PREDICT 6G

Can TSN be the standard communication protocol for robotics ?

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EuCNC WS10: Future deterministic programmable network for 6G

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About me

- Researcher at UC3M (~5 years).
  - Telematics department, part of NETCOM research group
- PhD in the field of Networked robotics
- Current research interests: JCAS, Semantic orchestration, TSN
- Background
  - AI for teleoperated robots
  - DLT for mobile robot services
  - Robot as a Network Service

Outline

- Provide a brief introduction of Networked robotics
- Present the current Networked robotics communication protocols
- Time Sensitive Networking for robotics

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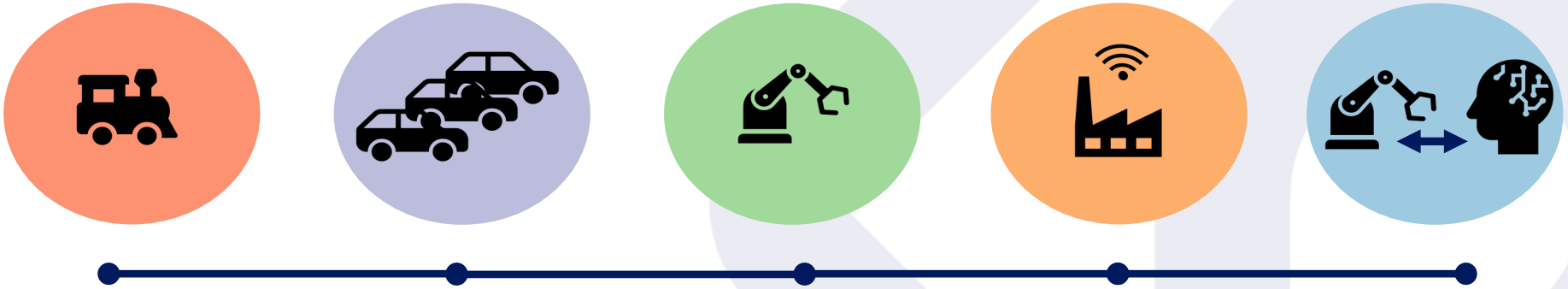
Industrial revolutions



Industry 1.0

Mechanization, *water and steam powers*

1800

Industry 2.0

Mass production, *electric power, assembly line*

1900

Industry 3.0

Automation, *electronics, IT and robotics*

2000

Industry 4.0

Connectivity, *Cyber-physical systems, ML*

2010

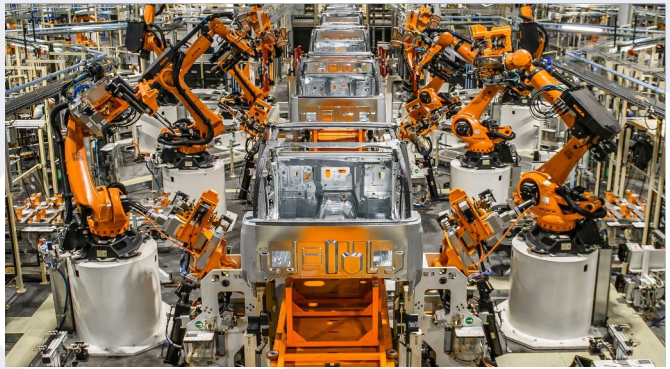
Industry 5.0

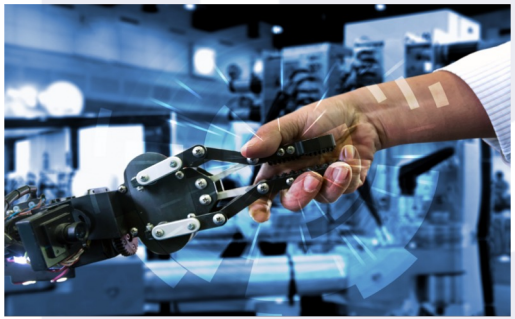
Customization, *human-robot collaboration*

