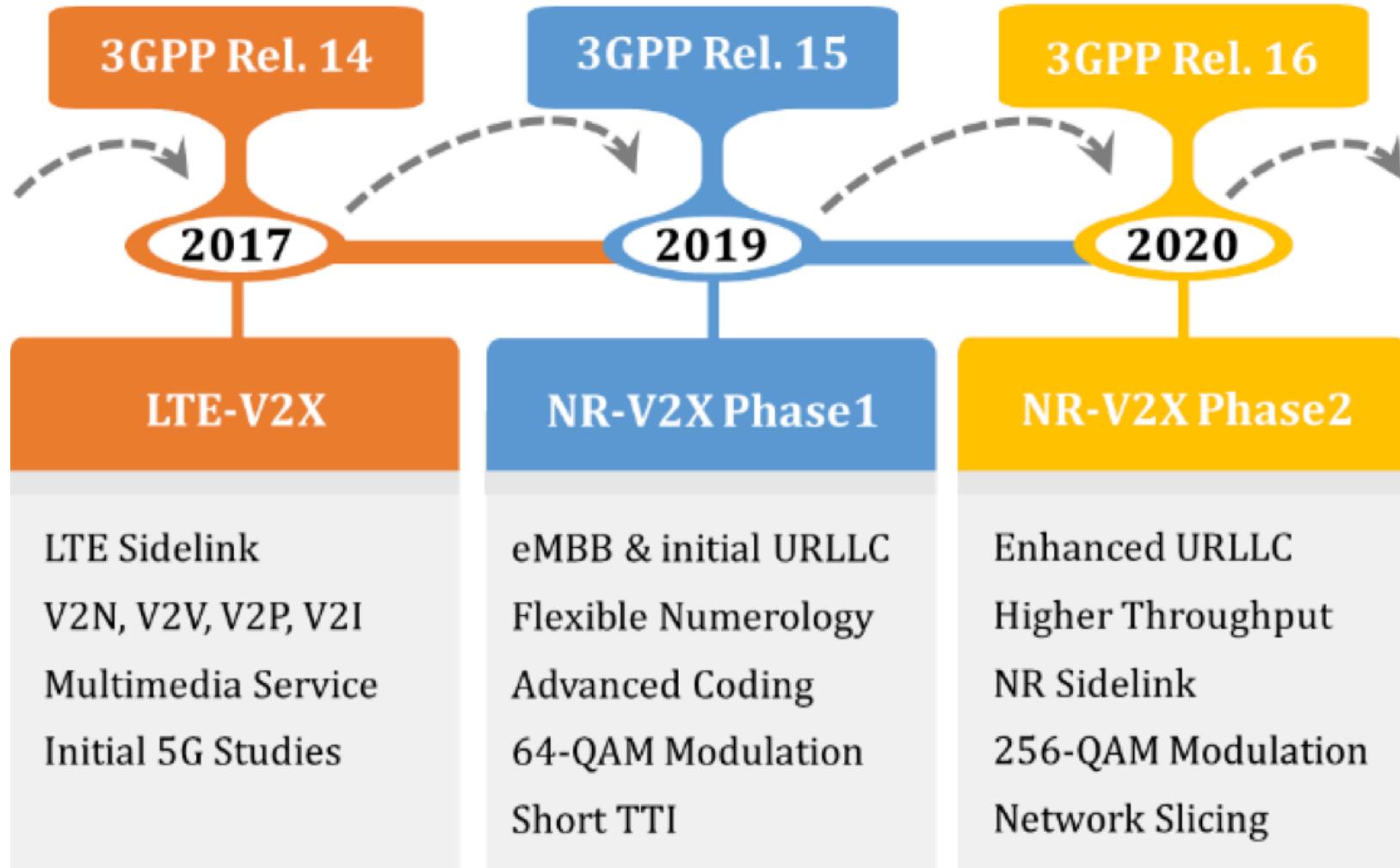
FeNB-IoT : Further Enhancement NB-IoT

NB-IoTEnh3 (NB-IoTEnh4) : Additional enhancements for NB-IoT

Release 13 NB-IoT	Release 14 eNB-IoT	Release 15 FeNB-IoT	Release 16 NB-IoTEnh3	Release 17 NB-IoTEnh4
Cat NB-1	Cat NB-2	Mixed Mode Multicarrier	Co-Existence with New Radio (NR)	Increase of Data Rates
Standalone/Guard band/In-Band	Enhance TBS/ Dual HARQ	SR Report	Connection to 5G Core	64 QAM Carrier Aggregation
Coverage Extension	Release Assistance Indicator	Wake Up Signal	Improve Multi carrier Operation	Power Enhancements
UL3.75 kHz and 15 kHz	Reconnection with RLF	Early Data Transmission	Mobile-Terminated (MT) Early Data Transmission	
Single Tone/Multi Tone	Positioning	New PRACH format	Enhance of SPS	
CP/UP	Measurement Report	Small Cell Support	Inter RAT-Cell Selection	
Multi-Carrier	Non-Anchor Carrier	TDD Support	UE group Wake up Signal	
PSM (Power Save Mode)	Single Cell Multicast	Reduced System Acquisition Time	SON	
eDRX	Maximum Tx Power 14dBm	UE Differentiation		

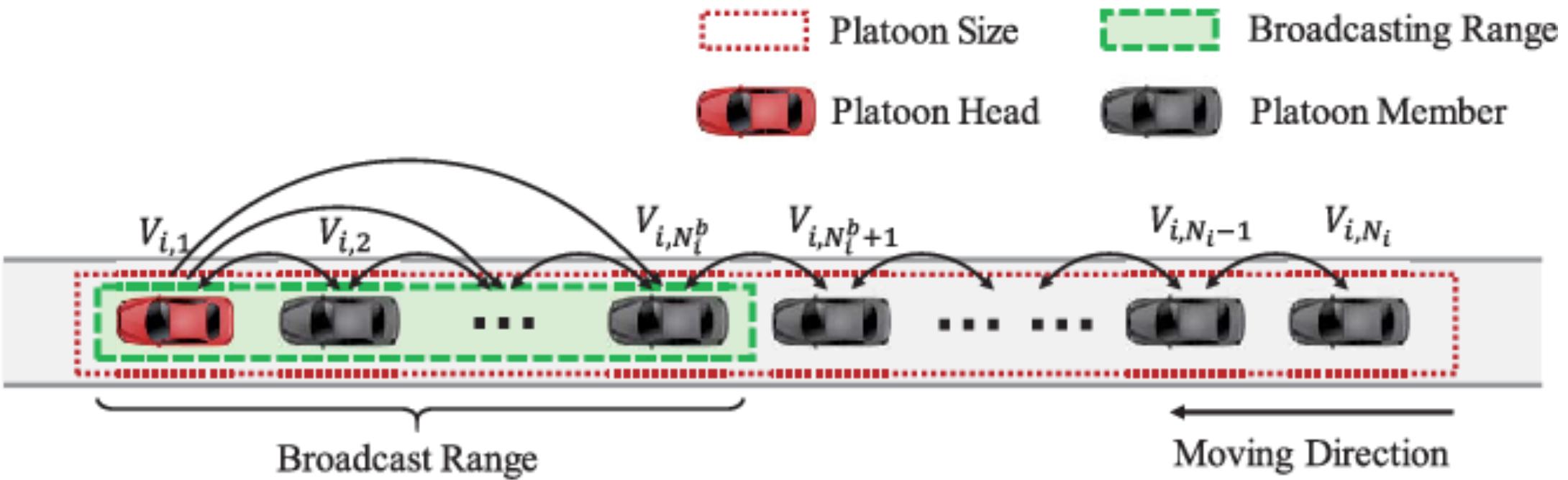
- V2X phase 3: platooning extended sensors, automated driving, remote driving
- URLLC enhancements (eURLLC)

V2X Phases

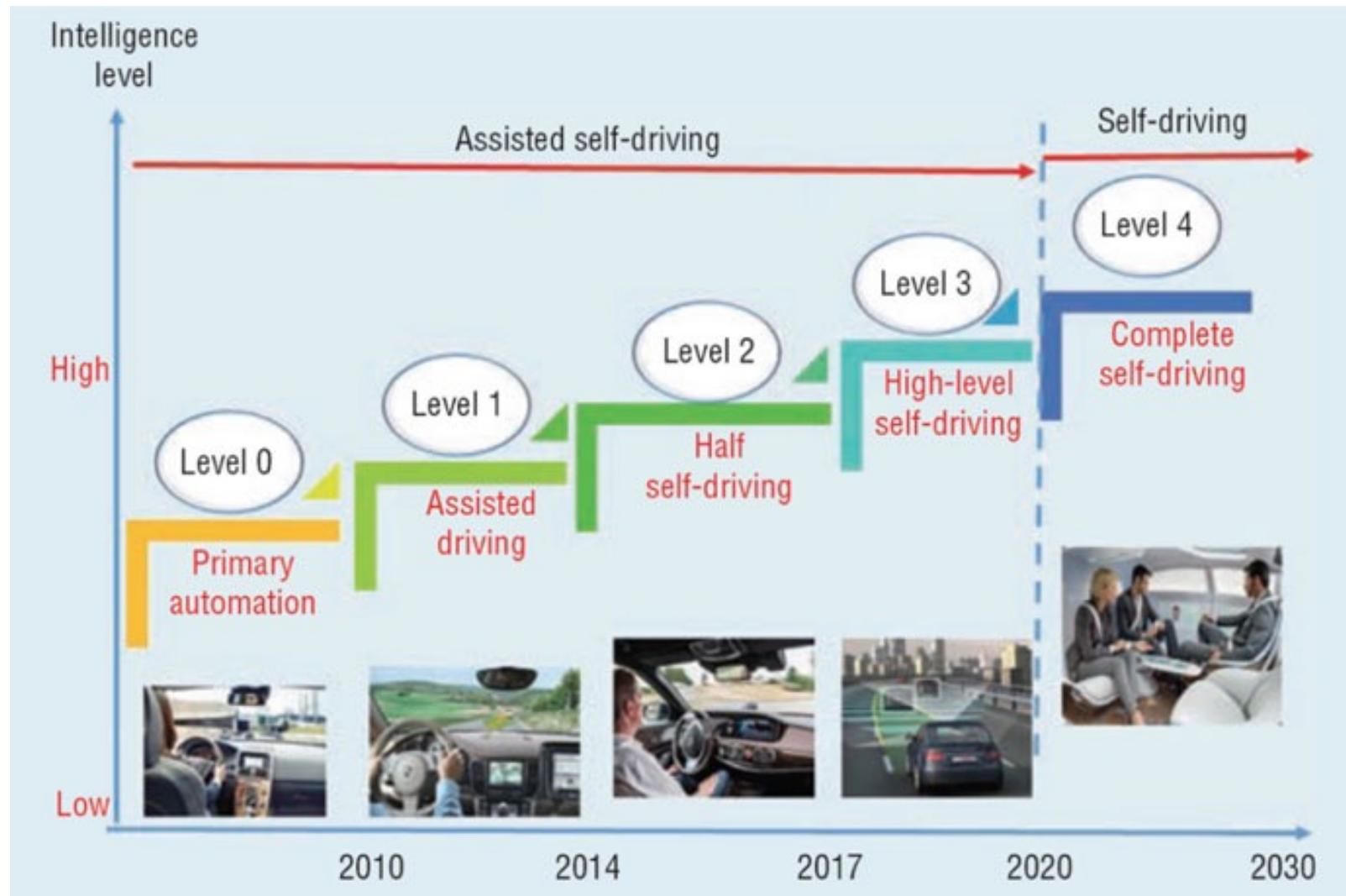


V2X Phase 3: Platooning Extended Sensors, Automated Driving, Remote Driving

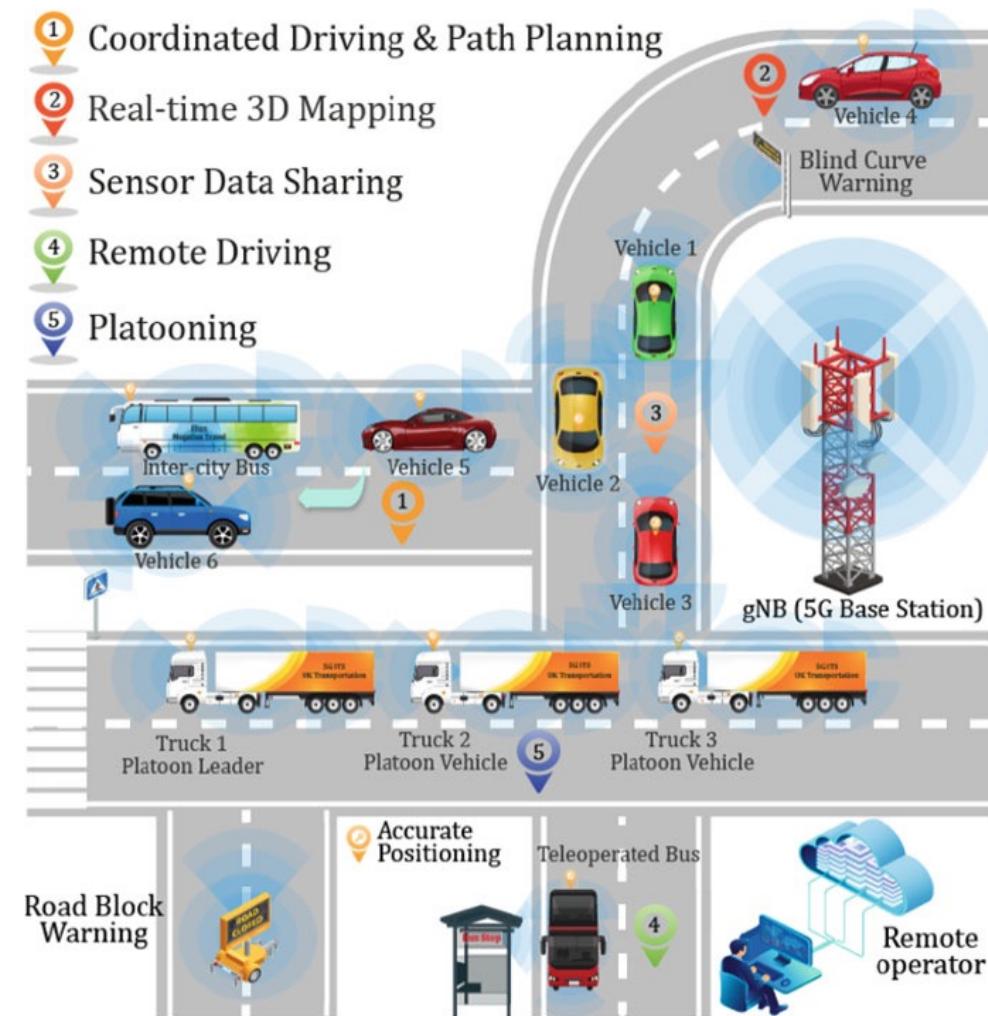




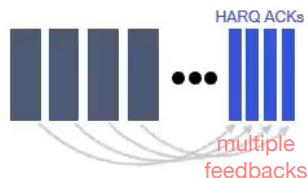
Evolutionary Roadmap of Autonomous Driving



Advanced Use Cases and Services Envisioned in 5G-V2X

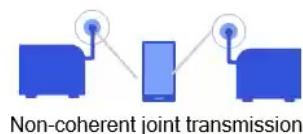


eURLLC



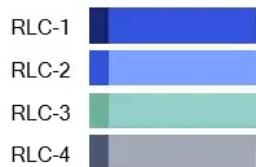
Improved HARQ

Multiple HARQ-ACK feedbacks per slot for latency reduction



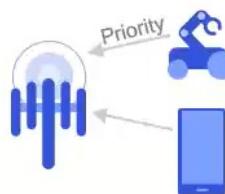
Coordinated multi-point (CoMP)

