Deterministic Communication

Technology evolution and typical scenarios

Dr. Joachim Sachs
Senior Expert, Ericsson Research

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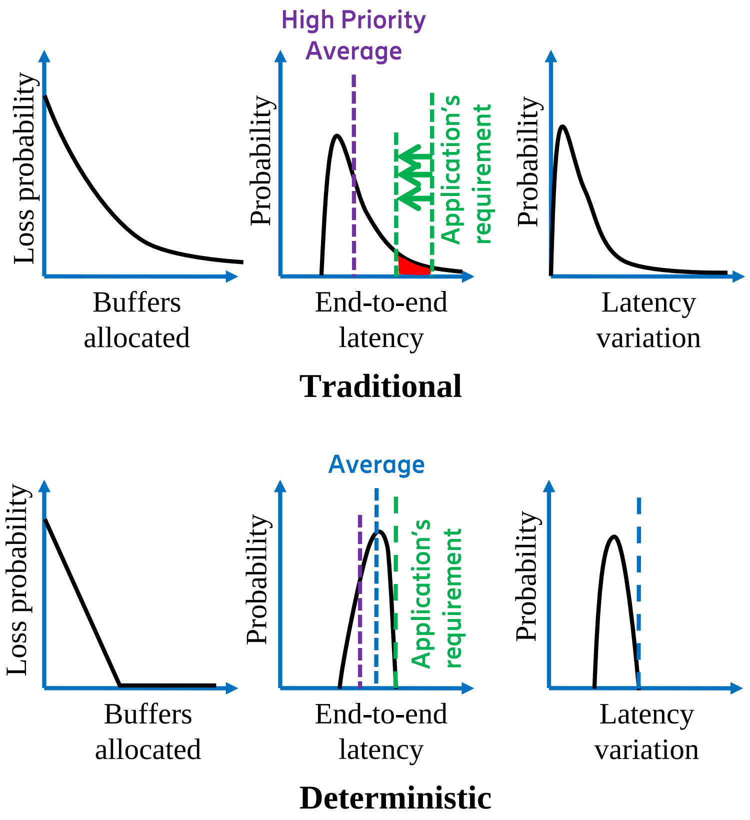
Deterministic Communication

IEEE ComSoc Technology News (Feb. 2021): B. Varga, J. Farkas, D. Fedyk, L. Berger, and D. Brungard, The Quick and the Dead: The Rise of Deterministic Networks

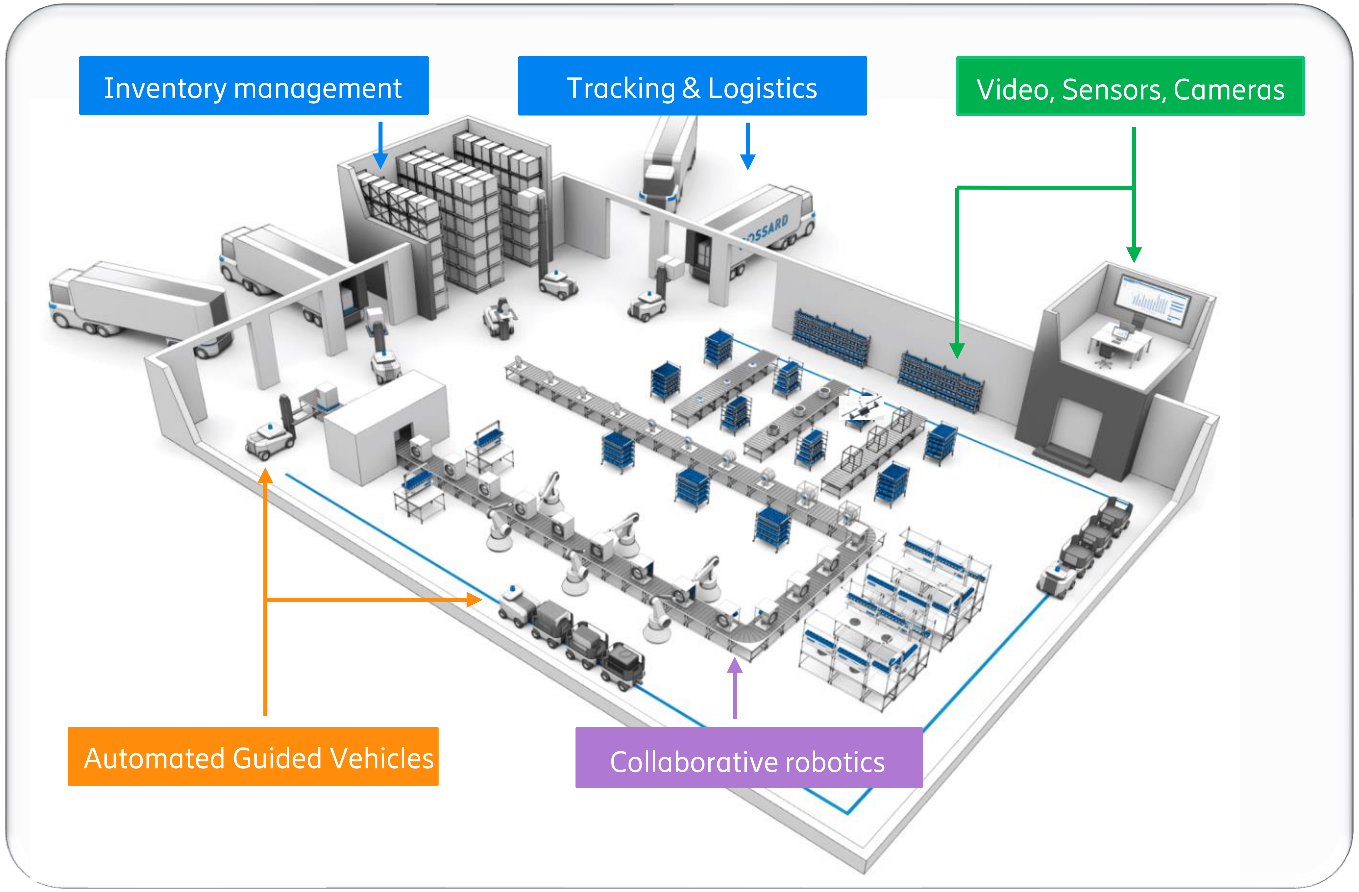
- ***Deterministic Networks***: reliable and predictable network services
  - guaranteed bounded latency and low delay variation per deterministic-flow
  - zero data loss due to congestion for admitted deterministic flows
  - may reject or degrade some flows to maintain the characteristic for the admitted deterministic flows
  - a wide range of applications with different QoS requirements
  - scalable from the localized network to a large, geographically dispersed network