2020

Robotics in manufacturing

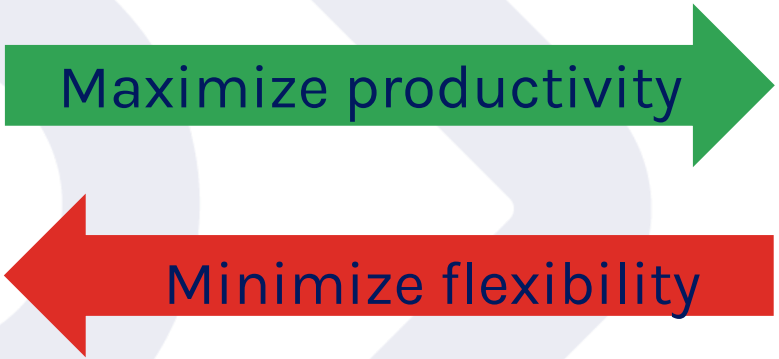
- In 2018, < 10% of the US manufacturing firms used robots
- In 2020 this number even decreased
- China is estimated to be roughly the same as in US





Productivity limits flexibility

1. Automation technologies are not adaptable to changes in external environment
2. Require specific, deep technical skills to program and repair them
3. Black boxes operating without the human feedback

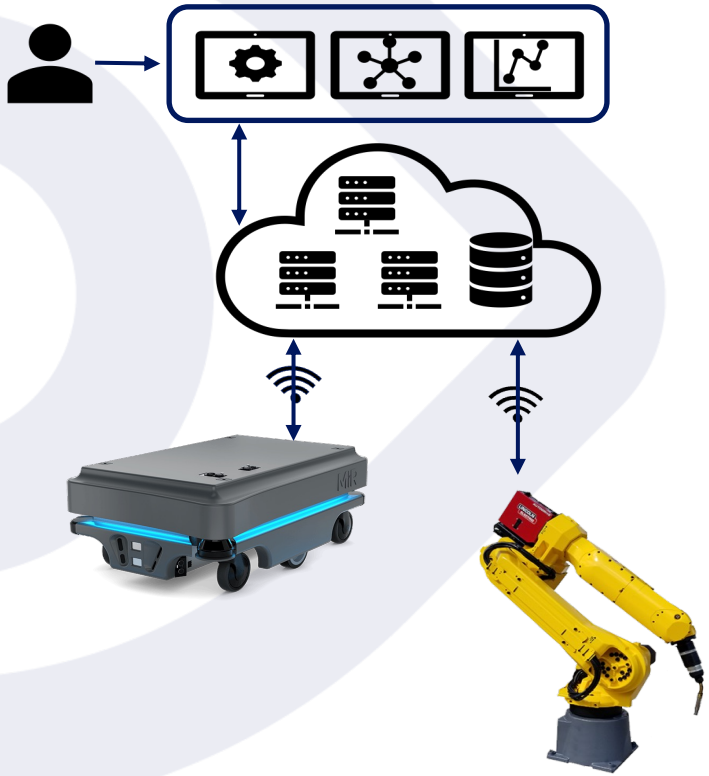


What is networked robotics?

- Set of evolving **Information and Communication Technologies (ICT)** that allow, at different levels of granularity to model a robot system as a set of individual components that are glued together.
  - Started from Online robot systems (Internet robots)
  - Allows for OT and IT to co-exist
- Provides flexibility by making robots:
  - Service oriented
  - Interoperable
  - Distributed
  - Programmable
- Target different use cases:
  - Industrial robots, telepresence robots, social robots, etc

Cloud robotics example

- Robots
  - Joint states
  - Multiple sensors
    - Camera
    - Lidar
    - Mics
- Control
  - Robot config
  - Monitoring
  - Cooperation and coordination
- Why networked robotics?
  - Optimize automation
  - Availability
  - Reduce costs



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Current infrastructure behind networked robotics