Multi-TRP¹ for redundant communication paths with spatial diversity



Increased redundancy

Number of PDCP² packet duplicates increasing to 4 from 2



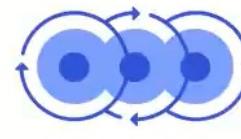
Inter-device service multiplexing

Uplink cancellation indicator and power boosting



Intra-device channel prioritization

Concurrently supporting differentiated levels of service (e.g., eMBB & mission-critical)



More flexible scheduling

Multiple active SPS³ configurations & reduced periodicity, more efficient DL control monitoring, UL repetition with cross-slot boundaries

HARQ : Hybrid Automatic Repeat Request

Multi-TRP : Multiple Transmission and Reception Point

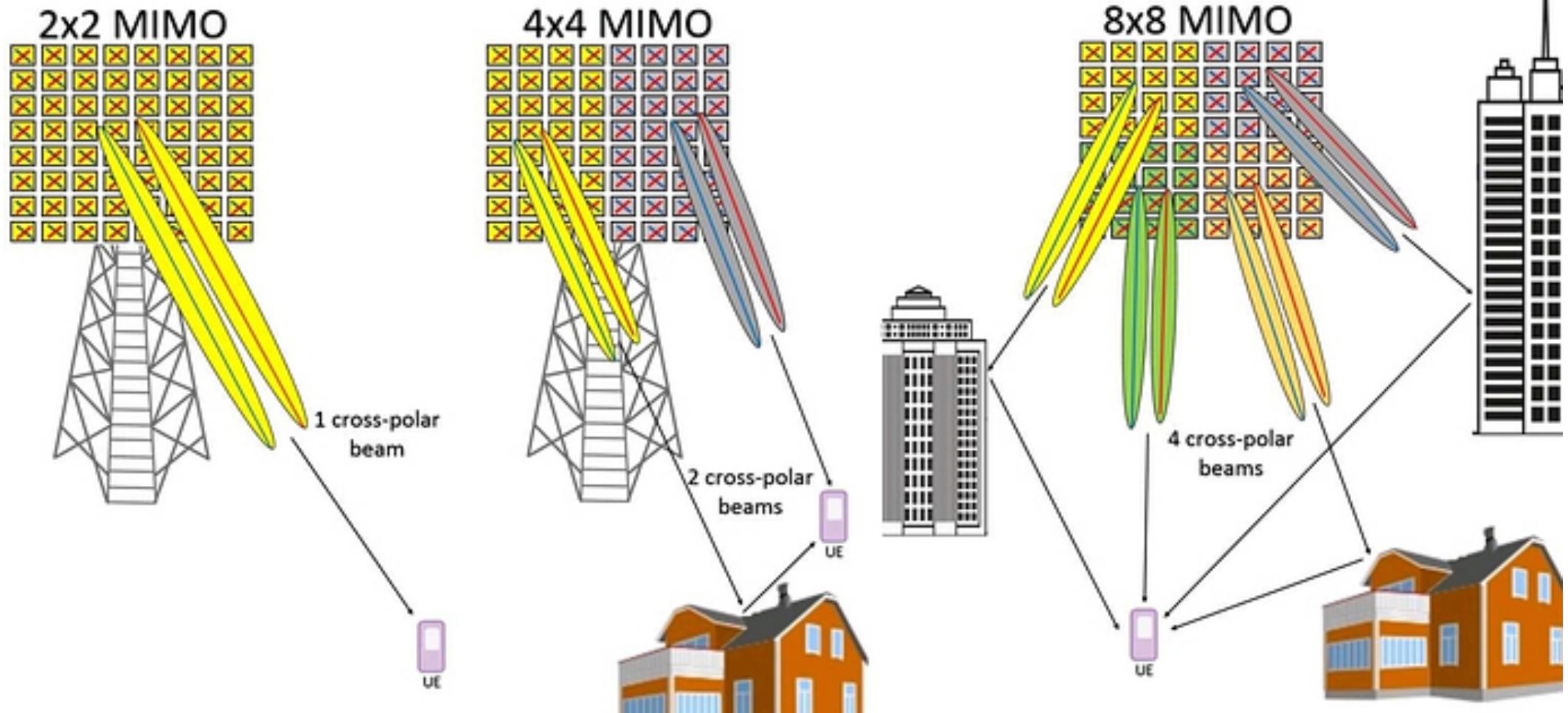
PDCP : Packet Data Convergence Protocol

RLC : Radio Link Control

SPS : Semi-Persistent Scheduling

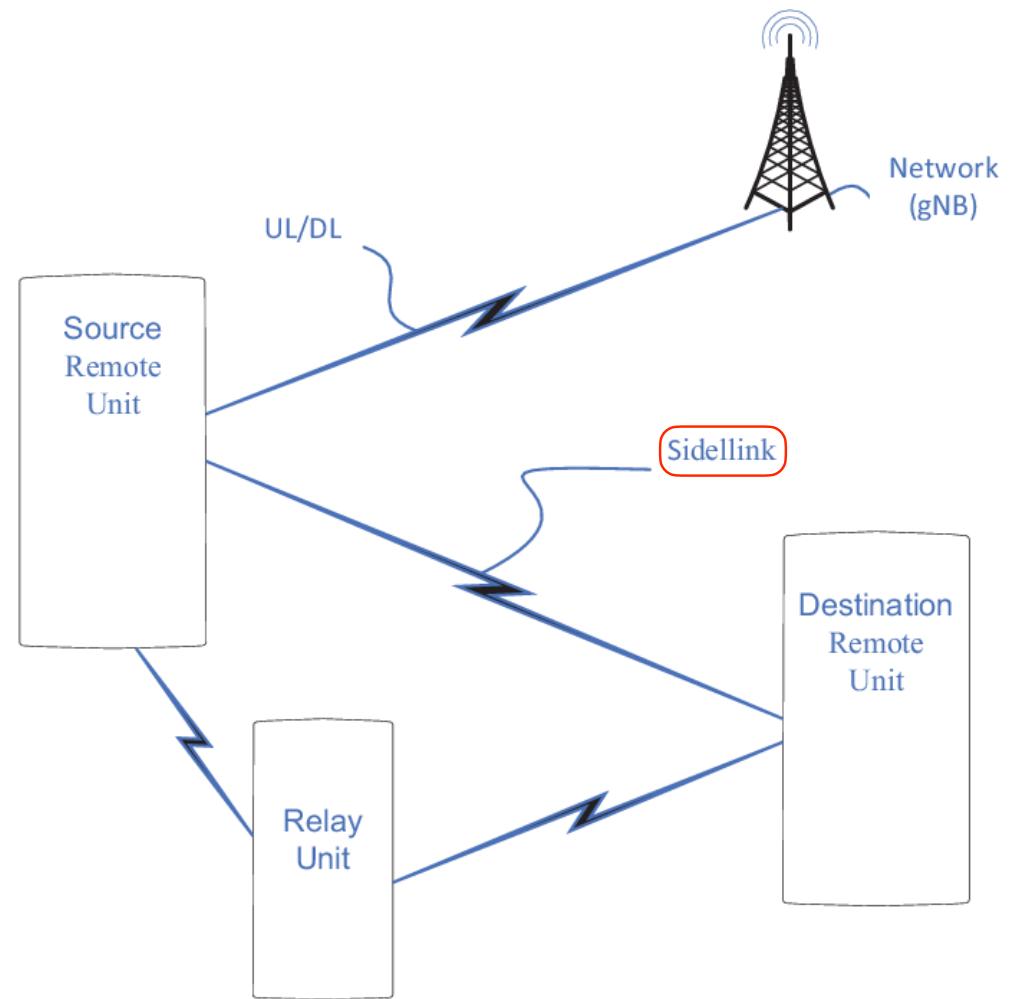
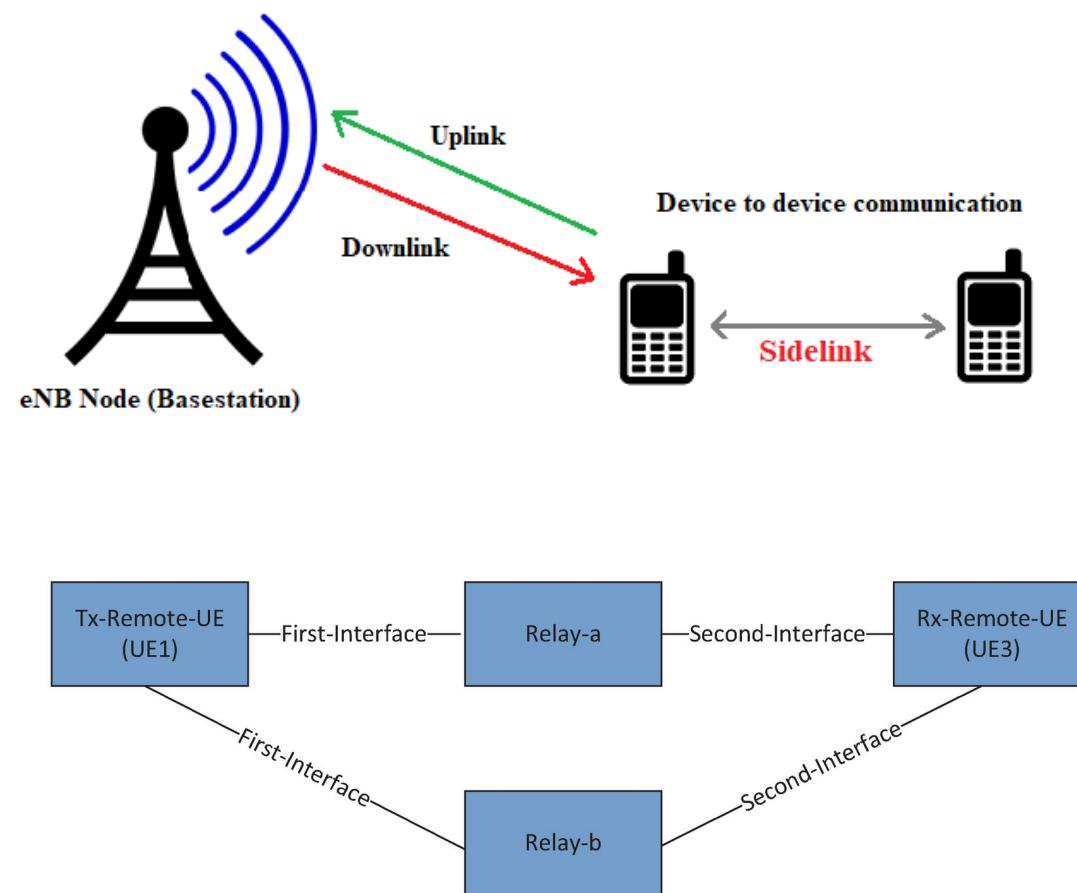
- Release 17
 - NR MIMO
 - NR sidelink enhancement
 - 52.6 - 71 GHz with existing waveform
 - Dynamic Spectrum Sharing (DSS) enh. Industrial IoT / URLLC enh.
 - Study - IoT over Non-Terrestrial Networks (NTN)
 - NR over Non-Terrestrial Networks (NTN)
 - NR positioning enh.
 - Low complexity NR devices power saving

