IEEE Webinar: 5G Technologies and Capabilities

August 31, 2020

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Outline

- Introduction
- Historical Cellular Evolution
- 5G Capabilities and Features

Speaker Introduction

- William is currently the Chief of the Communication Systems and Spectrum Division (CSSD) of the Information and Communications Lab (ICL) at the Georgia Tech Research Institute (GTRI) researching and developing leading-edge communications and spectrum sensing solutions and platforms

- Received B.Sc. and M.Sc. degrees from the University of Florida in 1998 and 2005, respectively
    - Specializations include Wireless Communications and Digital Signal Processing

- Contributed to the development of the powerline technology underlying the first generation for the HomePlug Powerline Alliance while working with Intellon (acquired by Atheros in 2009; acquired by Qualcomm in 2011)

- Prior to joining Georgia Institute of Technology in 2020, Bill spent 17 years with InterDigital Communications developing commercial cellular technologies, solutions and standards for UMTS, LTE and 5G New Radio (NR)

- He has received seven patents related to his powerline and cellular wireless innovations

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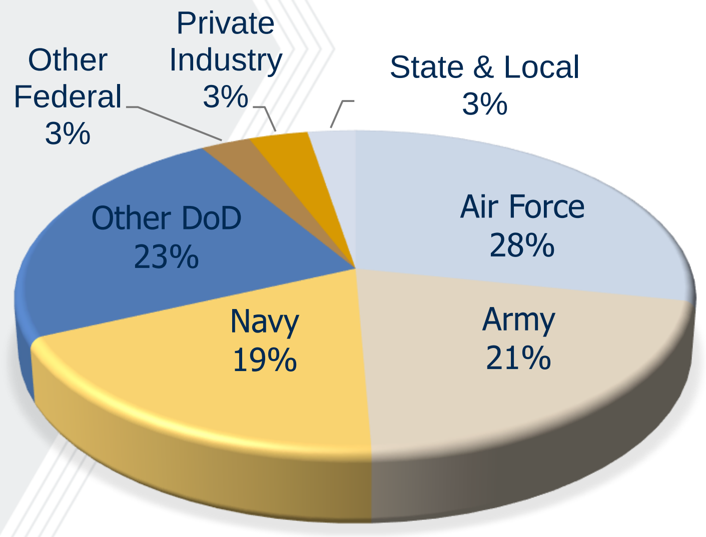
GTRI by the Numbers

Army's Largest University Affiliated Research Center (UARC)

- Second largest of 15 UARCs
- Operates under Federal Acquisition Regulation (FAR) 31.2
  - Non-profit electing to operate under cost principles for commercial organizations where fee is collected



FY19 Awards

FY19	GT	GTRI
Revenue Earned	$1.9B	$503.5M
Research Awards	$1.05B	$643M
Economic Impact to State	$3.35B*	$1.4B
Total Employees	8,295	2,444
Research Faculty	2,434	1,397

*FY19 number

End of FY19 – June 30, 2019

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How Did We Get Here?

1946 – The name “Georgia Tech Research Institute” is given to a non-profit corporation created to handle EES contract and patent issues.

1973 – The Agricultural Technology Research Program is established to support Georgia’s economically important poultry industry.

1984 – EES celebrates its 50th Anniversary by, among other things, changing its name to the Georgia Tech Research Institute (GTRI).

1930s | 1940s | 1950s | 1960s | 1970s | 1980s | 1990s | 2000s

TODAY – $643M in Research Awards & over 2,400 Employees

1952 – EES personnel help found Scientific Atlanta, later renowned for its satellite Earth stations and cable TV equipment.

1979 – The Huntsville Research Laboratory begins operations, giving EES a presence at Redstone Arsenal that continues to this day.

1995 – **GTRI** is designated a University Affiliated Research Center (**UARC**) by the Director of Defense Research and Engineering (DDR&E), Office of the Secretary of Defense (OSD).

1940 – Federal funding linked to World War II begins bringing in more projects, including work in wind-tunnel testing and communications technology.

1934 – The State Engineering Experiment Station (EES) opens in Georgia Tech’s Old Shop Building, with a little more than **$5,000 in state funding** and **13 part-time faculty researchers.**

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GTRI Laboratories

Advanced Concepts

Aerospace, Transportation & Advanced Systems

Applied Systems

Cybersecurity, Information Protection & Hardware Evaluation

Electronic Systems

Electro-Optical Systems

Information & Communications

Sensors & Electromagnetic Applications

The **Information and Communications Laboratory** (ICL) conducts research that solves complex problems in areas of computer science, information technology, communications, networking, and socio-technical systems.

Research areas include, but not limited to:

- ground EW/Communications systems
- emergency response
- integration of health care systems and health analytics
- smart city and Internet of Things development
- software defined radio development
- development of public policy
- commercial product realization
- technology strategy, planning, and geospatial decision support for C2

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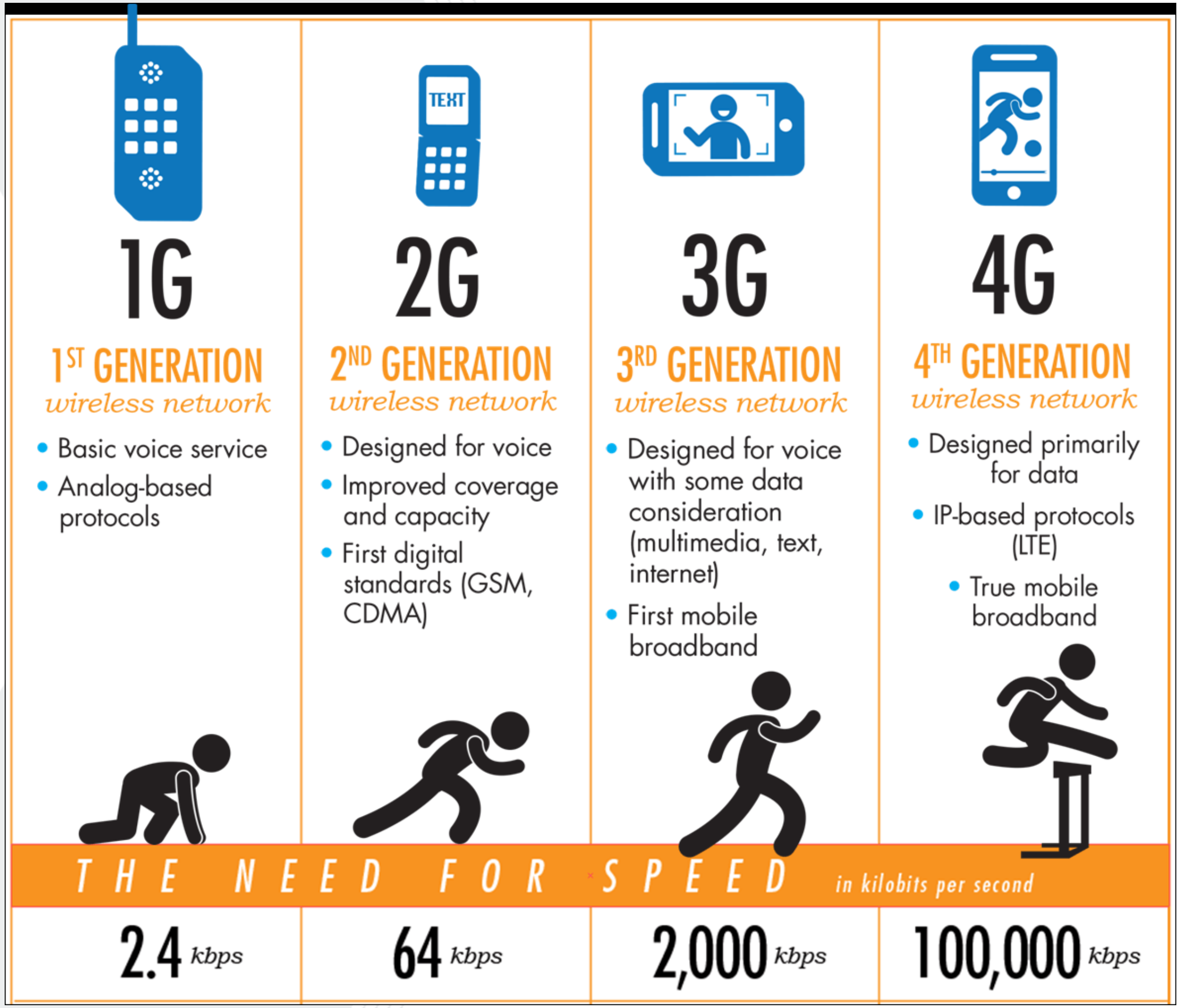
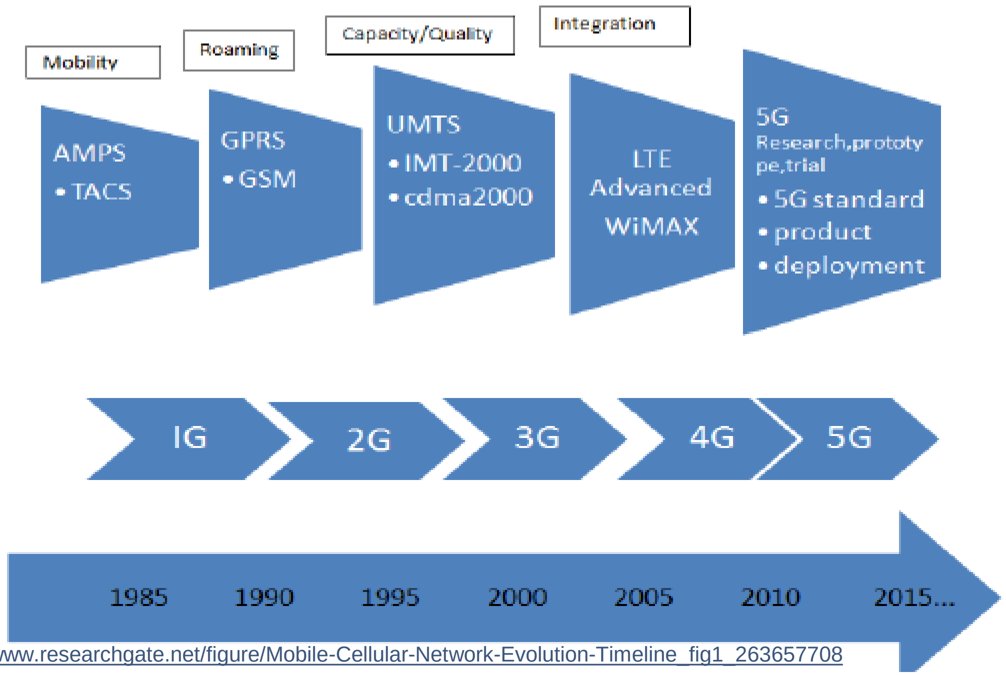
Historical Cellular Evolution



https://blog.commscopetraining.com/cellular-wireless-watch-the-evolution/



https://www.researchgate.net/figure/Mobile-Cellular-Network-Evolution-Timeline_fig1_263657708

- Note the distinction between each generation of cellular wireless and the supporting technologies
  - E.g. both WiMAX and LTE-A are “4G” technologies
  - LTE ≠ 4G; New Radio (NR) ≠ 5G
- ITU defines the requirements for each generation of wireless communication technology
- 3GPP has become the de-facto organization for defining the technology and standards to meet those requirements

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Device Evolution

1973

The first public wireless phone call was made in 3rd **April, 1973** by Martin Cooper of Motorola. Walking along in sixth avenue, New York he called Joel Engel (head of research, Bell Labs). The phone he used had the following features:
Weight: 2.5 pound
Length: 10 inches
Battery life: 20 minutes only.

That's right -- the first cell phone was involved in what some might refer to as a prank call!

1989

APR 25, 1989
Motorola MicroTAC 9800X
The first truly portable phone. Up until its release, most cellular phones were installed as car phones due to the inability to fit them into a jacket pocket.

1992

JUL 19, 1992
Motorola International 3200
The first digital hand-size mobile telephone
http://timerime.com/en/event/1217015/Motorola+International+3200/

1994

NOV 23, 1994
BellSouth/IBM Simon Personal Communicator
a "smartphone" is a device the size and shape of a cellphone, sporting a large sensitive screen instead of your regular keyboard, having internet communication features, complete PDA functions, and of course, all of the usual cellphone functions.
http://www.retrocom.com/bellsouth_ibm_simon.htm

2001

AUG 2, 2001
Ericsson T68
This was Ericsson's first handset with a color screen.

