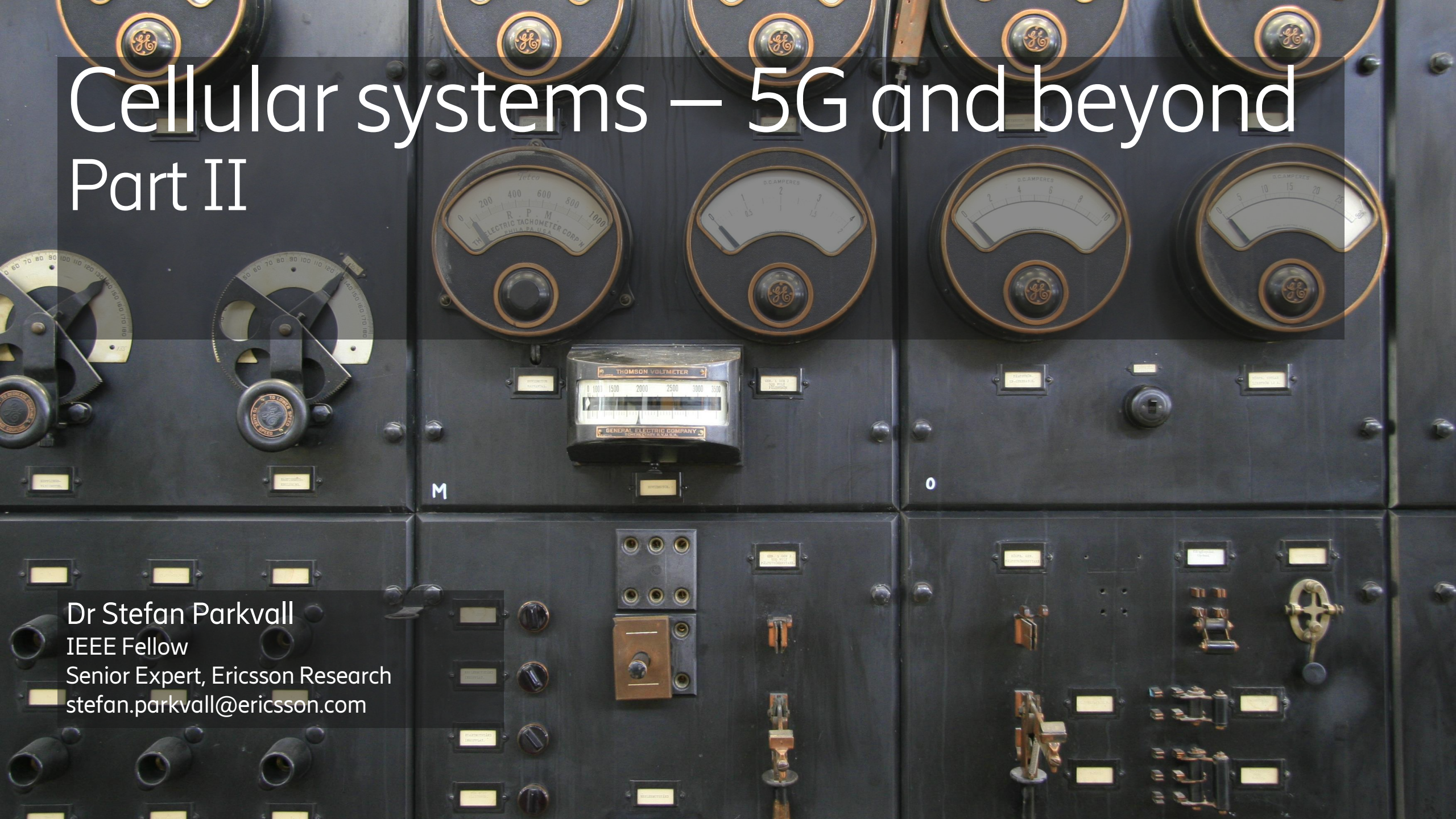
Cellular systems – 5G and beyond
Part II



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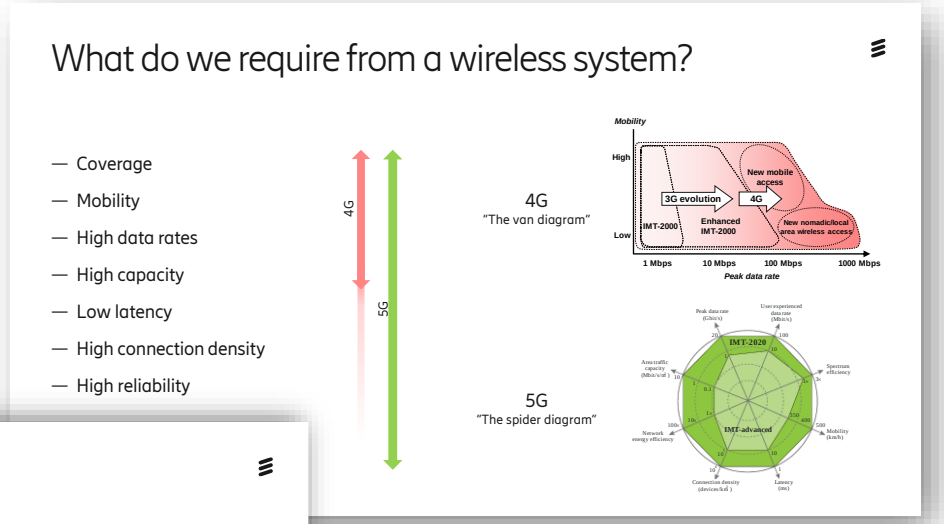
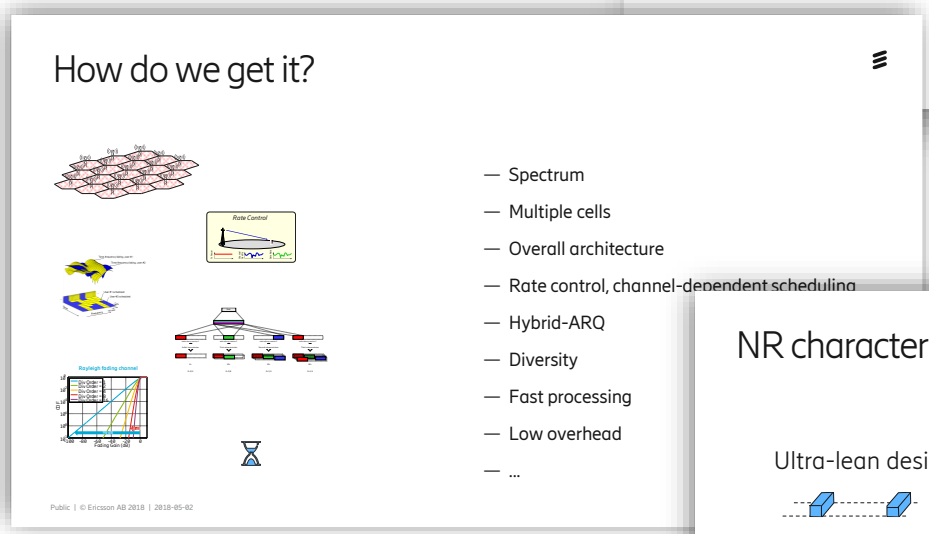
Outline

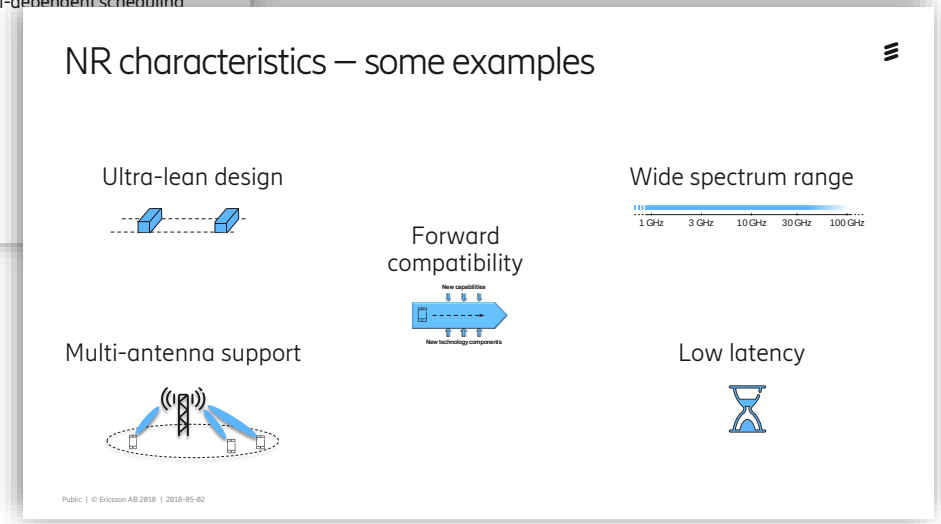
- Introduction
- Cellular systems and basics for LTE (4G) and NR (5G)
- LTE evolution
- NR
- Standardization in practice
- 6G

Recap from first session

- Basic principles
- 4G LTE and its evolution
- 5G NR







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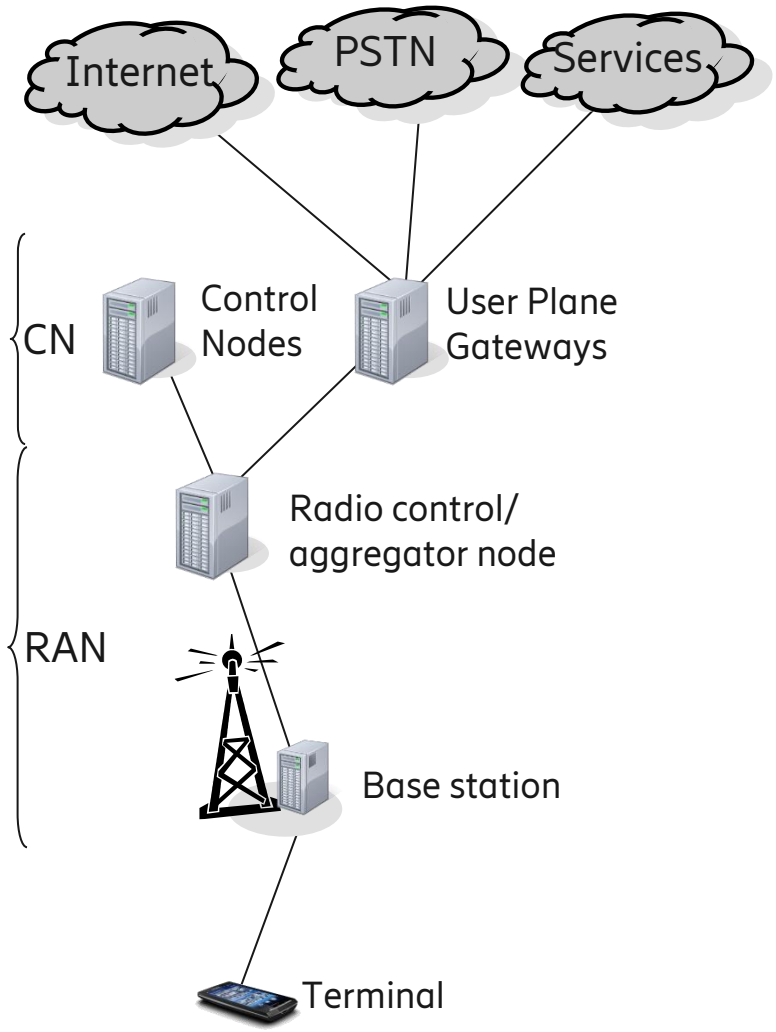
Why?

- Standardization is the process of developing and agreeing on technical standards
- A standard is a document that establishes uniform engineering or technical specifications, criteria, methods, processes, or practices.
- Standards can be
  - de facto standards – informal convention or dominant usage
  - de jure – legally binding contracts, laws or regulations
  - voluntary – published and available to consider for use

- Technology development – selecting the best solutions
- Interoperability – e.g. a Samsung phone in an Ericsson network
- Creates mass market! Economy of scale!

