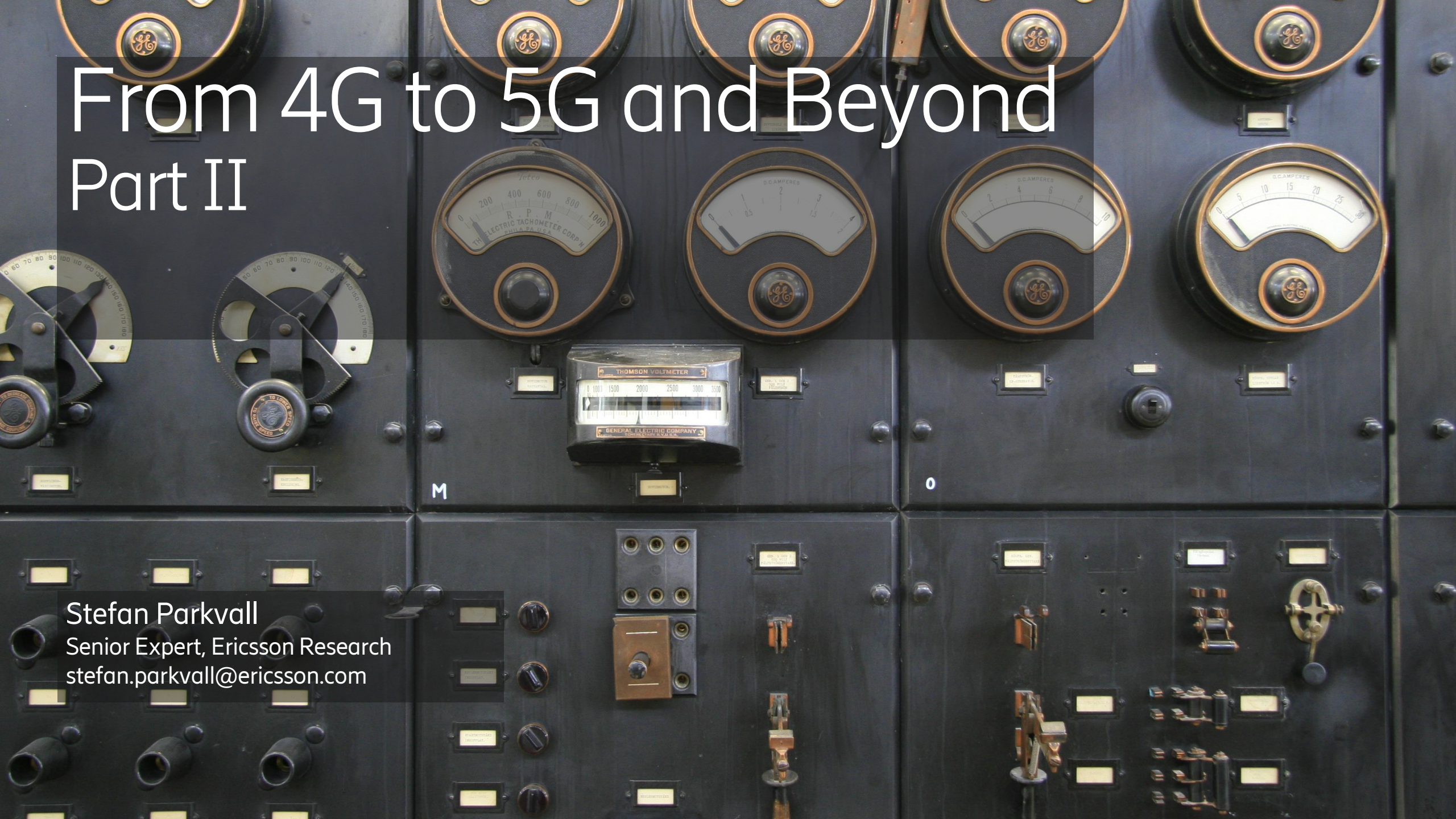
From 4G to 5G and Beyond
Part II



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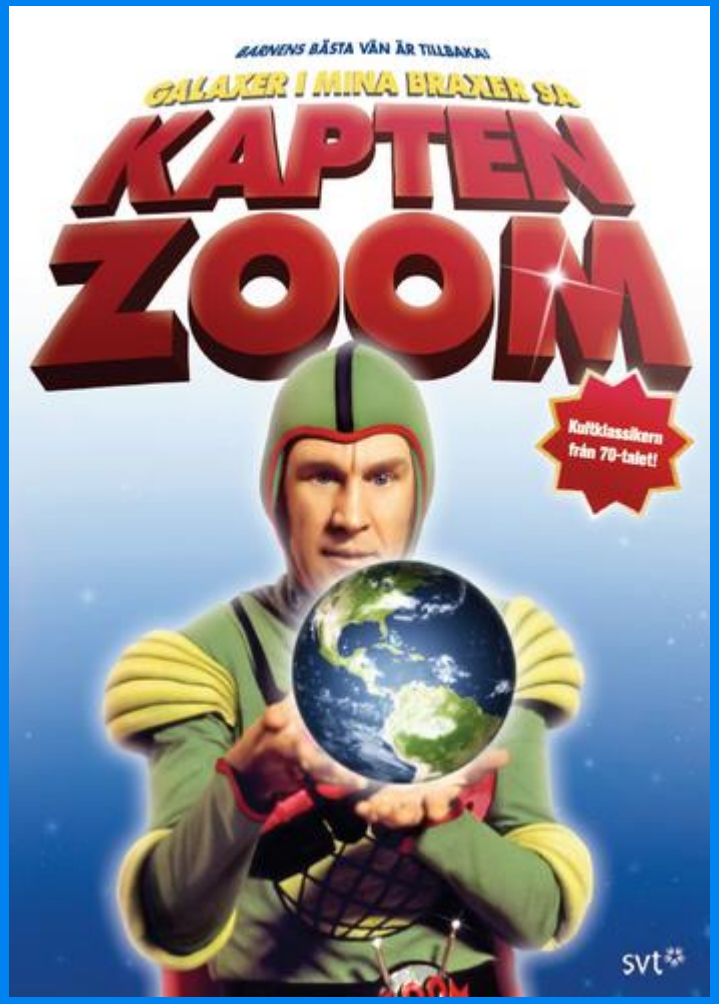
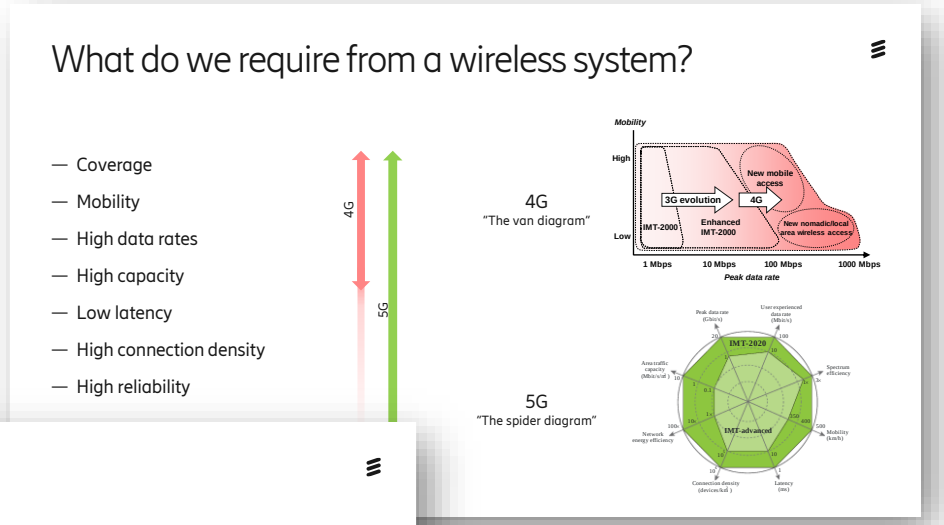
Outline

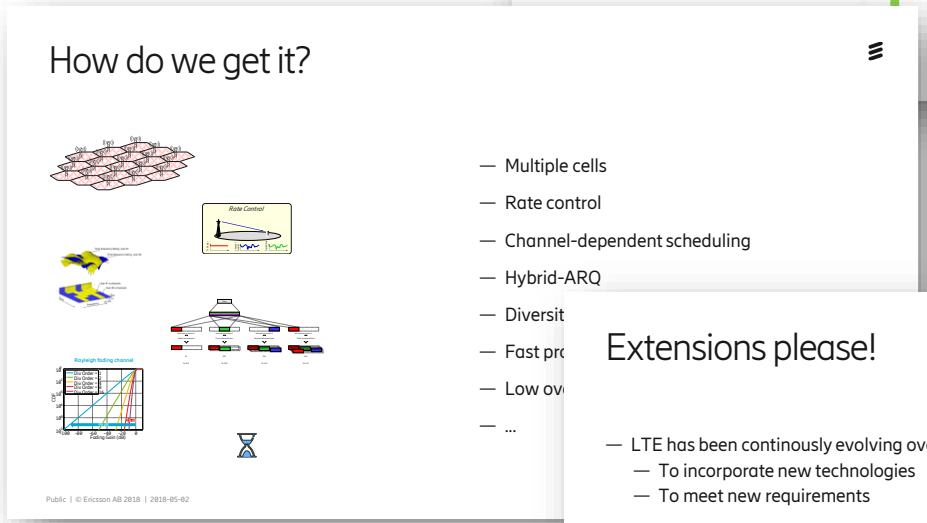
- Introduction
- LTE (4G)
- LTE evolution
- NR (5G)
- NR evolution and beyond
- Standardization in practice

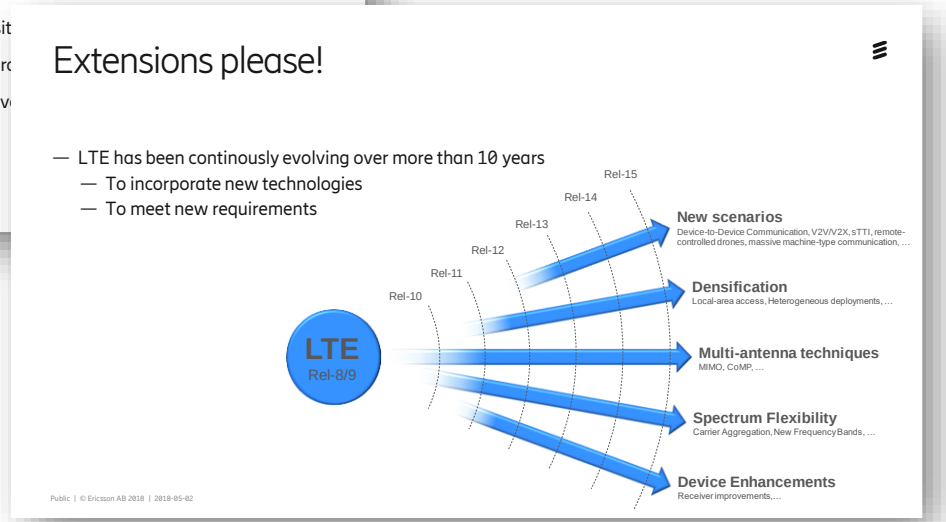


Recap from first session

- LTE – global standard
- Basic technologies in LTE
- LTE evolution







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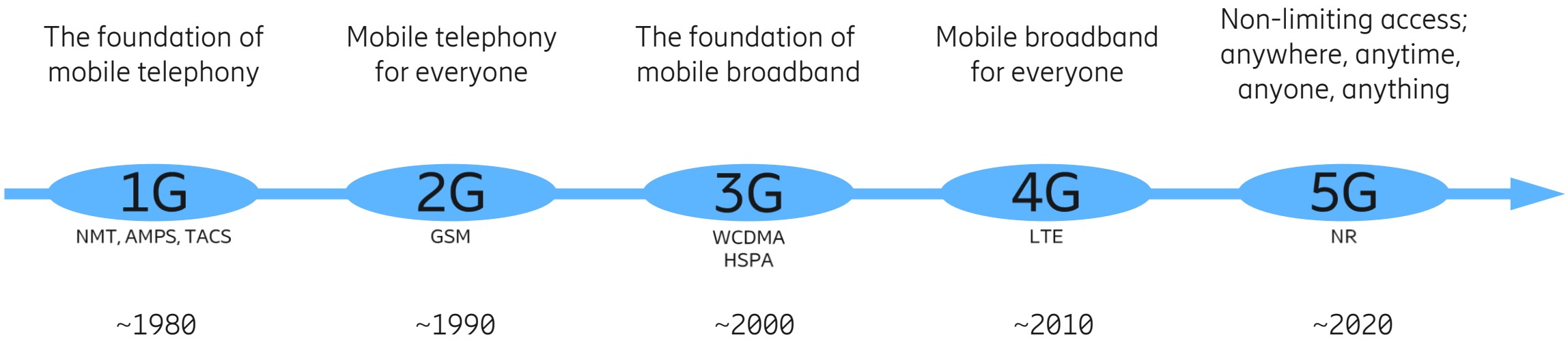
So…what's next?



