5G Era Presentation

Agenda topics

1. 5G ERA introduction
    a. Enhanced Mobile Broadband (eMBB)
    b. Massive Machine-type Communications (mMTC)
    c. Ultra-reliable and Low Latency Communications (URLLC)
2. Standards & Fora
3. System Architecture End-to-End (E2E)
    a. Network Function Virtualisation (NFV)
    b. 5G Core (5GC)
    c. 5G Service Based Architecture (SBA)
    d. Physical Architecture, Non-Standalone (NSA) and Standalone (SA)
    e. Backhaul, Mid-Haul and Fronthaul concepts
4. New Radio (NR) & Spectrum
    a) Spectrum
    b) New Radio air interface
5. Use Cases

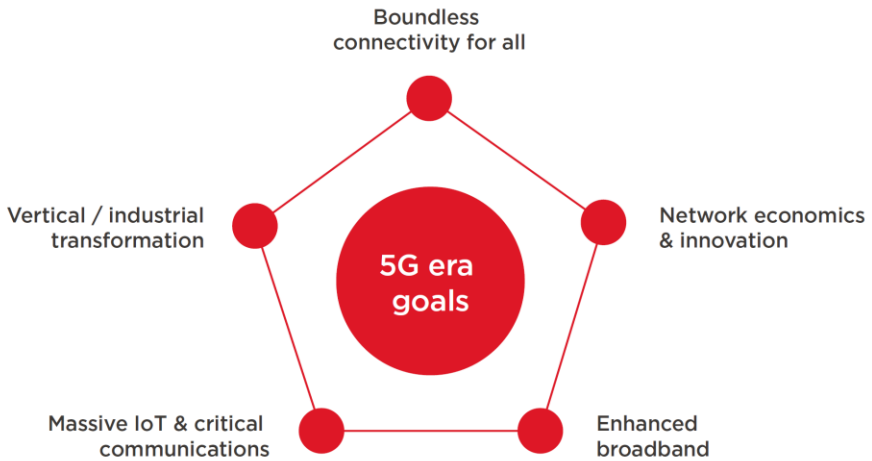
Stuart Revell, Managing Director, RTACS Ltd

Mobile +44 (0) 7836 512787
Email stuart.revell@rtacs.com

Warning – this is NOT how Networks and Services operate today

5G ERA Overview

5G Overview – the 5G ERA - five mobile industry goals

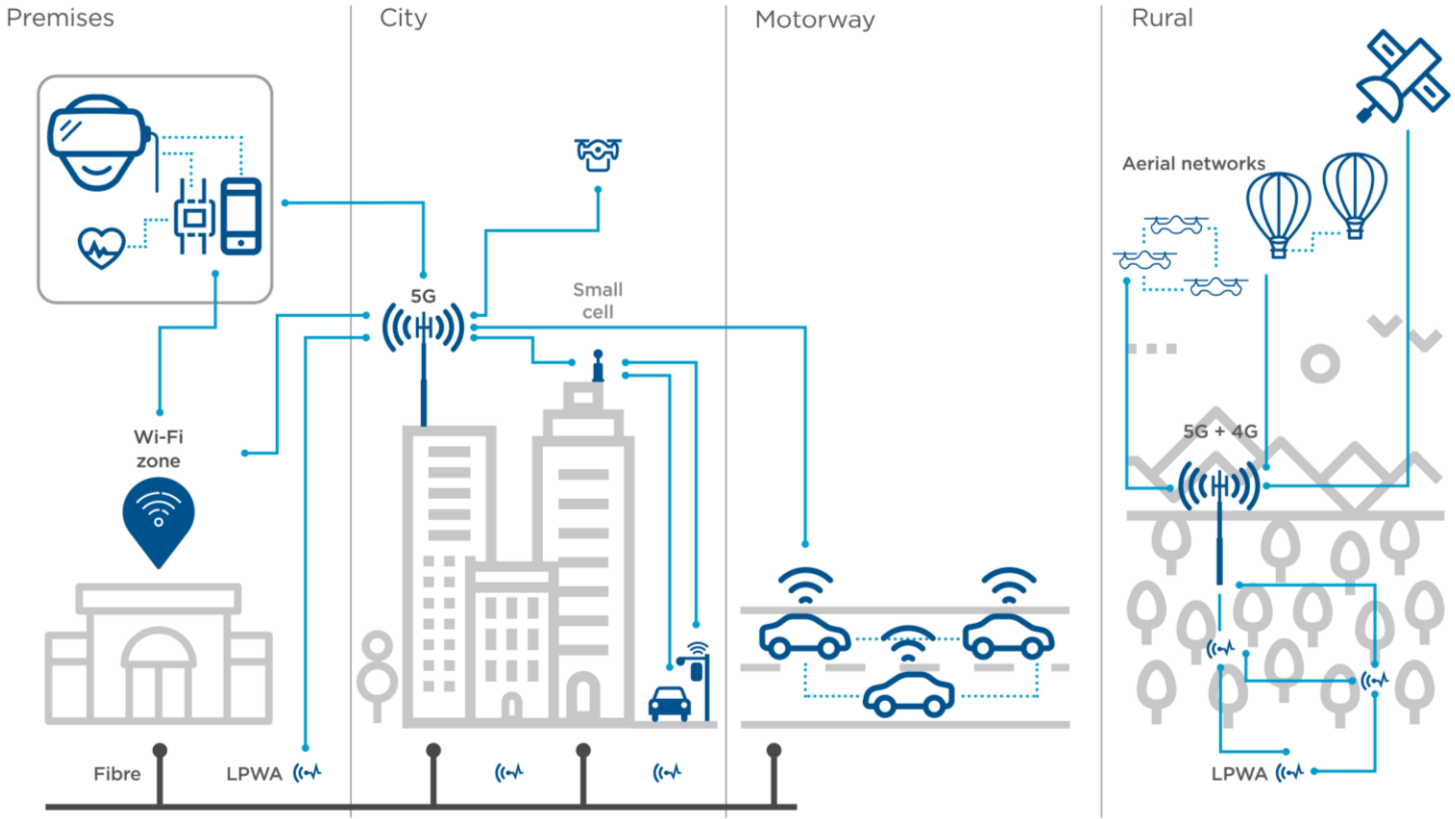


Source: "The 5G era: Age of boundless connectivity and intelligent automation", GSMA, 2017
https://www.gsma.com/futurenetworks/wp-content/uploads/2017/02/GSMA-The-5G-Era.pdf

1. **Provide boundless connectivity for all**: 5G networks will co-exist with 4G networks and alternative network technologies to deliver a boundless, high-speed, reliable and secure broadband experience, and support a plethora of use cases for society.
2. **Deliver future networks innovatively and with optimal economics**: All stakeholders will strive to cost-effectively deliver better quality networks either independently or through sharing and partnerships. Future networks will rely on a combination of mainstream and alternative technologies, and use both licensed and unlicensed spectrum, across different spectrum bands.
3. **Accelerate the digital transformation of industry verticals**: The mobile industry will provide the networks and platforms to drive the digitisation and automation of industrial practices and processes (including the fourth industrial revolution).
4. **Transform the mobile broadband experience**: 5G networks will provide an enhanced broadband experience of up to 1 Gbps and <10 ms, and provide the platform for cloud- and artificial intelligence-based services.
5. **Drive growth in new use cases for massive IoT and critical communications services**: 5G networks will support the massive rollout of intelligent IoT nodes for a multitude of scenarios, and provide a competent platform to support the widespread adoption of critical communications services.

5G ERA - 5G as the centre of a heterogeneous network environment

The 5G ERA will create in an age of boundless pervasive connectivity and intelligent automation – creating an agile, on-demand **5G Service Based Architecture (SBA)** to coordinate an ecosystem of heterogeneous, multi-access, multi-owner infrastructure.



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Roadmap evolution to 5G ERA

1780's	1840's	1870's	1920's	1950's	1960's	1970's	1980's	1990's	2000's	2010's	2020

CRITICAL CONTROL SYSTEMS

INDUSTRY 1.0	**INDUSTRY 2.0**		**INDUSTRY 3.0**		**INDUSTRY 4.0 - IIoT**
Mechanisation, Steam Power, Looms	Mass Production, Assembly Lines, Electricity	Electro / Mechanical System Evolution	Automation, Computers, and Electronics	Time Sensitive Networks (TSN) Evolution - Wired	Cyber Physical, Sensors, Actuators and Imaging

FIXED TELEPHONE / BROADBAND NETWORKS

Telegraph	Telephone	Transatlantic connectivity	Switching	Dial-Up Modems	Cable (DOCSIS)	Broadband (xDSL)	Fibre FTTC	Fibre FTTP	

BROADCAST NETWORKS

Radio & TV	Colour TV	Cable TV	Digital Radio & TV SD	HD	UHD	SHD		

INTERNET TECHNOLOGY

ARPANET	FTP & TCP/IP and Ethernet	Fixed Internet	Browser & WWW	Mobile Internet	Network Migration to Internet / Packet

Source: Stuart Revell, RTACS Ltd, July 2020

Roadmap evolution to 5G ERA

1970's 1980's 1990's 2000's 2010's 2020

2025 to 2040 5G ERA
UNIFIED TECHNOLOGY

MOBILE NETWORKS

Pre 1G	**1G**	**2G**	**3G**	**4G**	**5G**	**5G ERA TECHNOLOGY**
	1G	2G	2G + 3G	2G, 3G, 4G	2G, 3G, 4G 5G NSA eMBB	2G, 3G, 4G, 5G eMBB NSA, ***5G SA*** ***5G URLLC, 5G MMTC,*** ***Non 3GPP Access*** ***5G Service Based Architecture (SBA)***
Voice Calls		Voice Calls & Voicemails				Voice Calls, Voicemails ***and Accessibility Services***
		Text Messages	Text & Instant Messaging			Text, Instant and ***Critical Messaging***
		M2M & IoT		M2M & NB IoT		M2M, NB IoT & ***Wireless Industrial IoT***
		Mobile Data	Mobile Data & Internet			Mobile Data, Internet and ***Secure Data***
				Services & App	Services, Apps, Virtual Reality	Services, Apps, ***Broadcast & Mixed Reality***
						Critical Control System - Apps enabled

Source: Stuart Revell, RTACS Ltd, July 2020

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5G ERA
'Network of Networks'

Multiple Sectors Using Common Network Technology & Services

Global Economies of Scale and Standardisation (3GPP and non 3GPP)

MOBILE NETWORKS

Pre 1G	1G	2G	3G	4G	5G	5G ERA TECHNOLOGY
	1G	2G	2G + 3G	2G, 3G, 4G	2G, 3G, 4G 5G NSA eMBB	2G, 3G, 4G, 5G eMBB NSA, ***5G SA*** ***5G URLLC, 5G MIoT,*** ***Non 3GPP Access*** ***5G Service Based Architecture (SBA)***
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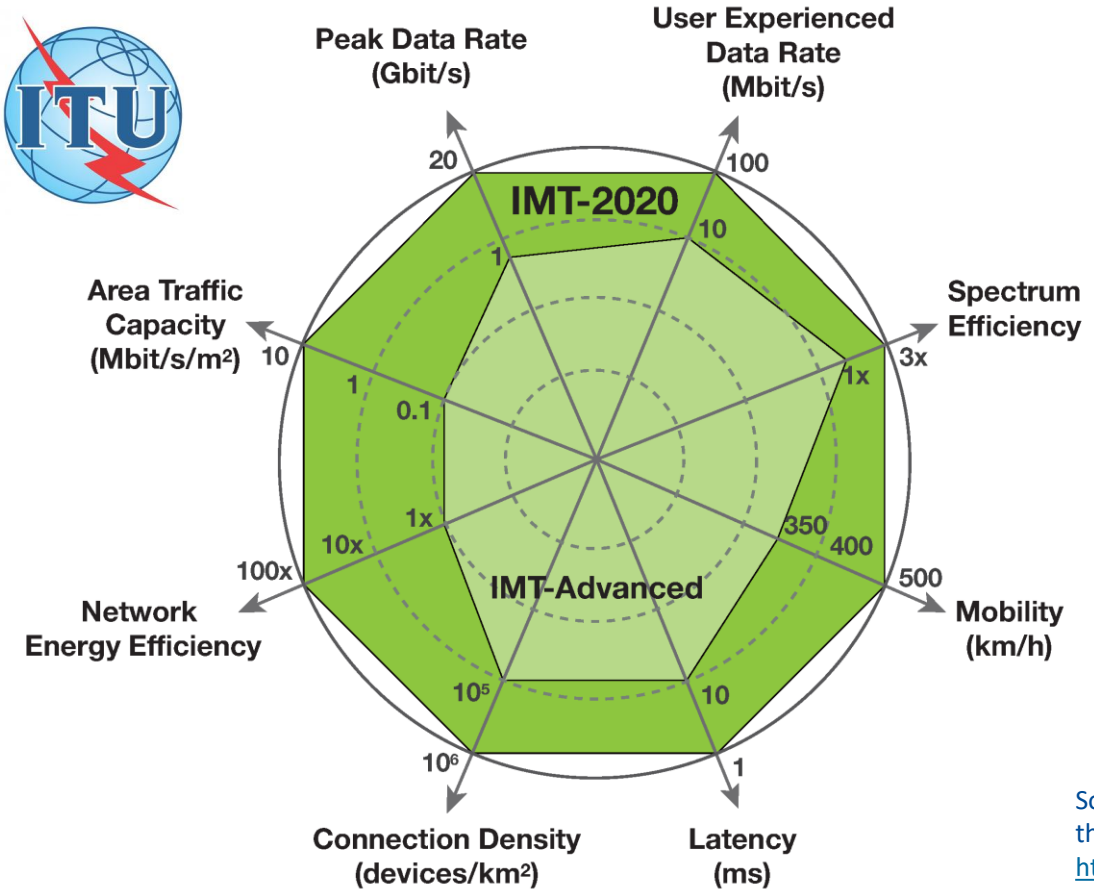
5G ERA Opportunity

… agile, on-demand 5G Service Based Architecture (SBA) to coordinate an ecosystem of heterogeneous, multi-access, multi-owner, infrastructure to provide secure connectivity and critical control system capability …

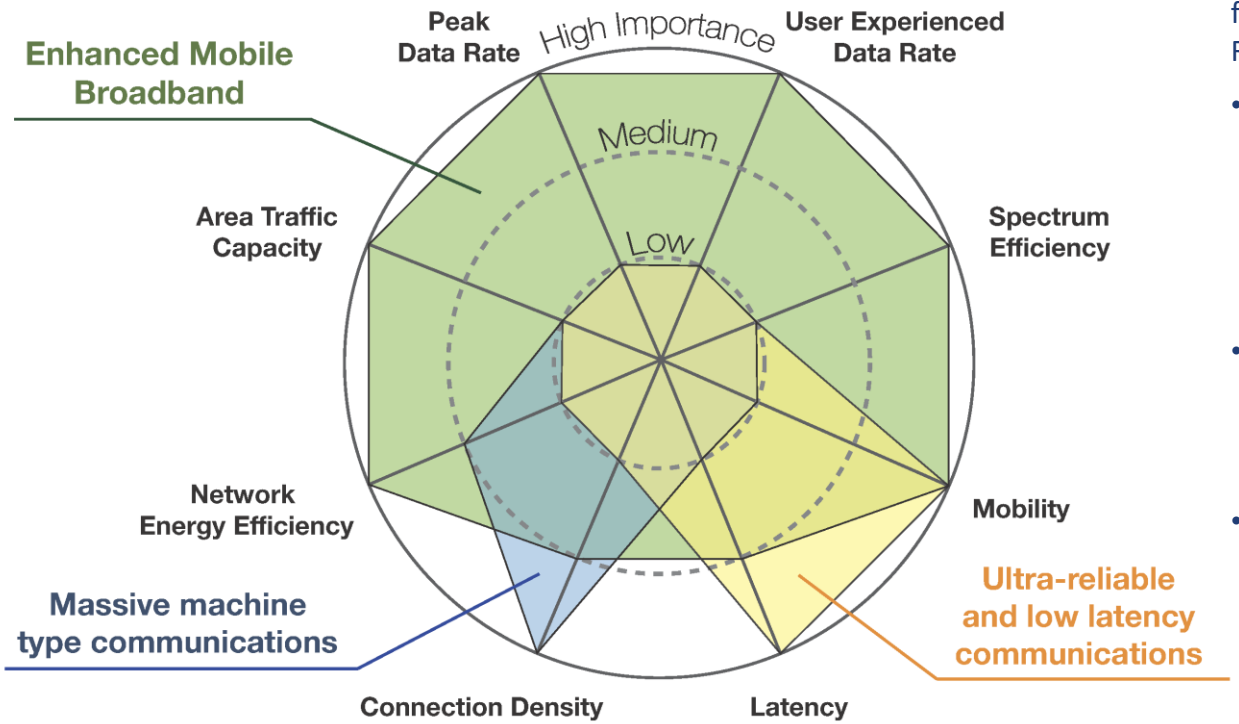
Source: Stuart Revell, RTACS Ltd, July 2020



Comparison of key capabilities of IMT-Advanced (4th generation) with IMT-2020 (5th generation) according to ITU-R M.2083

Source: M.2083 IMT Vision - Framework and overall objectives of the future development of IMT for 2020 and beyond. ITU website https://www.itu.int/rec/R-REC-M.2083-0-201509-P/en

5G ITU vision to address defined Use Cases



ITU-R defined the following main usage scenarios for IMT for 2020 and beyond in their Recommendation ITU-R M.2083:

- **Enhanced Mobile Broadband (eMBB)** to deal with hugely increased data rates, high user density and very high traffic capacity for hotspot scenarios as well as seamless coverage and high mobility scenarios with still improved used data rates
- **Massive Machine-type Communications (mMTC)** for the IoT, requiring low power consumption and low data rates for very large numbers of connected devices
- **Ultra-reliable and Low Latency Communications (URLLC)** to cater for safety-critical and mission critical applications

