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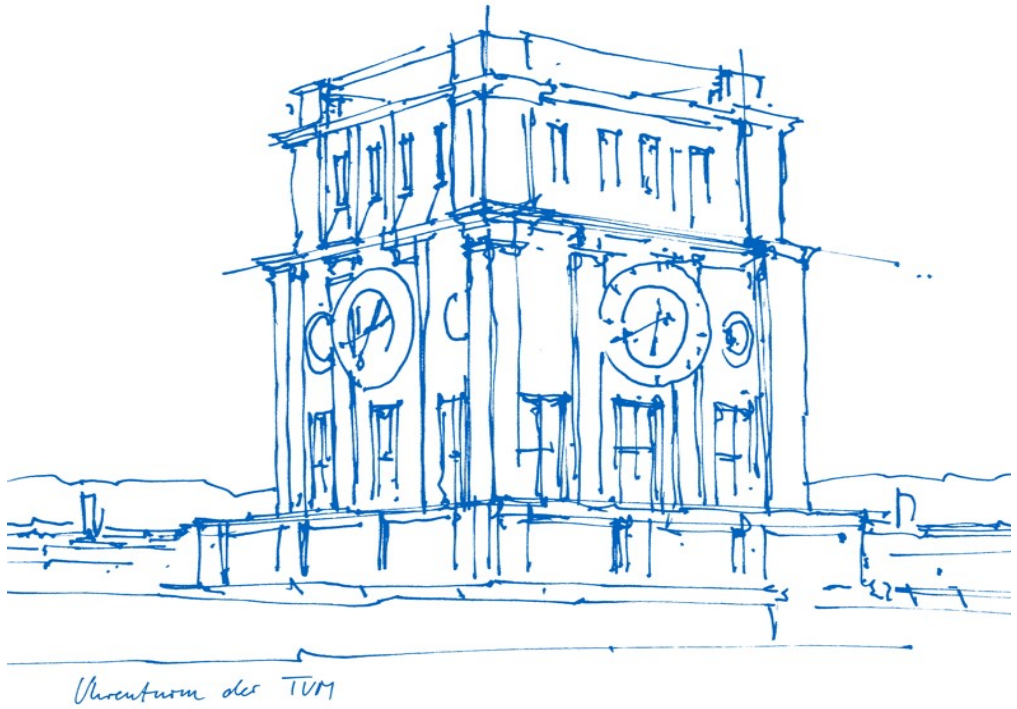
Quo vadis 6G ?