NR MIMO

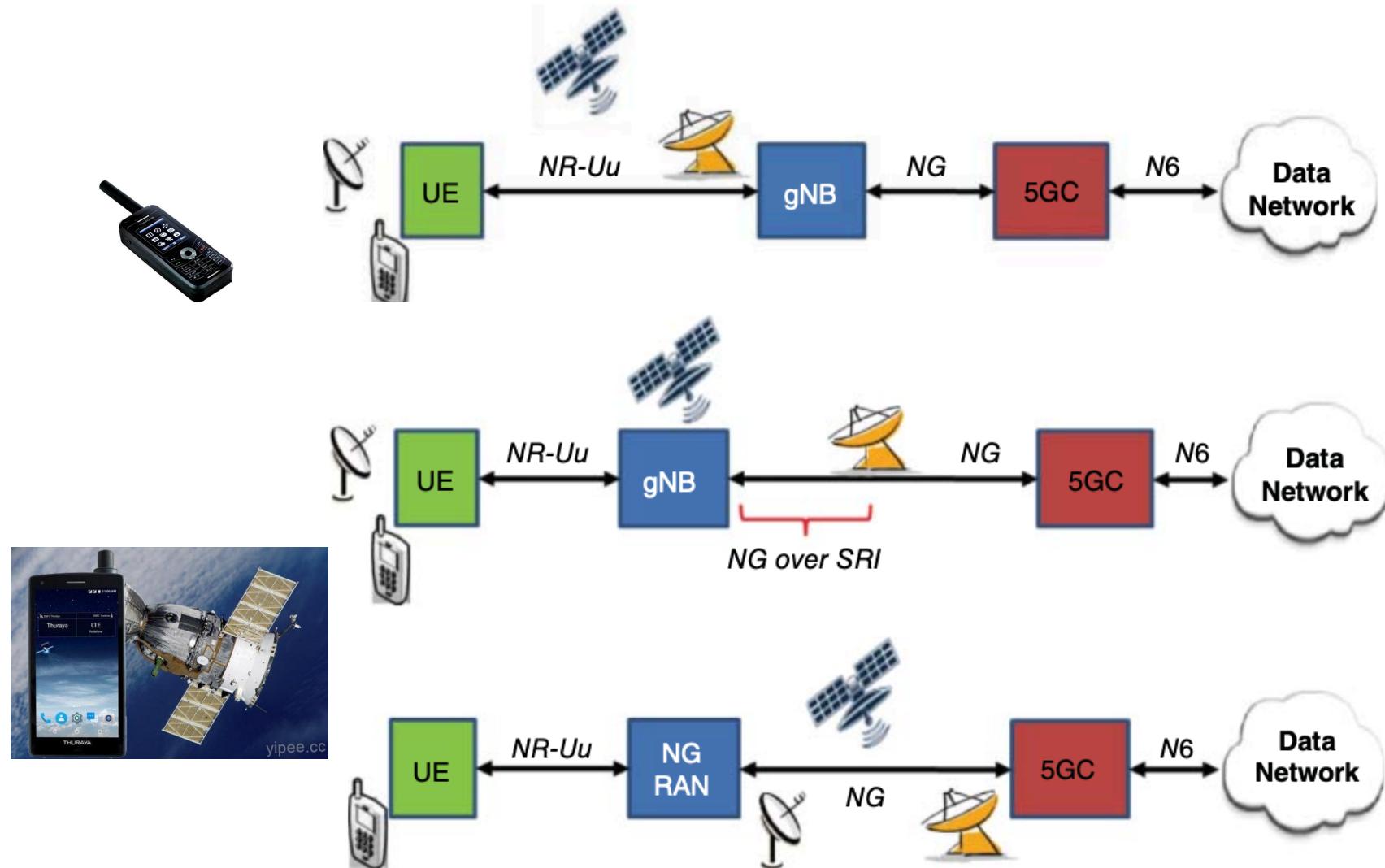


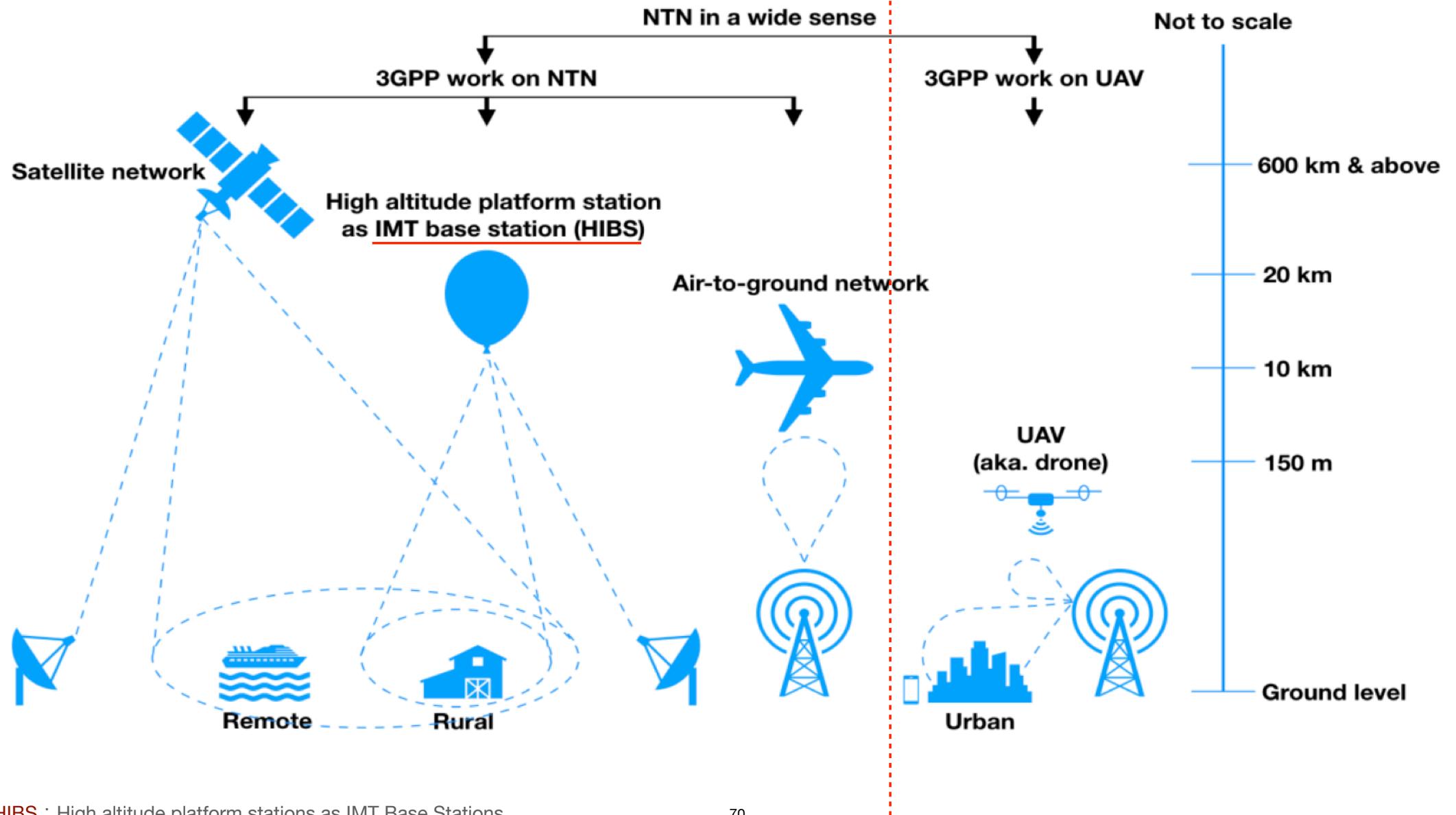
- **NR MIMO features**
 - High-resolution CSI for efficient MU-MIMO operation
 - Beam management for enabling mmWave communications
 - Support for multi-TRP (Multiple Transmission and Reception Point) transmissions
 - Enabling energy-efficient transmission and reliable channel measurement
 - Enabling new use cases and commercial deployment scenarios such as lower and higher frequency bands, non-terrestrial networks, and industrial Internet of Things (IIoT)
 - Extension of beam management for enhancing inter-cell user mobility

NR Sidelink Enhancement

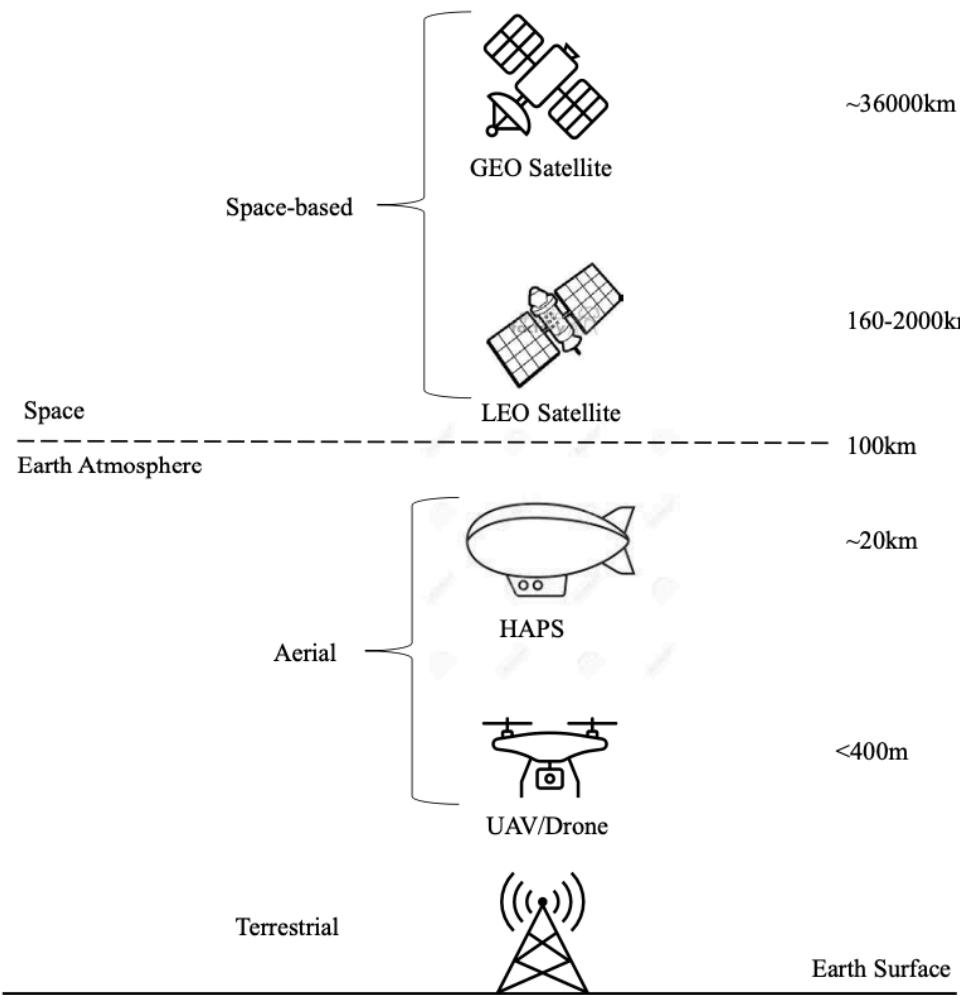


NR over Non-Terrestrial Networks (NTN)

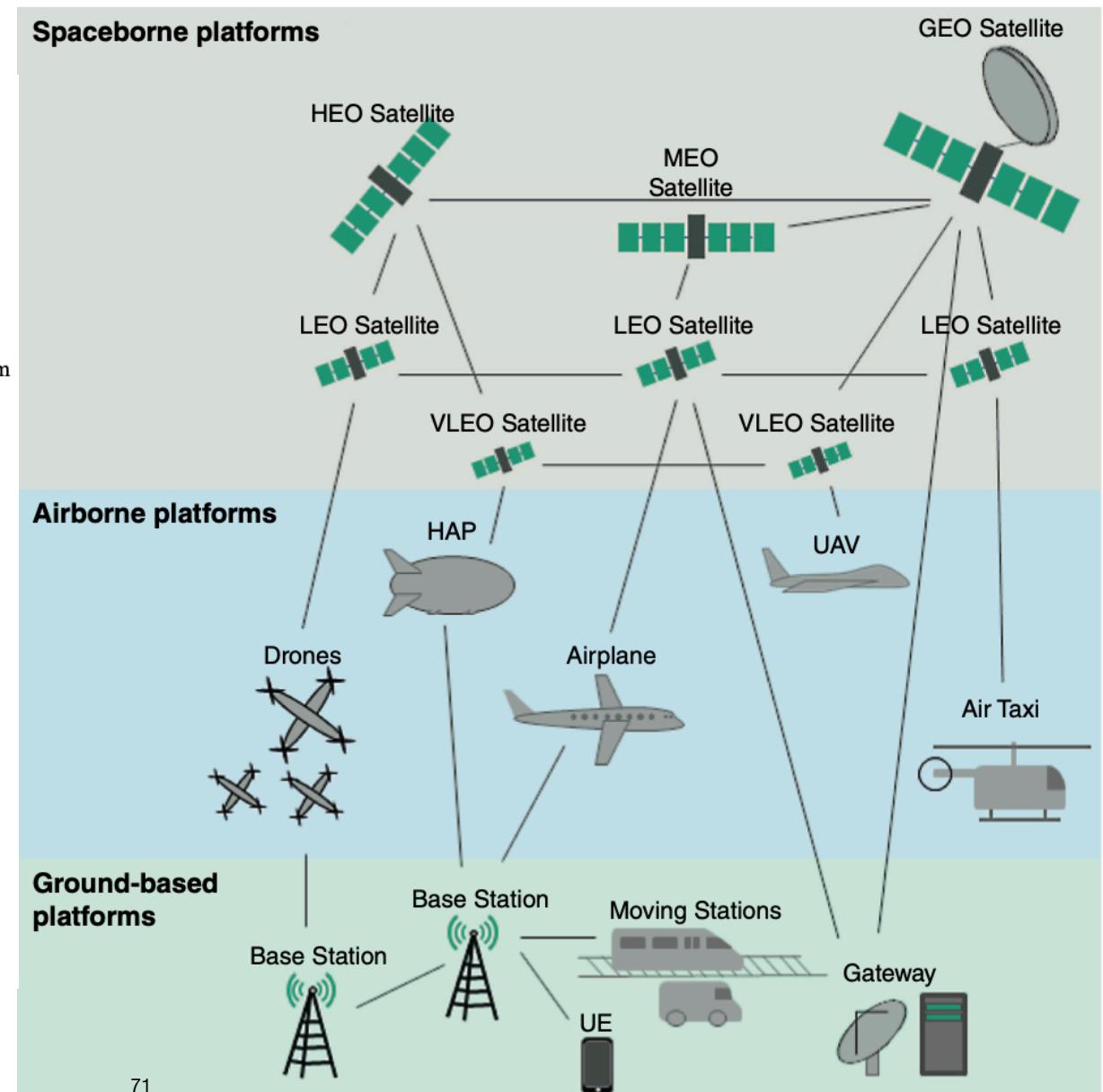




HIBS : High altitude platform stations as IMT Base Stations



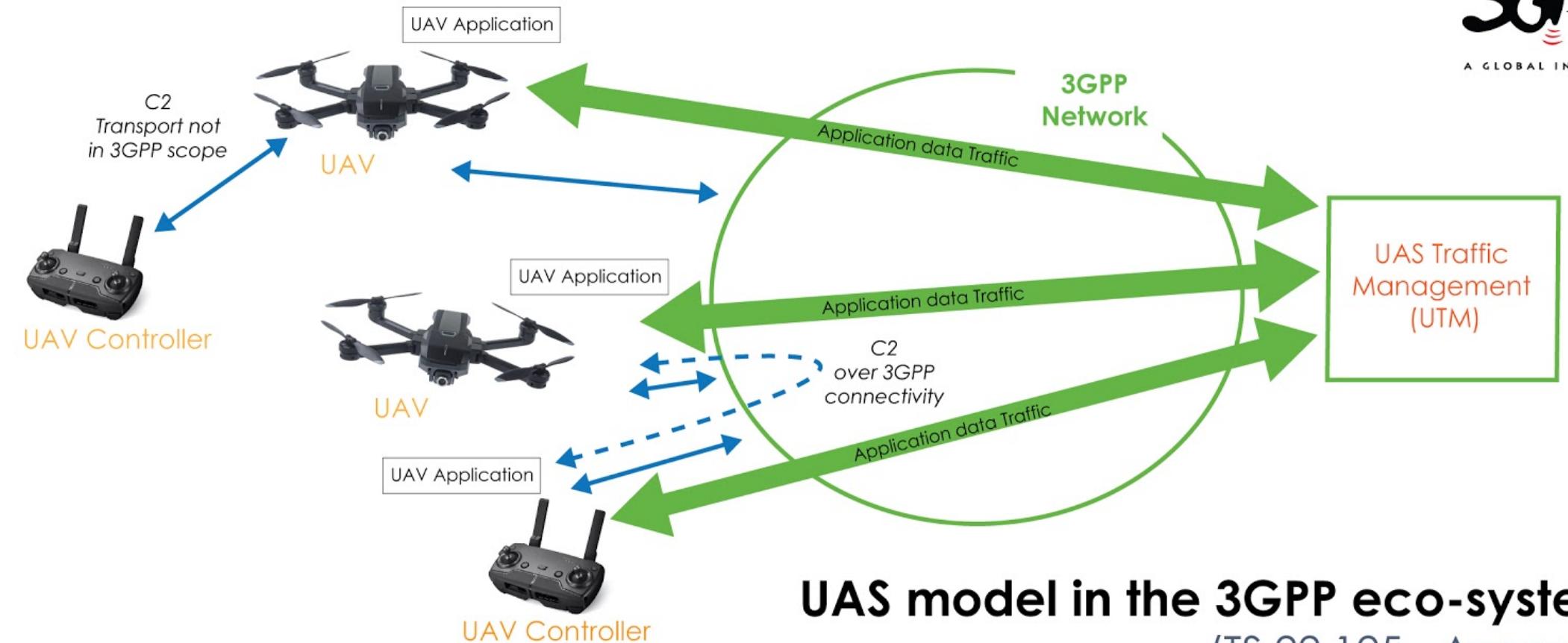
HAPS : High Altitude Platform Station



- NR coverage enh.
- Study - NR eXtended Reality (XR) NB-IoT and LTE-MTC enh.
- 5G multicast broadcast multi-radio DCCA enh.
- Multi SIM Integrated Access and Backhaul (IAB) enh.
- **Unmanned Aerial Systems (UAS)**
- 5GC location services
- Multimedia Priority Service (MPS)
- 5G LAN-type services
- 5G wireless and wireline convergence

Unmanned Aerial Systems (UAS)

- **Unmanned Aerial Vehicles (UAV)**
 - Aircraft that operates without an onboard pilot and carries no passengers
 - Applications
 - Defence
 - Agriculture
 - Cinema
 - Tourism
 - Surveillance
- **Unmanned Aircraft Systems (UAS)**
 - A system, which incorporates various subsystems, e.g.
 - Aircraft
 - Ground control station
 - Launch and recovery system
 - Navigation system
 - Payload
 - Onboard computer