What?



Standardized – ensures interoperability

- Logical architecture
- Protocol on interfaces
- Radio transmitters (RF aspects)
  - required by regulations/law
- Behavior required to fulfill functionality

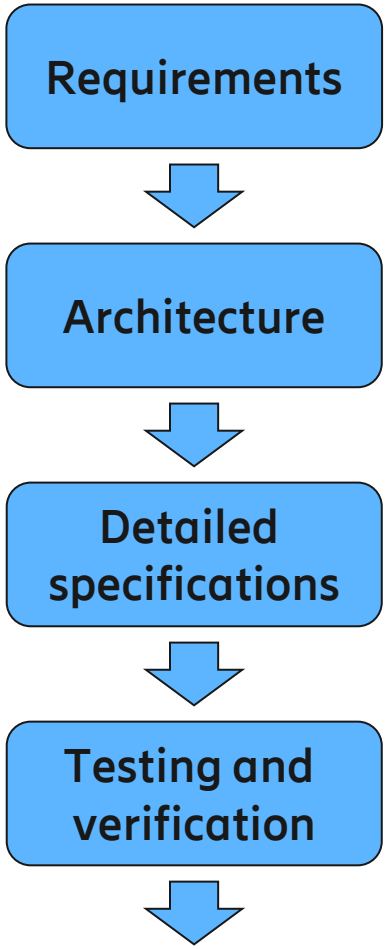
Not standardized – vendor differentiation

- Physical implementation
- Algorithms
  - Scheduler, handover, admission control, …
  - Receiver algorithms – sufficient to fulfill requirements

Where?

- Standard-developing organizations
  - Non-profit industrial organizations
  - Develops technical standards
  - Global/Regional/National
- Regulatory bodies
  - Governmental organizations
  - Spectrum usage, frequency management
  - Placing products on the market
- Industry fora
  - Promoting and lobbying for specific technologies

Standardization process



- Stage 1
  - Requirements, no detailed solutions
- Stage 2
  - Logical architecture, functional split, interfaces, protocol architecture, overall solutions
- Stage 3
  - All details, e.g., header formats, exact coding scheme, values in requirements, ...
- Test
  - Snapshots with test cases from standard to ensure proper operation

ITU

- United Nations agency for information and communication technologies
- Founded 1865
  - Second oldest international organization still in operation
- Main tasks
  - Standardization
  - Allocation of radio spectrum
  - Organizing interconnection arrangements to allow international phone calls

ITU-R

- Radio regulations
  - allocation of different frequency bands; WRC -93, -95, -97, -00, -03, -07, -12, -15, -19, -23, -27, ...
  - mandatory technical parameters to be observed
- Reports
- Recommendations
  - Approves standards fulfilling the ITU requirements; specifications developed elsewhere (e.g. 3GPP)
  - Examples of ITU-R families of standards: IMT-2000, IMT-Advanced, IMT-2020

IMT-2000

IMT-2000
CDMA Direct Spread
(UTRA/E-UTRA FDD)
3GPP

IMT-2000
CDMA Multi-Carrier
(CDMA2000, UMB)
3GPP2

IMT-2000
CDMA TDD
(UTRA/E-UTRA TDD)
3GPP

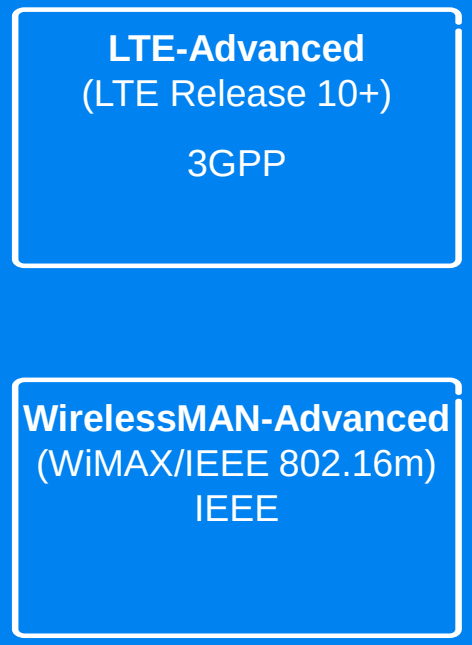
IMT-2000
TDMA Single-Carrier
(UWC 136)
ATIS/TIA

IMT-2000
FDMA/TDMA
(DECT)
ETSI

IMT-2000
OFDMA TDD WMAN
(WiMAX)
IEEE

- IMT-2000 – "3G"
- Family of 6 different technologies
  - First releases of LTE and WiMAX was added to IMT-2000 at a later stage

IMT-Advanced



- IMT-Advanced – "4G"
- Family of 2 different technologies
  - LTE-Advanced (Rel-10 and onwards)
  - WiMax (802.16m)

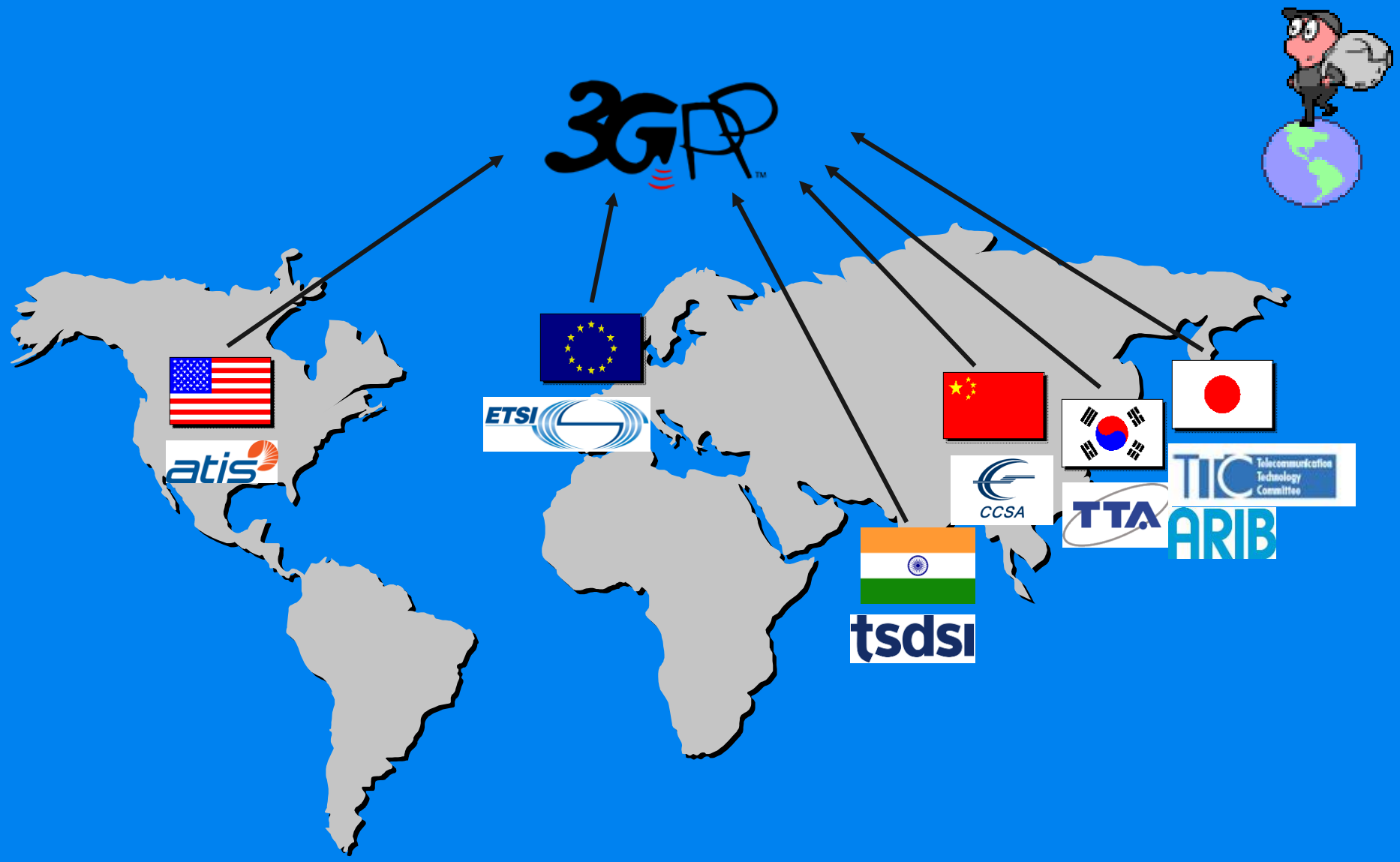
IMT-2020

- IMT-2020 – "5G"
- Family of 2 different technologies
  - NR
  - DECT-2020

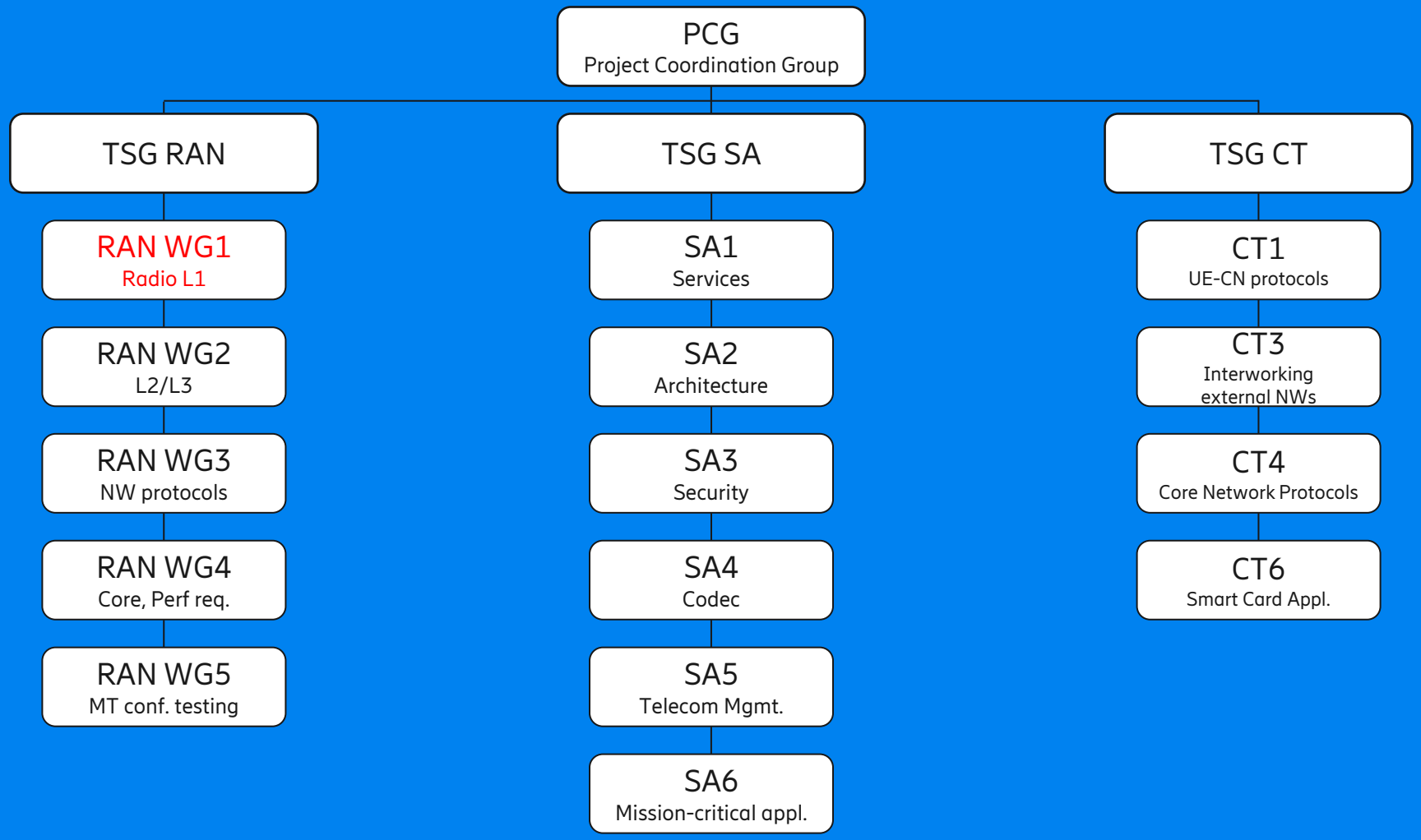
IMT-2030

- IMT-2030 – "6G"
- Work starting up on IMT-2030
  - Similar process as for IMT-2020

