

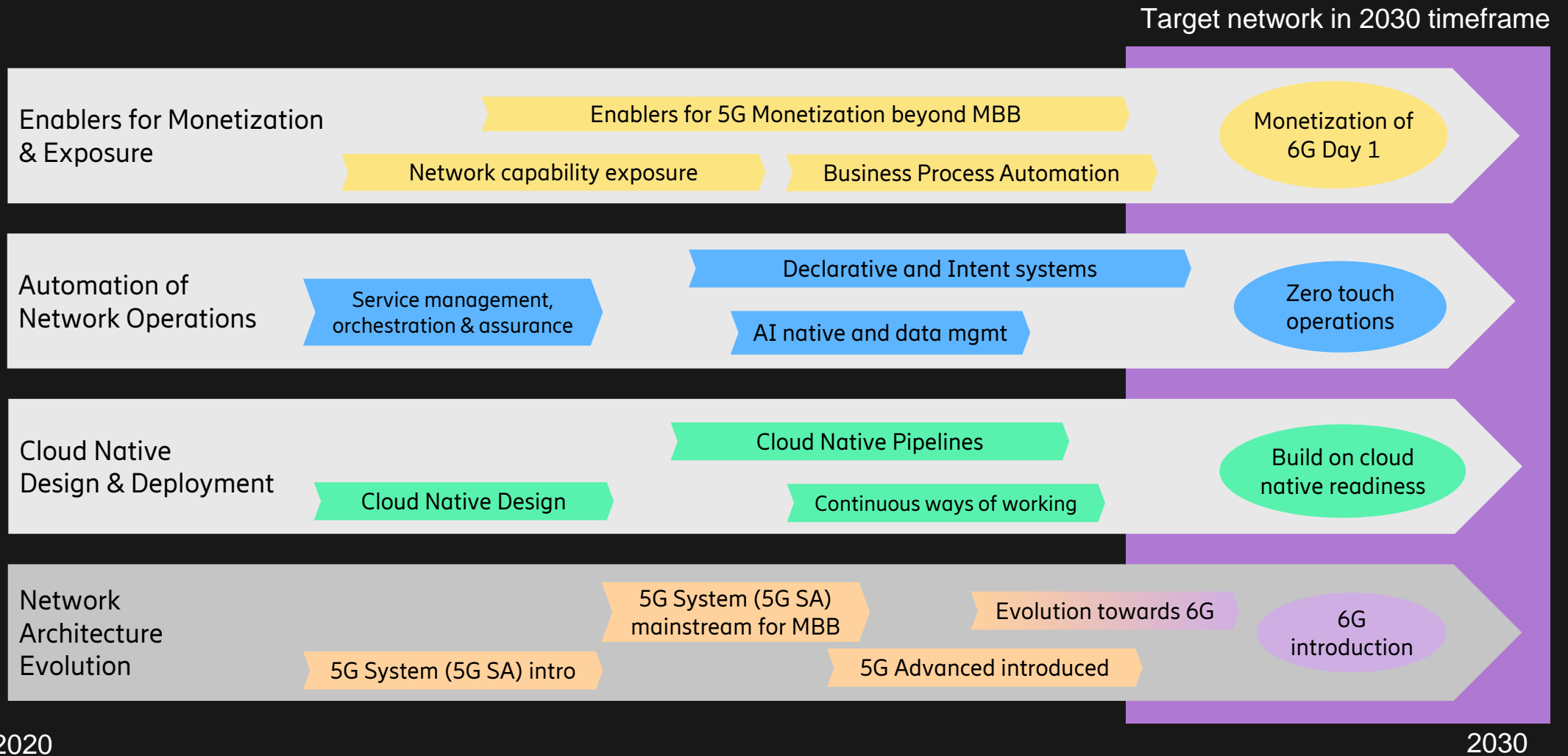
# The road to 6G



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