UAS model in the 3GPP eco-system

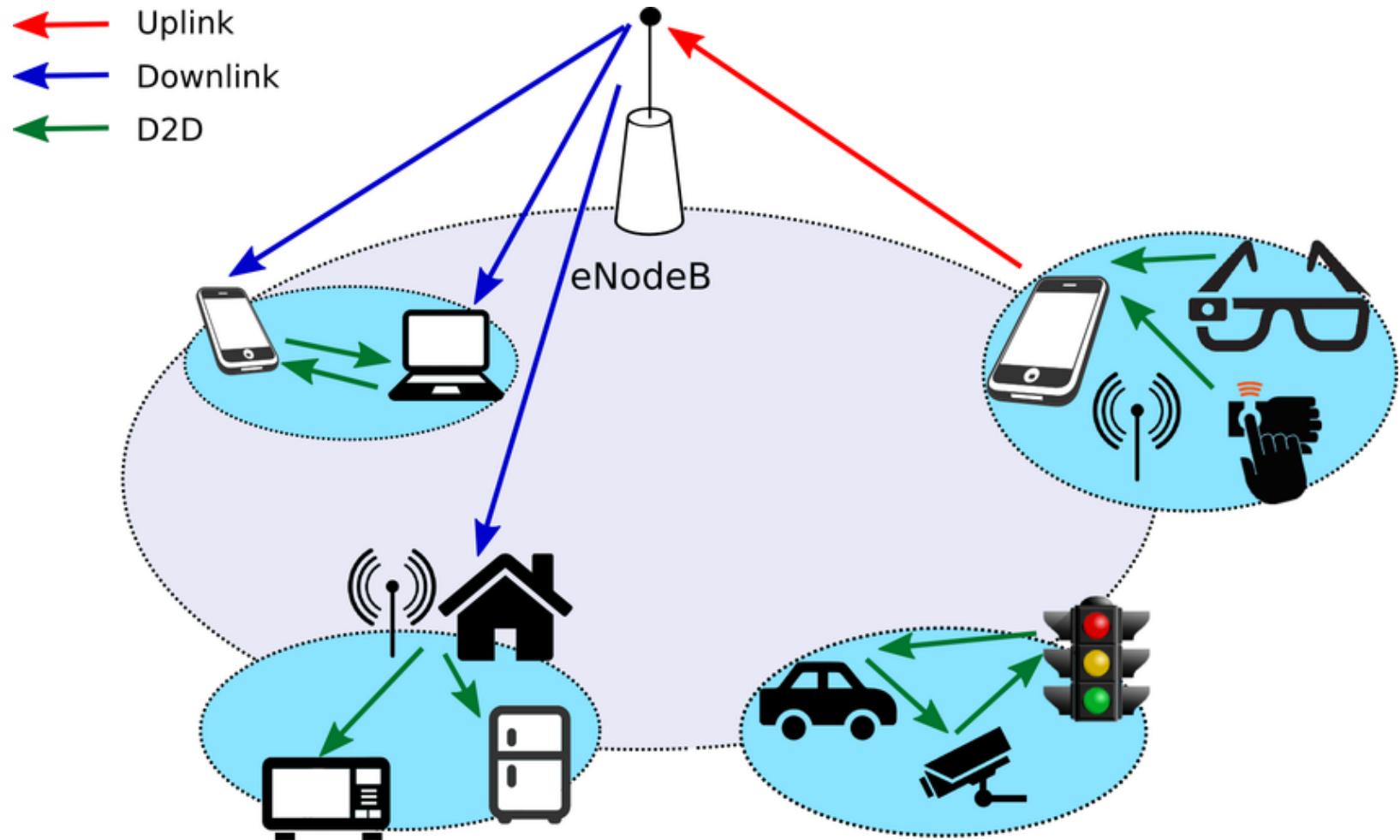
(TS 22.125 - Annex A)

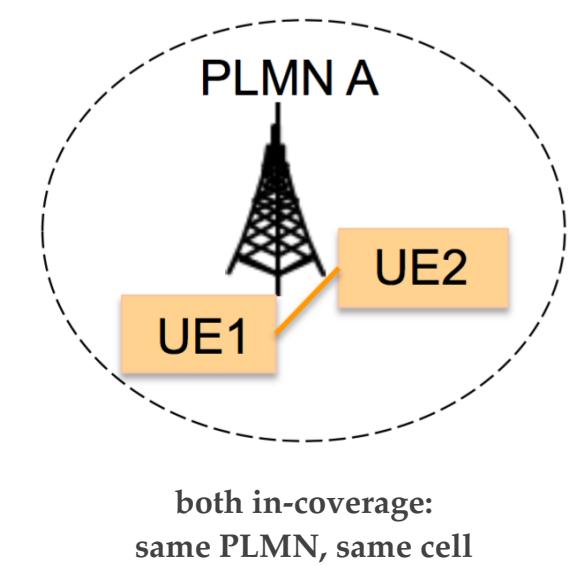
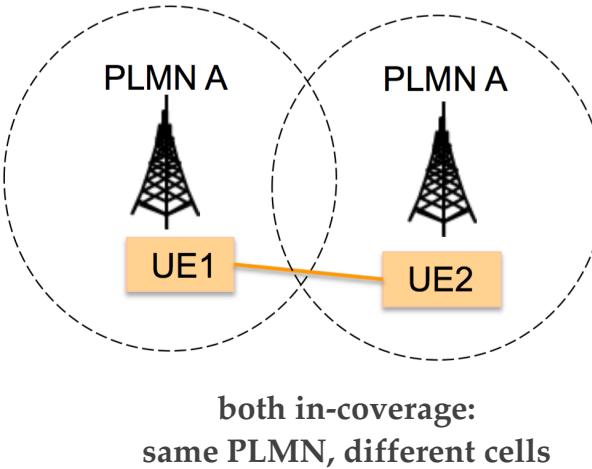
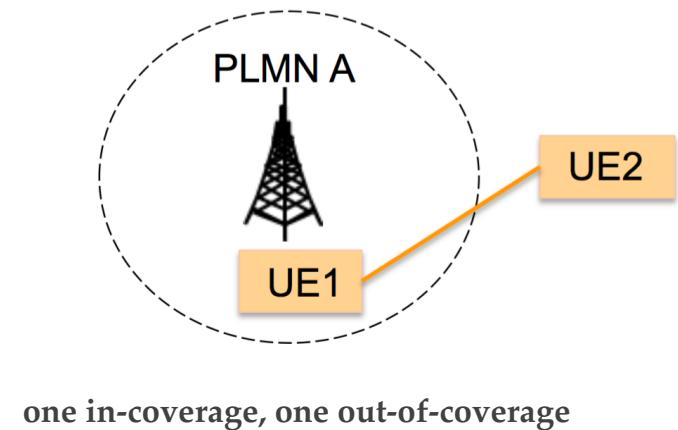
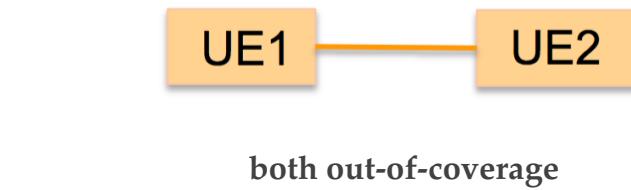
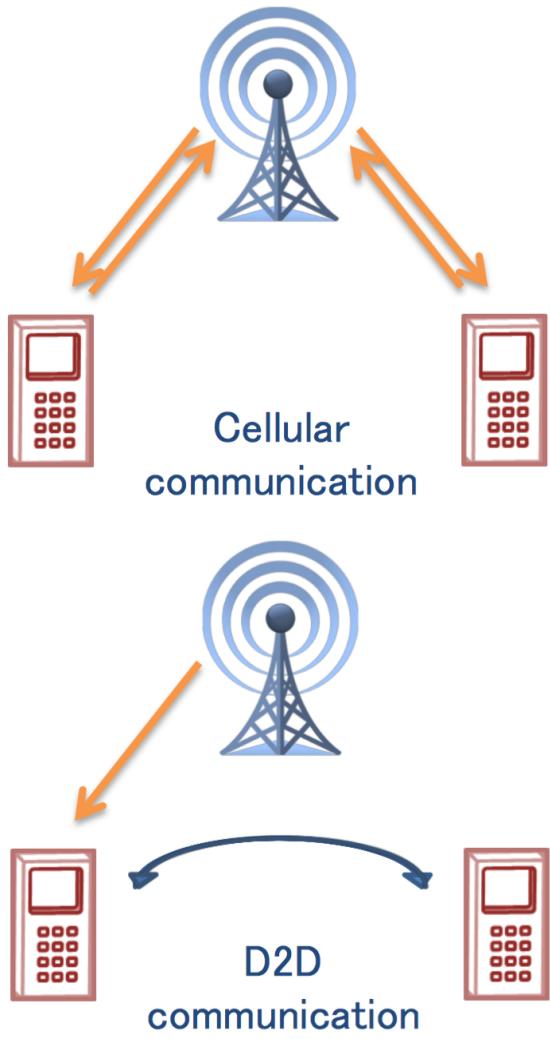
C2 : Command-and-Control infrastructure

- NR sidelink relay
- RAN slicing enh. for small data
- SON / Minimization of Drive Tests (MDT) enh. NR Quality of Experience
- eNB architecture evolution, LTE C-plane / U-plane split
- Satellite components in the 5G architecture
- Non-public networks enh.
- Network automation for 5G - phase 2 edge computing in 5GC

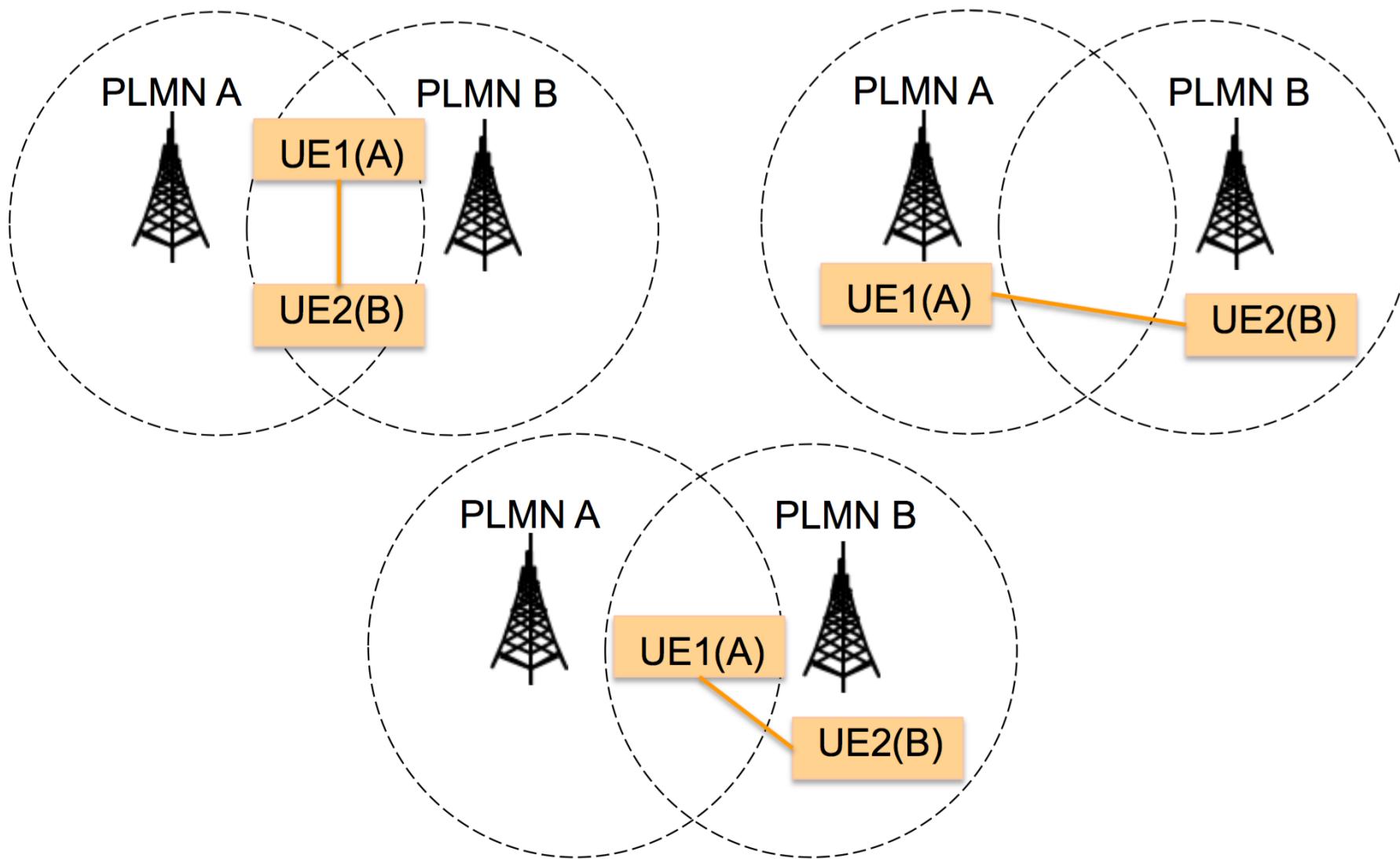
- Proximity based services in 5GS
- Network slicing phase 2
- Enh. V2X services
- Advanced interactive services
- Access Traffic Steering, Switch and Splitting (ATSSS) support in the 5G system architecture
- 5G LAN-type services
- User Plane Function (UPF) enh. for control and 5G Service Based Architecture (SBA)

