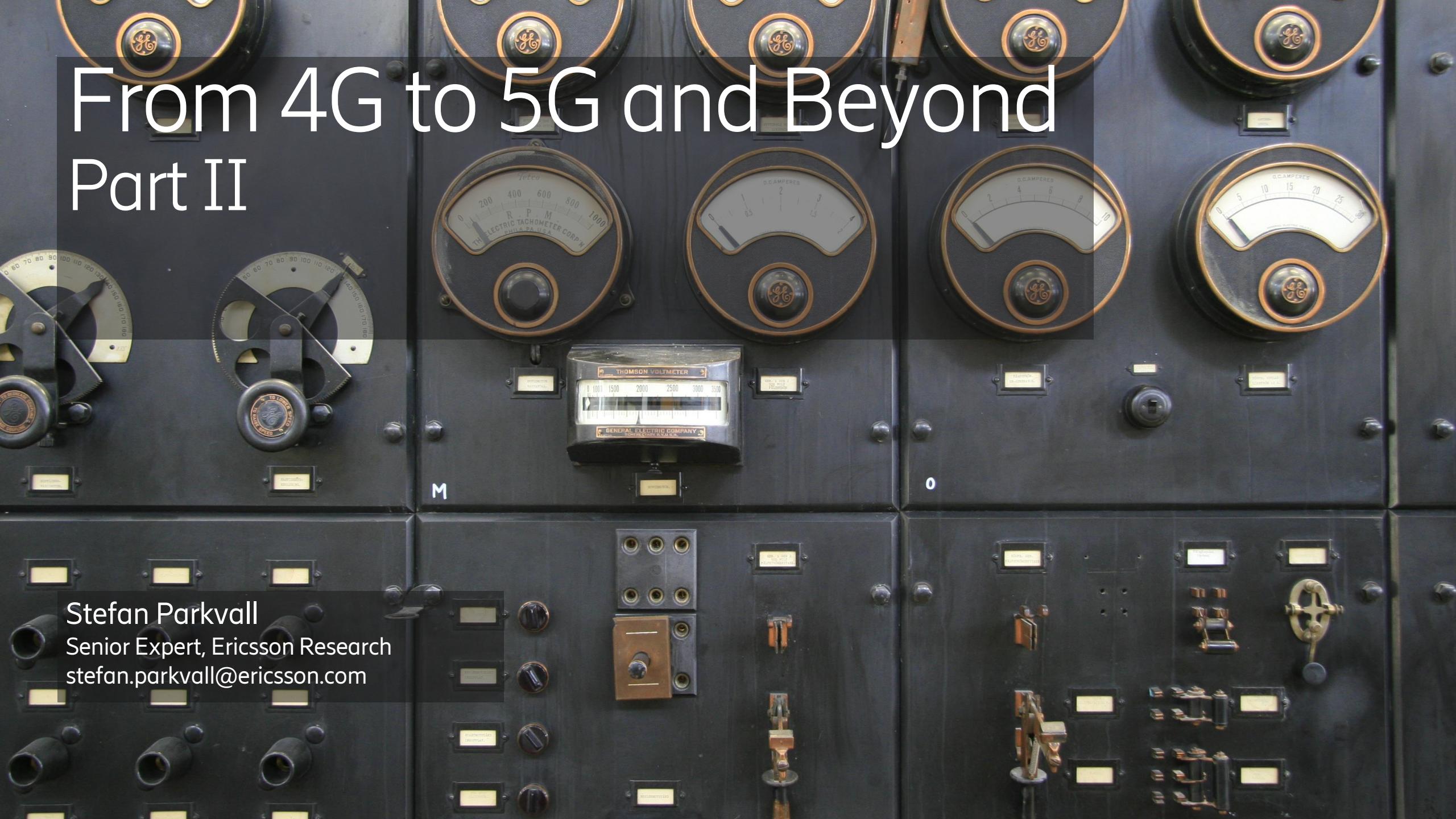


# From 4G to 5G and Beyond

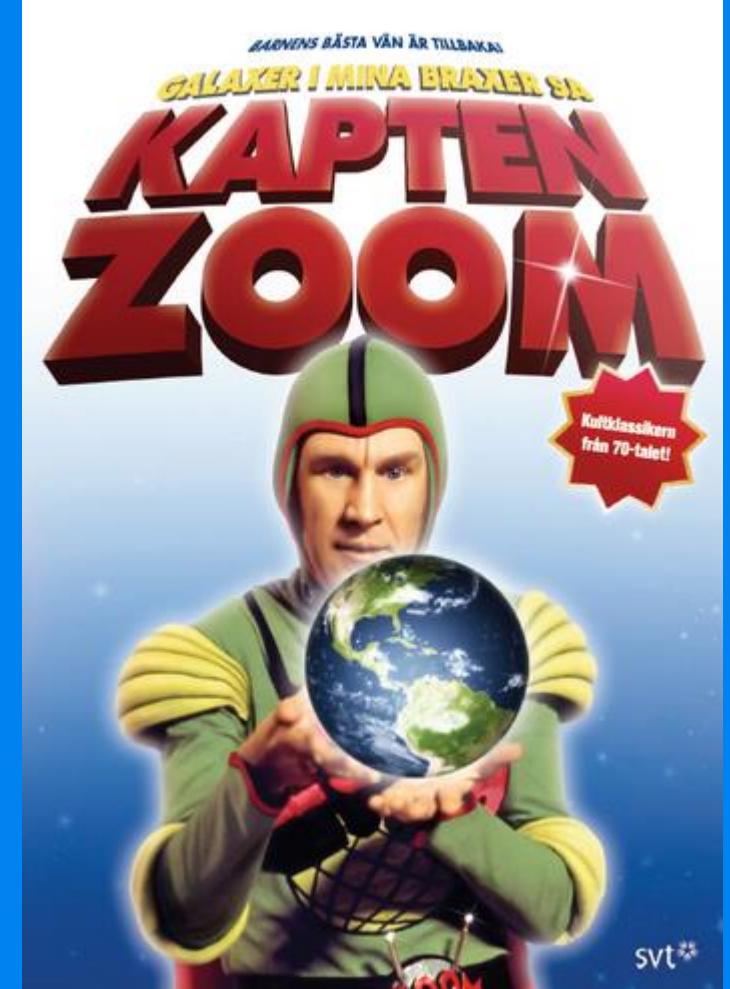
## Part II

Stefan Parkvall  
Senior Expert, Ericsson Research  
[stefan.parkvall@ericsson.com](mailto:stefan.parkvall@ericsson.com)



# Outline

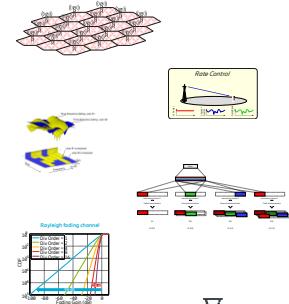
- Introduction
- LTE (4G)
- LTE evolution
- NR (5G)
- NR evolution and beyond
- Standardization in practice



# Recap from first session

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

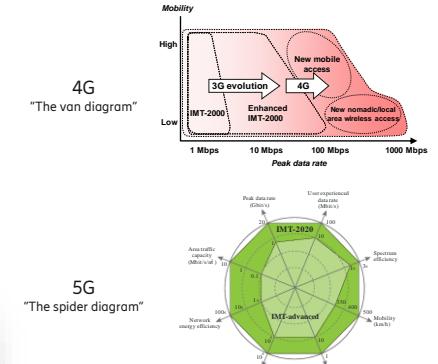
How do we get it?



Public | © Ericsson AB 2018 | 2018-05-02

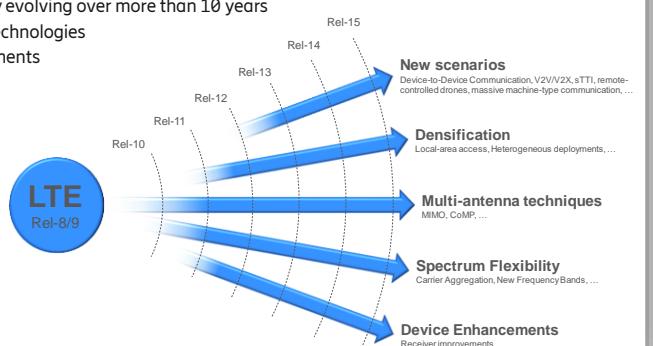
What do we require from a wireless system?

- Coverage
- Mobility
- High data rates
- High capacity
- Low latency
- High connection density
- High reliability



Extensions please!

- LTE has been continuously evolving over more than 10 years
- To incorporate new technologies
- To meet new requirements



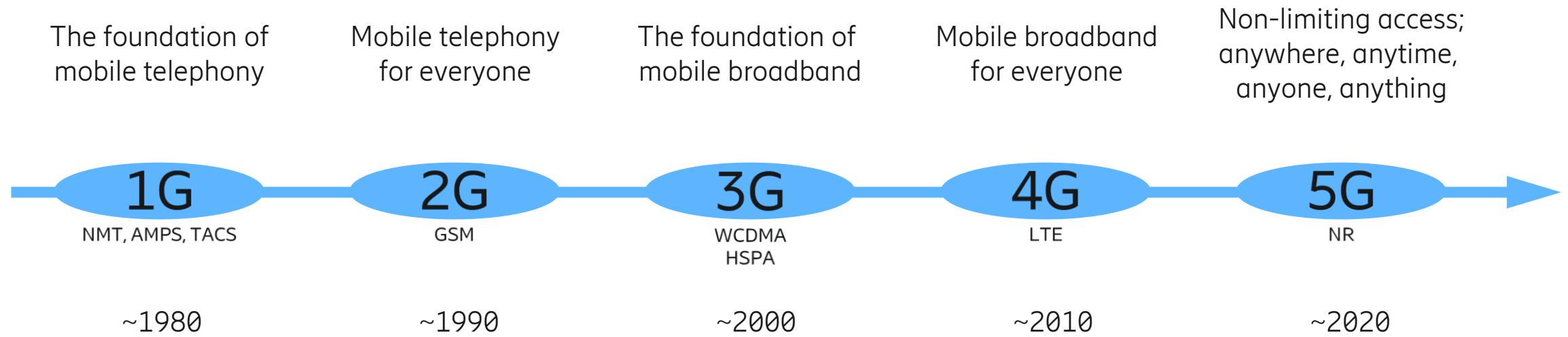


# Outline

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



# So...what's next?

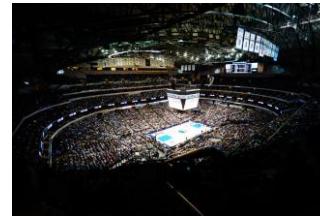


# 5G vision



Non-limiting access to information and sharing of data ...

... anywhere and anytime ...