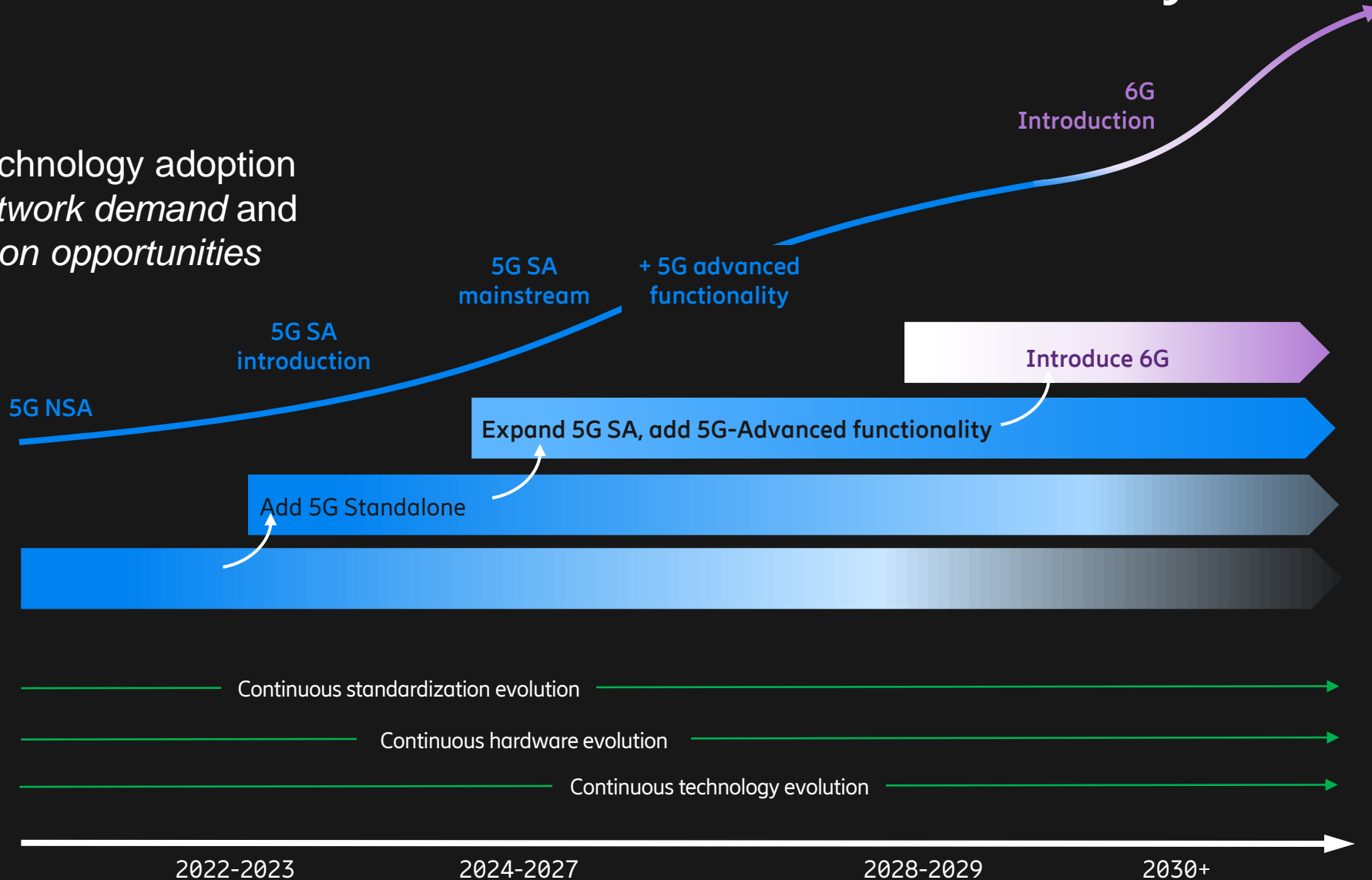
# Multiple evolution paths towards 6G timeframe



