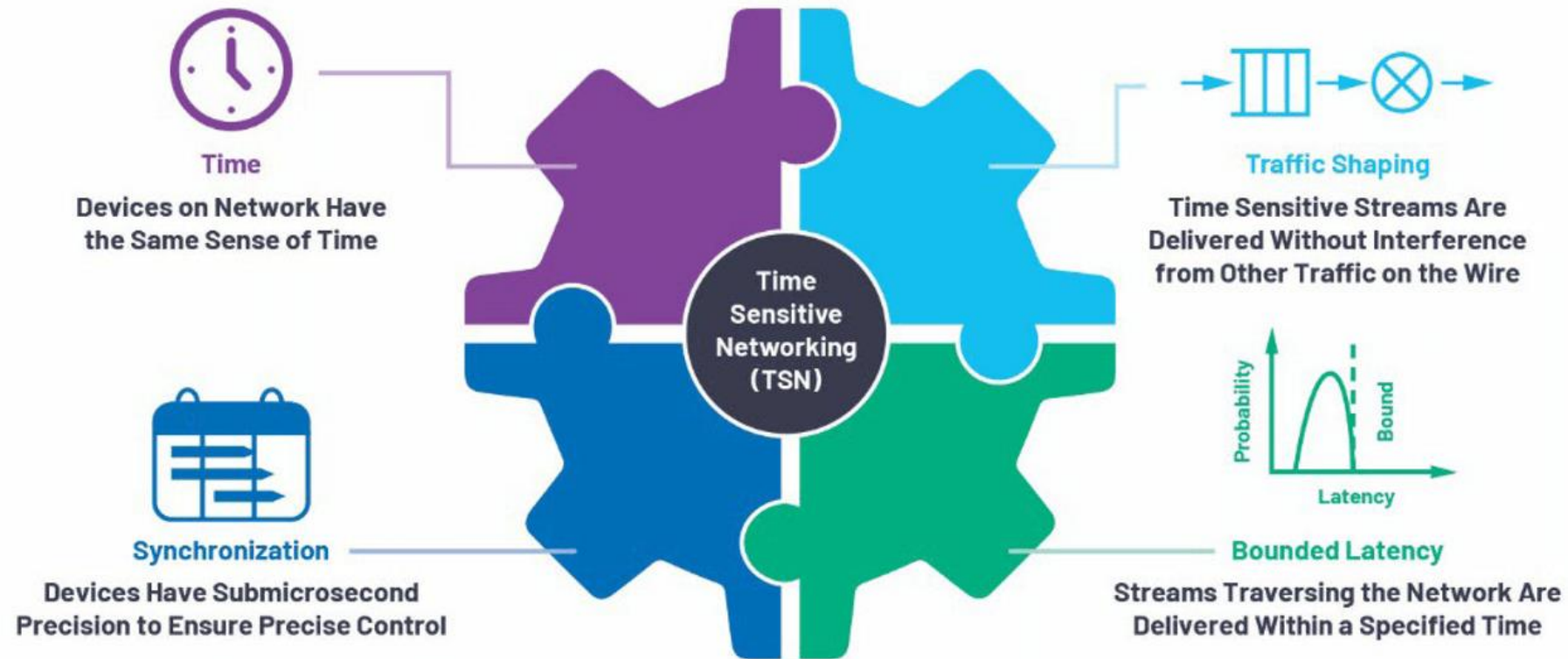




Experimental Evaluation of a Multi-Domain TSN Scenario in Industry 4.0

David Rico, Pablo Picazo & Antonio de la Oliva

Brief introduction and motivation

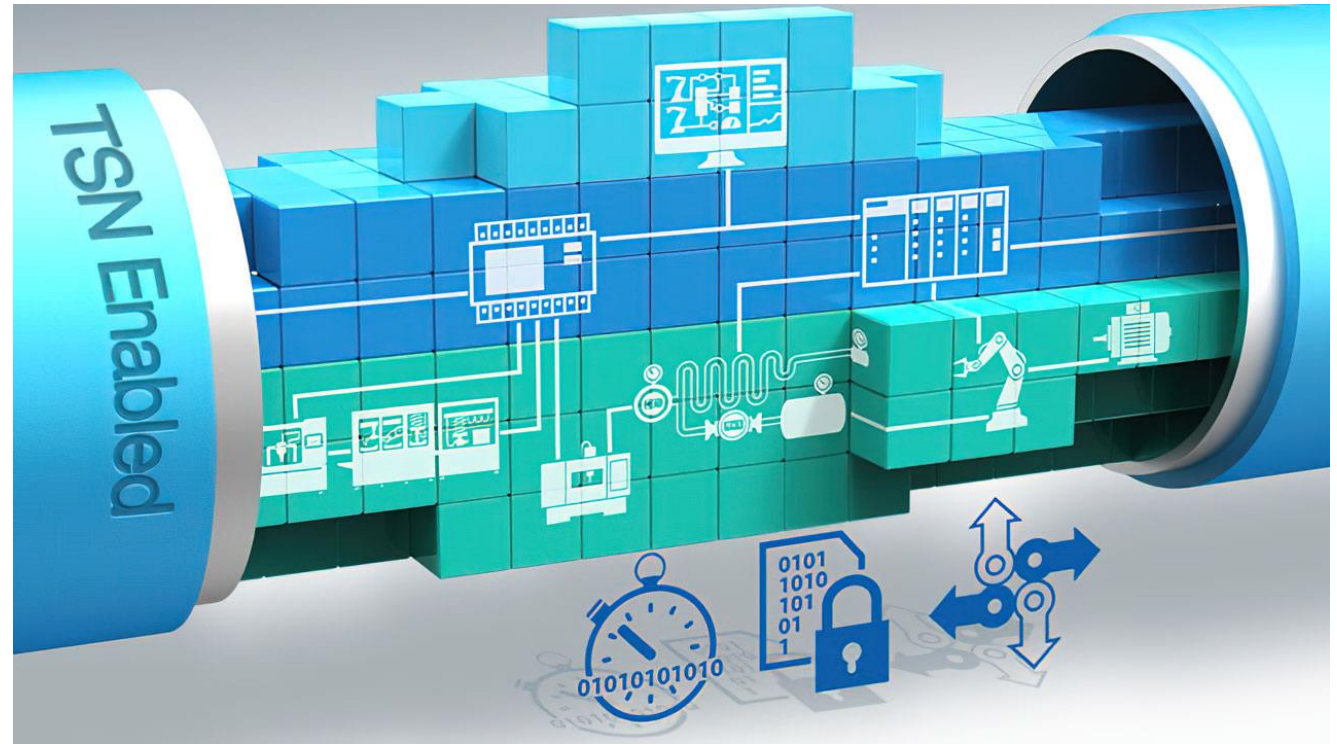


Brief introduction and motivation

How TSN helps in Industry 4.0?

TSN is the key to smart factory automation because deterministic, real-time communication allows different equipment to work seamlessly together.

As networks grow in size and complexity, TSN implements traffic management and prioritizes system resources to ensure that critical data gets delivered on time, which makes the network ultra-reliable and more secure