3GPP organizational partners



3GPP organization



Radio Access Network

Services, Overall System

Core Network

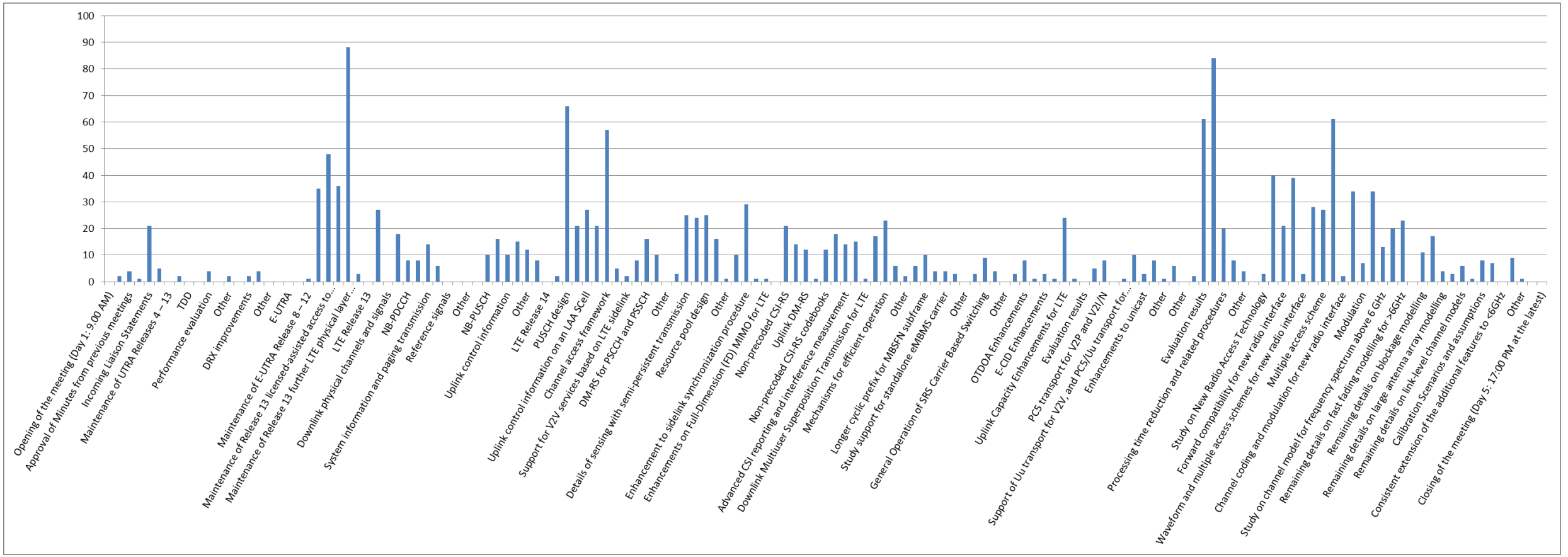
Standardization – a flying circus?

- RAN1 meetings held ~8 times a year
  - Meetings run from Monday to Friday
  - Held in various countries in Europe, North America, and Asia

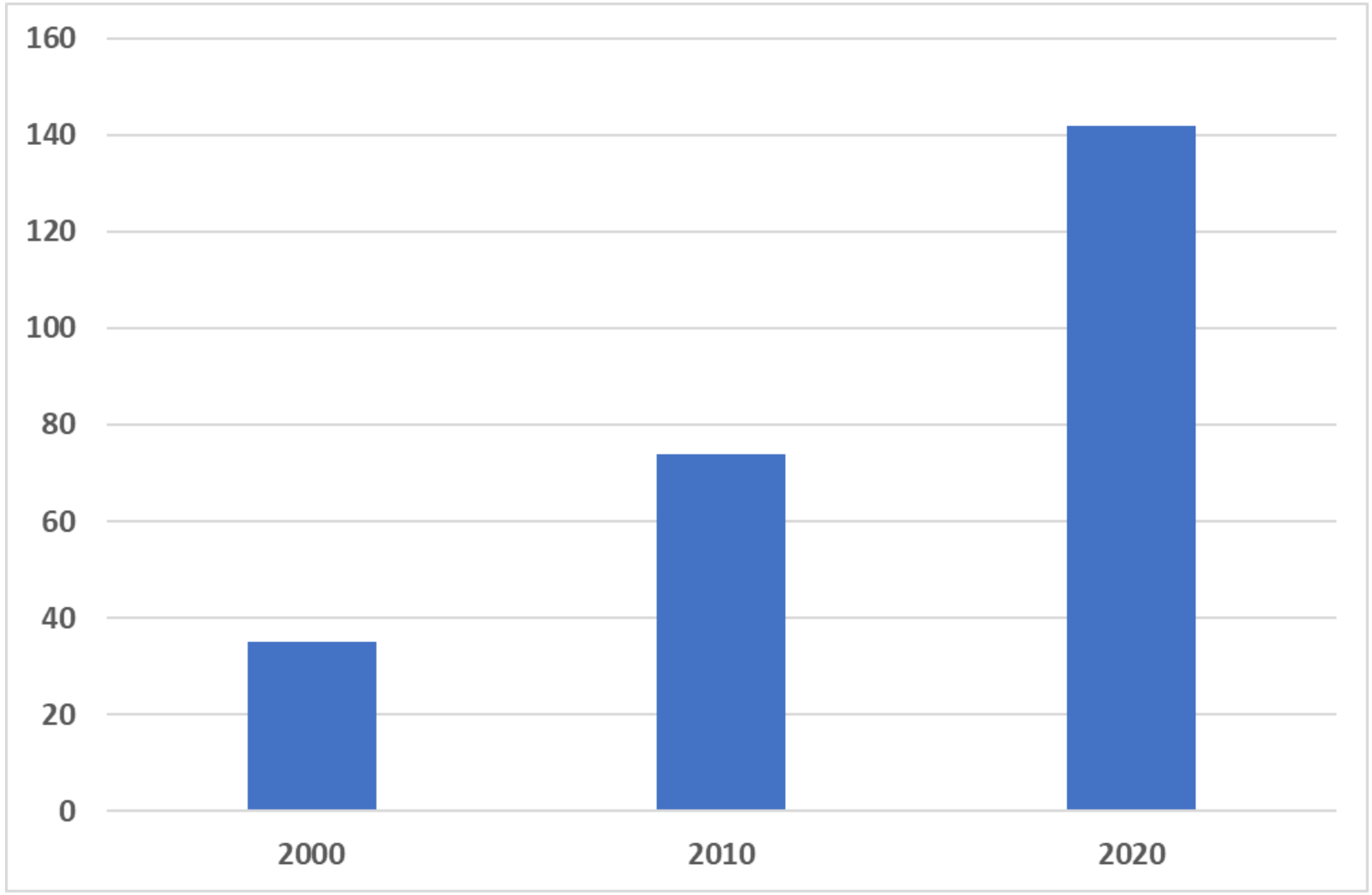
- Meeting schedule 2017
  - January 16 – 20 Spokane, USA
  - February 13 – 17, Athens, Greece
  - April 3 – 7, Spokane, USA
  - May 15 – 19, Hangzhou, China
  - June 27 – 30, Qingdao, China
  - August 21 – 25, Prague, Czech Republic
  - September 18 – 21, Nagoya, Japan
  - October 9 – 13, Prague, Czech Republic
  - November 27 – December 1, Reno, USA

Typical RAN1 meeting

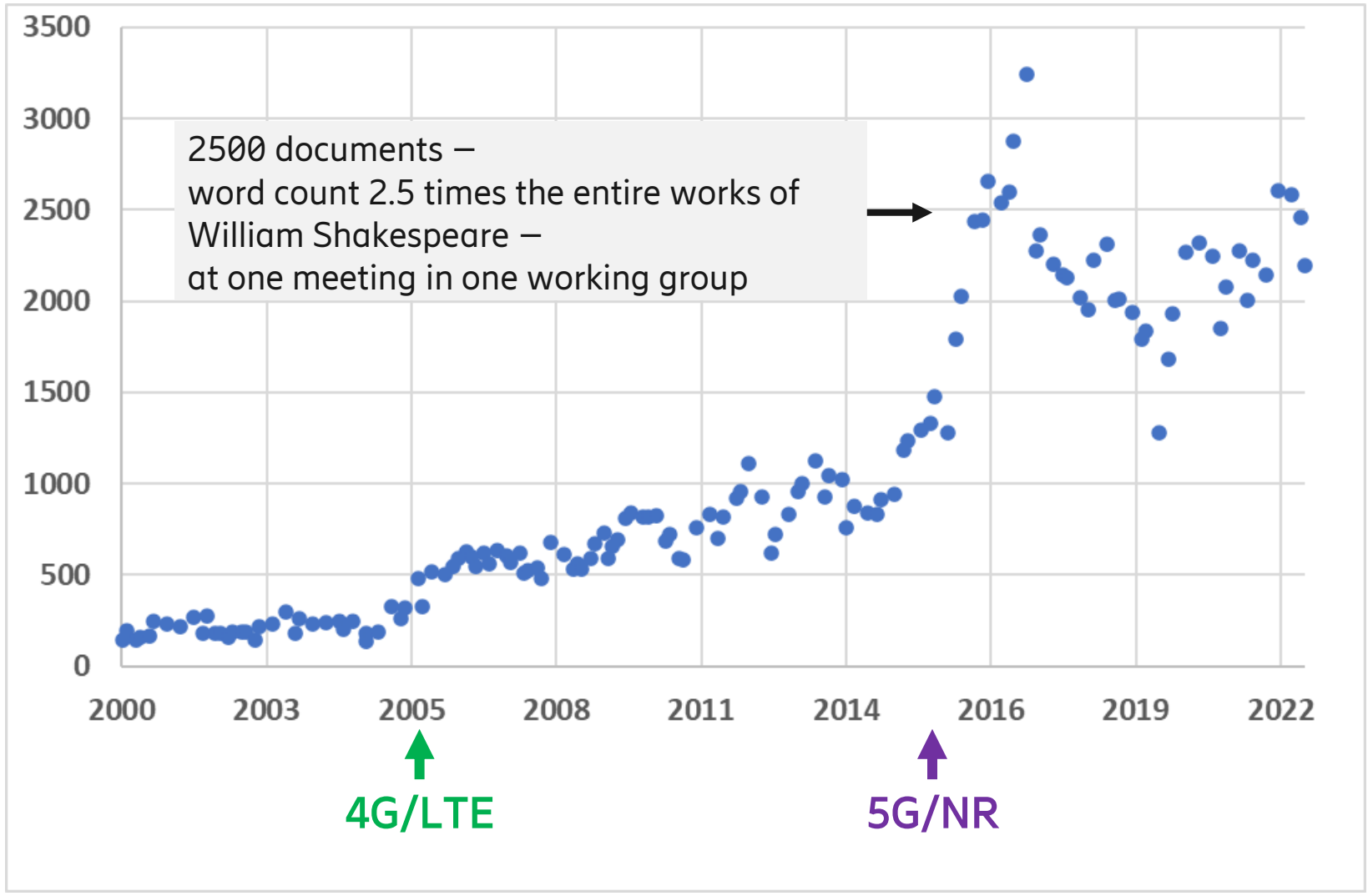
— Approx 600 delegates attending and ~2500 documents submitted...