Examples standards

- IEEE 802.1 Time-Sensitive Networking (TSN): deterministic Ethernet services
- IETF WG (IP-based) Deterministic Networking (DetNet)
- 3GPP 5G support of Ultra-Reliable and Low Latency Communication (URLLC)

Example: smart factory embracing industry 4.0



- **Real-time digital representation** of the production
- **Real-time monitoring** inside the factory for process, energy, fleet building the digital representation
- **Digital representation to optimize production**, quality, maintenance, supply, manufacturing management

Deterministic communication – the beginning in industrial automation

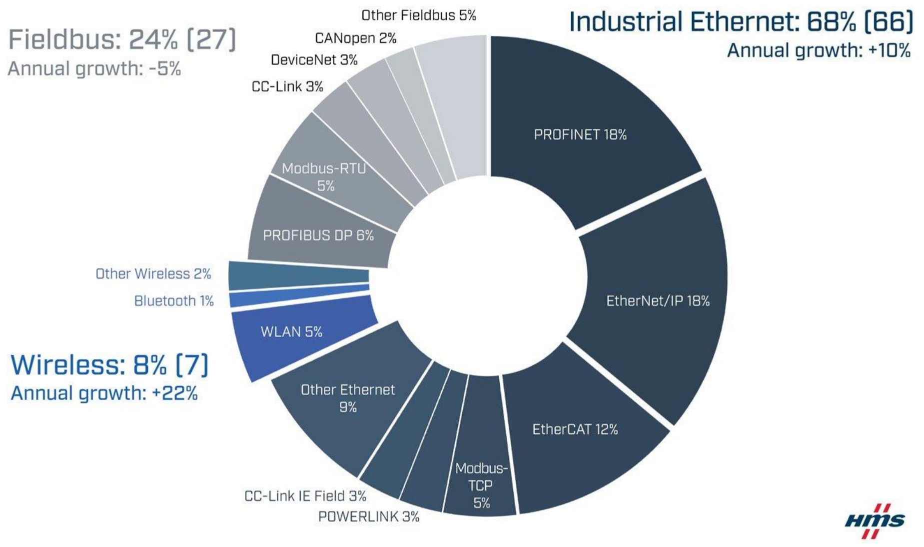
- Strong need for deterministic communication capabilities in industrial automation
  - Most demanding: real-time closed-loop control

- Appearance of many fieldbus technologies (1980's - 2000's)
  - Including Real-time "Industrial" Ethernet variants with (non-compatible) Ethernet modifications (2000's – 2010's)

- Fragmented, non-compatible market (proprietary solutions)
- Typically linked to certain applications
- Limited to smaller network segments
- Complex system integration

➔ Insufficient solution for general deterministic networks

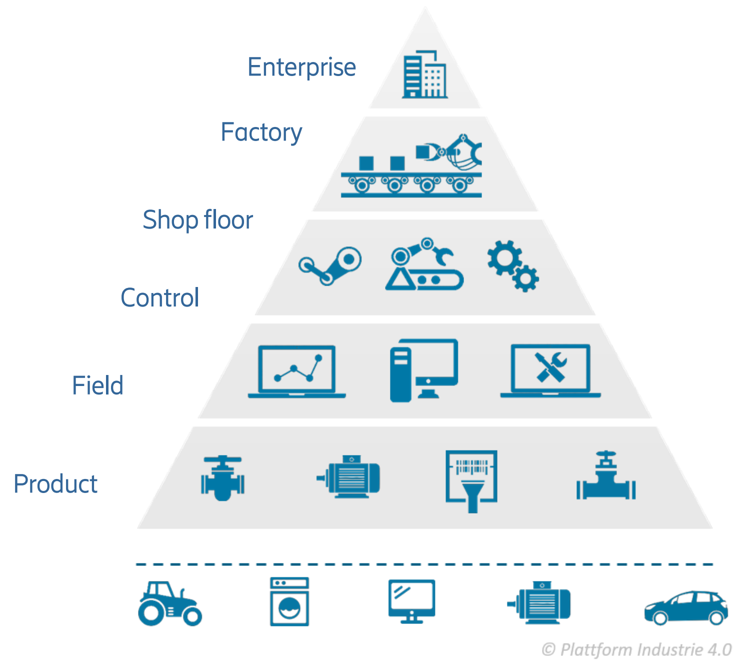
Industrial Network Market (May 2023)