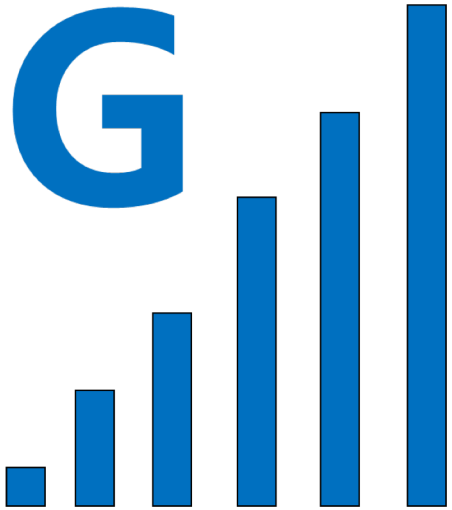
Prof. Dr.-Ing. Wolfgang Kellerer

BASTEI Workshop

16./17.09.2024
Herrsching am Ammersee



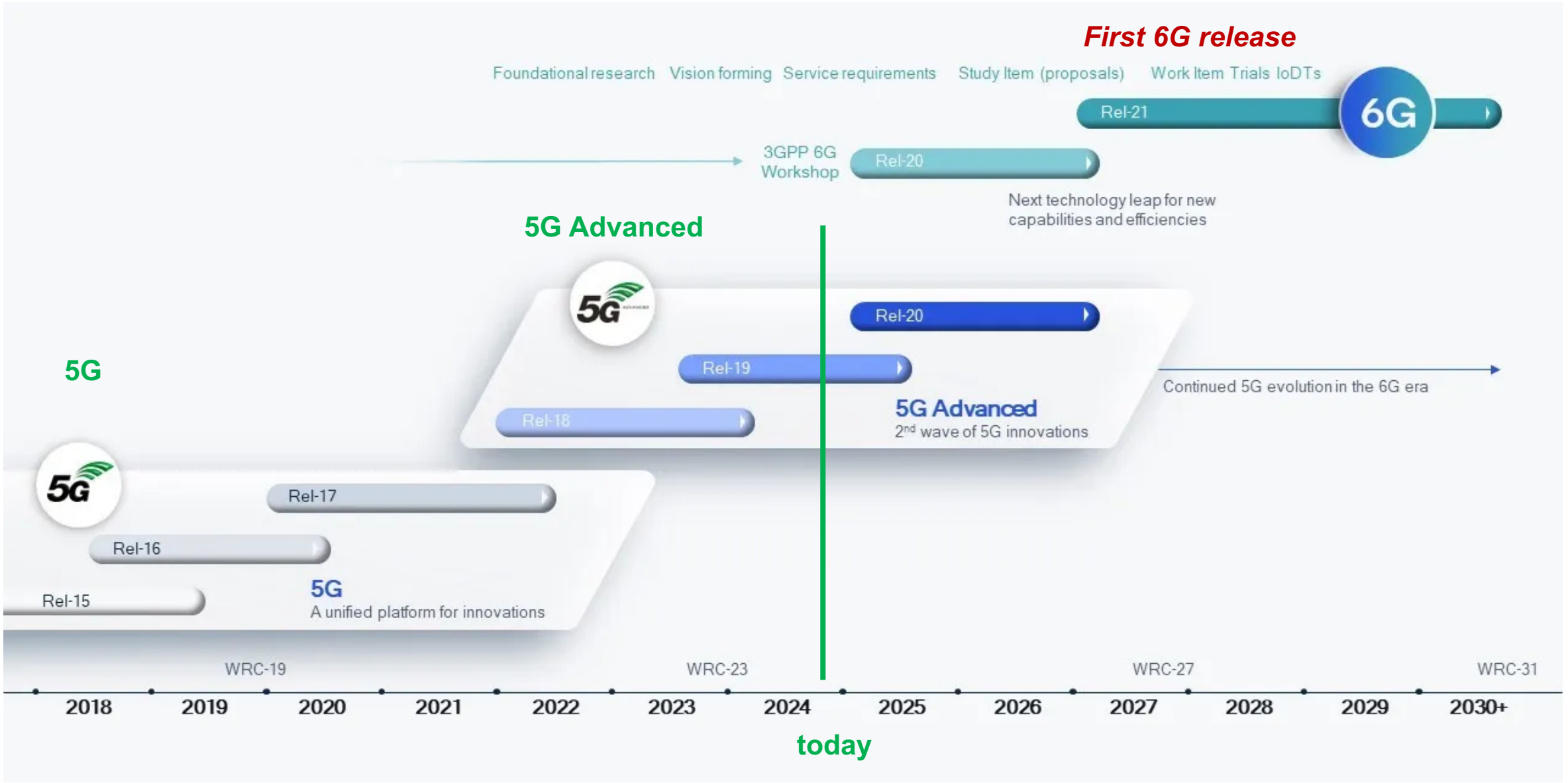
Ubi nunc sumus? *Where are we now?*



Ubi nunc sumus? *Where are we now?*

We have a logo (official 3GPP 6G logo as of April 23, 2024)

Where are we now?



What is 6G?