A real use case: DT & remote control of robotic dog

Illustrative Use Case: Digital Twin for Remote Robot Control

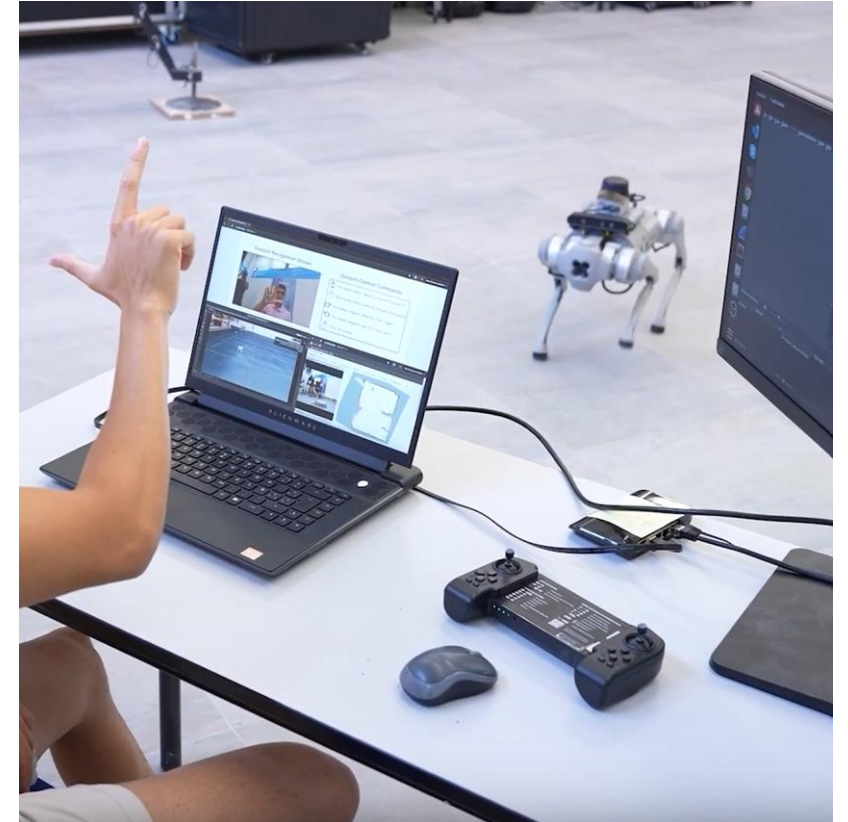
- Scenario:** Controlling a robot dog at a remote production plant via a Digital Twin (DT).
- Objective:** Real-time monitoring and precise control of the robot's actions.

