6G takes shape – technologies and timeline

Stefan Parkvall

What is 6G?

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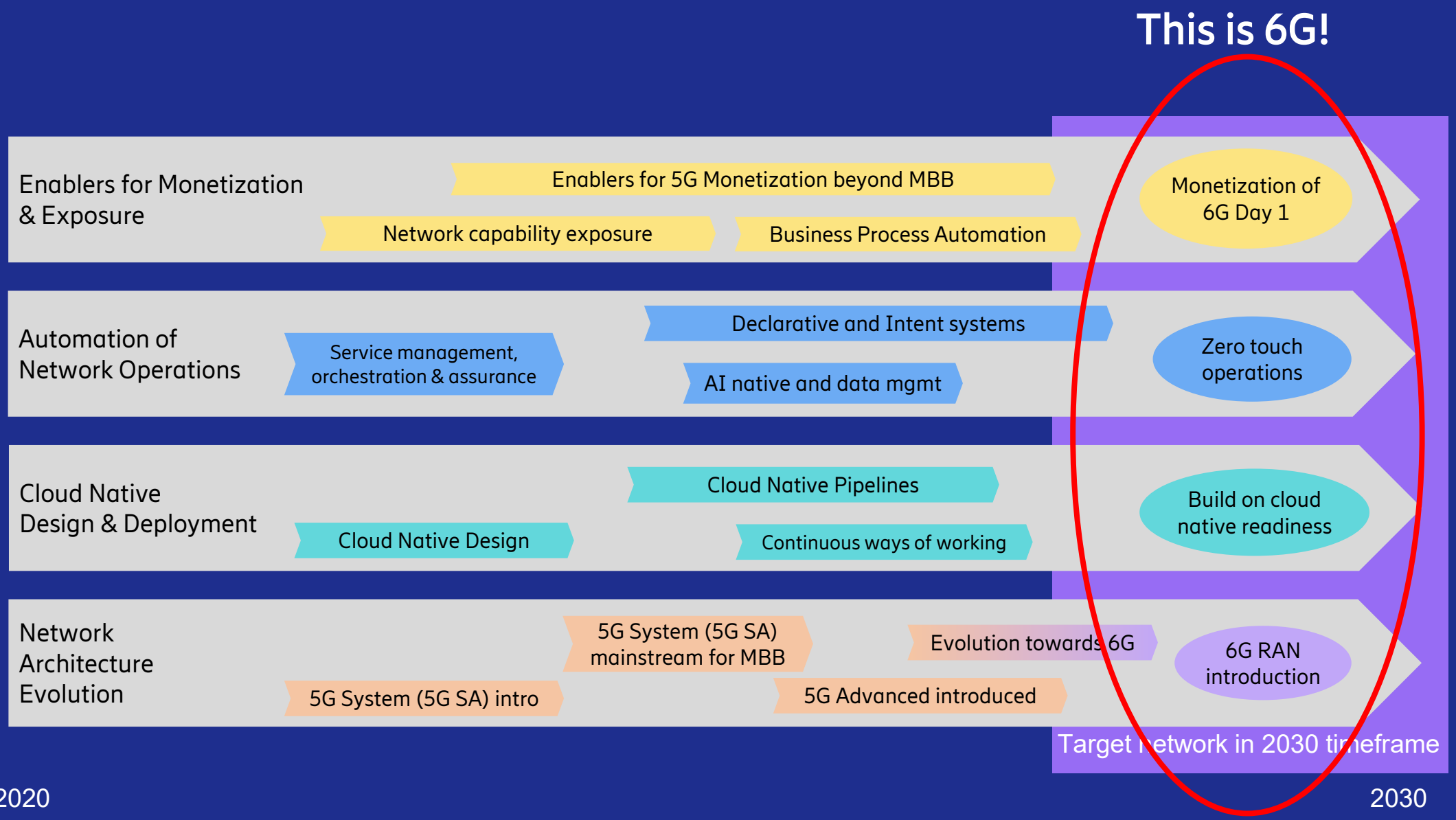
This is 6G!
Enablers for Monetization & Exposure
Enablers for 5G Monetization beyond MBB
Network capability exposure
Business Process Automation
Monetization of 6G Day 1
Automation of Network Operations
Declarative and Intent systems
Service management, orchestration & assurance
AI native and data mgmt
Zero touch operations
Cloud Native Design & Deployment
Cloud Native Pipelines
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Continuous ways of working
Build on cloud native readiness
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Target network in 2030 timeframe
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2030