Source:
M.2083 IMT Vision - Framework and overall objectives of the future development of IMT for 2020 and beyond. ITU website https://www.itu.int/rec/R-REC-M.2083-0-201509-P/en and ETSI https://www.etsi.org/technologies/mobile/5g

5G ERA vision, **common** technology, defined by sector **needs**:

eMBB - Enhanced mobile broadband
- 1-10Gbps connections
- Cell DL 20 Gbps / UL 10 Gbps
- Indoor 10 Mbps per M^2
- Peak spectral efficiencies DL 30 bit/s/Hz, UL 15 bit/s/Hz
- User experience DL 100Mbps / UL 50 Mbps
- Orchestration of fixed / mobile Networks and Services
- Latency 4ms user plane / 10 to 20 ms control plane

mMTC - Massive machine type communications
- 1,000,000 per KM^2

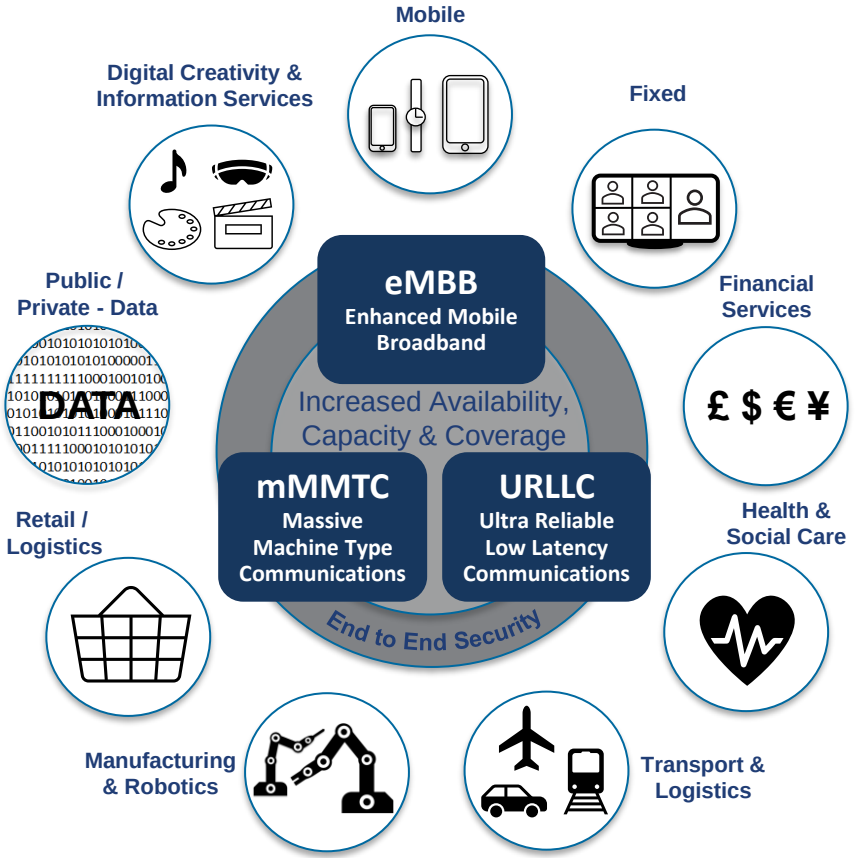
URLLC - Ultra-reliable and low latency communications
- Deterministic quality of service
- Low Latency 1ms user plane / 10 to 20 ms control plane
- Highly secure / resilient

Increased availability, coverage and capacity
- (Perception of) 99.999% availability
- (Perception of) 100% coverage

Mobility modes
- Stationary 0 km/h
- Pedestrian 10 km/h
- Vehicular 10 - 120 km/h
- High Speed 120 - 500 km/h

Operating seamlessly across boundaries
- Technical / Commercial

Source: RTACS and ITU-R M.2410-0 Nov '17



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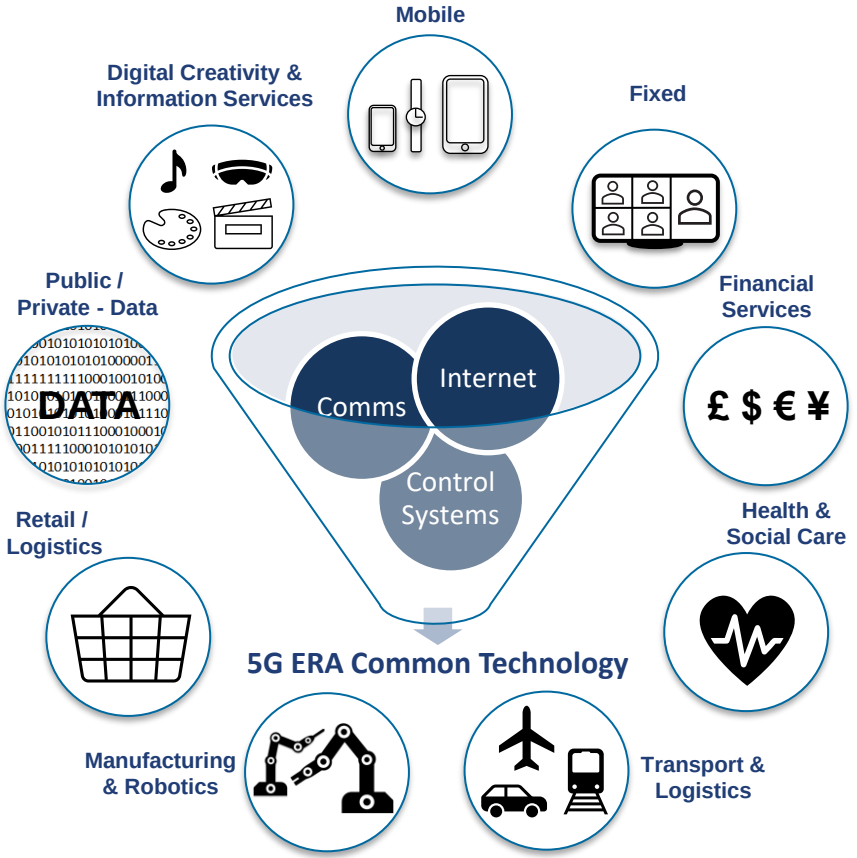


Standards and Fora

VISION **STANDARDS** **REALISATION**

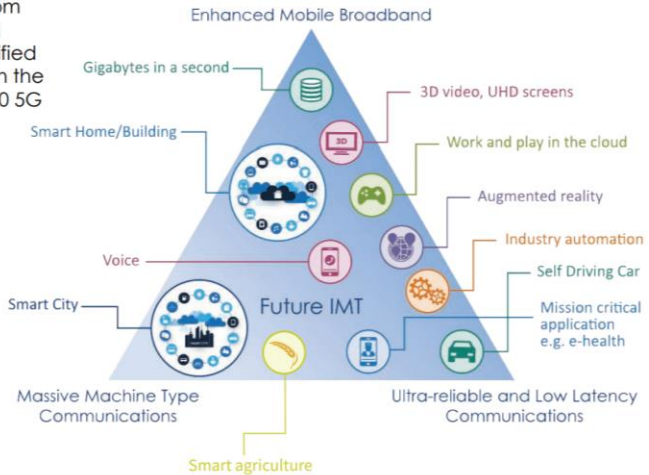
TIME

Source: https://www.3gpp.org/about-3gpp/about-3gpp and RTACS Ltd

ITU > 3GPP > 5G Standards

IMT-2020

The 5G NR access technology and the 5G core network from 3GPP will meet the potential deployment scenarios identified during the ITU-R discussion on the requirements for the IMT-2020 5G system



3GPP 5G NR

- Operation from low to very high bands: 0.4 –100Ghz
- Ultra wide bandwidth (Up to 100MHz in <6GHz, Up to 400MHz in >6GHz)
- Set of different numerologies for optimal operation in different frequency ranges
- Native forward compatibility mechanisms
- New channel coding
- Native support for Low Latency and Ultra Reliability
- Flexible and modular RAN architecture: split fronthaul, split control- and user-plane
- Native end-to-end support for Network Slicing

5G Core Network

- Functional entities → Services
- Virtual Core
- Internal Communication: APIs
- Harmonized protocols
- Function/service exposure
- CP / UP Separation

Machine Type Communications

- EC-GSM-IoT
- eMTC (LTE-M)
- NB-IoT
- 5G Cellular IoT
- NR IIoT

TIME

Source: https://www.3gpp.org/about-3gpp/about-3gpp and RTACS Ltd

3GPP Standards Developing Organisation (SDO) Partners:

ARIB	The Association of Radio Industries and Businesses, Japan	www.arib.or.jp
ATIS	The Alliance for Telecommunications Industry Solutions, USA	www.atis.org
CCSA	China Communications Standards Association	www.ccsa.org.cn
ETSI	The European Telecommunications Standards Institute	www.etsi.org
TSDSI	Telecommunications Standards Development Society, India	http://tsdsi.org/
TTA	Telecommunications Technology Association, Korea	www.tta.or.kr
TTC	Telecommunication Technology Committee, Japan	www.ttc.or.jp/e

Source: https://www.3gpp.org/about-3gpp/partners

3GPP Partners

5G-ACIA	http://www.5g-acia.org
5G Automotive Association	http://www.5gaa.org/
5G Americas	http://www.5gamericas.org
5G Deterministic Networking Alliance (5GDNA)	https://www.5gdna.org/
5G Infrastructure Association	https://5g-ppp.eu/association/
Automotive Edge Computing Consortium (AECC)	https://aecc.org/
Broadband India Forum	http://www.broadbandindiaforum.com/
Cellular Operators Association of India (COAI)	www.coai.com
China Society of Automotive Engineers (CSAE)	http://www.sae-china.org/
CTIA	http://ctia.org/
EMEA Satellite Operators Association (ESOA)	https://www.esoa.net/
GCF	www.globalcertificationforum.org/
GSA	www.gsacom.com
GSMA	www.gsma.com
IPV6 Forum	www.ipv6forum.com
NGMN Alliance	www.ngmn.org
Public Safety Communication Europe (PSCE) Forum	http://www.psc-europe.eu/
Small Cell Forum	www.smallcellforum.org
TCCA	https://tcca.info/
TD Industry Alliance	http://www.tdia.cn/
Wireless Broadband Alliance	http://www.wballiance.com/

Source: https://www.3gpp.org/about-3gpp/about-3gpp

3GPP Global Initiative (Source ETSI & RTACS Ltd)

Europe: ETSI

Japan: ARIB, TTC Telecommunication Technology Committee

Korea: TTA

China: CCSA

North America: atis

India: tsdsi

Reference to 3GPP specifications

SDO Partners referring to 3GPP Specs

Market partner and requirements

5GAA Automotive Association, 5GACIA 5G Alliance for Connected Industries and Automation, 5G americas, 5G DNA Deterministic Networking Alliance, 5G PPP The 5G Infrastructure Public Private Partnership, AECC Automotive Edge Computing Consortium, BIF Broadband India Forum "Think Tank for Digital Transformation", SAE China, COAI, ctia, ESOA EMEA Satellite Operators Association, GCF Test Certify Connect, GSA, GSMA, IPv6, ngmn the engine of wireless innovation, PSCEurope Public Safety Communication Europe, SCF, TCCA, TDIA, WIRELESS BROADBAND ALLIANCE

ITU R/T

Developing Recommendations

3GPP

A GLOBAL INITIATIVE

Referring to Specifications

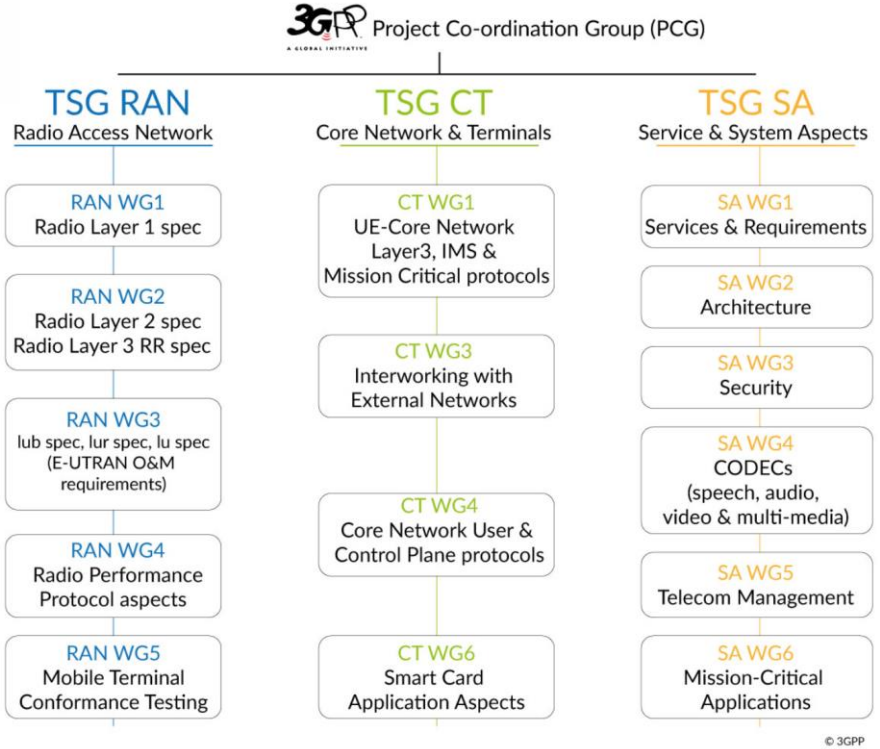
O-RAN ALLIANCE, TELECOM INFRA PROJECT, IETF

Cross reference to specifications

oma Open Mobile Alliance For a Connected World, tmforum, broadband forum, IEEE Advancing Technology for Humanity, Wi Fi ALLIANCE

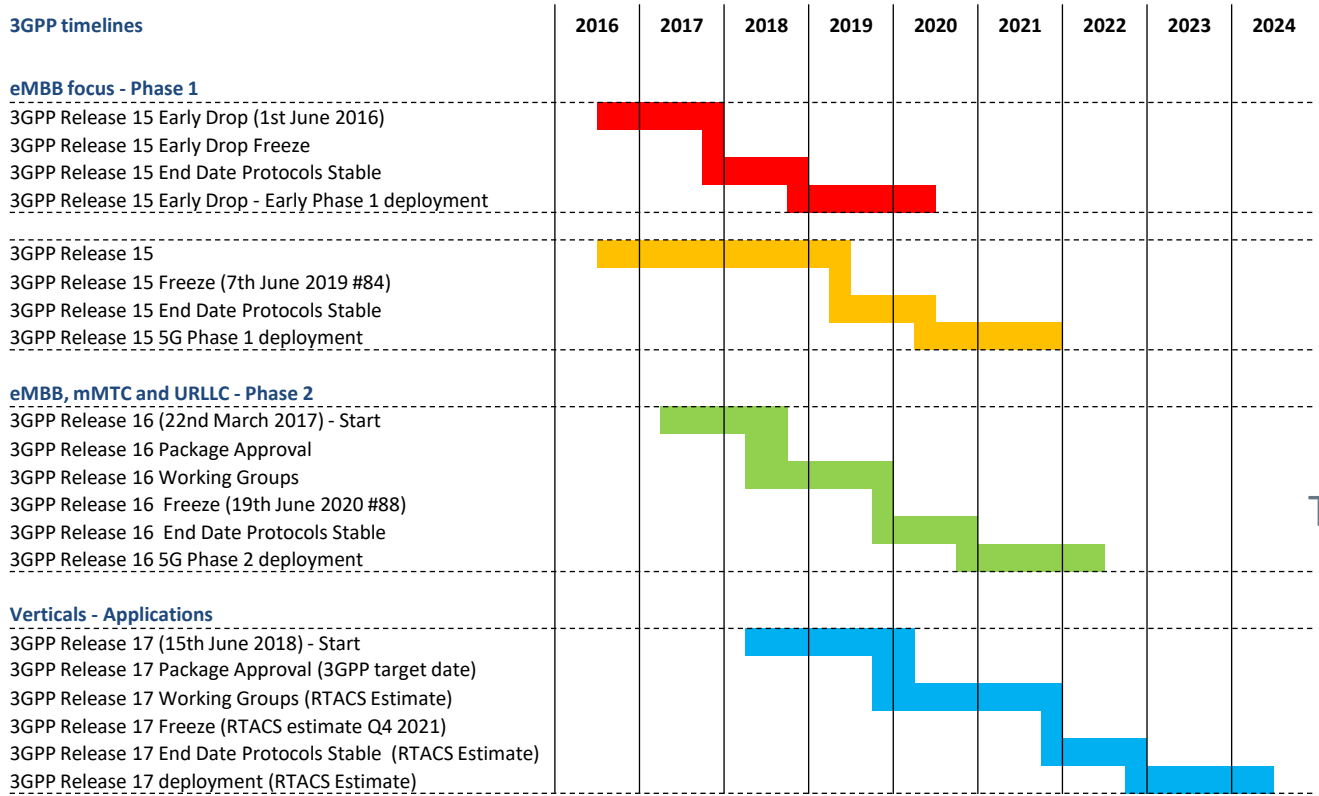
GCF Test Certify Connect — Certification based on 3GPP specifications

3GPP Working Groups:



Source: https://www.3gpp.org/about-3gpp/about-3gpp

3GPP 5G roadmap (Rel 15, 16 & 17)



Technologies for IMT - 2020

3GPP Releases 15, 16 & 17

Source: RTACS Ltd & https://portal.3gpp.org/#/55934-releases (July 2020)

5G Evolution across three major releases

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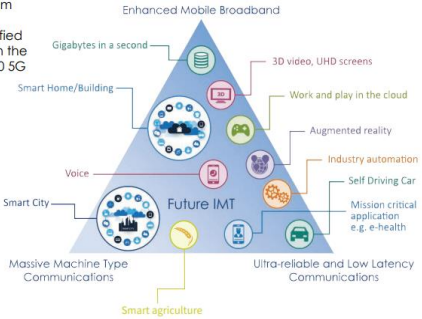