Source: HMS
https://www.hms-networks.com/news-and-insights/news-from-hms/2023/05/05/industrial-network-market-shares-2023

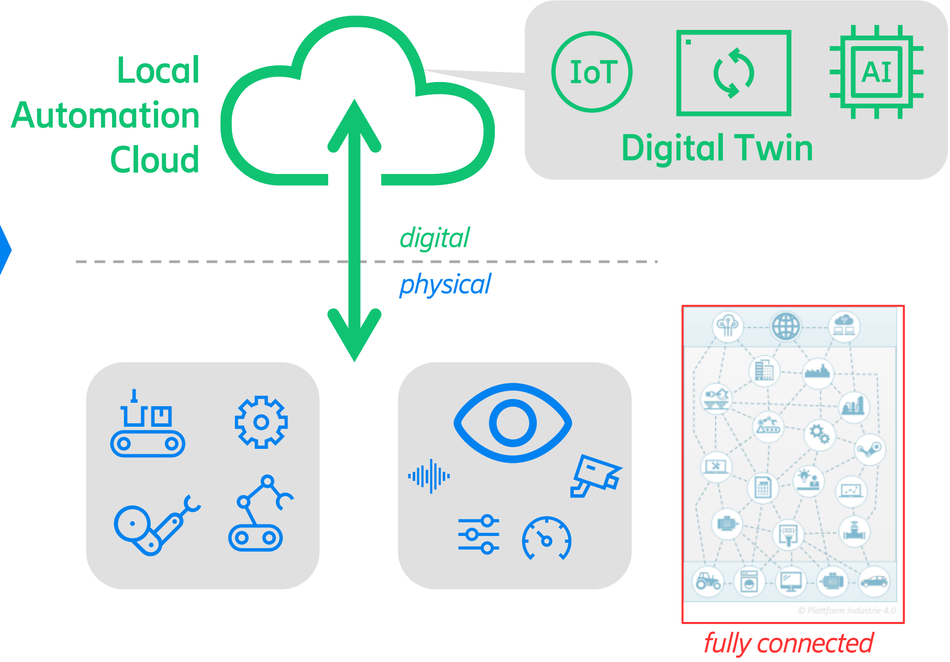
Industry 4.0 via digital transformation

Industry 3.0



- IoT & M2M
- ML and AI
- Automation and cyber-physical production systems
- …

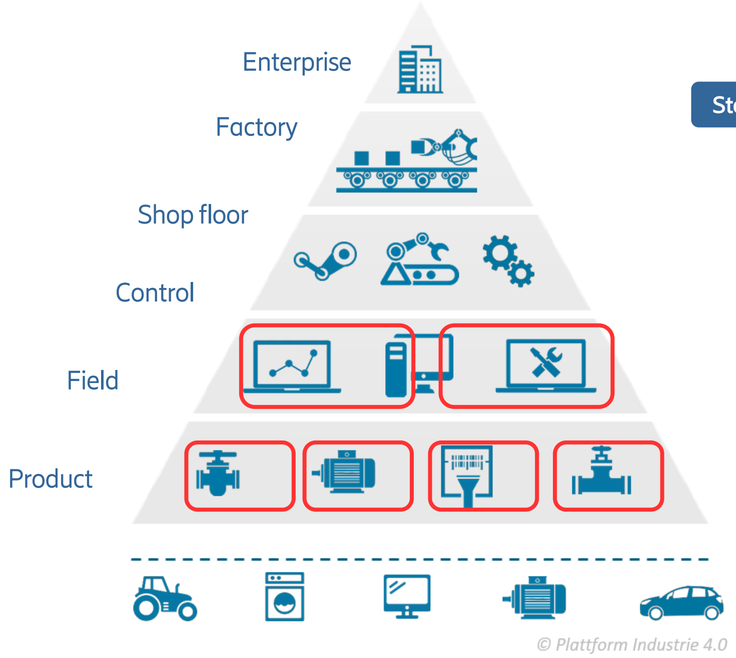
Industry 4.0

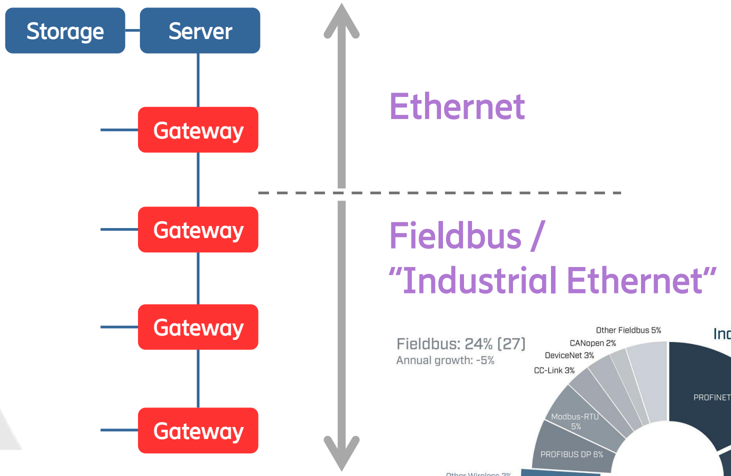


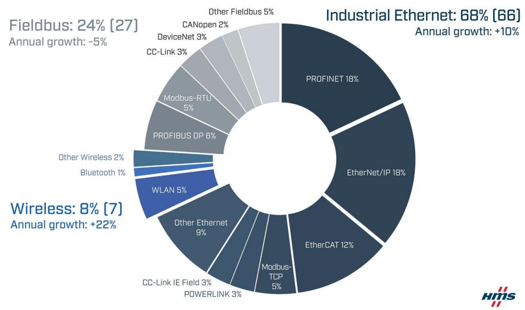
Industry 4.0 via digital transformation

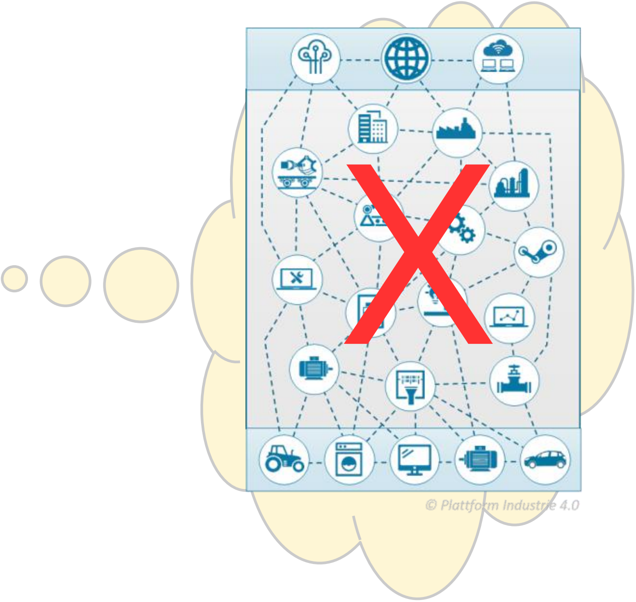
Segmentation and compartmentalization for deterministic network performance

→ "embedded compute" per segment instead of "central edge compute"









Network transformation via deterministic communication based on global open standards

Industry 3.0

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Hierarchical network design

Network transformation:
→ novel IIoT opportunities for Industry 4.0

- Simplified, harmonized communication network for all services
- Flexibility in network architecture and deployment
- → Fully transparency across all processes and assets at all times
- → Novel paradigms like (edge) cloud computing, digital twins, AI/ML

Time-Sensitive Networking (wired)

5G (wireless)

Industry 4.0

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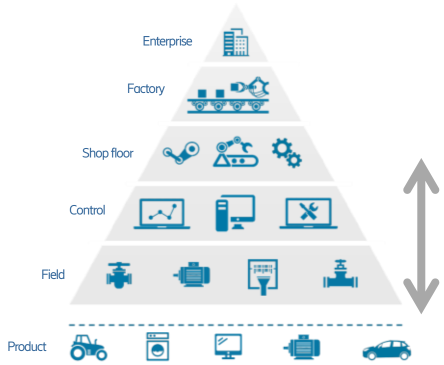
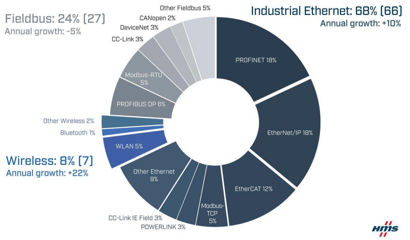
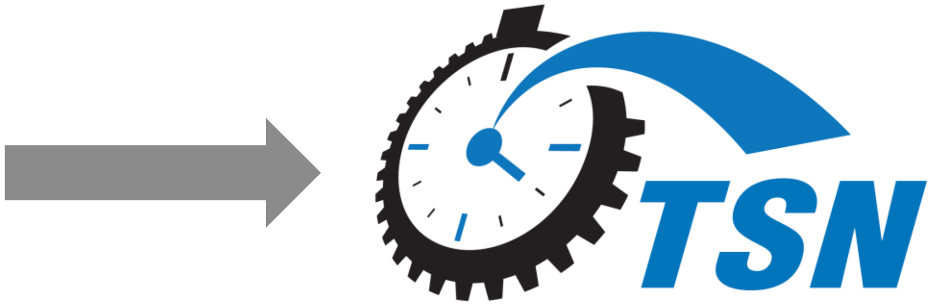
Fully connected design

TSN: the future of wired deterministic real-time communication in industrial automation



Fieldbus / "Industrial Ethernet"





Industry consensus: (industrial) deterministic wired networking will migrate to TSN.

IETF DetNet expands use cases to larger IP network domains.