2004

JUL 26, 2004
Motorola Razor V3
When this was introduced it set the standard for sleek design in the industry.
https://www.youtube.com/watch?v=h6ON1Tg_PgA

2007

JUN 29, 2007
iPhone
The original iPhone was released in June 2007 with an auto-rotate sensor, a multi-touch sensor that allowed multiple inputs while ignoring minor touches, a touch interface that replaced the traditional QWERTY keyboards, and many other features that helped to give Apple an almost instant healthy market share on its release.
Weight: 0.3 pound
Length: 4.5 inches
Battery life: 8 hours (talk)

https://www.timetoast.com/timelines/history-of-cell-phone-evolution

ITU Generational Requirements

- Goal of ITU in defining IMT requirement was to avoid global fragmentation in cellular standards
  - 4G was first time ITU was successful (WiMax nearly disrupted market)

	IMT-2000 (3G)	IMT-Advanced (4G)	IMT-2020 (5G)
Peak User Data Rate (Mbps)	0.144 (high mobility) 0.384 (low mobility) 2 (Enterprise)	100 (nominal) 1,000 (peak)	20,000 (DL) 10,000 (UL)
End-to-End Latency (msec)	Not defined	10	4 (eMBB) 1 (URLLC)
Connection Density (devices / km^2)	Not defined	100,000	1,000,000
Bandwidth (MHz)	5	5 – 20 (up to 40)	> 100
Frequency Bands (MHz)	806 – 960; 1429 – 1501 1710 – 1980; 2010 – 2025; 2110 – 2170; 2500 - 2690	450 – 6,000	FR1: 450 – 6,000 FR2: 24,000 – 52,600 FR3: TBD
Peak Spectral Efficiency (bits/sec/Hz)	“high”	15 (DL) 6.75 (UL)	30 (DL) 15 (UL)
Area Traffic Capacity (Mbit / sec / m^2)	Not defined	0.1	10
Recognized Technologies	UMTS (FDD/TDD) CDMA2000 EDGE WiMAX DECT LTE	HSPA+ LTE-Advanced	TBD, but New Radio (NR) is the leading technology

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Cellular Capabilities Evolution

	2G	3G	4G	5G
Services & Use Cases	Voice + SMS	Voice + Small Data	Mobile Broadband	Enhanced Mobile Broadband Massive Machine Type Communications Ultra-Reliable and Low-Latency Communications
Spectrum	200 kHz Channels Below 2 GHz	5 MHz Channels Below 3.6 GHz	Up to 20 MHz Channels Below 3.8 GHz	Up to 400 MHz Channels Below 100 GHz
RAT: Radio Access Technology	GSM/GPRS (single RAT)	UMTS/HSPA (single RAT)	LTE/LTE-A (single RAT)	Multiple RATs Integrated in a 5G Network: LTE-A Pro, WiFi, NB-IoT, 5G New Radio
Network Topology	Macro Cells	Macro and Small Cells	Hetero-geneous Macro and Small Cells	Ultra-Dense Networks, Mobile Edge Computing, Network Slicing, V2X

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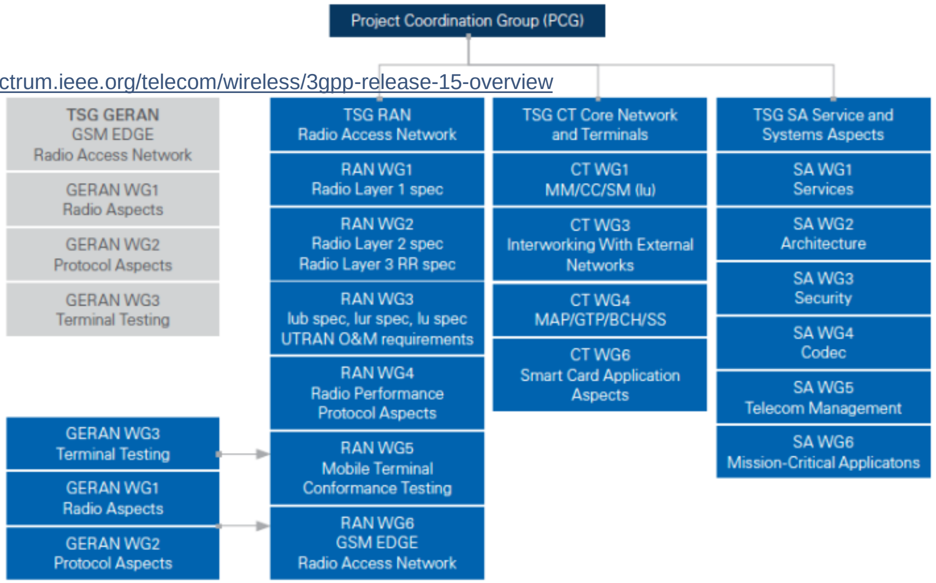
How the Sausage Gets Made

- 3GPP is guided by a Plenary meeting once per quarter
- Plenary Guides 3 Technical Specification Groups (TSG)
- Each TSG has 4-6 Working Groups (WG)
- Each WG meets 6-8 times per year in person at locations around the world
  - 1 week per session
  - 2020: meetings have gone virtual due to COVID-19
  - WG meetings can have upwards of 1,000 engineers, each
  - Plenty more back-office Engineers supporting
    - Not to mention lawyers, filing patents
- In contrast to IEEE, each member <u>organization</u> gets 1 vote
  - 71% majority required to reach decision

3GPP A GLOBAL INITIATIVE



https://spectrum.ieee.org/telecom/wireless/3gpp-release-15-overview

3GPP RAN Plenary

https://www.qualcomm.com/news/onq/2019/12/13/3gpp-charts-next-chapter-5g-standards

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Outline

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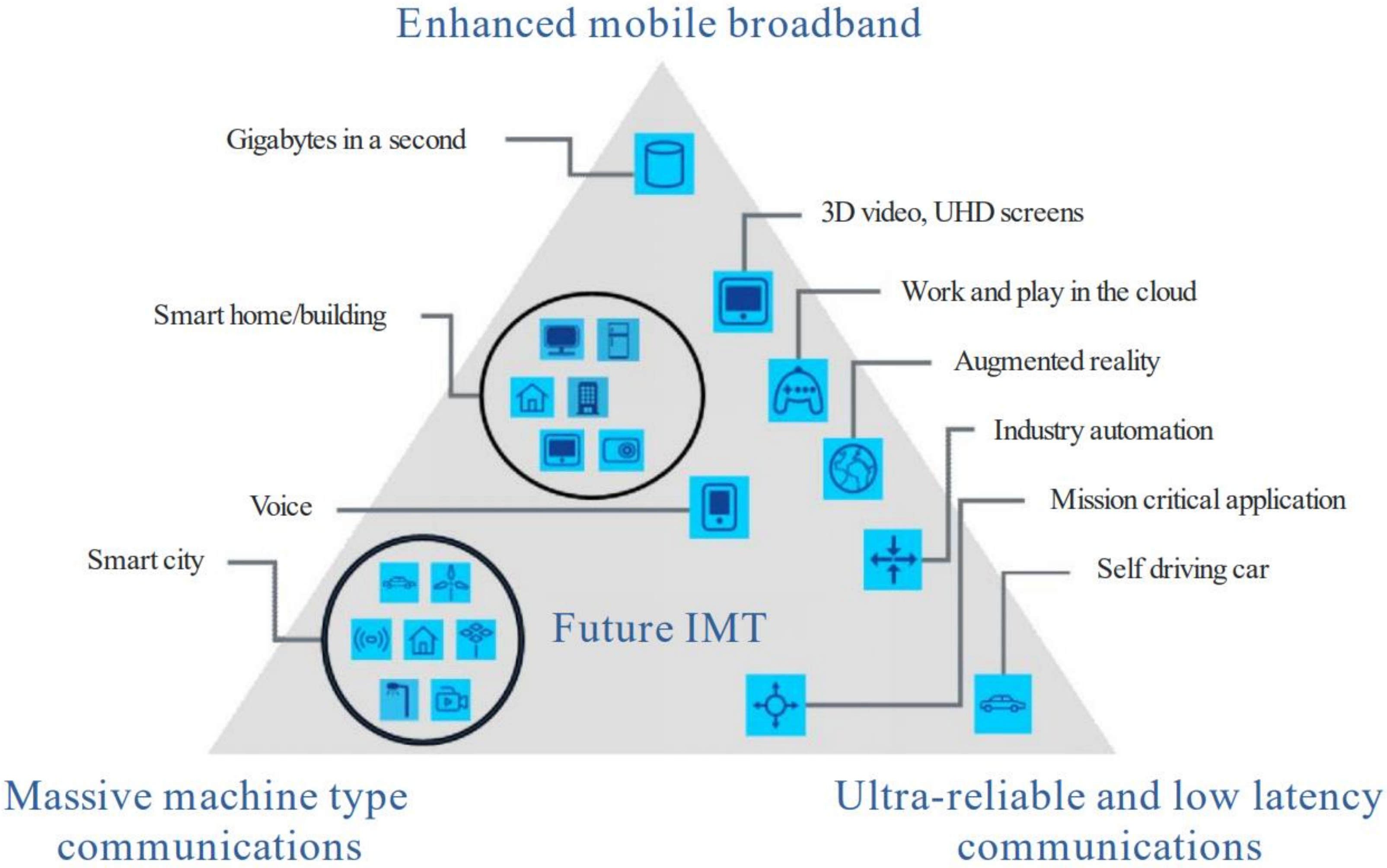
5G Use Cases

- 5G substantially expanding traditional service offering from mobile broadband to include:
  - Enhanced mobile broadband (eMBB)
    - Includes Fixed Wireless Access (FWA)
  - Massive machine type communication (mMTC)
  - Ultra-reliable and low-latency communications (URLLC)



https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2083-0-201509-I!!PDF-E.pdf

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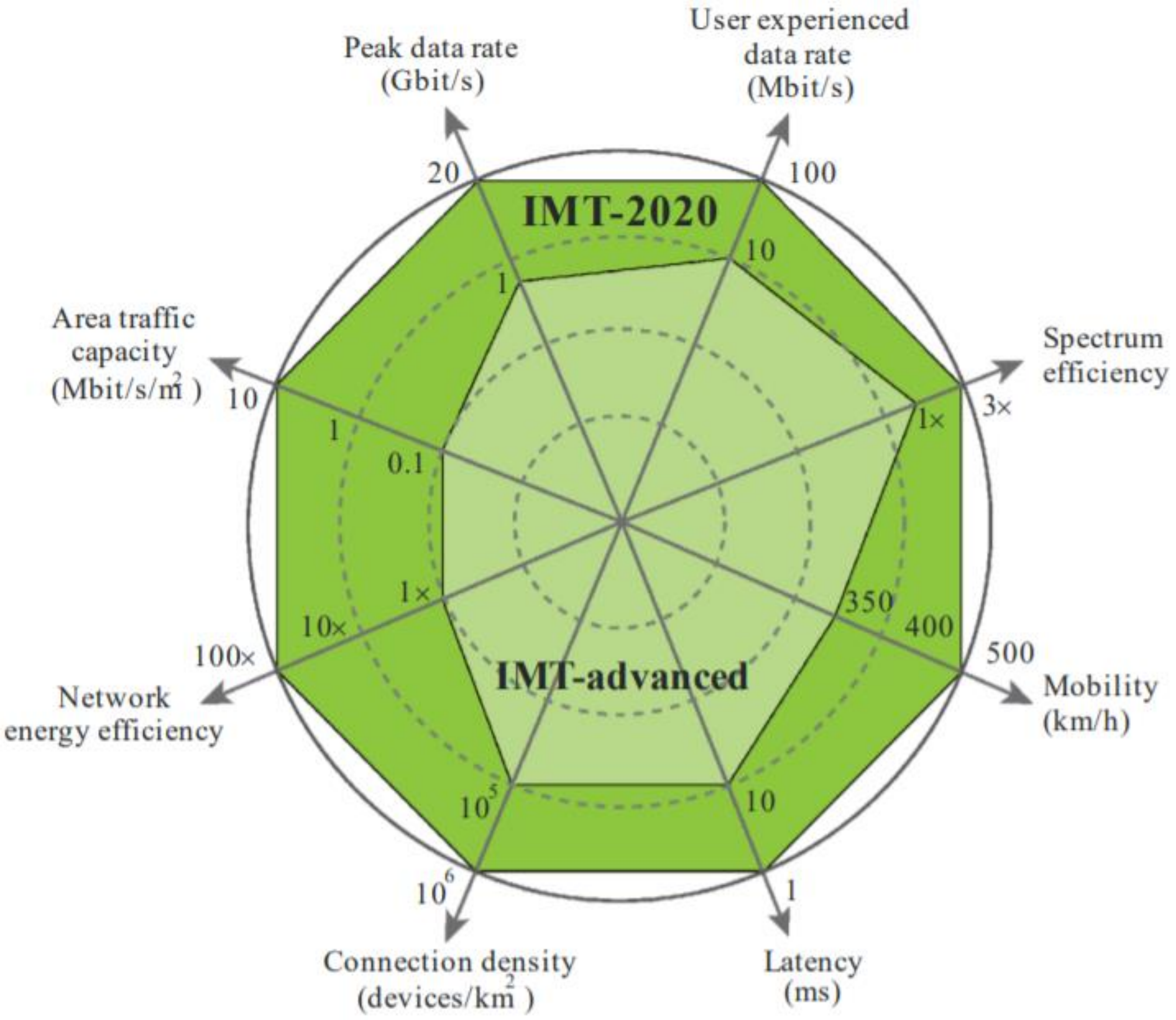
5G KPIs