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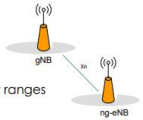

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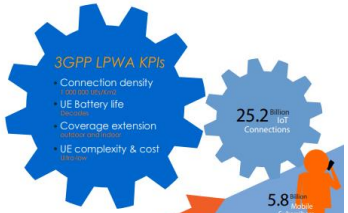

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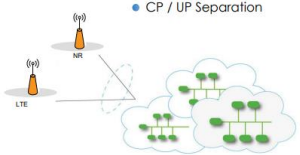
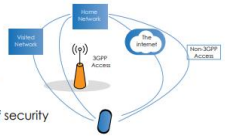


Security architecture and procedures for 5G systems

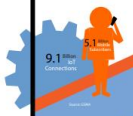
TS 33.501

- Network access security
- Network domain security
- User domain security
- Application domain security
- SBA domain security
- Visibility and configurability of security



Data Growth

The Mobile Broadband Standard



Release 15

- NR
- The 5G System – Phase 1
- Massive MTC 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
- 5GC LoCation Services
- 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)

These are the Rel-17 headline features, prioritized during the December 2019 Plenaries (TSG #86)

Start of work: January 2020

www.3gpp.org/specifications/work-plan

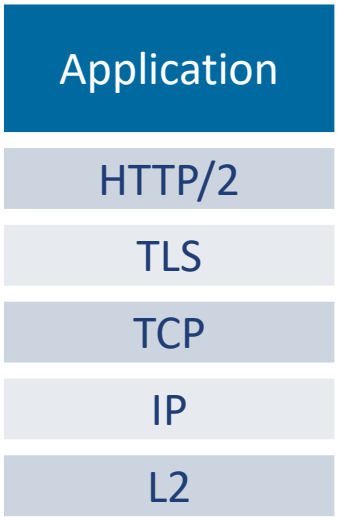
Self-driving Cars
Industry Automation
Smart Cities
Smart Homes
Work & Play in the Cloud
Augmented Reality
3D video, UHD screens
Gigabytes per second

Release15 2020 Release16 2021 Release17 2022 2023 2024 2025

Source: 3GPP https://www.3gpp.org/ftp/Information/presentations/presentations_2020/Poster_2020_MWC_v6_OPTIMIZED.pdf

System Architecture End-to-End (E2E)

Service Based Interface Protocol Stack



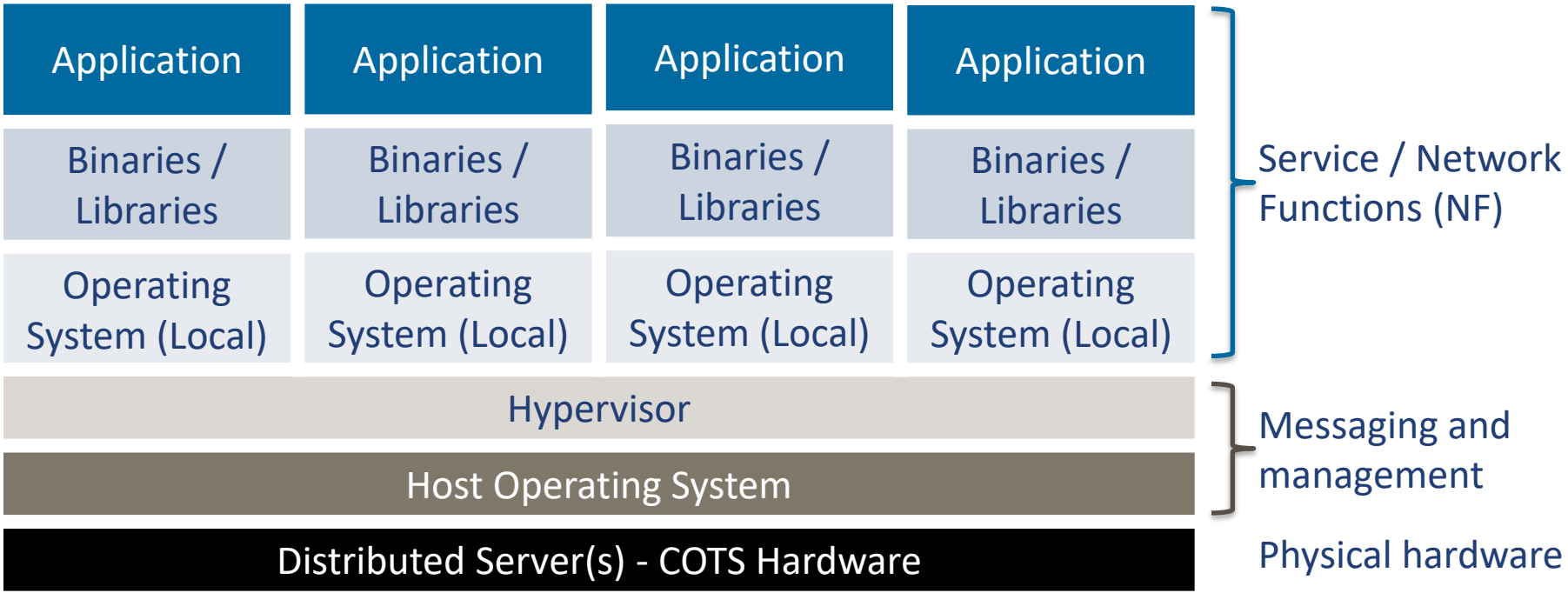
To reduce the coupling between clients and servers, the RESTful framework is used for the APIs

- the transport layer protocol is TCP as specified in IETF RFC 793
- transport layer security protection is supported with TLS
- the application layer protocol is HTTP/2 as specified in IETF RFC 7540
- the serialisation protocol is JSON as specified in IETF RFC 8259
- the OpenAPI 3.0.0 is adopted as the Interface Definition Language

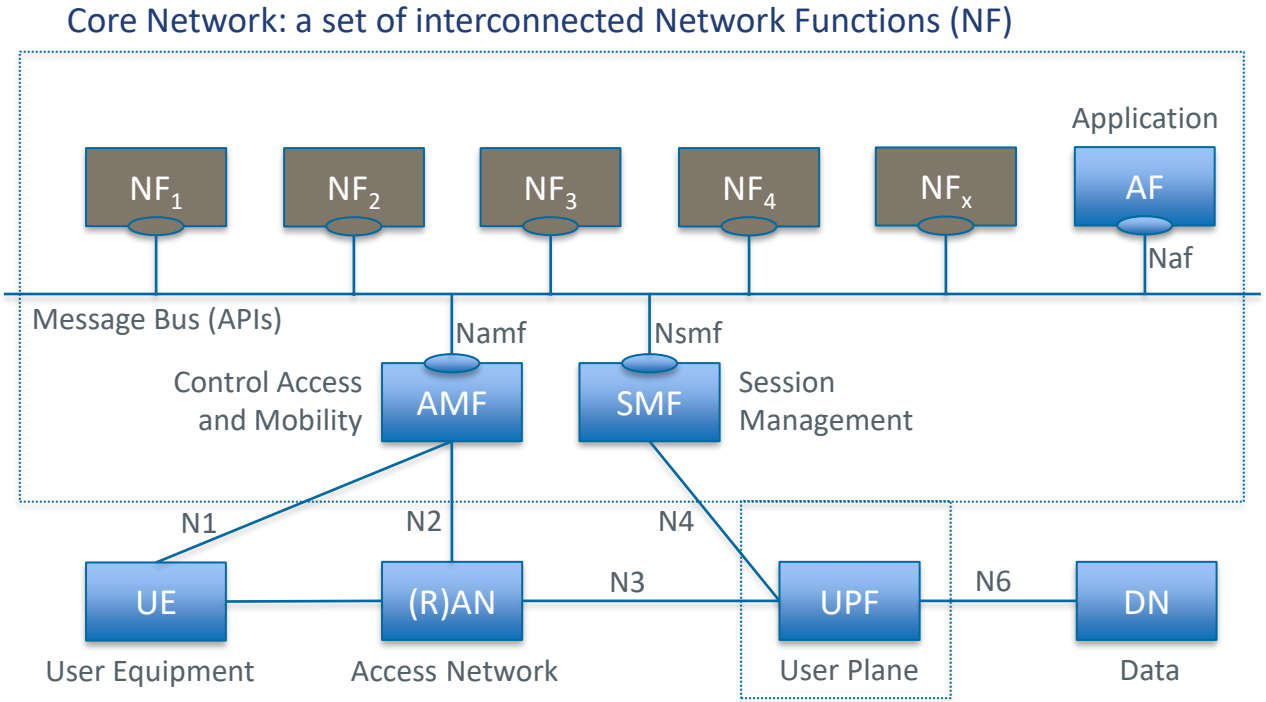
Source: 3GPP Technical report 3GPP TR 21.915 V15.0.0 (2019-09)

5G Network Function Virtualisation (NFV)

Virtual Machines / Functions running on distributed Commercial Off The Shelf (COTS) Hardware



5G Service Based Architecture (SBA)

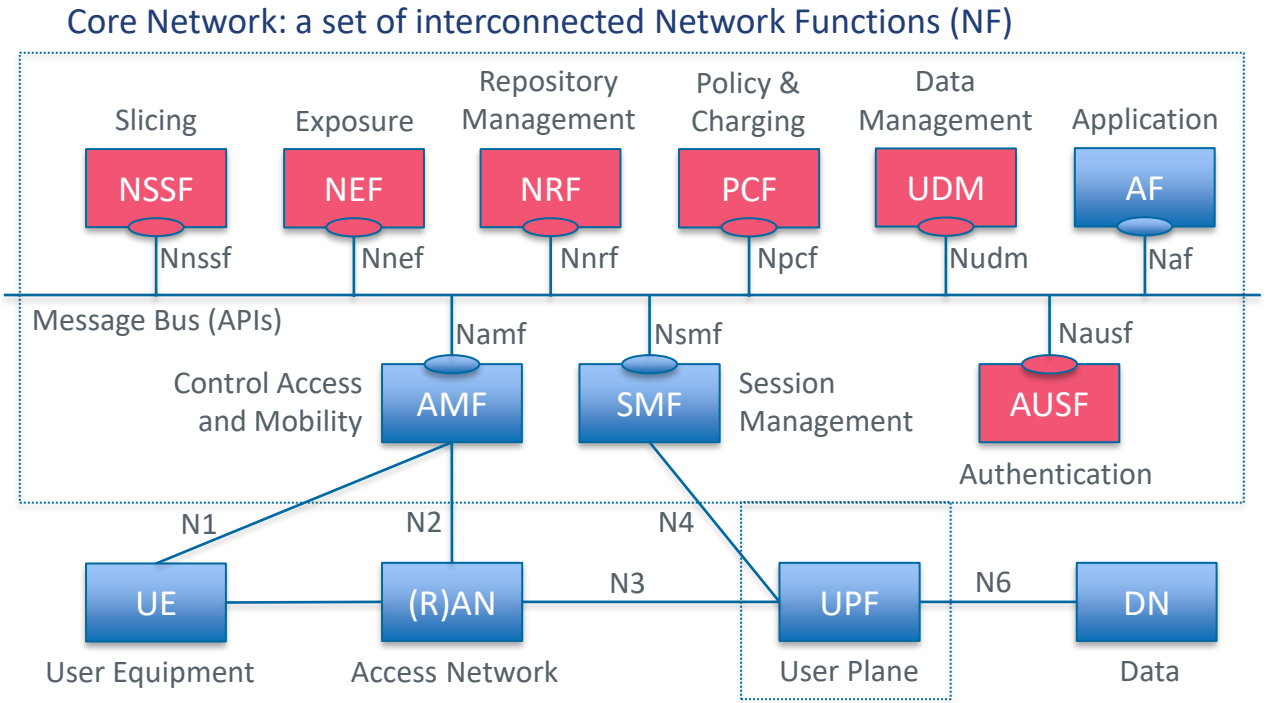


Network Functions and elements:

- The Access and Mobility management Function (AMF), that accesses the UE and the (R)AN
- The Session Management Function (SMF), that accesses the UPF. UE IP address allocation and management
- The User Equipment (UE)
- The (Radio) Access Network [(R)AN]
- The User Plane Function (UPF), handling the user data, mobility anchoring and Protocol Data Unit (PDU) session types - including IPv4, IPv6, IPv4v6, Ethernet and Unstructured
- The (external) Data Network (DN)
- The Application Function (AF), handling the application(s)

Source: RTACS Ltd and 3GPP Technical report 3GPP TR 21.915 V15.0.0 (2019-09)

5G Service Based Architecture (SBA)

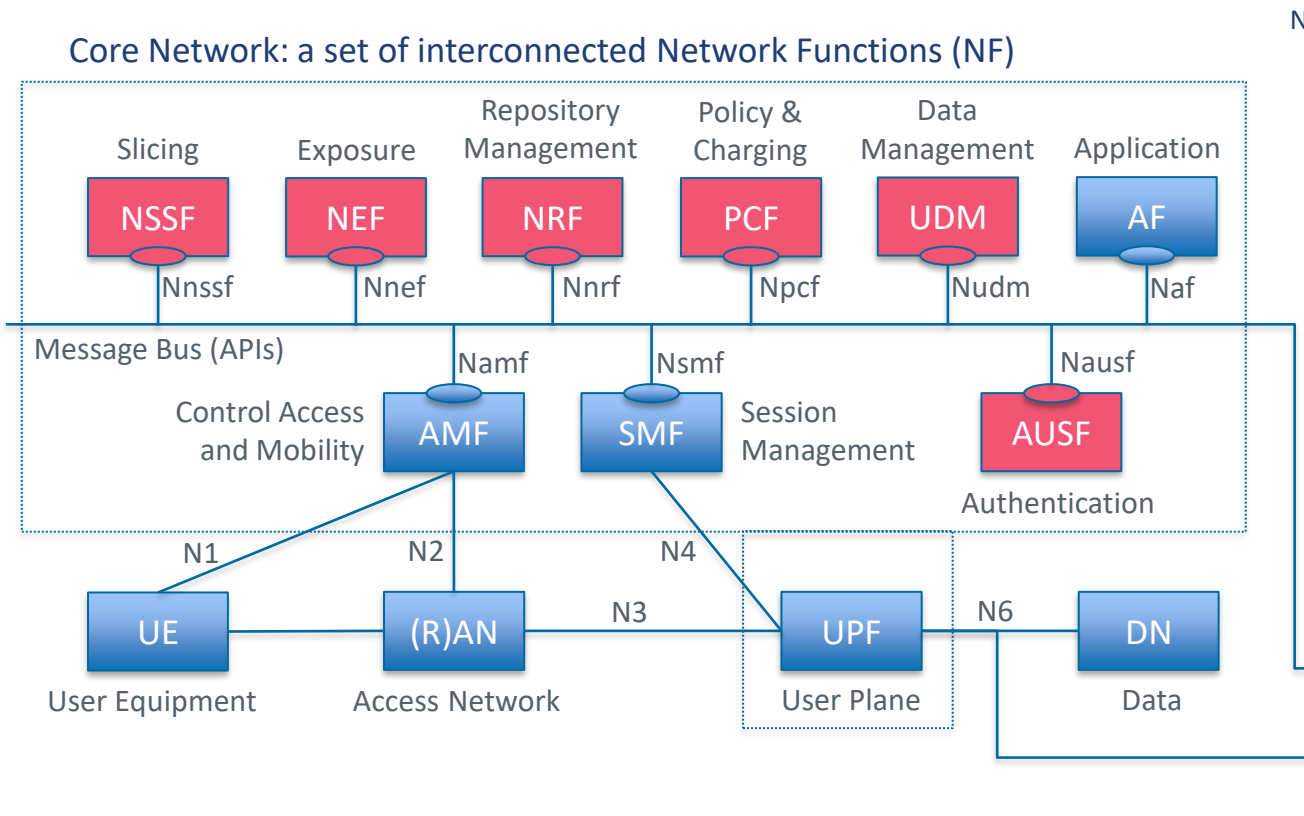


Network Functions and elements:

- Network Slice Selection Function (NSSF)
- Authentication Server Function (AUSF)
- Policy Control Function (PCF)
- The security-related NFs, i.e. SEAF, AUSF, ARPF, SEPP, are (also) presented in the section on 5G Security
- Network Repository Function (NRF): NF management including registration, deregistration, authorisation and discovery
- Network Exposure Function (NEF): Monitoring capability, Provisioning capability, Application influence of traffic routing and Policy/Charging capability
- Unified Data Management (UDM): the 5GC supports Data Storage architecture for Compute and Storage separation. The Unified Data Repository (UDR) is the master database. The Unstructured Data Storage Function (UDSF) is introduced to store dynamic state data

Source: RTACS Ltd and 3GPP Technical report 3GPP TR 21.915 V15.0.0 (2019-09)

5G Service Based Architecture (SBA)

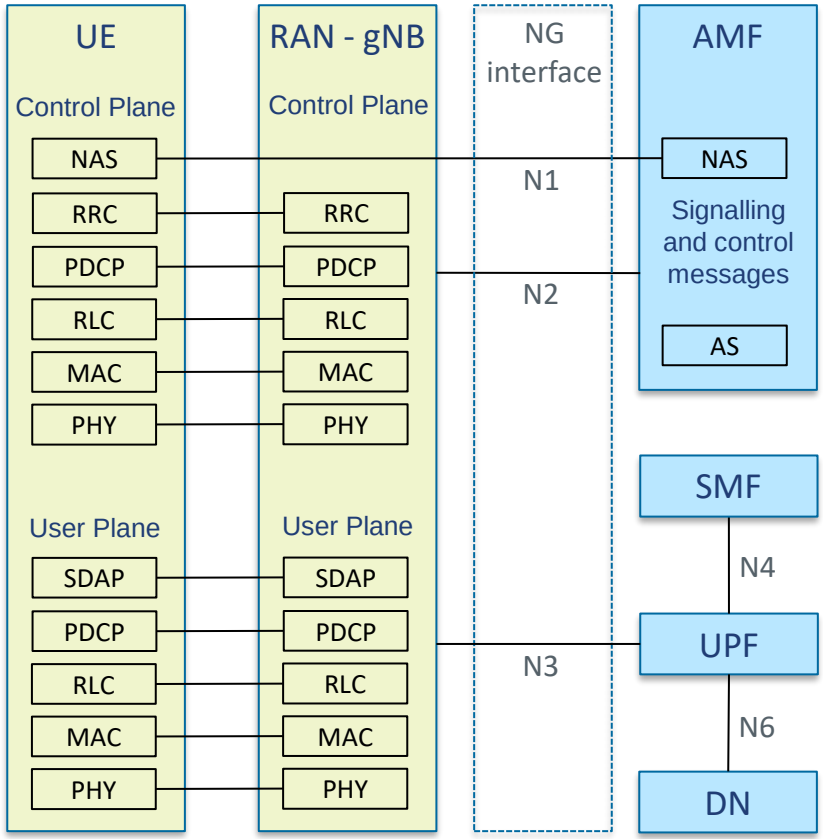


Network Functions and elements:

- Operation Support System (OSS)
- Business Support System (BSS)
- Network Operations Centre (NOC)
- Management and Network Orchestration (MANO), options:
  - Open Platform for NFV (OPNNFV) - Linux Foundation
  - Open Network Automation Protocol (ONAP) - Linux Foundation
  - ETSI Open-Source MANO (OSM)

Source: RTACS Ltd and 3GPP Technical report 3GPP TR 21.915 V15.0.0 (2019-09)

Control and User Plane Protocol Stacks



NAS (Non-Access Stratum) control protocol refers to all the aspects / protocols not linked to the Access Network and transported "transparently" by the Access Network, i.e. without interpretation - including authentication, mobility management and security control.