OPC Foundation: „Status of OPC UA over TSN Standardization", TSN Technology&Applications conference (TSN/A), October 2020. https://events.weka-fachmedien.de/tsna-conference/home/

Industrial Internet Consortium: Time Sensitive Networks, https://www.iiconsortium.org/time-sensitive-networks.htm

5G-ACIA, "Integration of 5G with Time-Sensitive Networking for Industrial Communications", Jan 2021. https://5g-acia.org/whitepapers/integration-of-5g-with-time-sensitive-networking-for-industrial-communications/

„An Introduction to OPC UA TSN for Industrial Communication Systems", Proceedings of the IEEE, June 2019. https://ieeexplore.ieee.org/document/8610105

Shortcoming of fixed connectivity

- Industry 4.0: from static to dynamic production environments, with frequent or on-the-fly configuration
  - ➔ significant limitations of cabled connectivity
- Mobility increasingly used in AMRs/AGVs, sensors connected to assets, HMI (incl. AR), …
  - ➔ impossible with cabled connectivity
- Ease of deployment of connected devices and broader adoption of Industrial IoT
  - ➔ difficult/costly to add connectivity for new sensor (actuator) deployments

Desire for "Wireless TSN" or "Wireless DetNet"

5G provides the "Wireless TSN/DetNet" opportunity
(Not possible with any other standardized wireless technology until today)

2030 – A cyber-physical world

Human and society needs

The Internet of Senses

Digitalized and programmable world

Connected intelligent machines

Connected sustainable world

Digital reality

Physical reality

Cyber-physical world enablement (examples)