5G vision

Non-limiting access to information and sharing of data …

… anywhere and anytime …



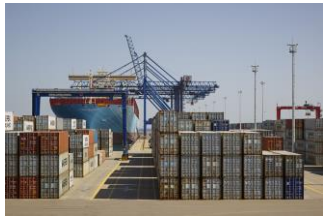



• • •

… for anyone and anything





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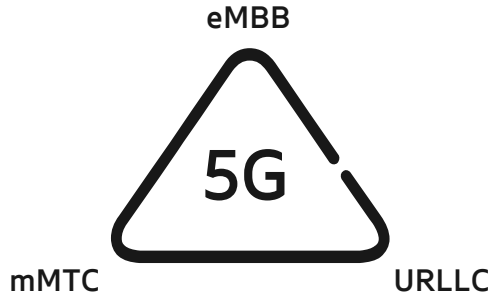
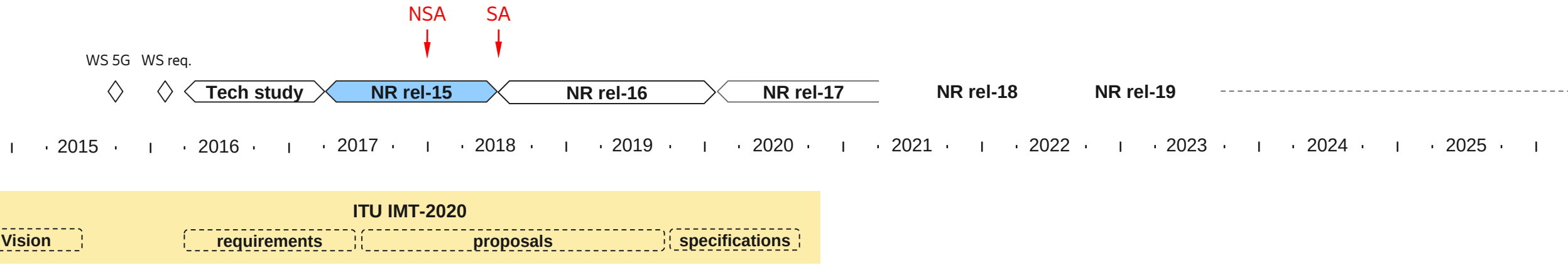
5G – going *beyond* the smartphone

NR Release 15 – The first 5G release

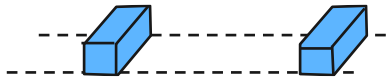
- Release 15 – the first release of NR radio access standardized by 3GPP
  - Completed in June 2018
  - Focuses on eMBB and (partially) on URLLC



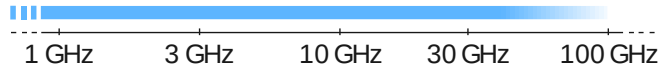


NR characteristics – some examples

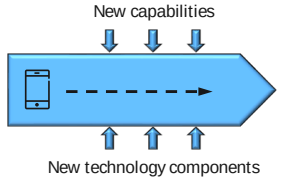
Ultra-lean design



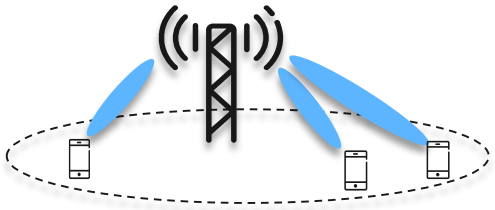
Wide spectrum range



Forward compatibility



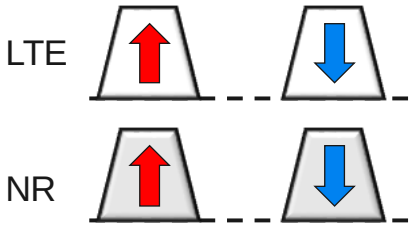
Multi-antenna support



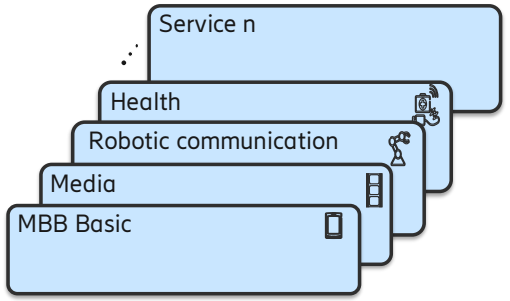
Low latency

NR characteristics – some examples

LTE – NR coexistence

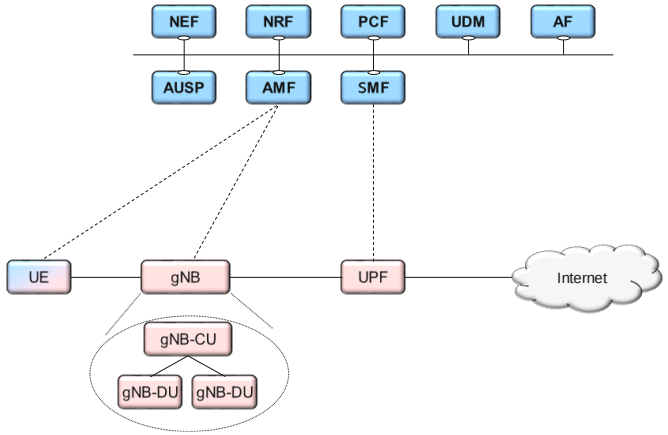


Network slicing



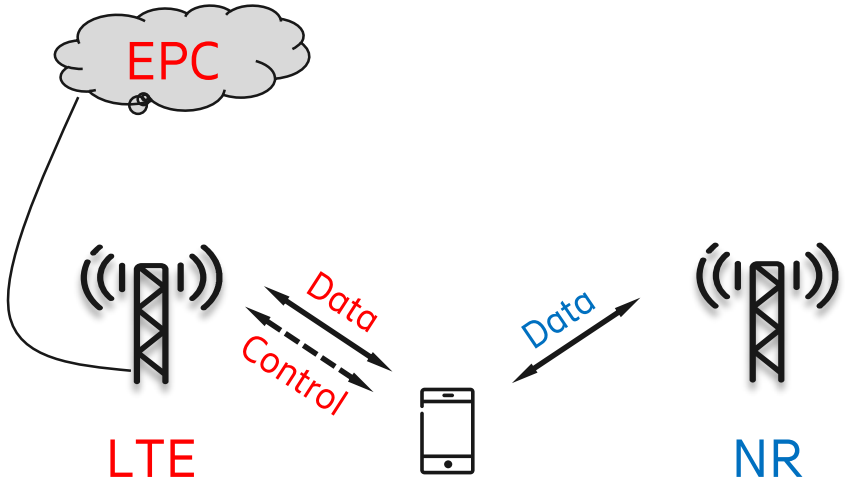
Modular architecture

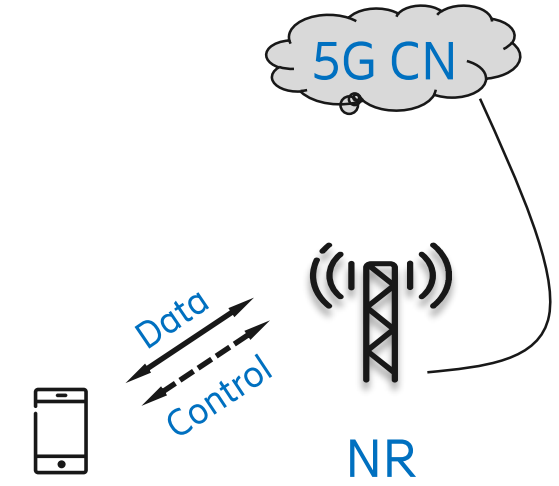
DU/CU split, CP/UP split



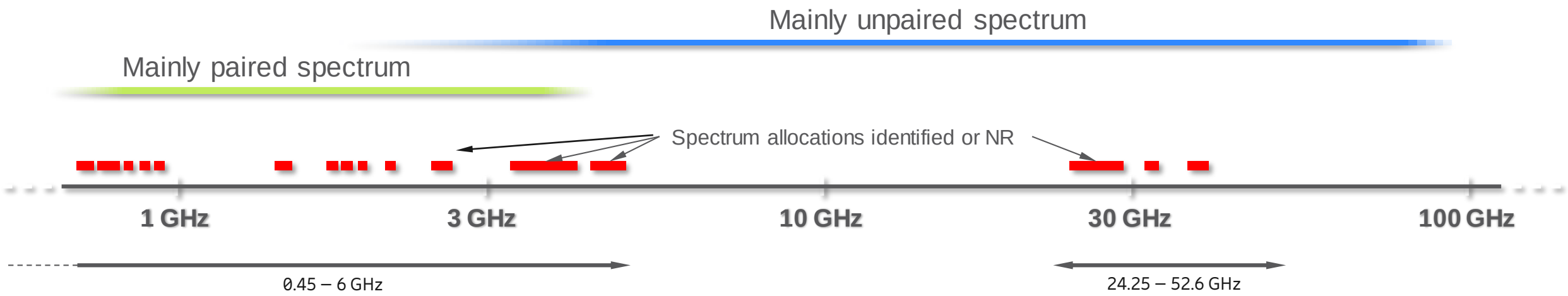
Architectural options

- Non-standalone NR (December 2017)
  - LTE handling initial access and mobility
  - NR is a "data rate booster"
  - Connects to EPC
- Stand-alone NR (June 2018)
  - NR handles initial access and mobility
  - Connects to 5G CN





5G spectrum



Frequency Range 1

Subcarrier spacing	15/30/60 kHz
Max carrier bandwidth	50/100/200 MHz

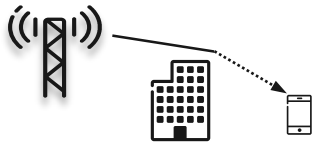
Frequency Range 2

Subcarrier spacing	60/120 kHz
Max carrier bandwidth	200/400 MHz

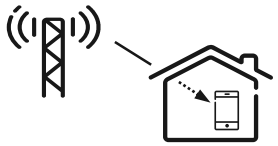
mm-wave challenges

Propagation

Diffraction



Outdoor-to-indoor penetration



Rain/atmospheric attenuation

(Less of an issue for small cells)

