SDOs and Communities

SDOs

Protocols are *standardized* by:

- Standardization Development Organizations (SDOs)
- Industry Standards Groups (ISGs)
- Government agencies
- Leading players
- Open Source Communities

Some important SDOs

- **I**nternet **E**ngineering **T**ask **F**orce (RFCs)
- **I**nstitute of **E**lectrical and **E**lectronics **E**ngineers (e.g., 802)
- **I**nternational **T**elecommunication **U**nion (e.g., X.###)
- **A**merican **N**ational **S**tandards **I**nstitute
- **E**uropean **T**elecommunications **S**tandards **I**nstitute
- 3rd Generation Partnership Project

ITU

The **I**nternational **T**elecommunication **U**nion is a specialized agency of the UN

The ITU HQ is in Geneva, Switzerland

The ITU has 3 sectors:

- ITU-T Telecomm standardization (previously CCITT)
- ITU-R Radio communications (previously CCIR)
- ITU-D Development (sustainable and affordable access to ICT)

Each sector is composed of Study Groups (and perhaps Focus Groups)
which are composed of Working Parties
which are composed of Questions

The ITU produces Recommendations, which may be absorbed into local law

ITU-R is responsible for

- the **M**aster **I**nternational **F**requency **R**egister
- coordinating satellite orbits
- requirements and architecture
  of the **I**nternational **M**obile **T**elecommunication system

IMT-2000 (3G)

In 1985 ITU-R started work on a blueprint for 3G called
International **M**obile **T**elecommunications 2000 (IMT-2000)

The “2000” referred both to the expected launch *year*
and to the intended frequency *band*

In 1992 the World Administrative Radio Congress (WARC'92)
allocated 1885-2050 MHz and 2110-2200 MHz for IMT-2000 use

IMT-2000 was a design architecture, a family of standards - not a standard
and several groups developed standards to meet IMT-2000 requirements

- **Universal Mobile Telecommunications System (UMTS)**
  originally proposed by ETSI (Europe) based on GSM
  passed to 3GPP for worldwide development and adoption
- **Universal Wireless Communications (UWC-136)**
  proposed by TIA (US)
- **CDMA2000**
  proposed by 3GPP2 (ANTI, ARIB, TTA, TTC)
  hardware upgrade to existing CDMA systems used in US and Asia

IMT Advanced (4G)

In 2008 the ITU-R proposed IMT-Advanced for 4G mobile and Internet

Requirements

- based on an all-IP network
- interoperability with existing networks
- global roaming
- increased simultaneous users in each cell
- QoS sufficient for multimedia applications
- smooth handoff
- nominal data rates of
  - 1 Gbps for stationary users
  - 100 Mbps for moving users
- link spectral efficiency of up to 15 / 6.75 bit/s/Hz
- cell spectral efficiency of up to 3 bit/s/Hz/cell
- multiple channel bandwidths

IMT-2020 (5G)

In 2012 ITU-R embarked on “IMT for 2020 and beyond” (IMT-2020)
kicking off 5G research activities around the world

The activity has produced:

- Report **M.2320** Future technology trends of terrestrial IMT systems
- Recommendation **M.2083** Framework and overall objectives of the future development of IMT for 2020 and beyond
- Report **M.2376** Technical feasibility of IMT in bands above 6 GHz

World radio-communication conferences (WRC) are held every 3-4 years
to review and revise the RF spectral allocations

At WRC-2019 (Sharm El Sheikh, October 2019)
ITU's 193 member states will allocate new frequency bands for IMT-2020

ETSI

The **E**uropean **T**elecommunications **S**tandards **I**nstitute
is the European telecommunications standardization organization headquartered in Sophia-Antipolis, France,

ETSI was created in 1988 and has produced > 30K standards since then, on:

- broadcast radio and television (analog and digital)
- satellite, maritime, rail, aeronautical communications
- broadband cable and DSL access
- radar, medical devices, secure AI,
- communications security
- public safety and emergency communications
- cybersecurity including digital signatures, quantum-safe cryptography, QKD
- Telephony and VoIP
- cellular communications, including GSM (2G)

3GPP

The most important SDO for 5G is the 3G Partnership Project

3GPP arose from an initiative between Nortel and AT&T
to migrate from GSM to a 3G packet switched network
(logistics are still handled by ETSI with HQ in Sophia Antipolis, France)

Building on the GSM infrastructure in ETSI, it now unites 7 SDOs:

- ARIB (Japan radio frequency coordination organization)
- ATIS (USA telecomm SDO accredited by ANSI)
- CCSA (China SDO founded by Ministry of Information)
- ETSI (European based telecomm SDO)
- TSDSI (India telecomm SDO)
- TTA (South Korea SDO and certification labs)
- TTC (Japan ICT industry group)

3GPP is presently tasked with

- maintenance of GSM and 3G standards
- continued development of LTE 4G standards
- development of 5G (release 15 and release 16) standards

3GPP organization

3GPP presently has 3 **T**echnical **S**pecifications **G**roups, composed of **W**orking **G**roups

Radio **A**ccess **N**etwork

- RAN WG1 Radio Layer 1 specification
- RAN WG2 Radio Layer 2 and Layer 3 specification
- RAN WG3 Interface protocols, O&M, synchronization
- RAN WG4 Radio performance and protocol aspects
- RAN WG5 Mobile terminal (UE) conformance testing
- RAN WG6 GERAN radio and protocol (2G and 3G)

Service and System **A**spects (requirements, architecture, and coordination)

- SA WG1 Services
- SA WG2 Architecture
- SA WG3 Security
- SA WG4 Codec (audio, video multimedia)
- SA WG5 Telecom management
- SA WG6 Mission-critical applications

Core Network and **T**erminals

- CT WG1 Mobility Management, Call Control, Session Management, and Location services
- CT WG3 Interworking with external networks
- CT WG4 MAP/CAMEL/GTP/BCH/SS (Call Processing and Mobility Management within the core)
- CT WG6 Smart Card Application Aspects (SIMs)

O-RAN Alliance

The xRAN Forum was formed by leading mobile carriers

AT&T, Deutsche Telekom, Telstra, Verizon and SK Telecom

joined by Intel, TI, Aricent, Radisys, Cisco, Altiostar, ASOCS and Stanford

to develop, standardize and promote a software RAN

The C-RAN Alliance focused on RAN cloudification, and included

ZTE, Huawei, Ericsson, Nokia, HP, Intel, Broadom, RedHat

The xRAN Forum merged with the C-RAN Alliance to form the O-RAN Alliance

to promote openness into the next generation RAN

Founding members include

AT&T, China Mobile, Deutsche Telekom, NTT DOCOMO, and Orange

Two main goals:

1. evolve RAN to be smarter (analytics, AI/ML) and more open
2. design open interfaces for virtualized network elements (SDN/NFV) including interfaces not being standardized by 3GPP

Linux Foundation Networking

LF NETWORKING

In 2018 the Linux Foundation announced that 6 of its OS networking projects (ONAP, OPNFV, OpenDaylight, FD.io, PNDA, & SNAS) would be united to form the Linux Foundation Networking Fund

The LFN presently hosts projects for Open Source ...