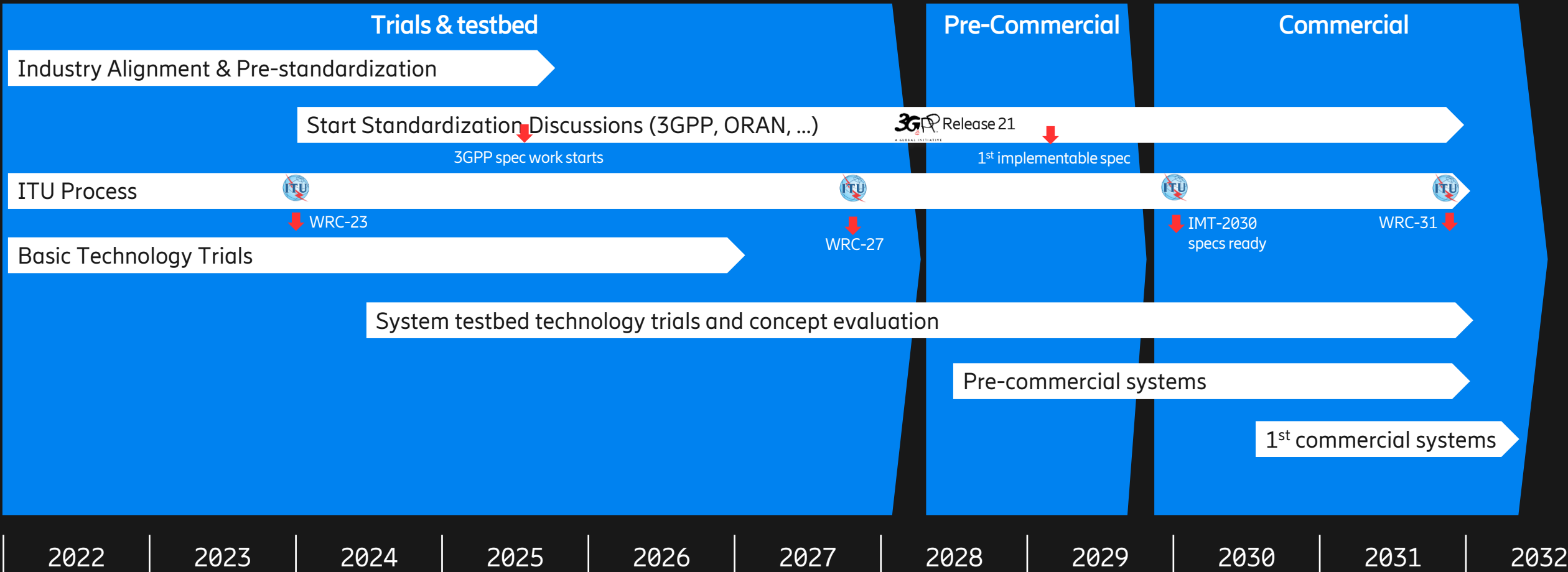
# Continuous evolution towards 2030 and beyond



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



# 6G timeline



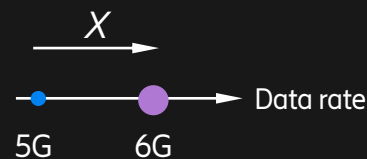
# 6G requirements



## Don't

scale individual metrics with a factor of  $X$

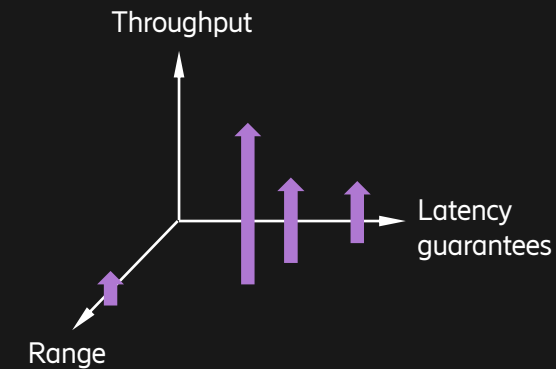
Can result in extreme numbers with limited relevance to actual applications



## Do

consider *joint* capabilities in a multi-dimensional space

Different applications have different requirement points in the multi-dimensional space