Body loss

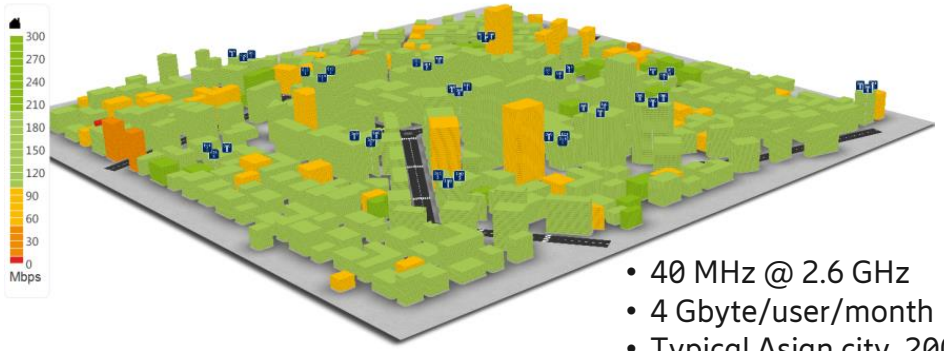
Regulation

Additional Tx power limitations above 6 GHz

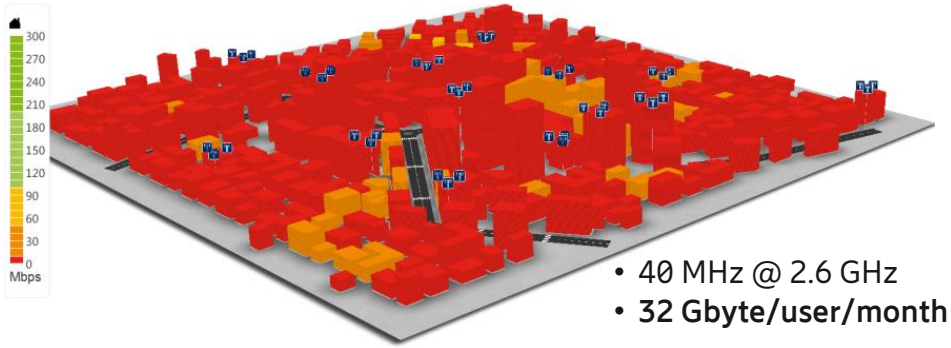
Implementation

Efficiency, dynamic range, output power, …

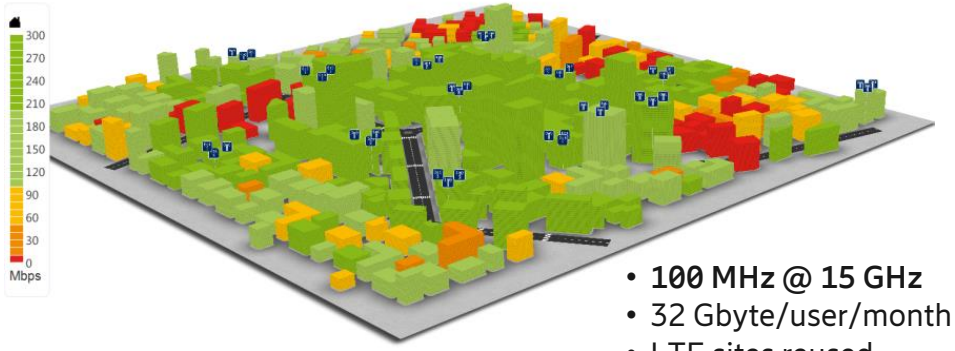
High-frequency operation



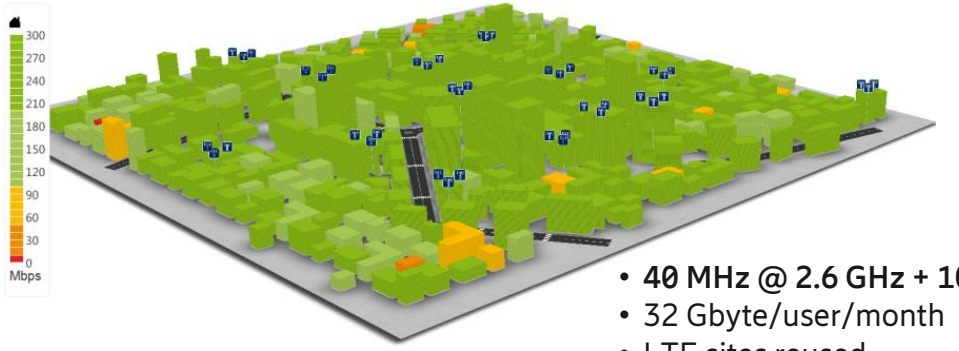
- 40 MHz @ 2.6 GHz
- 4 Gbyte/user/month
- Typical Asian city, 200-400 m ISD



- 40 MHz @ 2.6 GHz
- **32 Gbyte/user/month**



- **100 MHz @ 15 GHz**
- 32 Gbyte/user/month
- LTE sites reused



- **40 MHz @ 2.6 GHz + 100 MHz @ 15 GHz**
- 32 Gbyte/user/month
- LTE sites reused

— Higher-frequency spectrum needed to satisfy future traffic demands

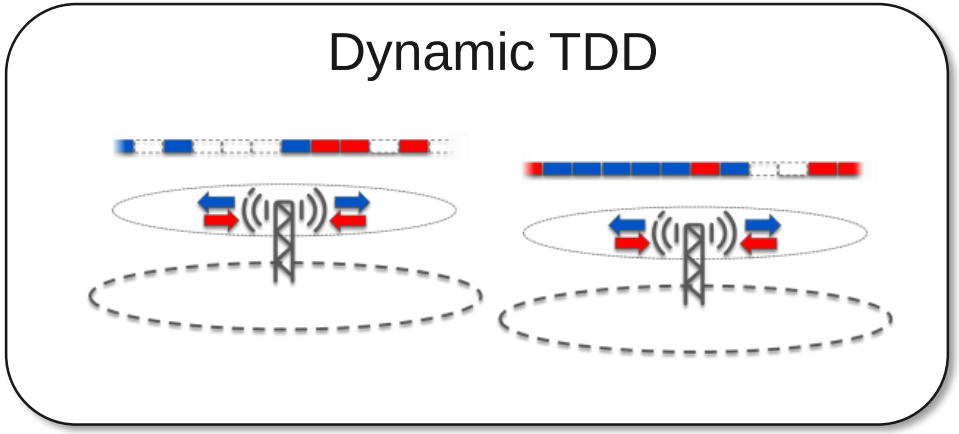
— Joint low-frequency/high-frequence operation needed for full-area coverage

Dynamic TDD

- Dynamic assignment of resources to downlink and uplink
  - Possible to inform the UE about a semi-static uplink/downlink allocation

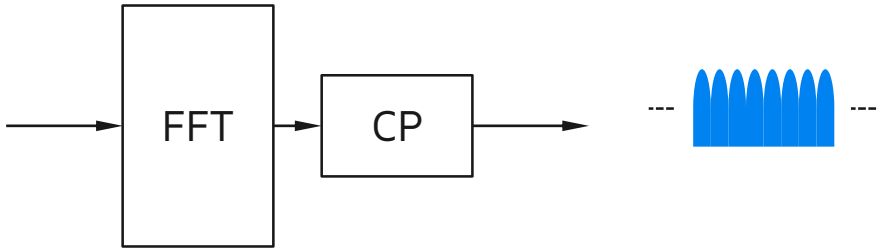
- "Macro" deployment – semi-static operation
  - Less dynamic traffic variations
  - Important to avoid TDD-specific interference

- "Small-cell" deployments – dynamic operation
  - More dynamic traffic variations
  - TDD-specific interference less critical

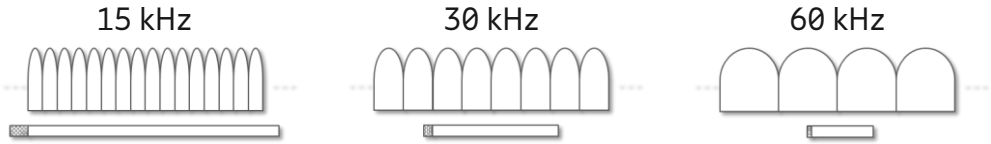


Basic waveform

- Conventional OFDM (DL and UL)
  - Uplink: possibility for DFT precoding for higher device PA efficiency

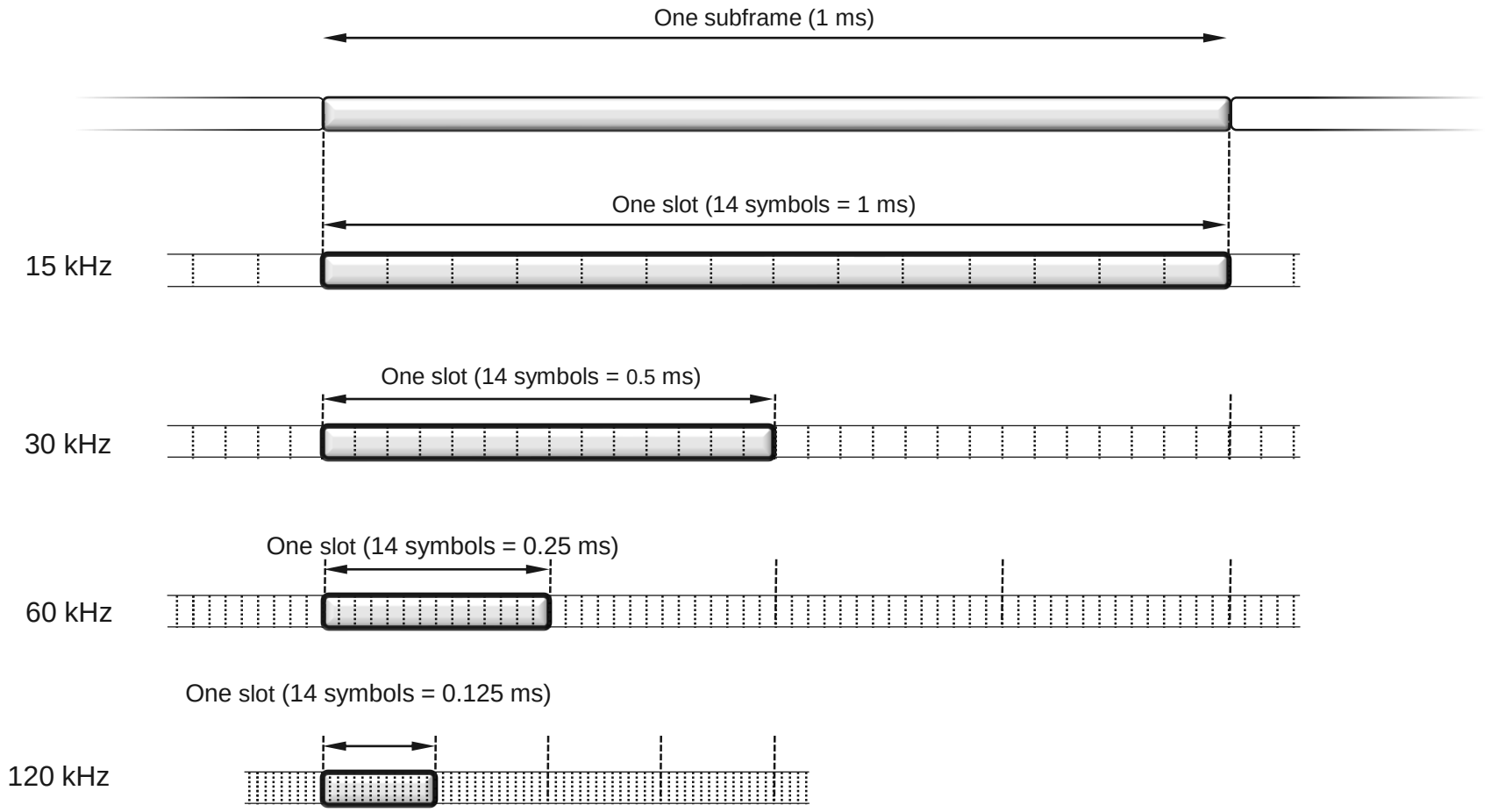


- Scalable numerology, $\Delta f = 2^{\mu} \cdot 15$ kHz
  - To handle a wide range of carrier frequencies