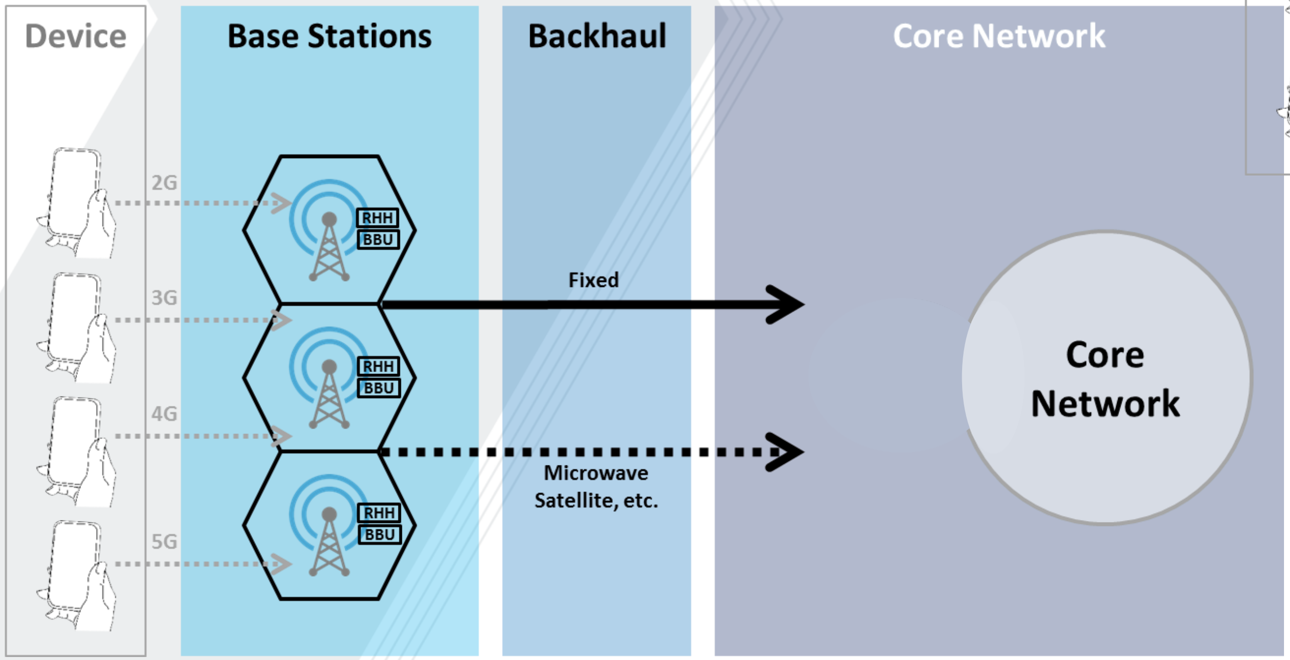
- 5G (IMT-2020) defined by ITU substantially improves many key performance indicators compared to 4G (IMT-Advanced)
  - Large system bandwidths and configurable numerologies (up to 400 MHz) contribute to provide lower latency and higher data rates
  - Higher carrier frequencies (mmWave) contribute to higher efficiencies and area capacity
  - Configurable reference signal densities allow higher mobility support while reducing pilot contamination
  - New network architectures allow for higher density deployments with sustainable costs



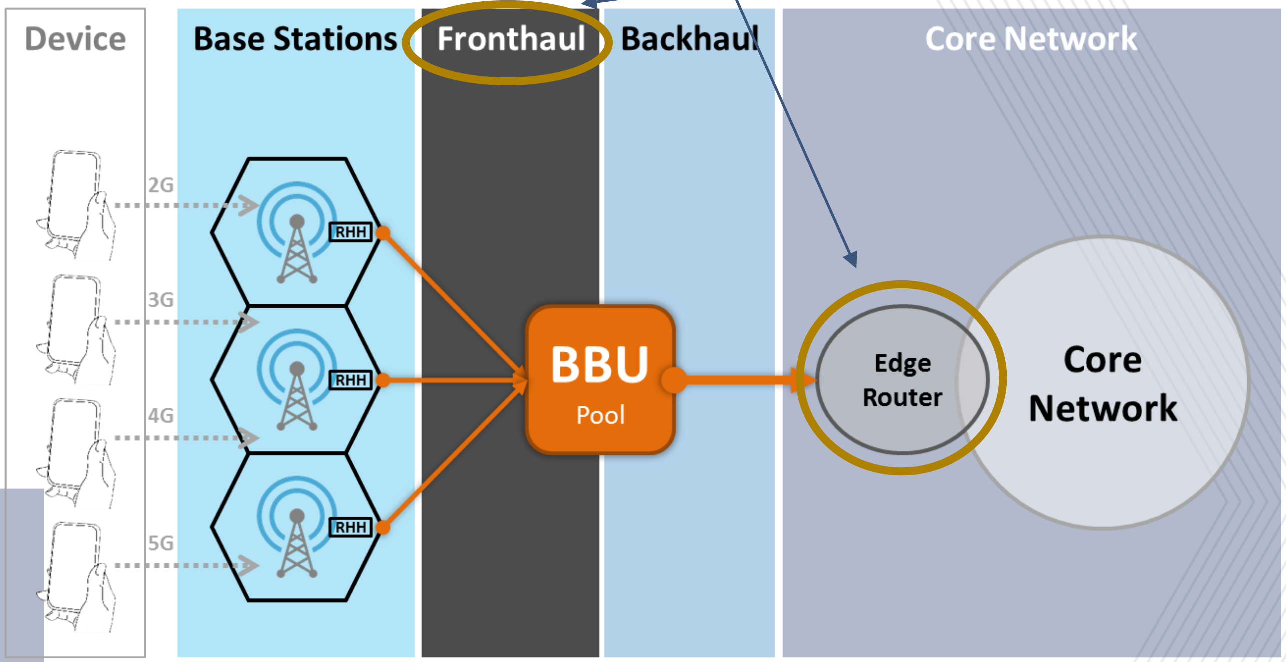
https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2083-0-201509-I!!PDF-E.pdf

Modern Cellular System Architecture

- Major elements of cellular system include:
  - **Core network**: manages all network functions and routing
  - **Base stations**: manage radio resources and communicate over-the-air to user devices and to the core network over backhaul
  - **Terminals (devices)**: provide end-user applications while communicating with cellular network



New elements



- Modern cellular systems evolving to include:
  - **Edge computing**: reduce latency by locating services near the user
  - Split base station into **Centralized and Distributed Units** (CU / DU) connected by a fronthaul

https://medium.com/@miccowang/5g-c-ran-and-the-required-technology-breakthrough-a1b2babf774

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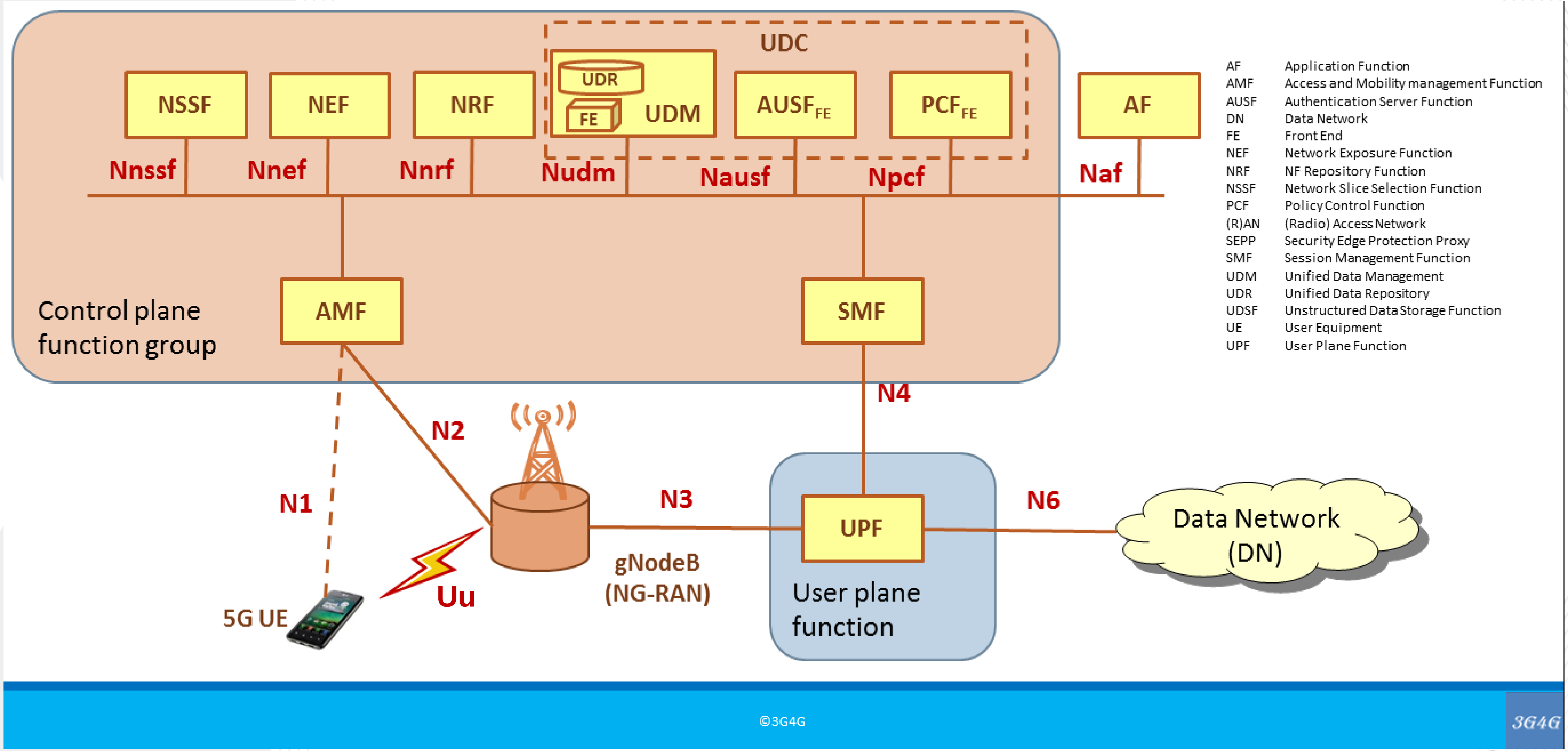
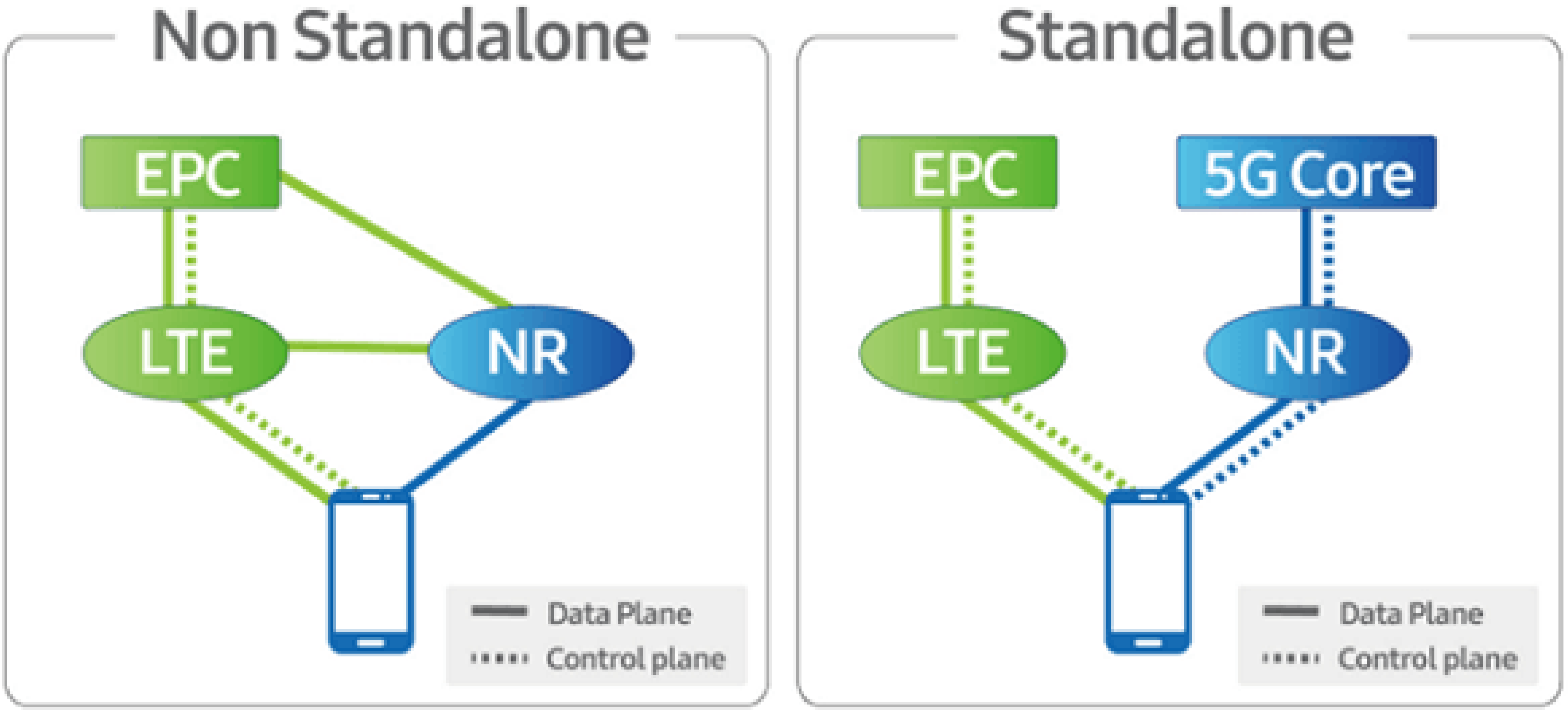
5G Network Service Based Architecture (SBA)



https://blog.3g4g.co.uk/2018/02/tutorial-service-based-architecture-sba.html

5G Deployment Scenarios

- 5G allows for smooth transition from LTE by supporting 3 primary deployment scenarios:
    - Non-standalone (NSA)
    - Standalone (SA)
    - LTE eNB connecting to 5G CN (not shown)



https://techblog.comsoc.org/2019/08/02/t-mobile-claim-1st-standalone-5g-data-session-on-a-multi-vendor-radio-and-core-network/