Proximity based Services in 5GS

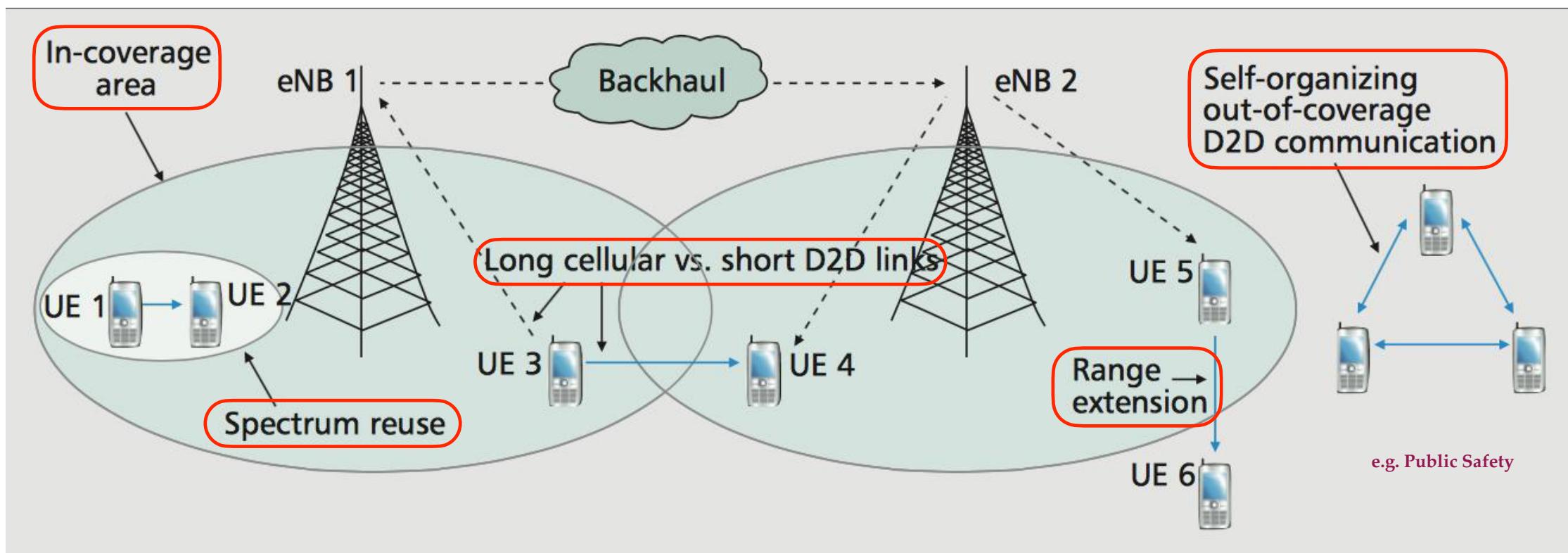




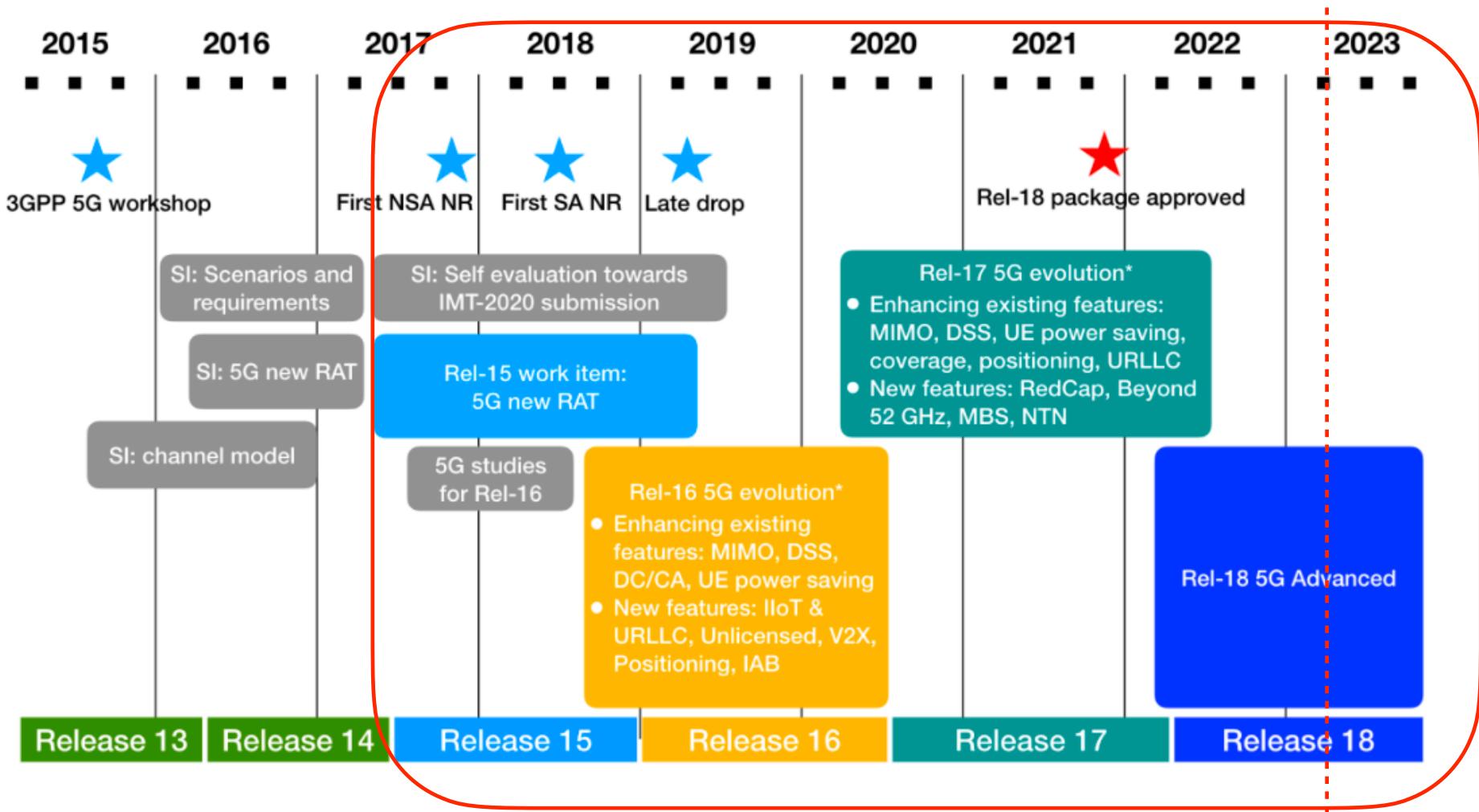
Source: TR 23.703



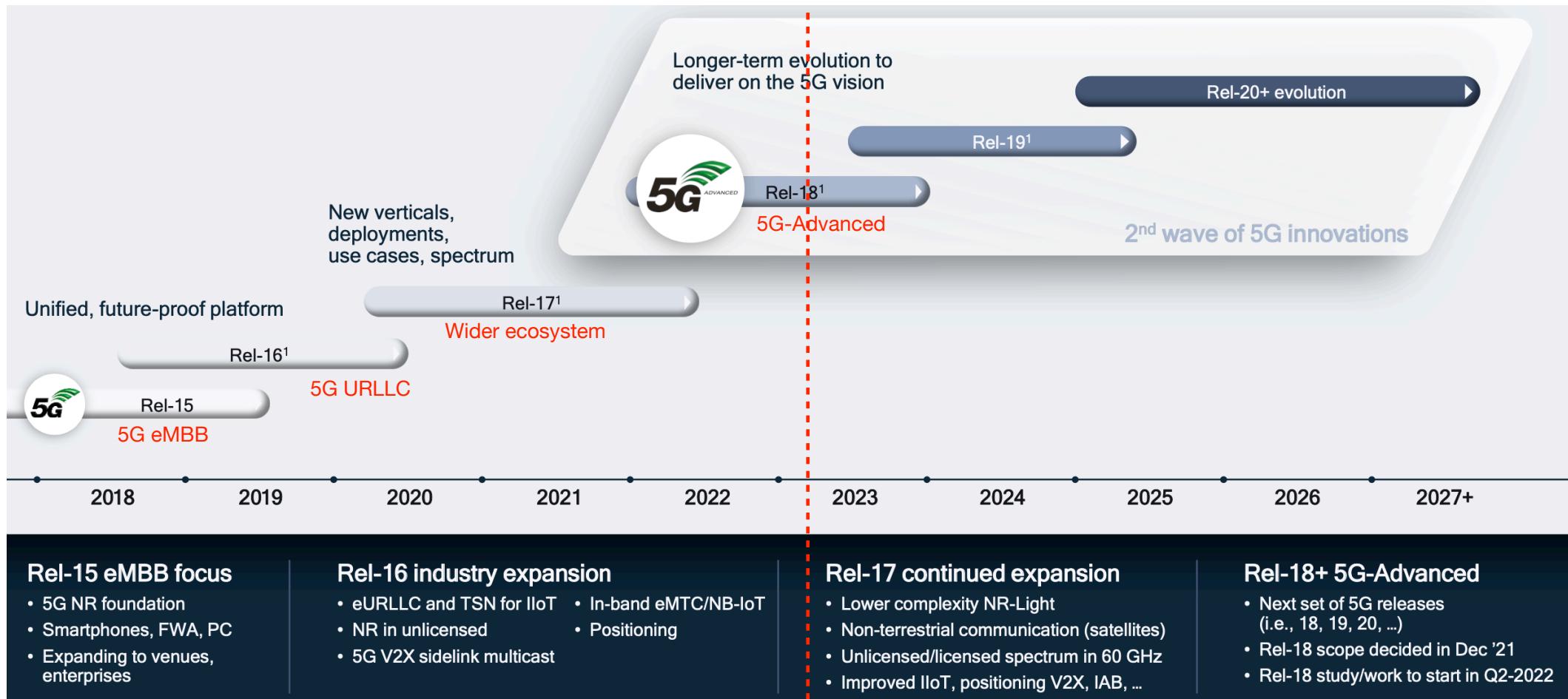
Source: TR 23.703



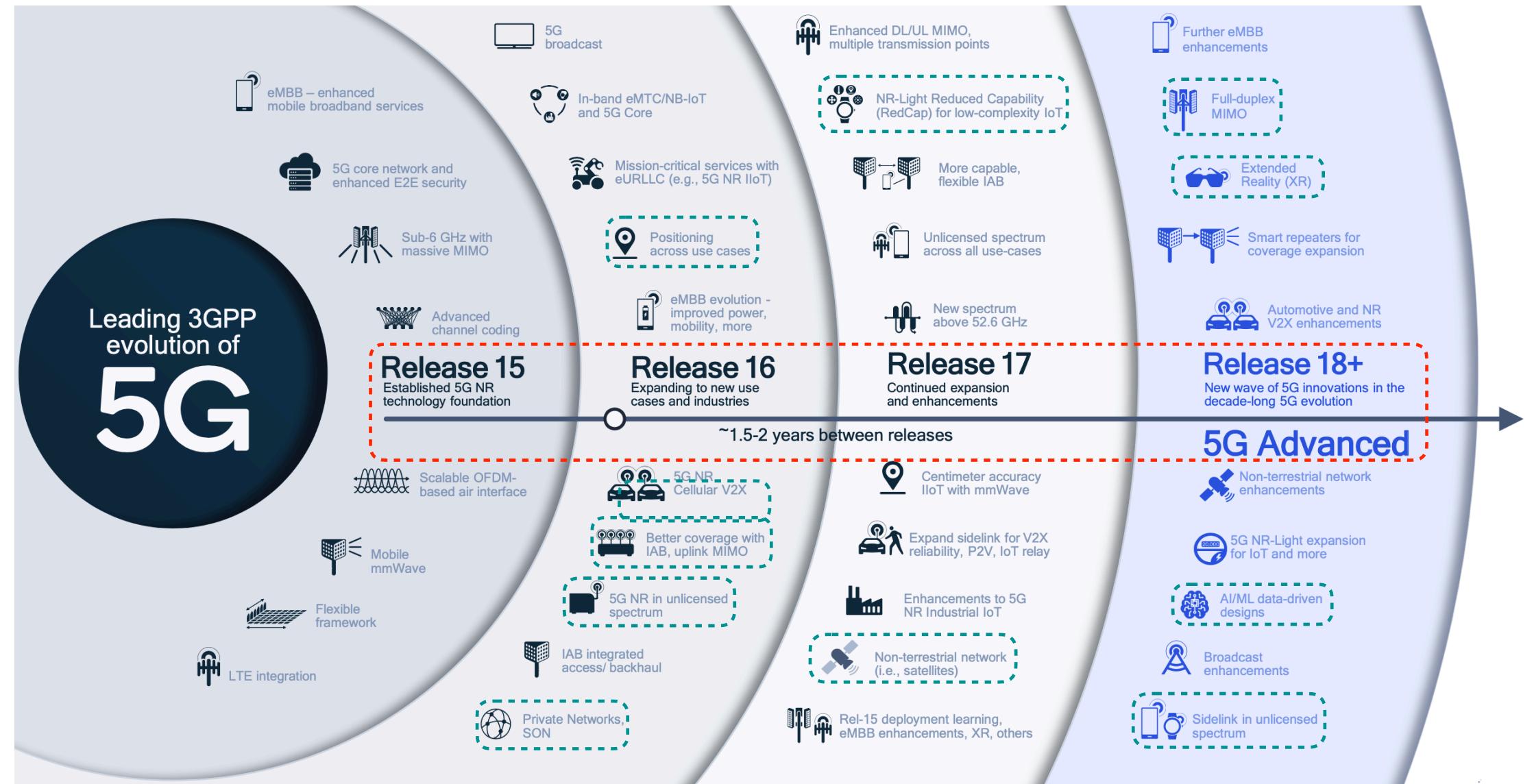
3GPP's 5G Evolution Roadmap from 5G to 5G Advanced



3GPP's 5G Evolution Roadmap from 5G to 5G Advanced



FWA : Fixed Wireless Access Service



• Release 18 (5G-Advanced)

- Extension
 - Uplink coverage
 - IoT optimized RedCap
 - Non-terrestrial networks (NTN)
 - UAV optimization
 - Sidelink enhancements
 - Sub 5MHz for verticals

- Expansion
 - Positioning
 - Resilient timing

- Experience
 - Extended reality (XR)
 - MIMO enhancements
 - Mobility enhancements
 - Duplex operations

- Excellence
 - AI/ML for NG-RAN
 - AI/ML for Air Interface
 - Network energy efficiency
 - Centralized unit resiliency
 - Network-controlled repeater
 - DSS enhancements
 - Mobile IAB

5G-Advanced brings Improvements in Many Areas



Enhanced mobility

- Reliability to 99.9%
- Break from 50 to 0 ms (FR2)
- Improved FR2 Scell setup



Enhanced coverage

- PUSCH 2 dB
- RACH 5 dB

PUSCH : Physical Uplink Shared Channel
RACH : Random Access Channel



MIMO performance

- Enhanced uplink
- Multi-cell uplink
- +20% for high speed mobiles



XR (AR, VR, gaming)

- Guaranteed
- Seamless
- Low power consumption
- Edge computing



Resilient timing

- No GPS required
- Timing service over 5G network



5G to replace GSM-R

- Enable GSM-R migration to 5G with <5 MHz support for dedicated spectrum



Enhanced sidelink

- Sidelink meeting public safety needs
- Sidelink to XR display etc. with unlicensed



IoT optimized RedCap

- 70% lower cost
- Lower power consumption

RedCap : Reduced Capacity



Accurate positioning

- <10 cm indoor positioning, using carrier phase
- Complement to GNSS outdoors

GNSS : Global Navigation Satellite System

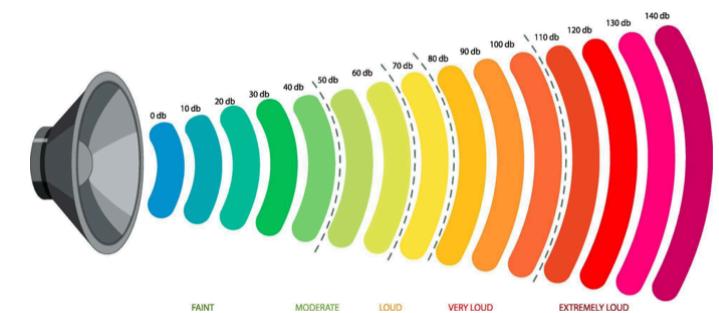
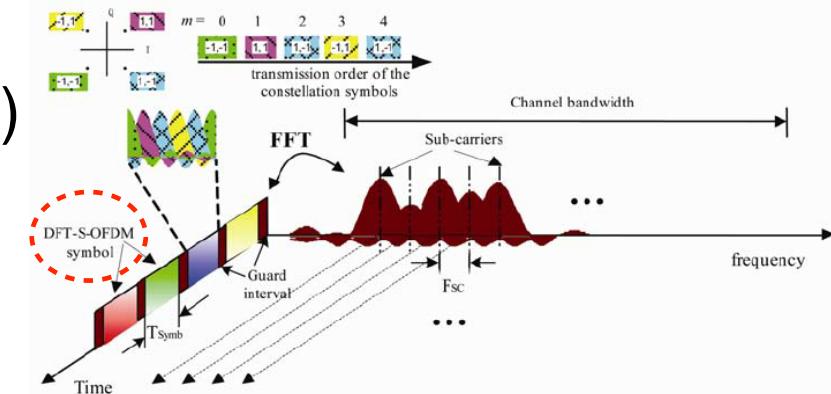
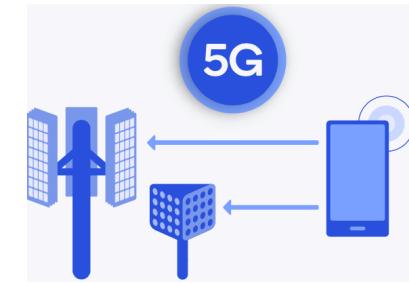


Network operation efficiency

- More flexible TDD spectrum use
- AI/ML automation
- Energy efficiency

Boosting 5G Uplink Coverage

- Dynamic DFT-S (Discrete Fourier Transform - Spread) and OFDM switching
 - Fast waveform change
- FDSS (Frequency Domain Spectrum Shaping) with spectrum extension enables up to 2 dB data coverage extension
 - FDSS function can be left for UE implementation
 - Applies both for FR1 and FR2
- RACH coverage up to 5 dB
 - RACH repetition with beamforming



$$N_{\text{dB}} = 10 \log_{10} \left(\frac{P_2}{P_1} \right)$$

RedCap

LPWA : Low-Power, Wide-Area

LPWA (mMTC)

- Extreme coverage
- Ultra-low UE complexity
- 10-15 years battery life

eMBB

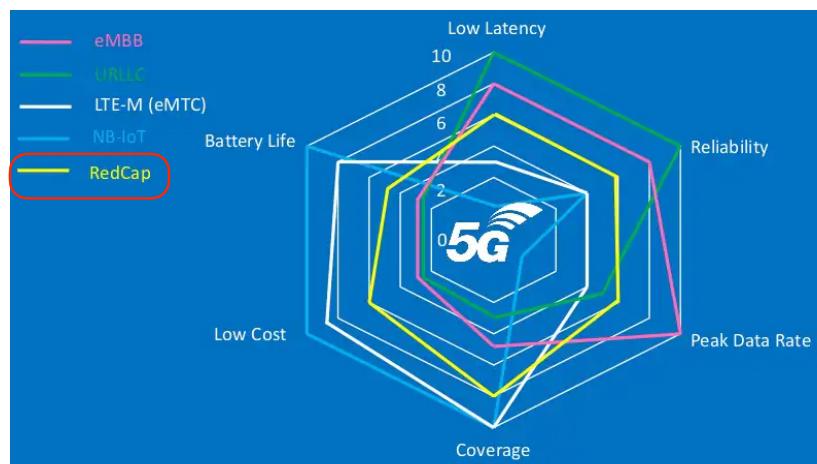
- Data rate
- Spectral efficiency

URLLC

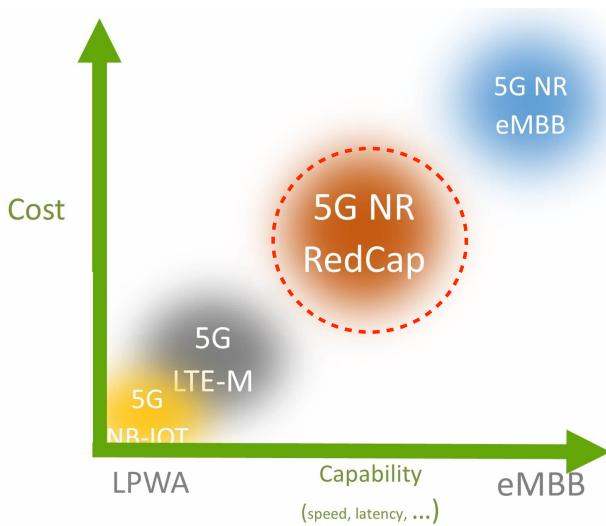
- Latency
- Reliability

RedCap
(NR-Light)