Subcarrier spacing	Symbol duration (incl. CP)	Cyclic prefix
15 kHz	71 µs	4.69 µs
30 kHz	36 µs	2.34 µs
60 kHz	18 µs	1.17 µs
120 kHz	9 µs	0.59 µs
240 kHz (SSB only)	4.5 µs	0.29 µs

Frame structure



Frame structure

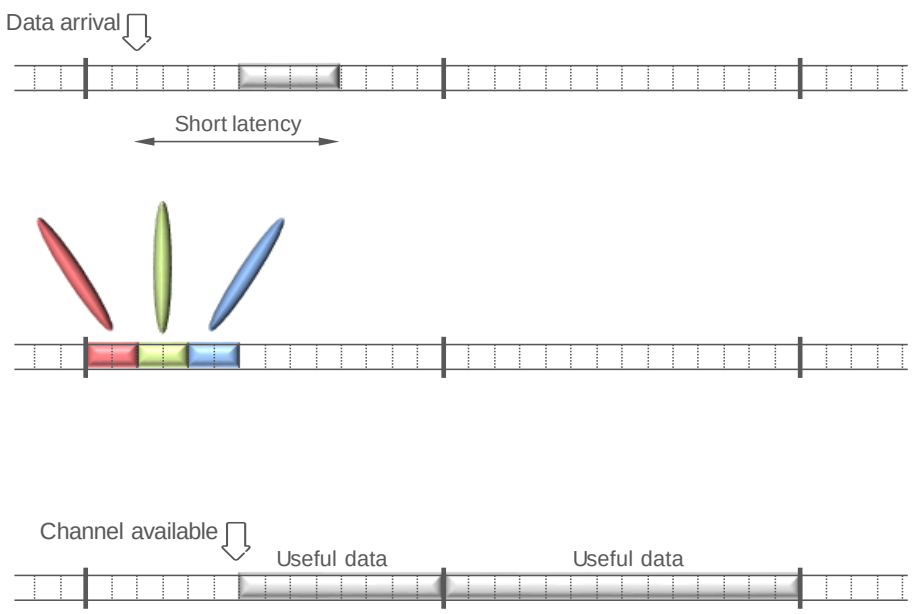
- Transmissions not restricted to slot boundaries
  - "Mini-slots" 2, 4, or 7 OFDM symbols long

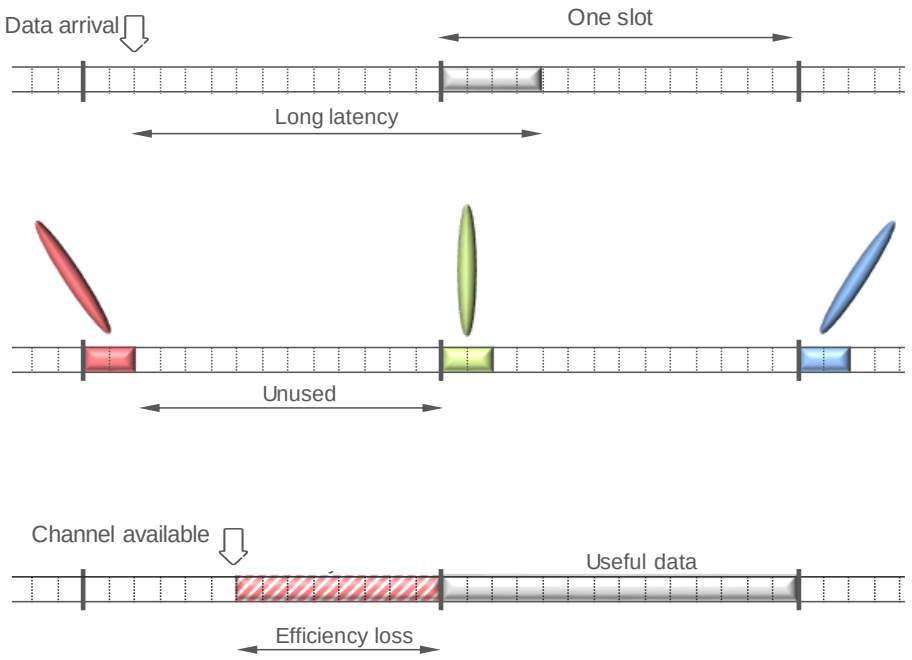
LET

5G

Not restricted to slot boundaries

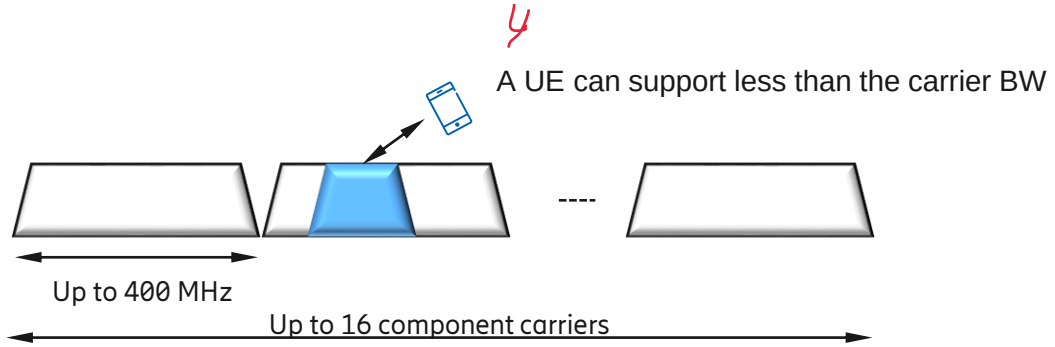
Restricted to slot boundaries



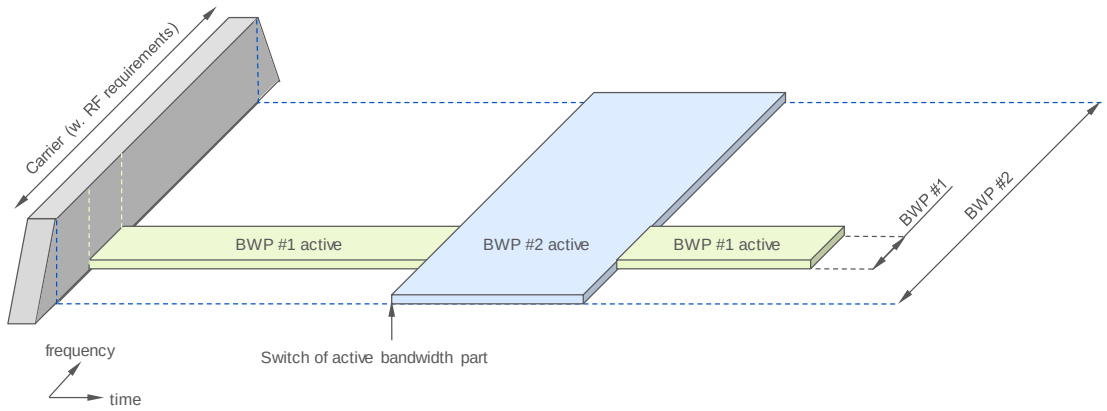


Bandwidths and bandwidth parts

- Up to 400 MHz carrier bandwidth
- Up to 16 component carriers

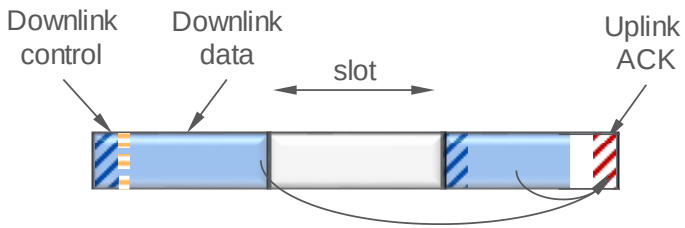


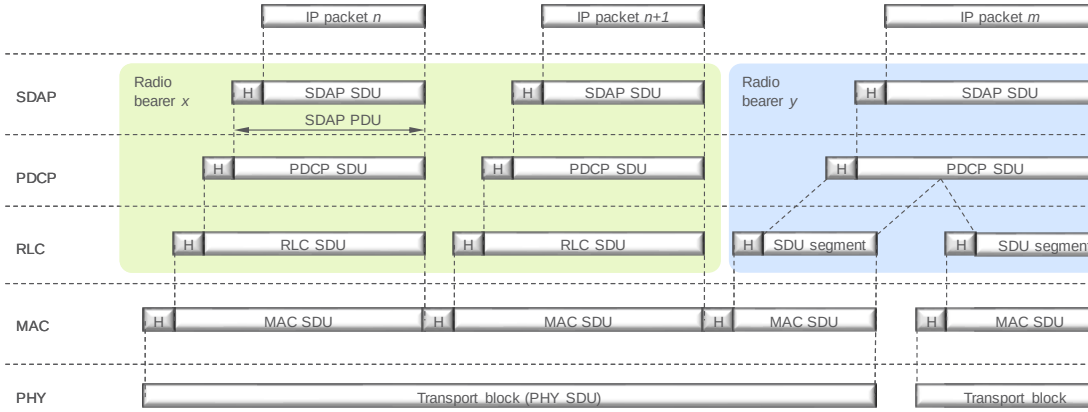
- Bandwidth parts (4 configured, 1 active)
  - UEs not capable of full carrier bandwidth
  - Bandwidth adaptation



Optimized for low latency

- Latency-friendly frame structure
  - Front-loaded DM-RS
- Fast processing time
  - ACK a few symbols after data ends (“same slot”)
- Higher-layer protocols (MAC, RLC)
  - Optimized header structure to enable preprocessing
  - No reordering in RLC

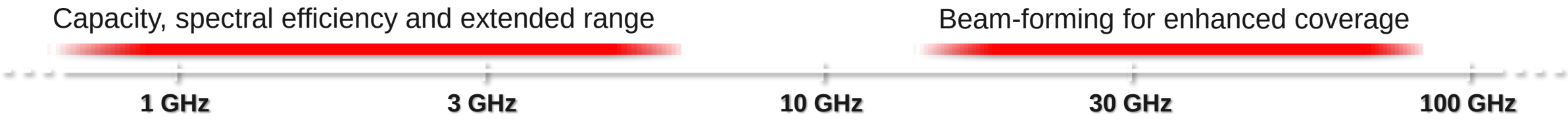




Multi-antenna transmission

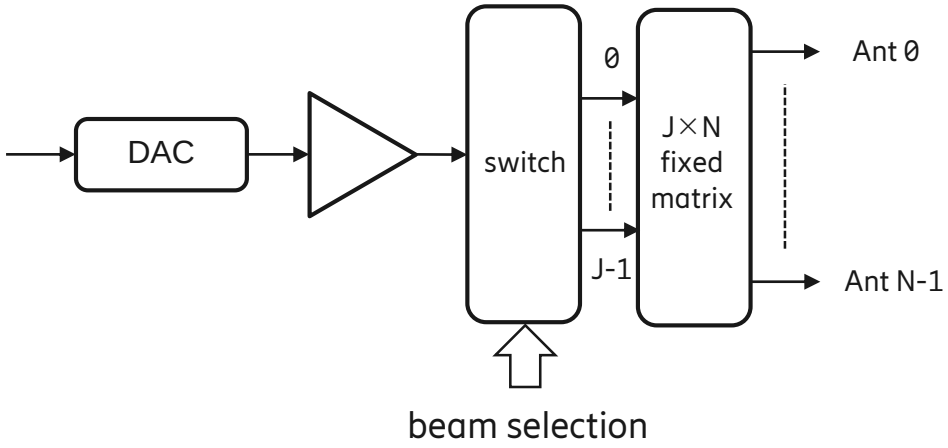
Common toolbox – but different tools suitable for different frequency ranges