- forwarding (VPP, OVS, OpenSwitch, Stratum)
- data analytics (pnda)
- edge cloud computing (Akraino)
- computing infrastructure (DPDK, P4, IoVisor)
- SDN (OpenDaylight, ONOS, Mininet)
- routing protocol stack (FRR)
- SDN (OpenDaylight, Mininet)
- security (Open Security Controller)
- orchestration (ONAP, CORD, TF)
- NFV (OPNFV)

OCP

Until recently Open Source was only applied to software

Creative Commons extended Open Source licensing to literature and art

OCP extends Open Source principles to hardware

In 2011 Facebook decided to share designs for data center servers
and today its data centers are 100% OCP

Members include: Facebook, Google, Alibaba, Microsoft, Rackspace,
Cisco, Intel, Dell, Lenovo, IBM, Nokia, Seagate, Goldman Sachs, Fidelity

OCP designs include:

- data center servers, motherboards, cards (Intel, AMD, ARM)
- data center storage vaults
- ToR and Leaf switches
- racks, power and cooling solutions
- cell site router

TIP

TELECOM INFRA PROJECT

In 2016 TIP was formed as a sister project to OCP
for building and deploying global telecom network infrastructure

Today TIP has >500 member organizations
and on its board: Intel, Facebook, Nokia, DT, Vodafone, Telefonica, BT

Projects:

- OpenRAN — enabling open ecosystem of GPP-based RAN solutions
- Millimeter Wave Networks — creating low-cost municipal networks
- Power and Connectivity — global connectivity through global electricity
- System Integration and Site Optimization
- Solutions Integration — development of interoperable RAN architecture
- Open Optical & Packet Transport — DWDM interoperable transport
  - DWDM Voyager optical switch is the 1st WB transponder/router device for open packet DWDM optical networks

Some more forums of interest to 5G ...

- 5G Americas
- 5G Infrastructure Association (5G-IA)
- 5G Infrastructure Public Private Partnership (5GPPP)
- 5G Forum
- Broadband Forum (BBF)
- Common Public Radio Interface (CPRI)
- GSM Association (GSMA)
- Heron (Israeli 5G consortium)
- IEEE 1914 (Next Generation Fronthaul) Working Group
- IEEE 802 Time Sensitive Networking Task Group
- MEF Forum
- METIS (ex EU project)
- Neptune (Israeli consortium for network programming)
- Next Generation Mobile Networks (NGMN)
- Open Networking Forum (ONF)
- Optical Internetworking Forum (OIF)
- Small Cell Forum (Femto Forum)

Motivation for 5G

What's wrong with 4G?

4G made possible:

- fast Internet access
- video reception and creation
- apps relying on location and identity
- always-on behavior

but suffers from numerous limitations:

- for some applications: data-rate too low
- for some applications: delay too high
- too few simultaneous connections (insufficient density)
- coverage too low / drop rate too high
- weak (if any) QoS guarantees
- price per bit too high (inefficient spectral use)
- power consumption too high (and thus battery life too low)
- poor support for new applications/markets (e.g., IoT, AR/VR, connected cars)
- no support for new mobility requirements (mobile hot spots, high speed)
- insufficient security/privacy

5G is being developed to address 4G limitations

5G importance

5G will enable entirely new market segments

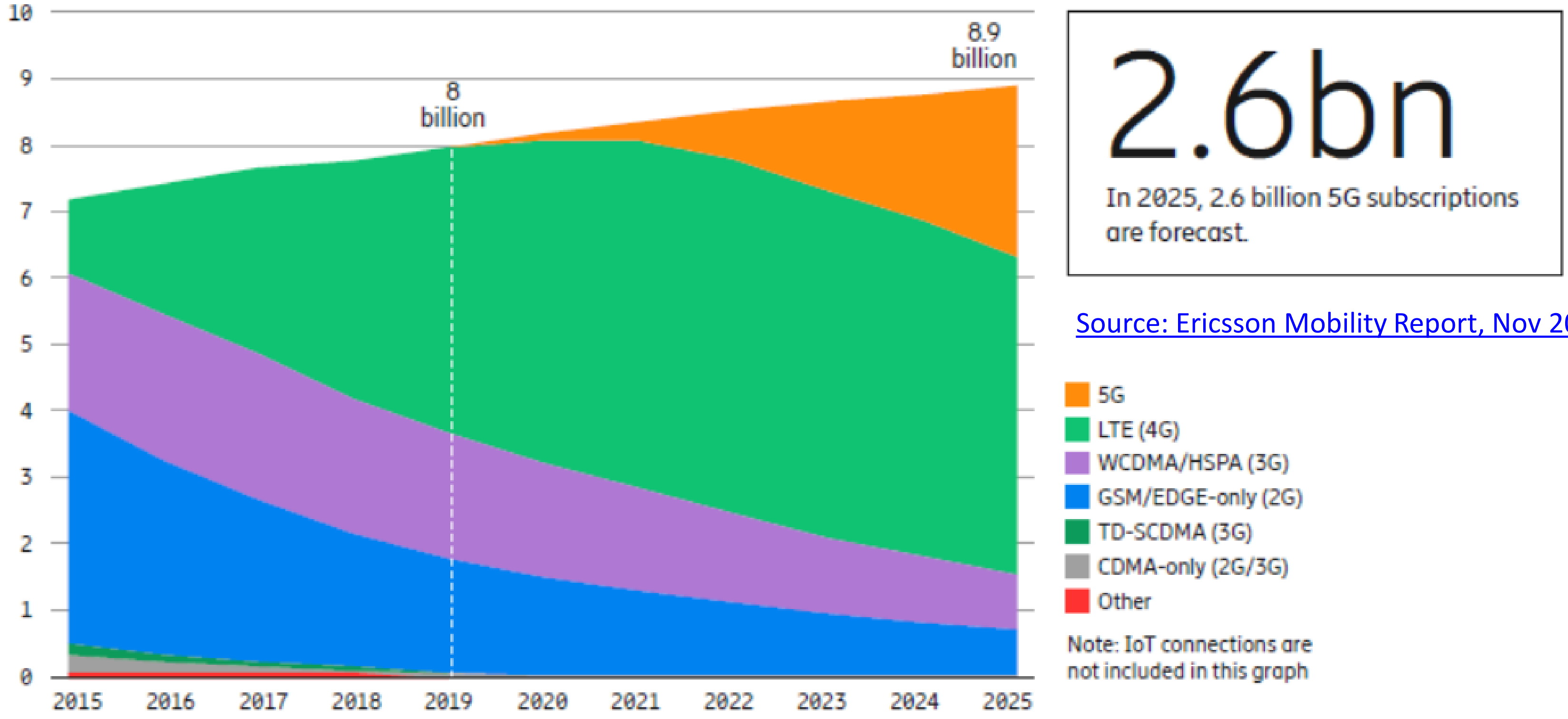
- *ubiquitous* wireless broadband (eMBB)
  - Wireless-to-the-Premises
  - broadband on high-speed trains, at events and in crowds
- *massive* IoT (20 B IoT devices connected by 2020)
- V2X (vehicle to vehicle, vehicle to infrastructure)
- Virtual Reality / Augmented Reality
- Industry 4.0

A study led by Qualcomm finds that by 2035

- $3.5 trillion in 5G direct yearly revenues
- $12.3 trillion worth of goods and services will be enabled by 5G
- 22 million jobs will be attributable to 5G
- 5G will boost global GDP growth by $3 trillion (compared to 2020)
  about the GDP of India

5G is coming fast!