... for anyone and anything



# 5G – going *beyond* the smartphone



**Complex metalworks not possible to monitor today**

Ericsson has together with the Fraunhofer IPT research center optimized the production of BLaded dISks, BLISKs, through 5G technology

- A BLISK is used in turbines such as jet engines. It consists of a rotor disk and multiple blades around it
- BLISKs are one of the most difficult machining parts to produce, and the rework rates are very high (~25%)
- A key aspect of BLISK production (and metal processing in general) is that the process is not monitored – if data can be collected during manufacturing and used to finetune the process, rework rates can be significantly reduced

Understanding 5G Industry Business Value - 1020k, Premarket | Ericsson Internal | © Ericsson AB 2017 | Open, Rev A | 2018-05-02

**5G NETMOBIL**

- Develop overall communication infrastructure for tactile connected driving beyond the self-contained sensor based autonomous driving
  - improved road traffic safety, less environmental impact, and higher efficiency of road transportation
- Provide 5G communication technologies and network architecture for tactile connected driving
  - Low latency required by real-time vehicle control and cooperative maneuvers
  - High reliability and availability for highly mobile environments
- Use cases:
  - Parallel cooperative driving of a fleet of farm machinery in off-road areas
  - Tactile connected driving of vehicles at intersections of urban roads
  - High-density platooning of trucks in automotive test field

Industry Collaborators | Ericsson Confidential | © Ericsson AB 2017 | Open, Rev A | 2018-05-02

**PIMM**

Pilot for Industrial Mobile Communication in Mining

- Explore future 5G Use Cases in underground mining
- Evaluate mobile communication infrastructure in an industrial context

Increased Productivity and Improved Safety

- Industrial 5G requirements
- Understand eco system, business models, etc.

TeliaSonera VOLVO ERICSSON SICS LKAB

Industry Collaborators | Ericsson Confidential | © Ericsson AB 2017 | Open, Rev A | 2018-05-02

**5GEM**

5G Enabled World Class Manufacturing

- Evaluate 5G technology in a manufacturing industry
- Understand ICT opportunities and solutions

Data analytics, Industrial Internet-of-Things, Factory wireless communication, Mission critical cloud

- Improved production efficiency
- Increased flexibility
- Excellent traceability
- Social and environmental sustainability

Partners: SKF CHALMERS ERICSSON

Photo: SKF

**CMA**

Test Site for Future Automated and Shared Mobility Systems

Exploring the use of 5G networks for intelligent transport systems

- Investigating "as-a-service" offerings for network operators and automotive OEMs

Reduced vehicle fleet operations cost, better service awareness and reduced travel time for passengers

Usage of cellular networks in new markets

ERICSSON

**REMOTE OPERATION**

Robot remote control with haptic feedback over LTE

Robot remote control with haptic feedback over LTE

Industrial mobile communication in industrial reliability

Autonomous Transport Systems

ERICSSON

**WITOOL**

Wireless Internet of Tools

- Enable IoT for construction equipment OEM (Husqvarna) and rental companies (Cramo)
- Capillary network connectivity, cloud, service enablement and machine analytics capabilities
- Demonstrated through automation of return process of machines at Cramo depot

Efficient fleet management enabled by predictive maintenance and resource planning

- Automated processes, for example return process
- New business models
- Making use of generated data to improve products

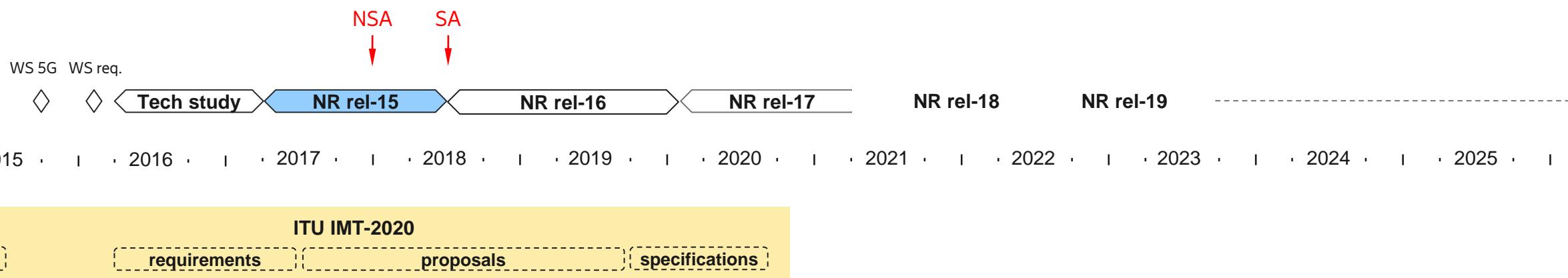
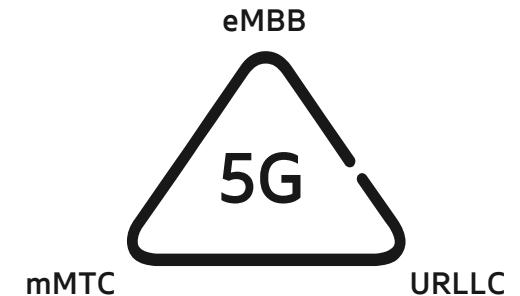
Partners: CRAMO Husqvarna ERICSSON

Commercial in confidence | © Ericsson AB 2017 | 1 March 2017

# 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



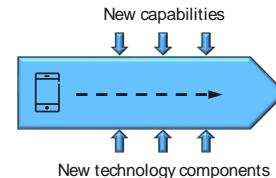
# NR characteristics – some examples



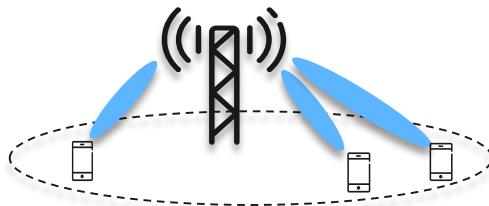
Ultra-lean design



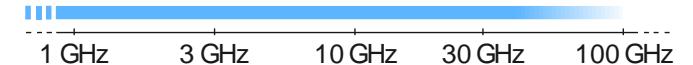
Forward compatibility



Multi-antenna support



Wide spectrum range

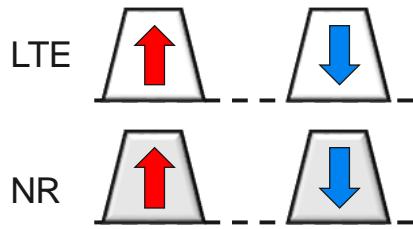


Low latency

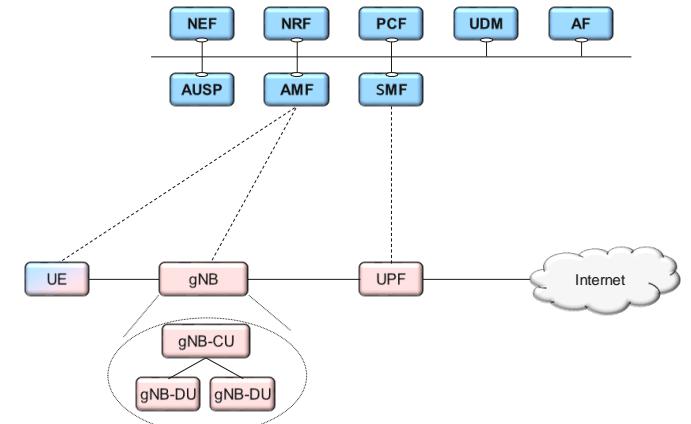


# NR characteristics – some examples

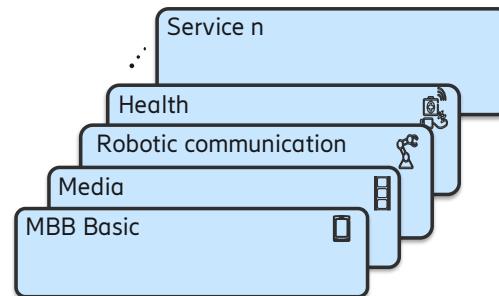
## LTE – NR coexistence



## Modular architecture DU/CU split, CP/UP split

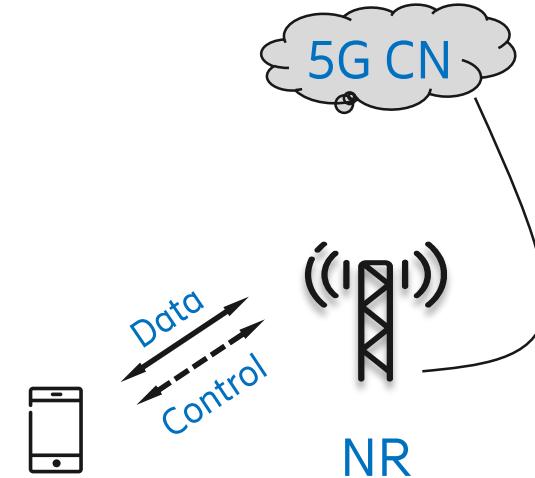
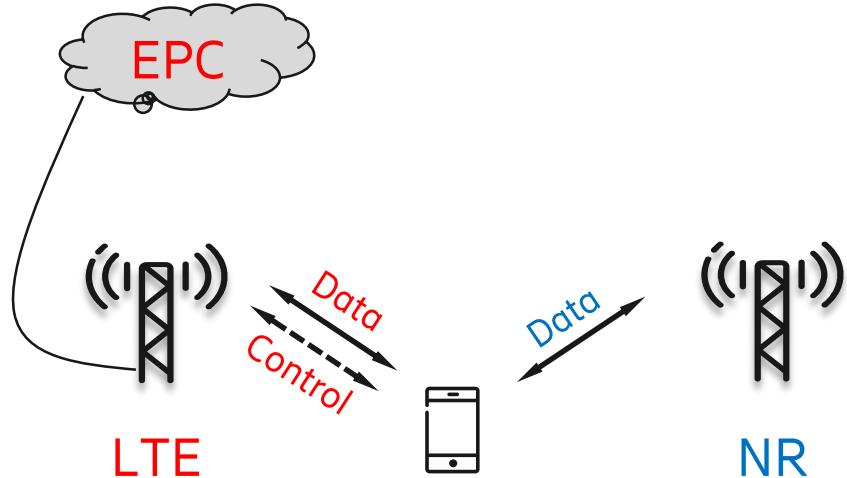