AS (Access Stratum) security control for the Access Node

RRC (Radio Resource Control), establishment, maintenance and release of an RRC connection between the UE and RAN. 3 states: disconnected/idle, connected inactive and connected active

PDCP control plane (Packet Data Convergence Protocol) transfer of control plane data, sequence numbering, reordering and duplicate detection, duplication of PDCP PDUs

SDAP user plane (Service Data Adaptation Protocol), mapping between a QoS flow and a data radio bearer and marking QoS flow ID (QFI) in both DL and UL packets.

PDCP user plane (Packet Data Convergence Protocol) transfer of the user plane data, sequence numbering, header compression and decompression

RLC (Radio Link Control), transfer of upper layer PDUs and lower-level sequence numbering

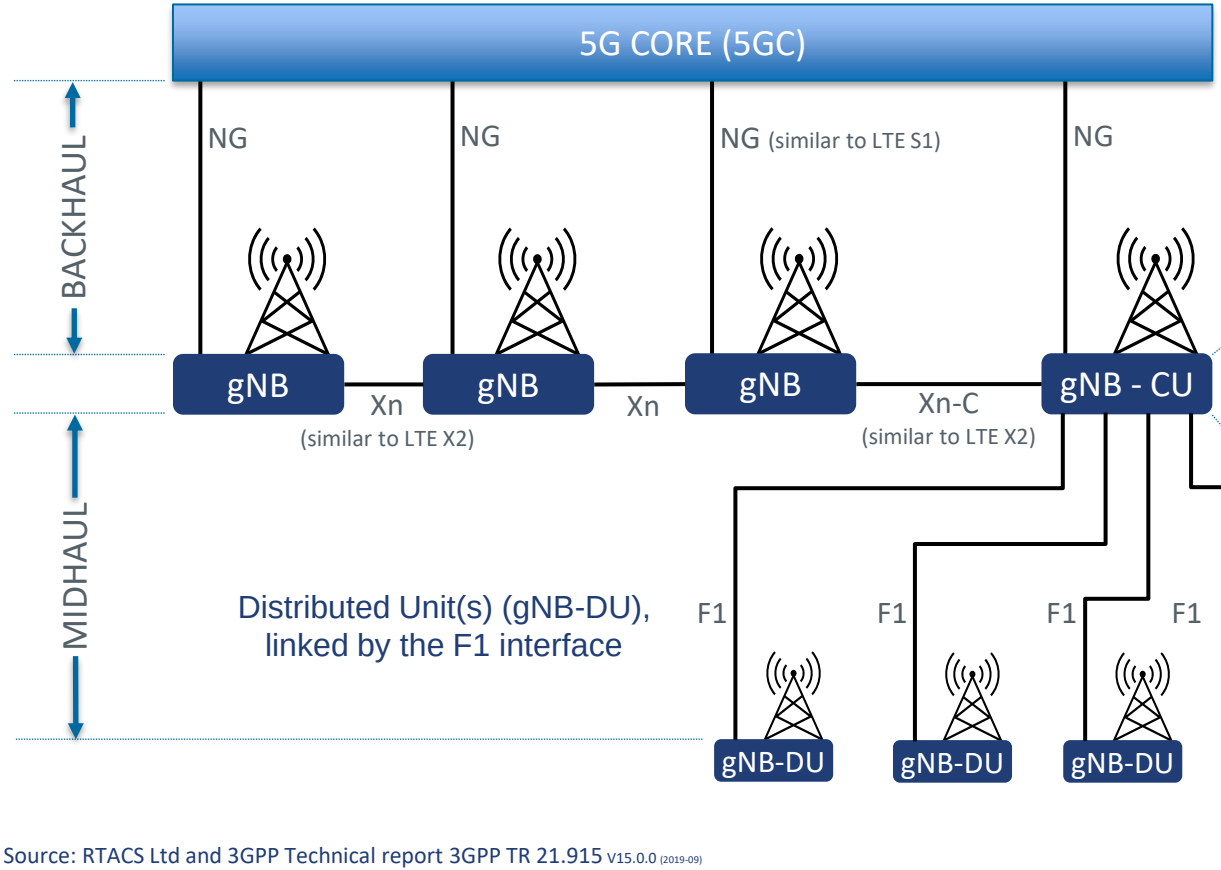
MAC (Medium Access Control), Mapping between logical channels and transport channels, dynamic resource scheduling, priority handling, error correction through Hybrid Automatic Repeat reQuest (HARQ)

PHY layer (physical layer) modulates and demodulates the signal onto the radio air interface

The only major difference between the uplink (UL) and downlink (DL) user plane stack is that the UL stack does not have support for carrier aggregation

Source: RTACS Ltd and 3GPP Technical report 3GPP TR 21.915 V15.0.0 (2019-09)

NG-RAN physical architecture

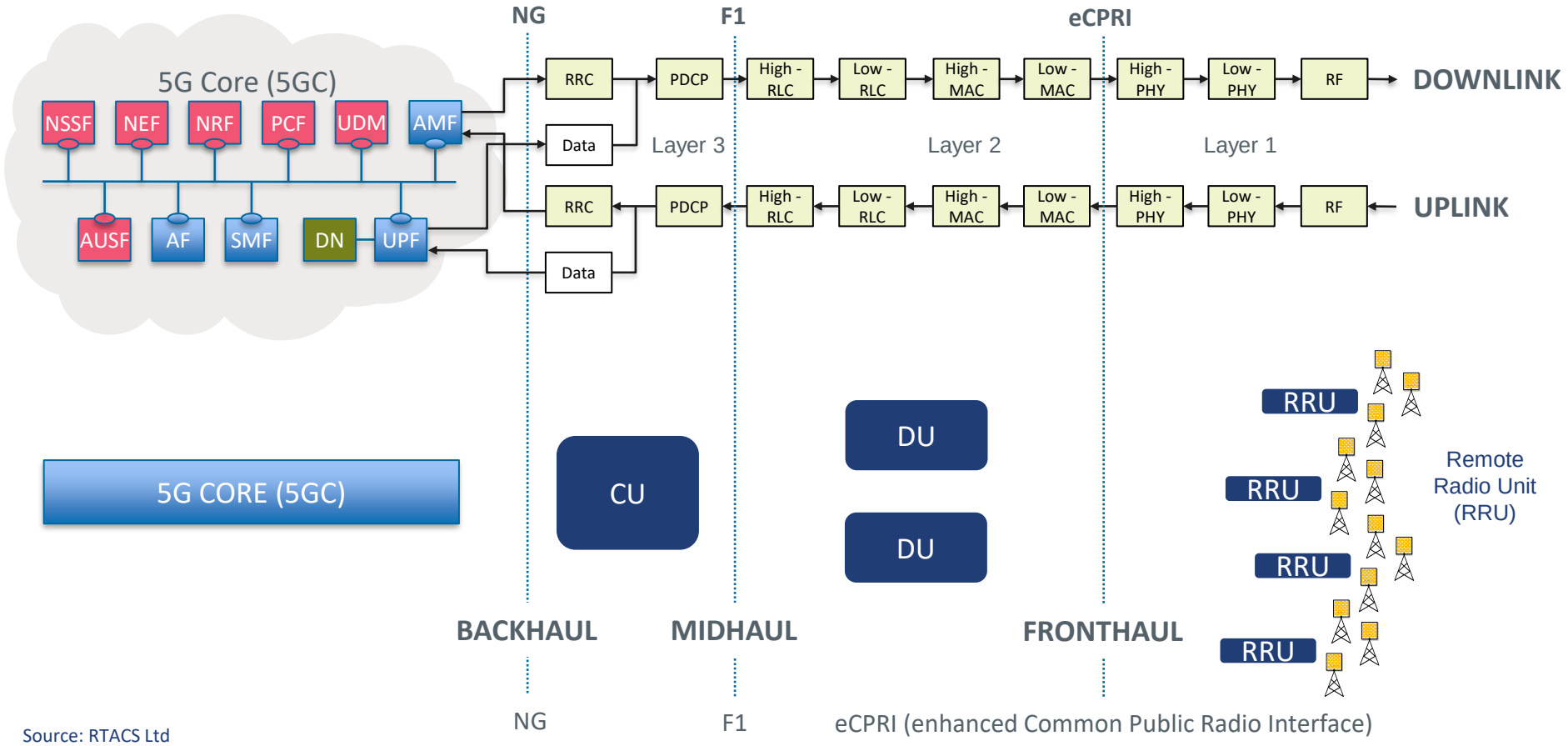


The NG-RAN consists of a set of gNBs connected to the 5GC through the NG interface, based on (and very similar to) the LTE's S1 interface.

The gNB (5G Node B) can be connected to another gNB through the Xn interface, based on (and very similar to) the LTE's X2 interface.

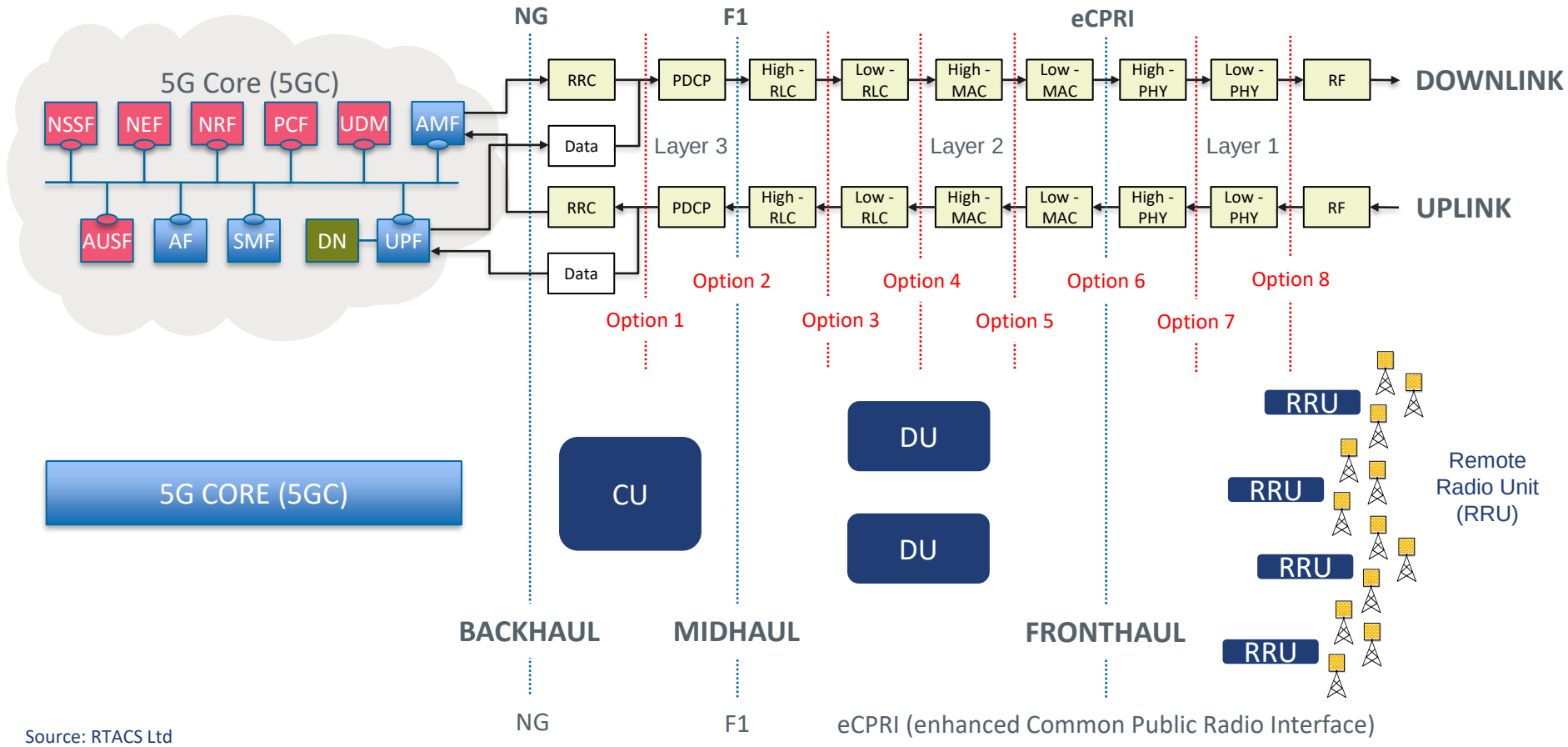
Source: RTACS Ltd and 3GPP Technical report 3GPP TR 21.915 V15.0.0 (2019-09)

NG-RAN functional splits



Source: RTACS Ltd

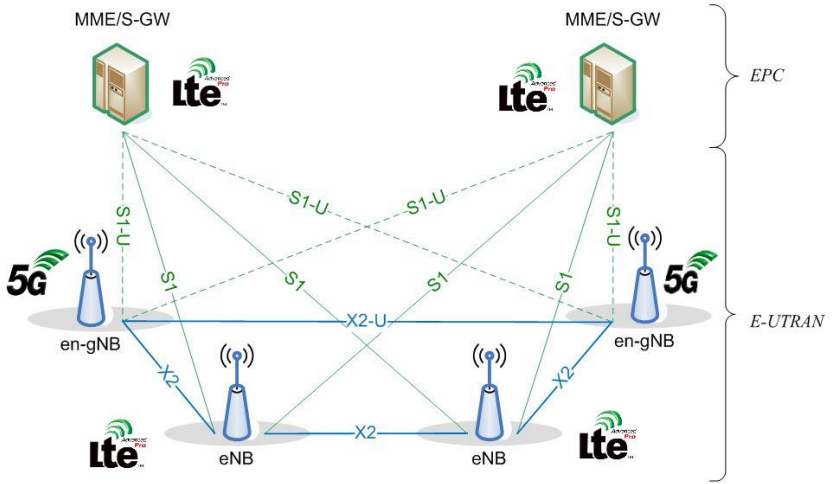
NG-RAN functional splits – OpenRAN options