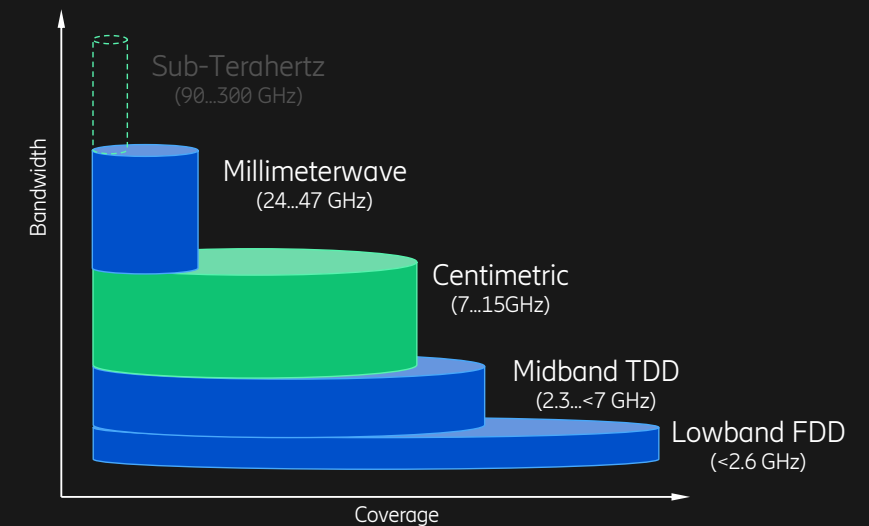
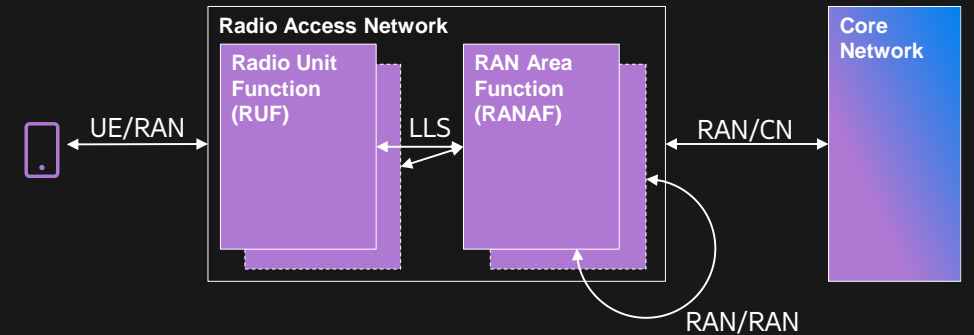


# Key 6G principles

*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

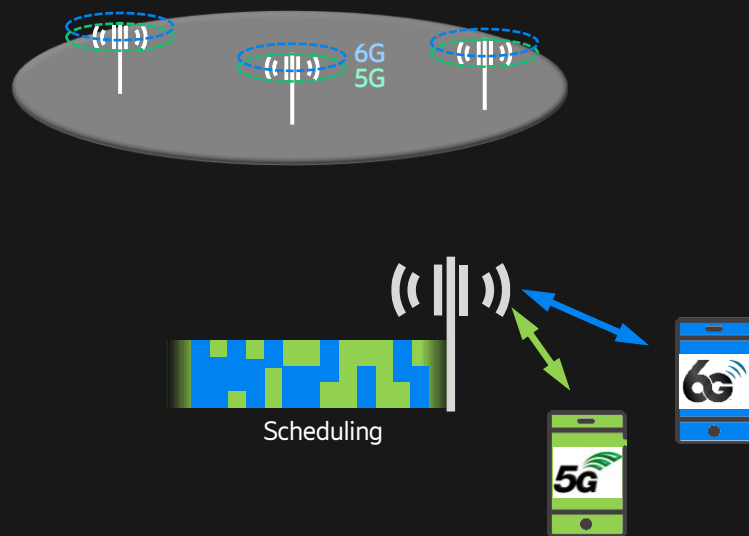


# Spectrum sharing



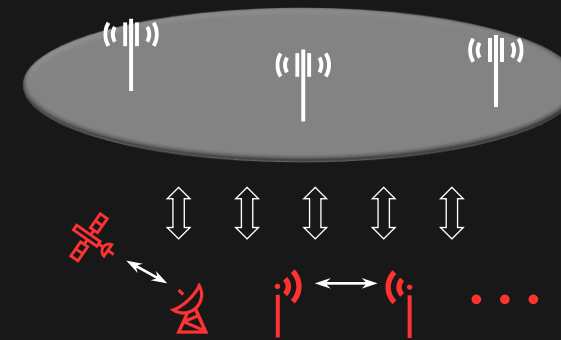
## 5G/6G intra-operator sharing (MRSS)

- **Absolutely necessary** (at least for FR1) due to limited availability of new spectrum
- Dynamic and highly efficient (5G "lean design")
- Smooth transition and mix of 5G/6G deployments