Communication Flow

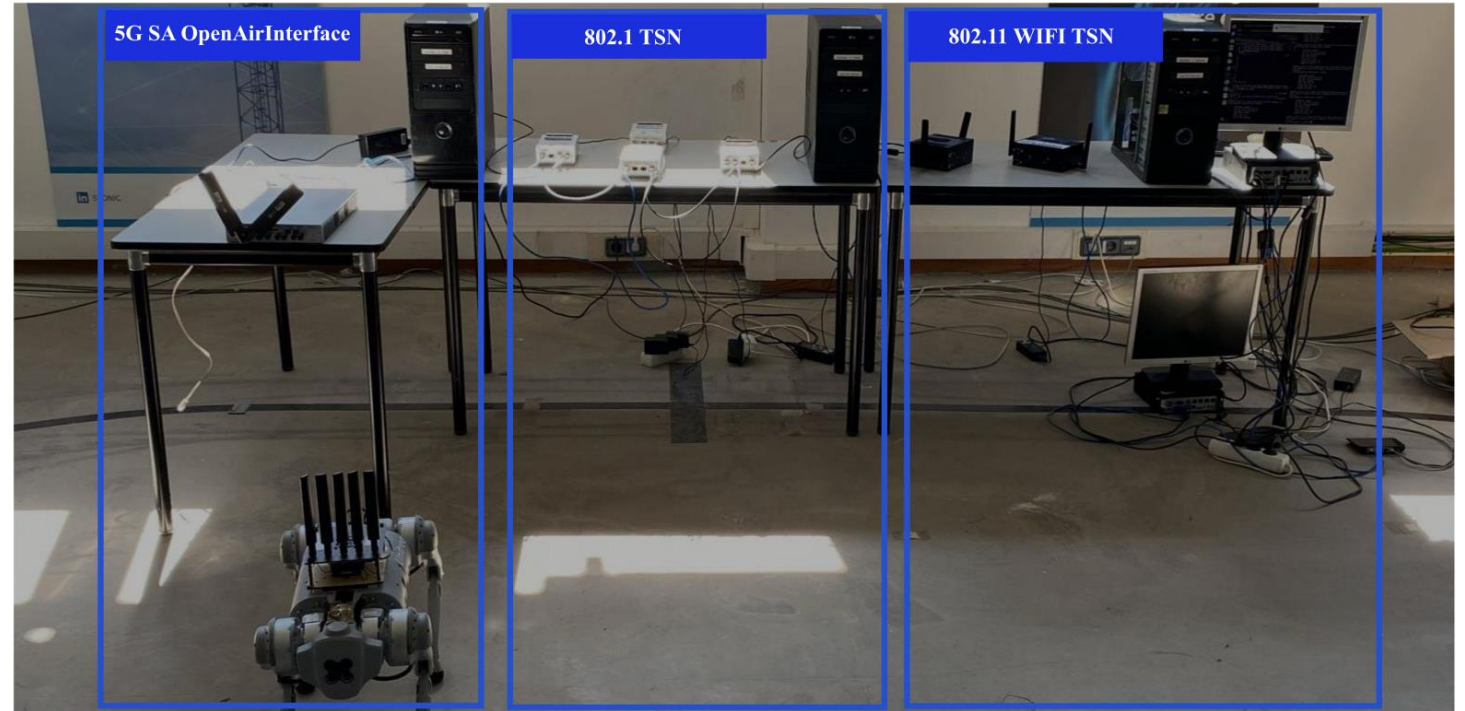
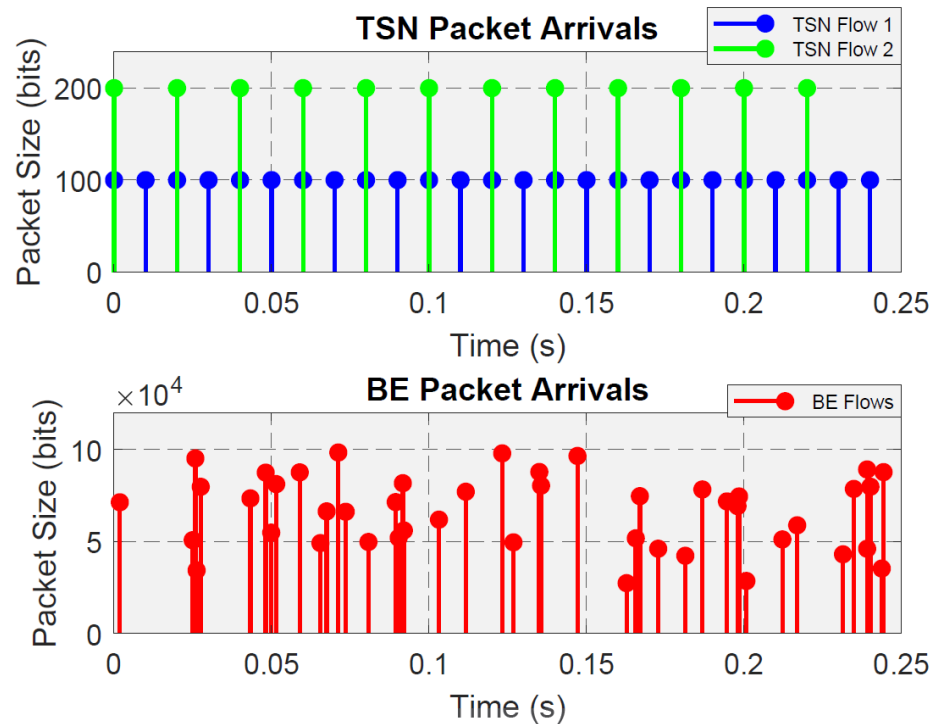
- Commands from the DT application sent over a **Wi-Fi network**.
- Transitions through a **wired network (FRER)**.
- Reaches the robot via **5G network using a 5G Hat**.