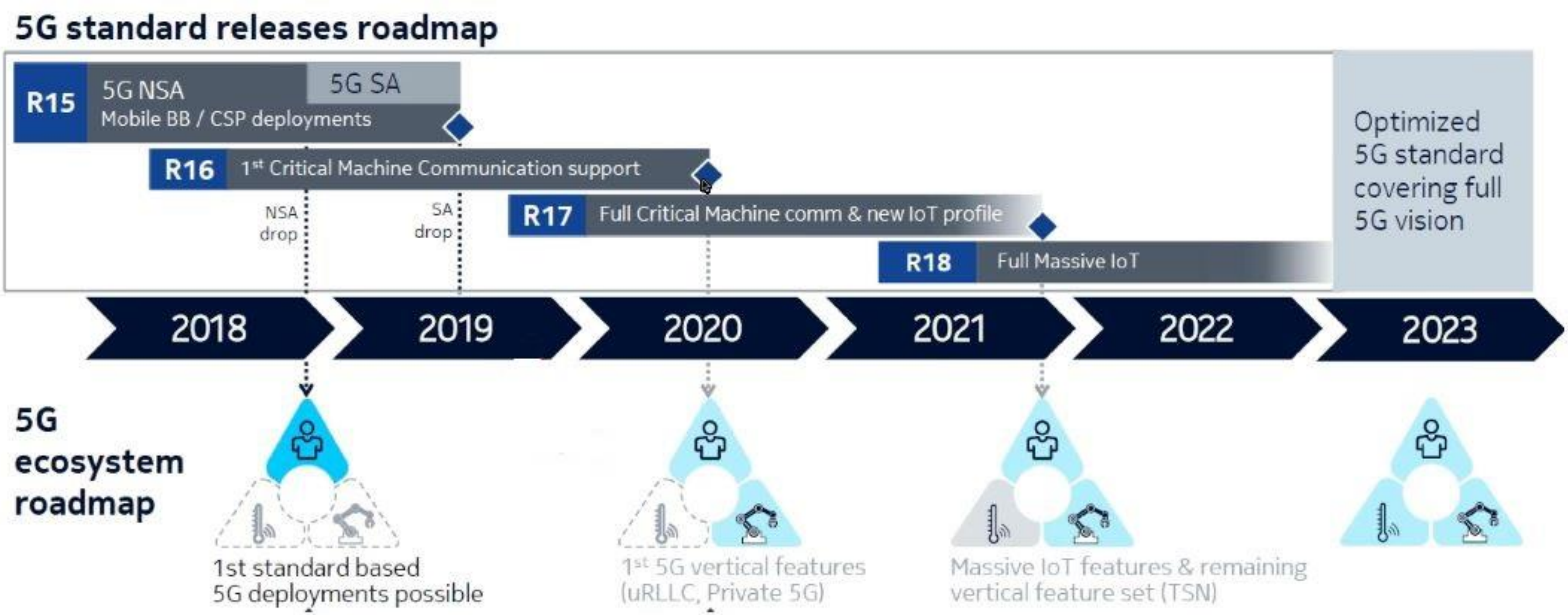
You may think that 5G is *futuristic*, but it is coming *fast*



[Source: Ericsson Mobility Report, Nov 2019]

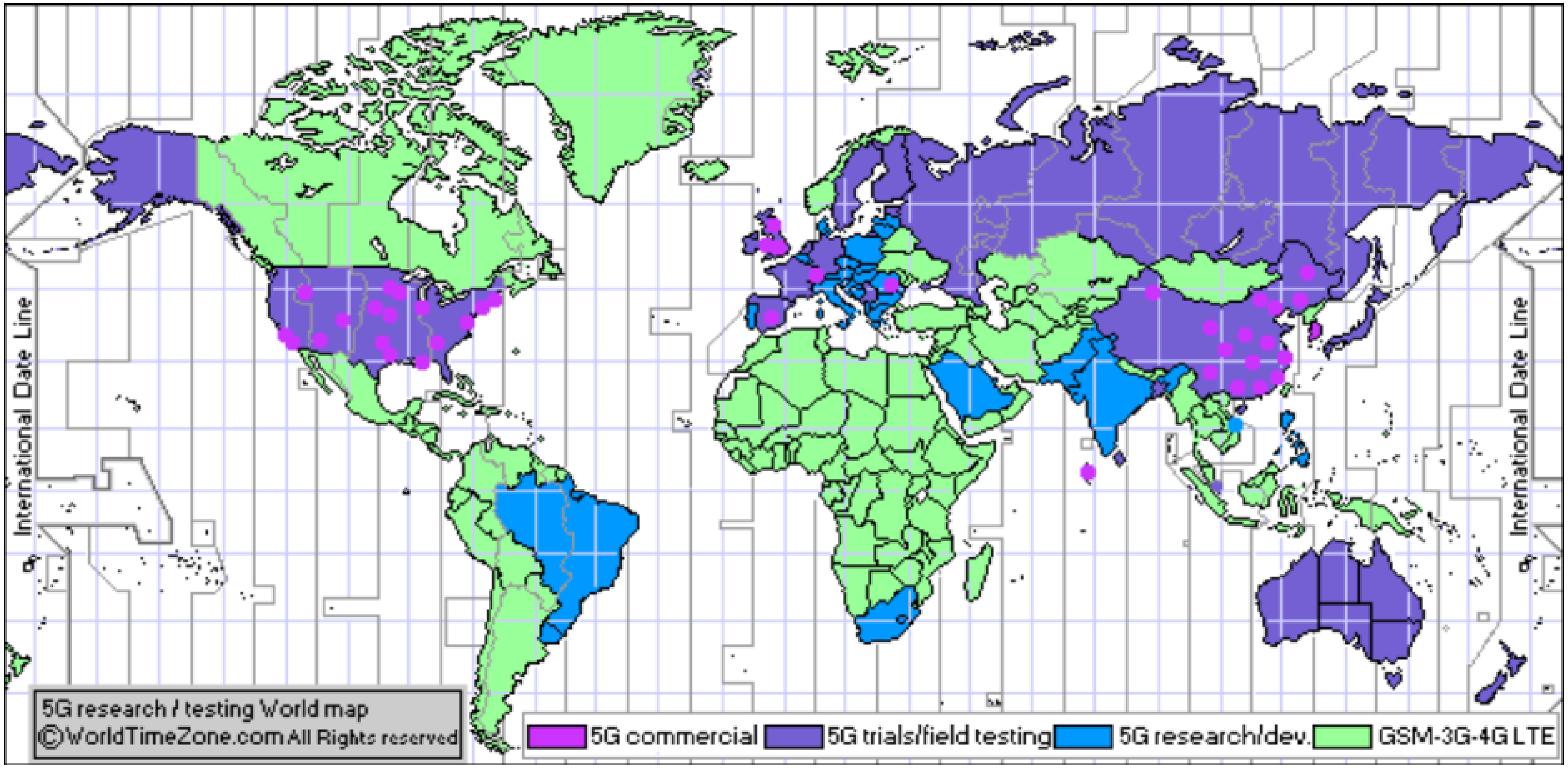
5G standardization is setting the pace

- 5G standardization was accelerated and proceeded at an unprecedented pace
- Release 15 had an *early drop* in Dec 2017 (a year earlier than planned) and the majority of the work was approved in June 2018
- Release 16 will be frozen in March 2020 and completed by June 2020



In a sense 5G is already here!

>7000 deployments >100 operators



WorldTimeZone Dec 12, 2019

Verticals

All earlier generations were designed for general purpose connectivity without considering requirements for specific use cases

Preliminary 5G work defined several vertical markets of interest, such as:

- residential Internet
- business services (incl. B2B, B2C)
- first responders
- smart city, smart utilities
- automotive (V2X)
- e-health
- manufacturing (incl. industrial robots)
- entertainment and gaming
- AR/VR
- critical infrastructure
- wearables
- mass transit
- e-government
- agriculture