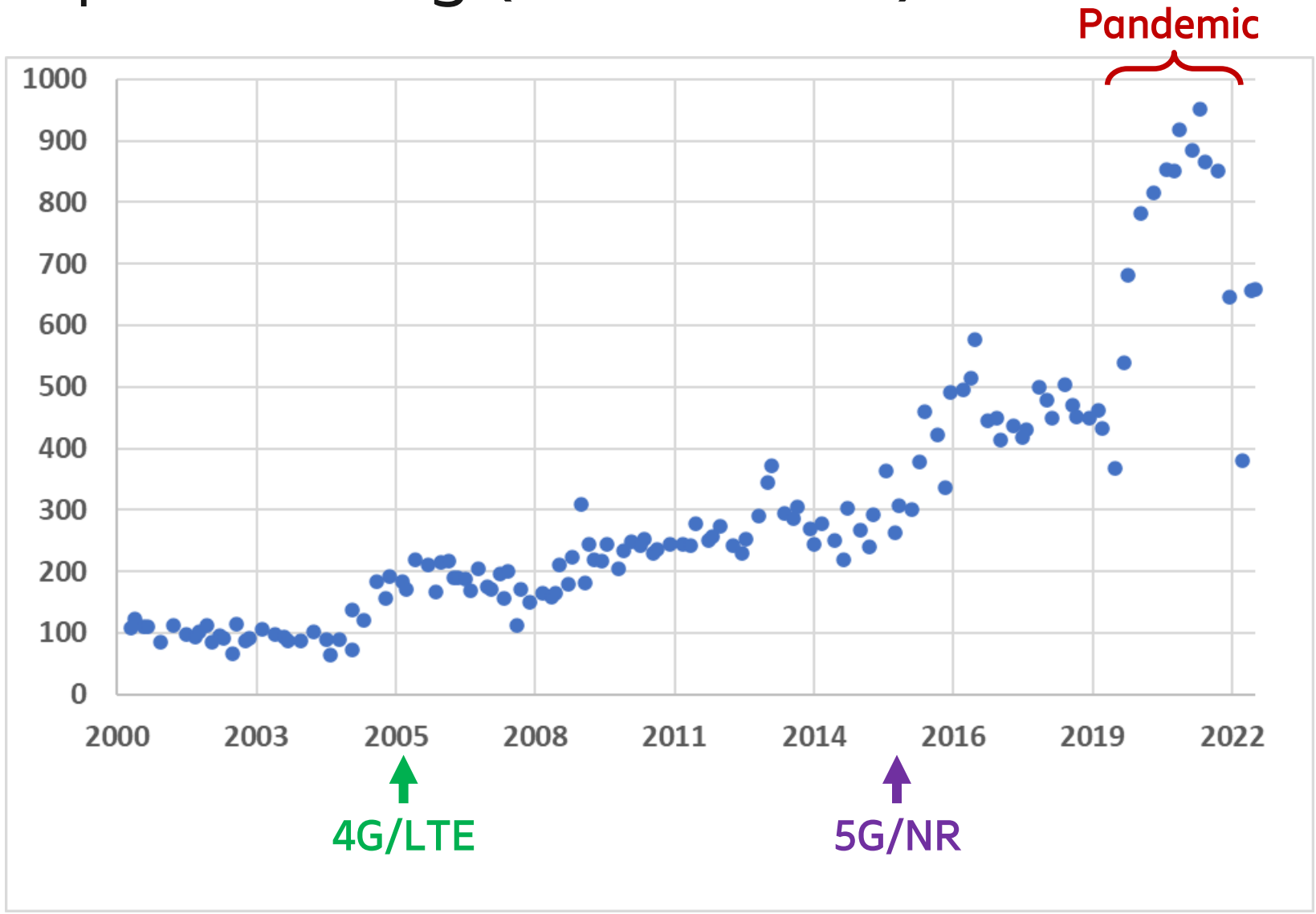
Number of companies per meeting (3GPP WG1)



Documents per meeting (3GPP WG1)



Persons per meeting (3GPP WG1)



Nice to work with standardization…

Cheju, Korea

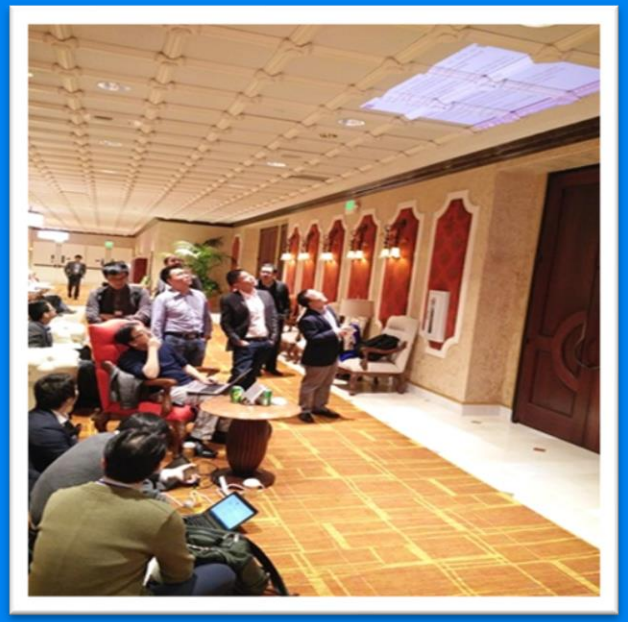
…well, maybe not always!

Cheju, Korea

Standardization in practice

- Contribution driven
- Decision by consensus
  - Coffee-breaks important part of meetings (off-line)
- Good relations important
  - Social relations across cultural borders
  - Mutual respect and co-operation
- One week meetings ➡ Long meeting days

Intense discussions…



O-RAN

- Industry initiative for additional disaggregation of RAN
  - Started 2018
  - Operator-driven (31 operators, 294 contributors)
  - All “big players” except Huawei
  - Ericsson is a member, three co-chair positions, several rapporteurships

Automation/Optimization

- Two new control loops
- Non-RT-RIC
- Near-RT-RIC

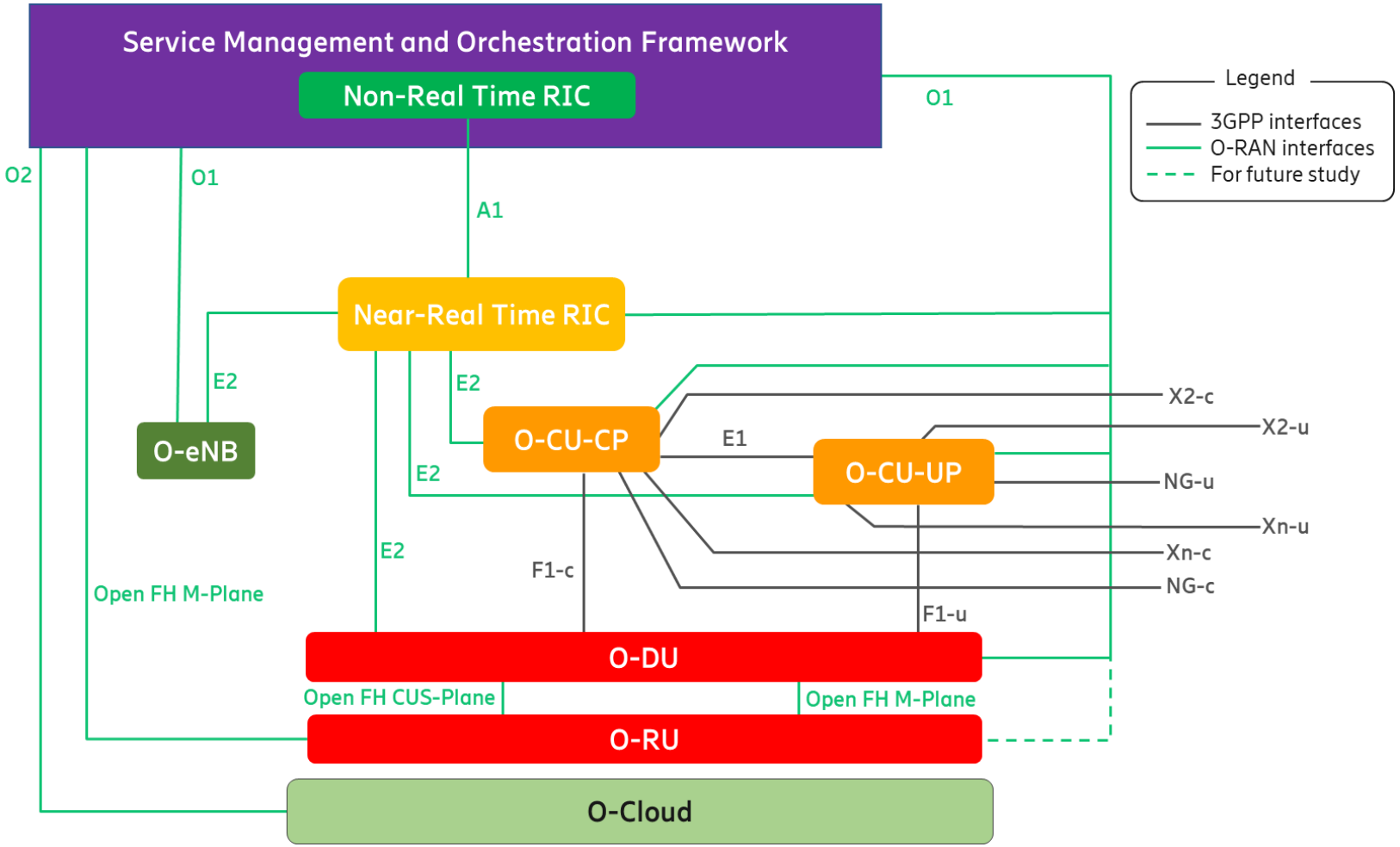
Virtualization & Open SW

- “Cloudification”
- HW and SW reference architecture
- Orchestration of (cloud) infrastructure

Disaggregation & Open Interfaces

- Multi-vendor interfaces within DU, between Radio and Baseband

O-RAN Architecture



RAN - overall

- **WG1: Overall architecture and use cases**
  - Chairs: AT&T, CMCC
  - (Ericsson **architecture** spec editor)
- **WG9: x-haul transport**
  - Chairs: AT&T, CMCC, Viavi
- **SFG: Security**
  - Chairs: DT, Orange, Altiostar

RAN intelligence and automation

- **WG2: Non-RT RI, A1 and R1 interfaces**
  - Chairs: KDDI, CMCC, Intel, Ericsson
- **WG3: Near-RT RIC and E2 interface**
  - Chairs: DT, CMCC, Nokia, Samsung
- **WG10: OAM architecture and O1 interface**
  - Chairs: AT&T, CMCC

Open internal RAN interfaces

- **WG4: Open Fronthaul (O-RAN LLS)**
  - Chairs: Verizon, Docomo, Nokia, Cisco
- **WG5: Open 3GPP interfaces (HLS)**
  - Chairs: Orange, Docomo, Ericsson

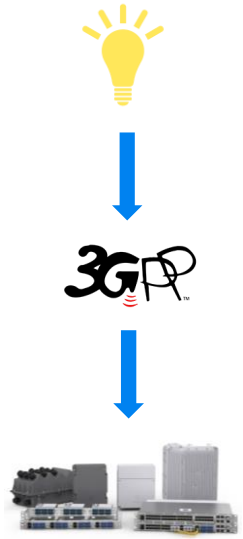
Cloudification:

- **WG6: RAN virtualization and AAL**
  - Chairs: AT&T, Vodafone, Lenovo, Ciena
  - (Ericsson O2 spec editor)
- **WG7: White box hardware**
  - Chairs: AT&T, CMCC, Qualcomm, Baicells

Open Source:

- **WG8: Software reference design**
  - Chairs: AT&T, CMCC, Intel, Radisys
- **O-RAN Open-Source Community (OSC)**
  - Non-RT RIC (Ericsson), Near-RT RIC, SMO projects

What is the role of academia in standardization?
Some personal reflections



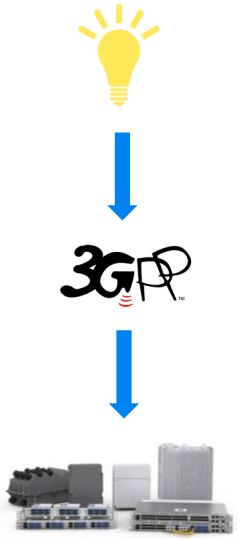
Research

...followed by...