Notable 5G Features and Capabilities

- Network Slicing
- Massive MIMO / Beamforming
- New Spectrum – mmWave
- URLLC using Mini-Slots
- Virtual RAN Enablers
  - Control Plane / User Plane Split
  - Central Unit / Distributed Unit Split
- Mobile Edge Computing
- Dynamic Spectrum Sharing
- Non-Terrestrial Networks
  - Satellites
  - High-Altitude Platforms
- Vehicle-to-Everything (V2X)
- Integrated Access & Backhaul
- Advanced Channel Coding
  - Polar Codes
  - LDPC Codes
- Multi-Layer Radio Network
- Service Multiplexing

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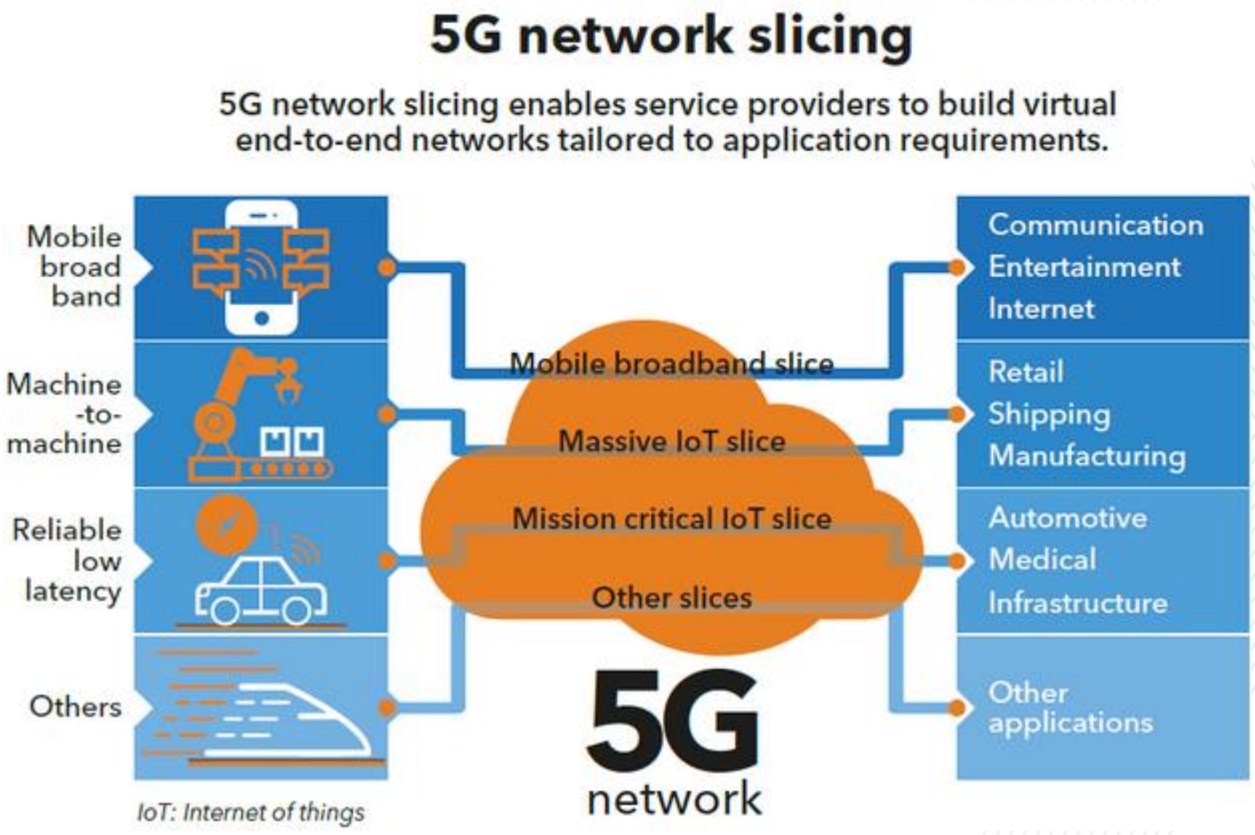
Network Slicing

- Operators have been able to “loan” use of portions of their network to enable Mobile Virtual Network Operators (MVNO)
- With Network Slicing, operators can readily partition their network to support unique attributes of specific devices or applications
    - Can be used for operators’ users or “loaned” to other operators for their users
- Network slices can be supported by other operator’s equipment (e.g. servers)
    - Ex: Army CU connected to Verizon DU



https://fr-fr.facebook.com/telecomnetworkingnews/photos/a.1065227206937957/1443780042416003/?type=3&theater

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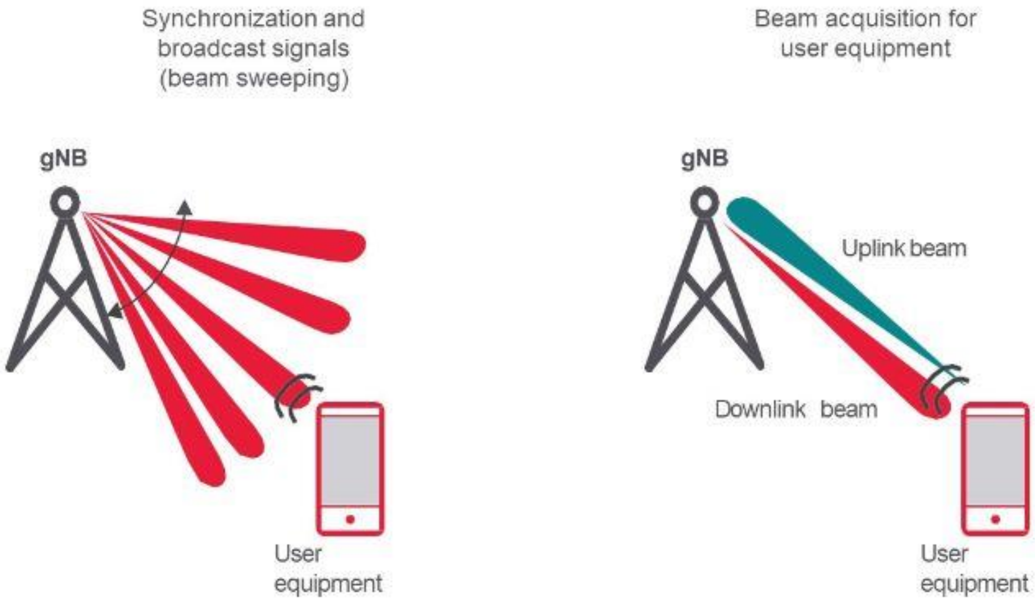
Spatial Processing – Radio Protocol Design

Support for mmWave with Massive Antenna Arrays (MAA)

- NR required rethinking of PHY and MAC design required for beamformed systems
  - MAAs need to be embedded in the air-interface design providing native support for spatial processing

- Sample technologies:
  - **Beamforming essential for coverage at mmWave**: native support of directional broadcast channels; Beamformed control channels with support for beam switching and failure recovery; HARQ with beam diversity; Heterogeneous beam type support
  - **Dynamic blockage / self-blockage causes abrupt loss in radio link**: Fast intra-node beam-tracking; Fast intra-layer mobility and intra/inter-node cooperation built-in; Tight multi-layer coordination with other radio layers
  - **Small cell deployments with flexible network topologies**: Native support for self-backhauling, Robustness to intra-later interference; Adaptive beam-steering for low-cost self-organizing deployments

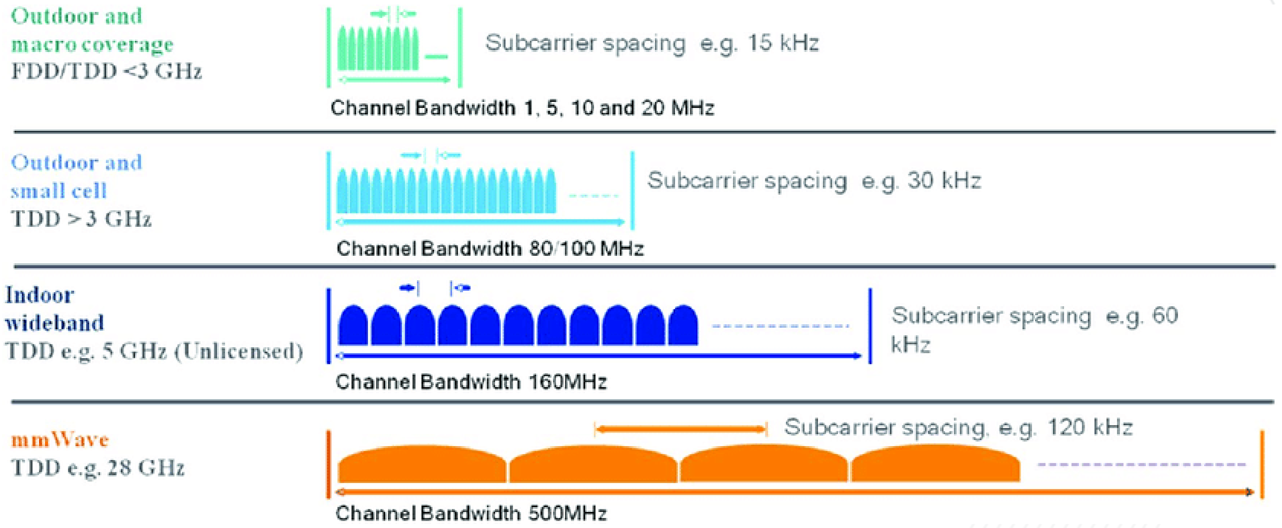


https://blogs.keysight.com/blogs/inds.entry.html/2020/02/28/5g_testing_3gpp_bea-wkdn.html

Flexible Numerologies

- LTE defined with single air-interface numerology
  - Essentially 15 kHz subcarrier spacing (SCS)
- NR defined with many numerologies to support different services and carrier frequencies
  - 15 kHz up to 120 kHz
  - Symbol size is inversely proportional to SCS

SCS (kHz)	15	30	60	120
Symbol duration (µs)	66.67	33.33	16.67	8.33
CP duration (µs)	4.69	2.34	1.17	0.58
Total symbol (µs)	71.36	35.67	17.84	8.91
Slot duration (µs)	1000	500	250	125
Supported FRs	1	1	1,2	2



https://www.researchgate.net/figure/Scalable-OFDM-numerology-with-scaling-of-subcarrier-spacing-3_fig1_332256378

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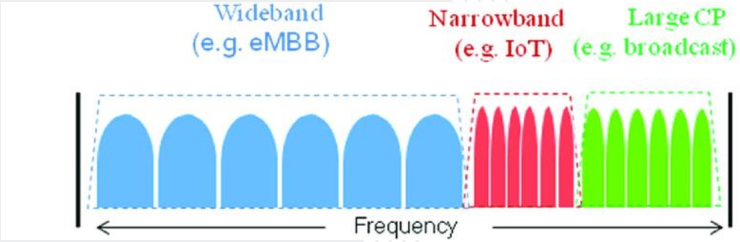
Service Multiplexing

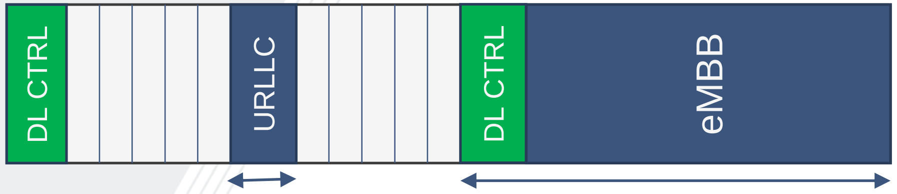
Various services can be efficiently multiplexed onto the same carrier