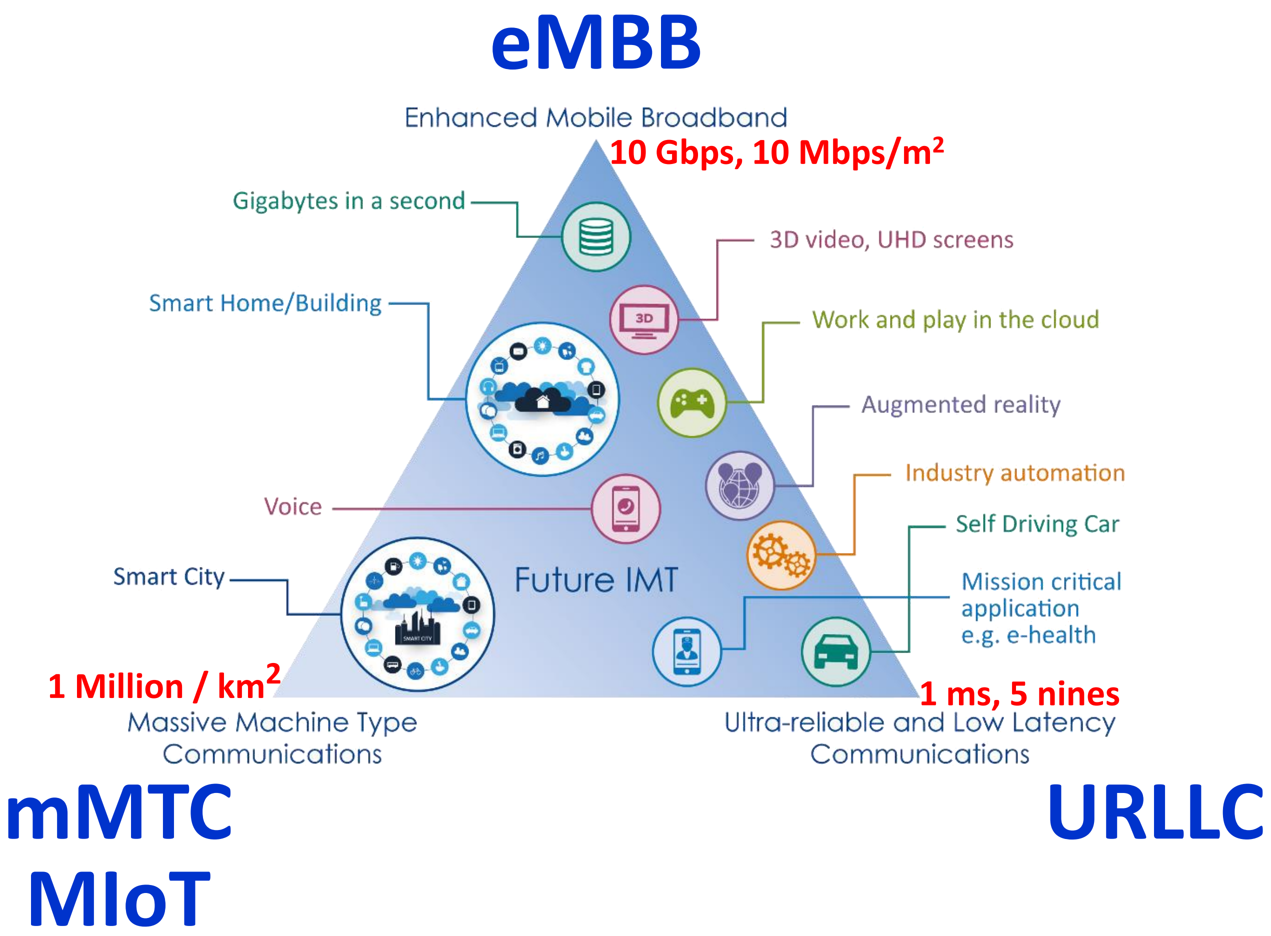
and collected specific requirements for each

Requirements naturally fell into 3 main categories

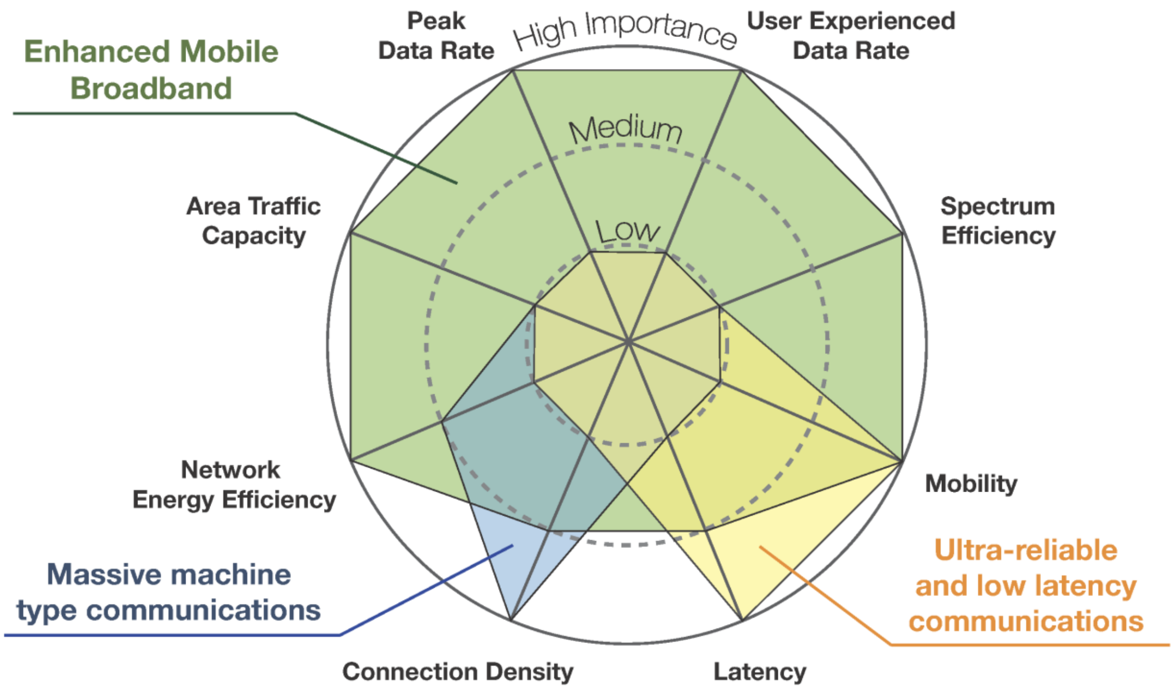
- eMBB enhanced mobile broadband
- URLLC ultra-reliable and low latency communications
- mMTC (AKA mIoT) massive machine type communications

These categories were the basis of ITU-R's framework

3 Categories

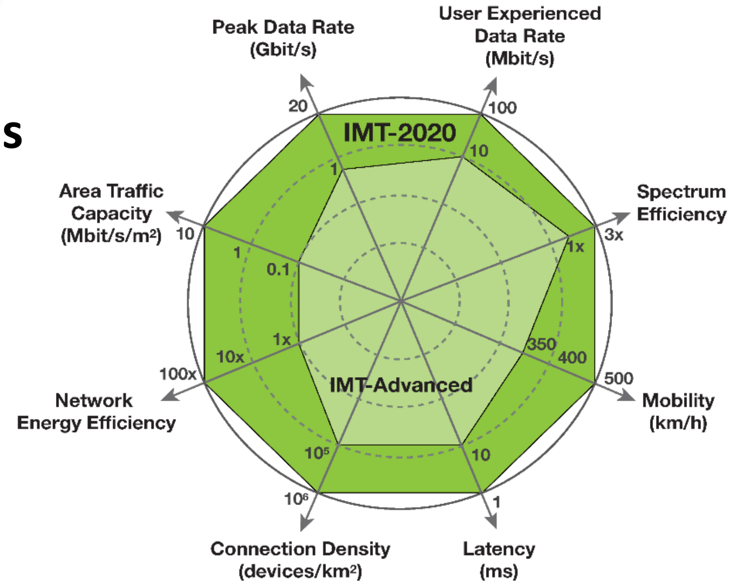


Requirements for categories



IMT-2020 goals

ITU-R published M.2083.0
IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond



which defined performance targets for 5G
that are 10 to 100 times *more* than 4G :

- **Peak data rate** (20 Gbps/device)
- **User experienced data rate** (100 Mbps)
- **Latency** (1 ms)
- **Mobility** (500 km/h and seamless transfer)
- **Connection density** (10^6 devices/km^2)
- **Energy efficiency** (1/100 Joule/bit for both air interface and network)
- **Spectrum efficiency** (3 times the bps/Hz of LTE-A)
- **Area traffic capacity** (10 Mbps/m^2)

However, it is recognized that it may not be possible to attain
all of these improvements for a single application *at the same time*!