## Network slicing



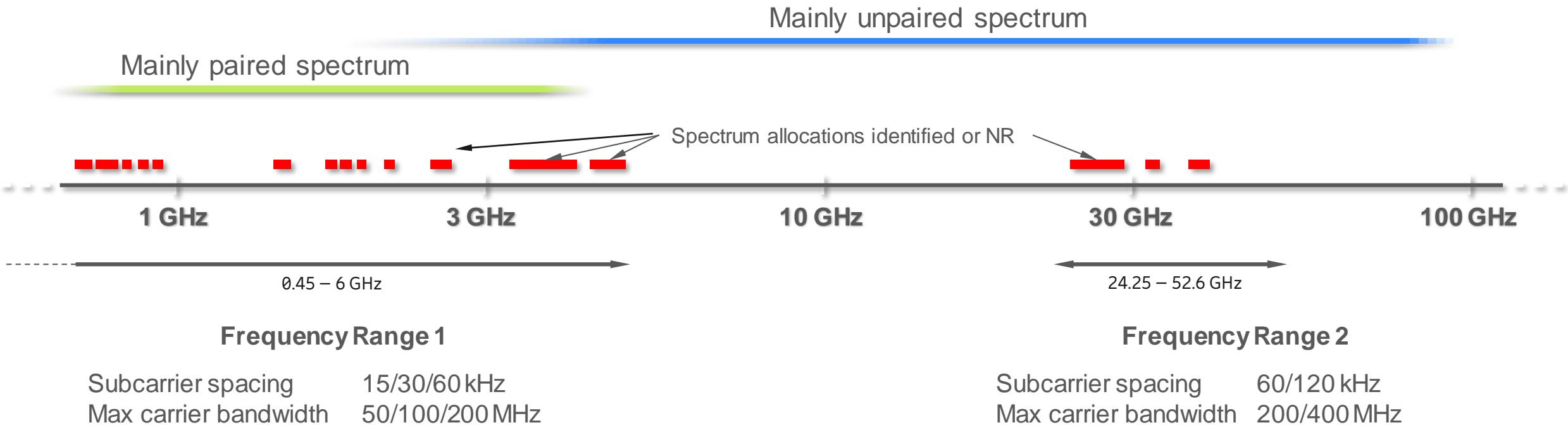
# Architectural options

- Non-standalone NR (December 2017)
  - LTE handles 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





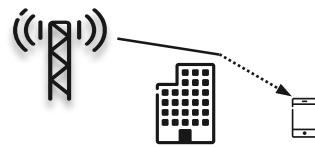
# 5G spectrum



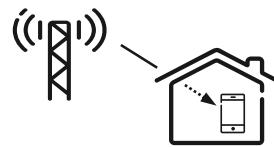
# mm-wave challenges

## Propagation

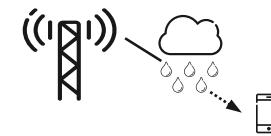
Diffraction



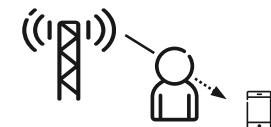
Outdoor-to-indoor penetration



Rain/atmospheric attenuation



Body loss



(Less of an issue for small cells)

## Regulation



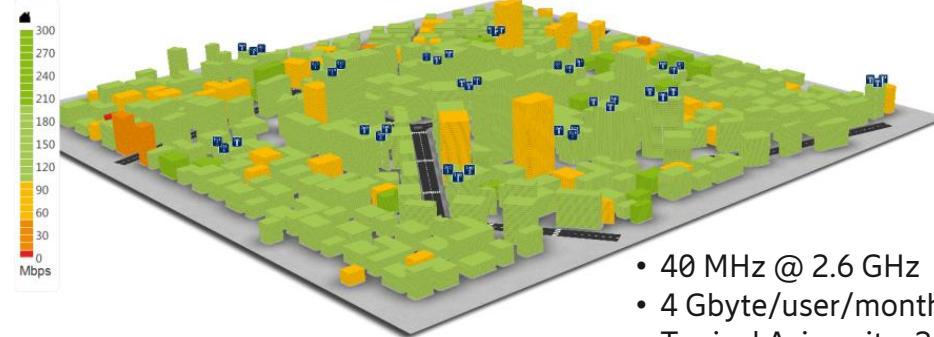
Additional Tx power  
limitations above 6 GHz

## Implementation

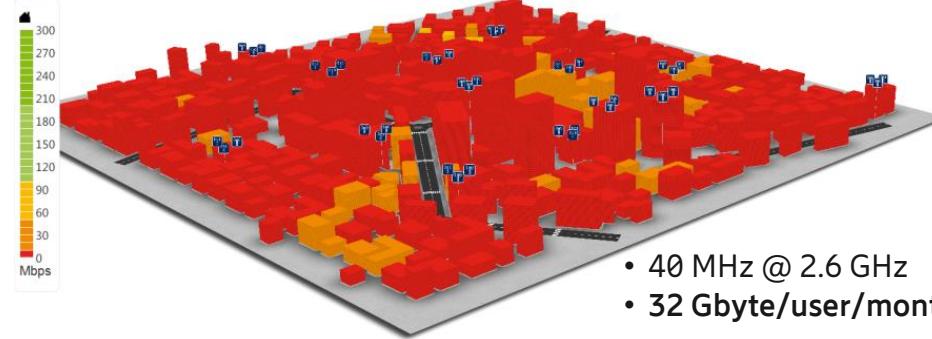


Efficiency, dynamic range,  
output power, ...

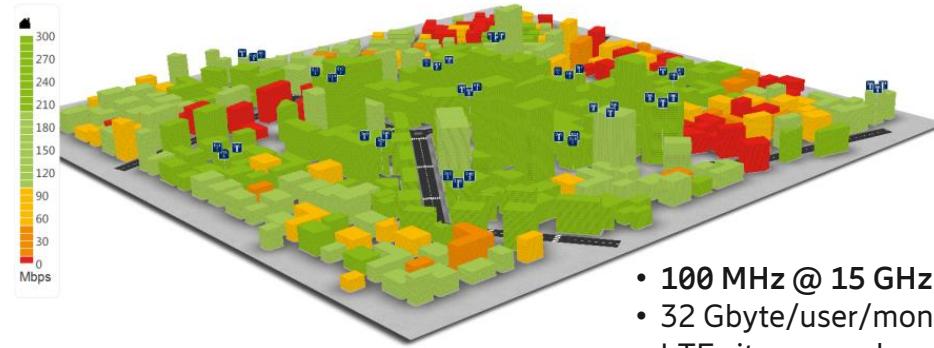
# High-frequency operation



- 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

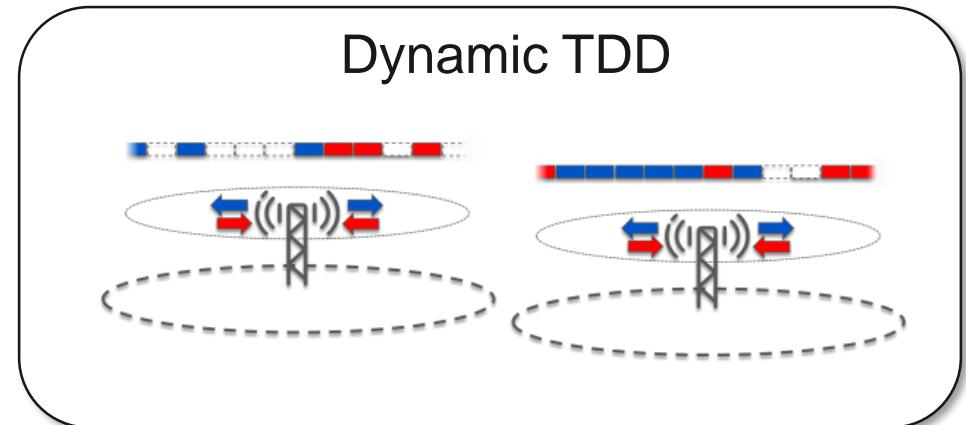


- 40 MHz @ 2.6 GHz + 100 MHz @ 15 GHz
- 32 Gbyte/user/month
- LTE sites reused

- 6 — Higher-frequency spectrum needed to satisfy future traffic demands  
— Joint low-frequency/high-frequency operation needed for full-area coverage

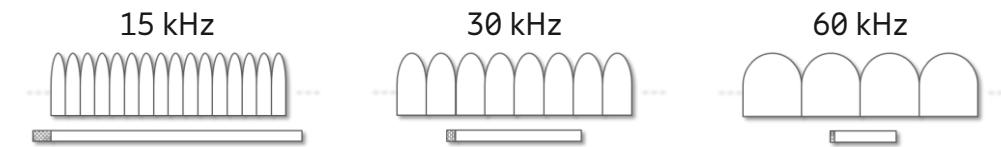
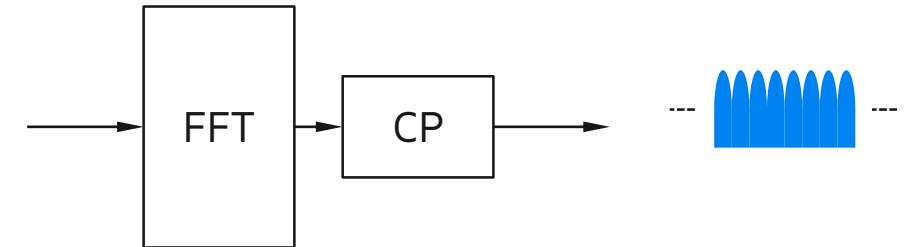
# Dynamic TDD