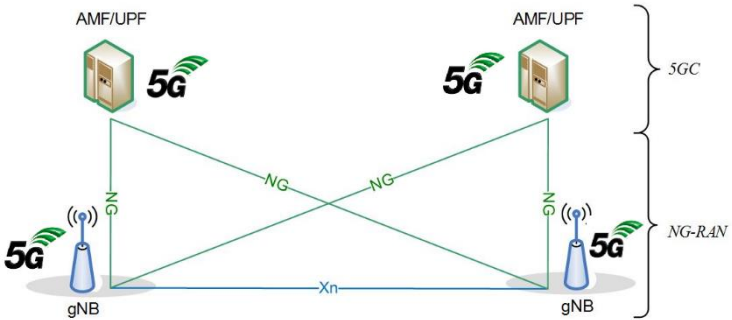
Source: RTACS Ltd

NSA and SA architectures

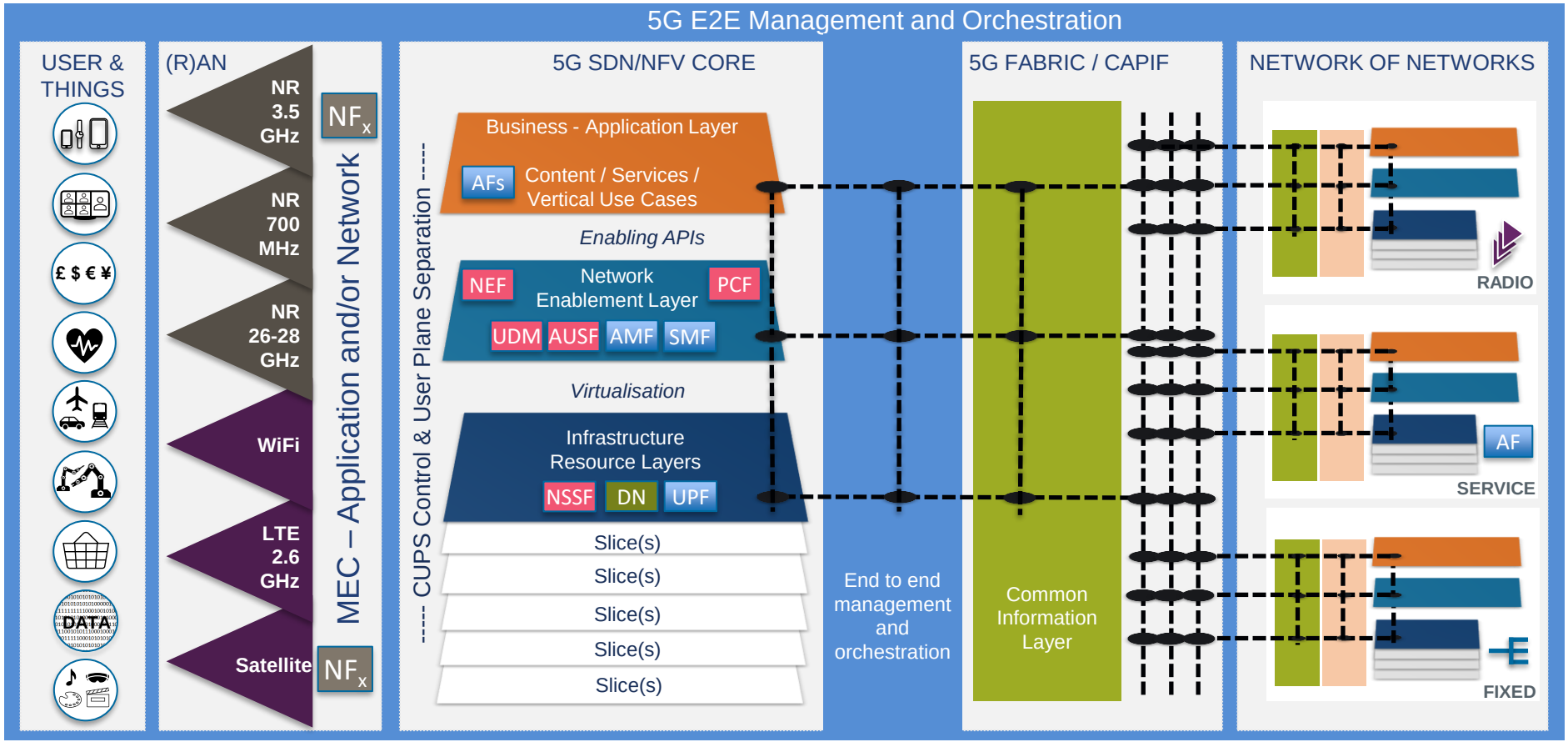
Non Standalone Architecture (NSA)



Standalone Architecture (SA)



Source: 3GPP Technical report 3GPP TR 21.915 V15.0.0 (2019-09)

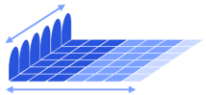


Source: Stuart Revell, RTACS Ltd

5G New Radio (5G NR) & Spectrum

5G New Radio (5G NR) & Spectrum

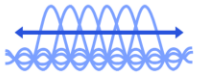
Flexible slot-based framework



Scalable OFDM numerology

Low latency, URLLC, forward compatibility

Scalable OFDM-based air interface



Self-contained slot structure

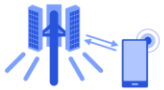
Address diverse services, spectrum, deployments

Advanced channel coding

Multi-Edge LDPC and CRC-Aided Polar

Support large data blocks, reliable control channel

Massive MIMO



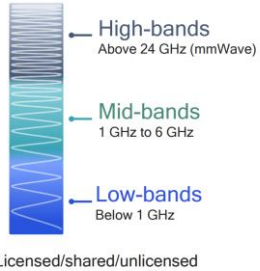
Reciprocity-based MU-MIMO

Large # of antennas to increase coverage/capacity

Mobile mmWave

Beamforming and beam-tracking

For extreme capacity and throughput



Diverse spectrum

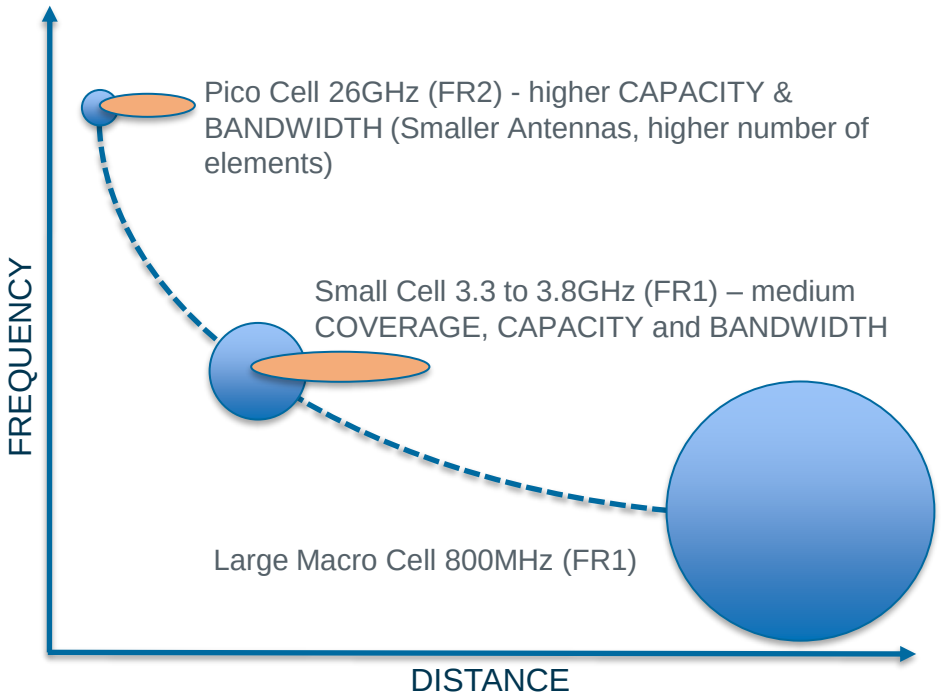
Source: Qualcomm - Future of 5G, Building a unified, more capable 5G air interface for the next decade and beyond (February 2020)

4G LTE compared to 5G

Parameter	4G LTE	5G NR
Component Carrier Bandwidth (BW)	Up to 20MHz	Up to 400MHz
Carrier BW	Full Carrier	Bandwidth Part(s) defined (BWP)
Subcarrier Spacing (SCS)	Fixed: 15kHz	Flexible: 15, 30, 60, 120, 240 kHz
Transmission Time Interval (TTI)	Fixed: 1ms	Flexible: 1, 0.5, 0.25, 0.125, 0.063 ms
Transmission Scheme (DL/UL)	DL: OFDM UL: SC-FDMA	DL: Cyclic Prefix-OFDM (CP-OFDM) UL: CP-OFDM or SC-FDMA UL: DFT-s-OFDM (OFDM with Discrete Fourier Transform precoding), can be used. Limited to single-layer transmission only - lower peak-to-average power ratio (PAPR)
Frame Structure	FDD – Type 1 TDD – Type 2	Same for TDD and FDD

Frequency Ranges and Channel Bandwidth

FREQUENCY ‘vs’ DISTANCE ‘vs’ COVERAGE



Frequency range	Carrier Frequency range	Supported channel bandwidth (MHz)
FR1	410 MHz – 7125 MHz	5, 10, 15, 20, 25, 30, 40, 50, 60, 80, 90, 100
FR2	24250 MHz – 52600 MHz	50, 100, 200, 400

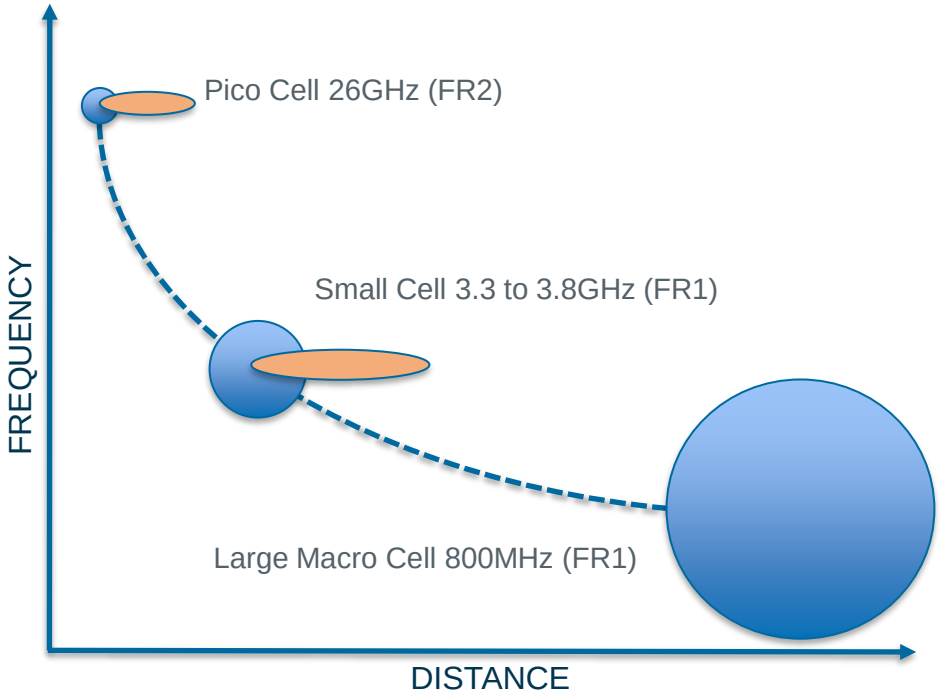
Lower Frequency – travels further, larger COVERAGE area, lower CAPACITY & BANDWIDTH (Larger Antennas)

Key: Cell Size – 360° Cells – directional capability to extend range (MIMO / Smart Antenna)

Source: RTACS Ltd

Frequency Ranges and Channel Bandwidth

FREQUENCY ‘vs’ DISTANCE ‘vs’ COVERAGE



Frequency Range nXX (TO SCALE)

Band n258: 24.25 - 27.5GHz TDD = 3.25GHz

Band n78: 3.3 - 3.8GHz TDD = 500MHz

Band n20: 791 - 862MHz (2 x 30MHz FDD) = 60MHz

Key: Cell Size – 360° Cells – directional capability to extend range (MIMO / Smart Antenna)

Source: RTACS Ltd

NR Spectrum specified in the Rel-15 time frame

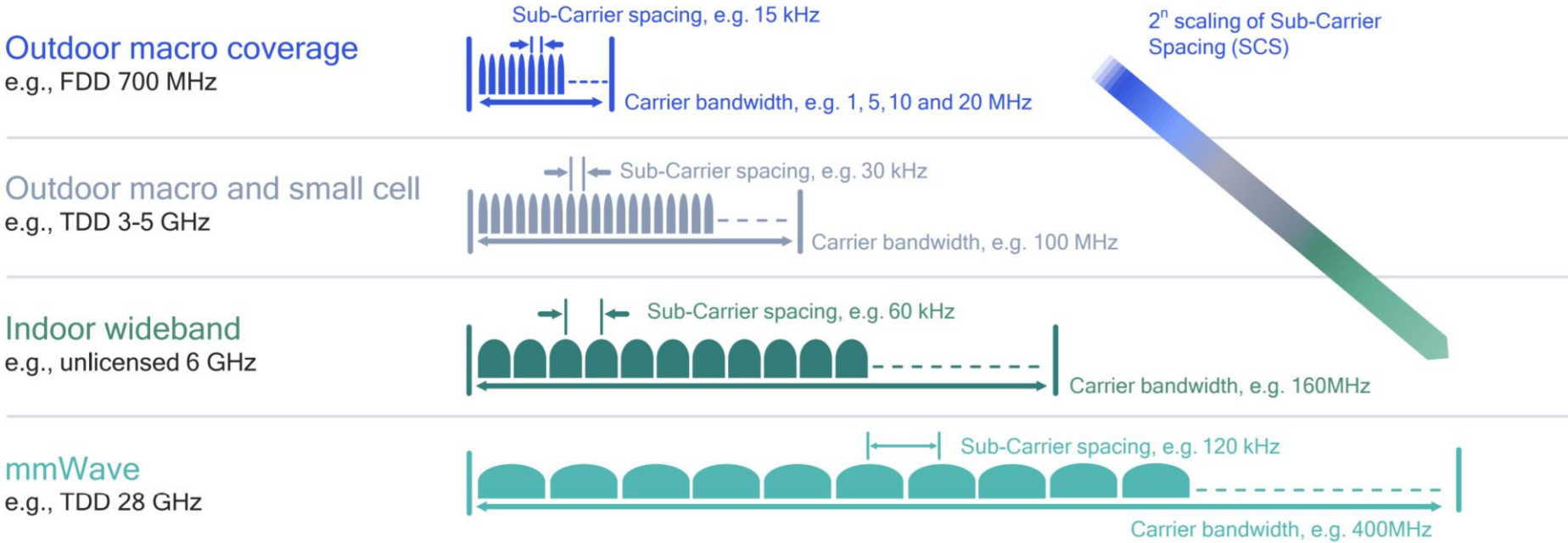
NR operating band	Uplink (UL) operating band	UL Band Size (MHz)	Downlink (DL) operating band	DL Band Size (MHz)	Duplex Mode	Frequency Range	Supported channel bandwidth [MHz]
n1	1920 MHz – 1980 MHz	60	2110 MHz – 2170 MHz	60	FDD	FR1	5, 10, 15, 20, 25, 30, 40, 50, 60
n2	1850 MHz – 1910 MHz	60	1930 MHz – 1990 MHz	60	FDD	FR1	5, 10, 15, 20, 25, 30, 40, 50, 60
n3	1710 MHz – 1785 MHz	75	1805 MHz – 1880 MHz	75	FDD	FR1	5, 10, 15, 20, 25, 30, 40, 50, 60, 80
n5	824 MHz – 849 MHz	25	869 MHz – 894 MHz	25	FDD	FR1	5, 10, 15, 20, 25
n7	2500 MHz – 2570 MHz	70	2620 MHz – 2690 MHz	70	FDD	FR1	5, 10, 15, 20, 25, 30, 40, 50, 60, 80
n8	880 MHz – 915 MHz	35	925 MHz – 960 MHz	35	FDD	FR1	5, 10, 15, 20, 25, 30
n12	699 MHz – 716 MHz	17	729 MHz – 746 MHz	17	FDD	FR1	5, 10, 15
n20	832 MHz – 862 MHz	30	791 MHz – 821 MHz	30	FDD	FR1	5, 10, 15, 20, 25, 30
n25	1850 MHz – 1915 MHz	65	1930 MHz – 1995 MHz	65	FDD	FR1	5, 10, 15, 20, 25, 30, 40, 50, 60
n28	703 MHz – 748 MHz	45	758 MHz – 803 MHz	45	FDD	FR1	5, 10, 15, 20, 25, 30, 40
n34	2010 MHz – 2025 MHz	15	2010 MHz – 2025 MHz	15	TDD	FR1	5, 10, 15
n38	2570 MHz – 2620 MHz	50	2570 MHz – 2620 MHz	50	TDD	FR1	5, 10, 15, 20, 25, 30, 40, 50, 60, 80, 90, 100
n39	1880 MHz – 1920 MHz	40	1880 MHz – 1920 MHz	40	TDD	FR1	5, 10, 15, 20, 25, 30, 40
n40	2300 MHz – 2400 MHz	100	2300 MHz – 2400 MHz	100	TDD	FR1	5, 10, 15, 20, 25, 30, 40, 50, 60, 80, 90, 100
n41	2496 MHz – 2690 MHz	194	2496 MHz – 2690 MHz	194	TDD	FR1	5, 10, 15, 20, 25, 30, 40, 50, 60, 80, 90, 100
n50	1432 MHz – 1517 MHz	85	1432 MHz – 1517 MHz	85	TDD1	FR1	5, 10, 15, 20, 25, 30, 40, 50, 60, 80
n51	1427 MHz – 1432 MHz	5	1427 MHz – 1432 MHz	5	TDD	FR1	5
n66	1710 MHz – 1780 MHz	70	2110 MHz – 2200 MHz	90	FDD	FR1	5, 10, 15, 20, 25, 30, 40, 50, 60, 80, 90
n70	1695 MHz – 1710 MHz	15	1995 MHz – 2020 MHz	25	FDD	FR1	5, 10, 15, 20, 25
n71	663 MHz – 698 MHz	35	617 MHz – 652 MHz	35	FDD	FR1	5, 10, 15, 20, 25, 30
n74	1427 MHz – 1470 MHz	43	1475 MHz – 1518 MHz	43	FDD	FR1	5, 10, 15, 20, 25, 30, 40
n75	N/A	0	1432 MHz – 1517 MHz	85	SDL	FR1	5, 10, 15, 20, 25, 30, 40, 50, 60, 80
n76	N/A	0	1427 MHz – 1432 MHz	5	SDL	FR1	5
n77	3300 MHz – 4200 MHz	900	3300 MHz – 4200 MHz	900	TDD	FR1	5, 10, 15, 20, 25, 30, 40, 50, 60, 80, 90, 100
n78	3300 MHz – 3800 MHz	500	3300 MHz – 3800 MHz	500	TDD	FR1	5, 10, 15, 20, 25, 30, 40, 50, 60, 80, 90, 100
n79	4400 MHz – 5000 MHz	600	4400 MHz – 5000 MHz	600	TDD	FR1	5, 10, 15, 20, 25, 30, 40, 50, 60, 80, 90, 100
n80	1710 MHz – 1785 MHz	75	N/A	0	SUL	FR1	5, 10, 15, 20, 25, 30, 40, 50, 60
n81	880 MHz – 915 MHz	35	N/A	0	SUL	FR1	5, 10, 15, 20, 25, 30
n82	832 MHz – 862 MHz	30	N/A	0	SUL	FR1	5, 10, 15, 20, 25, 30
n83	703 MHz – 748 MHz	45	N/A	0	SUL	FR1	5, 10, 15, 20, 25, 30, 40
n84	1920 MHz – 1980 MHz	60	N/A	0	SUL	FR1	5, 10, 15, 20, 25, 30, 40, 50, 60
n86	1710 MHz – 1780MHz	70	N/A	0	SUL	FR1	5, 10, 15, 20, 25, 30, 40, 50, 60
n257	26500 MHz – 29500 MHz	3000	26500 MHz – 29500 MHz	3000	TDD	FR2	50, 100, 200, 400
n258	24250 MHz – 27500 MHz	3250	24250 MHz – 27500 MHz	3250	TDD	FR2	50, 100, 200, 400
n260	37000 MHz – 40000 MHz	3000	37000 MHz – 40000 MHz	3000	TDD	FR2	50, 100, 200, 400
n261	27500 MHz – 28350 MHz	850	27500 MHz – 28350 MHz	850	TDD	FR2	50, 100, 200, 400