5G Quick Overview

or what are we going to learn?

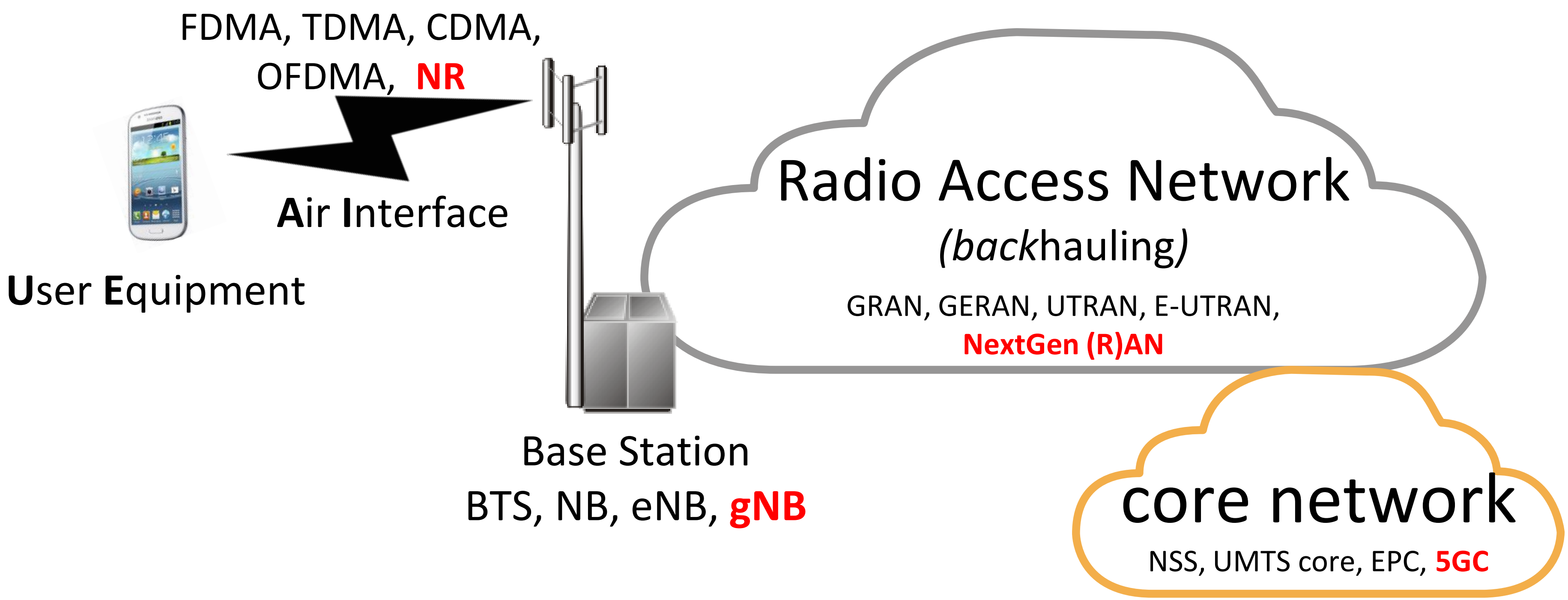
What do we want to accomplish?

How does 5G technology
satisfy the requirements
of all these applications ?

We need to answer the following questions:

- How does 5G attain higher speeds (data rates) ?
- How does 5G attain lower latencies (delays) ?
- How does 5G support new (innovative) applications?
- How do we migrate from 4G technology to 5G ?

5G changes all cellular segments



How will these aggressive targets be reached?

5G requires re-engineering *all* of the segments of the cellular system although until now the focus has been mostly on the air interface

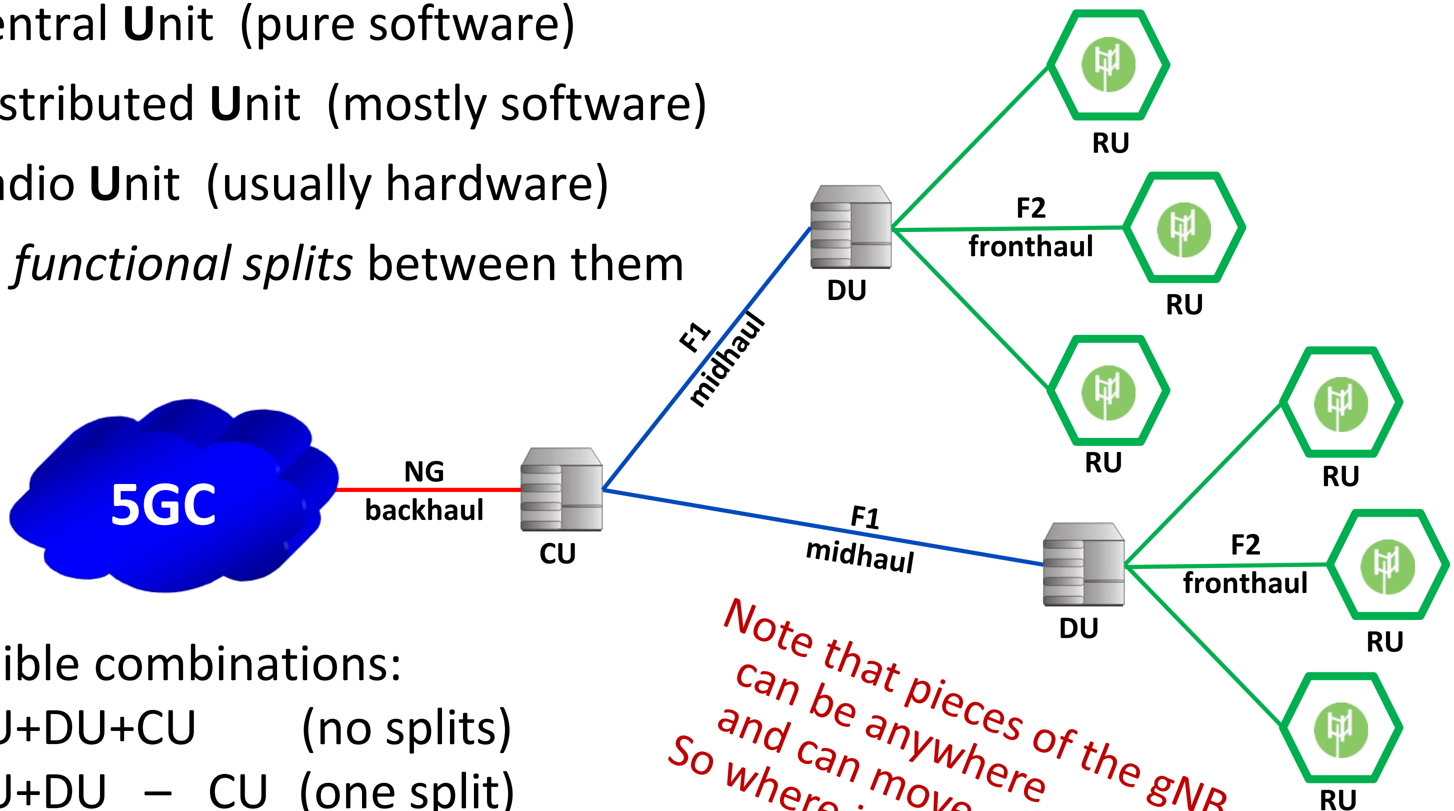
It is also understood that there will be *long* period of 5G/4G co-existence

What happened to my gNodeB ?

It turns out to be very useful to decompose the gNodeB into three parts:

- **C**entral **U**nit (pure software)
- **D**istributed **U**nit (mostly software)
- **R**adio **U**nit (usually hardware)

with *functional splits* between them



Note that pieces of the gNB
can be anywhere
and can move around over time
So where is the gNB ?