- 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



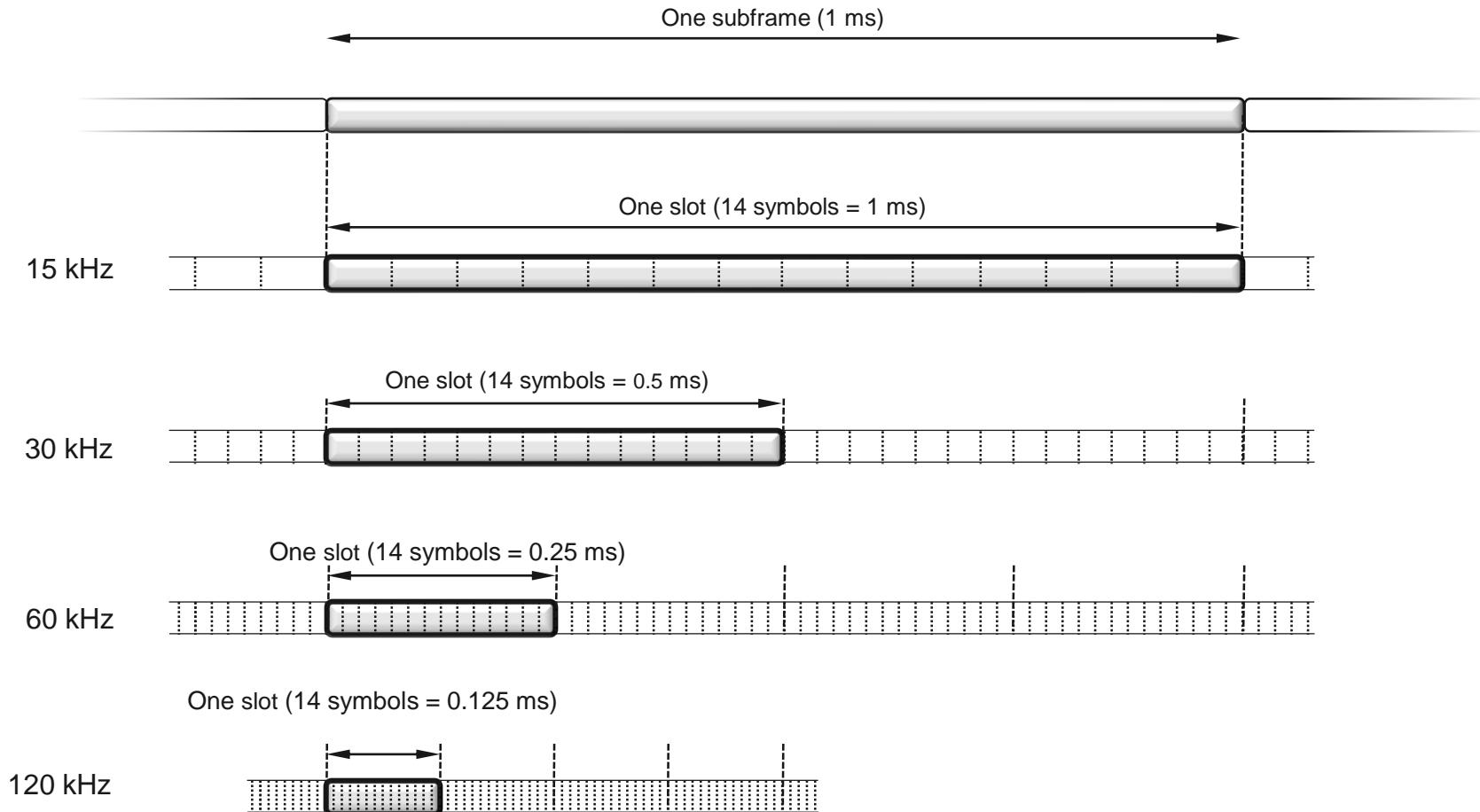
# Basic waveform

- Conventional OFDM (DL and UL)
  - Uplink: possibility for DFT precoding for higher device PA efficiency
- Scalable numerology,  $\Delta f = 2^{\mu} \cdot 15 \text{ kHz}$ 
  - 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

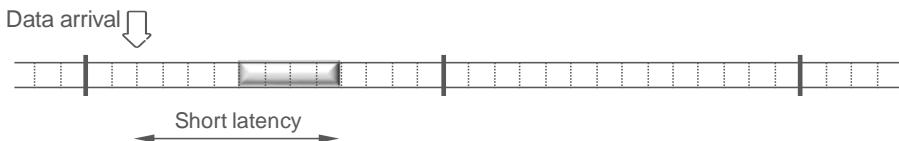
# Frame structure



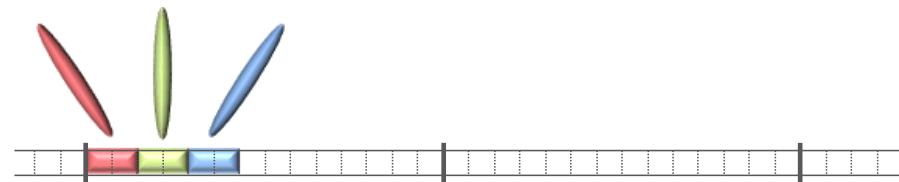
# Frame structure

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

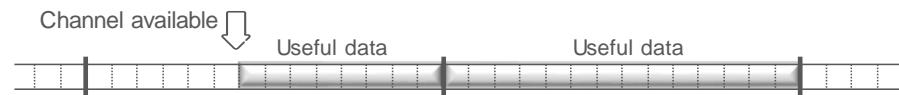
**Not restricted to slot boundaries** 5G



*Low latency*



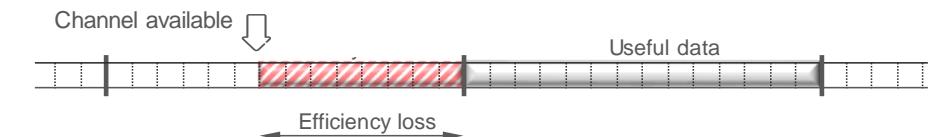
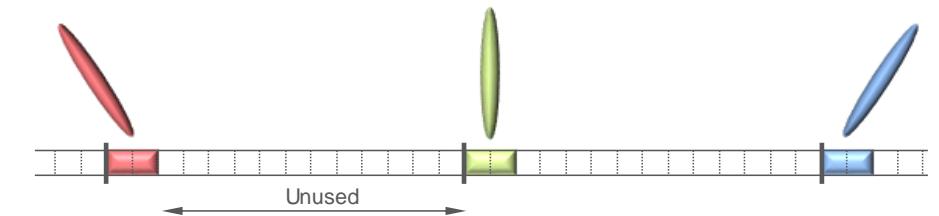
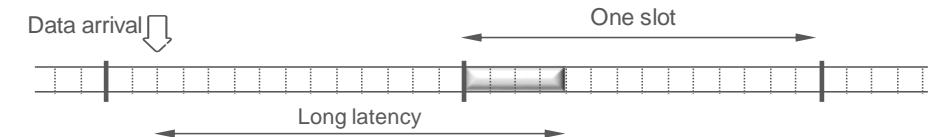
*Beam sweeping*



*Unlicensed spectrum*

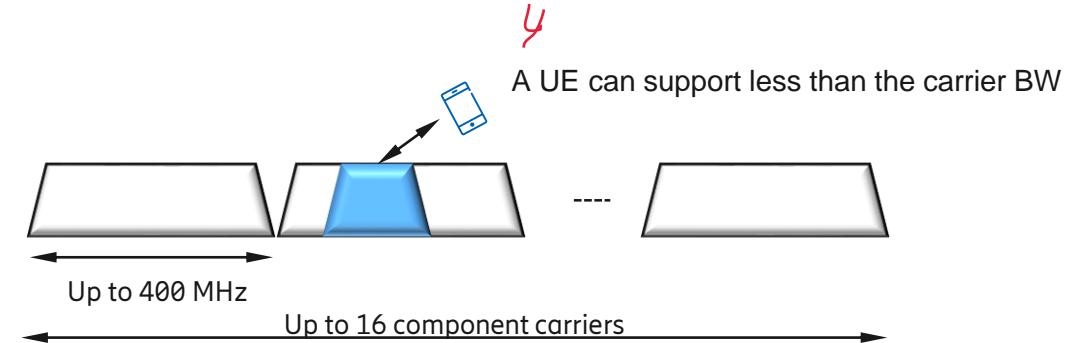


**Restricted** to slot boundaries

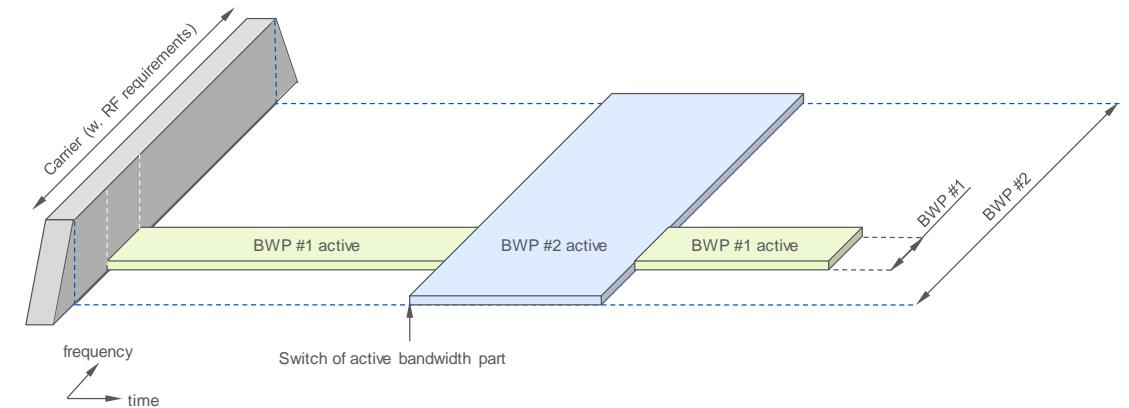


# Bandwidths and bandwidth parts

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

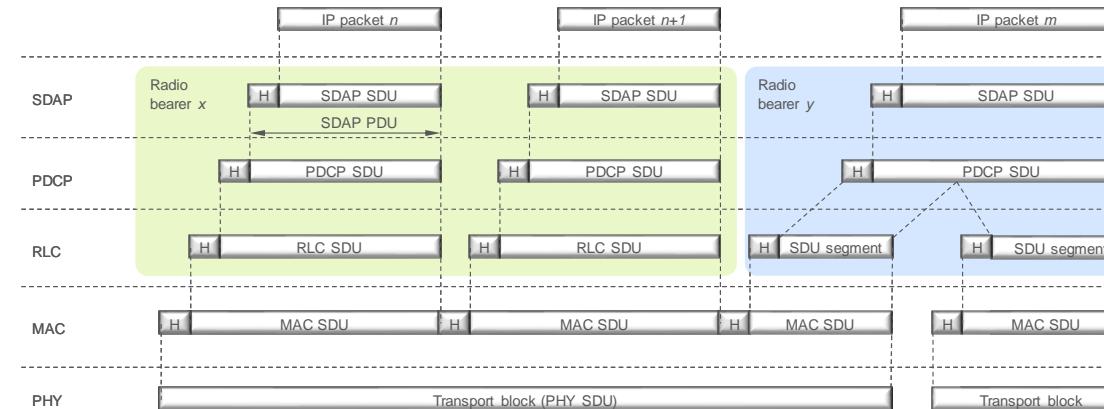
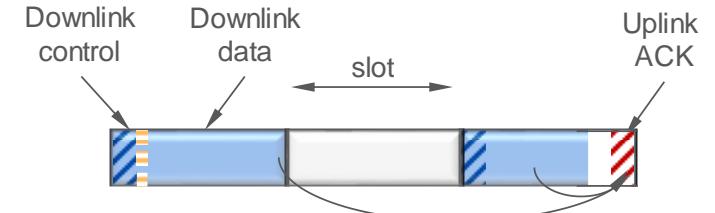


- Bandwidth parts (4 configured, 1 active)
  - UEs not capable of full carrier bandwidth
  - Bandwidth adaptation
- 