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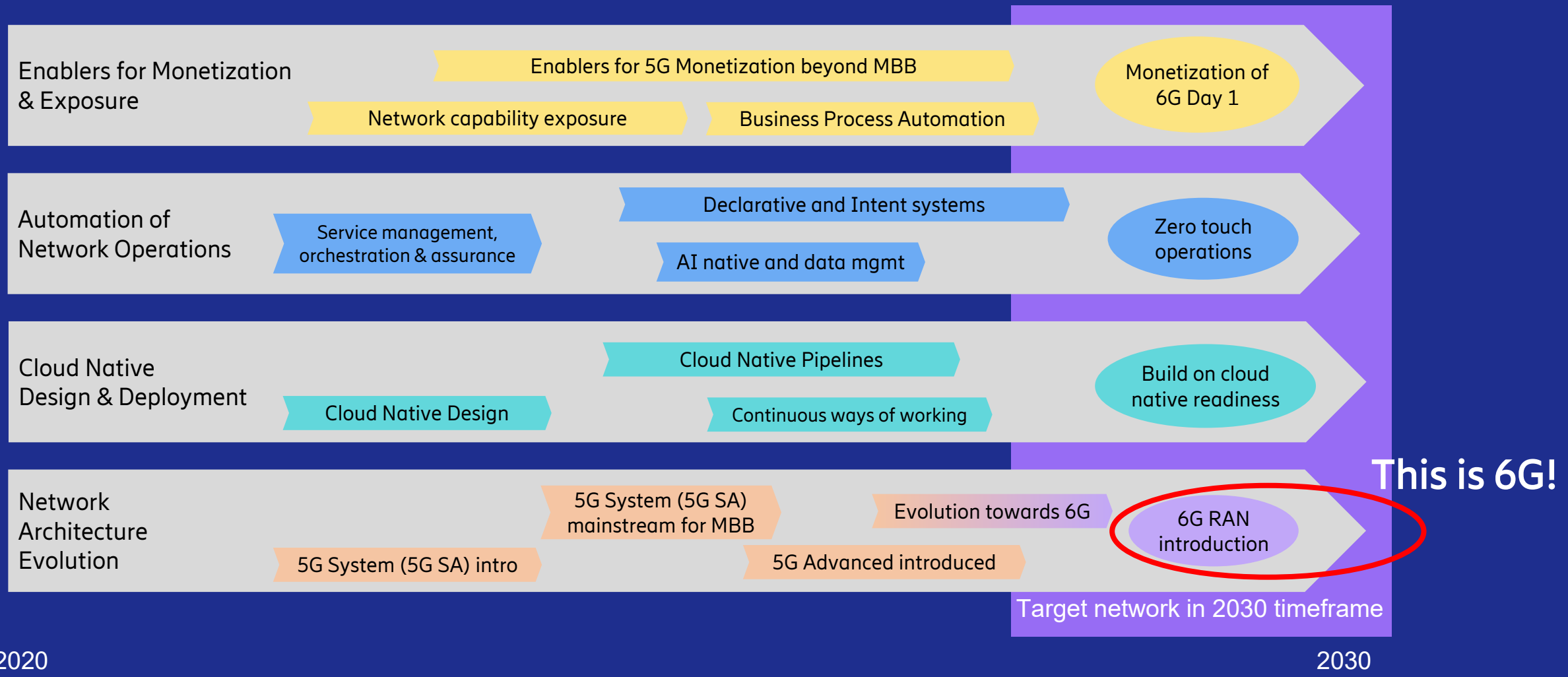
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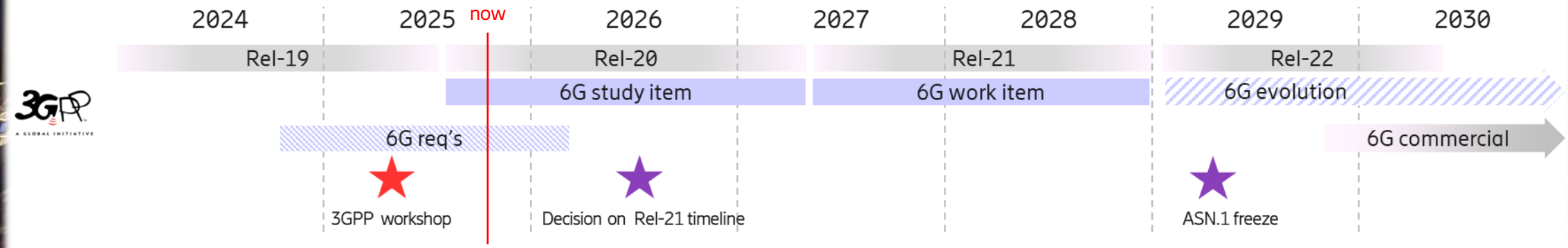
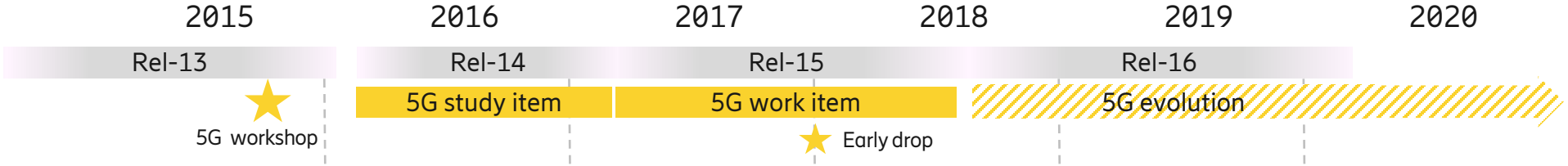
6G standardization has started!



Similar setup as in 5G – but a somewhat more relaxed timeline in 6G



What to achieve – some examples

Energy efficiency
Network and device

Uplink
Many emerging use cases require substantially better uplink

e2e performance
Improvements for real traffic – not peak rates

Beyond communication
ISAC, …

General improvements
capacity, coverage, …

Wide range of use cases
Scalable RAT –
AI agents, mIoT, …

…and more!

Real traffic is bursty

Efficient handling of small packets

- Do not optimize for full-buffer scenarios

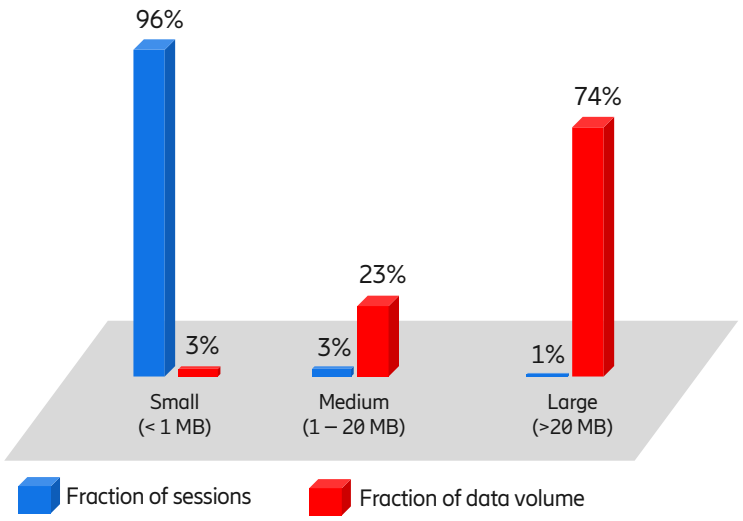
Quickly start transmitting data

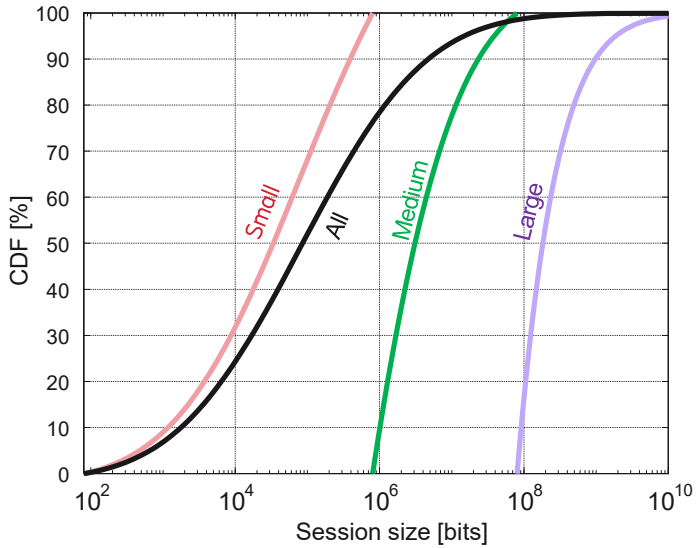
- Camp on the right carrier, rapid connection setup, early CSI reports, …