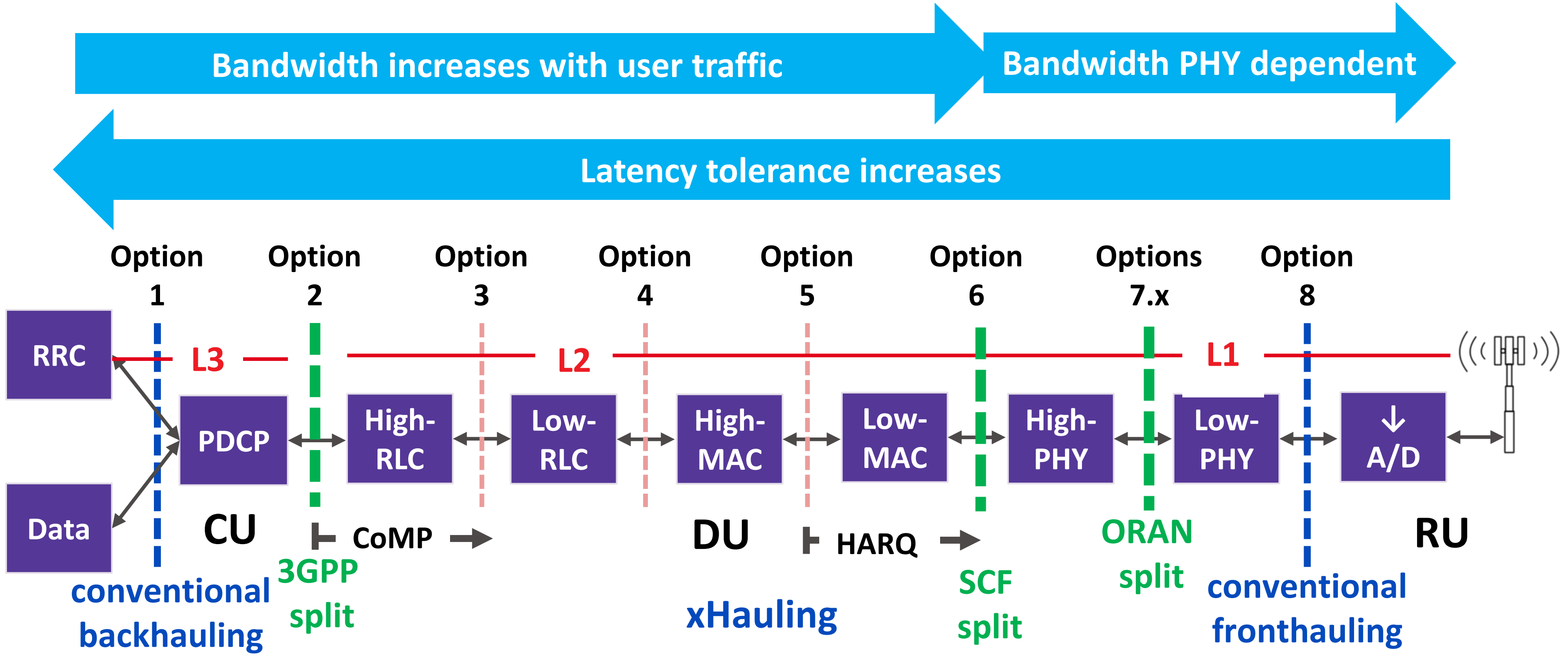
Possible combinations:

- RU+DU+CU (no splits)
- RU+DU – CU (one split)
- RU – DU+CU (one split)
- RU – DU – CU (two splits!)

Functional split options

How do we divide up the gNodeB ?

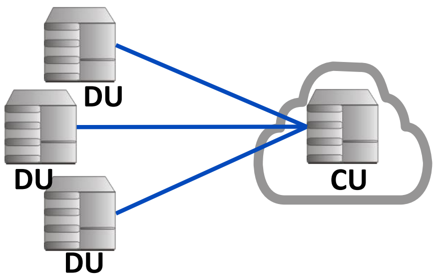
Don't be frightened by this diagram! (we'll understand it later)



CRAN, CRAN, and vRAN

In 4G it sometimes made sense
    to have one (remote) BBU serve many base-stations

The fronthaul links now need to be much longer (not at the base of the tower!)
    but processing mandates strict limits on the round-trip delay
        and thus on the fronthauling distance (e.g., 20 km for LTE)



This architecture is called **C**entralized **RAN** (CRAN)
    and was first promoted by China Mobile in 2010
    to improve scaling of the world's largest mobile network

Using load-balancing/resilience techniques developed for cloud computing
    may allow a central site to service 100s of RRHs

This is called BBU Hoteling or **C**loud **RAN** (also CRAN)

If we are already using cloud techniques
    we may implement at least some of the BBU functionality in software
    (such as packet processing, control functionality)
    running as virtual machines inside a Data Center

This architecture is called **V**irtualized **RAN**

How does 5G attain higher speed?

Air interface

- from the points of view of power, energy, and radiation
  - simply scaling up won’t work!
- NR more efficient (factor of 3 improvement)
- wider spectral bands (100 MHz, 1GHz), which requires
  - new RF bands (sub-1GHz, mmWaves: 24/28 GHz, 30-90GHz)
  - use of licensed/unlicensed unshared/shared spectrum
- smaller cells and densification
- massive (16 or more, up to 256) MIMO
    - < 6 GHz use multipath for spatial mux and multiuser MIMO
    - > 6 GHz use *coherent beamforming* (personal cells)

RAN

- new functional split options
- upgrade backhauling from 1Gbps to 10Gbps to 100Gbps
- 25 GbE (802.3by), 1-lane 50 GbE (802.3cd), NG 100/200/400 GbE (802.3bs)
- FlexE bonding

mmWaves

$\lambda = {}^{c}/_{f}$ where c = 300 m / µsec, so a radio wave with wavelength:

λ = 1mm has f = 30 GHz
λ = 5mm has f = 6 GHz

In 5G terminology, **mmWaves** are frequencies above 6 GHz

FR1 (< 6GHz)

Release 15 Frequency Bands

NR operating band	Uplink (UL) *operating band* BS receive / UE transmit F_{UL_low} – F_{UL_high}	Downlink (DL) *operating band* BS transmit / UE receive F_{DL_low} – F_{DL_high}	Duplex Mode
n1	1920 MHz – 1980 MHz	2110 MHz – 2170 MHz	FDD
n2	1850 MHz – 1910 MHz	1930 MHz – 1990 MHz	FDD
n3	1710 MHz – 1785 MHz	1805 MHz – 1880 MHz	FDD
n5	824 MHz – 849 MHz	869 MHz – 894 MHz	FDD
n7	2500 MHz – 2570 MHz	2620 MHz – 2690 MHz	FDD
n8	880 MHz – 915 MHz	925 MHz – 960 MHz	FDD
n20	832 MHz – 862 MHz	791 MHz – 821 MHz	FDD
n28	703 MHz – 748 MHz	758 MHz – 803 MHz	FDD
n38	2570 MHz – 2620 MHz	2570 MHz – 2620 MHz	TDD
n41	2496 MHz – 2690 MHz	2496 MHz – 2690 MHz	TDD
n50	1432 MHz – 1517 MHz	1432 MHz – 1517 MHz	TDD
n51	1427 MHz – 1432 MHz	1427 MHz – 1432 MHz	TDD
n66	1710 MHz – 1780 MHz	2110 MHz – 2200 MHz	FDD
n70	1695 MHz – 1710 MHz	1995 MHz – 2020 MHz	FDD
n71	663 MHz – 698 MHz	617 MHz – 652 MHz	FDD
n74	1427 MHz – 1470 MHz	1475 MHz – 1518 MHz	FDD
n75	N/A	1432 MHz – 1517 MHz	SDL
n76	N/A	1427 MHz – 1432 MHz	SDL
n77	3300 MHz – 4200 MHz	3300 MHz – 4200 MHz	TDD
n78	3300 MHz – 3800 MHz	3300 MHz – 3800 MHz	TDD
n79	4400 MHz – 5000 MHz	4400 MHz – 5000 MHz	TDD
n80	1710 MHz – 1785 MHz	N/A	SUL
n81	880 MHz – 915 MHz	N/A	SUL
n82	832 MHz – 862 MHz	N/A	SUL
n83	703 MHz – 748 MHz	N/A	SUL
n84	1920 MHz – 1980 MHz	N/A	SUL