## Co-existence with other usages

- "Sharing by design"
- Important for access to **cm-wave** band
- Slower time scale than MRSS



# Overall design guideline



## Keep

aspects of 5G that work well

## Change

when motivated by significant performance enhancements

## Add

selected functionality for new use cases

### Waveform, coding, and modulation

No major benefits seen from a radical change of waveform, coding, and modulation compared to 5G NR

- Retain 5G NR waveform (OFDM/DFTS-OFDM) and numerology (2<sup>n</sup>·15KHz)
  - Preserve for efficient 5G NR spectrum sharing
  - Consider BFT to enable larger carrier bandwidths
  - No need for multiple subcarrier spacings on the same carrier for data transmission
  - Stable for "one band, one numerology"

### MIMO and multi-antenna features

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

- Massive MIMO becoming even more massive
  - on sector support for significantly larger number of antenna elements
  - Support for massive MIMO (e.g., 64, 128, 256) and multi-beam design (e.g., low-tilt beam, multi-beam antenna)
  - Support for massive MIMO (e.g., 64, 128, 256) and multi-beam design (e.g., low-tilt beam, multi-beam antenna)
  - Make use of 3D MIMO (e.g., 3D beamforming, 3D MIMO)

### Spectrum aggregation

Highly dynamic spectrum resource usage

- Traffic is highly dynamic, must be low latency
- Requires wide carrier bandwidth, rapid
- Minimum requirements to be met
- UEs should be able to camp and connect on

### Energy performance

Aim for significantly improved system energy performance

- Network and UE

### Unified mobility

Unified measurement framework (merge RRM- and L1-CSI measurements)

- Configuration of reference signals (CSI-RS, SSB...)
- Configuration of report framework, conditions, triggers
- Measurement reports (see Unified Link Reporting)

### Scheduling and control signaling

Processing timeline - avoid scheduling complications from 5G's multiple timelines

- Long CSI reporting time, involves scheduling of PUSCH
- Separate CSI reporting from CSI measurement trigger by moving report to MAC-CE (see unified link reporting)
- Avoid synchronous HARQ-FB, become complex in 5G across carriers and numerologies

Uplink control signaling - no PUCCH

- All uplink control signaling sent in-band on L2 message
- Asynchronous reporting (flexible, lower coupling between UL and DL scheduler, cloud friendly)
- Enables flexible usage of uplink carriers for feedback in a simple way - no complex PUCCH switching cell mechanism

Downlink control signaling - PDCCH roughly similar to 5G

- Improve on backlog aspects (e.g., channel estimation limitations exposed late in 5G and not fully accounted for in the design)
- Improved support for PDCCH link adaptation and MU-MIMO
- Address privacy aspects (e.g. separate DM-RS and PDCCH scrambling)

### Observability

New measurements and features

- Supporting service level agreement opportunities and network verification purposes
- Automated network management
- Increasing the resiliency of

### Integrated sensing and communication

To enhance network performance and create new end-user services

Focus on "Detect-and-track" (radar-like) sensing

### Resilient communication

New business models and monetization opportunities based on agreements require that CSPs assure high connectivity service necessary resiliency is realized by means of:

- Efficient and cost-effective redundancy to minimize the im
- Fast detection of failures and fallback options

Resilient communications is enabled by 6G features for prevent service interruption time (e.g., due to link or functional failure)

- Improved observability, including measurements and report detection, enabling proactive actions
- Robust spectrum aggregation providing alternative radio

### Support for service-level agreements

Service-level agreements (SLAs) enable new business models and sources of revenues for CSPs by capturing value beyond best effort

- 6G provides features
- Prioritize connectivity KPIs such as latency

The first release of 6G should support connectivity

- Service assurance, time-critical communication
- Observability for SLA
- Enterprise use cases (e.g., dependable communications)
- SLA obligations (e.g., SLA obligations)
- Enter-driven RAN

### Intent-driven RAN

Transforming the capability of communication networks will need specific operations, including:

- the management of multiple, differentiated services beyond 5G NR
- the adoption of networks by users with heterogeneous (e.g., verticals)
- an increased level of automation and intelligent network management

### Time-critical communication

Many use cases of high commercial value have time-critical traffic that requires handling beyond best effort:

- Immersive communications (e.g., XR)
- Enterprise use cases (e.g., dependable communications)

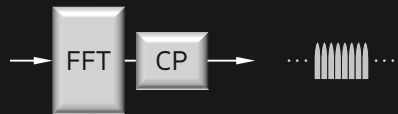
The first release of 6G includes a Time-critical communications (TCC) framework suitable for a wide range of use cases that enables having consistent and assessable latency. The framework may be extended in later releases to enhance performance (e.g., improved reliability).