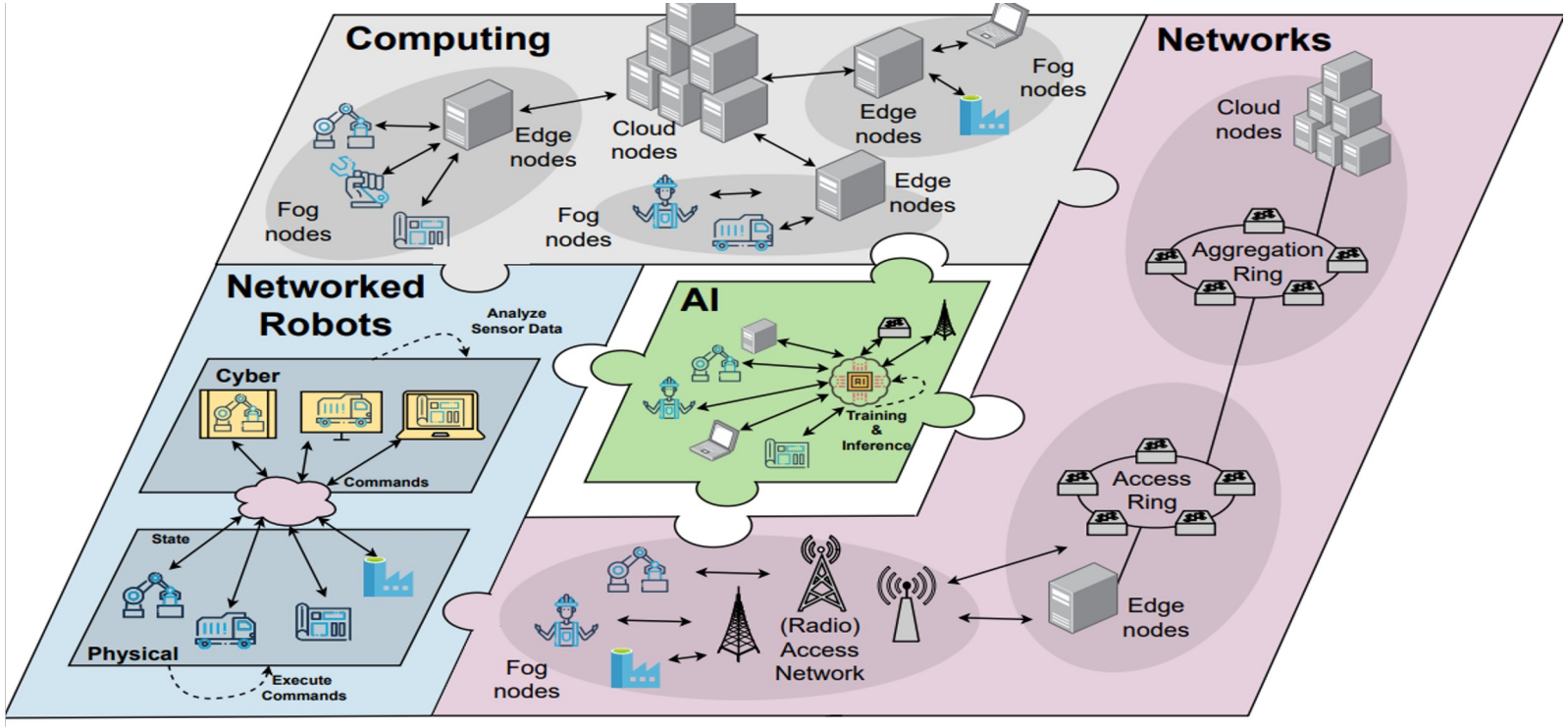

Figure 1: The computing and communication infrastructure [1].

[1] M. Groshev et. al., "Toward Intelligent Cyber-Physical Systems: Digital Twin Meets Artificial Intelligence," in *IEEE Communications Magazine*

Robots traffic profile connectivity requirements

Application	Traffic Profiles	Throughput	Latency	Reliability	Mobility	Availability
Remote control and navigation; Control loops; Visual analytics;	Isochronous flows; Asynchronous messages;	Low (isoc./ async.) Low to High (video)	100 - 0.1 ms 100 – 10 ms	99.9 to 99.99999%	Low mobility (mostly indoor)	High

Table 1: Robot traffic flows and connectivity requirements [2]

[2] D. Cavalcanti et al., "WiFi TSN: Enabling Deterministic Wireless Connectivity over 802.11," in *IEEE Communications Standards Magazine*