Spectrum-efficient transmission of large packets

- MIMO, accurate CSI, carrier aggregation, …

Most sessions (96%) are small
Few sessions (1%) carry most of the data (74%)

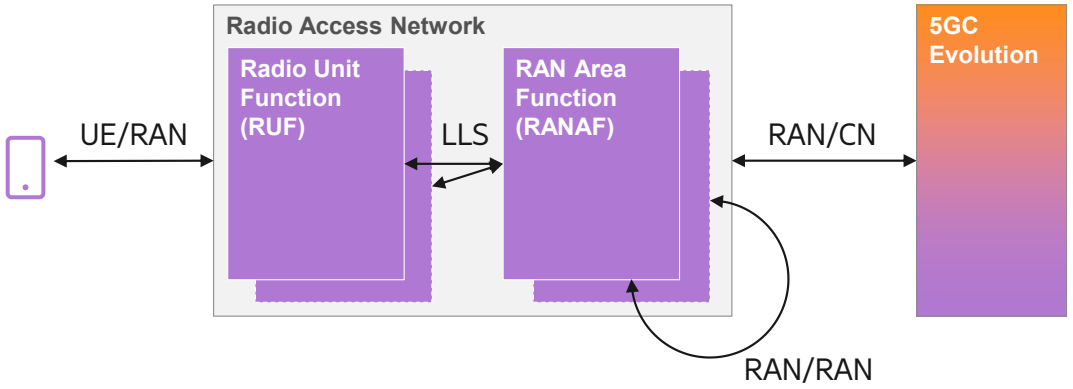


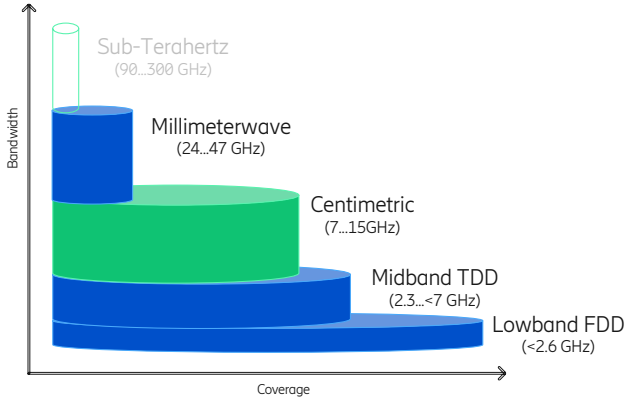


Key 6G Principles

Minimize complexity, Maximize performance

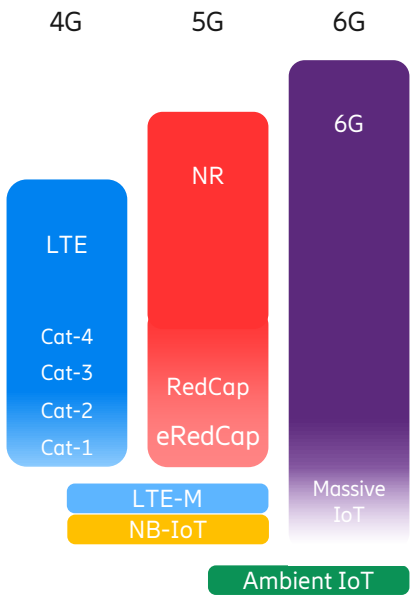
- 6G RAN shall have a standalone architecture only
- 6G RAN shall interface an evolved 5G Core
- 6G architecture shall be intent-based and programmable
- 6G architecture shall include selected open interfaces
- 6G shall operate in all existing 3GPP bands and in new cmWave bands
- Spectrum sharing shall be supported between 5G and 6G
- 6G shall support new and evolved use cases, efficiently & sustainably





Scalable 6G RAT for all device types

Scalable 6G RAT
for all device types



Fixed wireless access
large traffic volumes

NTN
integrated in 6G

Sensing and positioning
Reuse 6G sites and HW for sensing

…and more!

6G radio access

Keep
things that work well

Waveform, coding, and modulation

No major benefits seen from a radical change of waveform, coding, and modulation compared to 5G NR
- 3GPP should focus on areas with greater potential

MIMO and multi-antenna features

6G MIMO will build on an evolved 5G MIMO framework
- Take learnings from 5G and avoid unnecessary/not used flexibility/complexity

Massive MIMO becoming even more massive
- cm-wave ➡ support for a significantly larger number of antenna elements
- Support for different architectures (e.g., fully digital, hybrid) and for flexible antenna design (e.g., low sidelobe arrays, multi-band antennas)
- Unified PMI codebook for CSI reporting (e.g., avoid Type-I, Type-II, e Type-II, ...)
- Make reciprocity (SRS) based CSI acquisition work in practice (address NR SRS implementation problems and faster/flexible SRS over wide BW)

Multi-TRP becoming interference-aware D-MIMO
- Support more TRPs than in NR
  - Increased network deployment flexibility, reduce signaling (e.g., QCL)
  - Leaner structure, no TRS; UEs synchronize on SSB+ DMRS bundles
- Focus on DPS and CJT type solutions and target to maximize SINR instead of only SNR

Lean, dynamic and energy efficient based MIMO design
- Reduce reference signals and unnecessary transmissions, e.g. combine data reception with DM-RS-based CSI measurement
  - Dedicated CSI-RS measurements and CSI reporting is seen as an "add-on" to PDSCH based CSI
- Natively support dynamically adaptation of number of active RF chains to reduce network energy consumption
- CSI using unified uplink reporting (flexible and extensible report content with minimum spec effort)

UL MIMO
- Codebook based, non-coherent PUSCH
- Low PAPR design (including DFT-s-OFDM for all PUSCH ranks)

Change
when motivated

Scheduling and control signaling

Processing timeline – avoid scheduling complications from 5G's multiple timelines
- Long CSI reporting time, in-order scheduling of PUSCH
- Separate CSI reporting from CSI measurement trigger by moving report to MAC-CE

Unified mobility

Unified measurement framework (merge RRM- and L1-CSI measurements)
- Configuration of reference signals (CSI-RS, SSB, ...)
- Configuration of report formats, conditions/triggers
- Measurement reports (see Unified Uplink Reporting)

Unified mobility mechanism
- Combine L3 + CHO + LTM into a single, unified mobility mechanism, i.e., ...
  - Different ways to switch the UE's set of reference signals (for sync, measurements, QCL)
  - Optionally, reset/reestablish protocols, trigger RA...