- Lower frequencies (“sub-6 GHz)
  - Similar to LTE but enhanced
  - Approx 10 – 100 antenna elements
  - Capacity, end-user data throughput
- Higher frequencies (“mmw”)
  - Up to several hundred antenna elements (“Massive MIMO”)
  - Focus on beam-forming for coverage

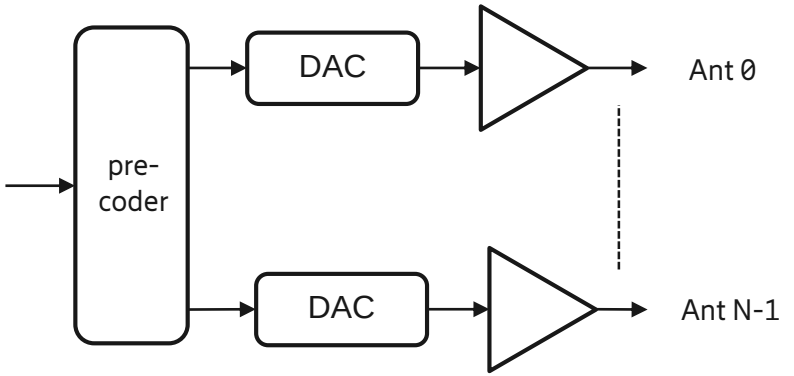


Analog vs Digital Beamforming

- Analog beamforming
  - Limited degrees of freedom

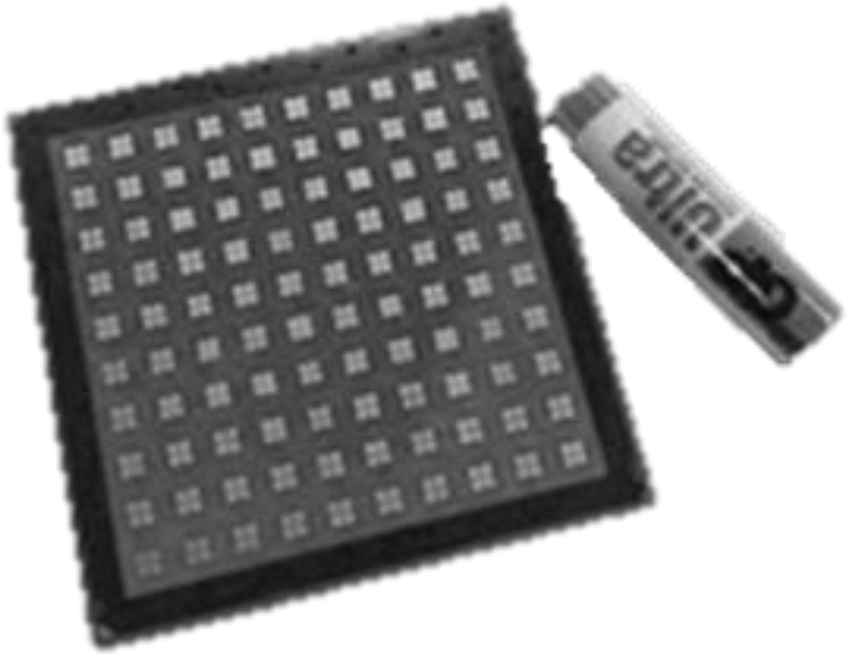


- Digital beamforming
  - Highest degree of freedom
  - Challenging implementation (at high freq.)



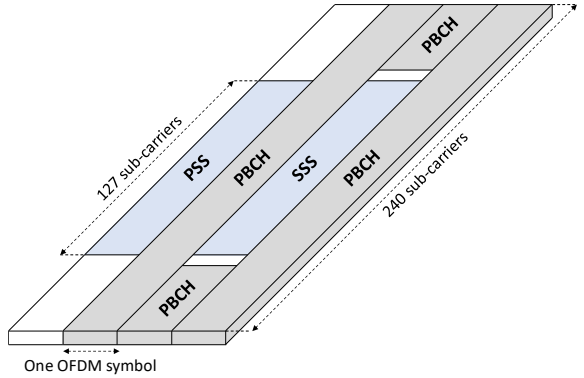
Both schemes (and hybrids) supported by NR

Antenna array

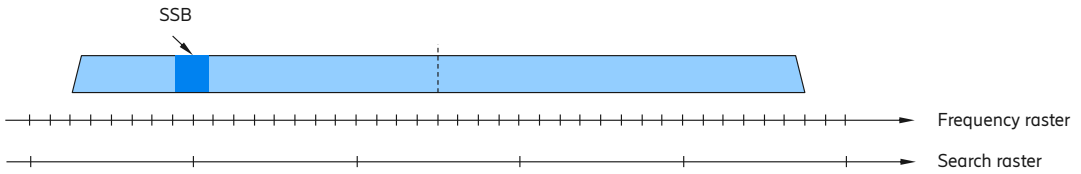


Initial access

- SS Block (SSB) it's good for timing where i can know where i start sampling
  - Relatively infrequent (20 ms periodicity)
  - Can be beamformed



- SSB not necessarily at the center of the carrier
  - Search raster sparser than frequency raster

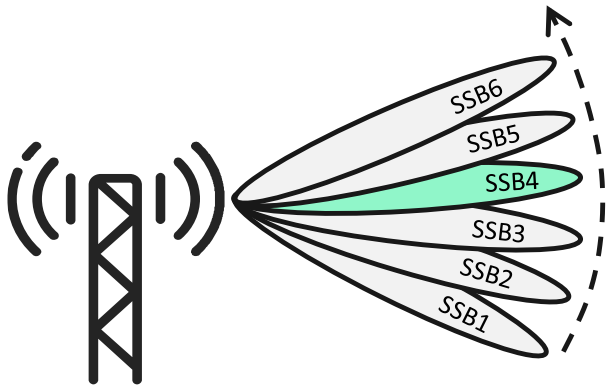


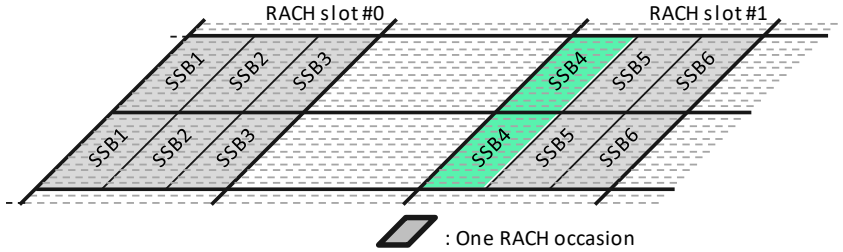
Initial access

- Beam sweeping of SSB possible
  - Max number of beams depends of frequency range

Frequency	Beams
– 3 GHz	4
3 – 6 GHz	8
mm-wave	64

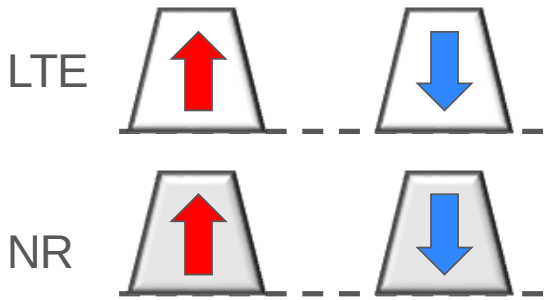
- Predefined association SSB time index ⇔ RACH time/frequency occasions
  - Base station knows the direction to listen for random access



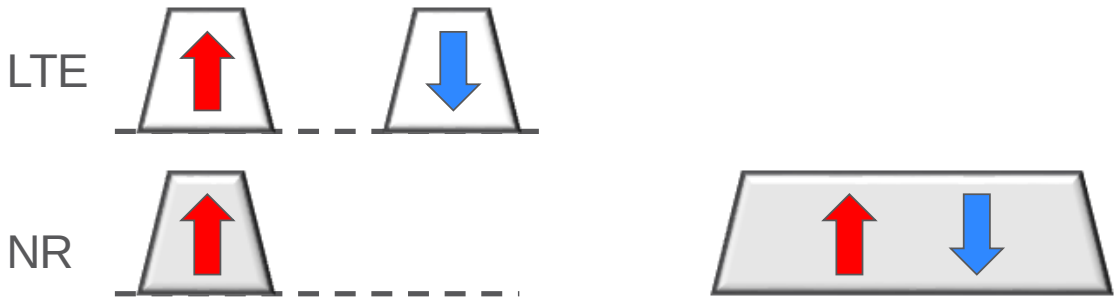


NR-LTE coexistence

— NR can coexist with LTE on the same carrier
  — Example: NB-IoT or cat-M for MTC on same carrier as NR



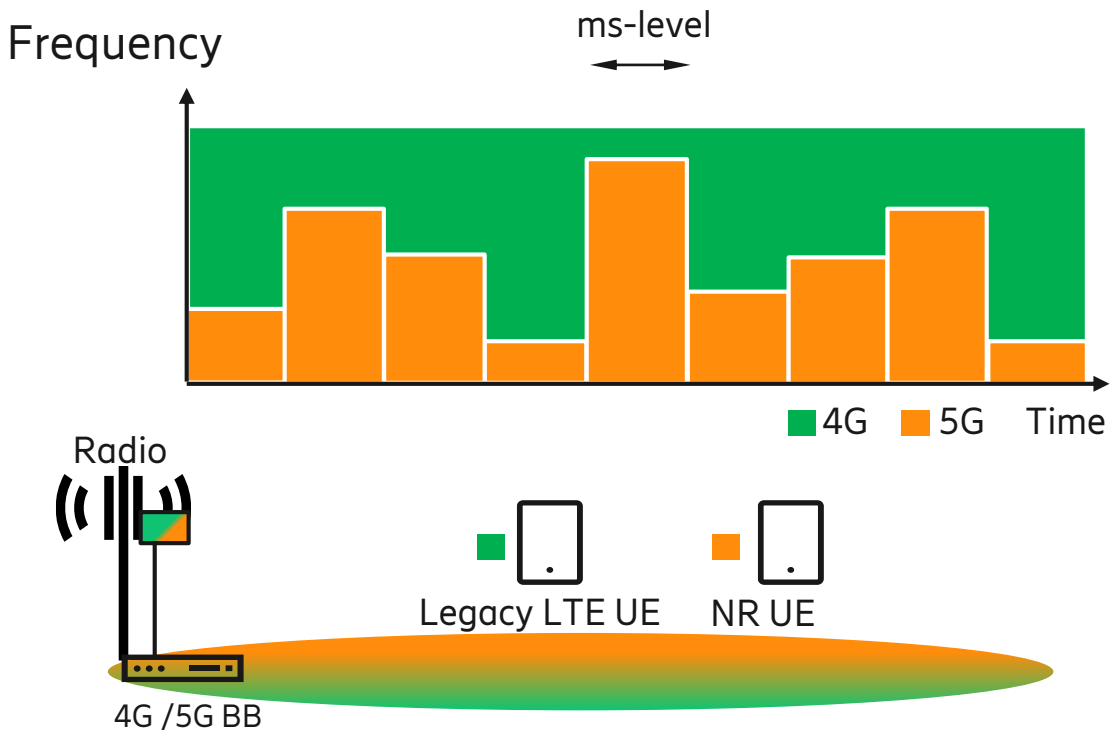
Downlink and uplink co-existence



Uplink-only co-existence

Ericsson spectrum sharing

- Gradually introduce 5G in 4G band based on NR device penetration
- Lowest cost 5G introduction:
  Shared radio + share baseband + shared spectrum
- Smooth and fast network migration