Standardization

...followed by...

Products



Important that academic research is bold and forward-looking!

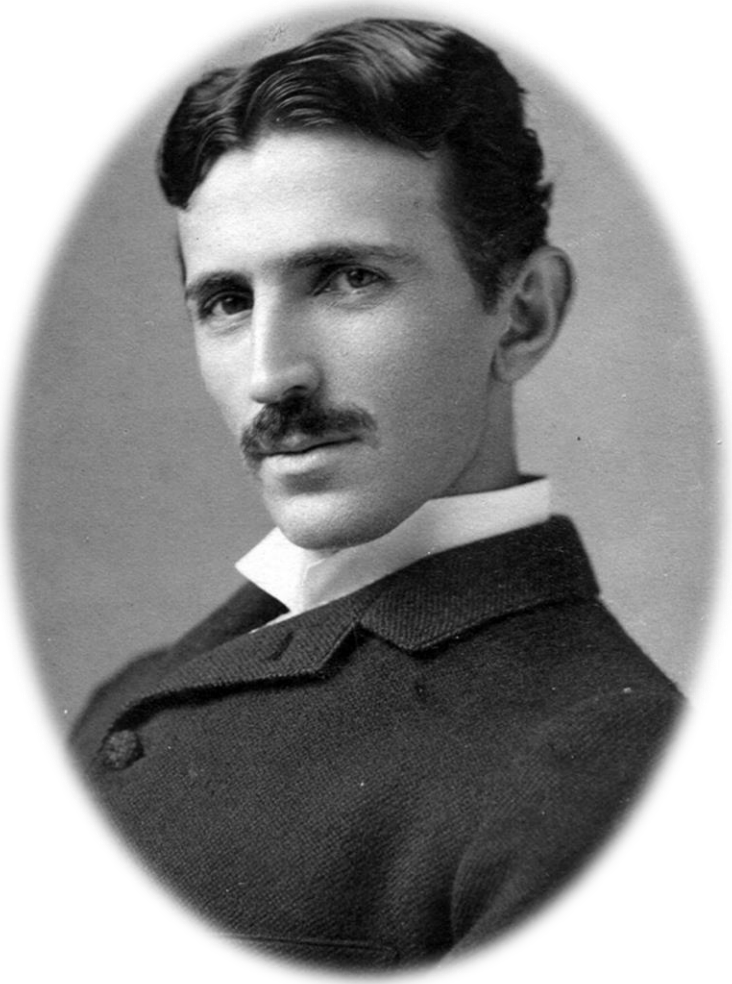
Your role is to explore the future, not to work on the current 3GPP release

What about the longer time perspective? (beyond 2030)

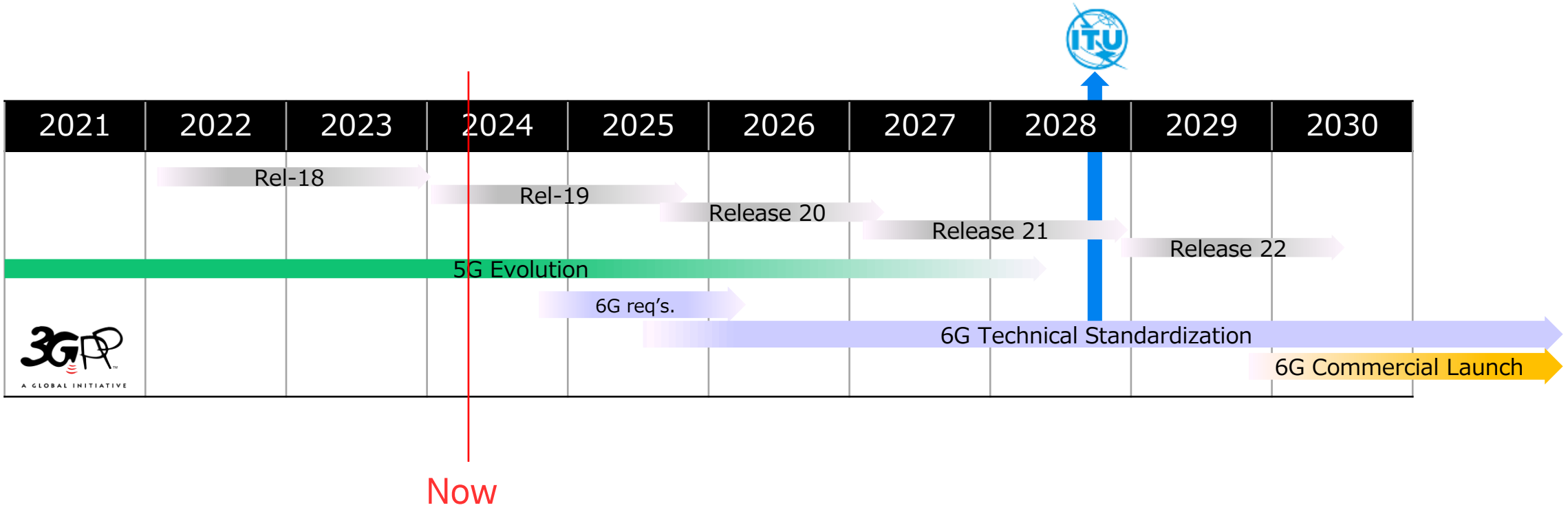
Vision of 1926

“When wireless is perfectly applied the whole earth will be converted into a huge brain, which in fact it is, all things being particles of a real and rhythmic whole. We shall be able to communicate with one another instantly, irrespective of distance. Not only this, but through television and telephony we shall see and hear one another as perfectly as though we were face to face, despite intervening distances of thousands of miles; and the instruments through which we shall be able to do his will be amazingly simple compared with our present telephone. A man will be able to carry one in his vest pocket.”

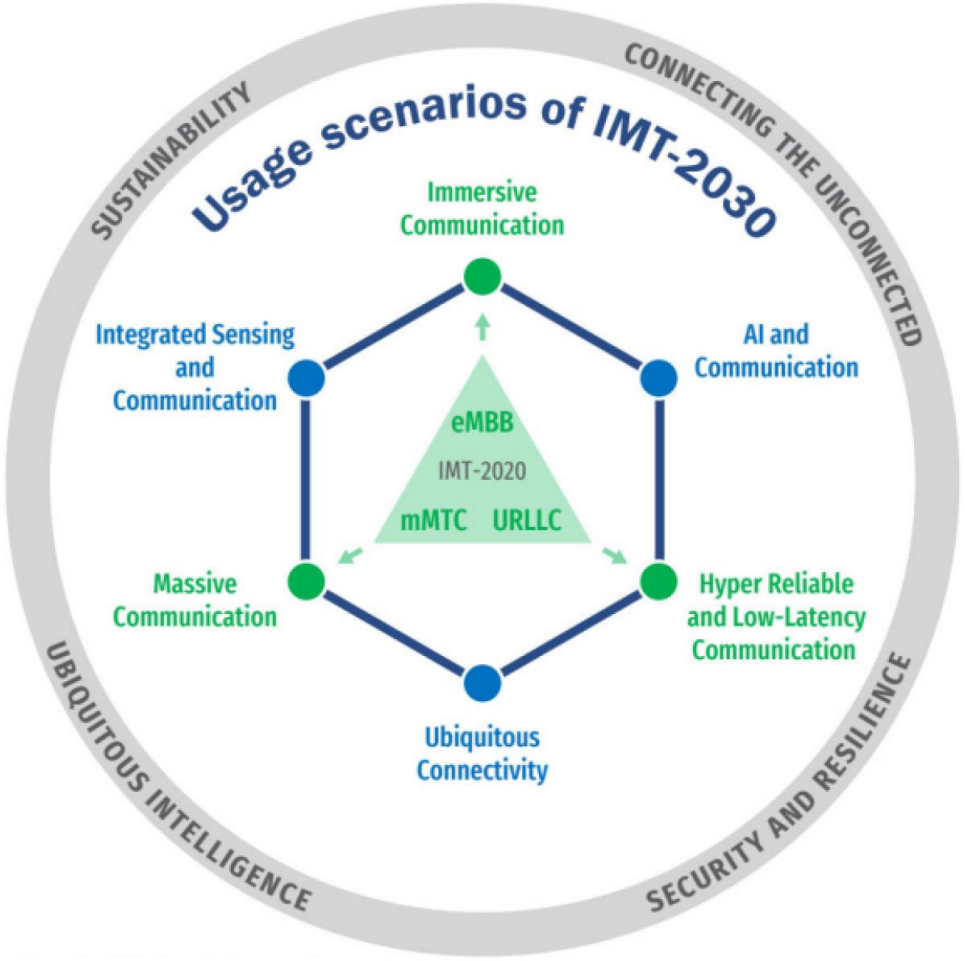
Nicola Tesla, 1926



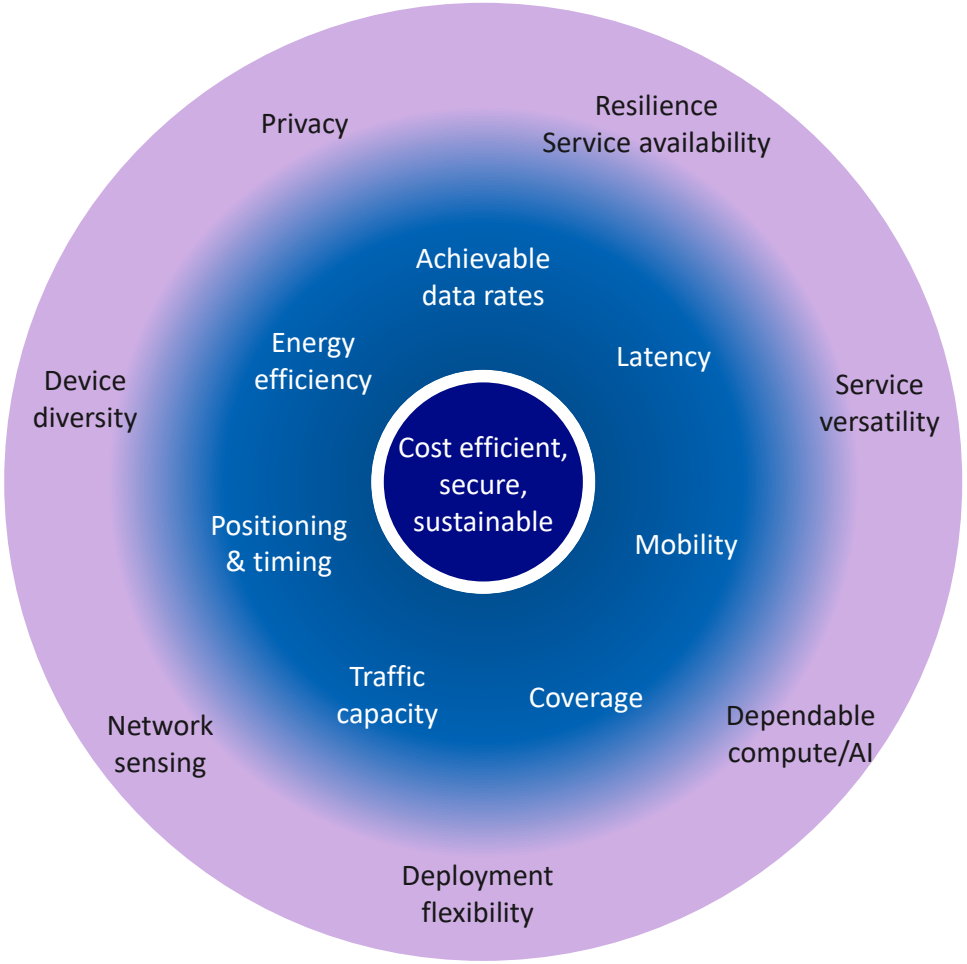
Timeline


2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
Rel-18
Rel-19
Release 20
Release 21
Release 22
5G Evolution
6G req's.
6G Technical Standardization
6G Commercial Launch
Now