Discuss means to accelerate HO execution
- Keep critical parts of the UE configuration unchanged
- Indicating properties (tight sync of source and target; shared QCL properties, ...) if beneficial for the UE

Procedures, measurements and conditions ready for using mobility to provide resilience

Mobility measurements in idle and connected mode may use separate signals
- Example: I-SSB for idle mode and M-SSB for connected mode

Add
functionality for new use cases

Integrated sensing

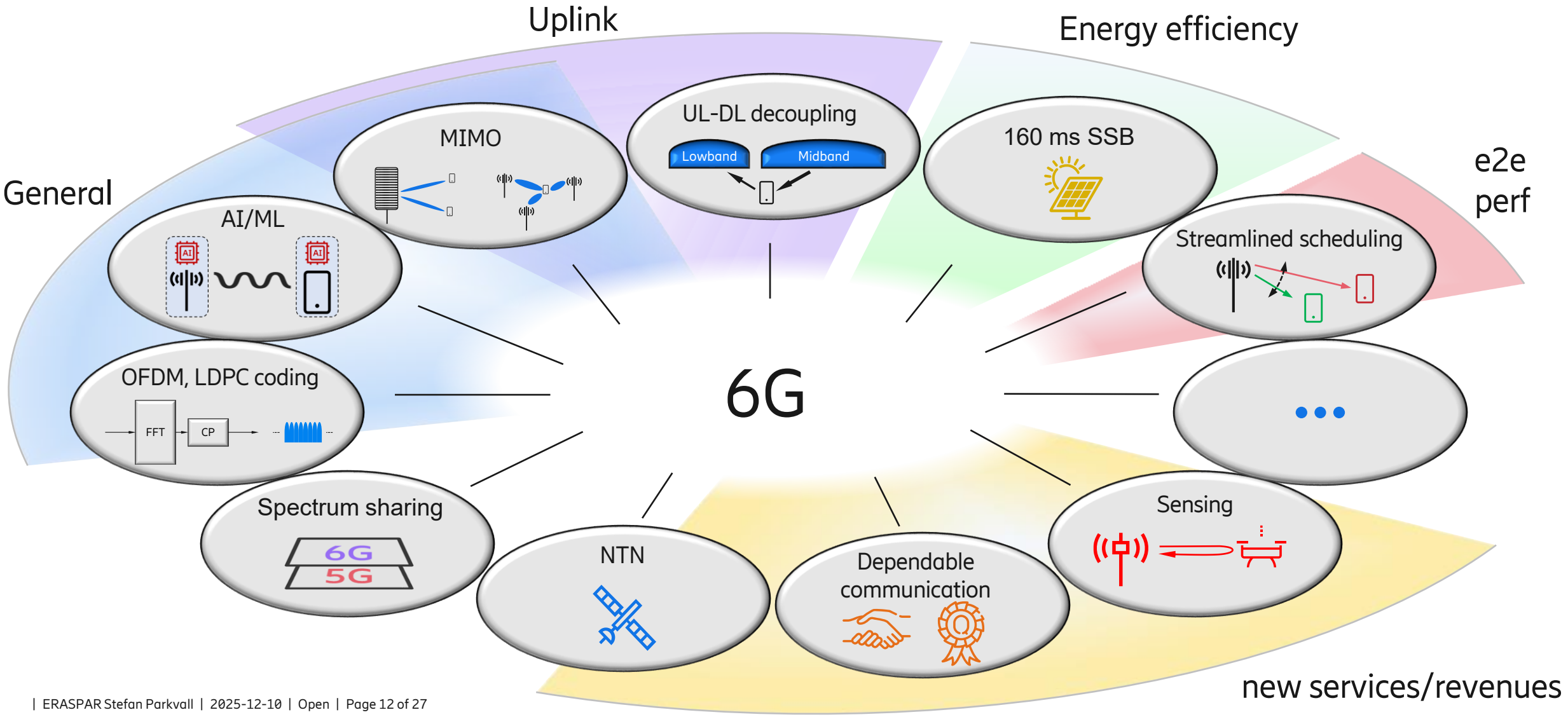
To enhance network performance and create new end-user services

Resilient communications

New business models and monetization opportunities based on service-level agreements require that CSPs assure high connectivity service availability. The necessary resiliency is realized by means of:
- Efficient and cost-effective redundancy to minimize the impact of failures
- Fast detection of failures and failover options

Resilient communications is enabled by 6G features for preventing and reducing service interruption time (e.g., due to link or functional failure):
- Improved observability including measurements and reports for failure detection, enabling proactive actions
- Robust spectrum aggregation providing alternative radio links (e.g., with minimal/no PCell/SCell distinction; CA from non-collocated RUs)
- Multi-TRP for spatial redudancy
- Mobility and RLM procedures allowing for handing over UEs from a failing carrier to a well-functioning one

Examples of technology areas



Waveform, numerology, and bandwidth

Retain 5G waveforms (OFDM in downlink and OFDM/DFTS-OFDM in uplink)

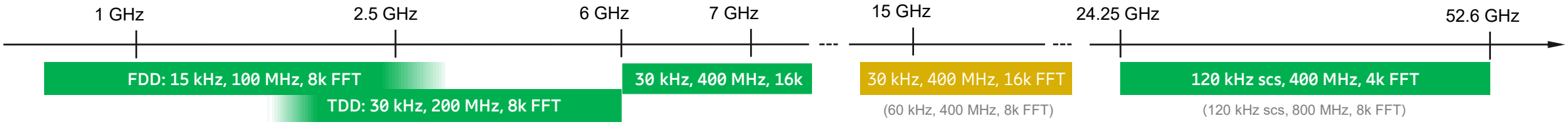
- We see no benefits from a radical change of waveform compared to 5G NR
- Support DFTS-OFDM for rank >1 in uplink