The Generations („G“) in Mobile Communications

Telephony and SMS

- 14 kbit/s

2G: GSM/GPRS

Internet

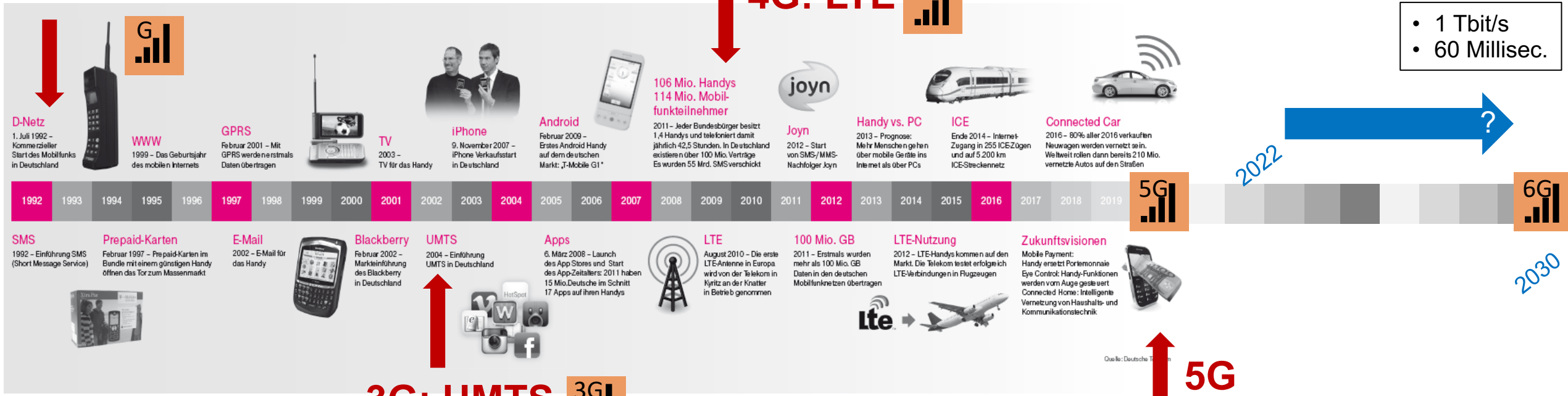
- 1 Mbit/s
- 16 Hrs

3G: UMTS

Data and Video

- 100 Mbit/s
- 9 Min.

4G: LTE



5G

- 1 Tbit/s
- 60 Millisec.

- 10 Gbit/s
- 5 Sec.

Machines communicate

For comparison:
- Data rates
- Download times for a 2 hours HD movie

Is 6G all new?

An evolution of 5G or

a brand new generation?

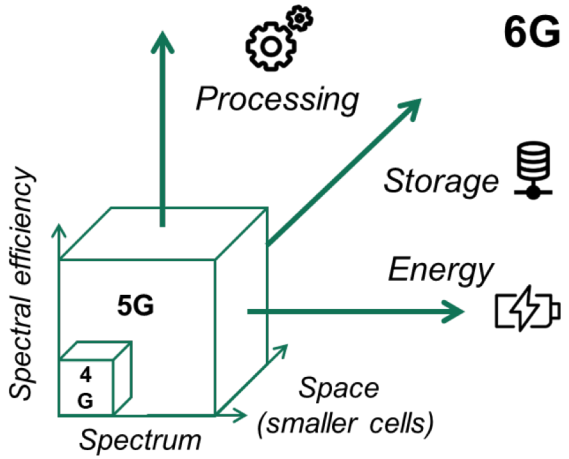
yes *and* yes

depends on your personal viewpoint … and your business

6G is an evolution of 5G

- 5G has paved the way for critical applications and verticals … 6G is realizing it for the masses