Diversified requirements for industrial wireless sensors, wearables, video surveillance and more

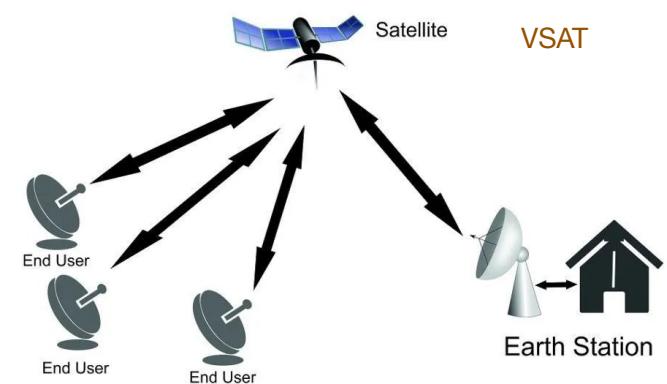
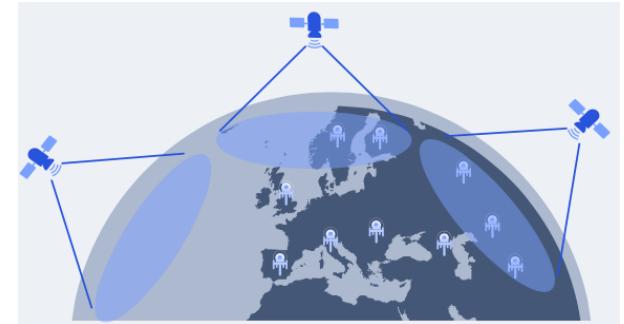


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5G NR for NTN

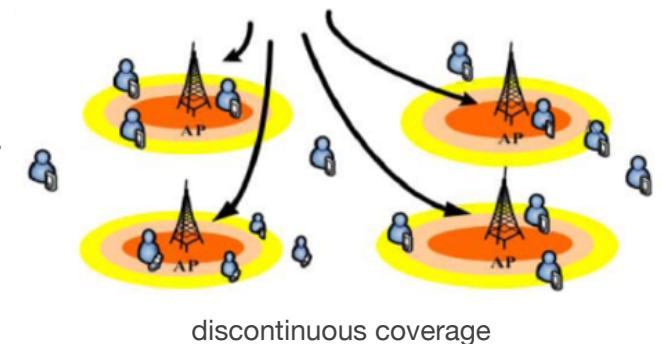
- Complementing terrestrial networks in underserved areas
 - Network verified device location based on satellites network
 - Coverage enhancements for voice and low-data rate services
 - Mobility enhancements for satellite and terrestrial networks
 - Deployment in 10+ GHz bands and support for VSAT/ESIM



VSAT : Very Small Aperture Terminal ESIM : Earth Stations in Motion

5G IoT for NTN

- Expanding addressable market for the 5G massive IoT
- Addressing remaining Rel-17 issues, e.g.,
 - Disabling HARQ 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



UAV (Drone) Support in 5G-Advanced

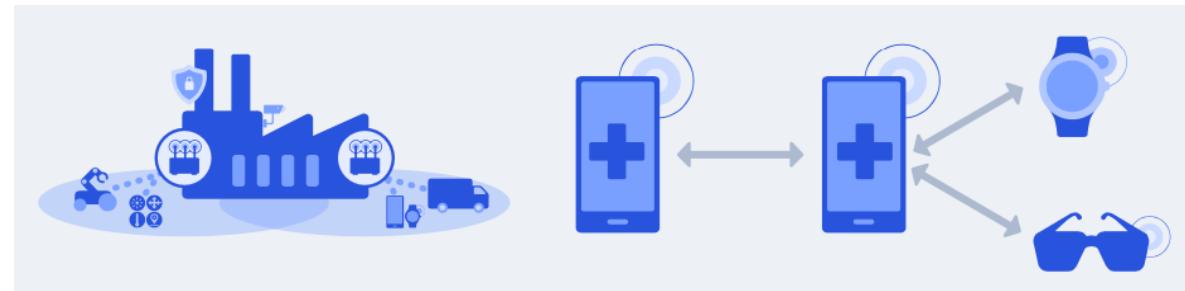
- First step in 5G-Advanced is to include solutions done with LTE
 - Flight path reporting, height reporting etc. as in LTE
- New areas in 5G-Advanced
 - Beamforming with UAVs to reduce interference they create
 - Subscription based UAV identification
 - UAV ID broadcast (ideally with unlicensed spectrum to avoid interference)



- Key benefits
 - UAV with HD-video stream transmission will create a lot of interference due to visibility to many base stations, thus use of 5G beamforming can greatly reduce the interference with the use of antenna directivity in UAVs
 - UAV identification important to secure responsible use of UAVs, avoiding interference for example to air traffic

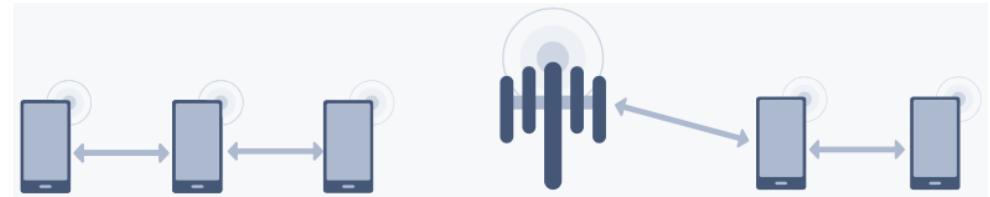
Sidelink Enhancements

- Unlicensed spectrum
 - Supporting optimized sidelink operations in unlicensed 5 and 6 GHz bands
 - Sidelink carrier aggregation
 - Supporting enhanced use cases that can benefit from wider bandwidths
 - Multi-beam operation
 - Supporting sidelink beam management by reusing and enhancing existing framework and concepts



Sidelink Relay Enhancements

- Device-to-device relay
 - Allowing single-hop operation for unicast with forward compatibility for more hops
- Multipath relay & UE aggregation/switching
 - Enhancing reliability and throughput for 1 direct (Uu) + 1 indirect (PC5 or ideal link) path within the same cell
- Service continuity enhancements for UE-to-NW relay
 - Supporting inter-gNodeB mobility and intra-gNodeB indirect-to-indirect path switching
- Remaining Rel-17 work
 - Completing features such as discontinued reception (DRX) for sidelink relay operations



5G Positioning Evolution

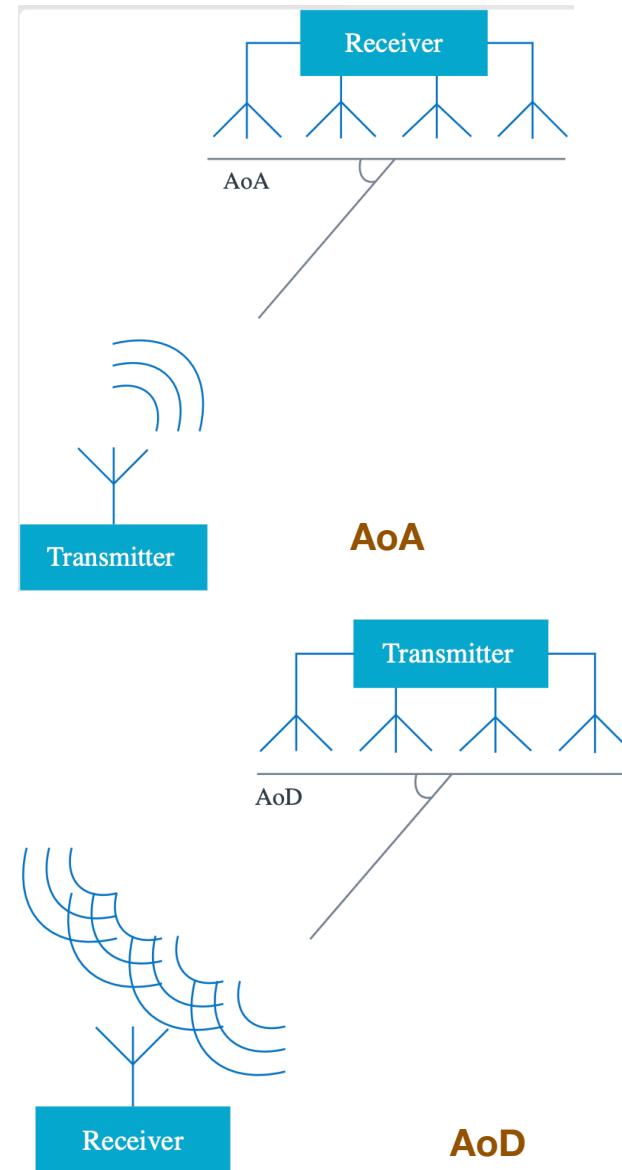
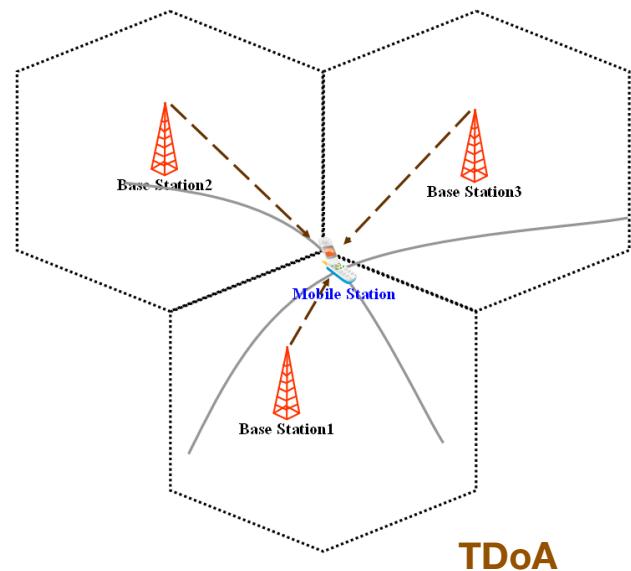
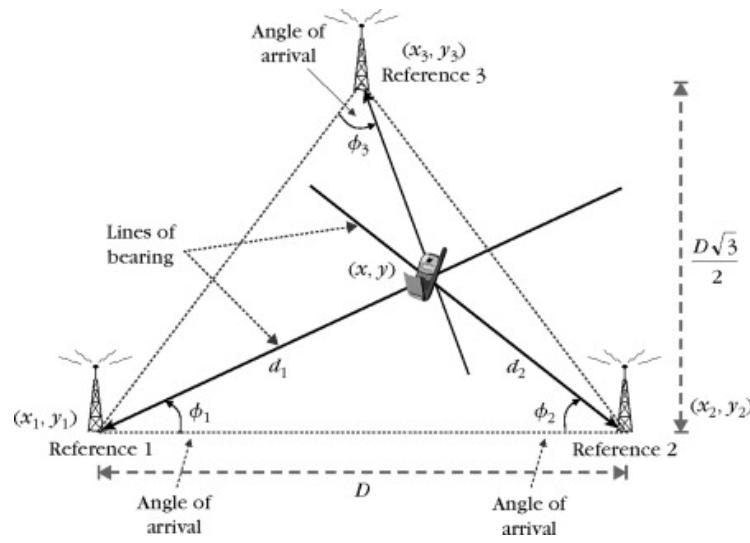
- **Release 16 - establishing foundation**
 - Achieving accuracy of 3m/10m (indoor/outdoor) for 80% of time
 - Supporting RTT, AoA/AoD, TDOA, single-cell positioning
 - Including new evaluation scenarios, i.e., industrial IoT

AoA : Angle-of-Arrival

AoD : Angle-of-Departure

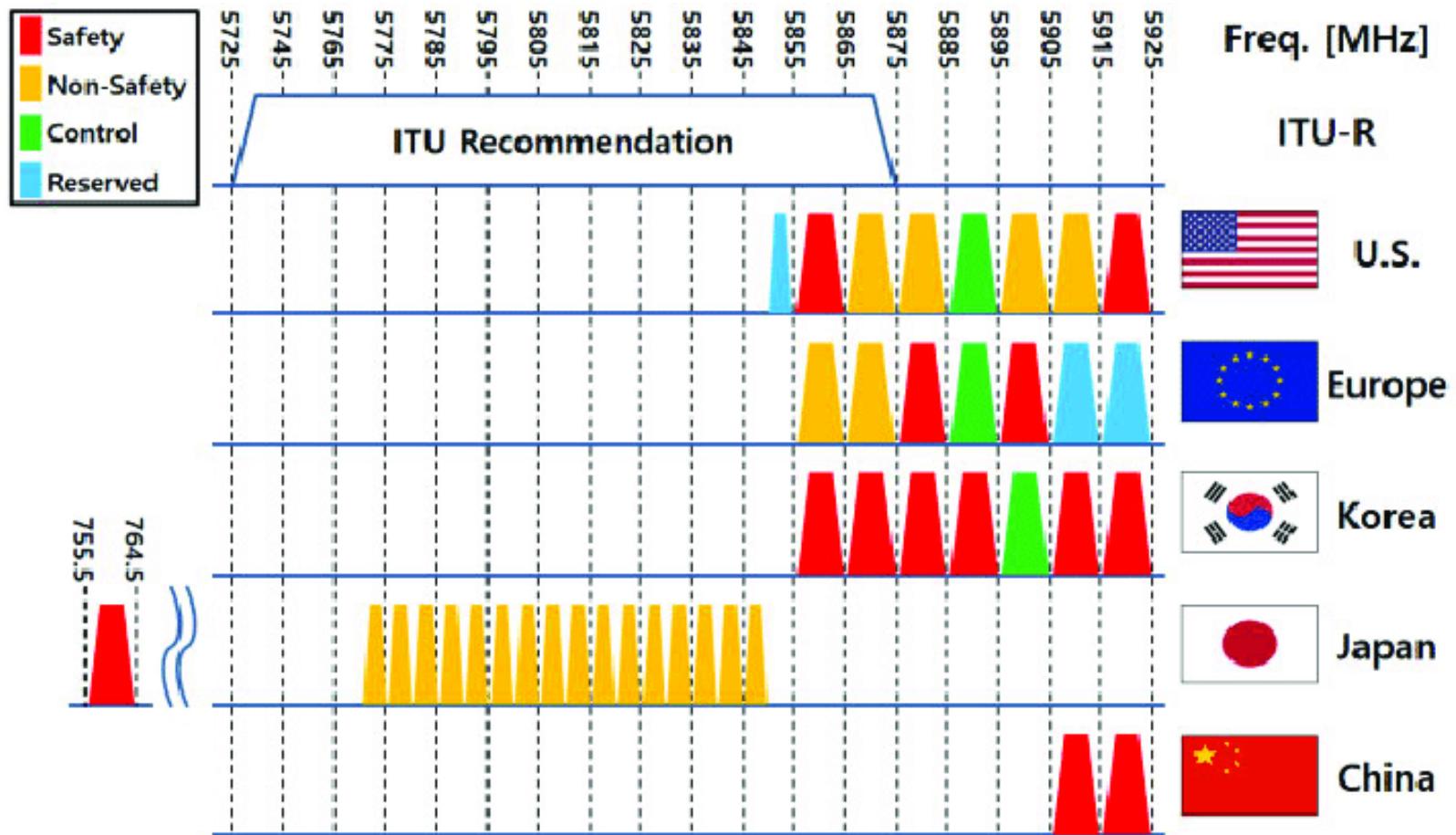
TDoA : Time Difference of Arrival

RTT : Round Trip Time



- **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)