# 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

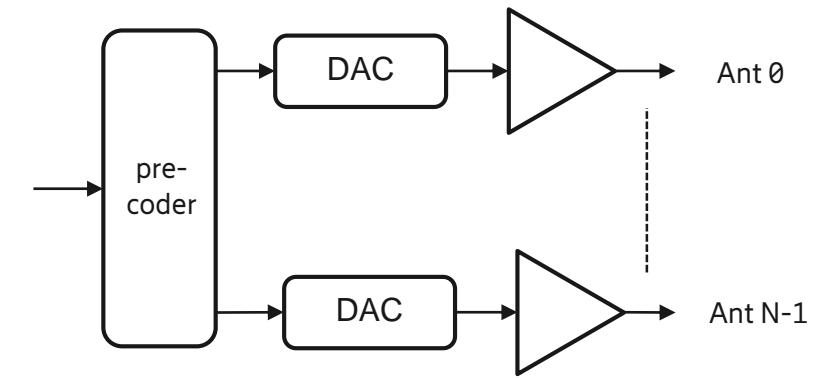
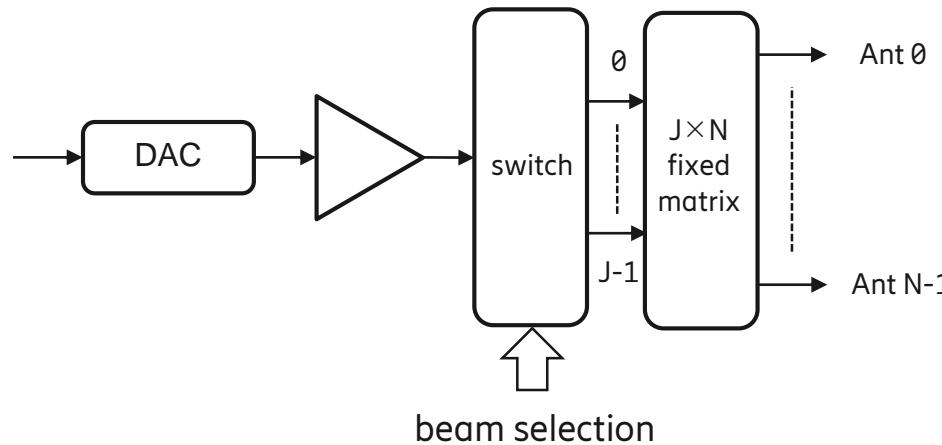
Capacity, spectral efficiency and extended range

Beam-forming for enhanced coverage



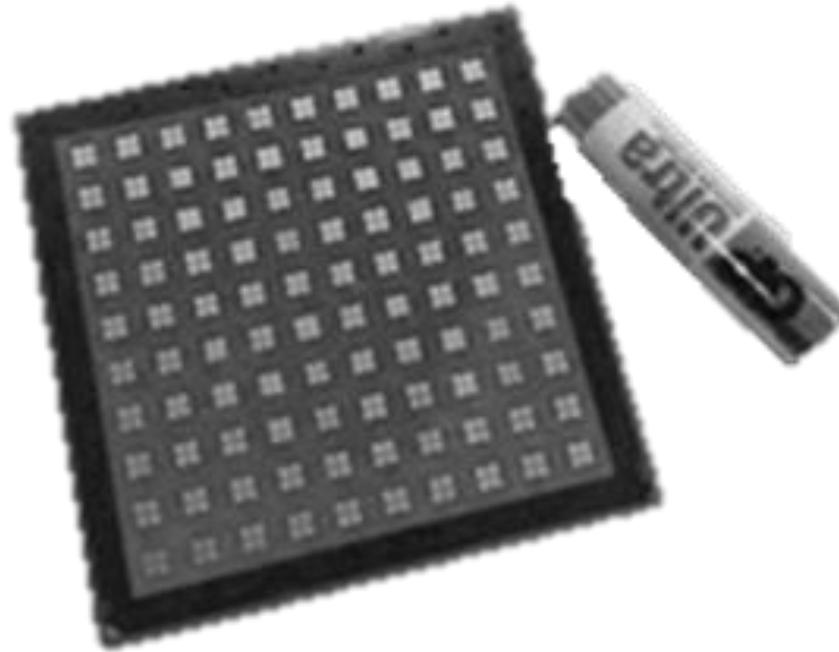
# Analog vs Digital Beamforming

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



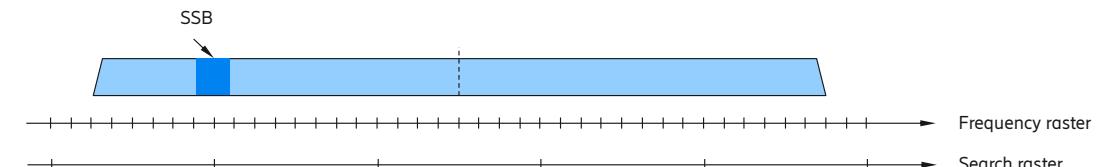
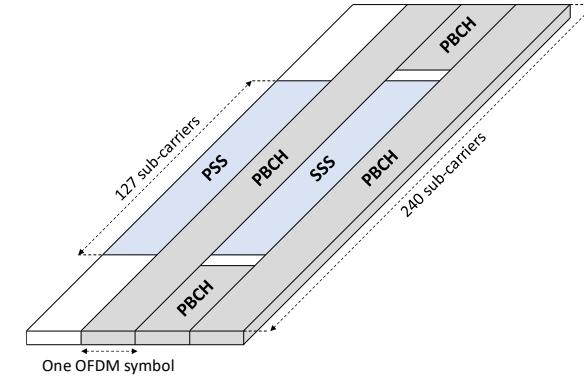
*Both schemes (and hybrids) supported by NR*

# 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

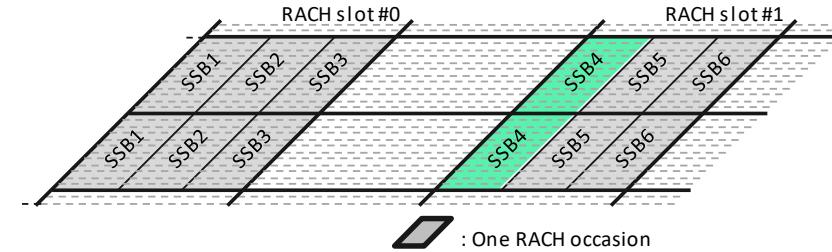
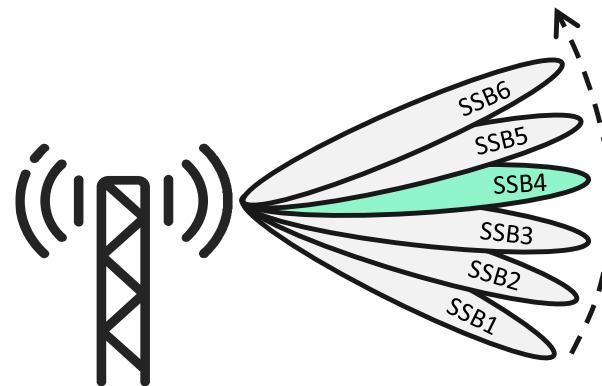


# Initial access

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

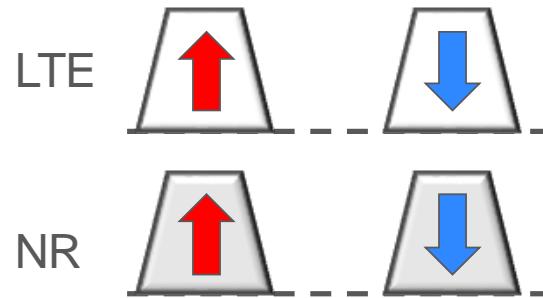
Frequency	Beams
– 3 GHz	4
3 – 6 GHz	8
mm-wave	64