Deterministic Traffic Characteristics

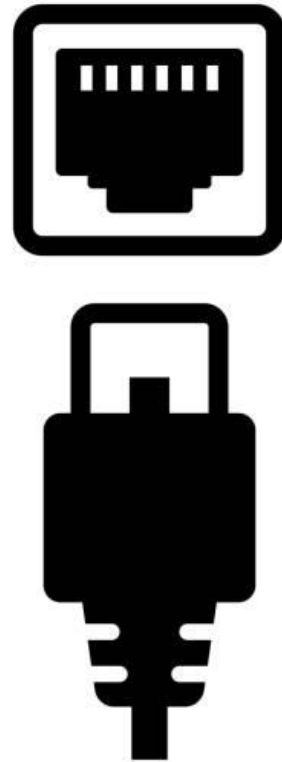
- Packets from control loop consists of a **100-byte packet every 10ms**, and the odometry data comprises a **1k-byte packet every 20ms**
- Ensures prompt and accurate response from the robot.



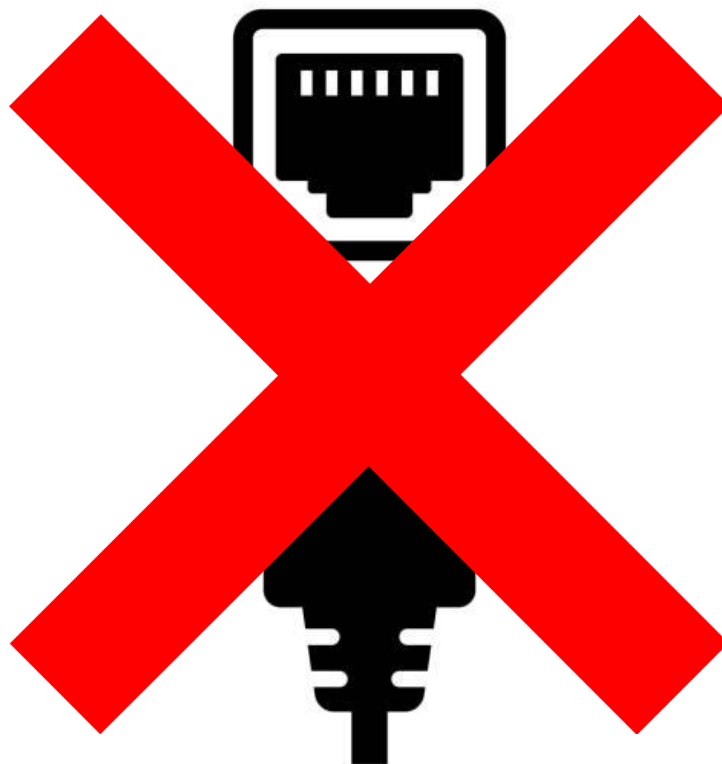
A real use case: DT & remote control of robotic dog



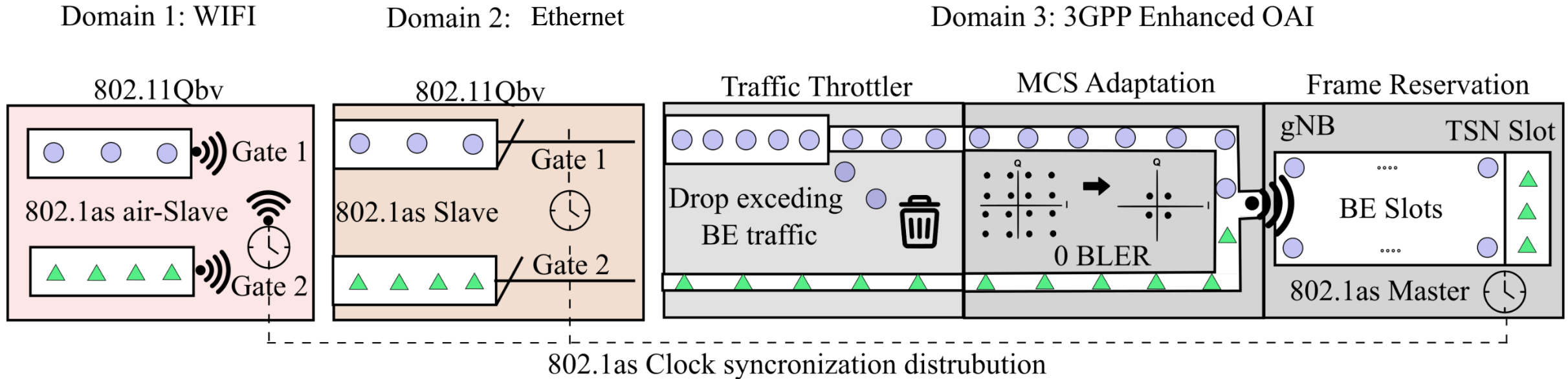
Plug and Play?