6G usage scenarios and capabilities

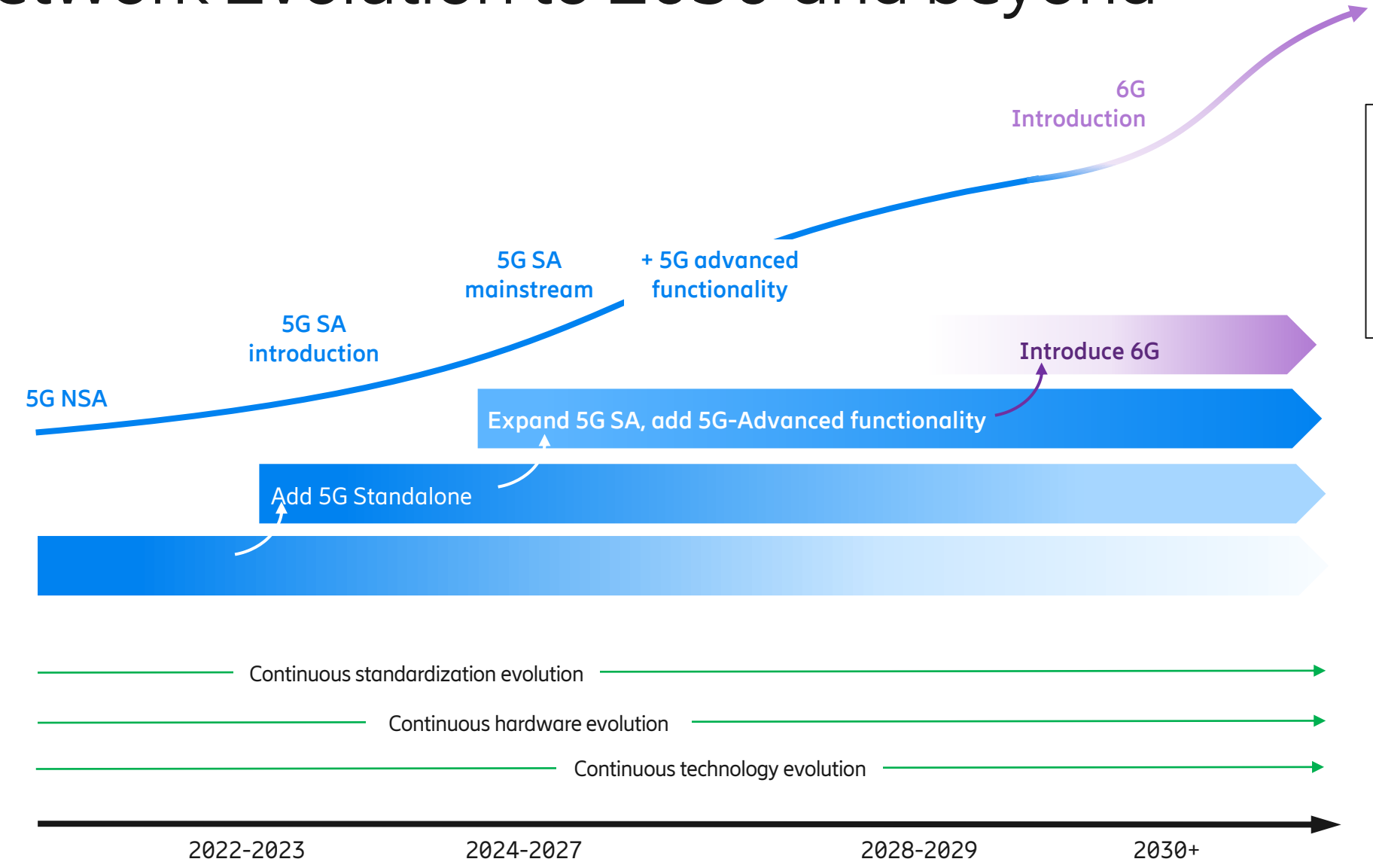


Usage scenarios (ITU "wheel diagram")



Requirements (Ericsson)

Network Evolution to 2030 and beyond



Step-wise technology adoption driven by *network demand* and *monetization opportunities*

Build on 5G

Smooth migration with 5G-6G spectrum sharing

Strong foundation for continued evolution

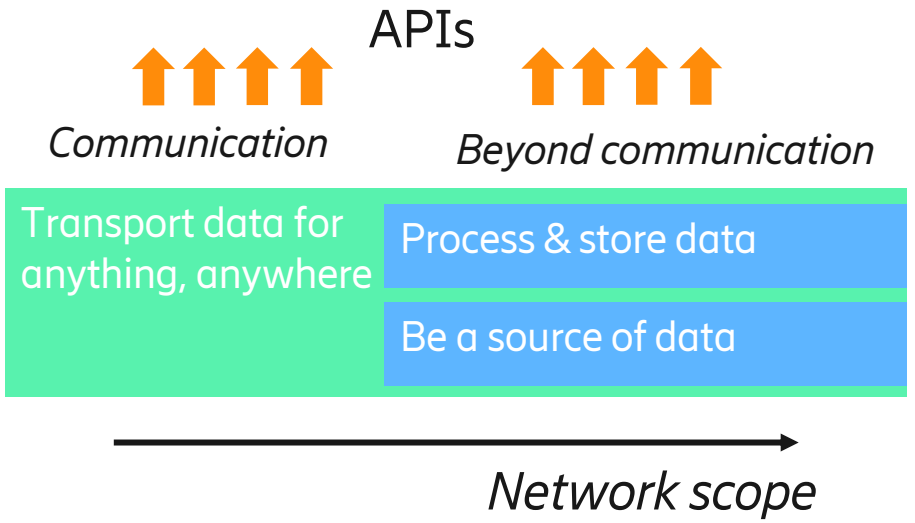
Networks taking a bigger role

Future networks should be designed to better interact directly with the app ecosystem

- Tailored communication service APIs

Future networks can also take a bigger role in the combined ecosystem

- Data and information service APIs

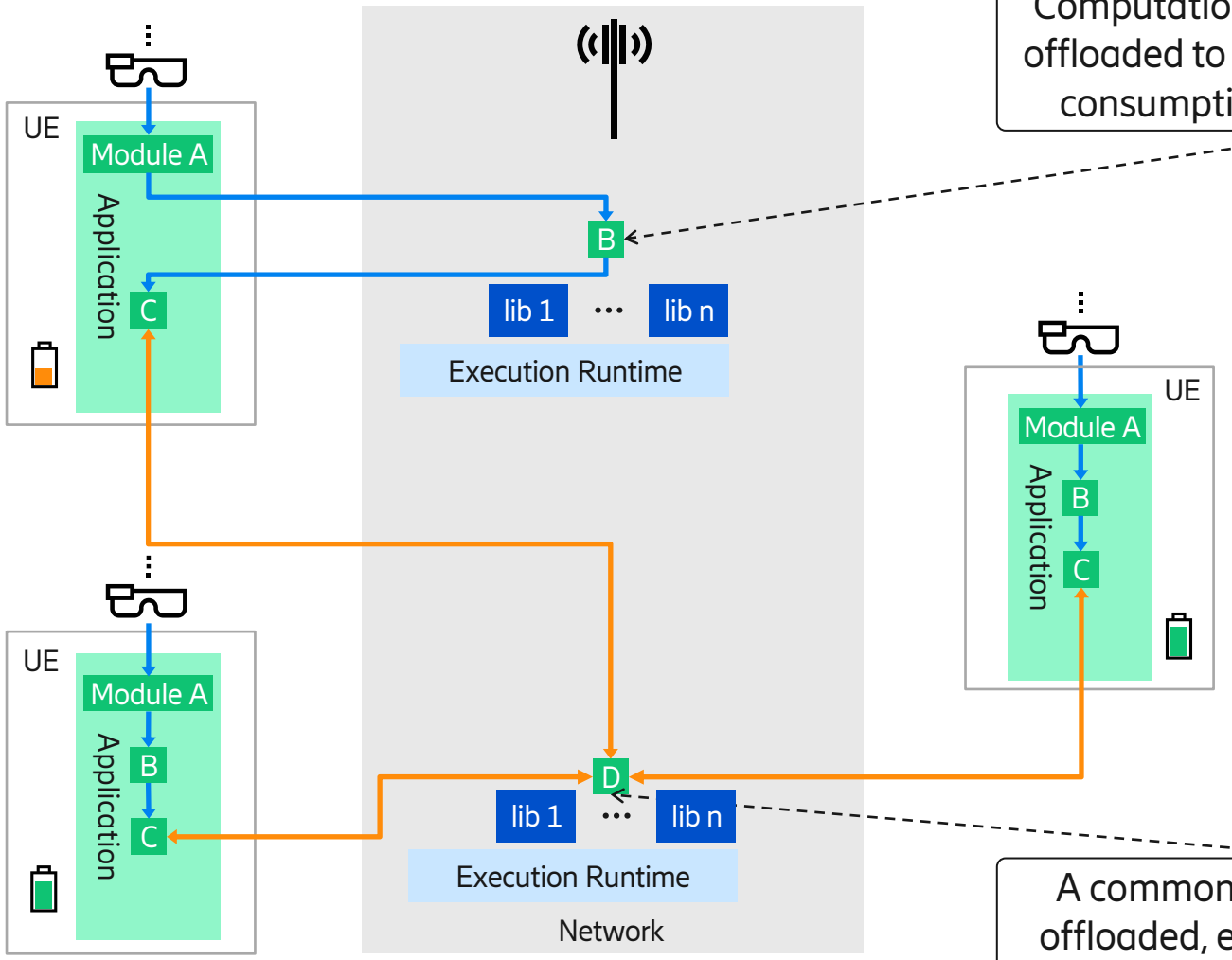


Dynamic computational offloading

Vision

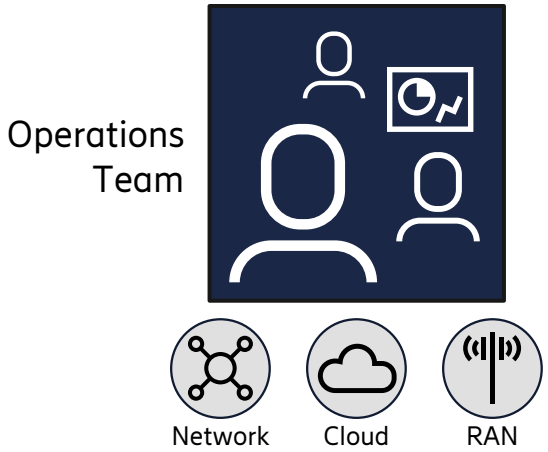
Computational heavy functions can be offloaded to reduce device heat, battery consumption, or computation times