Retain 5G numerology ($2^n \times 15$kHz)

- Prerequisite for efficient 5G/6G spectrum sharing
- Strive for "one band, one numerology" for communication (same subcarrier spacing for data and SSB)

Bandwidths

- *Specification-wise*, up to 100 MHz (FR1 FDD), 200 MHz (FR1 TDD), or 400 MHz (cm-wave, "at network side")
- Larger FFT sizes – up to 16k in cm-wave



Coding and modulation

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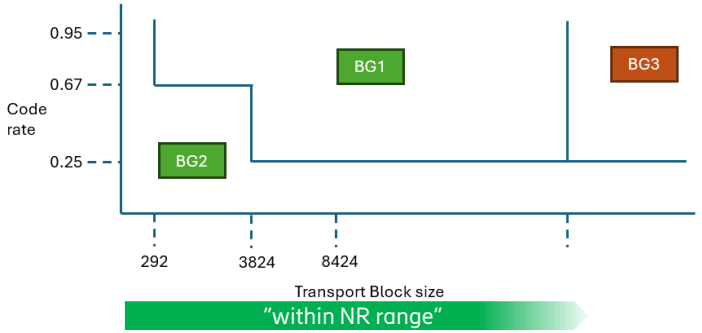
Keep 5G coding

- LDPC for data, Polar for L1 control agreed in 3GPP for "within NR range"
- We do not see any major performance benefits from alternative code designs
- Open to study enhancements "beyond NR range"

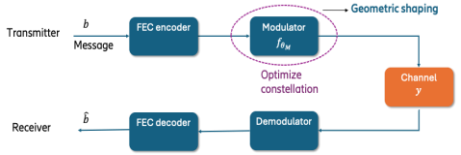


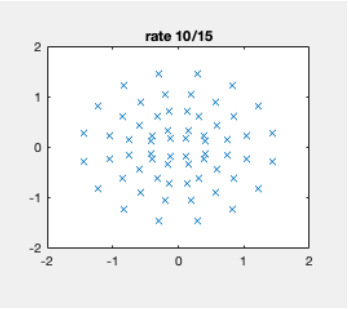
Baseline: reuse uniform QAM constellation

- At least up to 256 QAM in uplink and 1024 QAM in downlink

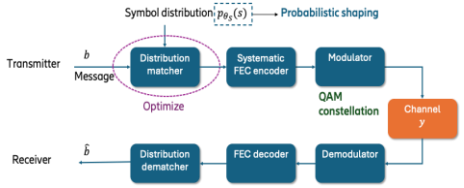
Constellation shaping – discussed in 3GPP

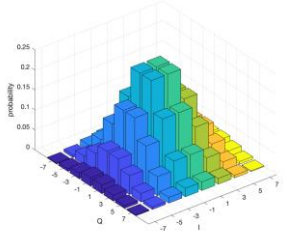
- uniform QAM has 1.53 dB gap to capacity (AWGN)
- Gains of ~2 dB seen for MIMO in fading channels
  if complex sphere decoding is used – no gains seen with MMSE
- Gains must persist also in realistic scenarios (HW impairments)
- Geometric shaping – simple at Tx, more complex at Rx
- Probabilistic shaping – more complex also at Tx





Geometric shaping (ATSC 3.0)

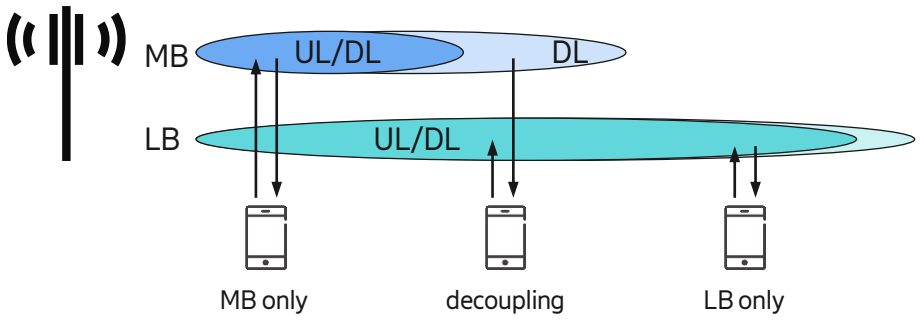




Probabilistic shaping

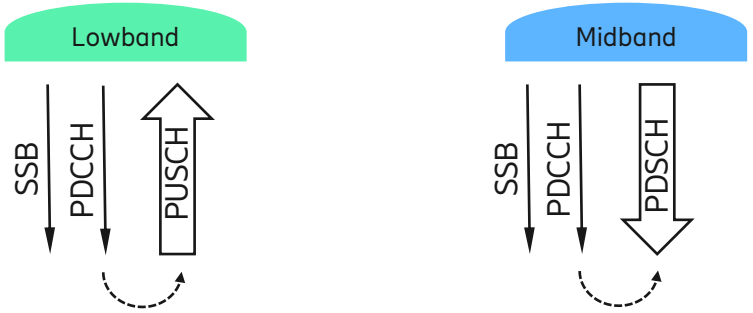
Uplink-downlink decoupling

- Best DL frequency band may not be the best UL frequency band



- UEs in idle/inactive state camp on single carrier
  - Maximize UE battery life,
  - Gains of UL/DL decoupling mainly in connected mode after DRB activation
  - Methods for fast CA setup applicable also to fast UL/DL decoupling

- UEs in connected state can be configured with UL/DL decoupling
  - Timing and pathloss reference (e.g. SSB) required on low band to support UL transmissions