Source: RTACS Ltd and 3GPP Technical report 3GPP TR 21.915 V15.0.0 (2019-09)

5G Technology – New Radio and Spectrum

Source: Qualcomm https://www.qualcomm.com/system/files/document/files/powerpoint_presentation_-_making_5g_nr_a_reality_february_2020_web_0.pdf

Flexible channel bandwidth and subcarrier spacing – OFDM numerology



NR uses a flexible frame structure, with different Subcarrier Spacings (SCS).
The SCS is the distance between the centres of two consecutive subcarriers, and the possible values for SCS are (in kHz): 15, 30, 60, 120 and 240 kHz. This is referred to as "multiple numerologies“ or “scalable numerology”

Source: Qualcomm https://www.qualcomm.com/system/files/document/files/powerpoint_presentation_-_making_5g_nr_a_reality_february_2020_web_0.pdf

Physical channels, coding, modulation and signals gNB

DOWNLINK INPUT DATA

Physical channel name		Channel Coding	Mapping and Modulation	Antenna Ports	TRANSMIT
PDSCH	Physical Downlink Shared Channel	LDPC (Low Density Parity Check) coding	QPSK, 16QAM, 64QAM, 256QAM		
PDCCH	Physical Downlink Control Channel	Polar coding	QPSK		
PBCH	Physical Broadcast Channel	Polar coding	QPSK		

UPLINK OUTPUT DATA

Physical channel name		Channel Decoding	Mapping and Demodulation	Antenna Ports	RECEIVE
PUSCH	Physical Uplink Shared Channel	LDPC coding for data, see table below for UCI	QPSK, 16QAM, 64QAM, 256QAM, pi/2 BPSK when DFT-s-OFDM is selected		
PUCCH	Physical Uplink Control Channel	see table below for UCI	pi/2-BPSK, BPSK, QPSK depending on PUCCH format and information bit size		
PRACH	Physical Random Access Channel	N/A*	N/A*		

* PRACH see page see Section 5.5.4.3. 3GPP TR 21.915 V15.0.0 (2019-09)

Channel coding for uplink control information (UCI)

UCI size including CRC, if present	Channel code
1	Repetition code
2	Simplex code
3-11	Reed Muller code
>11	Polar code

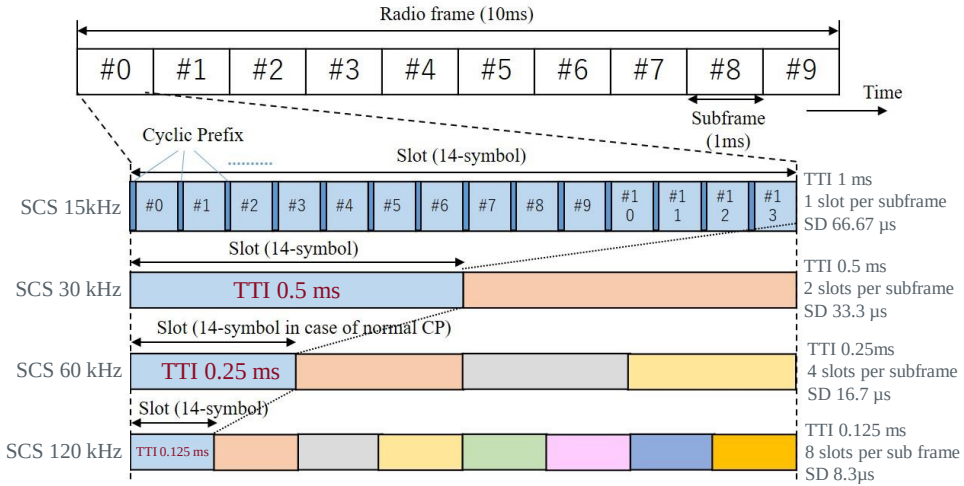
Physical signals in NR

DL/UL	Physical signal	Physical signal name
DL/UL	DM-RS	Demodulation reference signals
DL/UL	PT-RS	Phase-tracking reference signals
DL	CSI-RS	Channel-state information reference signal
DL	PSS	Primary synchronization signal
DL	SSS	Secondary synchronization signal
UL	SRS	Sounding reference signal

Source: RTACS Ltd & 3GPP Technical report 3GPP TR 21.915 V15.0.0 (2019-09)

Scalable Numerology – frame structure

Frame structure in NR



- Radio Frame = 10ms
- Radio Frame is Split into subframes of 1ms (#0 to #9)
- Each slot = 14 OFDM Symbols (#0 to 13)
- Subcarrier Spacing (SCS) determines the Transmission Time Interval (TTI) and Symbol Duration (SD)
- Numerology, µ classification
  - µ0 15 kHz SCS
  - µ1 30 kHz SCS
  - µ2 60 kHz SCS
  - µ3 120 kHz SCS
  - µ4 240 kHz SCS
- 5G NR Frequency Range 1 uses SCS 15, 30 and 60 kHz
- 5G NR Frequency Range 2 uses SCS 60, 120 and 240 kHz

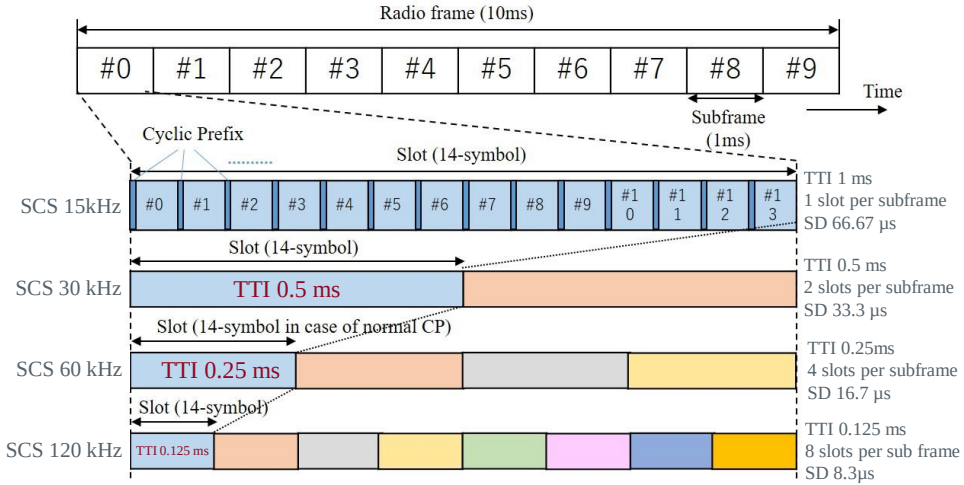
NR supports FDD and TDD using the same frame structure. TDD allows for flexible traffic adaptation, each OFDM symbol in a slot can be classified as 'DOWNLINK', 'UPLINK' or 'FLEXIBLE' (This can be configured semi-statically or it can change dynamically as part of the scheduling decision).

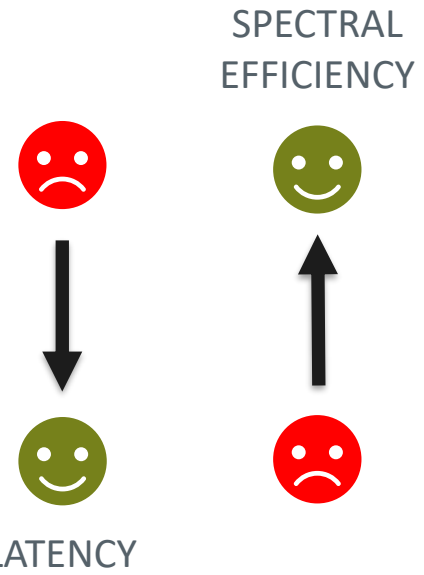
Transmissions are usually carried out over one slot. In specific cases, transmissions can be carried out over only a fraction of a slot, with the minimum set to only two symbols support target use cases requiring low latency, such as some URLLC (Ultra Reliable, Low Latency) services.

Source: RTACS Ltd & 3GPP Technical report 3GPP TR 21.915 V15.0.0 (2019-09)

Scalable Numerology – frame structure

Frame structure in NR

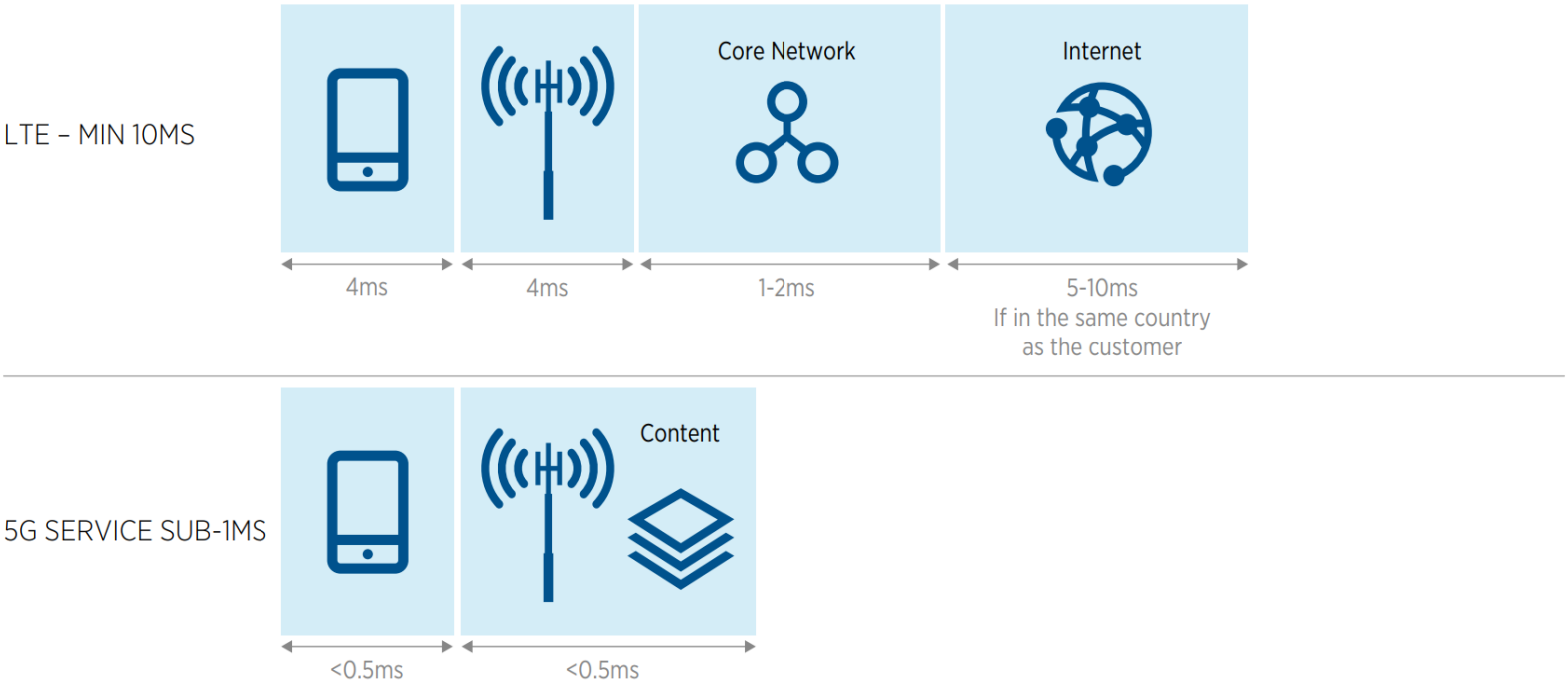




Source: RTACS Ltd & 3GPP Technical report 3GPP TR 21.915 V15.0.0 (2019-09)

4G LTE compared to 5G

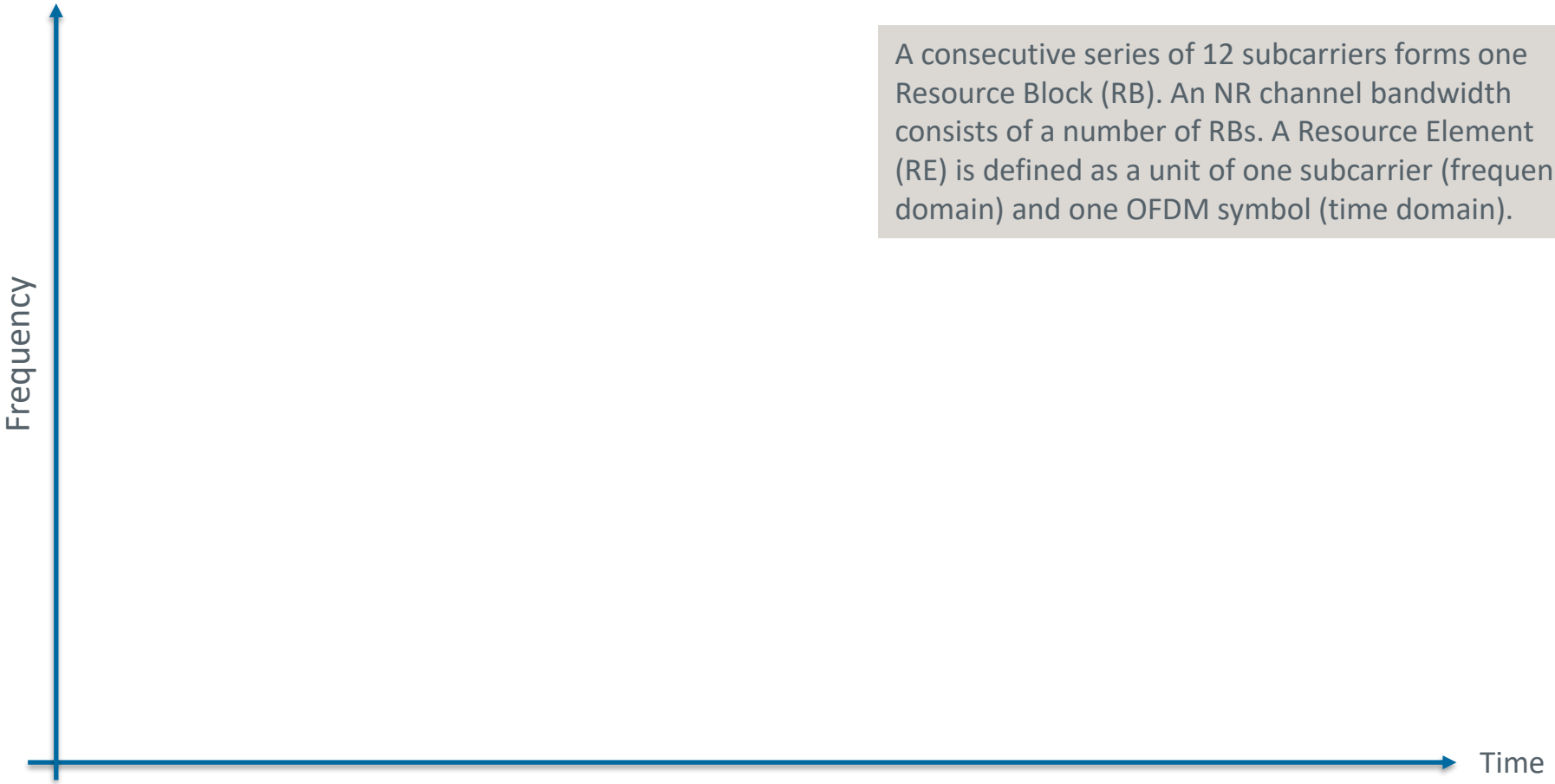
LATENCY PERFORMANCE FOR LTE COMPARED TO LATENCY REQUIREMENT FOR 5G



Source: GSMA | GSMA Unlocking Commercial Opportunities from 4G Evolution to 5G - Future Networks
https://www.gsma.com/futurenetworks/4g-evolution/gsma-unlocking-commercial-opportunities-4g-evolution-5g/

Scalable Numerology – frame structure, resource blocks / elements

A consecutive series of 12 subcarriers forms one Resource Block (RB). An NR channel bandwidth consists of a number of RBs. A Resource Element (RE) is defined as a unit of one subcarrier (frequency domain) and one OFDM symbol (time domain).