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

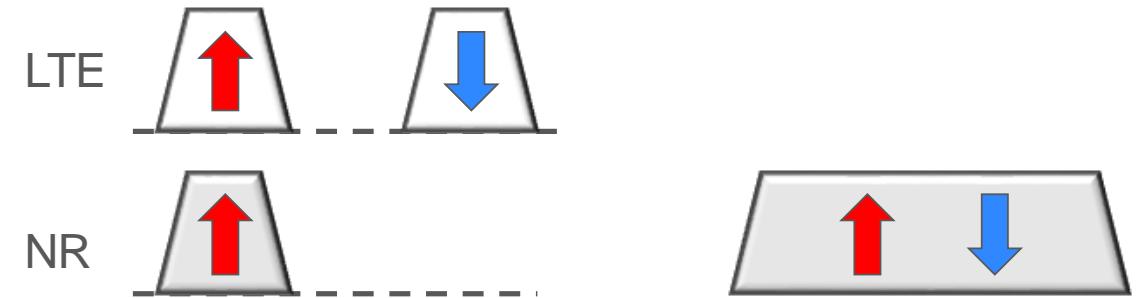


# NR-LTE coexistence

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



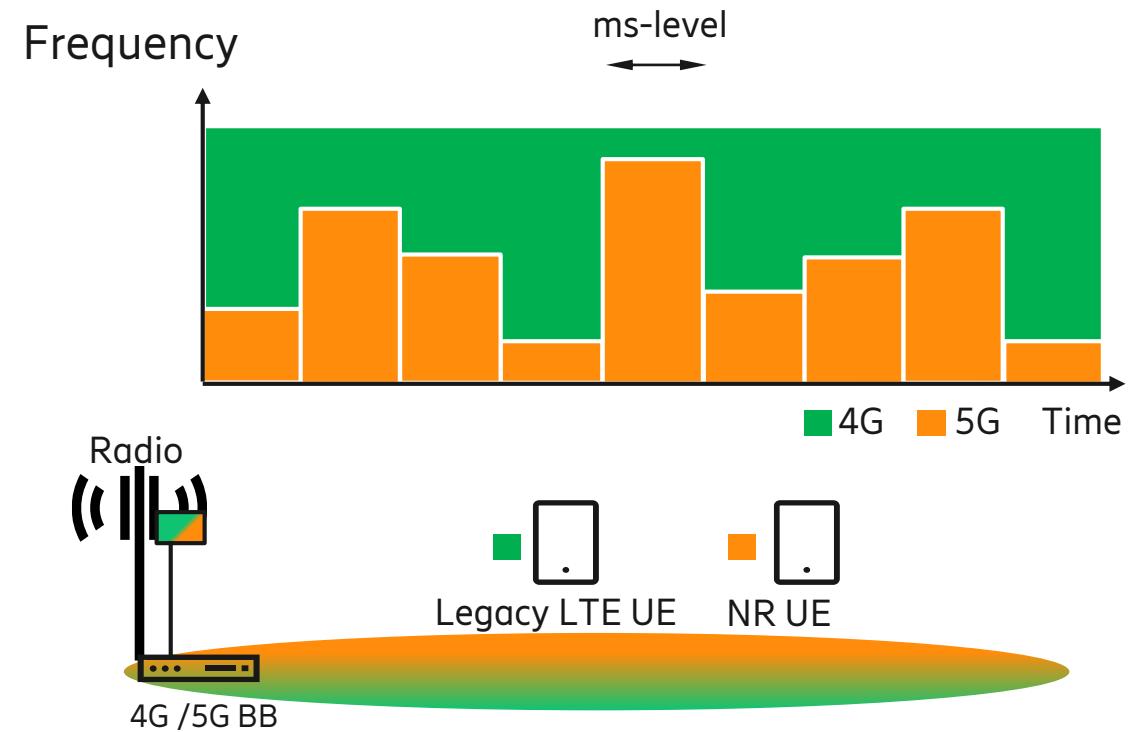
Downlink and uplink co-existence



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

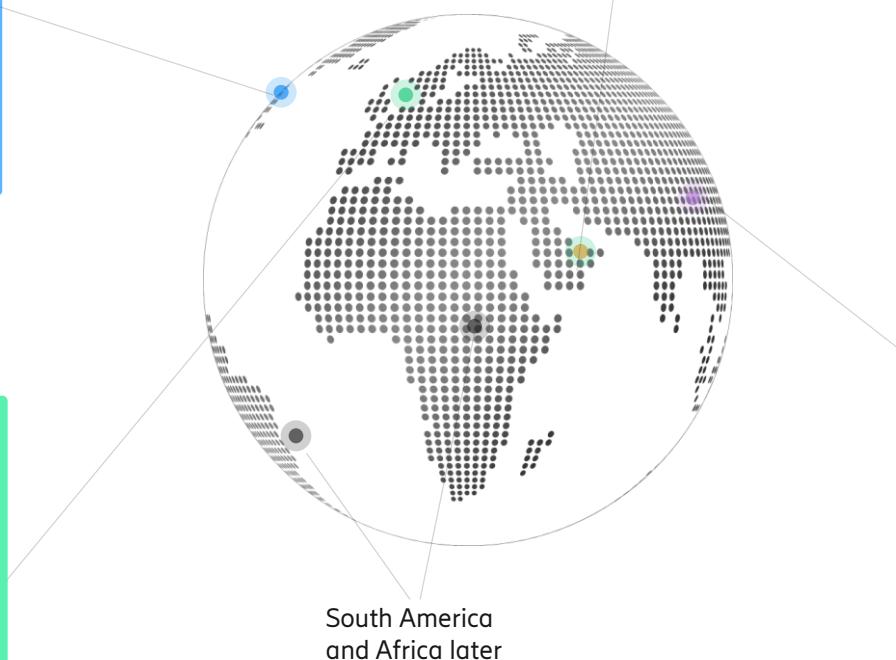
- 2018 launches on mid-band, with mmWave as second wave
- Mobile broadband and FWA

## 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

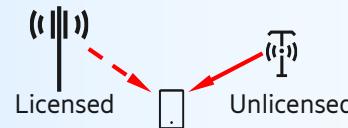
# Beyond Rel-15

- 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”

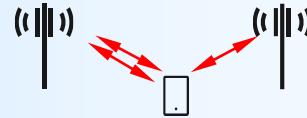


# Some topics in NR Rel-16

## Unlicensed spectrum *LAA and stand-alone*



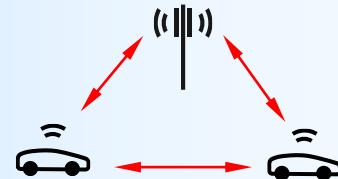
## CA/DC enhancements *Faster SCell activation, signaling enhancements, ...*



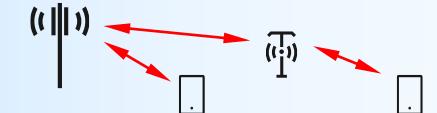
## Remote Interference Management *TDD, atmospheric ducts, ~300 km*



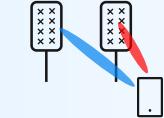
## V2X *Sidelink, Uu enhancements, QoS, ...*



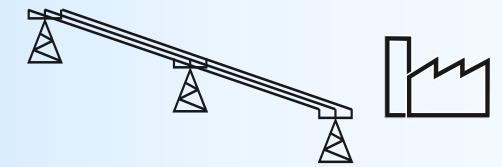
## Integrated Access Backhaul *NR for backhauling*



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



## URLLC enhancements *PDCCCH enhancements, ...*



## Positioning *Combination of techniques*



# NR in unlicensed spectrum

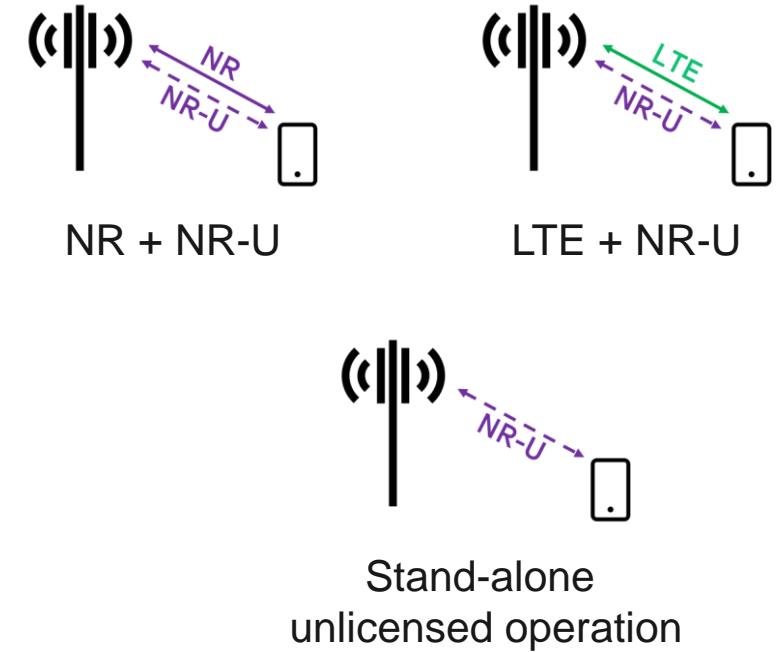
**Frequency bands: 5 GHz and 6 GHz**

## 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



# Integrated access-backhaul

## NR for wireless backhaul

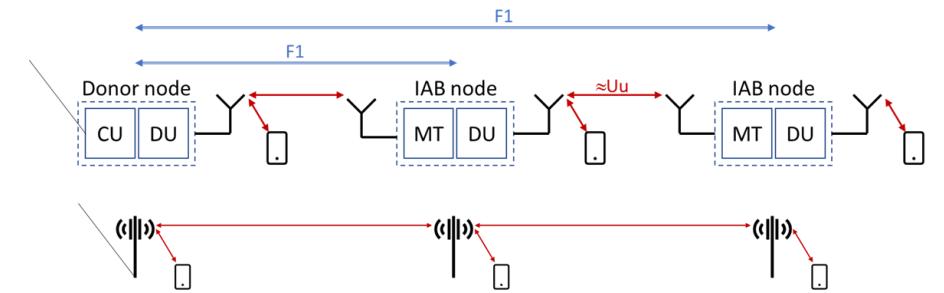
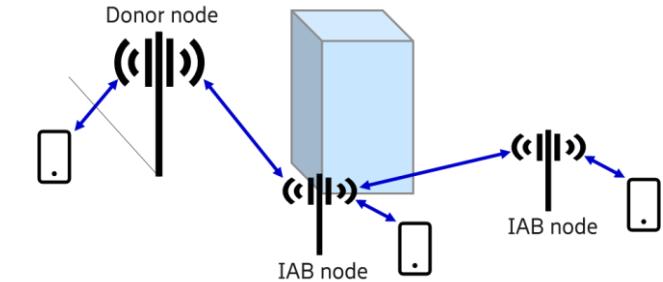
- When wired backhaul not available
- For rapid deployment
- Small cells

## 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

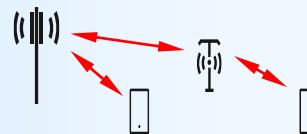
## 52.6 - 71 GHz

*Extending frequency range*



## IAB enhancements

*Partially moving relays*



## MIMO enhancements

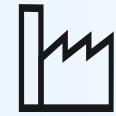


## Multicast/broadcast



## RedCap

*Reduced capability NR for IoT*



## Drone enhancements

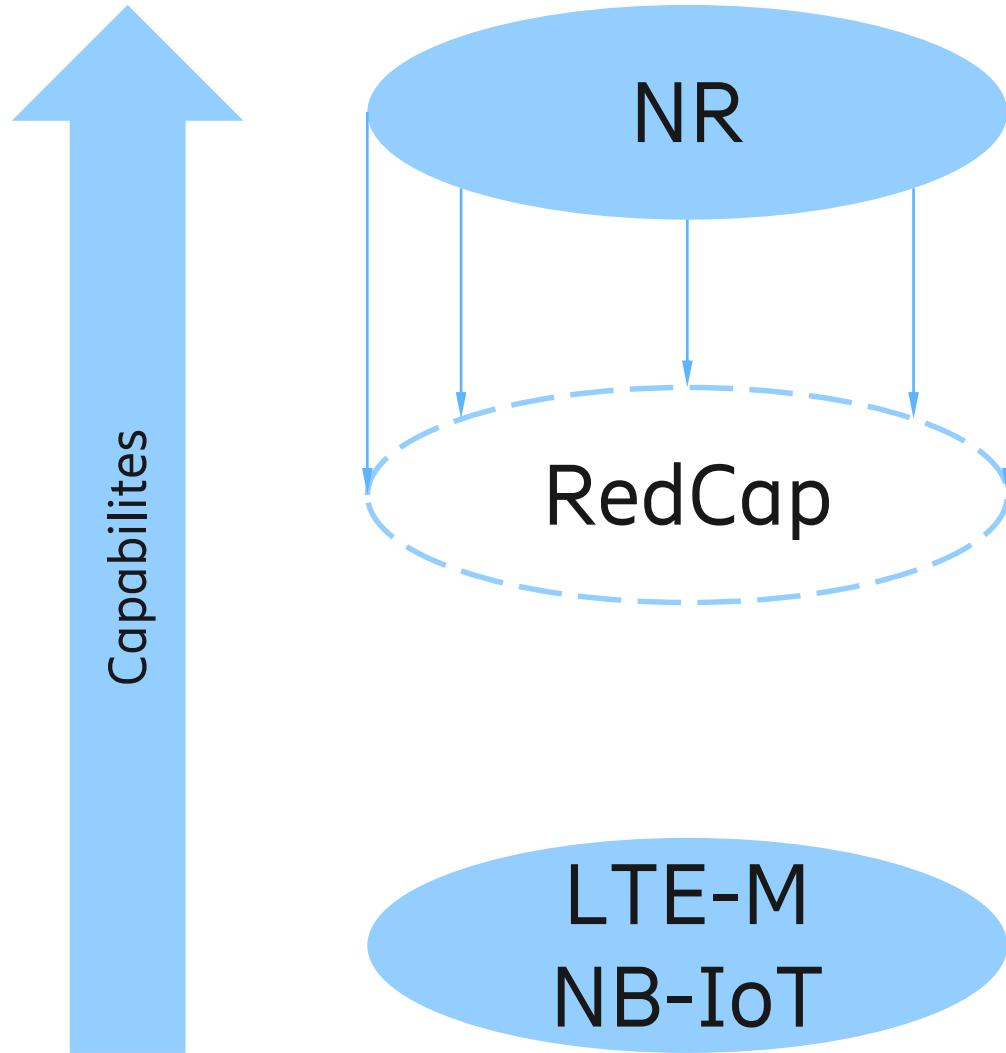


## Non-terrestrial access



...