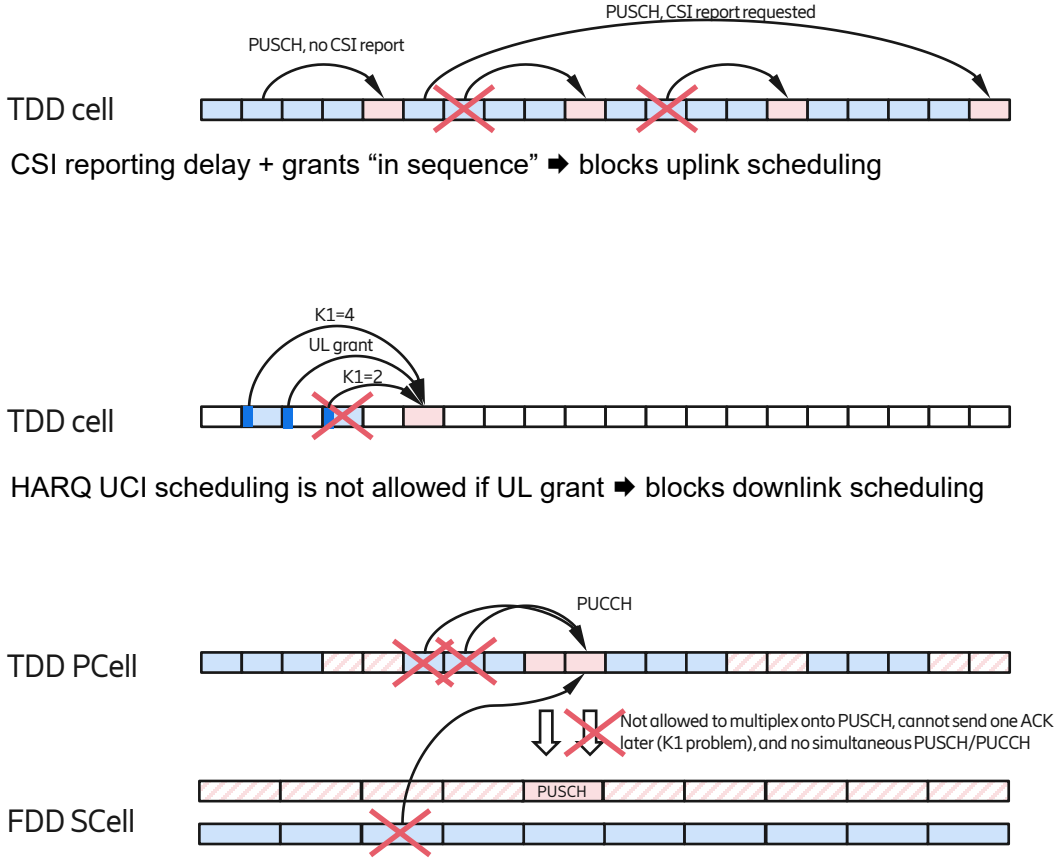


Scheduling timeline and control signaling

- Important to model uplink-downlink interaction to get the correct understanding of the performance
  - including higher-layer protocols (RLC, TCP, …) and lower-layer aspects such as DAI coordination

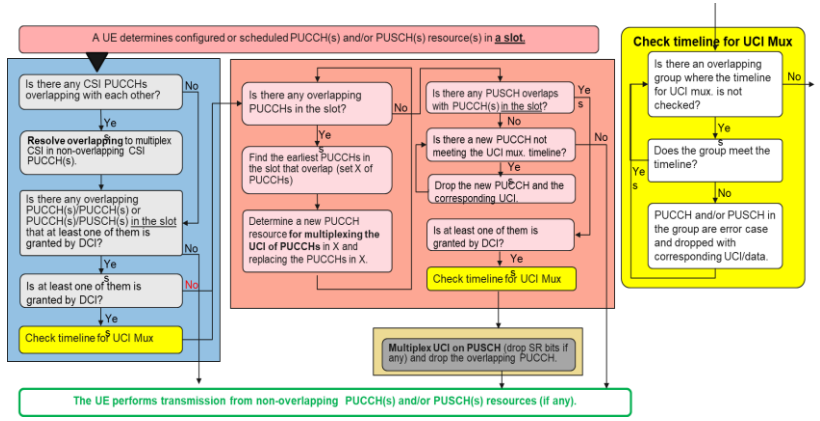
- **Strive for a more time-asynchronous UCI reporting mechanism**
  - cloud friendly, handling of non-collocated sites, supporting multiple UE capabilities (e.g. HARQ decoding), handling of long delays (NTN, long fronthaul, …), …
  - reduces scheduling restrictions to the right – more examples in the paper

- Proposal: treat UCI as L2 data instead of using a separate and inflexible physical channel – simulations results in R2-2508615



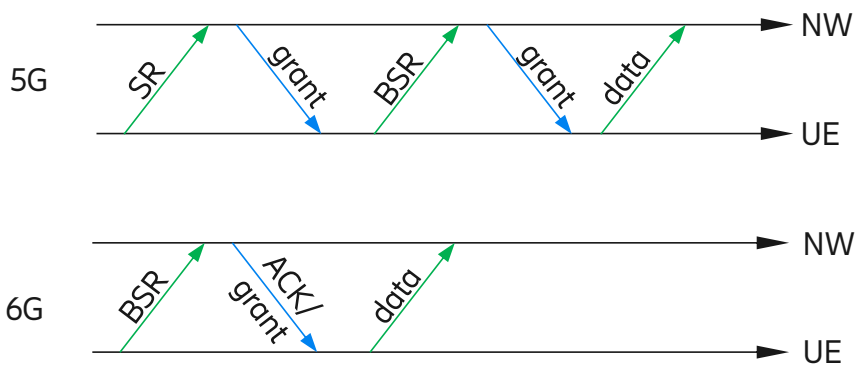
UCI on L2

- Complex and tailor-made multiplexing rule for all different UCI type combinations and corresponding PUCCH resources
  - Complex and less efficient gNB scheduling
  - Complex UE implementation
  - Difficult to introduce enhancements in later releases