Dynamic scheduling of offloadable modules is triggered by situational changes, during app runtime



A common coordination task can be offloaded, e.g., to realize collaborative perception or to save overall bandwidth

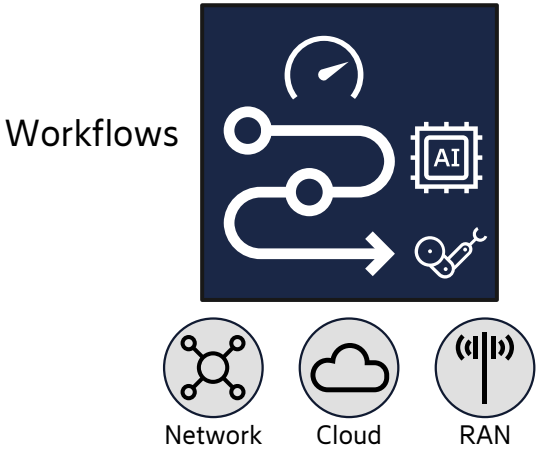
Manual → Automated → Autonomous Operation



Manual operations

Task execution
Human

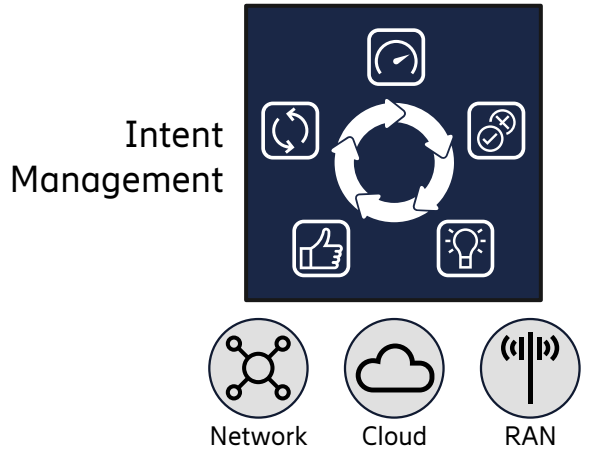
Which tasks to perform?
Human



Automated execution

Task execution
Automated

Which tasks to perform?
Still human

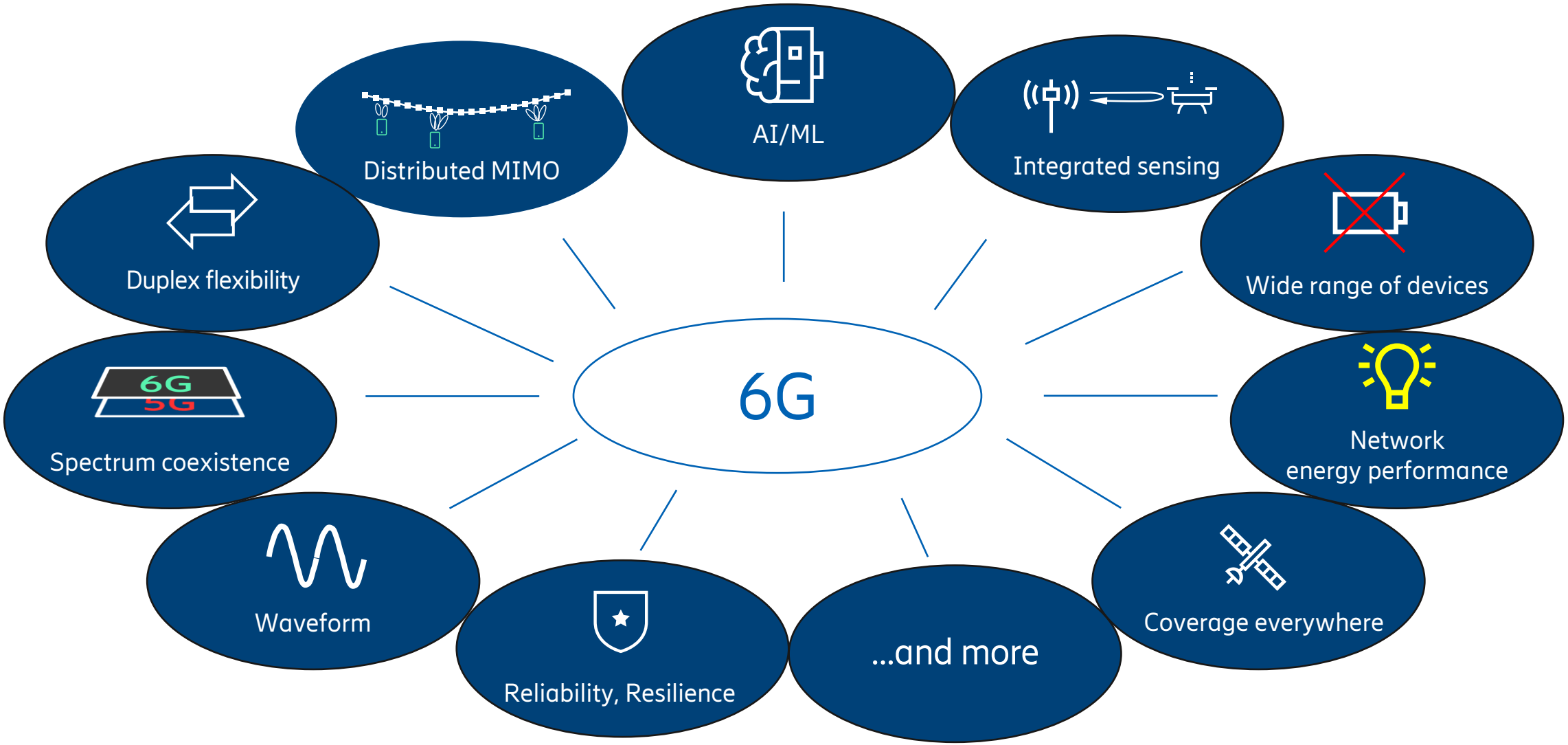


Adaptive autonomy

Task execution
Automated

Which tasks to perform?
Gradually more automated

6G technology components/areas



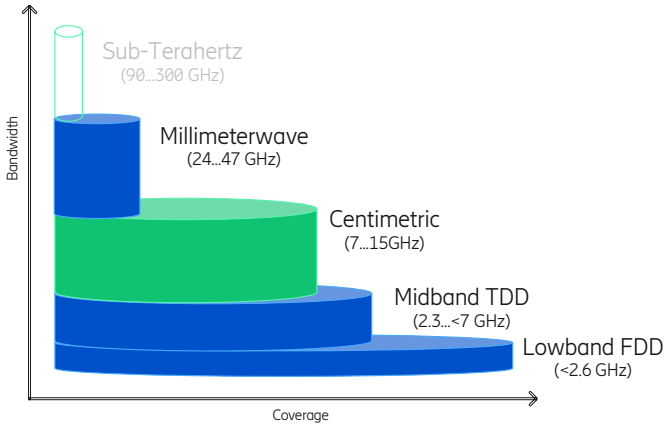
Spectrum for 6G

All spectrum currently used by 3GPP systems can be used by 6G

- FR1 (“sub-6”)
- FR2 (“mm-wave”)

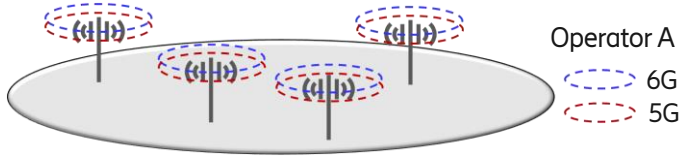
New spectrum, currently not used by 3GPP systems, can be used by 6G

- “cm-wave” – main focus on 7-15 GHz
- “sub-THz” – should not be part of the first 6G release



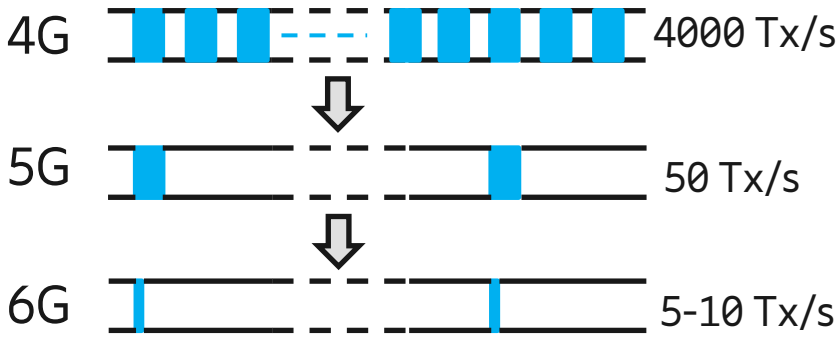
MRSS – highly efficient 6G – 5G sharing absolutely essential, primarily in FR1

- Waveform and numerology aligned with 5G highly beneficial
- Basic (semi-static) sharing between 6G and catM/NB-IoT; sharing with LTE less relevant



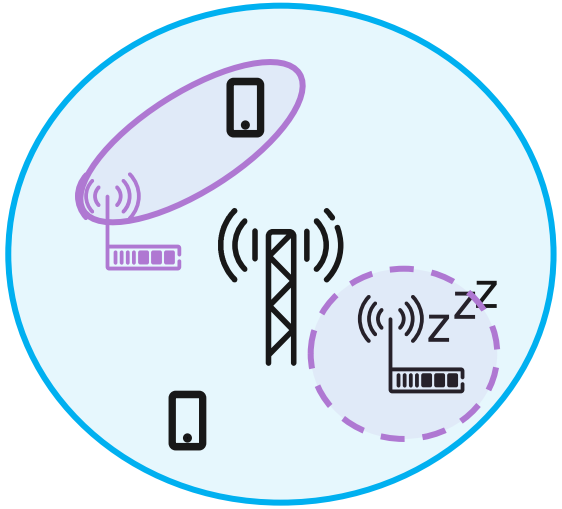
Lean design in 6G

Enhance lean design in Time domain



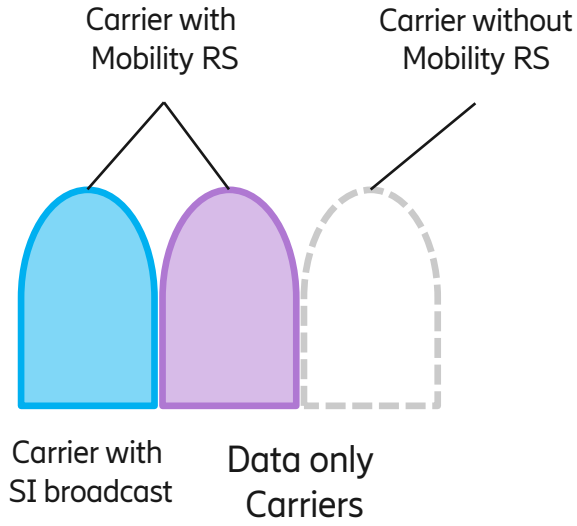
Further reduced duty cycle for "always on" signals

Extend lean design to Node domain



Nodes with different responsibility transmit different signals

Extend lean design to Frequency domain



Carriers with different purposes transmit different signals

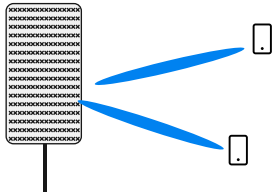
MIMO and antenna features

6G MIMO will build on an evolved 5G MIMO framework

- Learn from NR mistakes and remove unnecessary flexibility/complexity
- "Scalable design" – dynamically adapt number of RF chains to reduce energy consumption

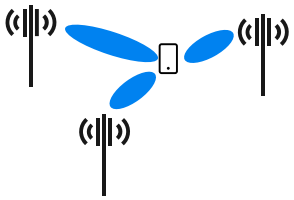
Massive MIMO becoming even more massive

- Support a significantly larger number of antenna elements
- Flexible support for different antenna architectures/irregular subarrays,..