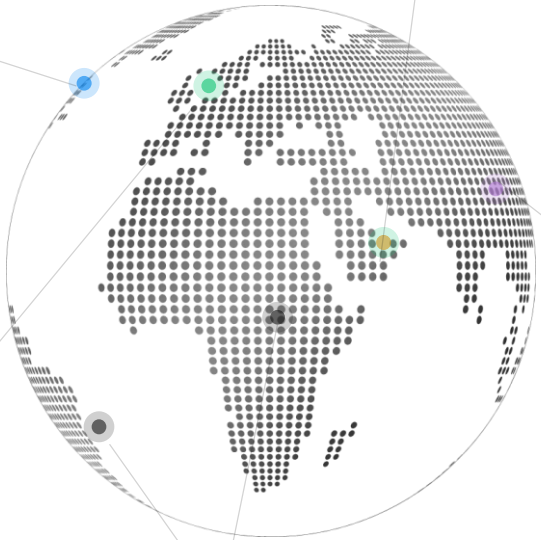
Initial NR focus per region

North America

- 2018 launches on mmWave
- Early 2019 low-band, mid-band
- Mobile broadband and FWA

Middle East

- 2018 launches on mid-band, with mmWave as second wave
- Mobile broadband and FWA



South America and Africa later

Europe

- Initial focus on mid-band
- Focus on industry use-cases
- Low-band NR for coverage
- High-band as capacity booster

Asia

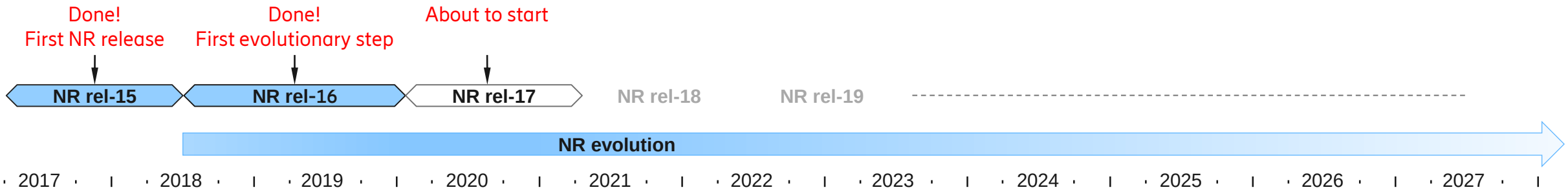
- Initial focus generally on mid-band, with high-band as second wave
- China taking lead in SA deployment
- Australia and Korea early movers with 2018 launches
- China and Japan driving volumes in 2020 with large scale rollouts

Outline

- Introduction
- LTE (4G)
- LTE evolution
- NR (5G)
- NR evolution and beyond
- Standardization in practice

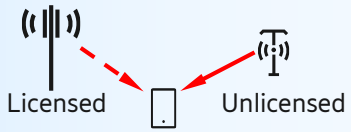
Beyond Rel-15

- First release concluded (Rel-15)
- Evolution of NR
  - Substantial extensions already in release 16
  - Continued evolution in subsequent releases
- New technologies beyond NR
  - Technologies implying a more fundamental step
  - May be part of "5G evolution" or "Beyond 5G"

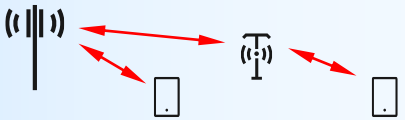


Some topics in NR Rel-16

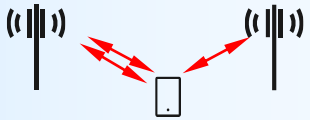
Unlicensed spectrum
LAA and stand-alone



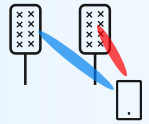
Integrated Access Backhaul
NR for backhauling



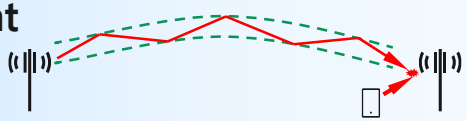
CA/DC enhancements
Faster SCell activation, signaling enhancements, ...



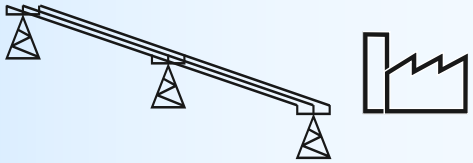
Multi-antenna enhancements
Multi-TRP, CSI reporting, ...



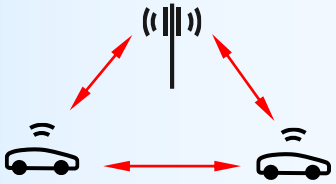
Remote Interference Management
TDD, athmosperic ducts, ~300 km



URLLC enhancements
PDCCH enhancements, ...



V2X
Sidelink, Uu enhancements, QoS, ...



Positioning
Combination of techniques

NR in unlicensed spectrum

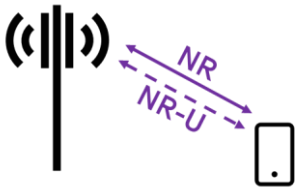
Frequency bands: 5 GHz and 6 GHz

Deployment

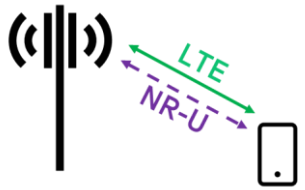
- Licensed-assisted access, NR + NR-U
- Licensed-assisted access, LTE + NR-U
- Stand-alone unlicensed operation

NR well prepared for unlicensed operation

- Flexible frame structure, ...
- Add LBT, also for initial access



NR + NR-U



LTE + NR-U

Stand-alone
unlicensed operation

Integrated access-backhaul

NR for wireless backhaul

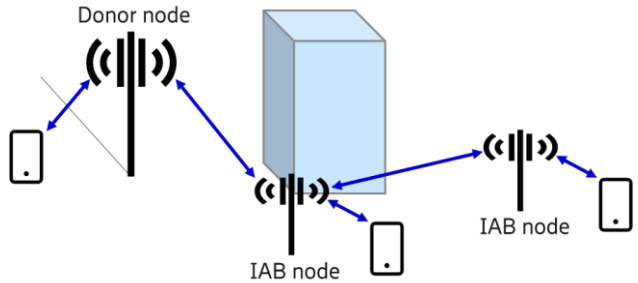
— When wired backhaul not available
— For rapid deployment
— Small cells

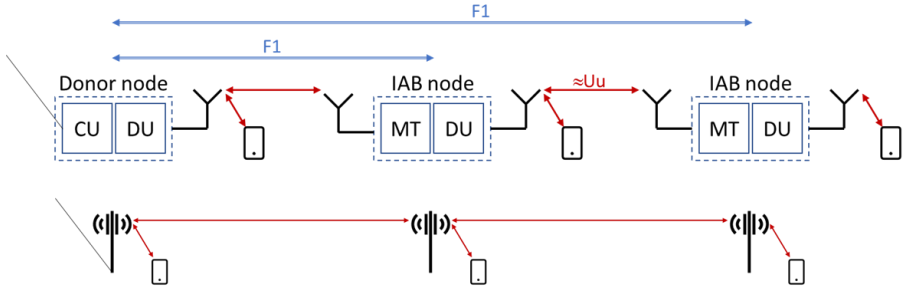
Focus on backhaul in mmw spectrum

— Both inband and outband backhaul

Based on specified CU/DU split

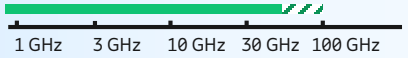
— Smooth migration to wired backhaul





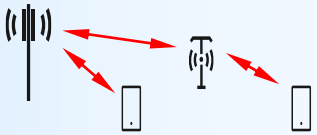
Some topics in Rel-17

52.6 - 71 GHz
Extending frequency range



RedCap
Reduced capability NR for IoT

IAB enhancements
Partially moving relays



Drone enhancements

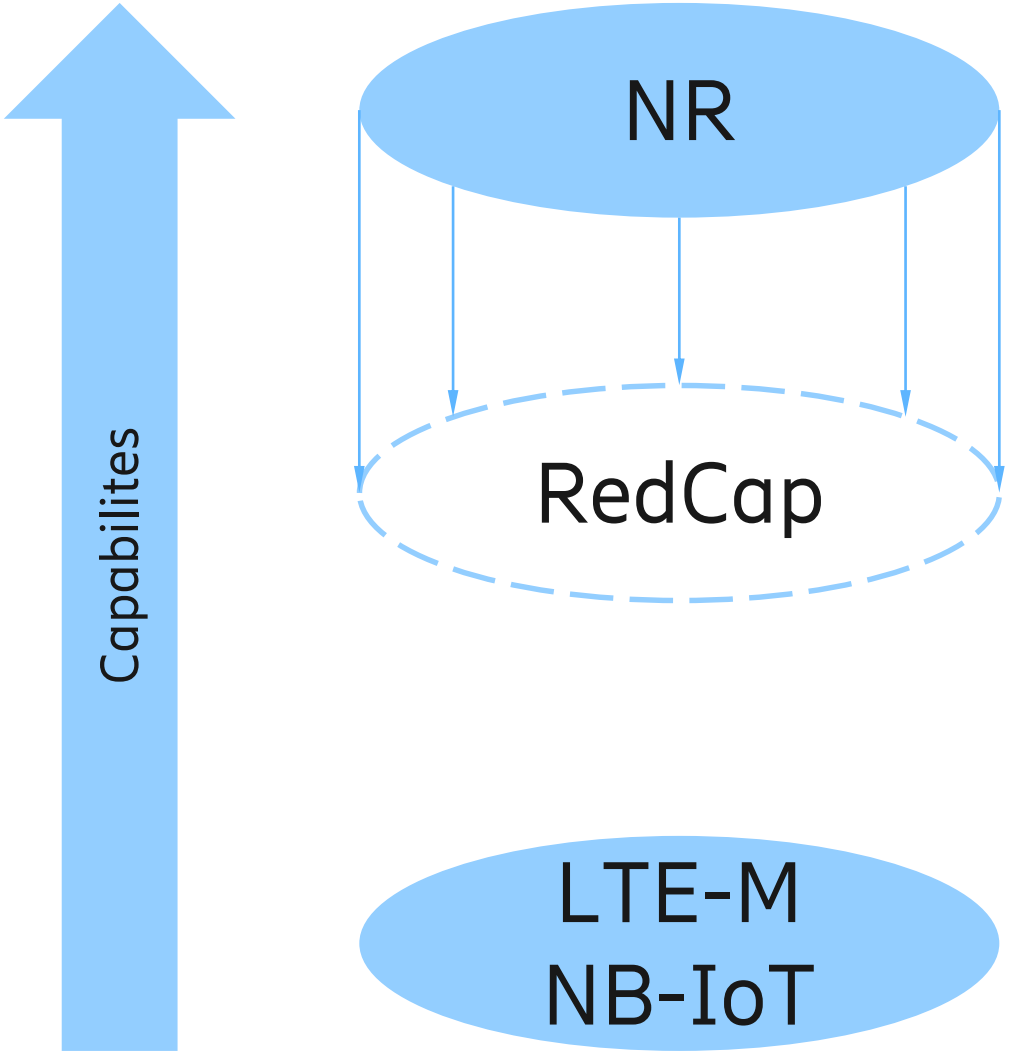
MIMO enhancements

Non-terrestrial access

Multicast/broadcast

...