➡ Multiplex UCI and data on L2

- Scheduling latency dominated by "SR-grant-BSR-grant" cycle

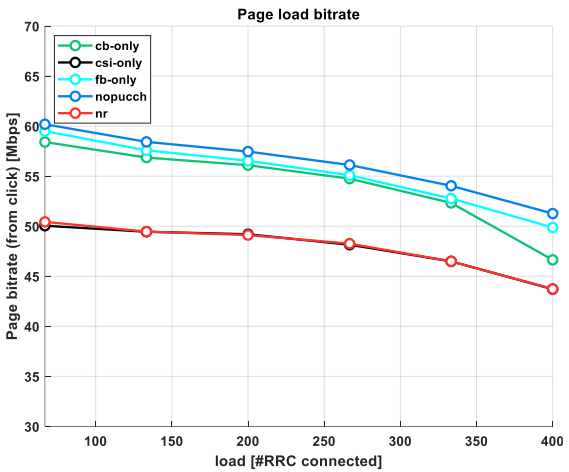


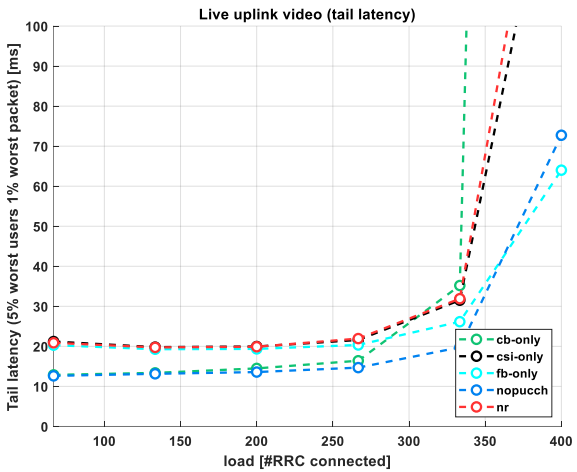
➡ Contention-based buffer-status reports

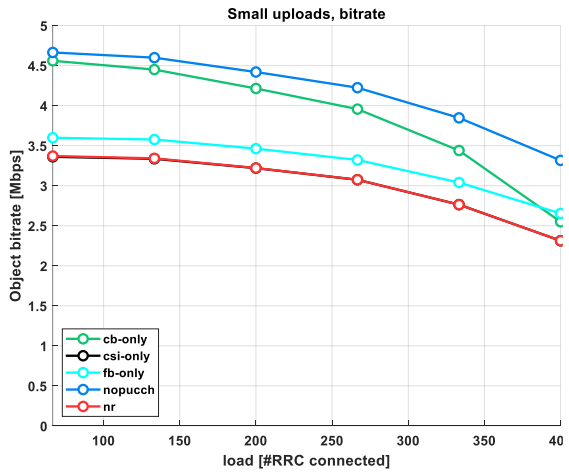
UCI on L2 - performance improvement

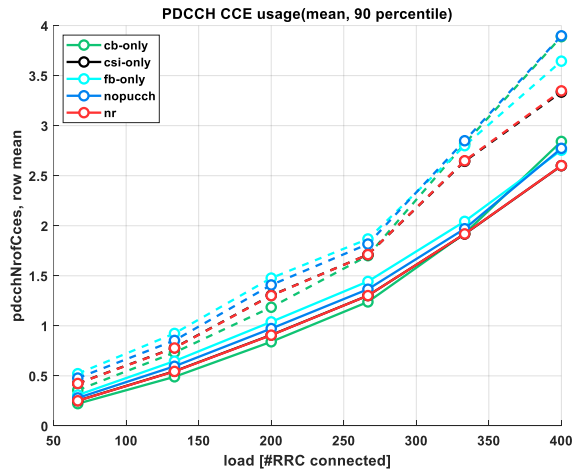
- Reduced UL latency and increased e2e performance due to CB-PUSCH and due to efficient multiplexing of control & data on PUSCH (free-ride effect)
- Reduced UL resource utilization since CB resources scale better with increasing load
- Same service coverage which is anyway limited by PUSCH (would not benefit from better PUCCH capacity)

- Substantially reduced system complexity accelerates development of other performance enhancing features.









Energy Efficiency

NW Energy Performance

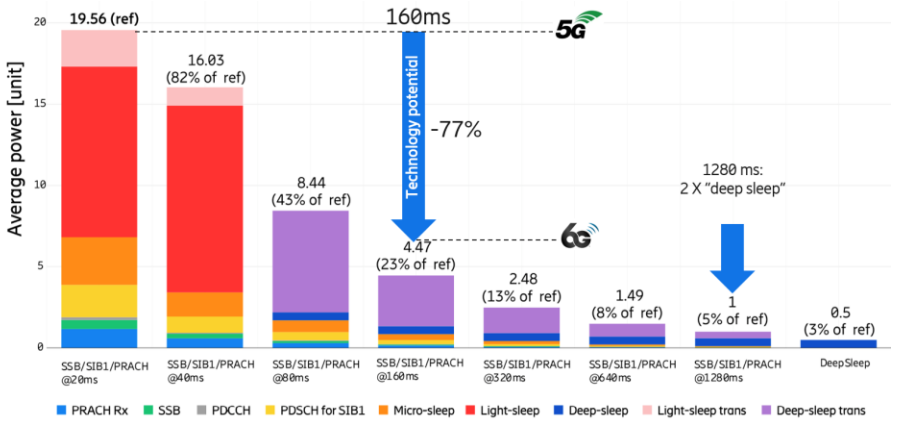
- New G ➡ unique opportunity to enhance lean design
- Minimize NW activity during "Idle" periods
  - Longer SSB periodicities (160 ms)
  - Adaptive use of reference signals based on need (e.g., OnDemand-SSB/CSI-RS/TRS).

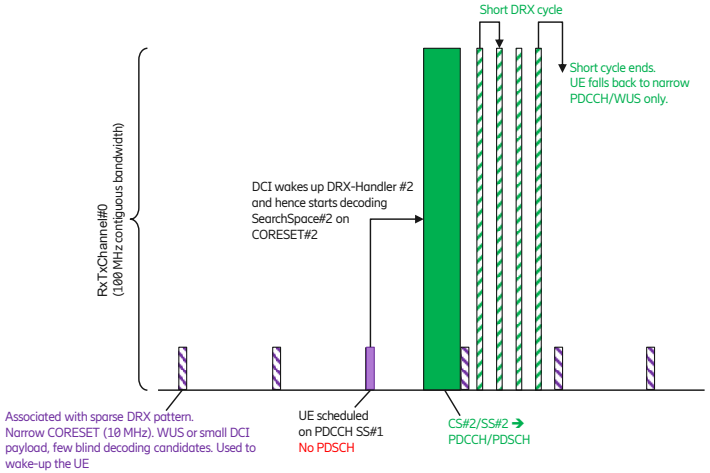
General Principles

- Advanced UE/NW capabilities do not justify constant power-hungry operations
- High energy demand is fine ***if limited in time and space***
- OK to spend energy on Gbps – Mbps must stay lean

UE Energy Efficiency

- WUR can enable significant savings
- WUS *must* reach cell edge
- Streamline and simplify connected mode power-saving mechanisms ("DRX handler", determines times at which a UE is ***not*** required to monitor PDCCH)