- eMBB and URLLC multiplexing
  - eMBB and URLLC traffic can be multiplexed in different BWPs with different numerology
    - URLLC may need larger SCS to meet low latency requirements

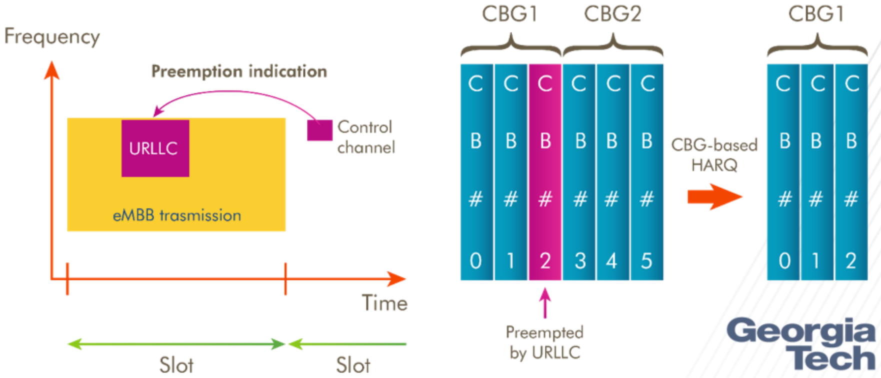


https://www.researchgate.net/figure/G-NR-with-efficiently-multiplexing-of-different-services-3_fig2_332256378

  - eMBB and URLLC transmission can be scheduled with different timing granularity



- URLLC traffic can be transmitted over the resources scheduled for the eMBB traffic
  - Substantially lowers the latency for URLLC applications
  - Pre-emption indication transmitted in PDCCH at the beginning of the subsequent slot notifies the eMBB UE regarding the partial pre-emption of its resources
  - Pre-empted transmission can be handled by HARQ so that pre-empted Code Block Group (CBG) can be retransmitted



https://ofinno.com/technologies/ultra-reliable-and-low-latency-communications/

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Other Air Interface Differences between NR and LTE

- NR is still based on Orthogonal Frequency Division Multiple Access (OFDMA) with Discrete Fourier Transform spread Orthogonal Frequency Division Multiplexing (DFT-S-OFDM) as an option to reduce Peak-to-Average Power Ratio (PAPR)

- Channel Coding changed from Turbo (data) and Convolutional (control) codes to Low Density Parity Check (LDPC) (data) and Polar (control)
  - LDPC codes used by WiFi since 802.11n, but 3GPP has enhanced the capability by adding flexible rate matching since all transmissions are constrained within specific time & frequency boundary

- Differences in Broadcast channels (PSC, SSC, PBCH) to allow for scalable beam-sweeping to support wide variety of antenna structures
  - Traditional cellular bands typically employ sectorized (3 – 6 sectors / cell) or omnidirectional antennas
  - mmWave requires sophisticated antennas with a large number of 2-dimensional apertures to create large number of potential beams to improve coverage

- Dynamic TDD to allow fast changes to UL / DL patterns per frame
  - LTE used semi-static configurations depending on long-term traffic trends

- Bandwidth Parts (BWP): allow a terminal to reduce it's front-end BW to reduce power consumption
  - Especially important since NR supports much larger system BWs (up to 400 MHz)

- Many, many others

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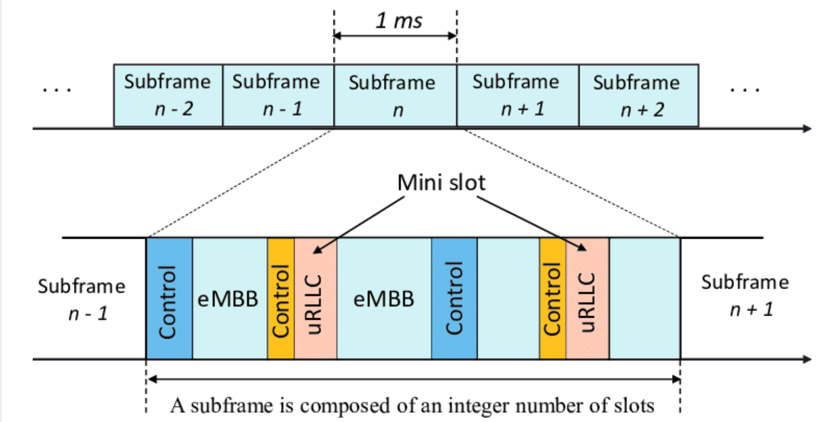
Ultra-Reliable and Low-Latency Communication (URLLC)

Several mechanisms in NR to enable URLLC

Low Latency

- Mini-slot
- Self-contained slot



https://www.researchgate.net/figure/5G-NR-Frame-structure-48_fig5_334668971

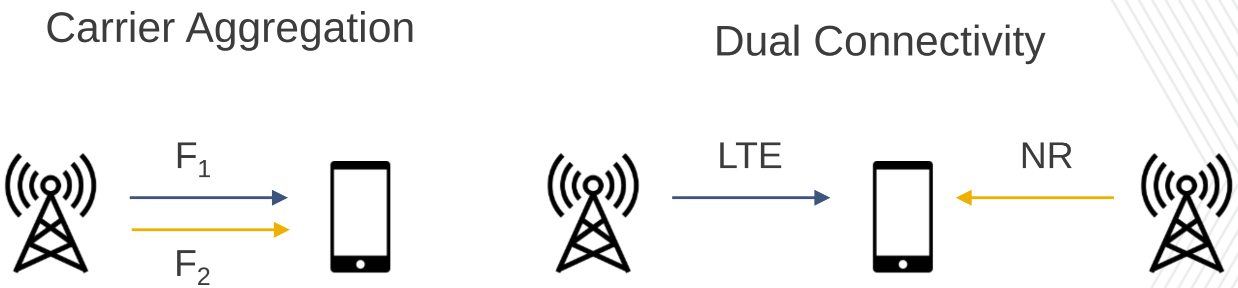
Smaller time units for data scheduling

Transmitting HARQ-ACK in the self-contained slot immediately after receiving the DL data

- **Grant-free UL transmission**
- **Very low periodicity scheduling request**
- **Pre-emption**

High Reliability

- Diversity via duplication



Same PDCP PDU over two carriers

Same PDCP PDU over different RAT (DC)

- **Control channel duplication**
- **Control channel polar coding**
- **New CQI table for low target BLER**

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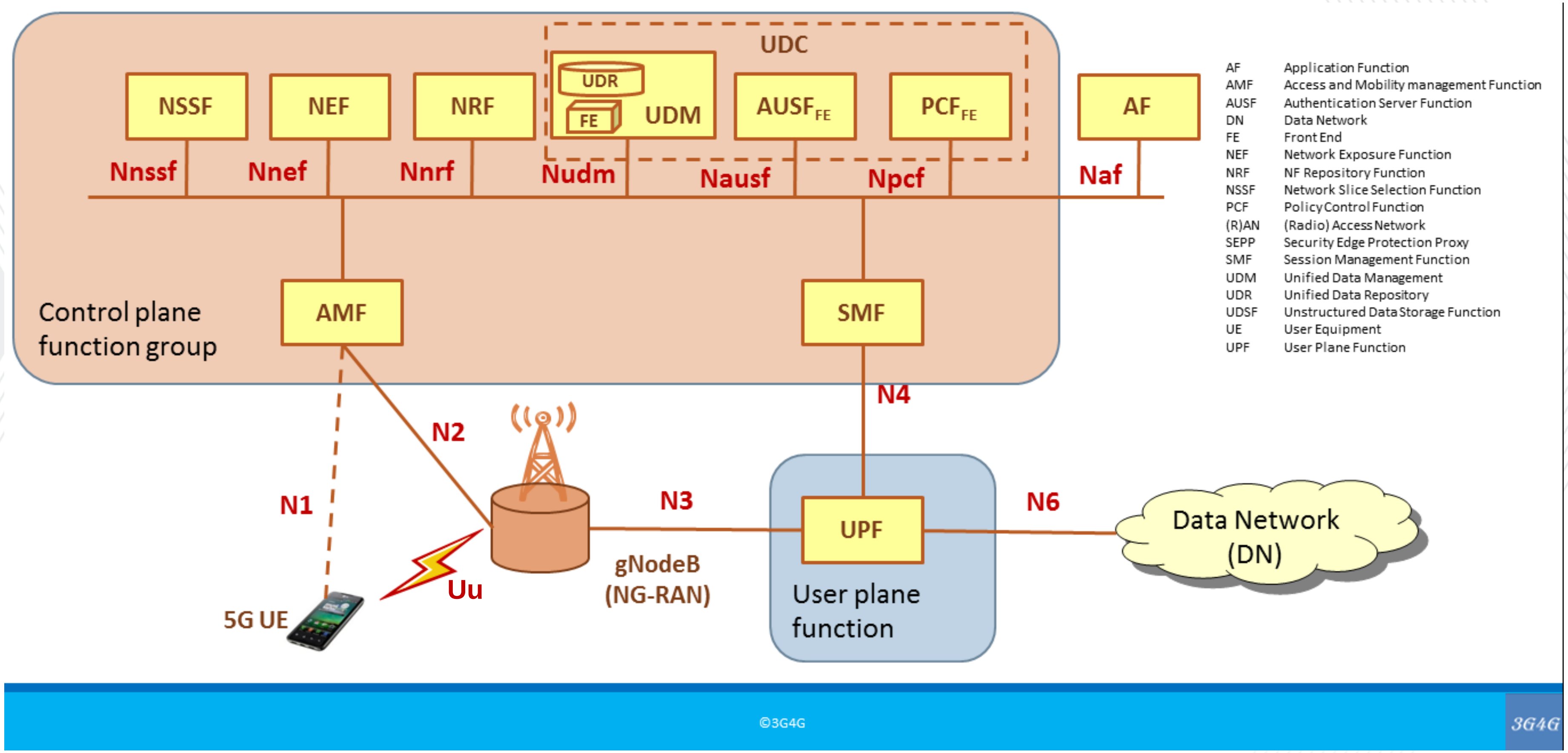
Control and User Plane Separation (CUPS)

- Actually introduced in LTE (Rel-14) but NR is architected from ground up for CUPS
    - Reduces user plane latency
    - SBA allows Network Functions (NF) to offer services via API discovery
- CUPS can be utilized to provide control plane over separate air interface from user plane



https://blog.3g4g.co.uk/2018/02/tutorial-service-based-architecture-sba.html

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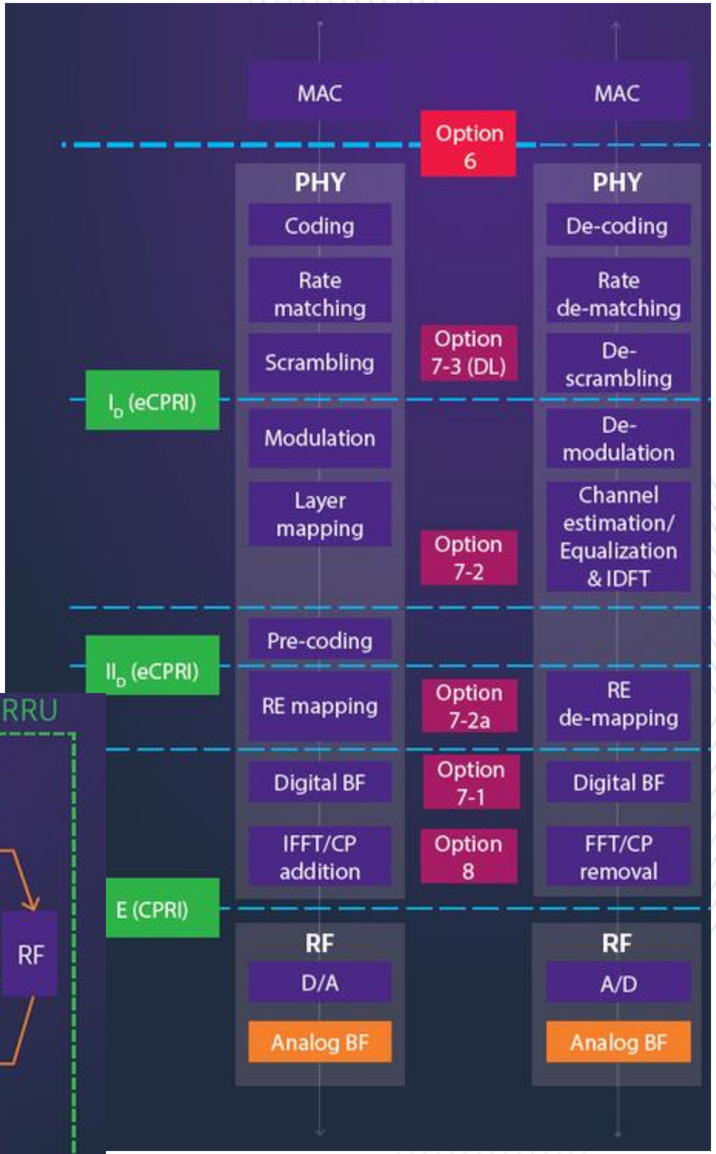
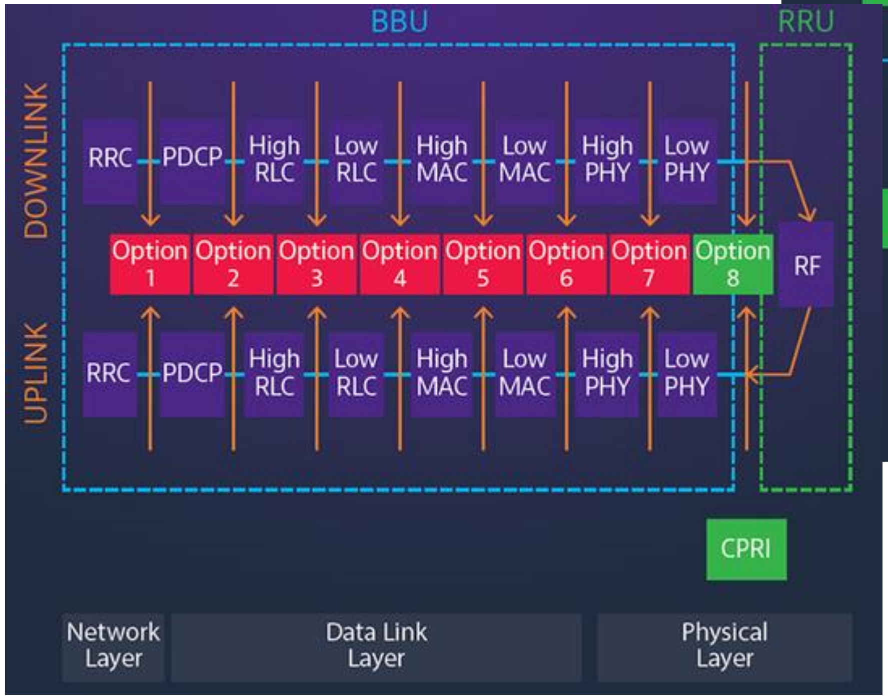
Network Functional Split