Sensing

Cyber-physical mapping and analysis

Preventive action

6G network platform

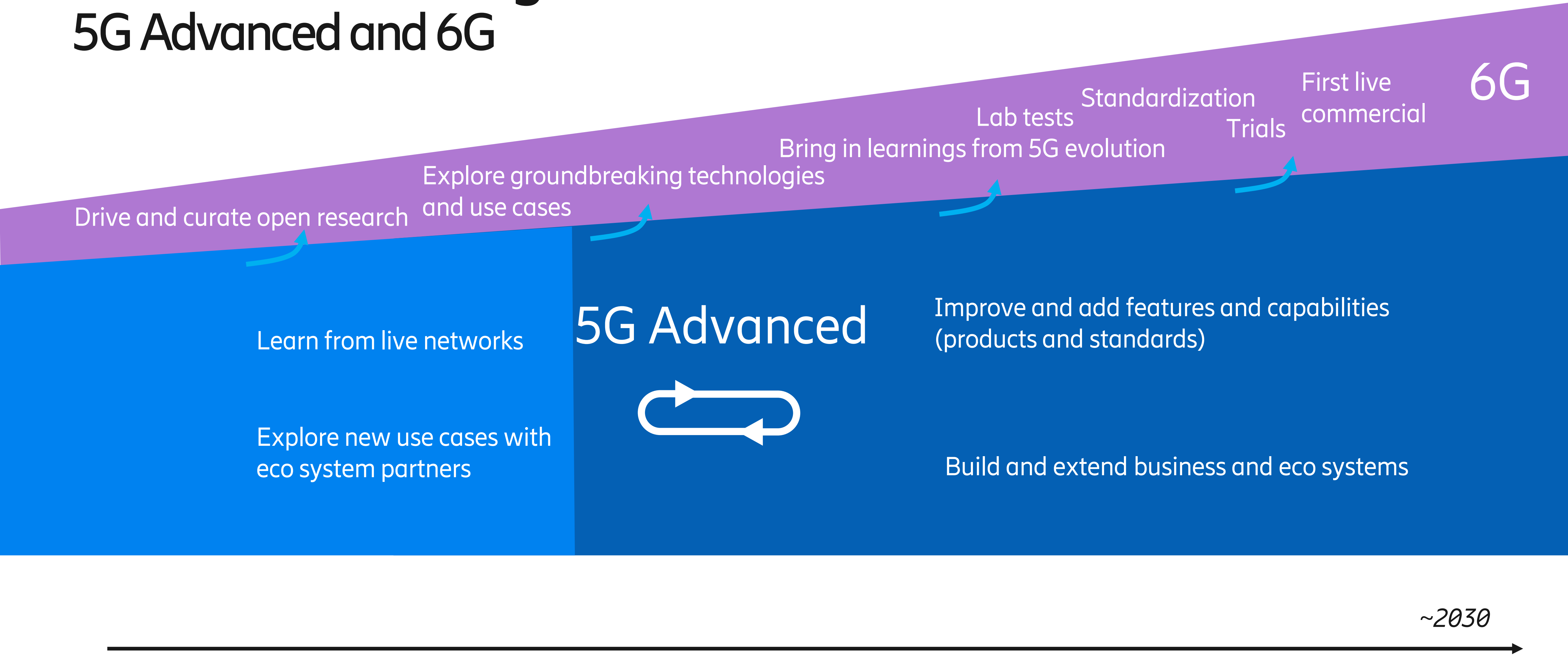
Limitless connectivity

Trustworthy systems

Cognitive network

Network compute fabric

Evolution and long-term horizon
5G Advanced and 6G



5G integration with TSN in Non-public networks

Non-public Network

Dedicated 5G network service to the industry customer

→ guaranteed availability, data security & privacy

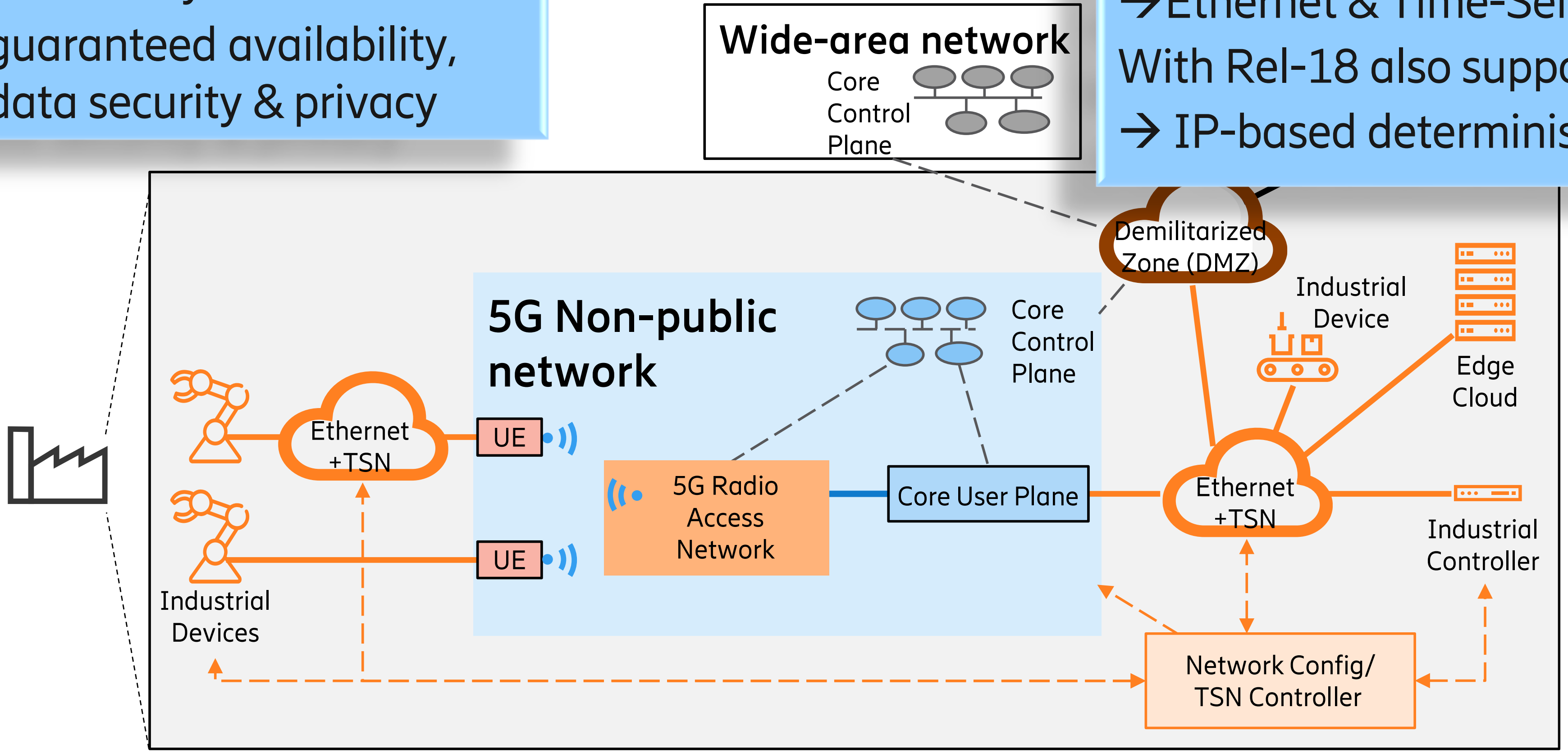
TSN support

5G network integration with (fixed) industrial networks

→Ethernet & Time-Sensitive Networking (TSN)

With Rel-18 also support for **DetNet support**