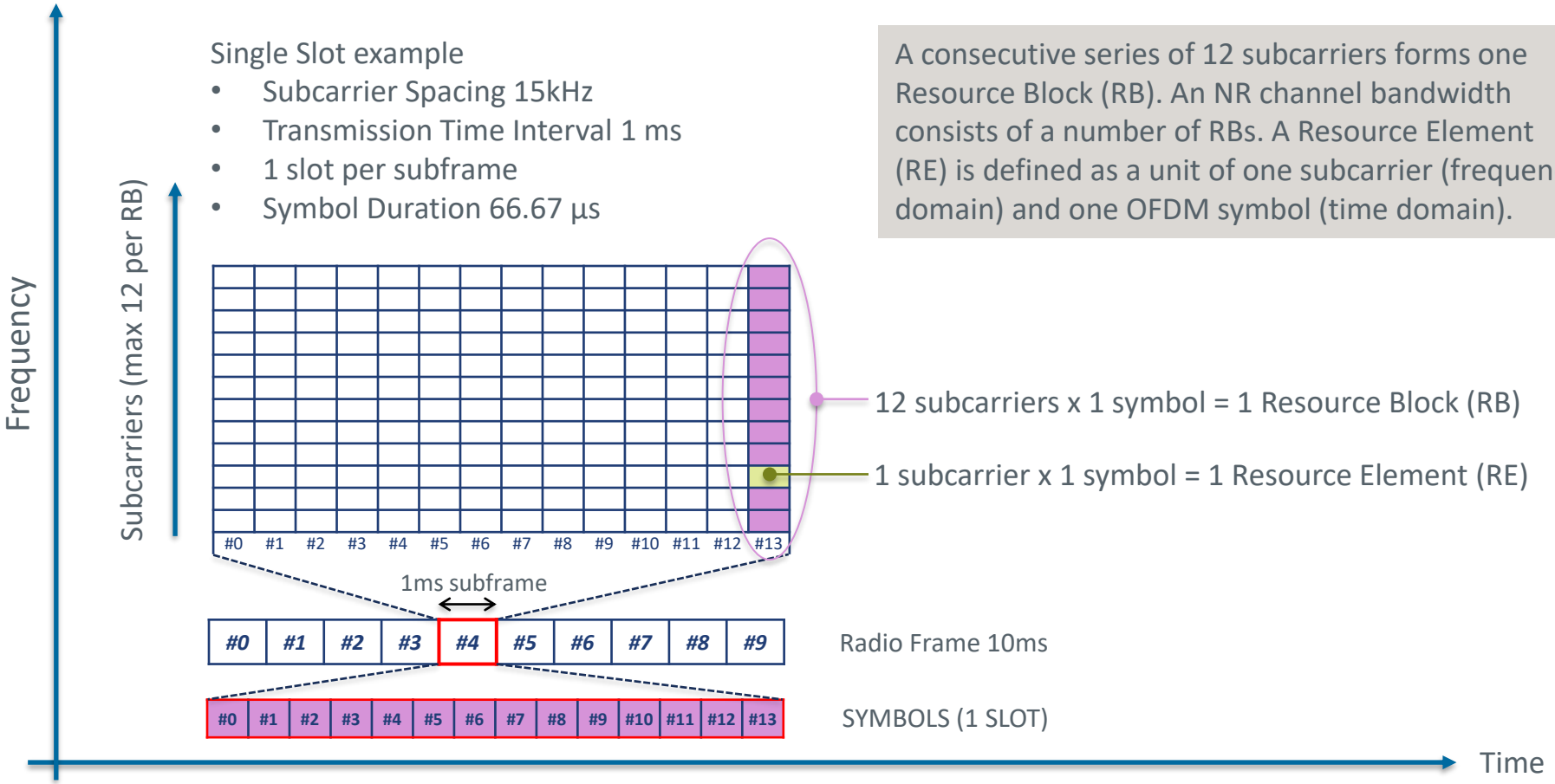


Scalable Numerology – frame structure, resource blocks / elements

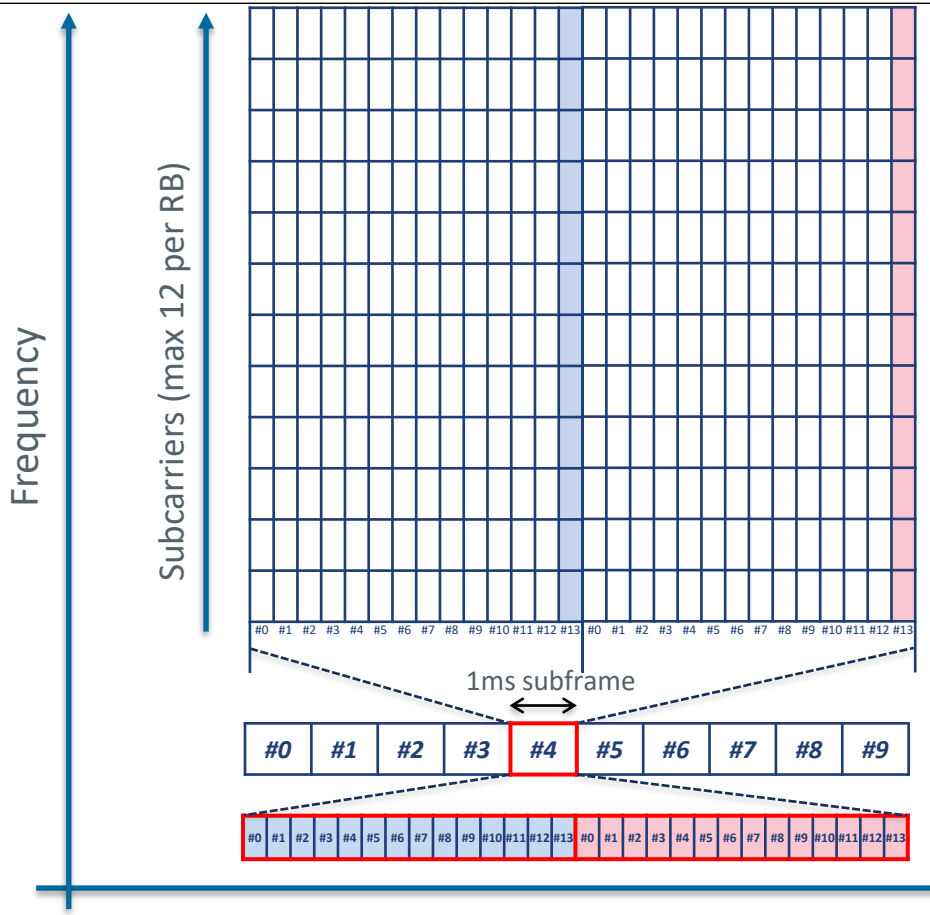
Single Slot example

- Subcarrier Spacing 15kHz
- Transmission Time Interval 1 ms
- 1 slot per subframe
- Symbol Duration 66.67 µs

A consecutive series of 12 subcarriers forms one Resource Block (RB). An NR channel bandwidth consists of a number of RBs. A Resource Element (RE) is defined as a unit of one subcarrier (frequency domain) and one OFDM symbol (time domain).



Scalable Numerology – frame structure, resource blocks / elements



A consecutive series of 12 subcarriers forms one Resource Block (RB). An NR channel bandwidth consists of a number of RBs. A Resource Element (RE) is defined as a unit of one subcarrier (frequency domain) and one OFDM symbol (time domain).

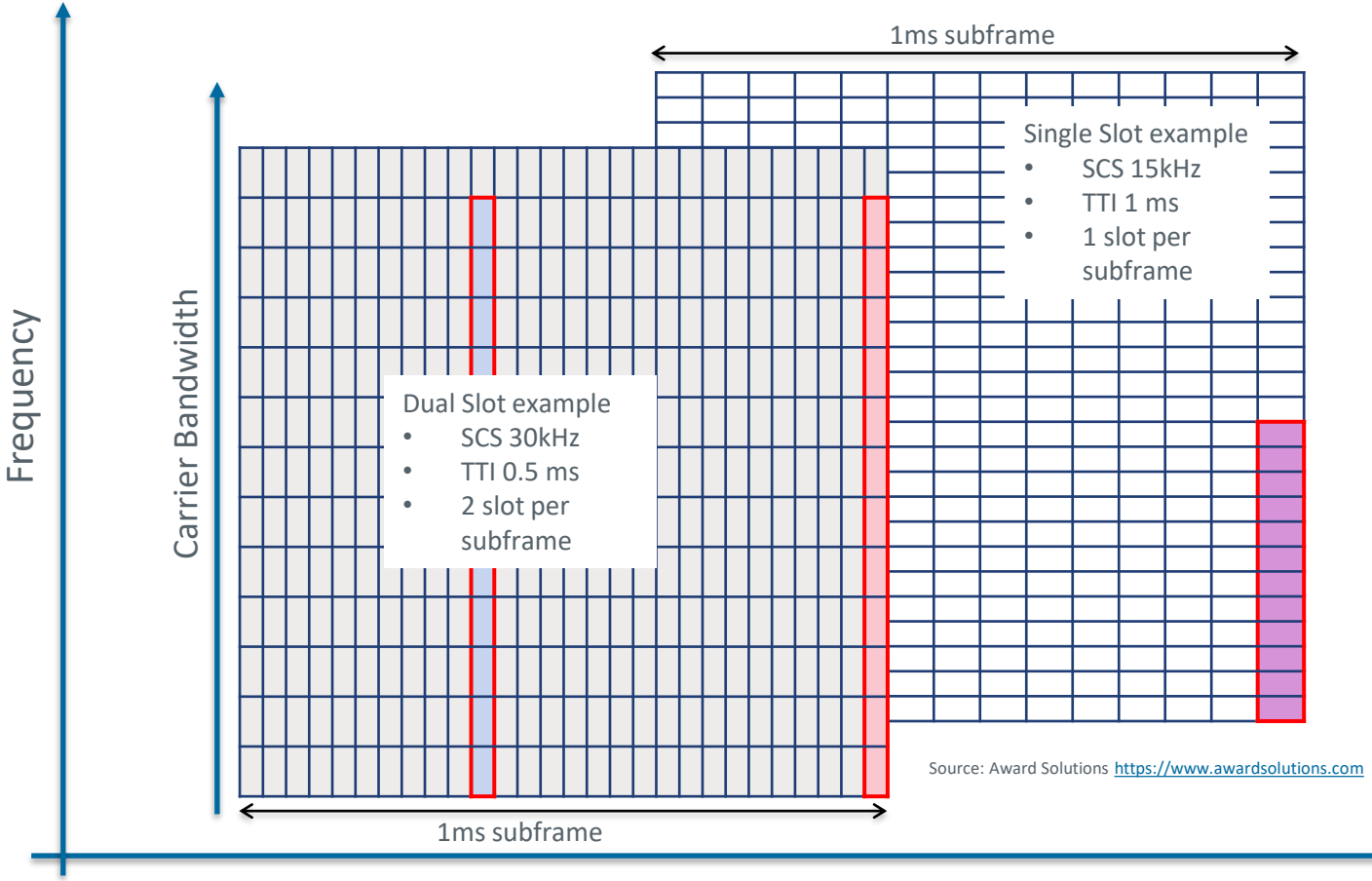
Dual Slot example

- Subcarrier Spacing 30kHz
- Transmission Time Interval 0.5 ms
- 2 slot per subframe
- Symbol Duration 33.3 µs

Radio Frame 10ms

SYMBOLS (2 SLOTS)

Scalable Numerology – frame structure, resource blocks / elements

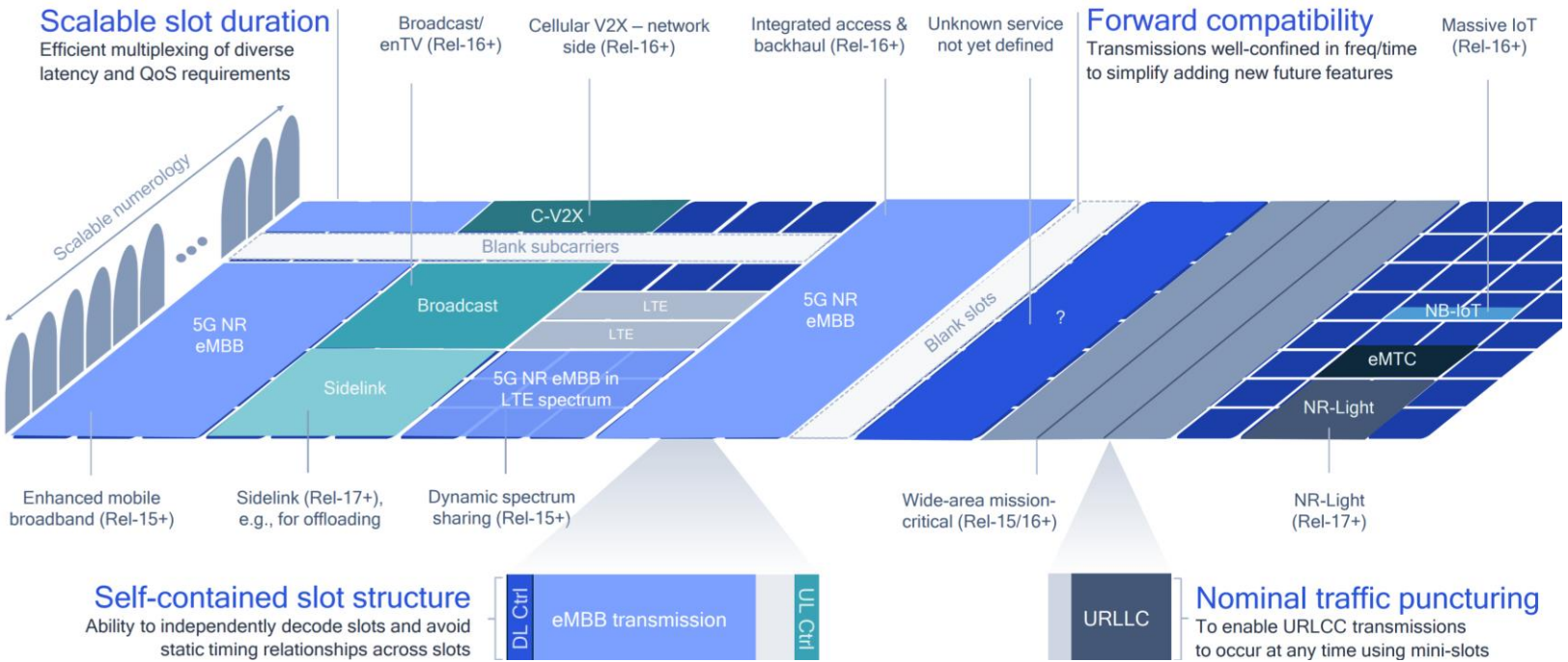


Source: Award Solutions https://www.awardsolutions.com

- One resource grid per numerology per port
- Multiple numerologies on the same carrier

Expanding 5G with the flexible slot-based framework

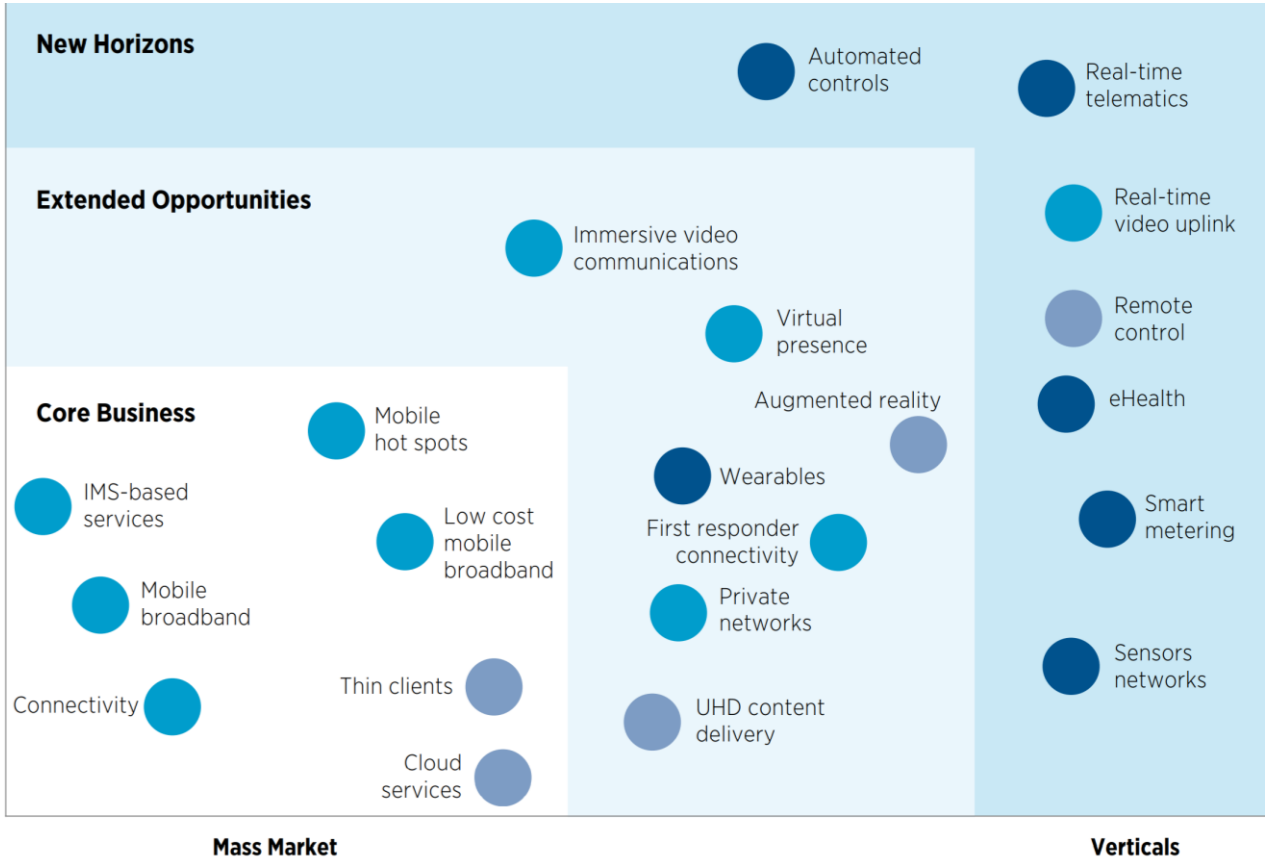
Efficiently multiplex envisioned and future 5G services on the same frequency



Source: Qualcomm https://www.qualcomm.com/system/files/document/files/powerpoint_presentation_-_making_5g_nr_a_reality_february_2020_web_0.pdf