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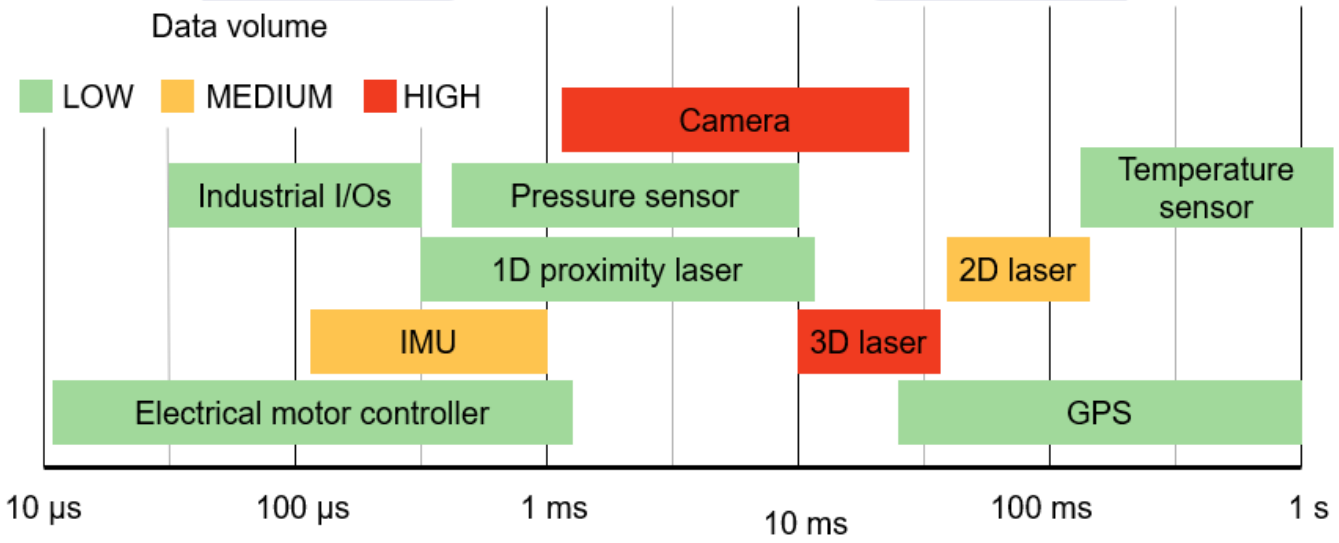

Figure 2: Typical response-time of common robotic components

Networks

- Wired technologies
  - Serial-based field busses
    - RS-485, CAN
  - Ethernet-based field-busses
    - IEEE 802.3
- Wireless technologies
  - Licensed spectrum
    - 3GPP
  - Unlicensed spectrum
    - IEEE 802.11