# Examples of technology components



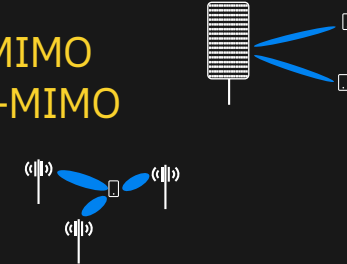
Keep basics of 5G PHY  
OFDM, LDPC coding



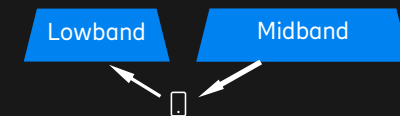
Carrier aggregation  
CA with loosely coupled carriers  
No dual connectivity



MIMO  
Extremely massive MIMO  
Interference-aware D-MIMO



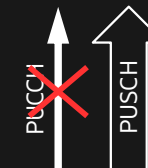
UL-DL decoupling  
Best DL band might not be best UL band



Energy efficiency  
Separate signals for idle and connected mode



Unified uplink reporting  
Asynchronous reports  
Minimize scheduling restrictions



...and more!

# Day 1 verticals and deployments



Support high-value verticals/use cases and deployments *with the general 6G radio access solution*

- Economy-of-scale – leverage mass-market products
- In later releases, evolve solutions *when needed* for use cases that gained *market traction*
- Focus on *needs* of the verticals not on technology evolution

5G

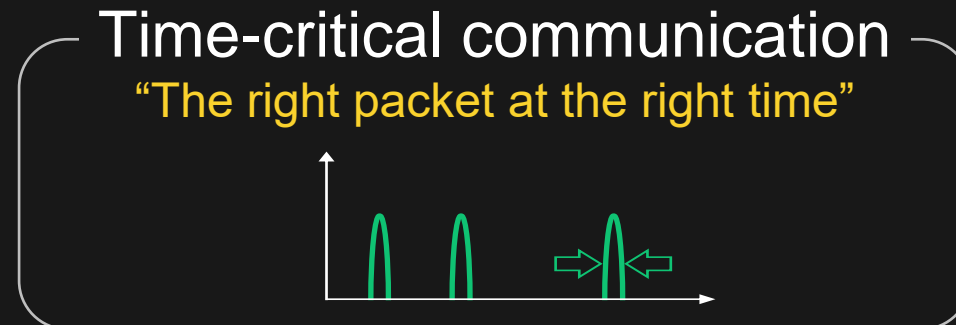
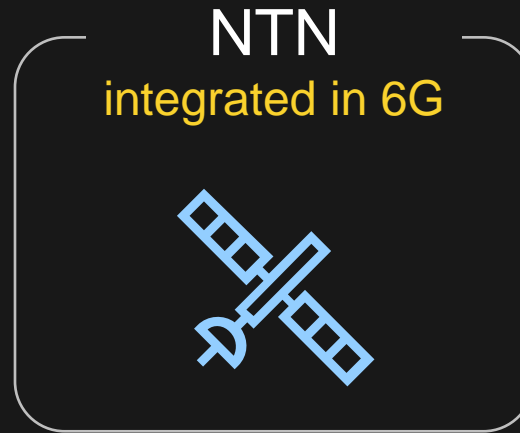
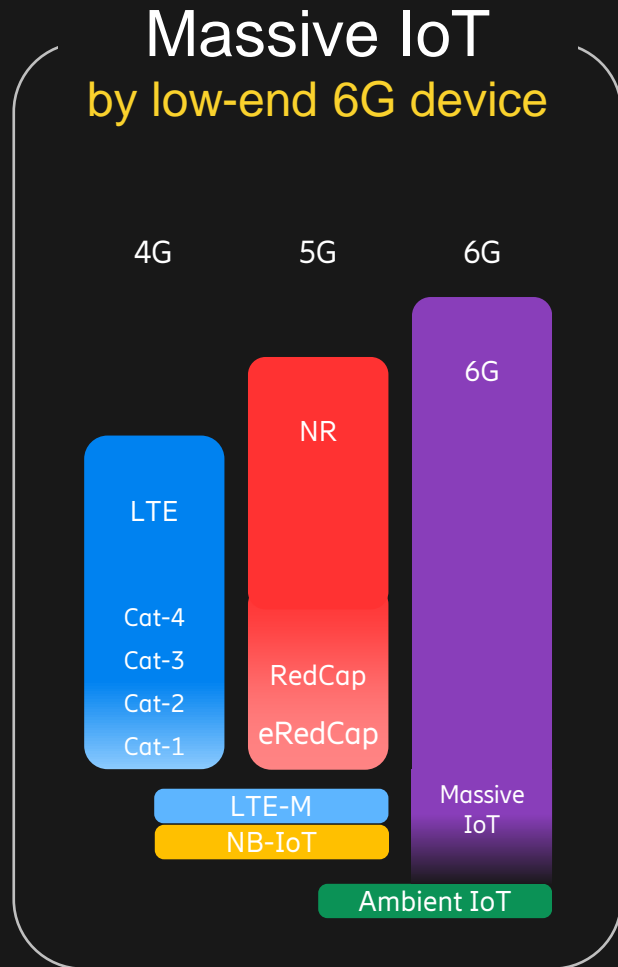
Initial 6G deployments