# 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, ...

≡

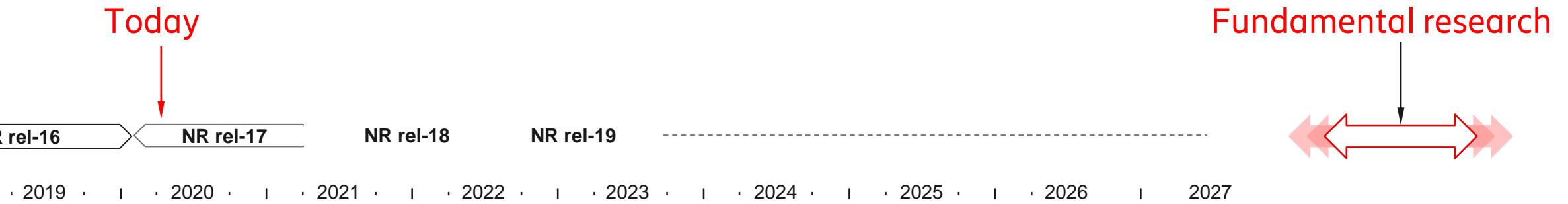
# What about the longer time perspective?



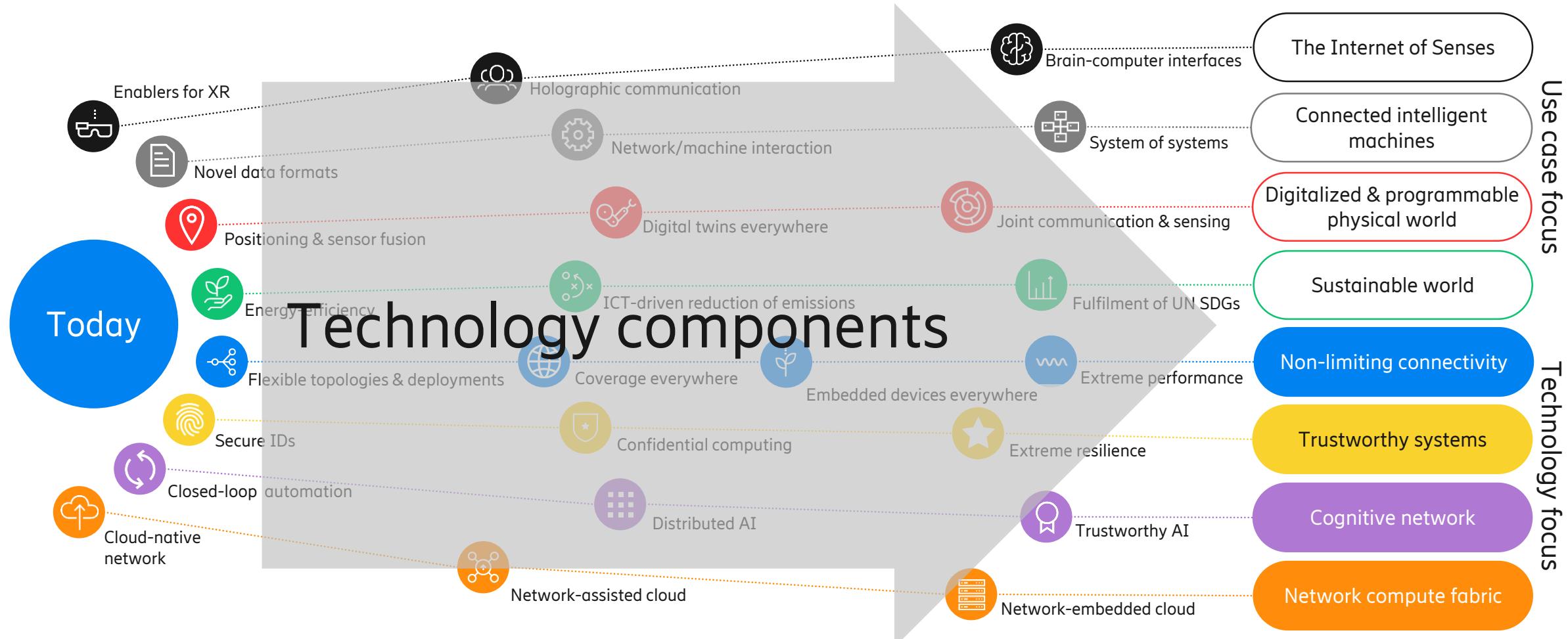
# Wireless access in the 2030 timeframe



- What are the needs?
- Use cases?
- Technology components?



# Technology journeys





# Outline

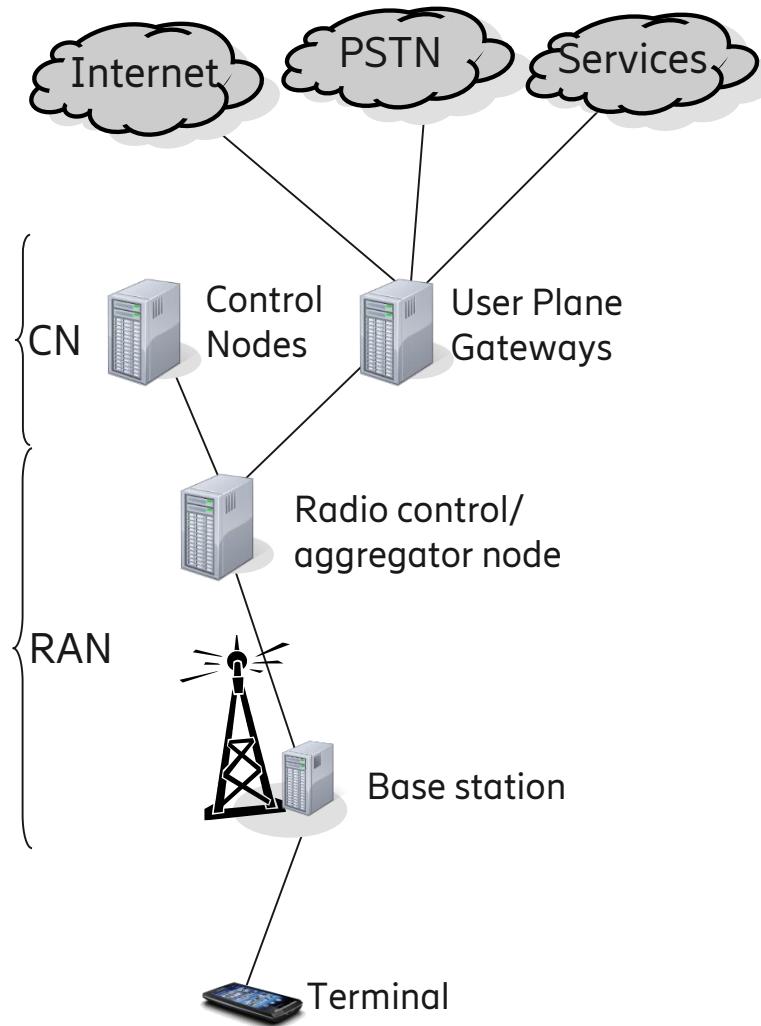
- Introduction
- LTE (4G)
- LTE evolution
- NR (5G)
- NR evolution and beyond
- Standardization in practice

# 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

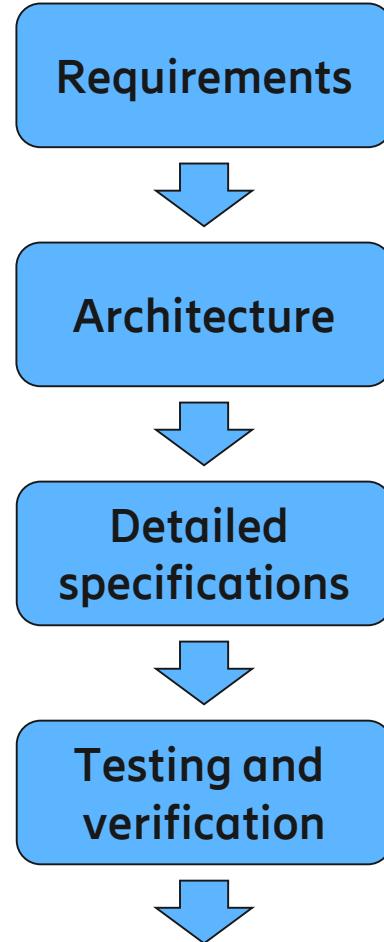


# Where?

- 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

- 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





- 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



**LTE-Advanced**  
(LTE Release 10+)

3GPP

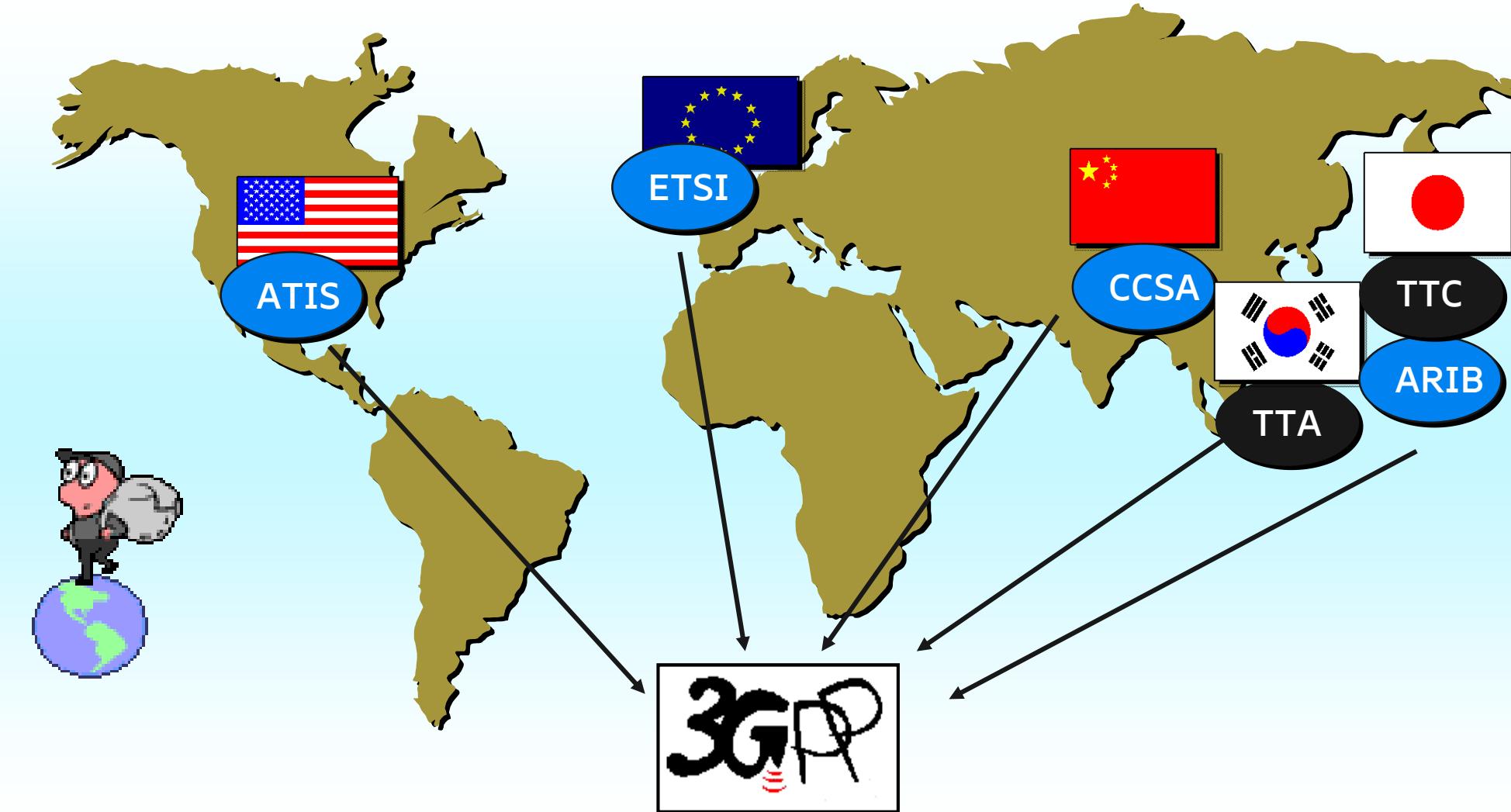
**WirelessMAN-Advanced**  
(WiMAX/IEEE 802.16m)  
IEEE