RedCap

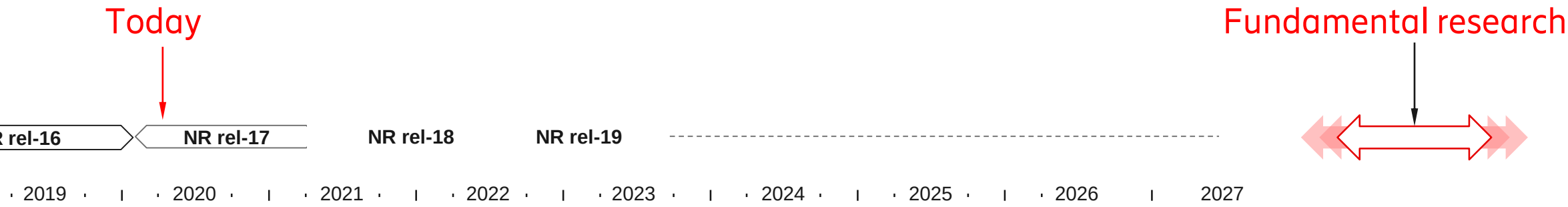


- MBB, URLLC, …
  - Very high data rates, very low latency, …
- Factory automation, wearables
  - Data rates ~10 Mbit/s
  - Bandwidth ~10 MHz
  - Lower cost than "regular" NR
  - Low power consumption, coin cell operation
  - …
- Massive MTC
  - Low data rates, low power consumption, …

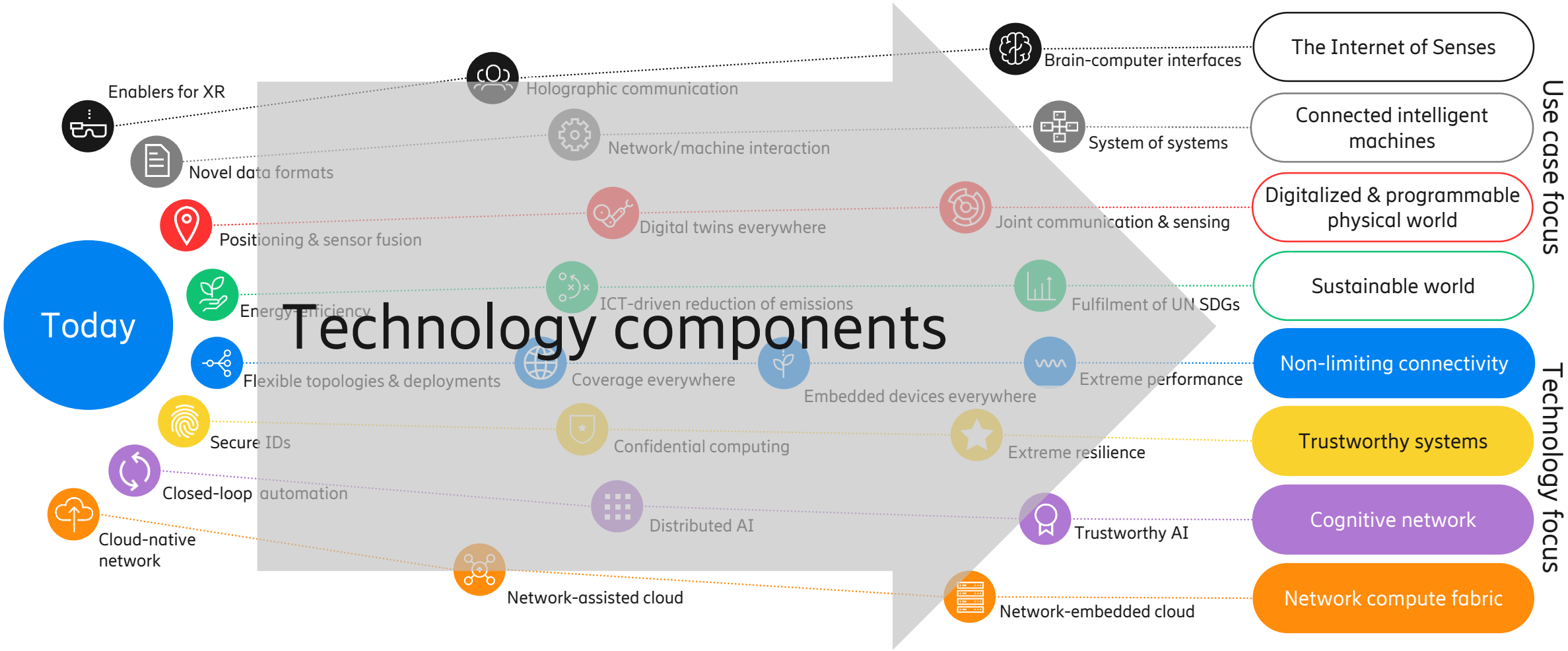
What about the longer time perspective?

Wireless access in the 2030 timeframe

— What are the needs?
— Use cases?
— Technolgoy components?



Technology journeys



Outline

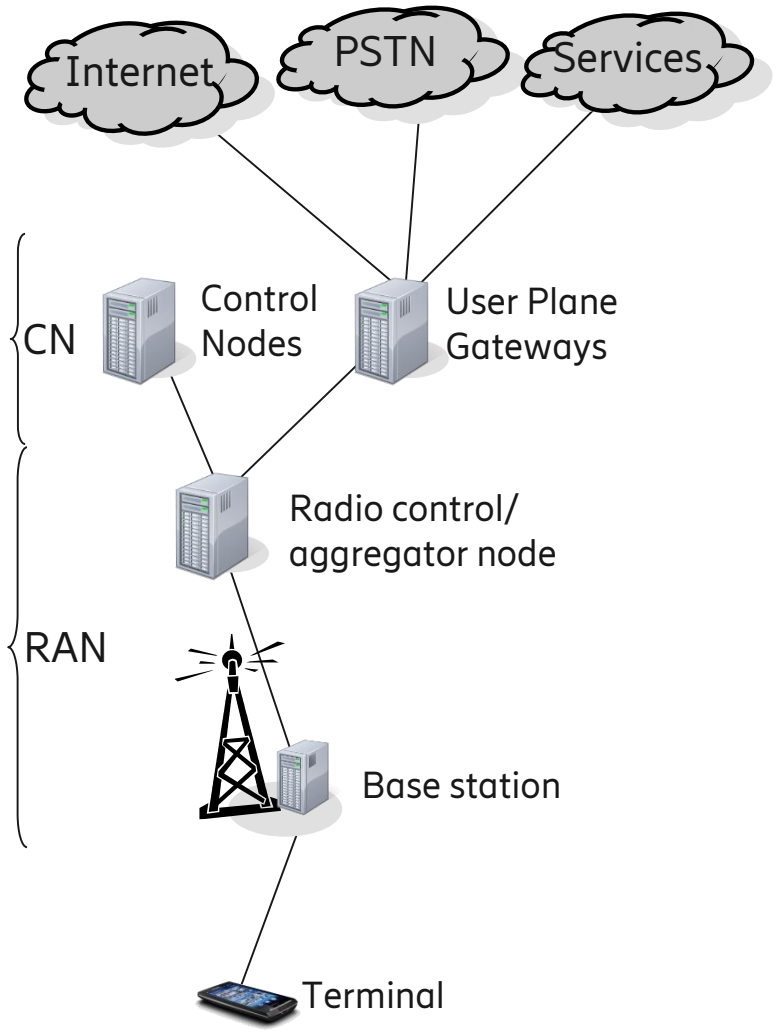
- Introduction
- LTE (4G)
- LTE evolution
- NR (5G)
- NR evolution and beyond
- Standardization in practice

Why?

- From Wikipedia
  - Standardization is the process of 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
  - The goals of standardization can be to help with independence of single suppliers (commodification), compatibility, interoperability, safety, repeatability, or quality.

- Interoperability – e.g. Samsung phone in 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
  - Terminals standardized according to "master-slave principle"

Not standardized – vendor differentiation

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

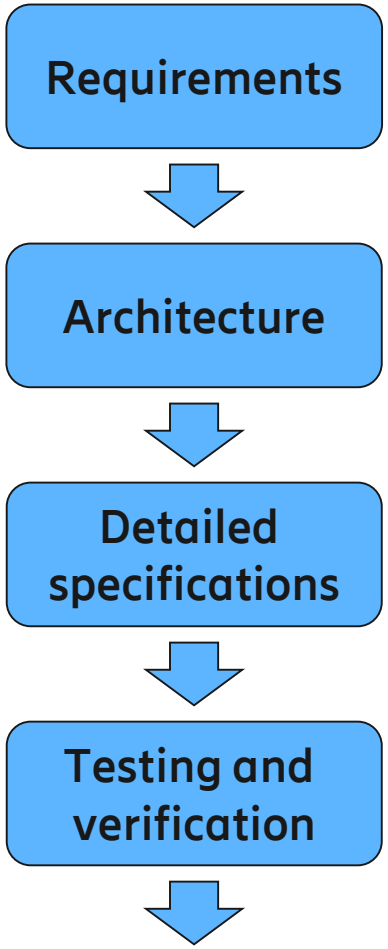
Where?

- 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, ...
  - mandatory technical parameters to be observed

- Reports

- Recommendations
  - Approves standards fulfilling the ITU requirements
    - Specifications developed outside ITU (e.g. in 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

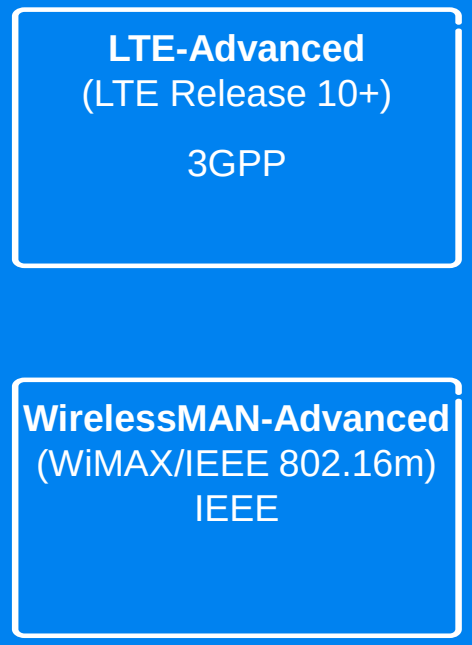
IMT-2000
TDMA Single-Carrier
(UWC 136)
ATIS/TIA