→ IP-based deterministic networks



3GPP 5G standard addresses industrial needs

Rel-15

Foundation for URLLC (Ultra Reliable Low Latency)
- First 5G release
- Key features for low latency and high reliability

Rel-16

Industrial IoT
- Support for IEEE time sensitive networking (TSN)
- Non-public network enhancements, positioning, time-sync

Rel-17

Efficiency and scale
- Enhanced efficiency and capacity for URLLC
- Improvements for positioning and time sync

Rel-18

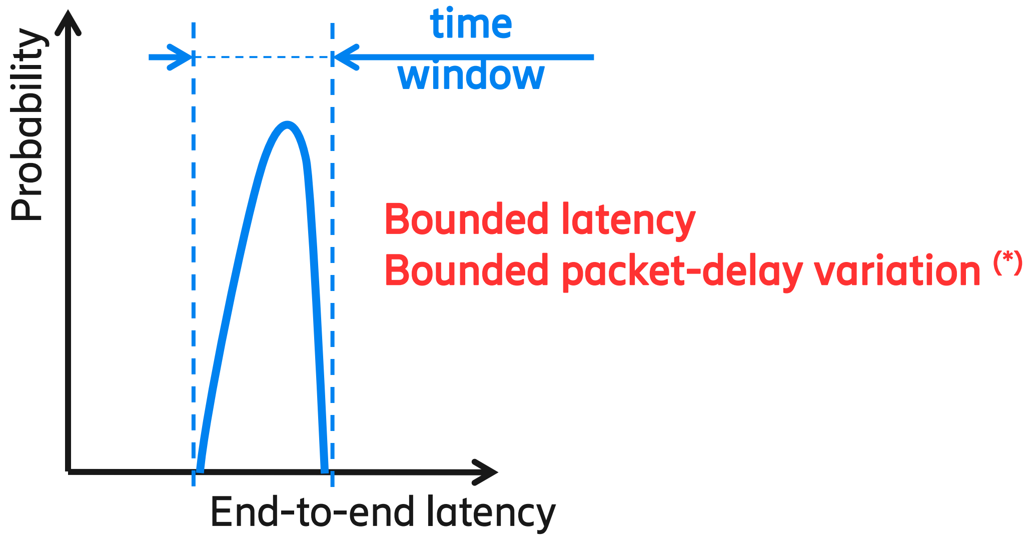
Expand use cases
- Support/optimizations for eXtended Reality (XR)
- Support for IETF deterministic networking (DetNet)