- Previous cellular standards' architectures allowed for a fronthaul interface between the base station and remote radio unit (RRU)
    - Usually over CPRI interface
    - Option 8 Split for NR

- 5G allows for much more flexibility by splitting the base station into a centralized unit (CU) and distributed unit (DU) in addition to a separate RRH





https://www.viavisolutions.com/en-us/fronthaul

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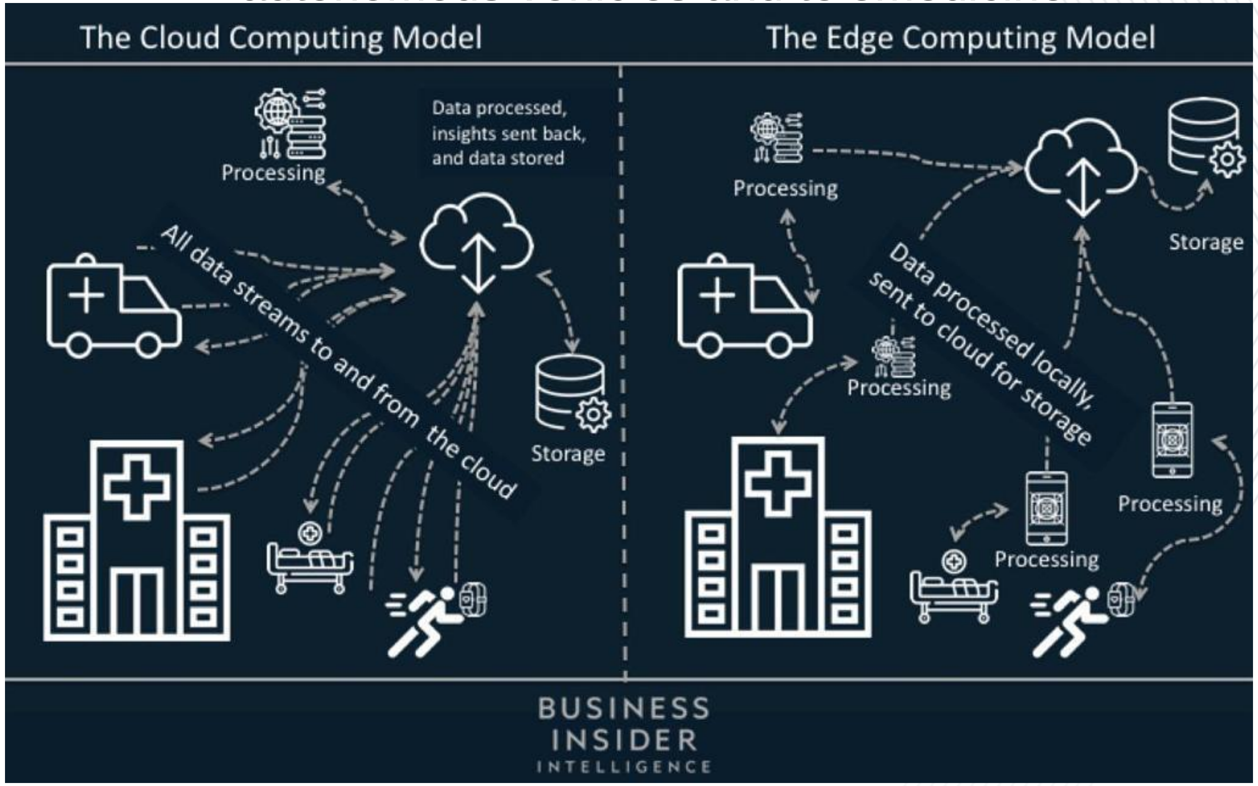
Mobile Edge Computing (MEC)

- MEC brings cloud computing and service hosting to the edge of the network
- Provides end-to-end latency reduction due to proximity to the end-user
- Allows network traffic reduction through traffic localization
- Rich content and RAN co-location support new services

Cloud services cannot provide the latencies required for next wave of mobile services including AR/VR, autonomous vehicles and telemedicine

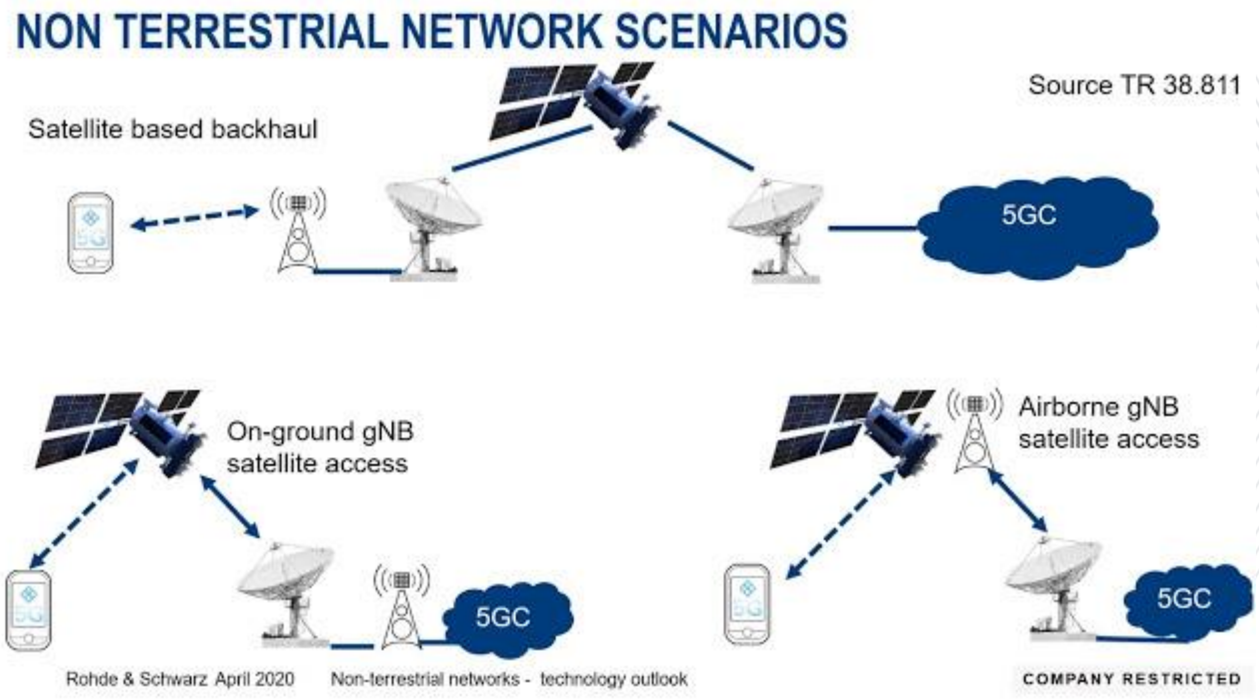


https://www.businessinsider.com/verizon-5g-network-edge-computing-2019-2

Non-Terrestrial Networks (NTN)

- NTN SI Focus
  - Space-borne (GEO, MEO, LEO) vehicles as well as High-Altitude Platform Stations (HAPS)
  - Initial activity is to study the channel model for NTN links, to define deployment scenarios/parameters and identify the key potential impacts on NR
  - Second activity evaluates solutions and studies impact on RAN protocols/architecture
  - Rel-16 SI priority on pedestrian and on-board vehicle usage scenarios; only mandatory features enabling operation of NR in NTN considered

- NTN Challenges
  - Very long propagation delay
    - Up to 600 msec round trip
  - Large cell sizes and moving cells
  - Very high mobility (1000 km/hr)
  - Service continuity between handoffs between NTN and TN



https://www.connectivity.technology/2020/05/r-technical-explainer-on-3gpp-5g-non.html

Cellular Vehicle-to-Everything (C-V2X)

- Leverages Sidelink channel for device-to-device communication
- Can operate in Infrastructure or Intrastructure-less modes
  - Infrastructure-less mode useful when devices are outside of range of network
- Sidelink channel capable of using same flexible numerology in order to reduce latency and increase throughput
- V2X Evolution:
  - V2X established in Rel-14 with LTE (2017) targeting Safety applications with limited capability
    - Used for sharing non-time critical position information
  - eV2X in Rel-15 with LTE increased performance with higher throughput and lower latency
  - C-V2X in Rel-16 with NR supporting advanced use cases
    - Flexible design supporting services with low latency and high reliability
    - NR Sidelink framework to support further extensions for advanced V2X services for Rel-17 and beyond

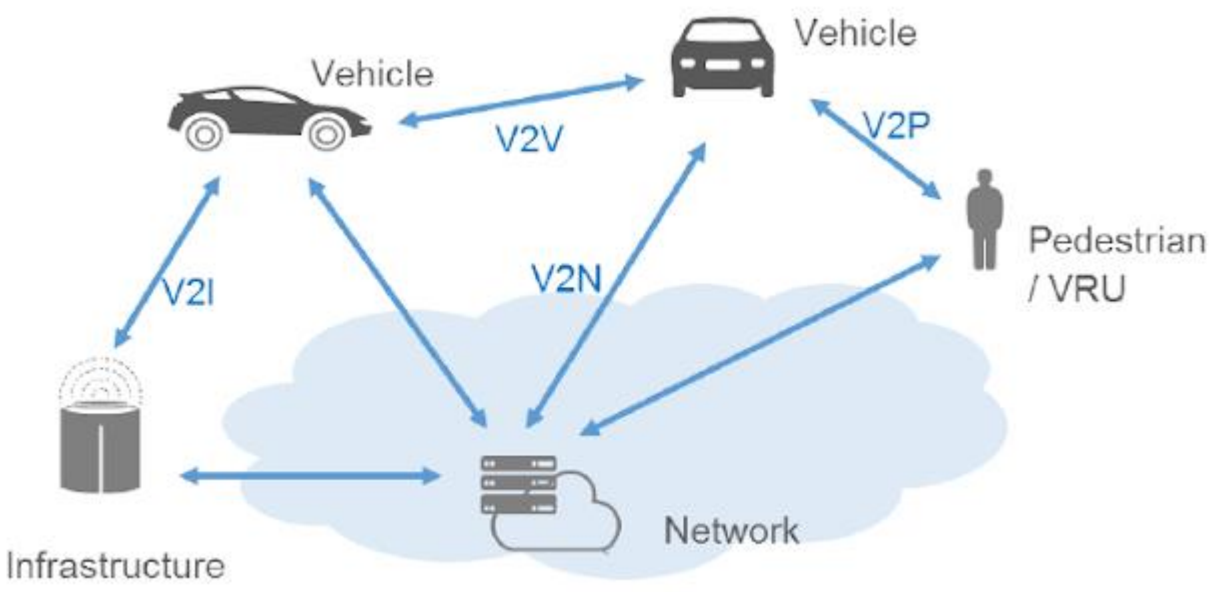


Figure 1: V2X Types.