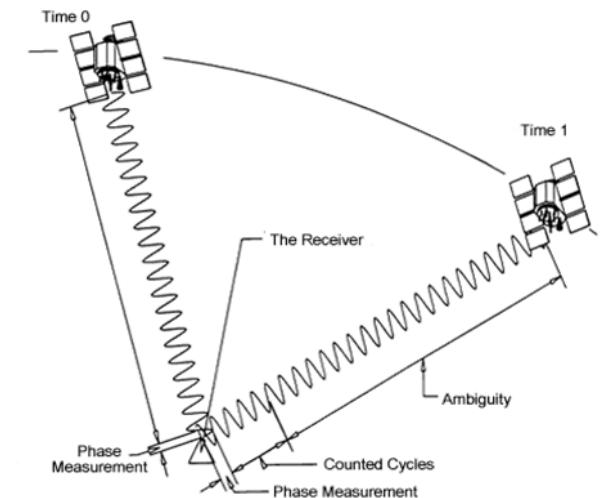
- **5G Advanced in Release 18** - improving performance, expanding to new devices and deployments
 - Sidelink positioning and ranging
 - Defining methodologies, reference signals, measurements, procedures for absolute and relative (e.g., ranging) sidelink positioning in licensed and ITS (Intelligent Transport Systems) spectrum



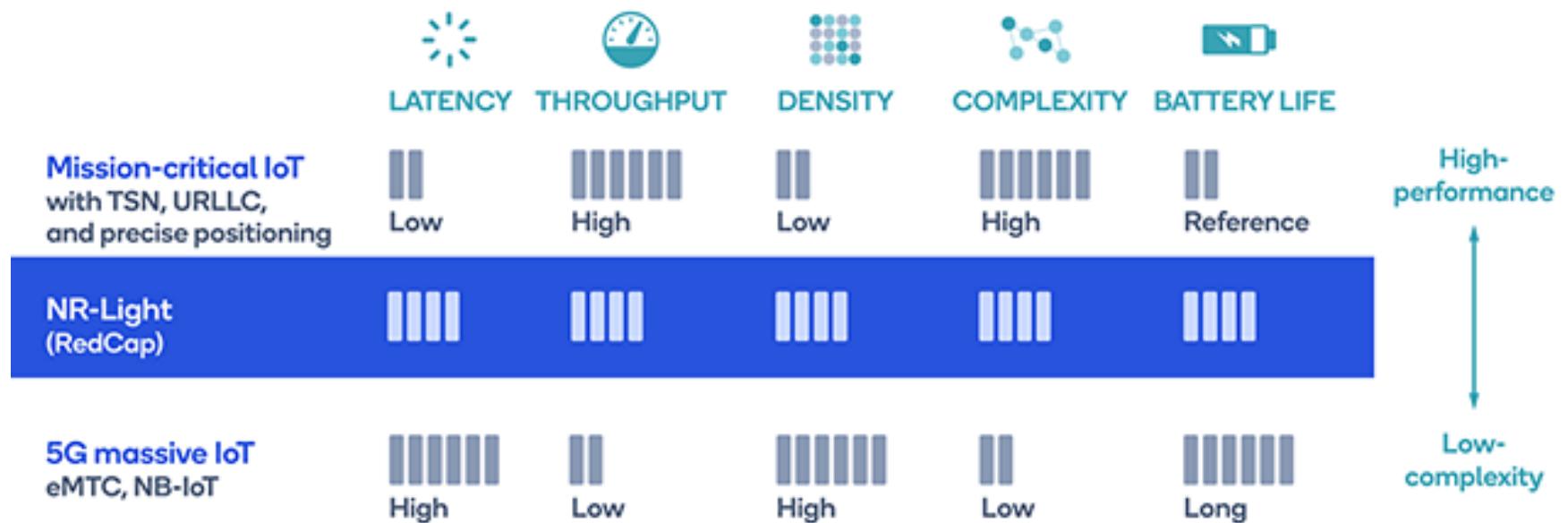
ITS spectrum usages for U.S., Europe, Korea, Japan, and China

- Improved positioning performance
 - Specifying higher layer solutions for
 - RAT dependent positioning techniques
 - Accuracy improvement based on PRS/SRS bandwidth aggregation
 - Carrier phase measurements

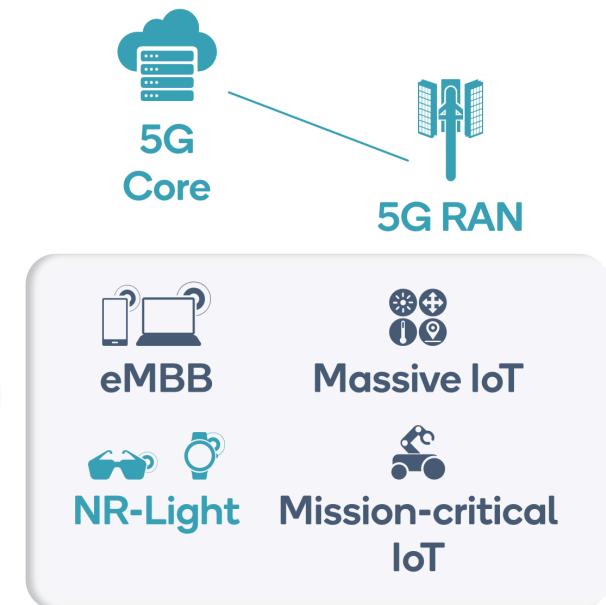
PRS : Positioning Reference Signal
SRS : Sounding Reference Signal



- NR-Light (RedCap) positioning
 - Setting performance requirements, evaluating performance for R17 positioning procedures, and identifying potential enhancements



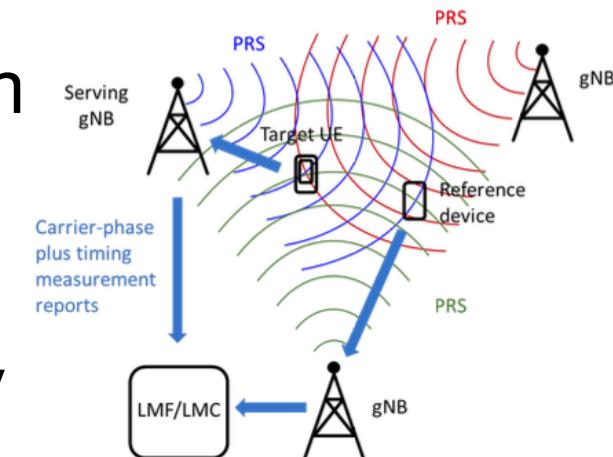
	LTE Cat-1bis	LTE Cat-4	5G NR-Light (Rel-17)
Bandwidth	20 MHz	20 MHz	20 MHz (sub-7 GHz)
Peak data rate DL/UL	10/5 Mbps	150/50 Mbps	150/50 Mbps or higher
Duplexing	FD-FDD, TDD	FD-FDD, TDD	HD-FDD, FD-FDD, TDD
Tx/Rx chain	1 Tx, 1 Rx	1 Tx, 2 Rx	1 or 2 Tx, 1 or 2 Rx
MIMO layers DL/UL	1/1	2/1	1 or 2/1
Maximum coupling loss	140 dB	144 dB	140 dB



Unified 5G platform for all use cases can simplify system management and security

Super-Accurate Positioning

- Carrier-phase positioning using signals from the NR base stations gives sub-10cm accuracy
 - Factor of ~10 higher accuracy than purely time-based positioning methods
 - Based on proven techniques from GNSS-RTK, but applied to NR base station signals without reliance on satellites
 - Uses carrier-phase measurements on 5G NR signals on top of time measurements



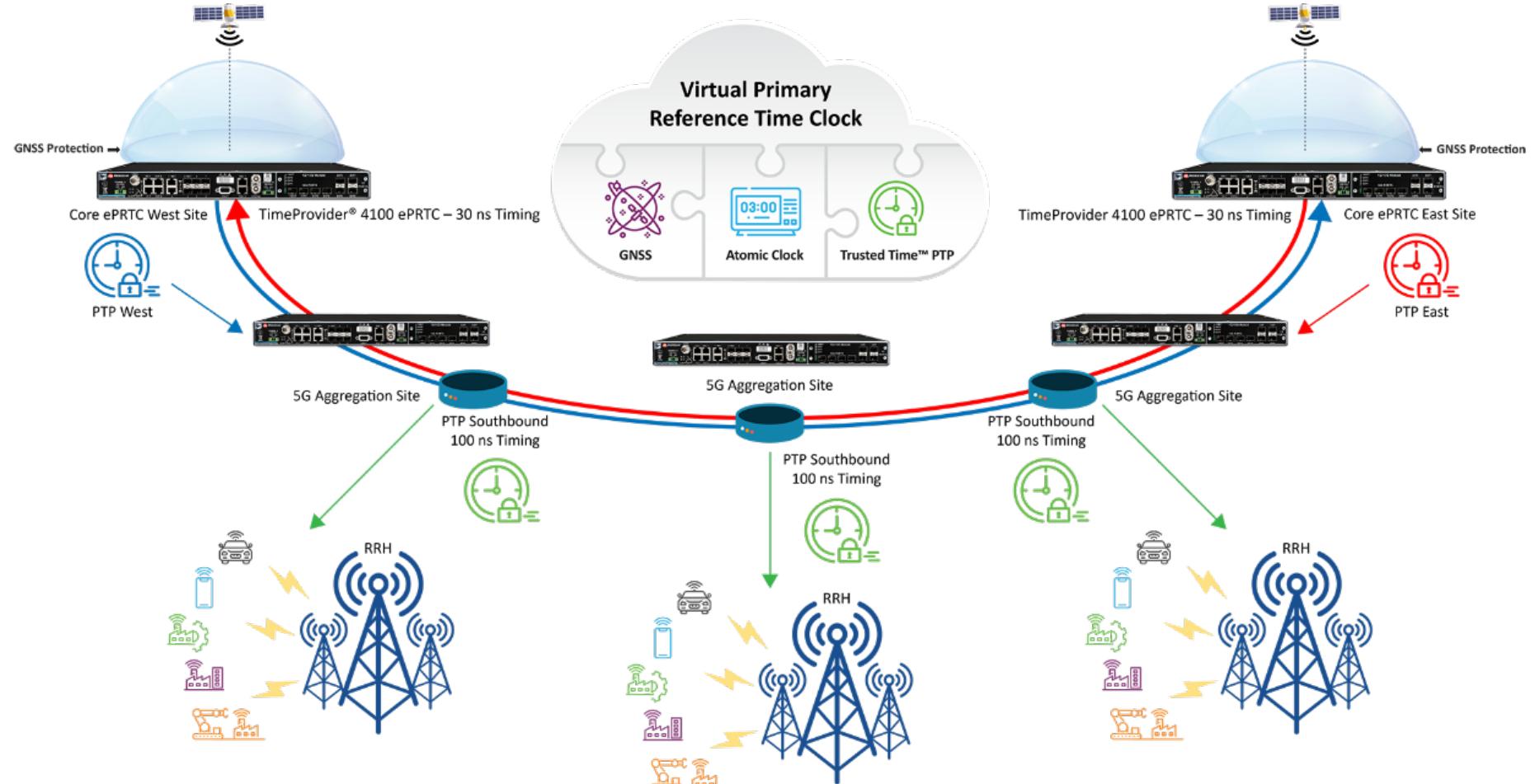
PRS : Positioning Reference Signal
LMF : Location Management Function
LMC : Location Management Component
RTK : Real Time Kinematic

- Enables consistently accurate positioning service, indoors and outdoors
 - Indoors as a complement to outdoor GNSS
 - In buildings (industrial automation/logistics)
 - In tunnels (automotive, public safety)
 - Outdoors as a resilient alternative to GNSS
 - e.g. in case of GNSS non-availability / interruption

- Other positioning enhancements in Rel-18
 - Sidelink positioning / ranging: especially targeting automotive
 - Integrity for RAT-based positioning (only GNSS integrity was handled in Rel-17)
 - RedCap positioning: evaluate accuracy achievable with reduced bandwidth, and consider enhancements where possible

Resilient Timing

vPRPC : virtual Primary Reference Time Clock
ePTC : enhanced Primary Reference Timing Clock
PTP : Precision Time Protocol



XR (Extended Reality) - Boosting AR, VR and Cloud Gaming Experience



Capacity & Low Latency

- Match scheduling with XR (AR/VR) services
 - Periodicity, multiple flows, jitter, latency, reliability
- Low Latency
 - Files received within delay budget
- Enhancements
 - SPS (Semi-Persistent Scheduling) and configured grant enhancements
 - Dynamic scheduling/grant enhancements

Device Power Savings

- Extended usage with limited space for battery
 - Energy efficiency
 - Extended battery life time
- Enhancements
 - Adaptive and dynamic DRX PDCCCH monitoring

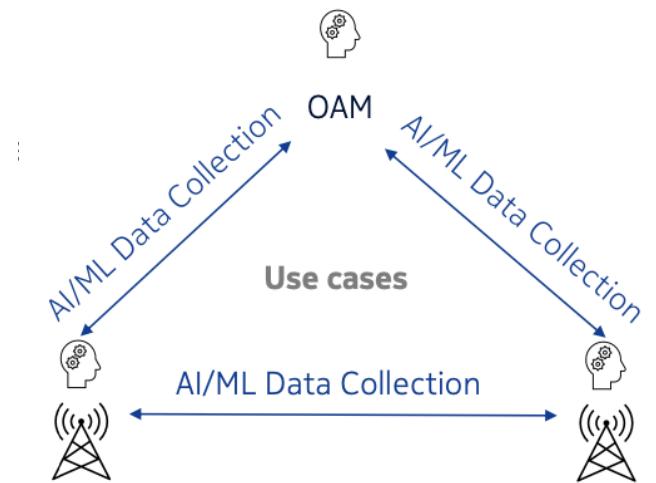
XR-awareness in radio

- Guaranteed XR QoS
 - gNB-awareness Information to aid XR-specific traffic handling

DRX : Discontinuous reception

AI/ML for NG-RAN

- Network optimization
 - Specify enhanced data collection and signaling support for AI/ML-based
 - Network energy saving
 - Load balancing
 - Mobility optimization
- Future study
 - New use cases (e.g., AI/ML for slicing, QoE)
 - Network functionality
 - Interface procedures (e.g., multi-vendor interoperability)