The foundation of Deterministic Communication

➔ **The Right Packet at The Right Time**

Deterministic data packet delivery =

Data packet delivery within a time window without loss or delay due to congestion or errors



Deterministic Communication makes the communication **plannable** for the external domain:

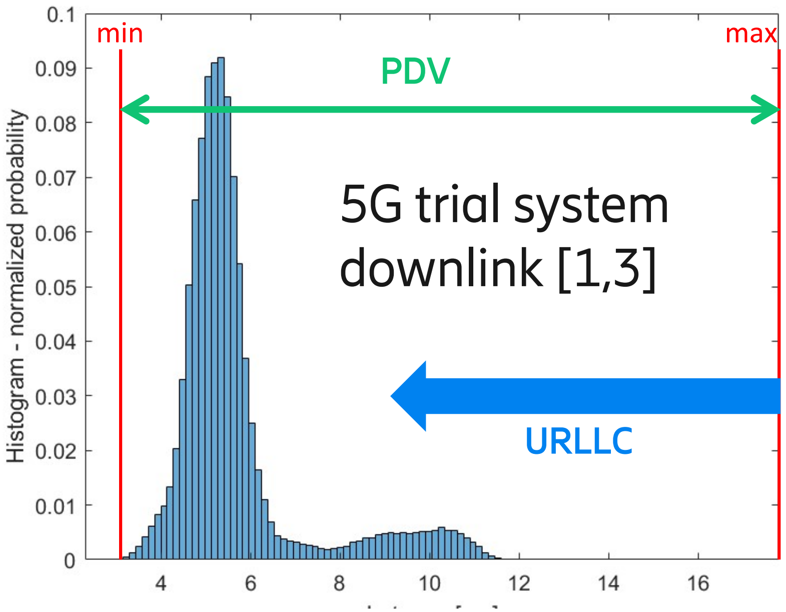
- the applications
- the TSN / DetNet network domains

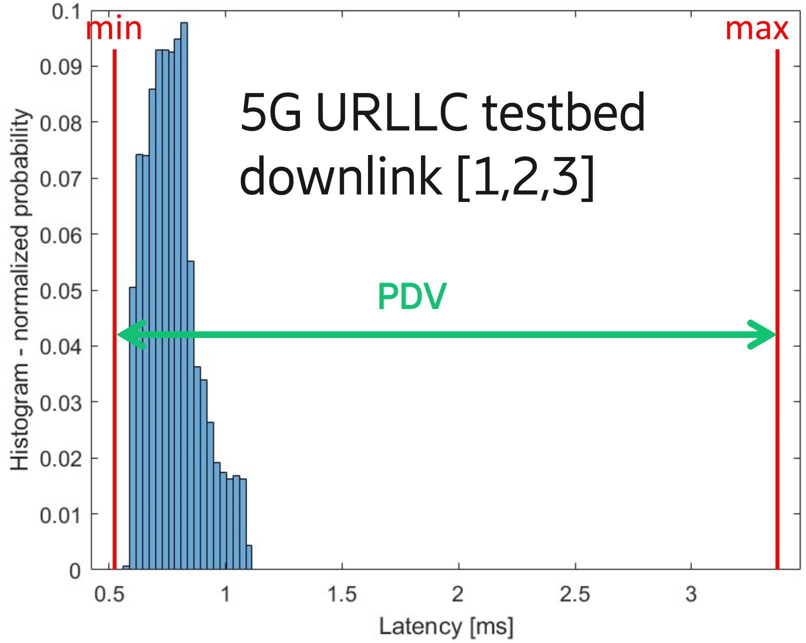
(*) also referred to as jitter

Latency performance in 5G

- Trial activities with 5G
  - Bounded latency performance with large packet delay variation (PDV), due to e.g. TDD pattern, HARQ
  - Large PDV difficult to plan for by TSN controller [4]

- URLLC can push down the maximum, i.e. latency bound
  - But still with large packet delay variation





[1] J. Ansari, C. Andersson, P. de Bruin, J. Farkas, L. Grosjean, J. Sachs, J. Torsner, B. Varga, D. Harutyunyan, N. König, R. H. Schmitt, "Performance of 5G Trials for Industrial Automation. Electronics", 2022; 11(3):412. https://doi.org/10.3390/electronics11030412