FR2 (> 6GHz)

NR Operating Band	Uplink (UL) operating band BS receive UE transmit F_{UL_low} – F_{UL_high}	Downlink (DL) operating band BS transmit UE receive F_{DL_low} – F_{DL_high}	Duplex Mode
n257	26500 MHz – 29500 MHz	26500 MHz – 29500 MHz	TDD
n258	24250 MHz – 27500 MHz	24250 MHz – 27500 MHz	TDD
n260	37000 MHz – 40000 MHz	37000 MHz – 40000 MHz	TDD

Upgrading the RAN data-rate

Yes, there *is* a data-rate problem in the front/back-haul segments as well!

- initial R15 backhaul expectations are 5 Gbps per site (plus 4G traffic)
  which already exceed present 1G links, and challenge 10G interfaces
- fronthaul options can become ridiculous
  with multi Tbps for some scenarios

Fronthaul ball-park over-estimate:

The *sampling theorem* tells us that we need to sample at least twice the BW

Bit-rate > 2 BW $N_{bits/sample}$ $N_{sectors}$ N_{MIMO} + overhead

- a single 100 MHz signal requires 200 Msps or 3.2 Gbps (without overhead)
- with 400 MHz, 16 bits, 3 sectors, 16 MIMO this exceeds 614 Gbps !
- with 1.6 GHz, 3 sectors, 256 MIMO antennas : ≈ 40 Tbps

for comparison EoY 2016 the *entire* Internet was 100 PB/month ≈ 300 Tbps

There are also major latency and reliability issues in the RAN !

That’s why 5G defines all the new kinds of **x**haul (x= back, mid, front, …)

How does 5G attain lower latencies?

Air interface

- more flexible OFDM frame structure
- self contained integrated subframes

RAN

- **S**oftware **D**efined **N**etworking or **S**egment **R**outing
- **N**etwork **F**unctions **V**irtualization
- **M**obile **E**dge **C**omputing (moving functionality closer to UE)
- **T**ime **S**ensitive **N**etworking / **Det**erministic **Net**working
  - IEEE 802.1CM for Ethernet fronthaul
  - IEEE 802.1Qbv scheduled traffic enhancements
  - IEEE 802.1Qbu frame pre-emption
  - IETF DetNet (Deterministic Networking) for IP
- Network slicing

SDN and NFV

Software **D**efined **N**etworking and **N**etwork **F**unctions **V**irtualization
are widely considered to be essential technologies for 5G

SDN advocates replacing standardized networking protocols
with centralized software applications
that configure *whitebox switches* in the network

Segment Routing is an alternative to SDN

NFV advocates replacing hardware network elements
with software running on *whitebox servers*
that may be housed in data-centers or POPs or cell-sites

In short

- NFV replaces network *equipment* with *software*
- SDN replaces networking *protocols* with *algorithms*

Review: 5G RAN transport technologies

The 3 main challenges for the 5G transport segment are:

- data-rate
- latency
- reliability (including very low **P**acket **L**oss **R**atios)

Multiple transport innovations aid supporting 5G xHaul requirements

- 10GbE, XGS-PON, NG-PON2
- 25 GbE (802.3by), 1-lane 50 GbE (802.3cd)
  100/200/400 GbE (802.3bs)
- FlexE
- **M**obile (**M**ulti-access) **E**dge **C**omputing
- Synchronization (SyncE, IEEE 1588, DGM)
- Network slicing
- **T**ime **S**ensitive **N**etworking (and **Det**erministic **Net**working)
- **F**rame **R**eplication and **E**limination (IEEE 802.1CB)

high data rates

low latency

ultra high reliability

Mobile Edge Computing

Another solution to both data-rate and latency requirements
is **M**obile (**M**ultiaccess) **E**dge **C**omputing

MEC was studied in the ETSI MEC ISG

MEC enables terminating traffic close to the gNb or first aggregation nodes
rather than backhauling all the way to the core

By providing processing power close to the UE
network congestion and latency are both reduced

Some MEC applications

- Internet breakout
- caching (DNS caching, Content Delivery Networks)
- fog networking (IoT aggregation and local processing)
- mobile big data analytics
- connected car (V2x)

MEC concepts have been absorbed into the new 5G core network

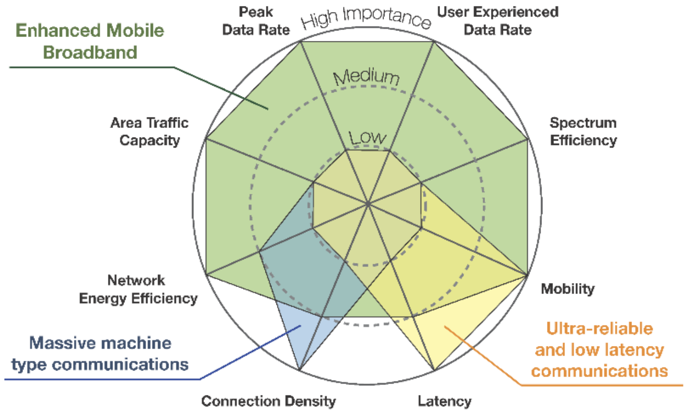
Like the gNB, the 5G core can be distributed (where is the core?)

Network slicing

We already said that no single application will require all the improvements

For example:

- enhanced mobile broadband
  - needs high data rates
  - doesn't need very low latency
- massive IoT
  - needs high connection density
  - doesn't need high data rates



But the 5G *network* needs to simultaneously support different applications

5G employs *network slicing* to satisfy requirements of different apps

Network slicing means:

- each slice is effectively an independent network
- *strong isolation* of applications
  - no security dependencies
  - no performance interference regardless of congestion
- *on-demand* assignment of networking/computational resources

How does 5G support new applications?

5G service and network requirements
    necessitate a fundamental change to the core architecture

Some 4G network cores presently support 10s of millions of subscribers
    5GC will need to support many more subscribers and sessions