https://blog.3g4g.co.uk/2016/11/lte-5g-and-v2x.html

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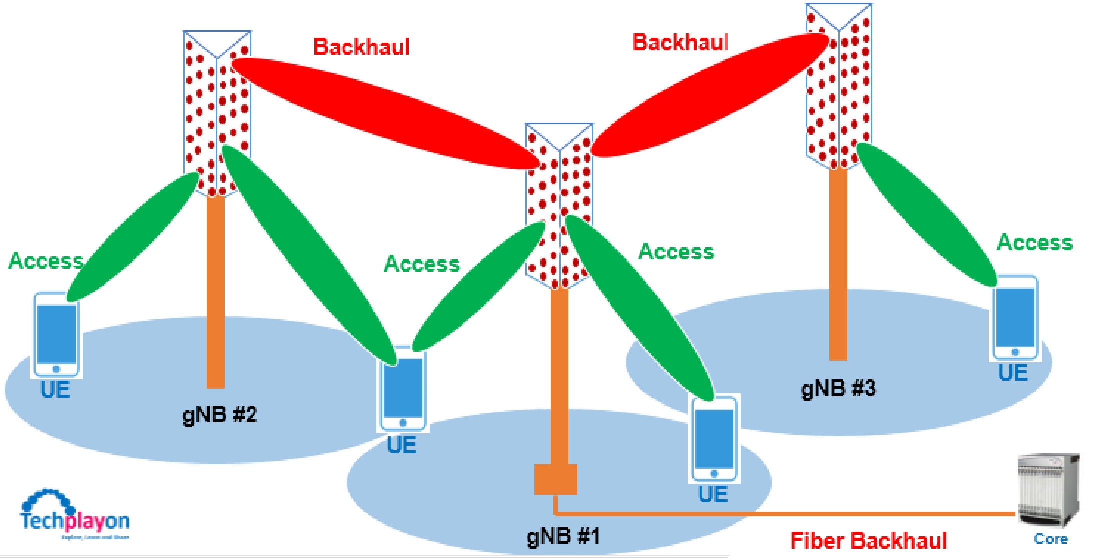
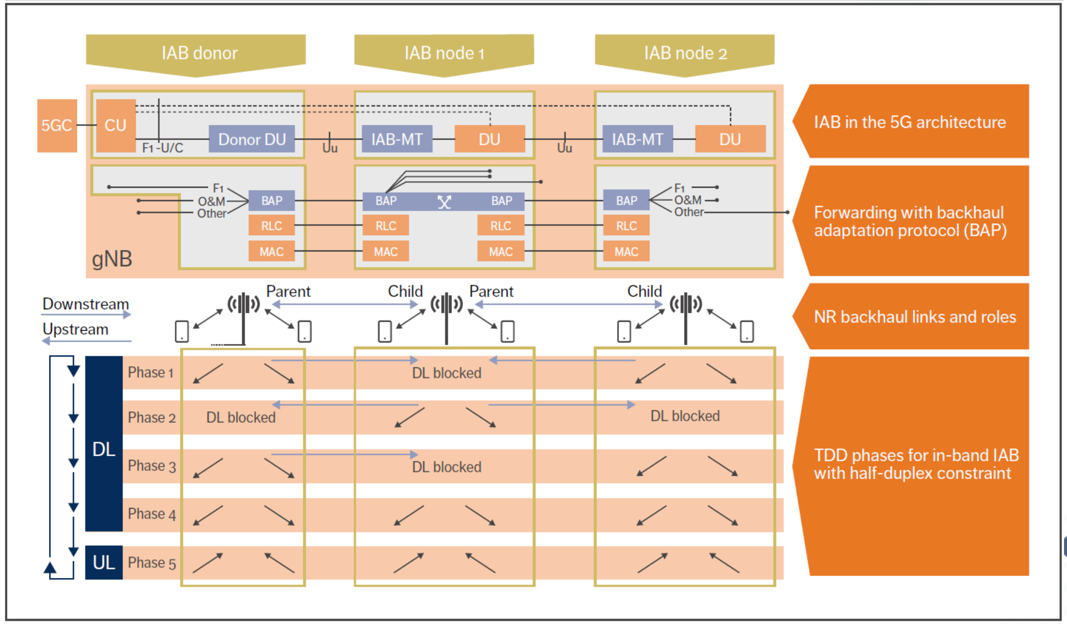
Integrated Access and Backhaul (IAB)

- Rel-16 adds IAB to 5G
  - Motivated by reducing cost of installing wired backhaul throughout densely deployed networks such as mmWave hotspots
- IAB extends range beyond a typical gNB
  - Single CU can control multiple DUs linked by wireless backhaul
  - Highly beneficial for mmWave but also effective at sub-6 GHz frequencies (e.g. CBRS)
  - Requirement to operate backhaul links in half-duplex (note: mmWave already operates in TDD mode)
  - Backhaul carrier frequency can be same or different from access carrier

http://www.techplayon.com/5g-self-backhaul-integrated-access-and-backhaul/





file:///I:/Projects/5G%20in%20Tactical%20Env%20(PEO%20C3T)/References/introducing-integrated-access-and-backhaul.pdf

Access Agnostic Core Network

- Common Access Network (AN) – CN interface integrating different 3GPP and non-3GPP access types
- Converged CN with common procedures across different access types
  - Mobility Management, Session Management, Security/Authentication, etc.
- Non-3GPP Ans connected to 5G-CN via N3IWF, Unified Nx interfaces for UEs across different accesses
  - Network maintains one UE context for multiple accesses
- Some 3GPP-specific services (e.g. SMS over NAS) have been enabled over non-3GPP access
- Future releases will enable more flexible traffic steering, switching and splitting between 3GPP access and non-3GPP access

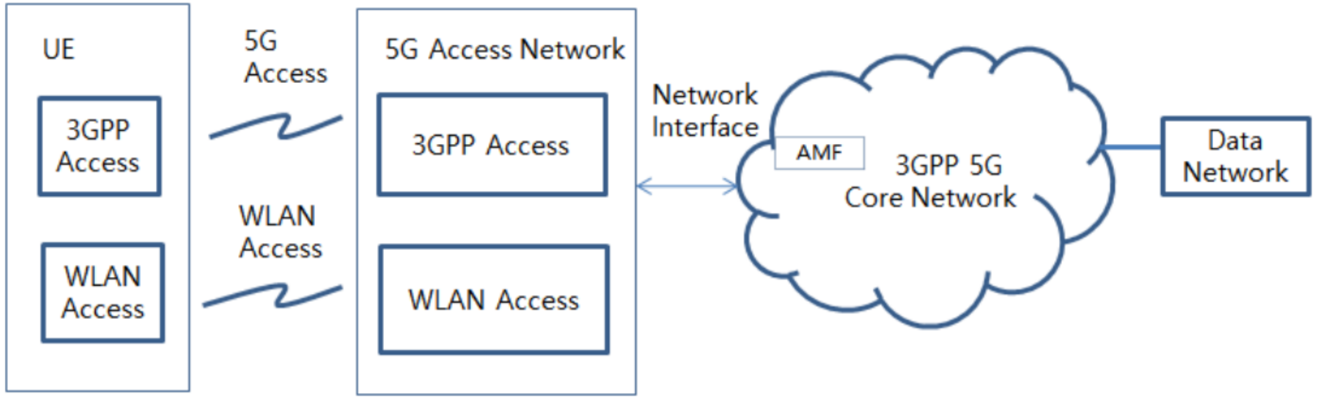


Figure 2. Tightly coupled interworking reference model between 5G core network and WLAN

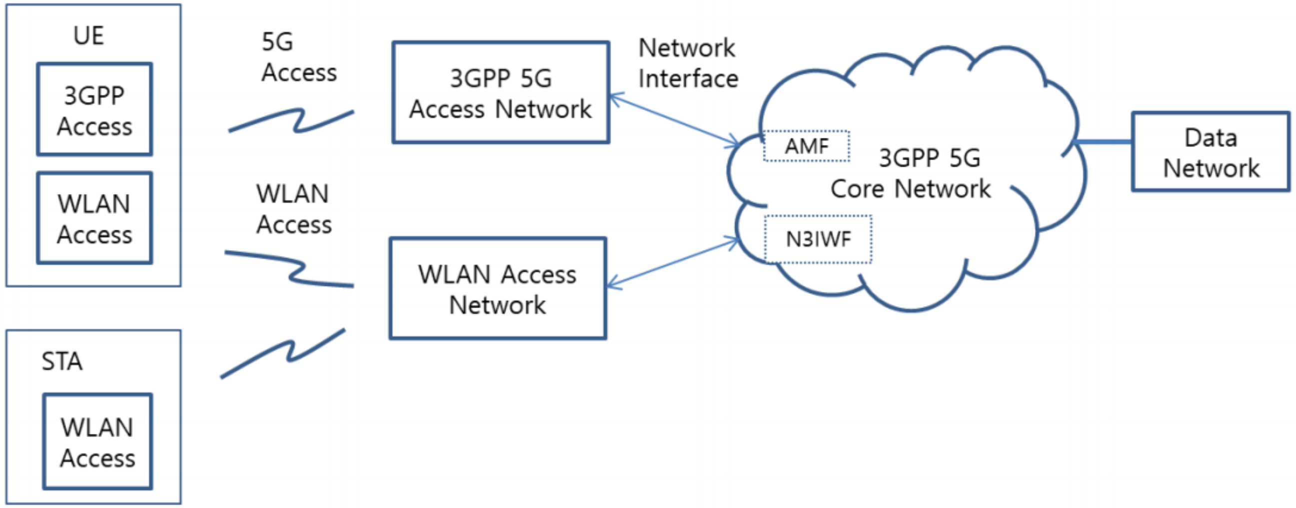


Figure 3. Loosely coupled interworking reference model between 5G core network and WLAN

* N3IWF = non-3GPP Interworking Functions

https://mentor.ieee.org/802.11/dcn/20/11-20-0013-05-AANI-draft-technical-report-on-interworking-between-3gpp-5g-network-wlan.pdf

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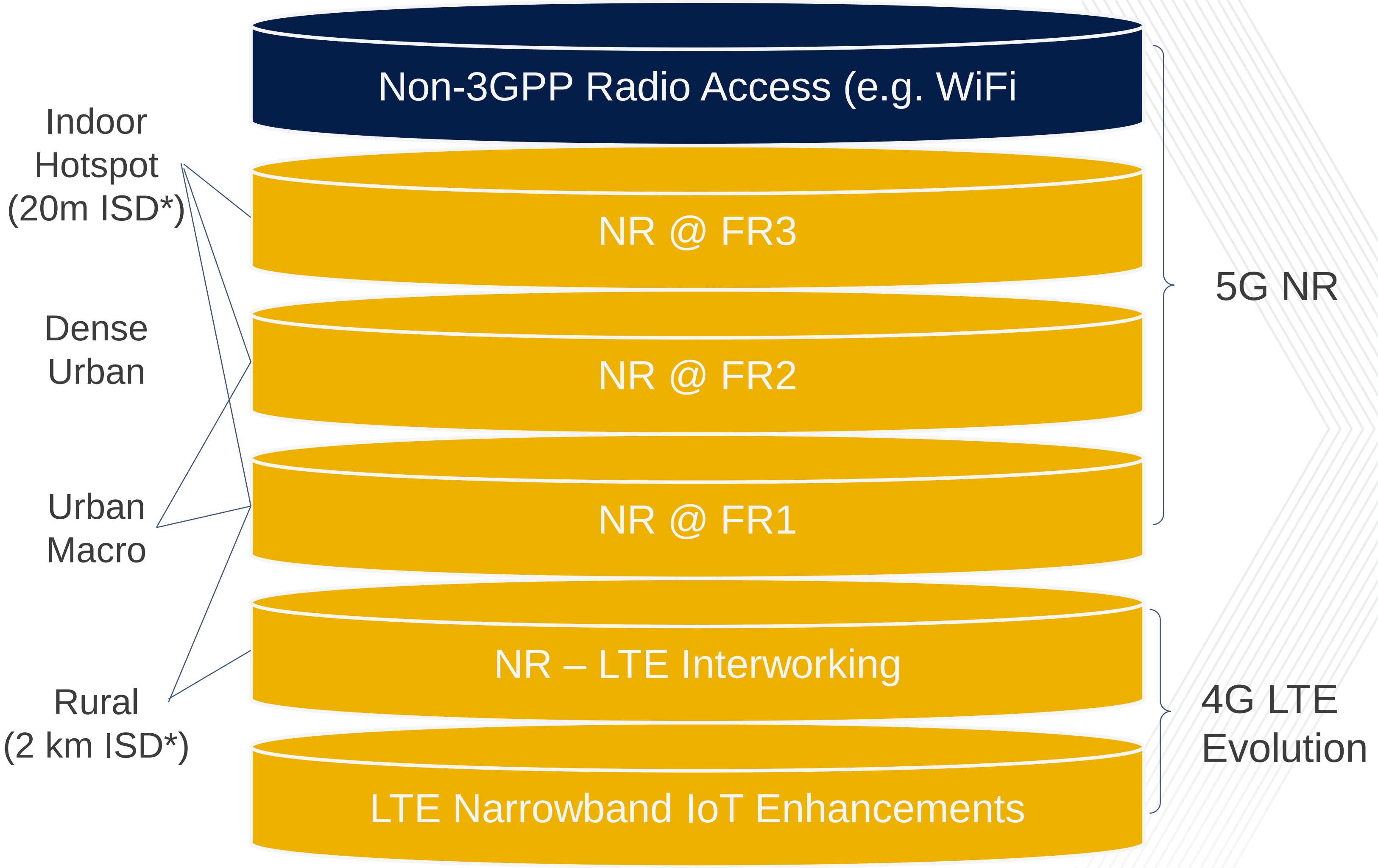
Multi-Layer Radio Network