Use Cases

5G ERA Use Cases



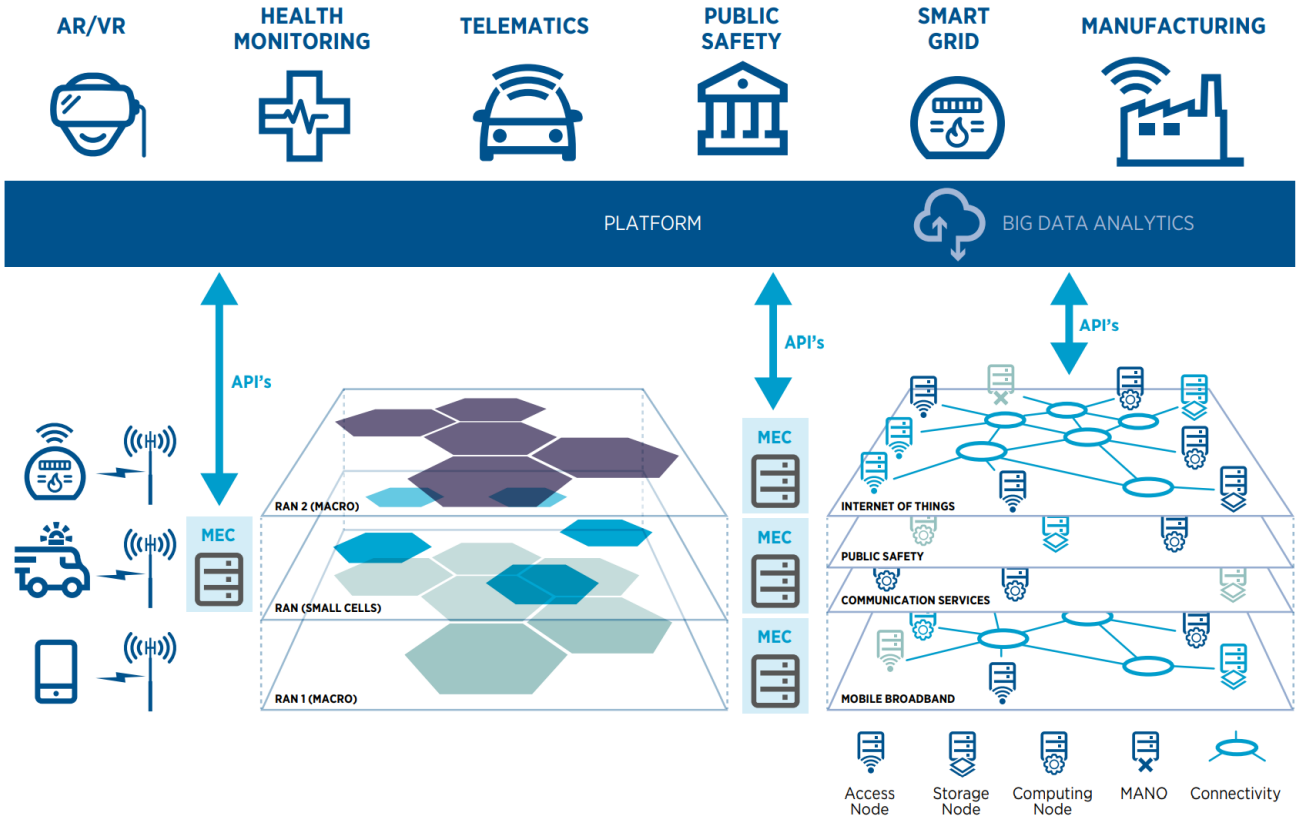
Machine to machine

Person to machine

Person to person

Source: GSMA | GSMA Unlocking Commercial Opportunities from 4G Evolution to 5G - Future Networks https://www.gsma.com/futurenetworks/4g-evolution/gsma-unlocking-commercial-opportunities-4g-evolution-5g/

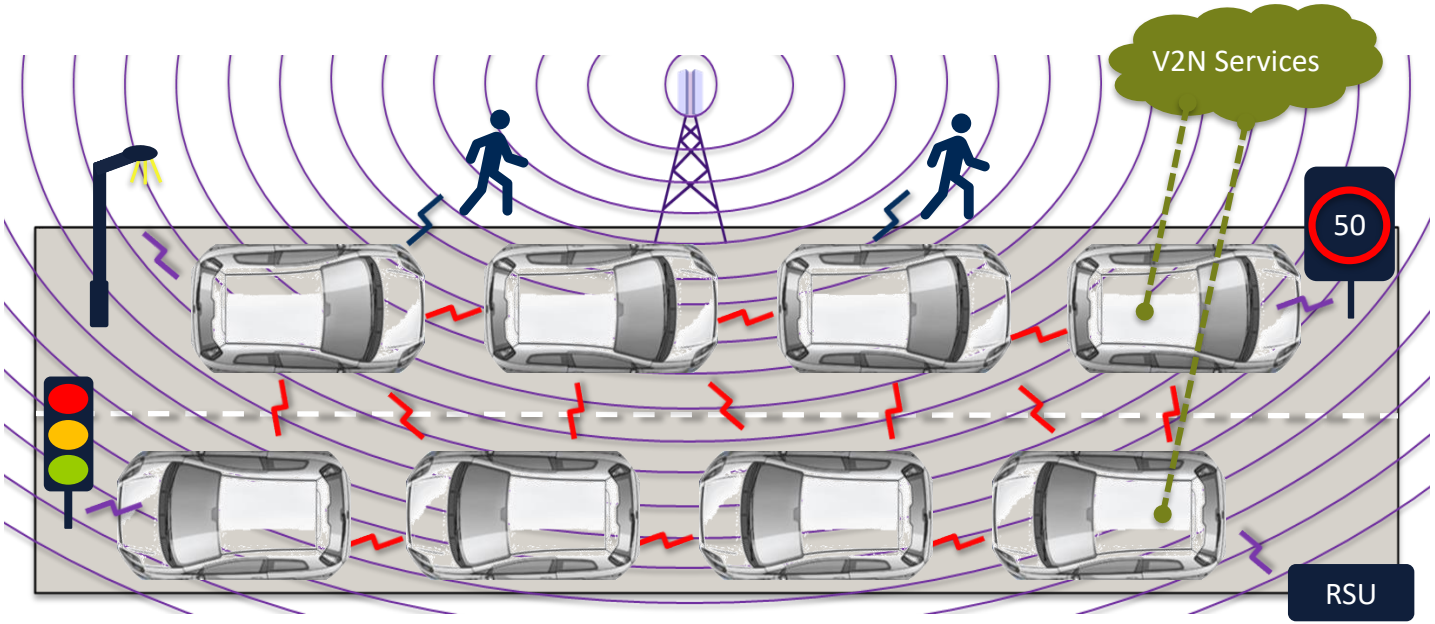
5G ERA Use Cases



Source: GSMA | GSMA Unlocking Commercial Opportunities from 4G Evolution to 5G - Future Networks
https://www.gsma.com/futurenetworks/4g-evolution/gsma-unlocking-commercial-opportunities-4g-evolution-5g/

Vehicle to Everything (V2x) use cases

Common infrastructure and eco-system, delivering multiple use cases:



- Mobile to consumers on the move
- Secure communications to professionals and emergency services
- Machine to machine for safety, critical services and autonomy (e.g. Vehicle to Vehicle and Vehicle to Infrastructure)
- Critical infrastructure monitoring and preventive maintenance
- Enhanced routing and load balancing – increasing transport utilisation and efficiency.

Vehicle to Vehicle V2V

Vehicle to Infrastructure V2I

Vehicle to Network V2N

Vehicle to Pedestrian V2P

Source: Stuart Revell, RTACS Ltd

End-to-End use case examples (V2X and Industry 4.0)

Car showroom or website

Car ordered
Specification:
1. Blue
2. Red Wheels
3. Safety sensor

Automated design, test and purchasing

Raw Materials Ordered:
1. Blue
2. Red Wheels
3. V2V Safety sensor
4. 5G IIoT Module

Customer design information
1. Specification
2. Software
3. V2V Safety sensor
4. 5G IIoT Module

Orders

Supplier A
Car body

Supplier B
Wheels

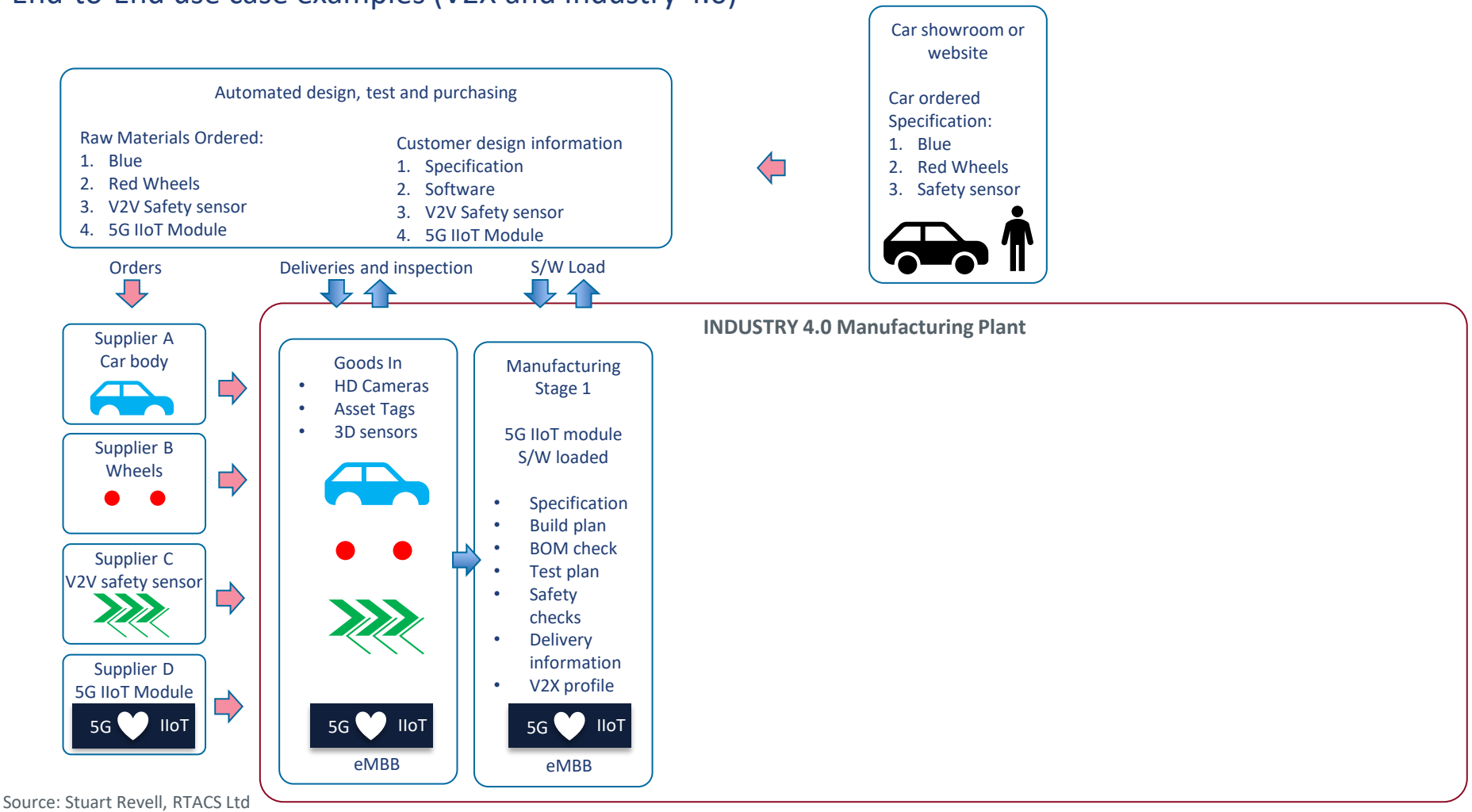
Supplier C
V2V safety sensor

Supplier D
5G IIoT Module

5G IIoT

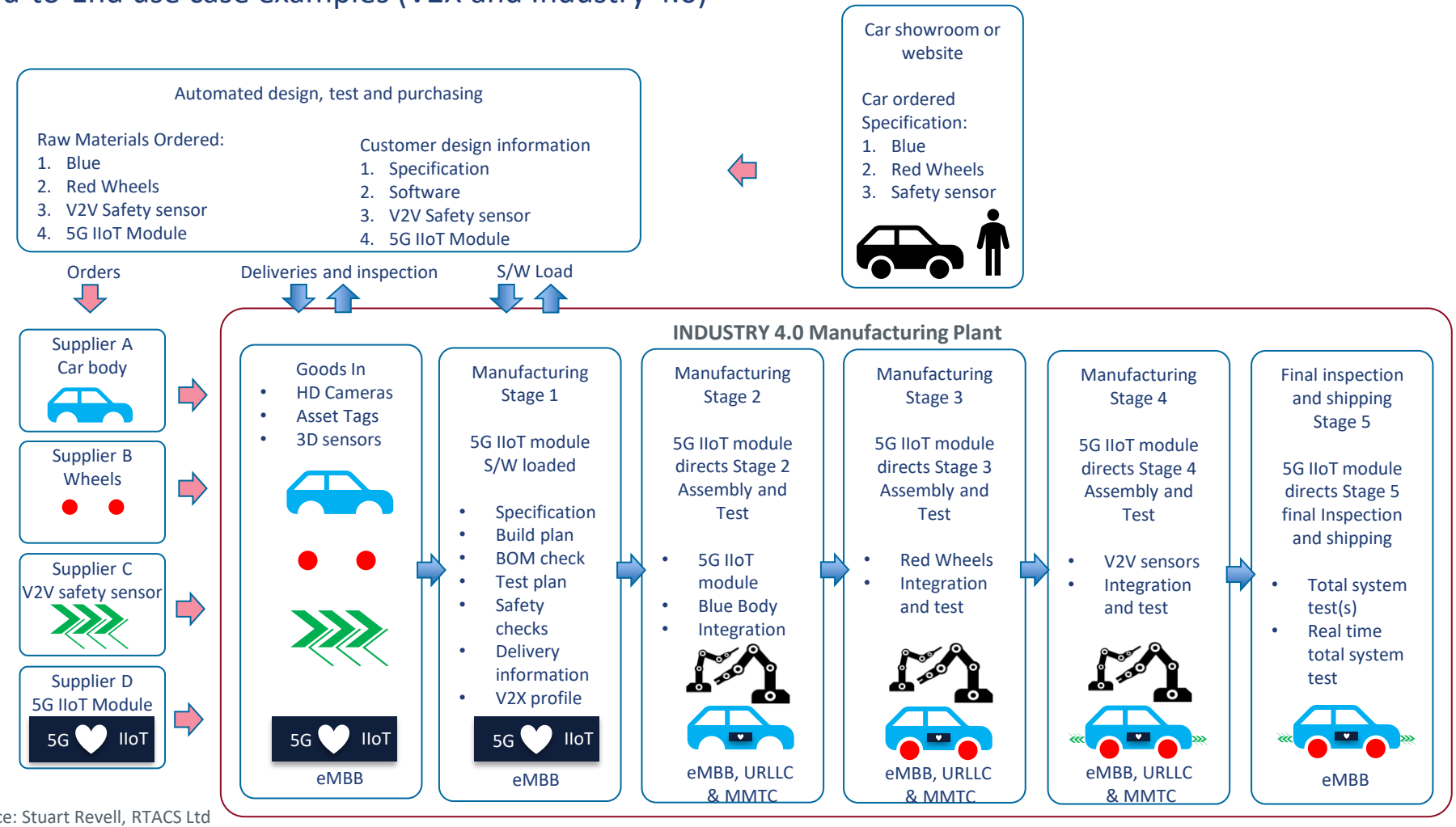
Source: Stuart Revell, RTACS Ltd

End-to-End use case examples (V2X and Industry 4.0)



Source: Stuart Revell, RTACS Ltd

End-to-End use case examples (V2X and Industry 4.0)



Source: Stuart Revell, RTACS Ltd

End-to-End use case examples (V2X and Industry 4.0)

Automated design, test and purchasing

Raw Materials Ordered:
1. Blue
2. Red Wheels
3. V2V Safety sensor
4. 5G IIoT Module

Customer design information
1. Specification
2. Software
3. V2V Safety sensor
4. 5G IIoT Module

Car showroom or website

Car ordered
Specification:
1. Blue
2. Red Wheels
3. Safety sensor

Car Delivered

Specification:
1. Blue
2. Red Wheels
3. Safety sensor

V2X activated for customer use

Orders

Deliveries and inspection

S/W Load

Supplier A
Car body

Supplier B
Wheels

Supplier C
V2V safety sensor

Supplier D
5G IIoT Module

5G ♥ IIoT

INDUSTRY 4.0 Manufacturing Plant

Goods In
- HD Cameras
- Asset Tags
- 3D sensors

5G ♥ IIoT

eMBB

Manufacturing Stage 1

5G IIoT module S/W loaded

- Specification
- Build plan
- BOM check
- Test plan
- Safety checks
- Delivery information
- V2X profile

5G ♥ IIoT

eMBB

Manufacturing Stage 2

5G IIoT module directs Stage 2 Assembly and Test

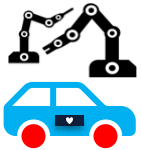
- 5G IIoT module
- Blue Body
- Integration

eMBB, URLLC & MMTC

Manufacturing Stage 3

5G IIoT module directs Stage 3 Assembly and Test

- Red Wheels
- Integration and test

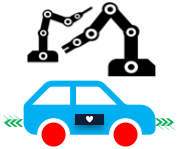


eMBB, URLLC & MMTC

Manufacturing Stage 4

5G IIoT module directs Stage 4 Assembly and Test

- V2V sensors
- Integration and test



eMBB, URLLC & MMTC

Final inspection and shipping Stage 5

5G IIoT module directs Stage 5 final Inspection and shipping

- Total system test(s)
- Real time total system test

eMBB

Source: Stuart Revell, RTACS Ltd