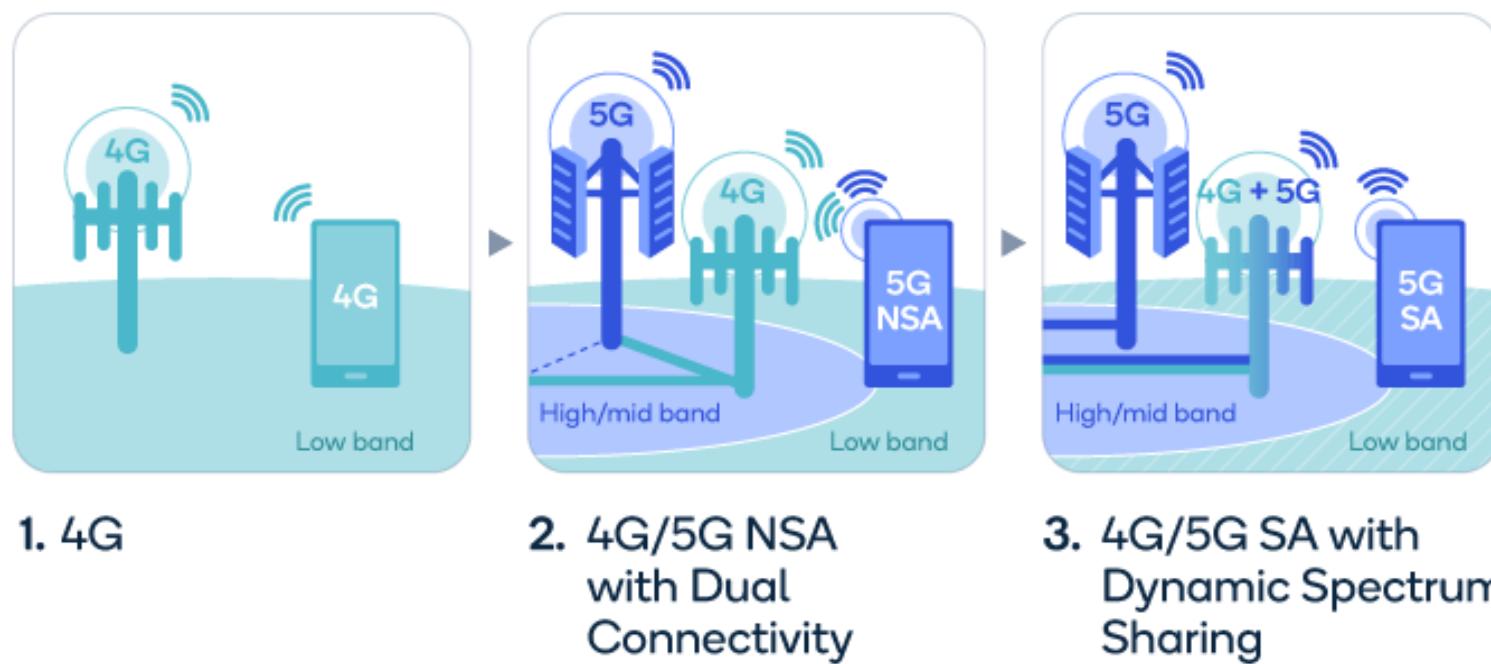
AI/ML-enabled Air Interface Design

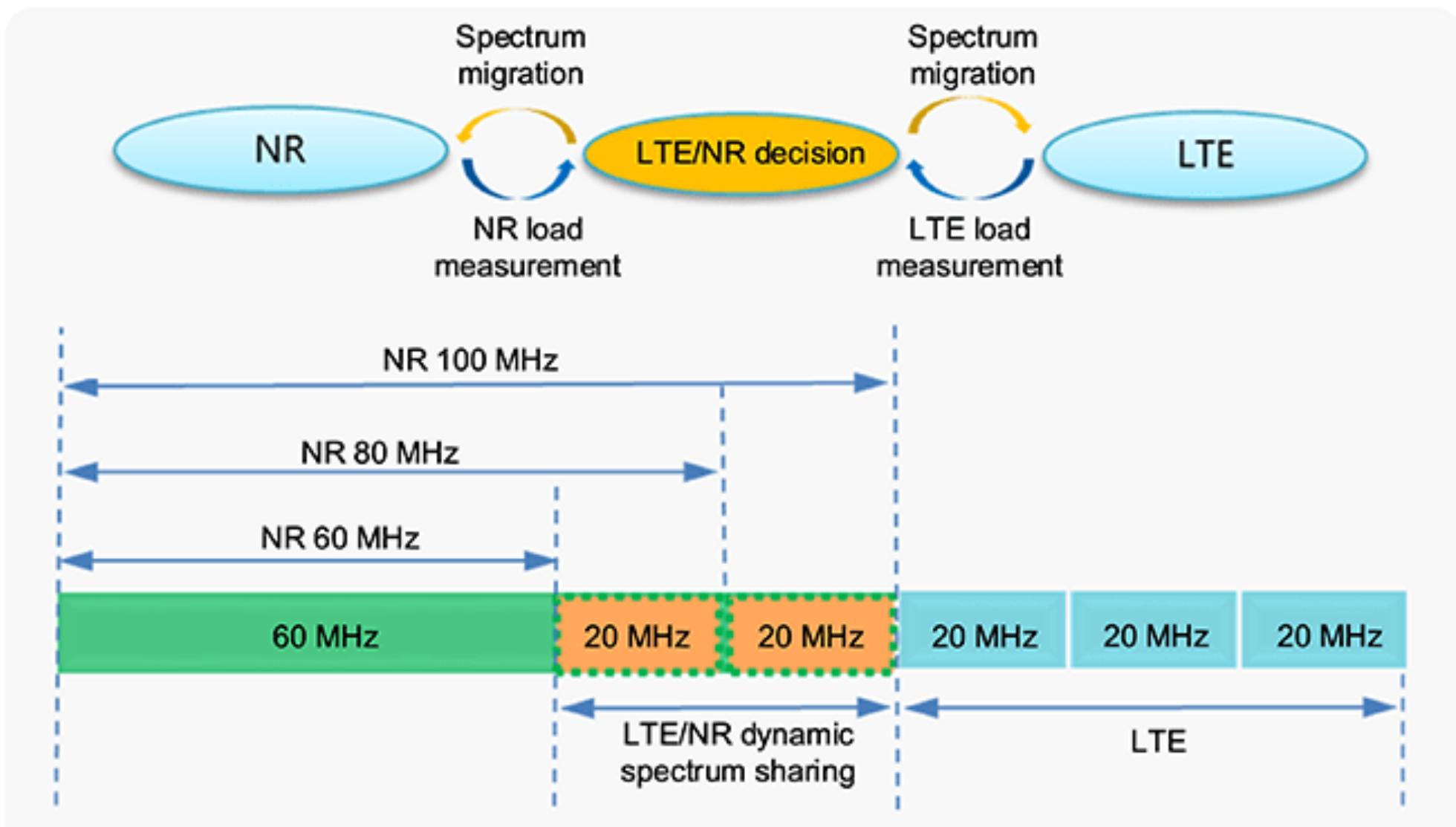
- Use cases
 - Enhanced channel state information (CSI) feedback, beam management
 - Positioning accuracy (including heavy non-line-of-sight conditions)
- AI/ML models
 - Identifying collaboration models, from no collaboration to cross-node ML
 - Life cycle management of models
 - Characterizing model 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

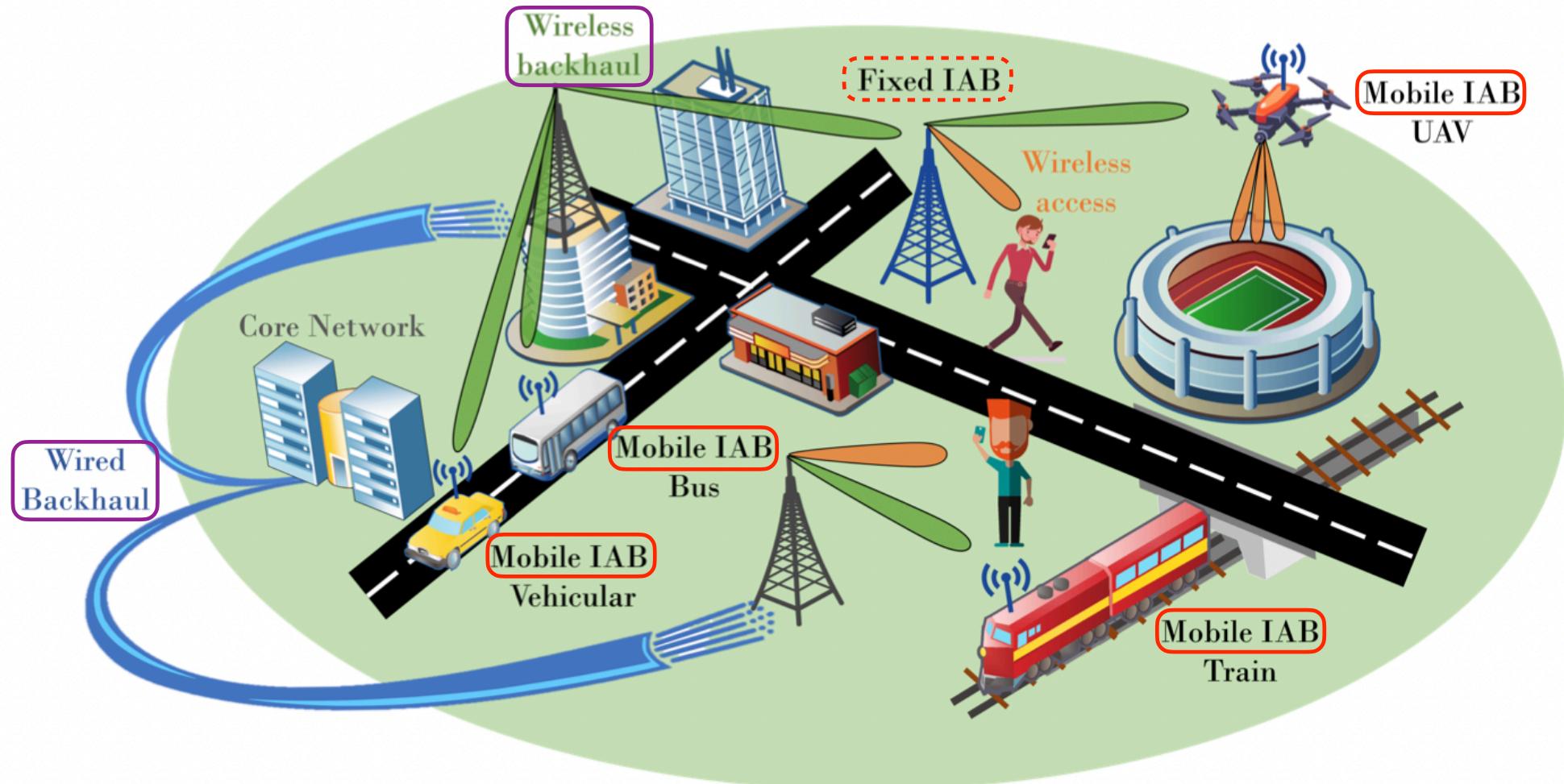
Dynamic Spectrum Sharing (DSS)

- Allow both 4G and 5G to share the same spectrum and make the 5G deployment faster



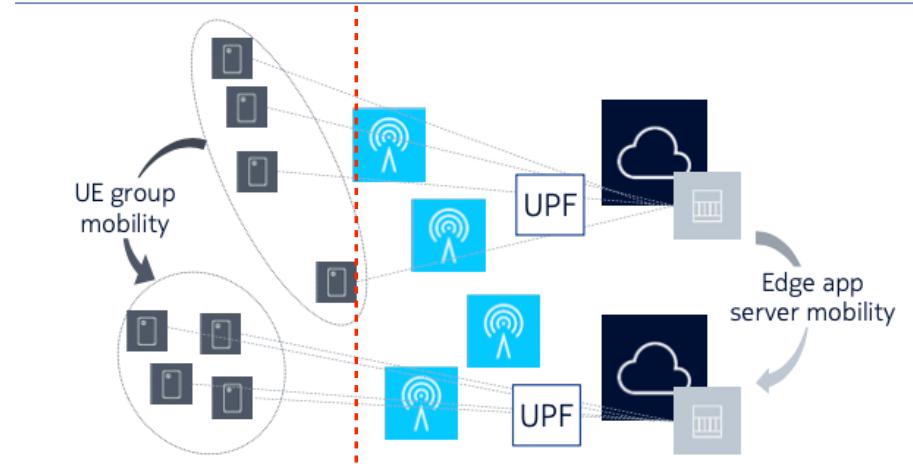


Mobile IAB (mIAB)



Edge Computing

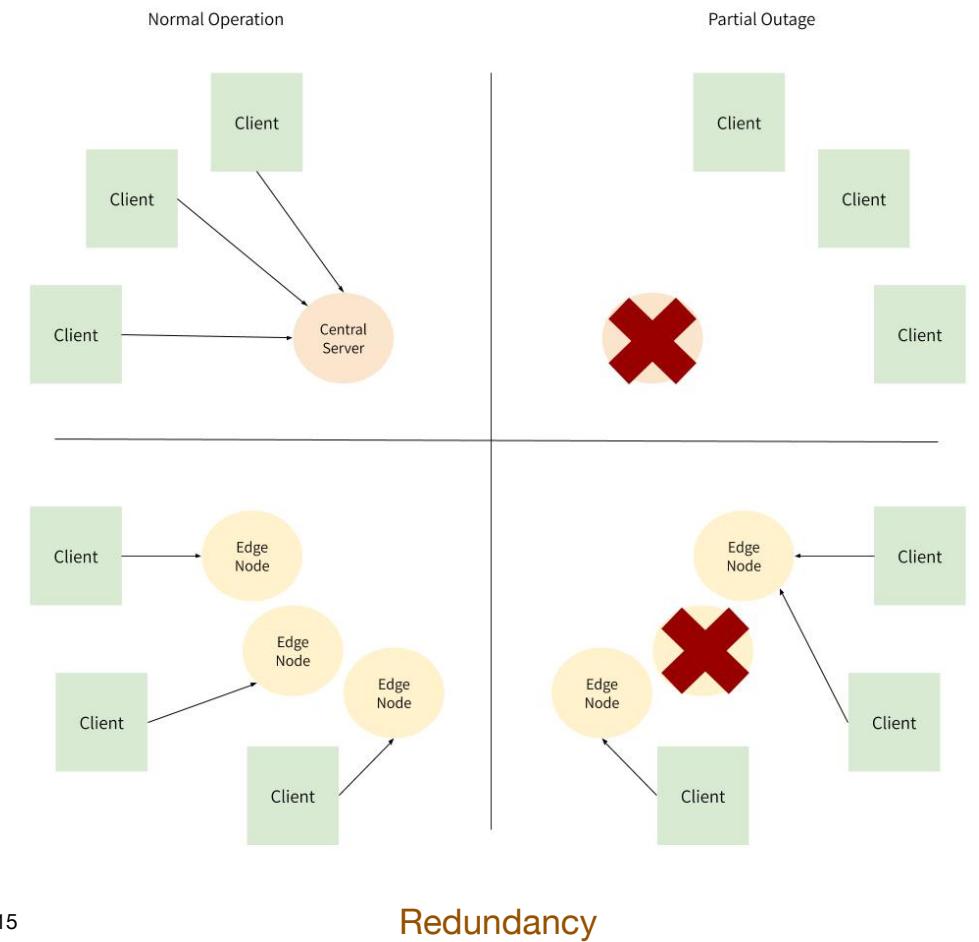
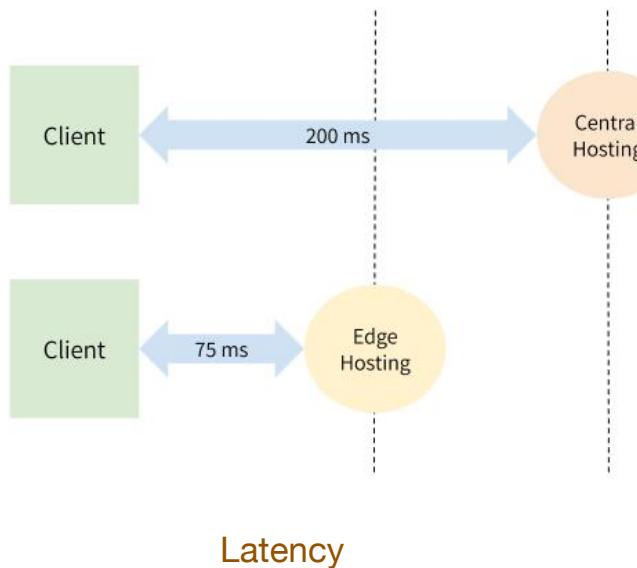
- Previous releases
 - **Rel-15:** Edge computing basic functionality
 - User Plane Function (UPF) offload capability
 - Application Function influence on traffic steering
 - **Rel-17:** Dynamic insertion of offload capability depending on actual traffic



• Rel-18

VPLMN: Visited Public Land Mobile Network

- Roaming support to access Edge Hosting Environment (EHE) in VPLMN



- Further enhancements for scenario where 5G Core and EHE are operated by different organizations
- Improved network exposure of UE traffic related information to Edge Application Server (e.g. for XR services or AI / ML applications)
- Offload policies for more granular sets of UE(s)