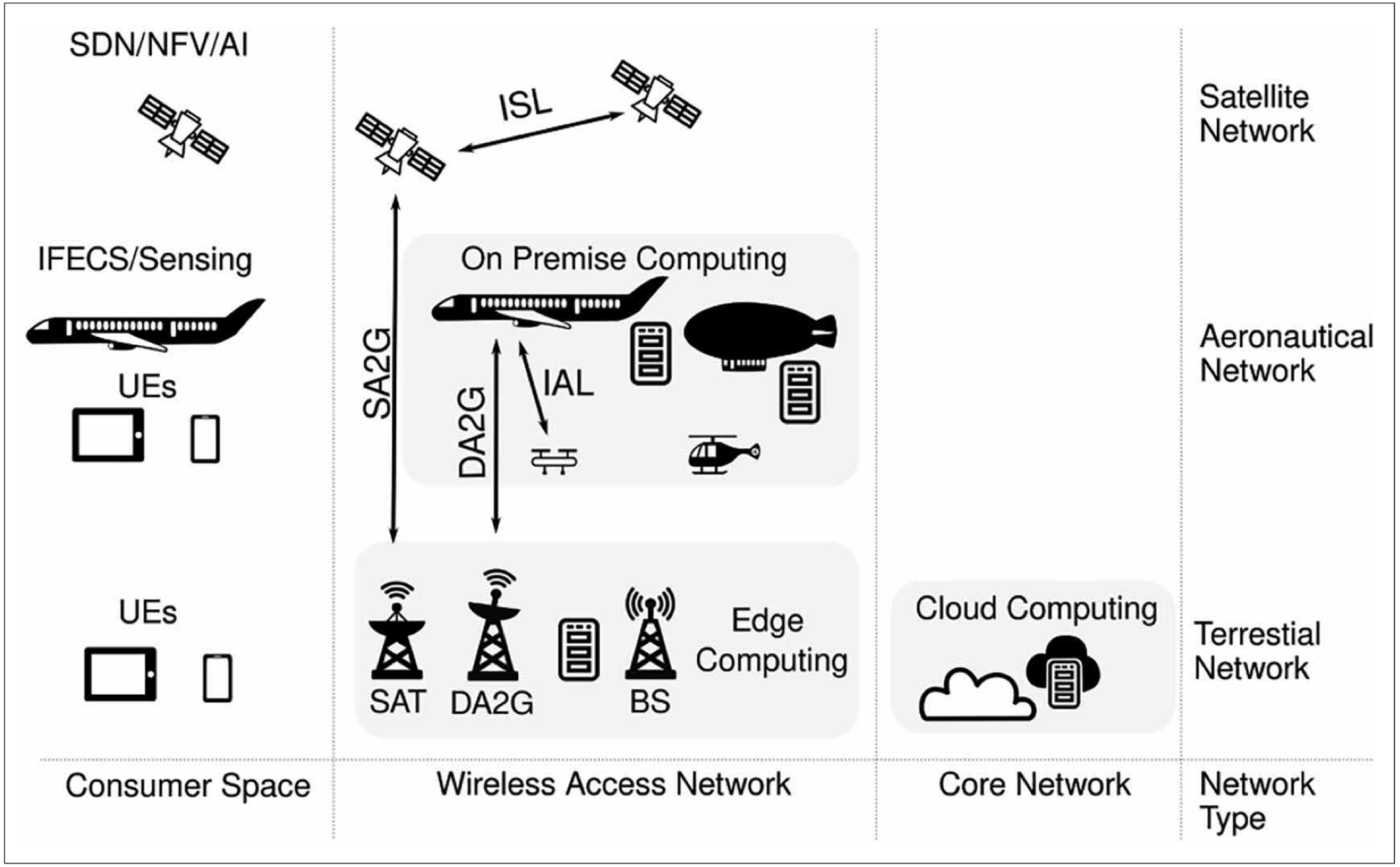
- Ultra low latency, ultra reliable communication
- Network adaptation (communication + processing + storage)
- In-network computing (Mobile Edge Computing)
- Multi-network (network-of networks): Non-terrestrial, LiFi,…
- Security, privacy and trust by design



Processing, storage and energy are included in the 6G system optimization

[6qu22] Trommler, Hafner, Kellerer, et al. Six Questions about 6G, Bayern Innovativ, Münchner Kreis, White Paper, Feb 2022.