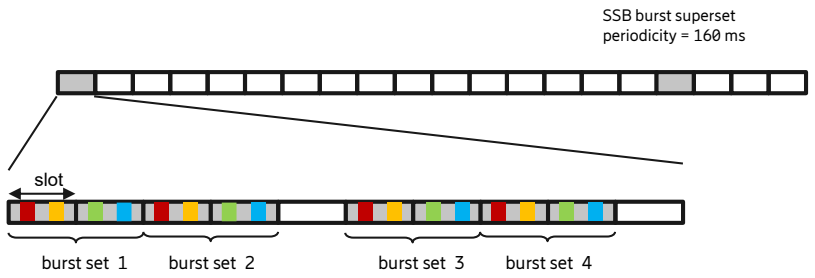




Initial access

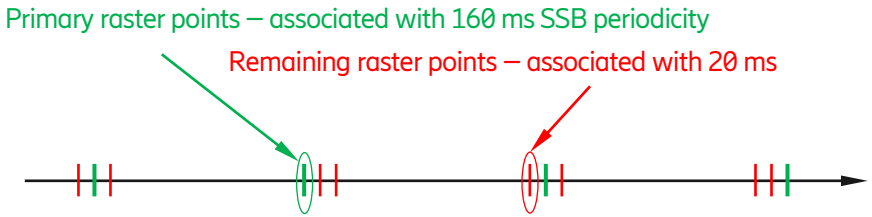
Increase SSB periodicity to 160 ms

- Burst set repetition within one SSB superset period of 160 ms (UEs typically require 2-3 SSBs for AGC setting, etc)



Sync raster based on 5G – add dual search grid

- Very few raster points used in practice
- Primary raster points associated with 160 ms SSB periodicity
- Remaining points associated with 20 ms



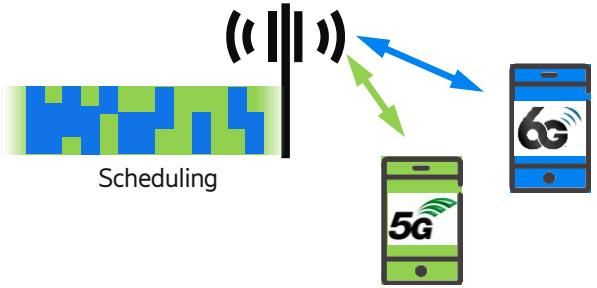
Two types of SSBs

- CD-SSB – always on, 160 ms periodicity, the only SSB seen by idle-mode devices
- OD-SSB – transmitted when needed, can only be used by connected-mode devices

Random access

- 4-step random access as baseline – see no need for 2-step random access
- New long-sequence format(s) with shorter duration ➡ increased number of preambles

MRSS

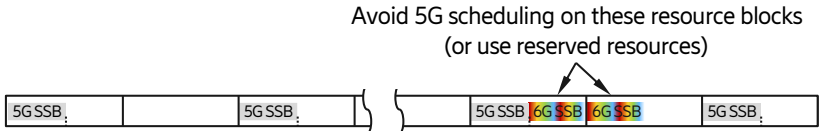


MRSS – dynamic 5G-6G spectrum sharing

- Part of scheduling
- Semi-static sharing with NB-IoT/LTE-M sufficient
- No need for sharing with 4G

SSB

- Schedule 5G around 6G SSBs (or use reserved resources)
- Different PSS or SSS for 5G and 6G to avoid 5G detecting 6G SSBs

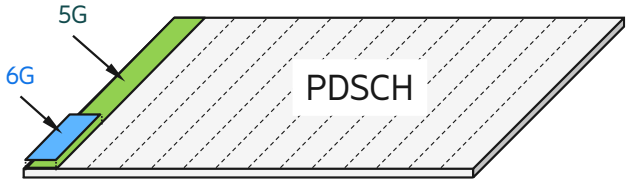


Random access

- Use different preambles for 5G and 6G – gives an early indication of 5G or 6G UE to the gNB
- Can reuse 5G time/frequency locations and/or configure new 6G-only locations

PDCCH

- Can have overlapping CORESETs/search space sets *if* 5G and 6G hashing functions are decently similar
- Non-overlapping sets also possible (at a higher overhead)



6G performance potential – some early examples

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Energy efficiency

Up to **77%**

reduction in network energy consumption

at low loads by reducing the transmission of always-on signals

Up to **35%**

reduction in modem energy consumption

by wake-up signals and other power-saving mechanisms

Capacity and throughput

Up to **+200%**

downlink capacity increase

by adding cm-wave M-MIMO on the existing site grid

Up to **+25%**

uplink throughput

by using AI native channel estimator

Uplink performance

Up to **+56%**

experienced uplink data rates for small packets

by redesigning and streamlining scheduling and control signaling

Up to **10X**

uplink throughput for cell-edge users at low load

by selecting the frequency band independently for uplink and downlink

New service opportunities

Up to **+23%**

positioning accuracy

using AI-based positioning algorithms capable of learning and exploring the environment

2-3m

average error in ISAC drone tracking

in horizontal location using a live test communication network

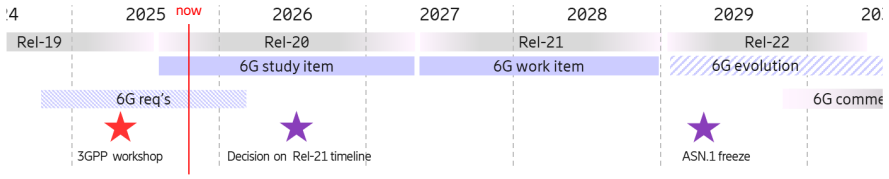
5G-6G spectrum sharing with <3% overhead

For more details see: 6G taking radio access technologies to new heights - Ericsson

Conclusion

6G standardization has started

Commercial availability ~2030



6G key principles

Stand-alone architecture, evolved 5G core, open interfaces, spectrum sharing

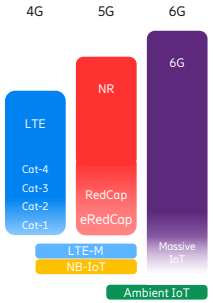
Keep
aspects of 5G that work well

Change
when motivated by significant performance enhancements

Add
selected functionality for new use cases

6G will further extend the capabilities of wireless access

Dependable communication, situational awareness, ...



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