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

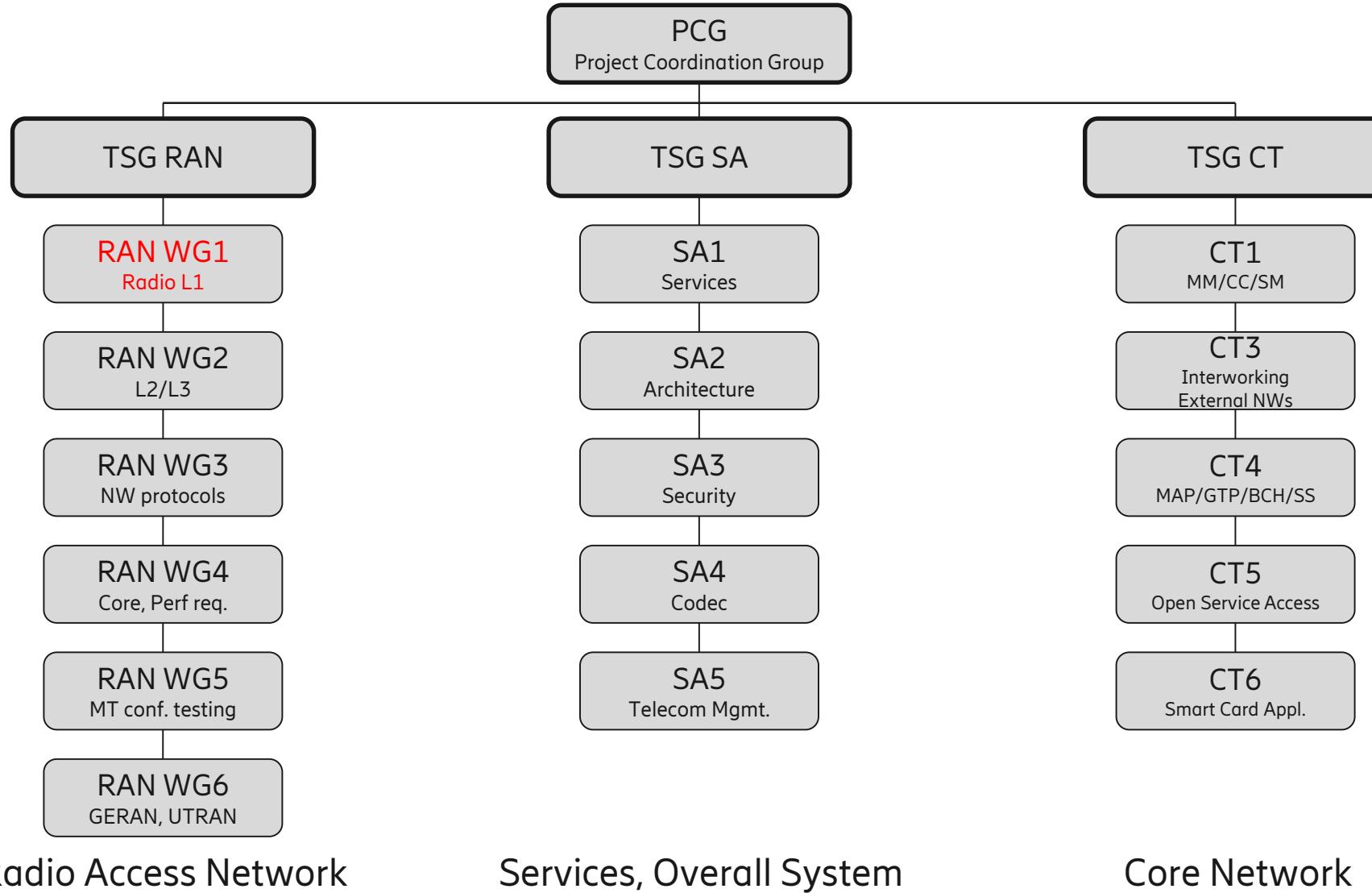


- IMT-2020 – “5G”
- Work ongoing on IMT-2020
  - Similar process as for IMT-Advanced
- WRC-15
  - Frequency allocations up to 6 GHz
- WRC-19
  - Higher frequencies

# 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

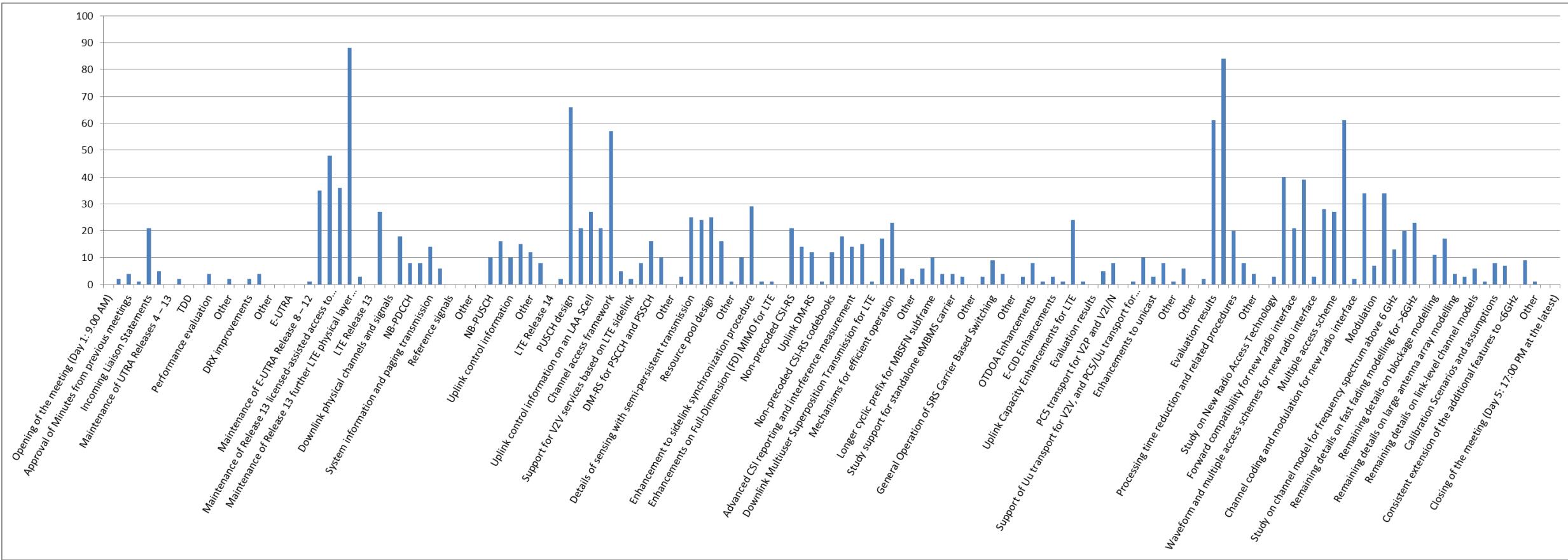
- January 16 – 20
- February 13 – 17,
- April 3 – 7,
- May 15 – 19,
- June 27 – 30,
- August 21 – 25,
- September 18 – 21,
- October 9 – 13,
- November 27 – December 1,

Spokane,	USA
Athens,	Greece
Spokane,	USA
Hangzhou,	China
Qingdao,	China
Prague,	Czech Republic
Nagoya,	Japan
Prague,	Czech Republic
Reno,	USA

# Typical RAN1 meeting



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



Nice to work with standardization...

Cheju, Korea

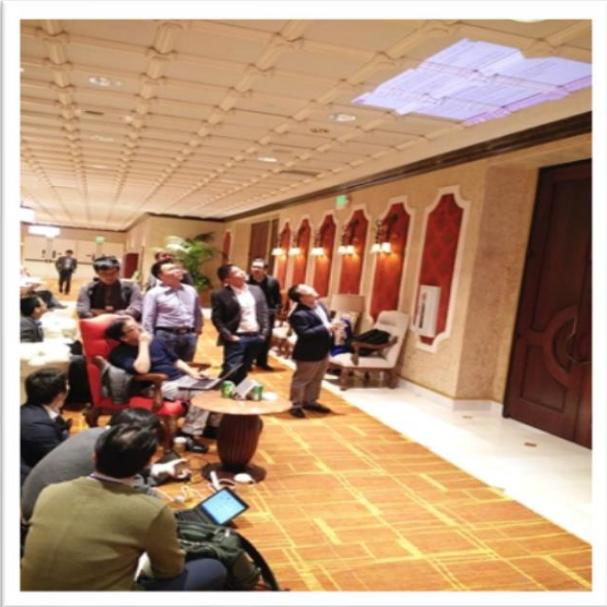


...well maybe not always!

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

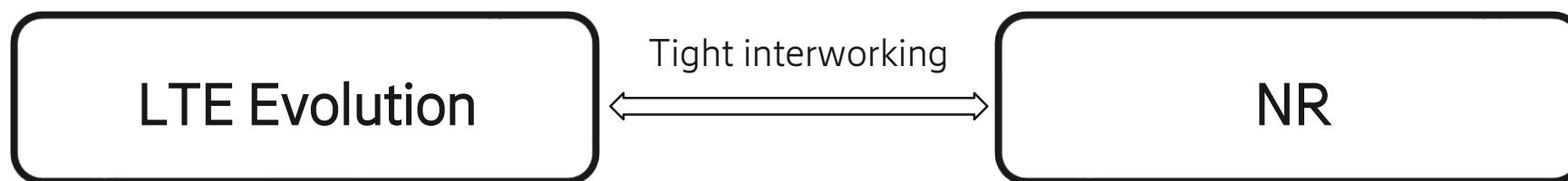




# Summary

# 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.