Example: Non-Terrestrial-Networks



Papa, Arled; Mankowski, Jörg von; Vijayaraghavan, Hansini; Mafakheri, Babak; Goratti, Leonardo; Kellerer, Wolfgang:
Enabling 6G Applications in the Sky: Aeronautical Federation Framework. IEEE Network **38** (1), 2023, 254-261

Ex: Demonstration of haptic-based teleoperation btw. Dresden and Munich

6G is a new generation

New features in 6G include (*that we have not seen before*)

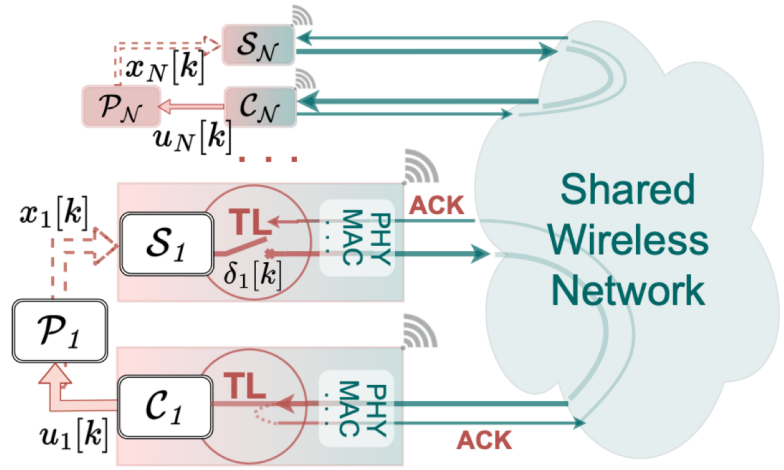
- Terahertz-frequency spectrum
- Joint Communication and Sensing
- Semantic Communications
- AI/ML native
- Digital Twins
- Autonomous Network Management
- Sustainability: end-to-end energy efficiency

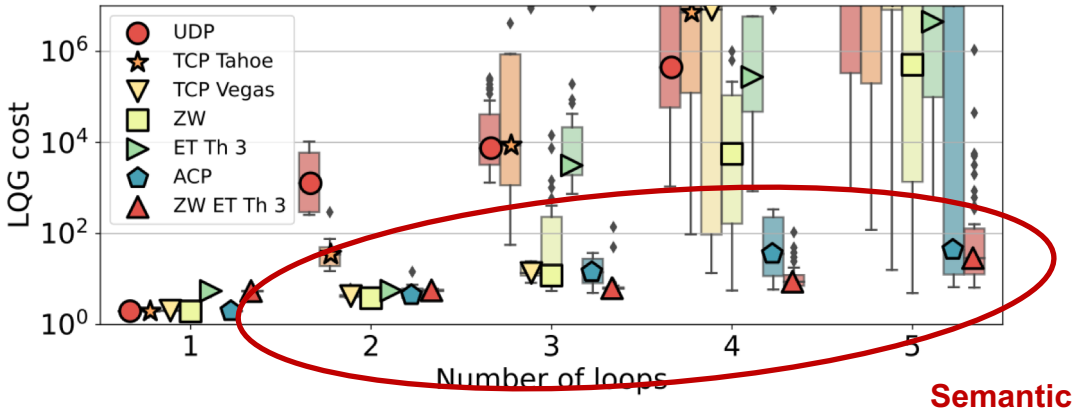
- *Beyond* paradigms: post-shannon communication, quantum networks, molecular networks