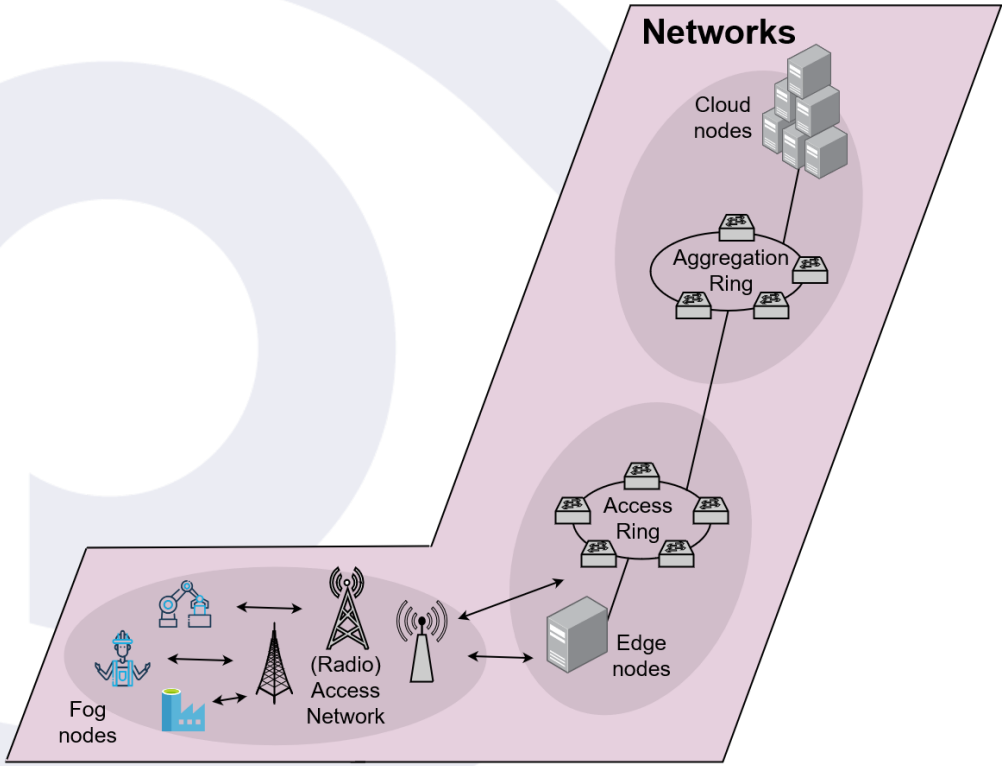

Figure3: Different network segments that the robot flows need to travers

Industrial communication protocols today

- Natively designed for local connections or other applications (e.g., IoT, Web).
- Can not meet all the requirements of different robot applications.
- Interoperability.
- Difficulties to cope with the unreliable and interface prone wireless channel.

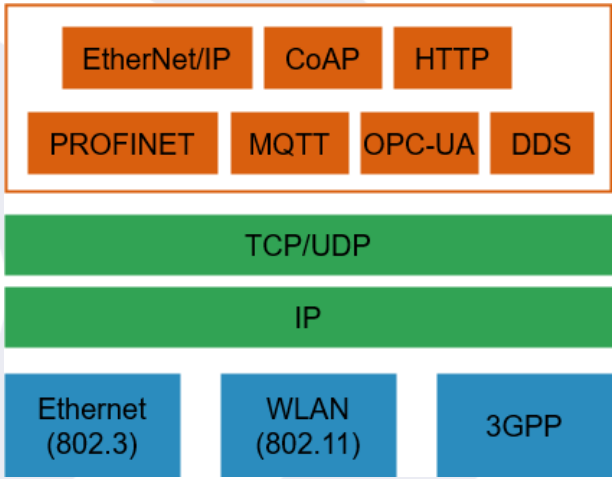

Figure4: Classification of real-time industrial protocols for robotics

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TSN reference model

- Set of evolving standards developed by IEEE to allow for time-sensitive traffic on Ethernet, WiFi and 5G.
- Provides time synchronization and bounded latency.
  - Determinism is prioritized over throughput
- TSN tools include time synchronization (802.1 AS), scheduled traffic (802.1Qbv) and network management (802.1Qcc)
- Bring to robotic systems:
  - Scalability, **flexibility**, interoperability, coexistence, latency guarantees, reliability

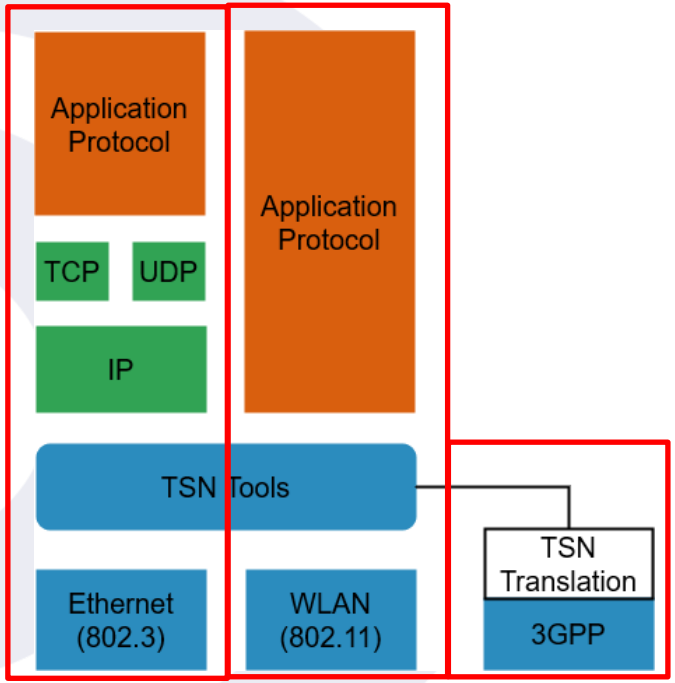
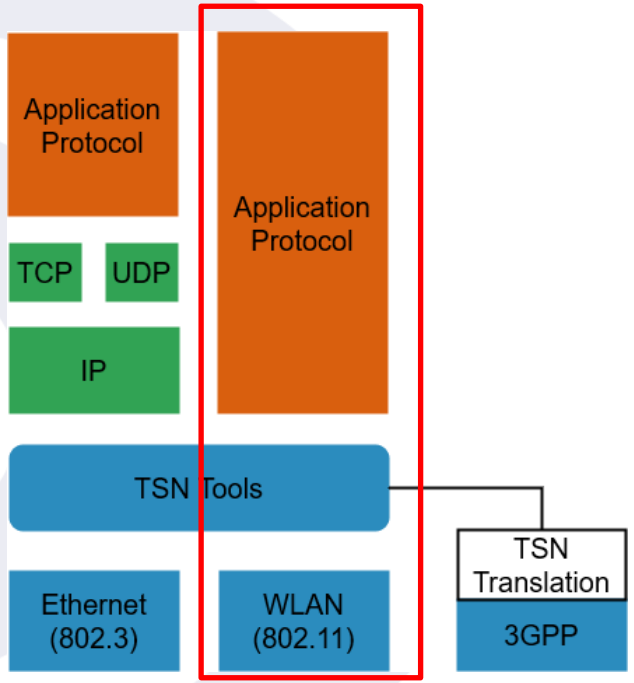