*Leverage mass-market products*

Later 6G deployments

*Specific features if commercially motivated*

# Support high-value use cases/deployments *with the general 6G solution* - Examples



# Time-critical communication

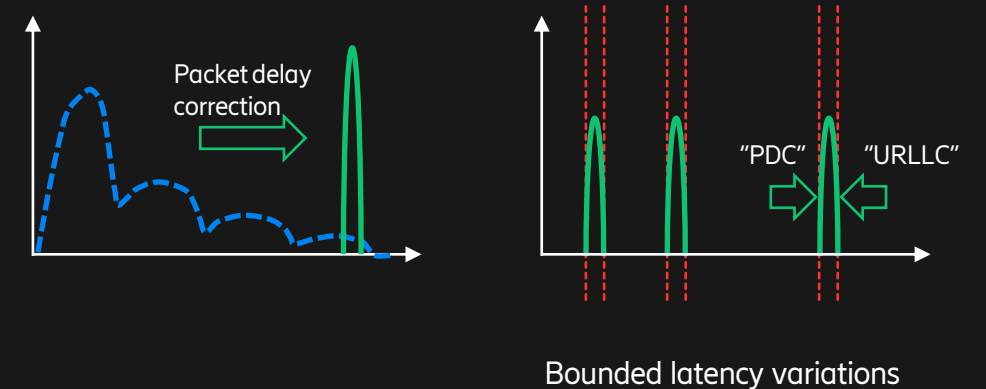
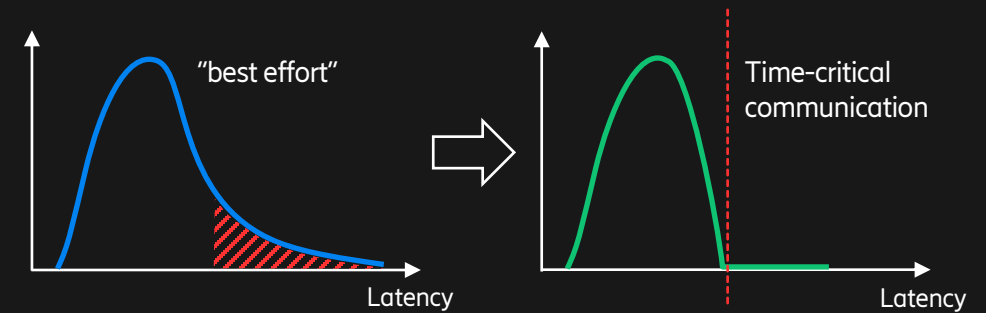


## From best-effort to bounded latency

- Immersive communications (e.g., XR)
- Enterprise use cases (e.g., dependable communications)
- ...