- 5G designed with native support for connectivity across multiple technology layers

- Mature 5G networks (i.e. 2025+) envisioned to include all radio layers working together
  - LTE and NB-IoT expected to evolve as components within 5G networks



*Inter-site distance

What’s Next

- Non-Orthogonal Multiple Access (NOMA)
- NR-U (NR in Unlicensed Band)
- Full-Duplex MIMO
- Additional Bands Above FR2 (> 52.6 GHz)

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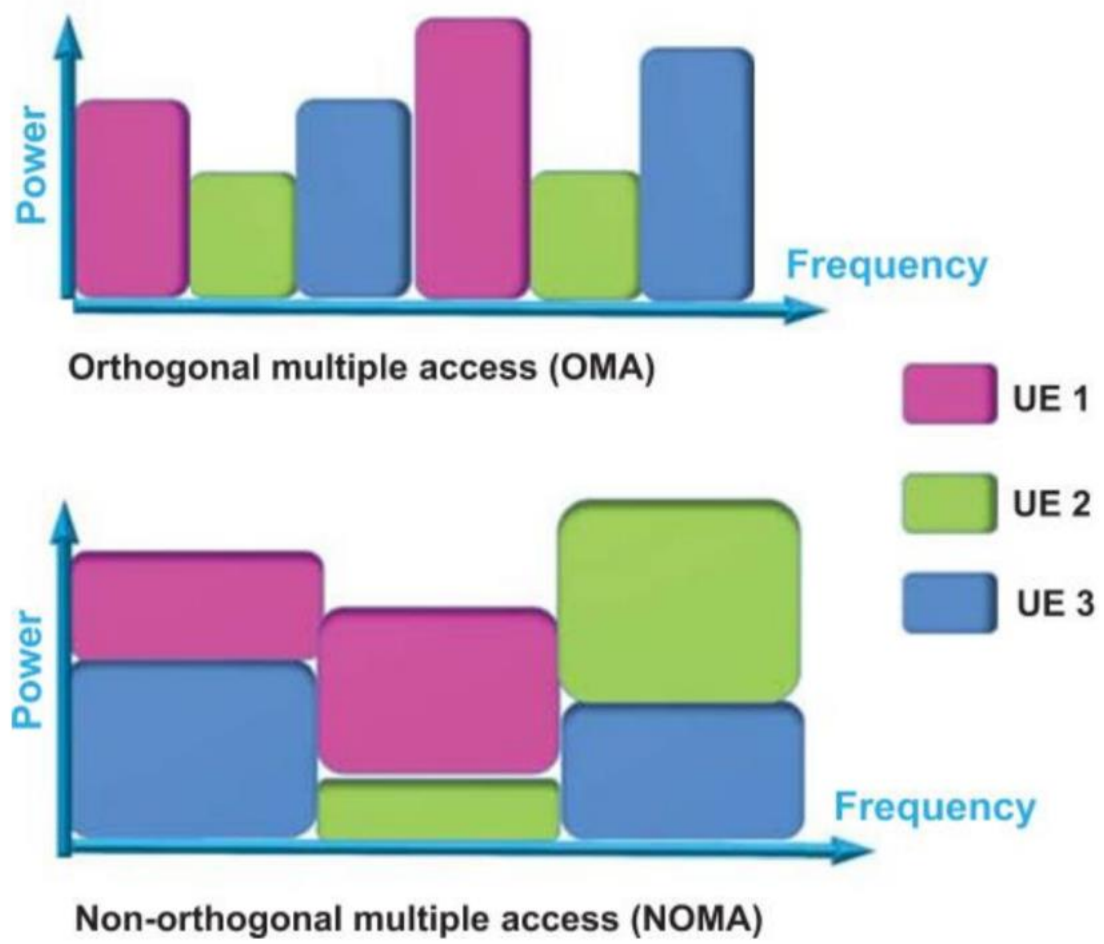
Non-Orthogonal Multiple Access (NOMA)

- NOMA Study Item:
  - NOMA purposely transmits non-orthogonal signals on the same time/frequency resources utilizing MAS and the use of advanced receiver processing to recover the non-orthogonal signals with optional signal power offsets
  - NOMA allows for more transmission opportunities making it helpful for mMTC, URLLC and eMBB
  - Study item completed in Dec 2018



http://www2.ee.unsw.edu.au/~derrick/Stella_Ho_UNSW_thesis.pdf

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NR-U (NR in Unlicensed Band)

- NR-U Work Item
  - Key PHY components: Inheriting choices of duplex mode, waveform, carrier BW, SCS, frame structure and PHY design made from NR study
  - Spectrum: The SI phase focused on 5 GHz unlicensed band and 6 GHz band is under discussion. While these bands are of most interest, other unlicensed bands in FR2 or FR3 could be considered in later releases
  - Regulatory aspects (e.g. LBT): changes in initial access, channel access, scheduling/HARQ, mobility operation and radio-link monitoring / failure
  - Possible deployments: a) standalone NR-U, b) Carrier aggregation NR/NR-U and NR-U/NR-U, c) dual connectivity between licensed NR/LTE and NR-U

Band	Availability
800-900 MHz	No global availability
2.4 GHz	Global availability
3.7 – 4.2 GHz	500 MHz, US
5.1 – 5.9 GHz	Global availability
5.9 – 6.4 GHz	500 MHz, EU/US
3.5 GHz GAA	150 MHz, US
57 – 71 GHz	14 GHz

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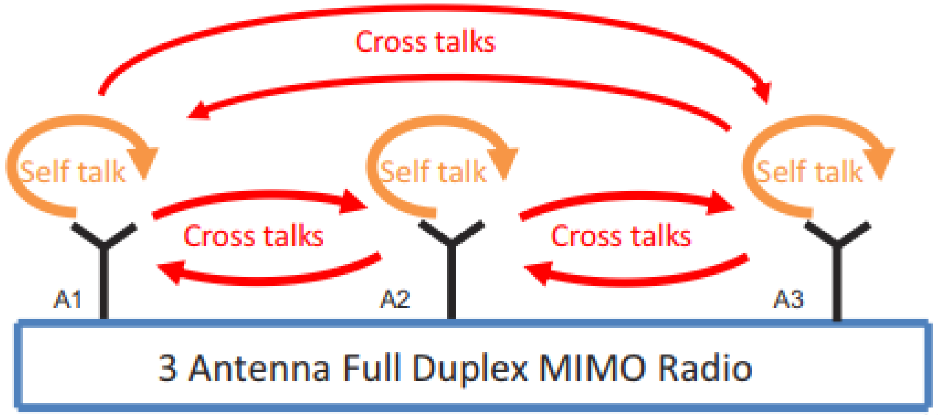
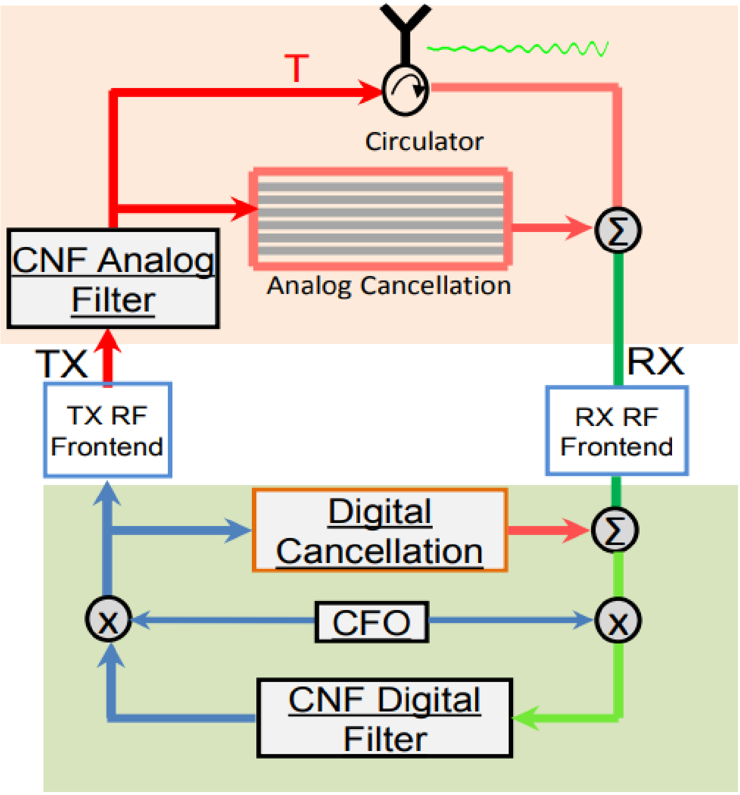
Full-Duplex MIMO

- Since 3G, cellular technology has been based on TDD or FDD modes
  - TDD: each slot defined as UL or DL; time-multiplexed transmission and reception using the same carrier frequency
  - FDD: UL and DL exist simultaneously using paired carriers

- Full-Duplex would greatly increase network capacity by allowing transmit and receive on the same carrier simultaneously
  - However, requires sophisticated self-interference cancellation technology to enable





http://wcsng.ucsd.edu/fullduplex.html

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5G FR3 Use Cases (above 52.6 GHz)

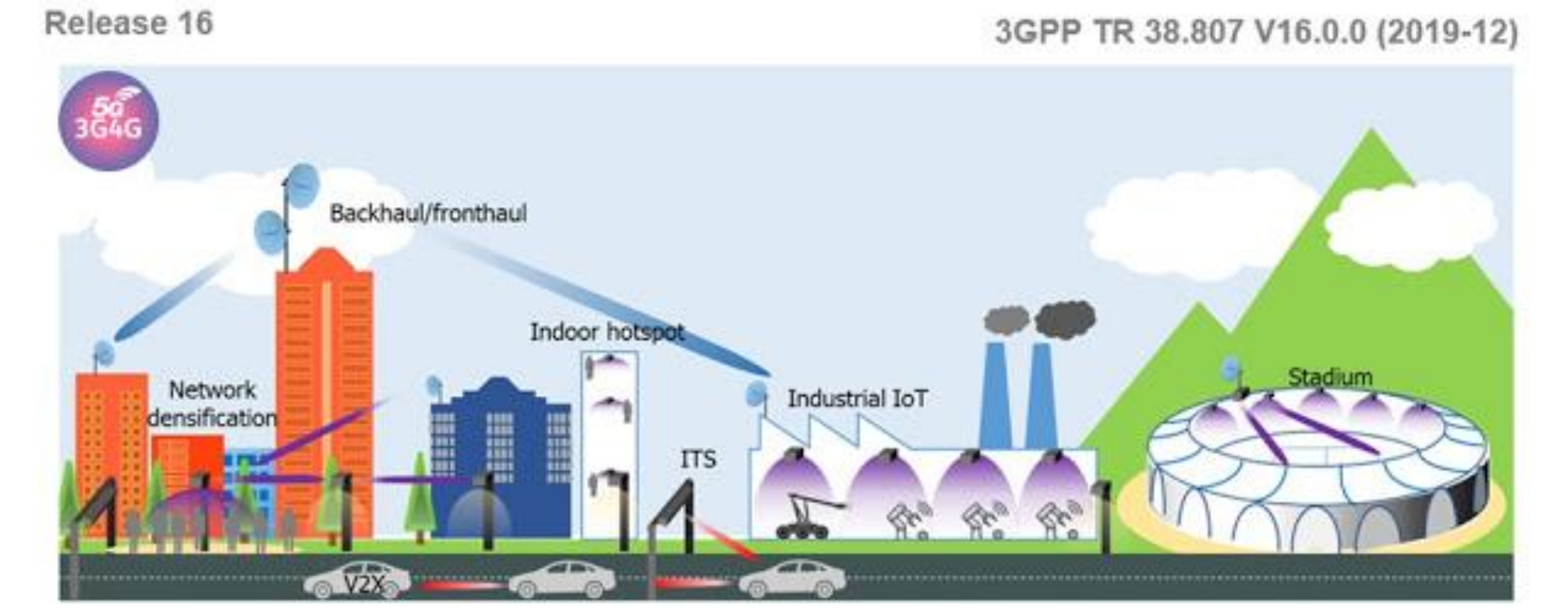

Figure 5.1-1: Use Cases for NR above 52.6GHz

https://blog.3g4g.co.uk/search/label/ITU

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Thank You!

- Thanks to the IEEE Atlanta chapter for arranging today’s webinar
- Contact information:
  - William.Lawton@gtri.gatech.edu
- Have a great week!

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