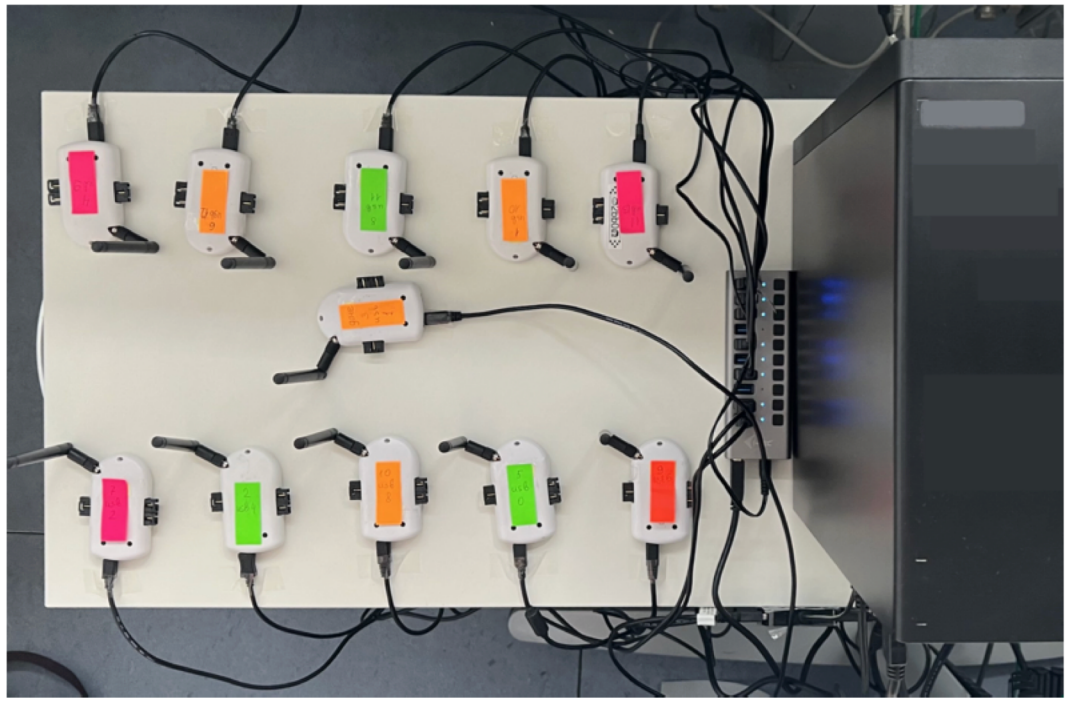
- For integration, 6G needs a **new system concept** – there is no 6G architecture yet

[6qu22] Trommler, Hafner, Kellerer, et al. Six Questions about 6G, Bayern Innovativ, Münchner Kreis, White Paper, Feb 2022.

Example: Semantic Communication (for industrial control processes)







Semantic communication approach shows consistently lower cost

Kutsevol, Polina; Ayan, Onur; Pappas, Nikolaos; Kellerer, Wolfgang:
Experimental Study of Transport Layer Protocols for Wireless Networked Control Systems. IEEE SECON, 2023
Kutsevol, Polina; Ayan, Onur; Pappas, Nikolaos; Kellerer, Wolfgang:
Goal-Oriented Transport Layer Protocols for Wireless Control. IEEE SECON, 2023

Example: Digital Twin supported Indoor Handover

- video

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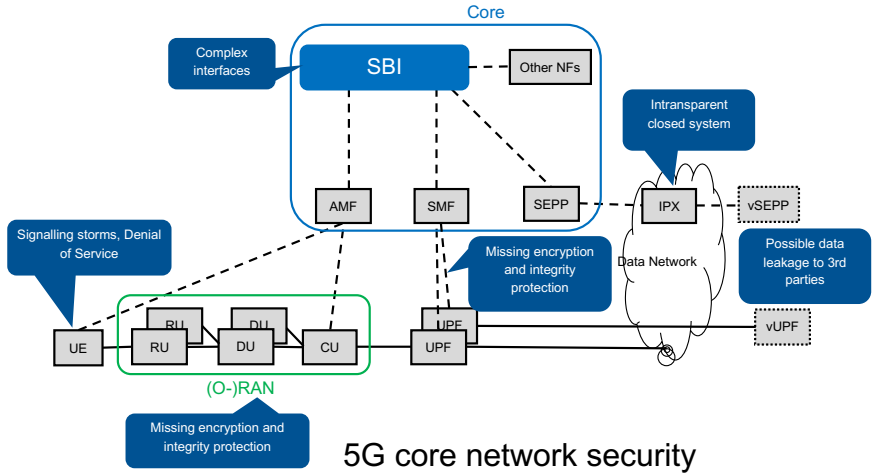
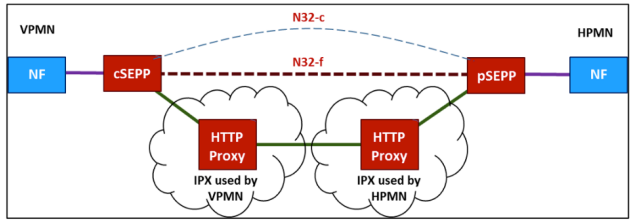
A system view on 5G/6G