## "The right packet at the right time"

- Low jitter can often be more important than low latency
- Consistent and observable latency



Bounded latency variations

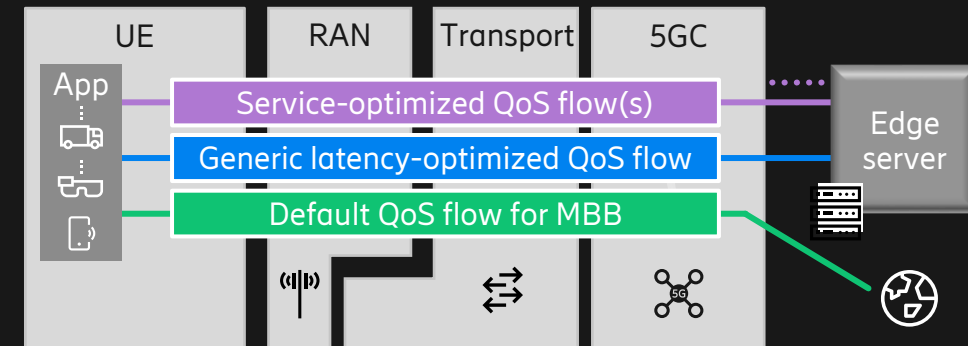
# Time-critical communication



Support of time-critical communication should be part of the first 6G release

## Technology examples

- **Scheduling** – dynamic and configured grants, LCH multiplexing, link adaptation, de-jittering, ...
- **Time synchronization** – end-to-end
- **Observability** – delay-status reports, ...
- **Mobility** – conditional handover, reduced interruption time, ...
- **Congestion control** – ECN marking in L2 headers, ...
- **Slicing** – separate handling of best-effort and time-critical traffic



# Resilient communication



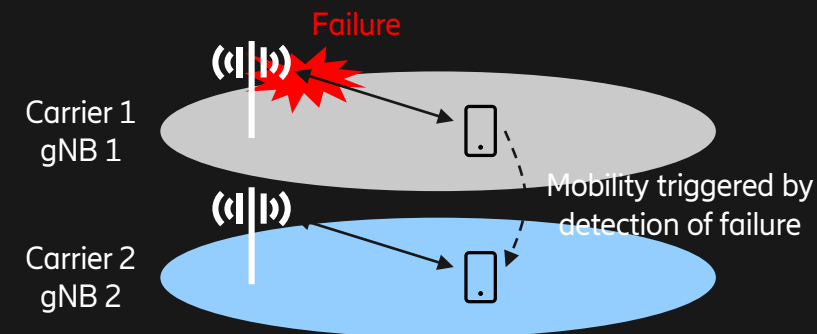
New business models based on service-level agreements and high service availability

- Efficient and cost-effective redundancy to minimize the impact of failures
- Fast detection of failures and failover options



## Technology examples

- **Observability** – measurements and reports, enabling proactive actions
- **Carrier aggregation** and **D-MIMO** providing alternative radio links
- **Mobility** and RLM procedures allowing for handing over UEs from a failing carrier to a well-functioning one

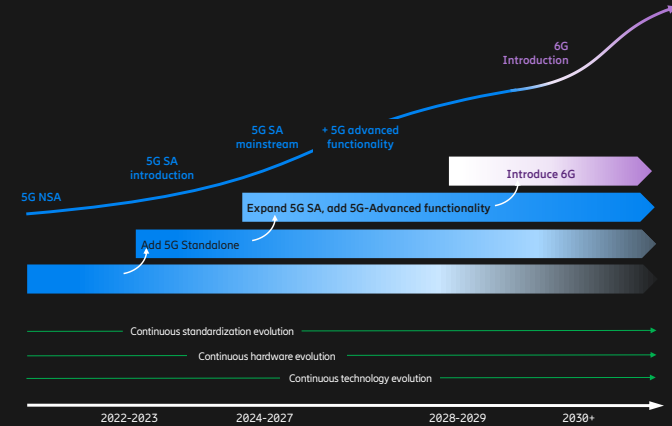


# Conclusion



## 6G standardization is about to start

Commercial availability ~2030 – continuous evolution from 5G



## 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

Support high-value verticals/use cases and deployments *with the general 6G radio access solution*

Time-critical communication  
"The right packet at the right time"