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-200 at a later stage

IMT-Advanced

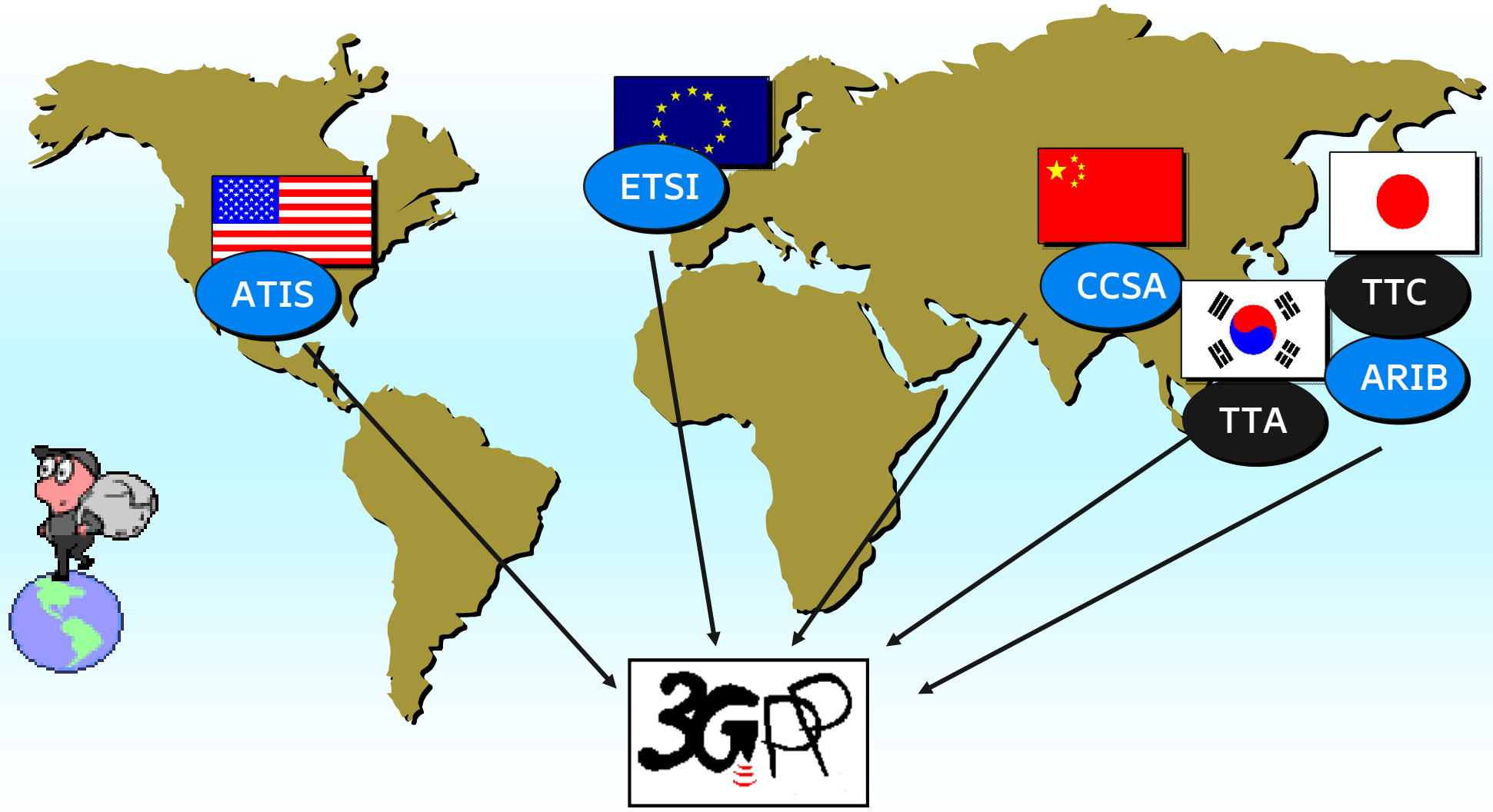


- IMT-Advanced – "4G"
- Family of 2 different technologies
  - LTE-Advanced (Rel-10 and onwards)
  - WiMax (802.16m)

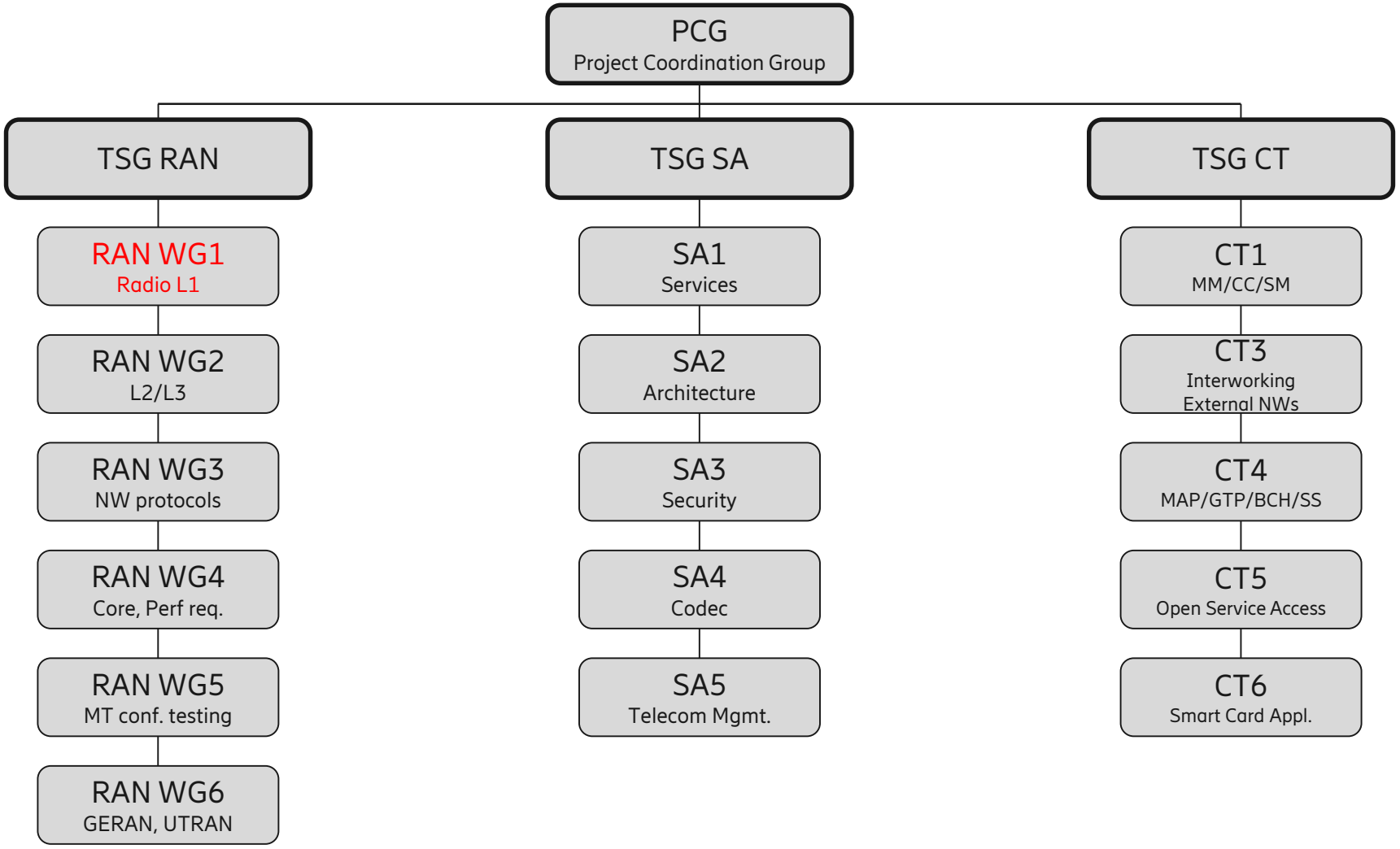
IMT-2020

- IMT-2020 – "5G"
- Work ongoing on IMT-2020
  - Similar process as for IMT-Advanced
- WRC-15
  - Frequency allocations up to 6 GHz
- WRC-19
  - Higher frequencies

3GPP organizational partners



3GPP organization



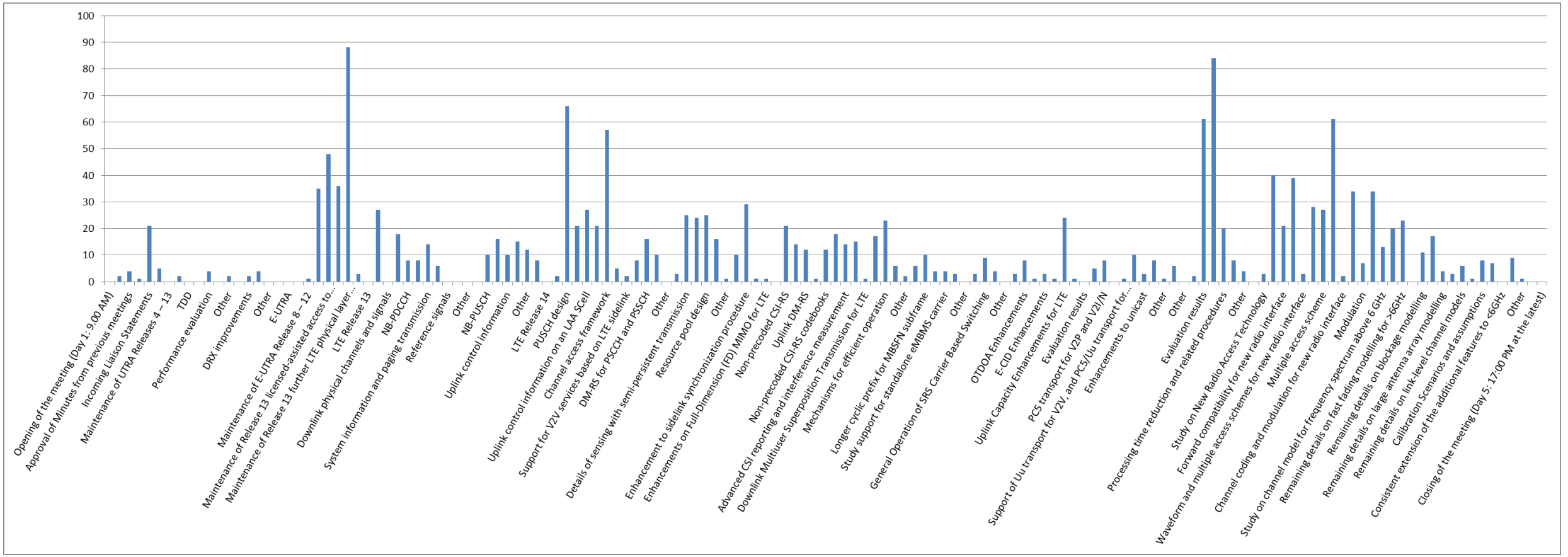
Standardization – a flying circus?

- 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...



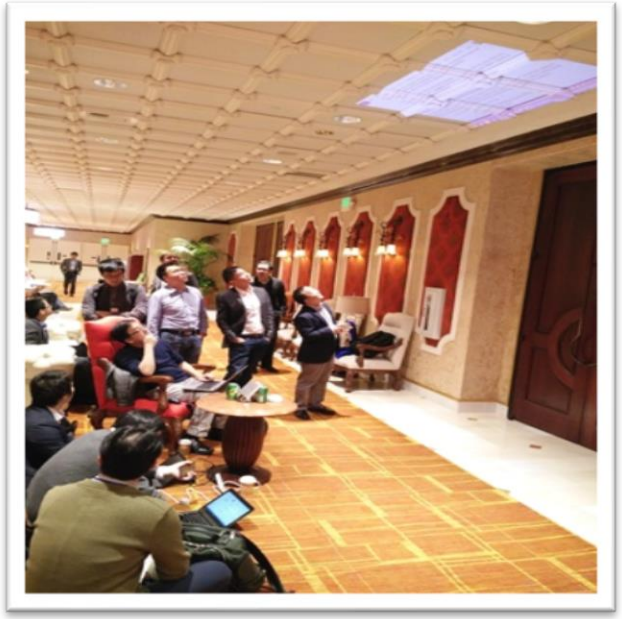
Nice to work with standardization…

Cheju, Korea

…well maybe not always!

Cheju, Korea

Intense discussions…



Standardization in practice

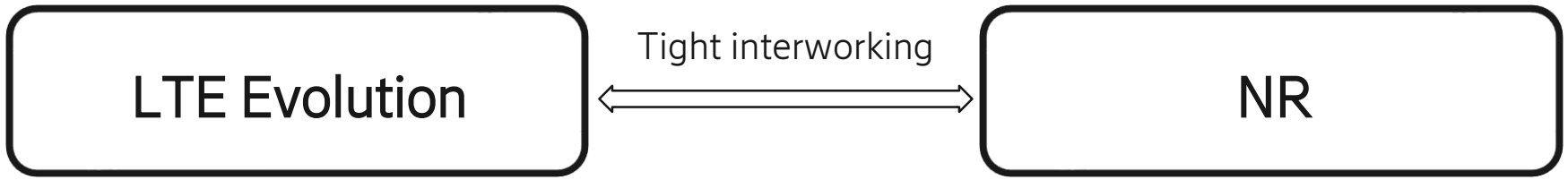
- Contribution driven
- Decision by consensus
  - Coffee-breaks important part of meetings (off-line)
- Good relations important
  - Social relations across cultural borders
  - Mutual respect and co-operation
- One week meetings ➡ Long meeting days

Summary

Summary – LTE and NR

— LTE – the global 4G standard for mobile broadband

— NR – new 5G radio access



Summary – standardization

- Interfaces and protocols standardized
  - Implementation is not

- 3GPP
  - Standardization of radio-access and core network for the major mobile technologies

- ITU
  - Radio regulations, spectrum allocations

For further information…

Open the 3GPP specifications…

…or read The Books!

Available in English, Chinese, Korean and Japanese.