Figure5: Wired and Wireless TSN Reference Protocol Stack [2]

[2] D. Cavalcanti et al., "WiFi TSN: Enabling Deterministic Wireless Connectivity over 802.11," in *IEEE Communications Standards Magazine*

IEEE 802.11 TSN for robotics

- **Time Synch over 802.11**
  - **802.11AS**
- Time-Aware Scheduling for missing-critical robotics flows over 802.11
  - 802.1Qbv
- Redundancy to improve reliability
  - FRER (IEEE 802.1 CB)
- Network Management Models to meet the end-to-end robotics requirements
  - IEEE 802.1Qcc
- IEEE 802.11bf (WiFi7)
  - Multi-link Operation
  - rTWT for scheduling



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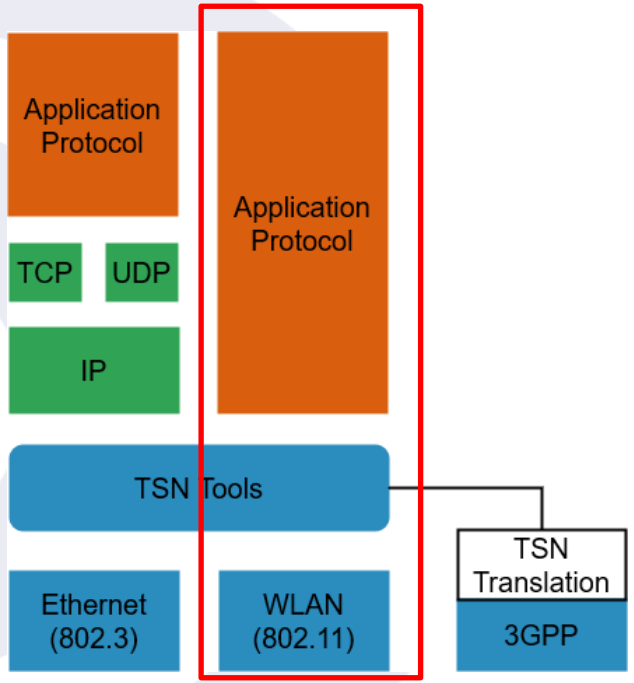

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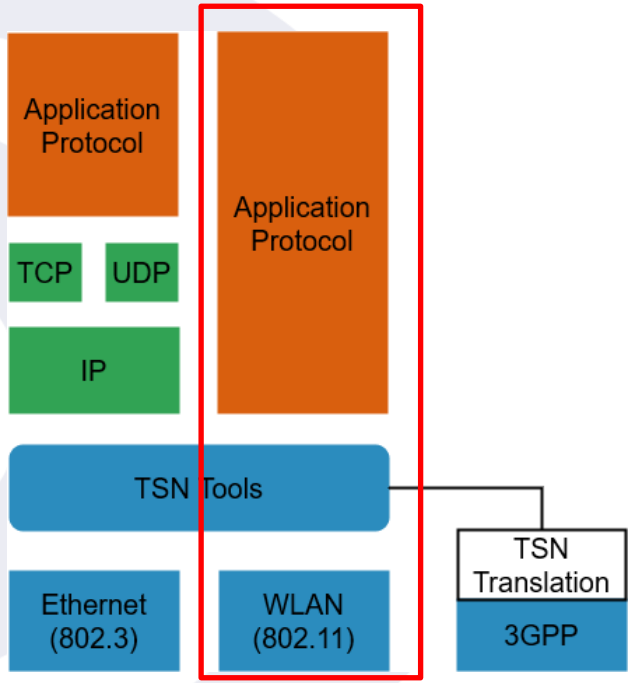