Flexible distributed MIMO

- Focus on DPS and CJT type solutions
- Target maximizing DL SINR instead of only DL SNR

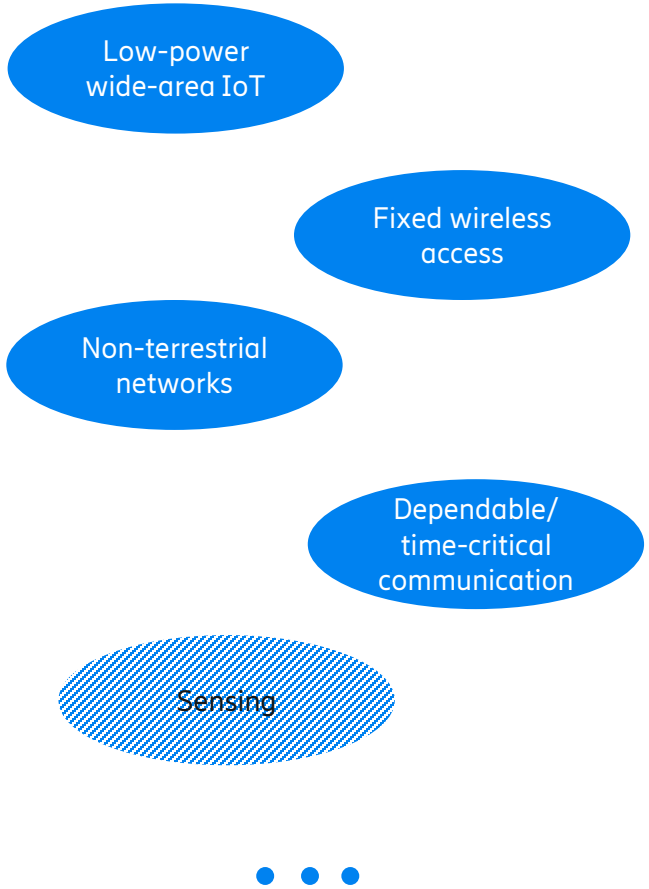


Day 1 verticals and deployments

New verticals/deployments has emerged after the introduction of 5G

- Addressed by 5G evolution – take the learnings into account when designing 6G

Support key use cases and deployment scenarios with general 6G



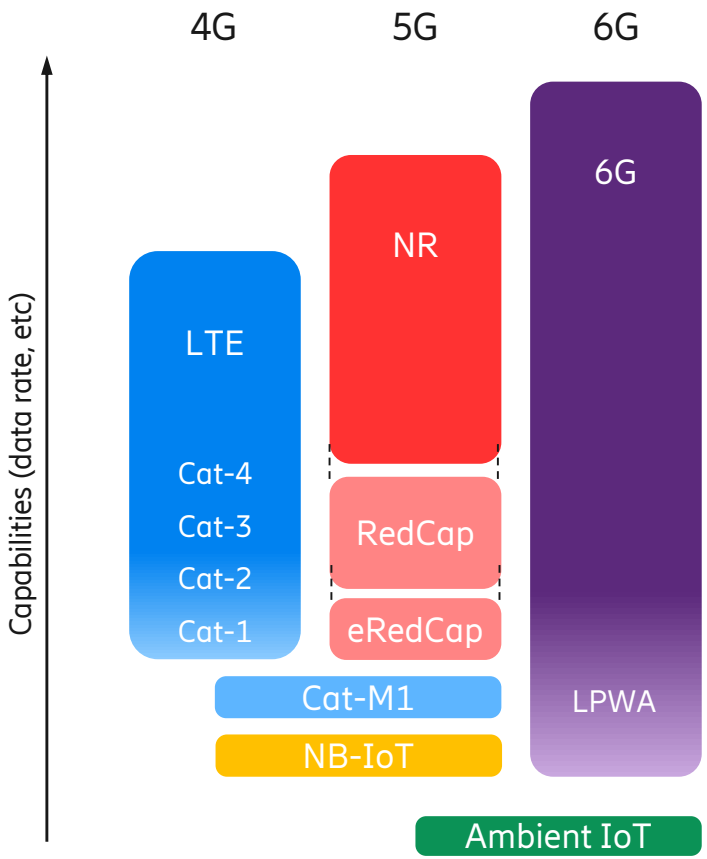
Massive IoT in 6G

LPWA support integrated as part of overall 6G from day 1
without compromising 6G performance

- To gradually replace cat-M/NB-IoT
- Avoid add-on solutions introduced at later stages

Key technologies used for LPWA are also relevant for 6G in general
➡ limited amount of work needed for to support LPWA as part of the overall 6G design

- LPWA is essentially a low-end 6G device type



Non-terrestrial access

NTN as a *complement* to terrestrial access to provide coverage and add resilience

- Deployments: Focus on LEO, both handheld and VSAT terminals
- Bands: existing spectrum, new bands for satellite industry (e.g., IRIS2)

Common track for TN and NTN

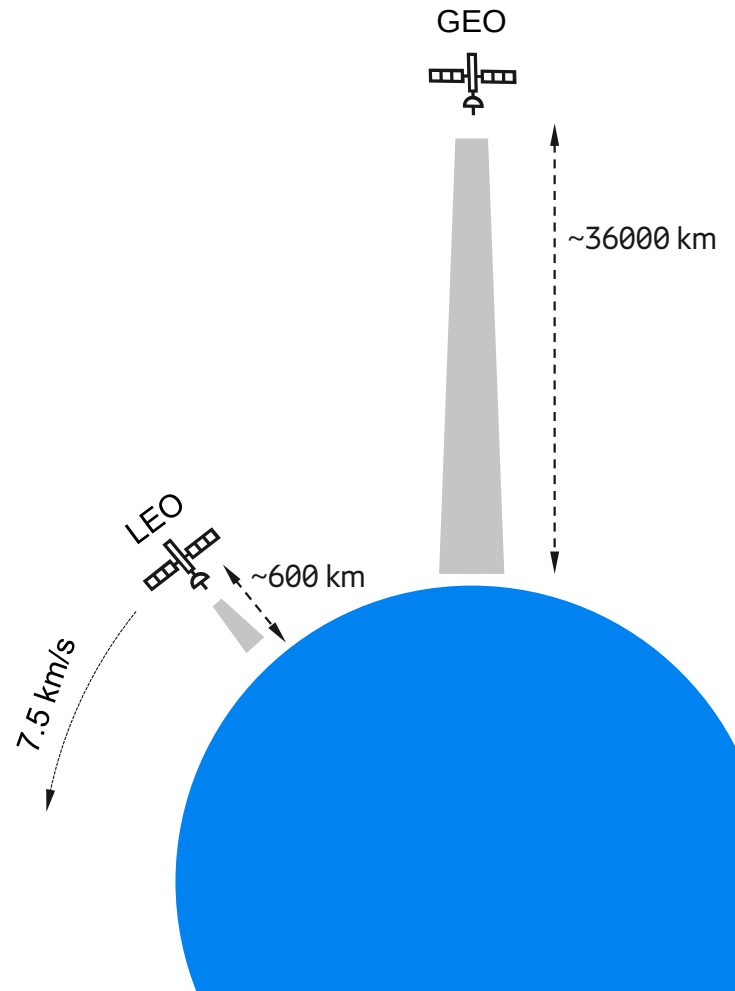
- Separate tracks fragments the market, increase implementation cost, and hampers wide adoption
- Basic NTN connectivity is possible with 6G mandatory UE features

Main challenges

- Long delays
- High Doppler shift

Transparent to the UE

- Pre-compensations (e.g., delay, Doppler) handled by the NW for LEO
- Avoid dependencies on external technologies (e.g., GNSS)

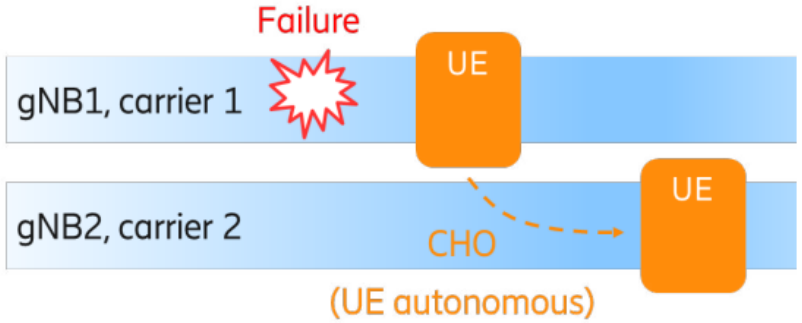


Reliability, Availability, Resilience

5G – focus primarily on link performance (URLLC)

6G – overall system view important

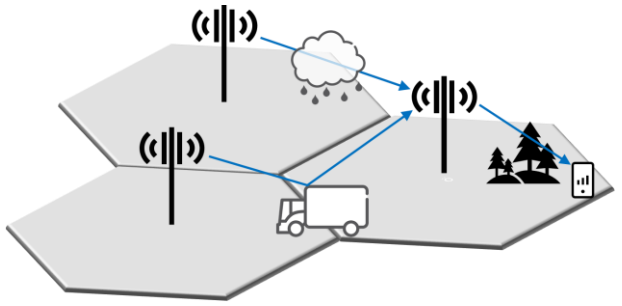
- Carrier aggregation for robustness
- Radio protocols suitable for handling failures
- Architecture aspects, leverage cloud for resilience, e.g. switching software instances



Sensing

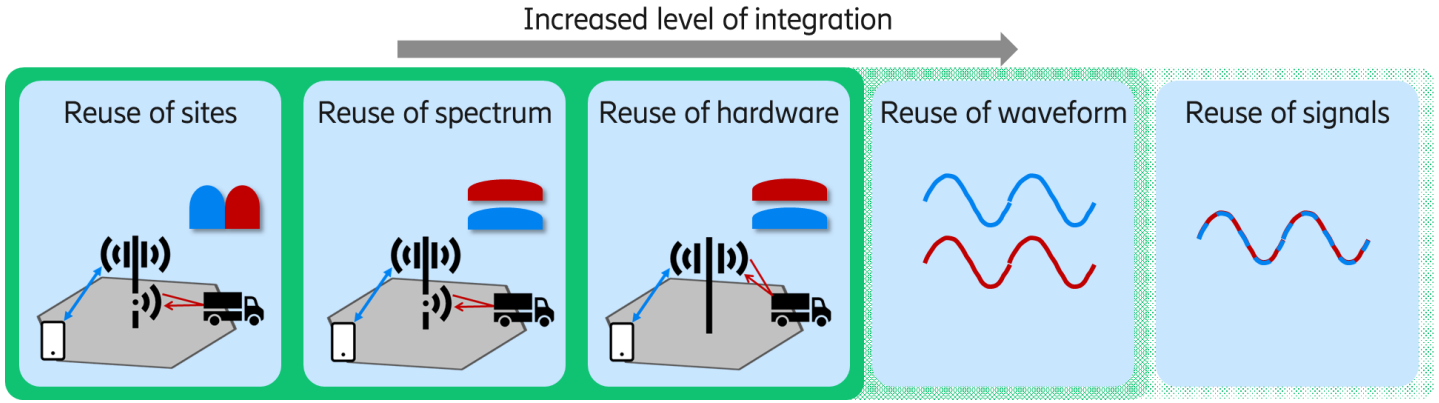
Sensing functionality as an *integrated* part of the communication network

- Reuse the communication spectrum for sensing
- Reuse the communication infra-structure for sensing



Low-cost introduction of sensing functionality

Benefit from huge number of co-operative network nodes



Summary

"6G" is broader than radio access alone

A trusted platform delivering ever-present intelligent communication including connectivity, data, and compute

"6G" is the overall solution around 2030

"6G" is still in the research/pre-standardization phase

For further information…

Open the 3GPP specifications…

…or read The Books!

Available in English, Chinese, Korean, Japanese, and Greek.