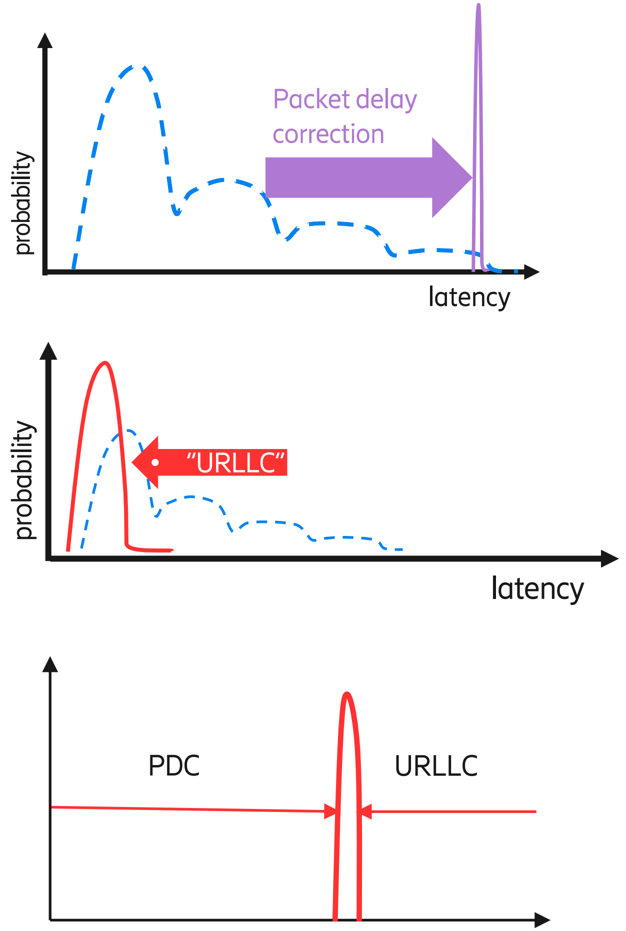
[2] P. Kehl, J. Ansari, M. H. Jafari, P. Becker, J. Sachs, N. König, A. Göppert, R. H. Schmitt, "A Prototype of 5G Integrated with TSN for Edge-Controlled Mobile Robotics" Electronics 11, no. 11: 1666, 2022. https://doi.org/10.3390/electronics11111666

[3] DETERMINISTIC6G, "Digest on First DetCom Simulator Framework Release", deliverable D4.1, Dec. 2023, https://deterministic6g.eu/index.php/library-m/deliverables

[4] DETERMINISTIC6G, "Report on 6G convergence enablers towards deterministic communication standards", deliverable D3.1, Dec. 2023, https://deterministic6g.eu/index.php/library-m/deliverables

Deterministic Latency performance in 5G

- Deterministic latency can be achieved by removing latency variation in the 5G system
  - “Packet Delay Correction” [1]
  - Discussed in SA2 Rel-16 as de-jittering via Hold-and-Forward buffering
- Alternatively, TSN & DetNet could be made more robust against delay variations [2]
  - Relevant for wireless connectivity, but also cloudified applications



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[2] DETERMINISTIC6G, “Report on 6G convergence enablers towards deterministic communication standards”, deliverable D3.1, Dec. 2023, https://deterministic6g.eu/index.php/library-m/deliverables

From Deterministic Communication to Dependable Communication

- Strict review of *determinism*:
  - a system without or with negligible stochastic variations
  - a system behaves in a pre-determined way from a certain state with a given input
- But stochastic variations are fundamentally included in some digitalization enablers
  - Cloud computing, wireless communication, (adaptive) applications
- Eliminating stochastic elements not always feasible,
  - ➔ Embrace stochastic elements that are not pre-determined
  - ➔ … make them predictable and plannable,
  - ➔ … manage them to fullfill the requirements of the applications and utilize flexibility and adaptability
  - Provide *dependable communication* for time-critical services

[1] DETERMINISTIC6G, "DETERMINISTIC6G use cases and architecture principles", deliverable D1.1, Dec. 2023, https://deterministic6g.eu/index.php/library-m/deliverables

[2] DETERMINISTIC6G, "Report on 6G convergence enablers towards deterministic communication standards", deliverable D3.1, Dec. 2023, https://deterministic6g.eu/index.php/library-m/deliverables

Dependable Mobile Networks for Time-Critical Applications

Dependable communication :

Be able to quantitatively ascertain the delivery of required service performance for the communication as it has been agreed.

- Builds on time-critical communication enabled with Ultra-reliable and low latency communication capabilities
- Requires service specification with application requirements via network exposure
- Requires observability for service performance monitoring and prediction
- Potential for feedback to the application domain and enabling application-network coordination

Dependable E2E communication with 6G

Project coordination: Ericsson, Technical coordination: KTH, Project start: January 2023, Project duration: 30 months, Contact: coordinator@deterministic6g.eu, deterministic6g.eu

E2E dependable system architecture

6G challenges and vision

System aspects for dependable E2E communication

- 6G use cases requiring dependable tme-critical communication
- Deterministic service definition (KPI/KVI)
- Security analysis

Dependable communication technology enablers

- Deterministic 6G wireless transmission design
- Data driven characterization for 6G wireless system
- E2E time synchronization

- Deterministic communication standards (TSN, DetNet) Evolution
- Edge computing solution for dependable communication
- Situational awareness via digital twins
- Security countermeasures

Validation framework

- System level modelling
- Data driven model evaluation and validation
- System level simulations

Beyond DETERMINISTIC6G

DETERMINISTIC6G has received funding from the Smart Networks and Services Joint Undertaking (SNS JU) under grant agreement No.101096504. The SNS JU receives support from the European Union's Horizon Europe research and innovation programme

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