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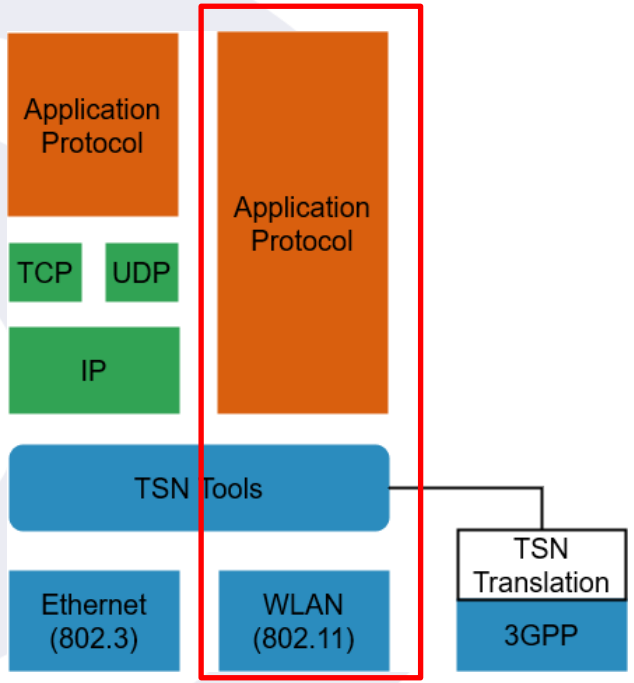

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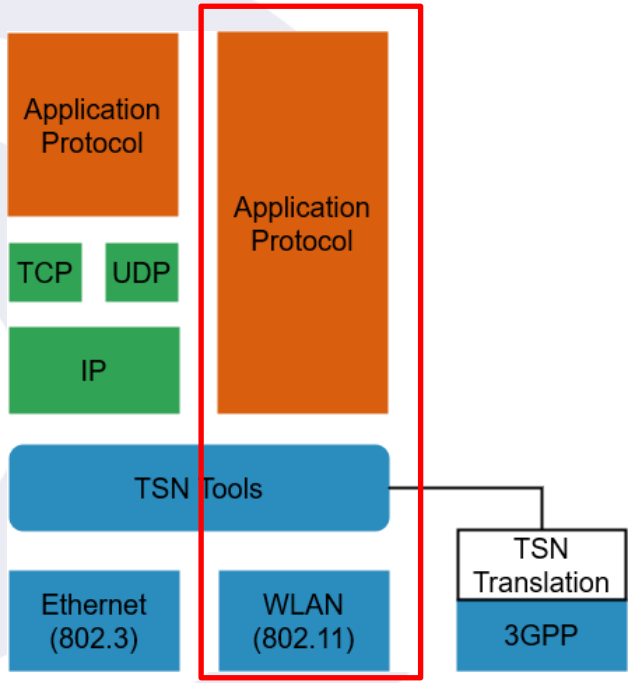

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Challenges ahead

- Ultra-low latency.
- Time-synchronization and TSN flows
- Coexistence with other non-time-sensitive traffic.
- Bounded latency when robots are roaming between APs.
- Integration of hybrid TSN networks that guarantee end-to-end latency over shared wired and wireless infrastructure.
- Performance tradeoffs and interference issues
- Integration, testing and validation

Wrap up

- Robotic systems must improve flexibility.
- In robotics, the lack of a real standard protocol burdens the component integration or robot to infrastructure communications
- TSN aims to provide bounded latency on Ethernet, WLAN and 3GPP.
- Current TSN tools for WLANs are suitable for Robotics traffic.
- Multiple challenges ahead related to:
  - Ultra-low latency
  - Interoperability with non-time-sensitive flows
  - Mobility
  - Interference

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Thanks!

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