The only technology proven to scale up to such sizes is cloud computing

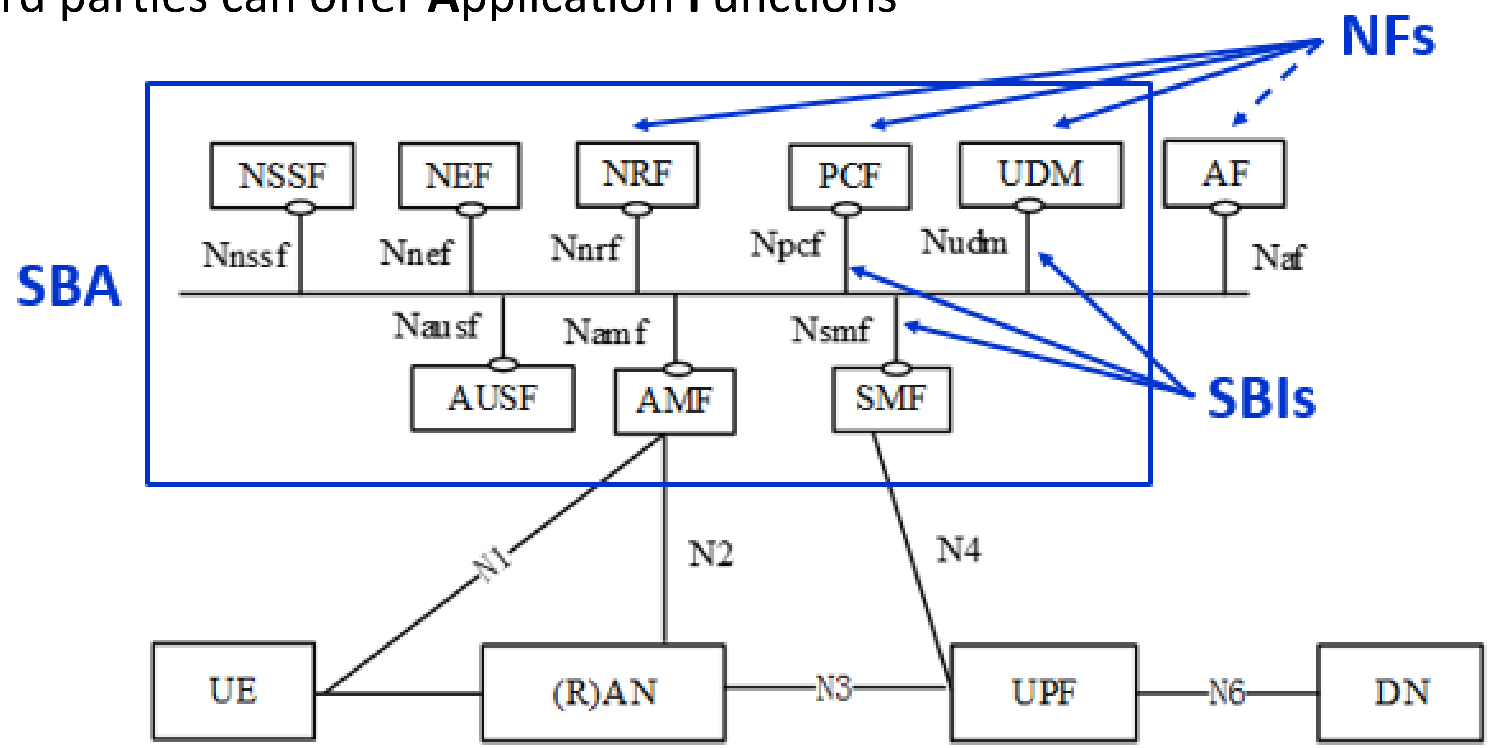
The new core has to support
- automation (DevOps)
- rapid *reprogrammability*
- capability *exposure* functionality
- *virtual* mobile/network functions
- strong *security*

which are all IT functions available in cloud technologies

Upgrading the core network

3GPP has defined a radically new 5G Core architecture
based on a *cloud-native* **S**ervice **B**ased **A**rchitecture (SBA)
with modular **N**etwork **F**unctions instead of **N**etwork **E**lements (boxes)

- NFs can be hardware or (virtual) software – even **VM**s in a cloud
- NFs are *micro-services* for improved scaling
- third parties can offer **A**pplication **F**unctions

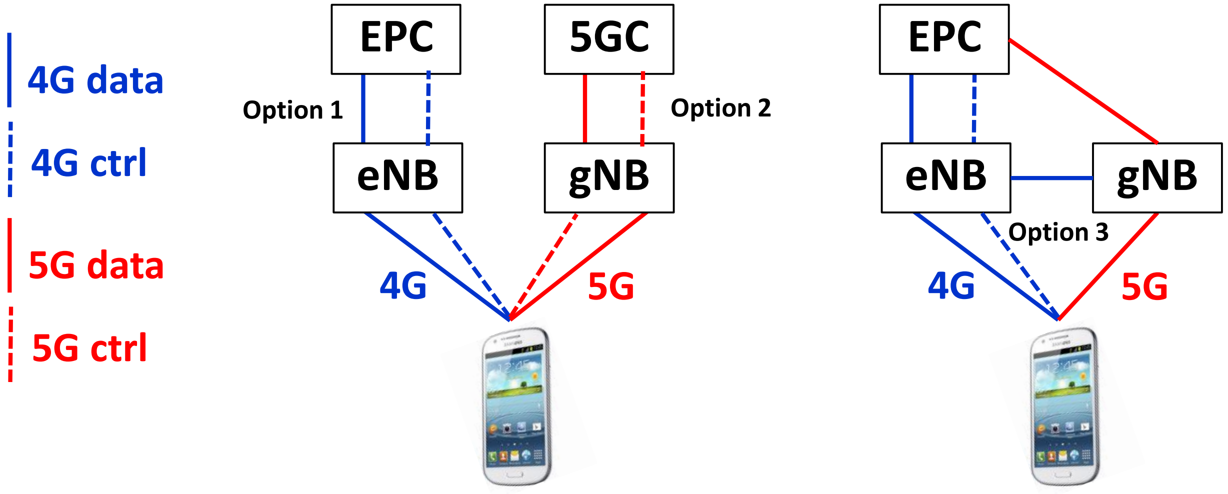


How do we get there from here?

Initial 5G deployments focus on eMBB
and so require NR but not the 5G core

In order to facilitate this first stage 3GPP defined **N**on **S**tand**A**lone (NSA)
i.e., 5G supported by the existing 4G infrastructure (E-UTRAN, EPC)

Later deployments will tackle URLLC and mMTC
requiring more RAN and core support, leading to **S**tand**A**lone operation



Standalone **Non-standalone**

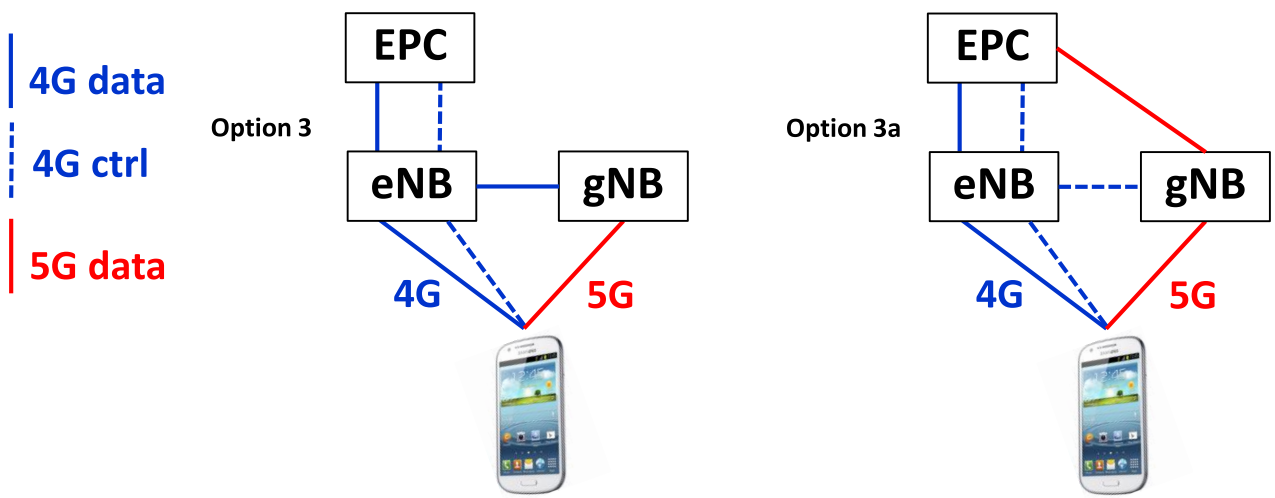
Option(s) 3

Current deployments use NSA option 3

- which assumes installation of a gNB (to gain the advantages of NR)
- but does not (yet) upgrade the core to 5GC
- and so provides higher data rates but not full 5G capabilities

Option 3 will overload the routing capabilities of the eNodeB

- so the next step (3a) connects the 5G data directly to the 4G EPC



For the distant future there are options in which there is only a 5G core

- but still support legacy 4G UEs