- If we want to see 6G features work, we need to take an end-to-end system view
  … and an end-to-end integrated architecture
- 5G
  - 1. RAN NSA
  - 2. Core SBA (see presentation Oliver Zeidler)
  - 3. Open-RAN (O-RAN)
  - 4. Core serves NTN, private network roaming
  - 5. RAN JCAS … (6G)



5G core network security

- 6G: we hope for an integrated end-to-end architecture
  - Joint resource management for RAN, (in-network) processing and data center
  - True end-to-end slicing (for Time Sensitive Networking)
  - Digital Twins for autonomous network management
  - (hope for an) end-to-end security solution …



5G roaming security

6G Security – *by design?*

- Security is an (partially unsolved) issue in all cellular generations
- My take: security is end-to-end - we cannot / should not separate in RAN / Core
- Example: 5G protocol stack
  a) 3GPP security: key derivation and key visibility
  b) IETF: TCP/IP and layer 2 security enhancements

(see presentation by Nicolai Kröger)

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- Security is an (partially unsolved) issue in all cellular generations
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- 6G is a chance
  - New solution concepts, e.g. AI/ML
  - New challenges, e.g. AI/ML

- Examples
  - 6G promises higher flexibility and self-management e.g. to automatically adapt attack detection/mitigation, but AI/ML may open new attack vectors
  - 6G „roaming“ across networks (private, public, NTN,…) opens new interfaces and protocols

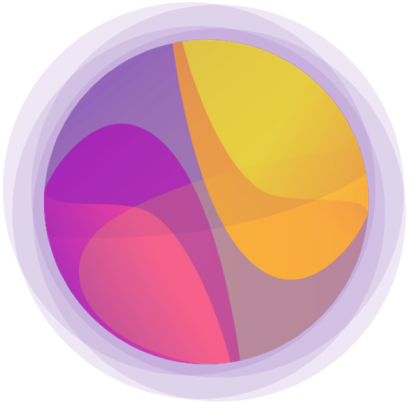
Quo vadis 6G? - Executive Summary

- 6G promises to advance many 5G features
- 6G promises several fundamentally new features
- Standardization starts soon: Release 21 is first 6G release in 2030 (comparable to Rel. 15 in 5G)
- There is no agreed 6G architecture yet
- Security needs more than ever an end-to-end concept
- Challenges
  - New interfaces (O-RAN, multi networks)
  - Flexibility and adaptation
  - AI/ML

This is part of a Future Communications initiative at TUM

- BMBF 6G Research Hub 6G-life
- BMBF 6G Lighthouse 6G-ANNA

- StMWi Bayern 6G Future Lab Bavaria
- StMWi 5G Testbed mit Schwerpunktanwendung eHealth
- StMWi 6G und Quantentechnologie
- STMWi Bayern Innovativ Thinknet 6G



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Literature

- K. Trommler, M. Hafner, W. Kellerer, P. Merz, S. Schuster, J. Urban, U. Baeder, B. Gunzelmann, A. Kornbichler: ***Six Questions about 6G*** – White Paper.
  Bayern Innovativ / Münchner Kreis, 2022.

- K. Trommler, M. Hafner, W. Kellerer, P. Merz, S. Schuster, J. Urban, U. Baeder, B. Gunzelmann, A. Kornbichler: ***Six Insights into 6G***.
  Bayern Innovativ / Münchner Kreis, 2022.

- **The Future of Communication Technology**. Trend Report 2023. Available in the CDTM Bookshop (CDTM – research - bookshop)