Plug and Play?

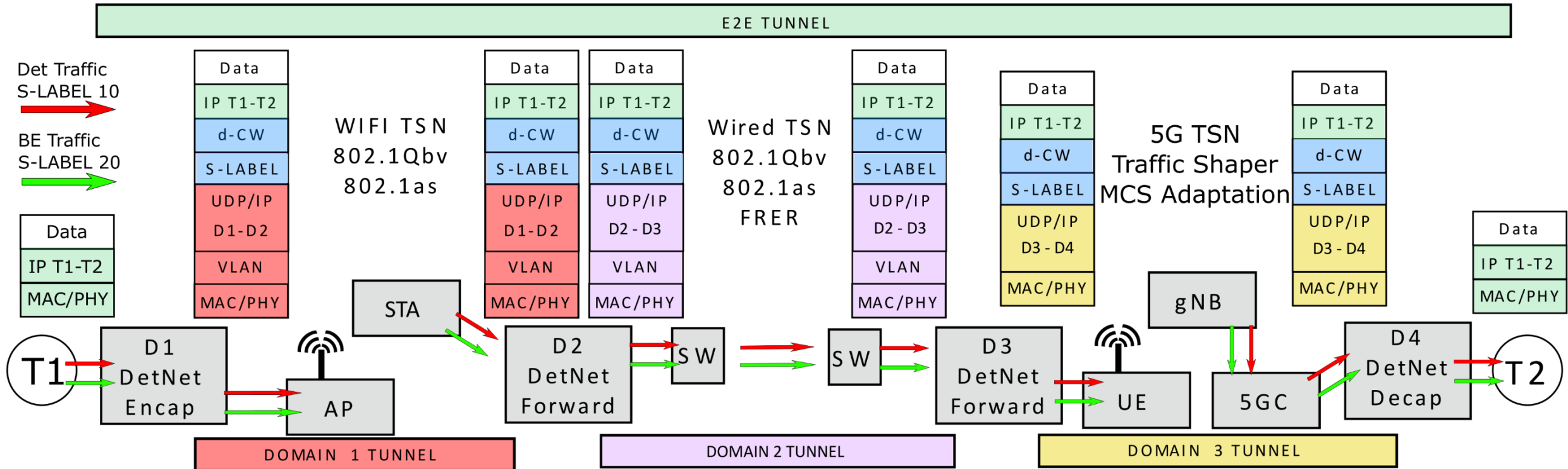


Multidomain Data Plane: TSN capabilities & sync

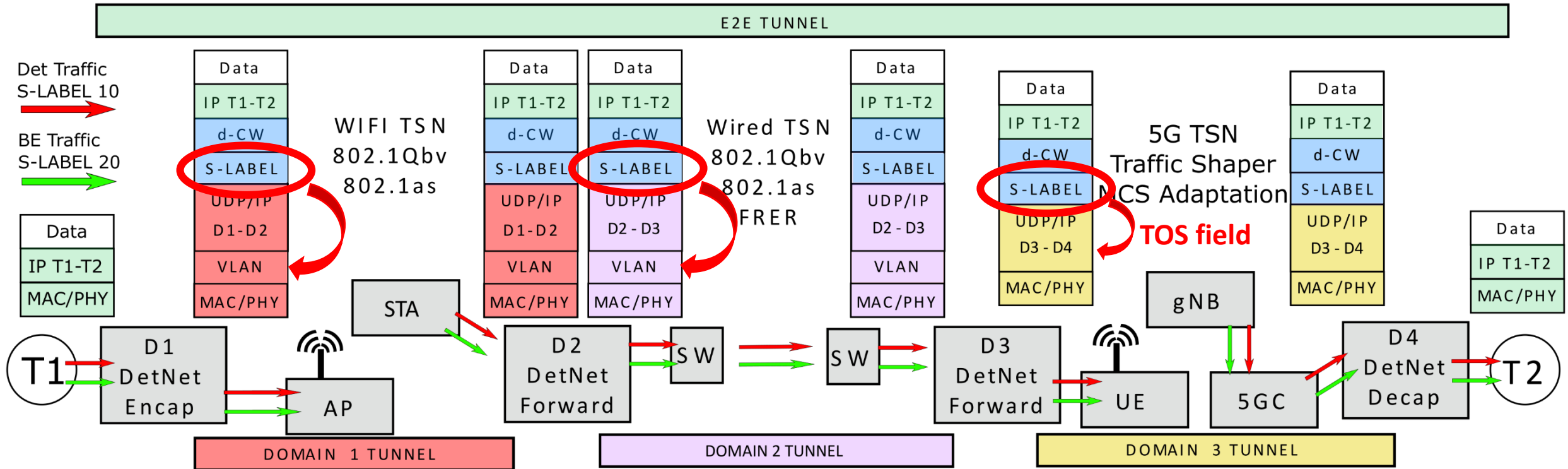


- Time sync
Wireless PTP
- Qbv scheduling
- Time sync
Wired PTP
- Qbv up to 8 traffic classes
- Dynamic Traffic Throttler: adapted to the quality of the link
- MCS Adaptation algorithm to target BLER 0
- Radio Frame Slot reservation

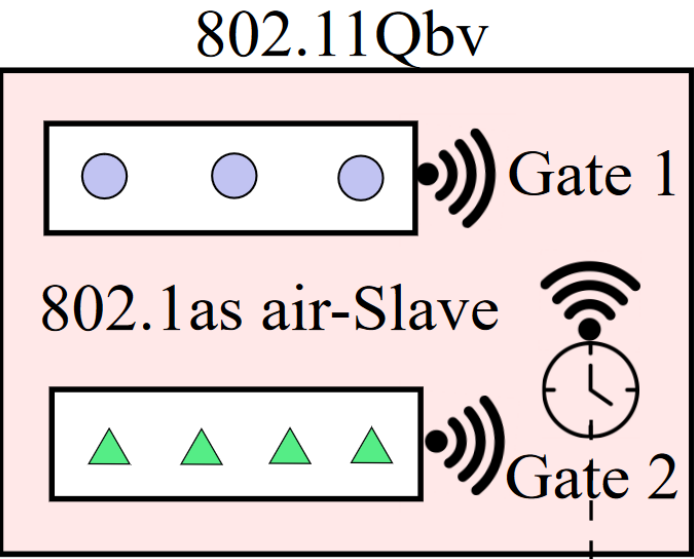
Multidomain Data Plane: Detnet Dataplane



Multidomain Data Plane: Detnet Dataplane (as translators)



Wi-Fi TSN-Enabled Domain



| | 1 Flow | 2 Flow | 5 Flow | 10 Flow |
|-----|--------|--------|--------|---------|
| BE | 1.2 ms | 1.3 ms | 1.6 ms | 4 ms |
| TSN | 1.2 ms | 1.2 ms | 1.2 ms | 1.3 ms |

Latency worst case < 1.3 ms
for TSN traffic

Sync between AP & STA of ns
precision

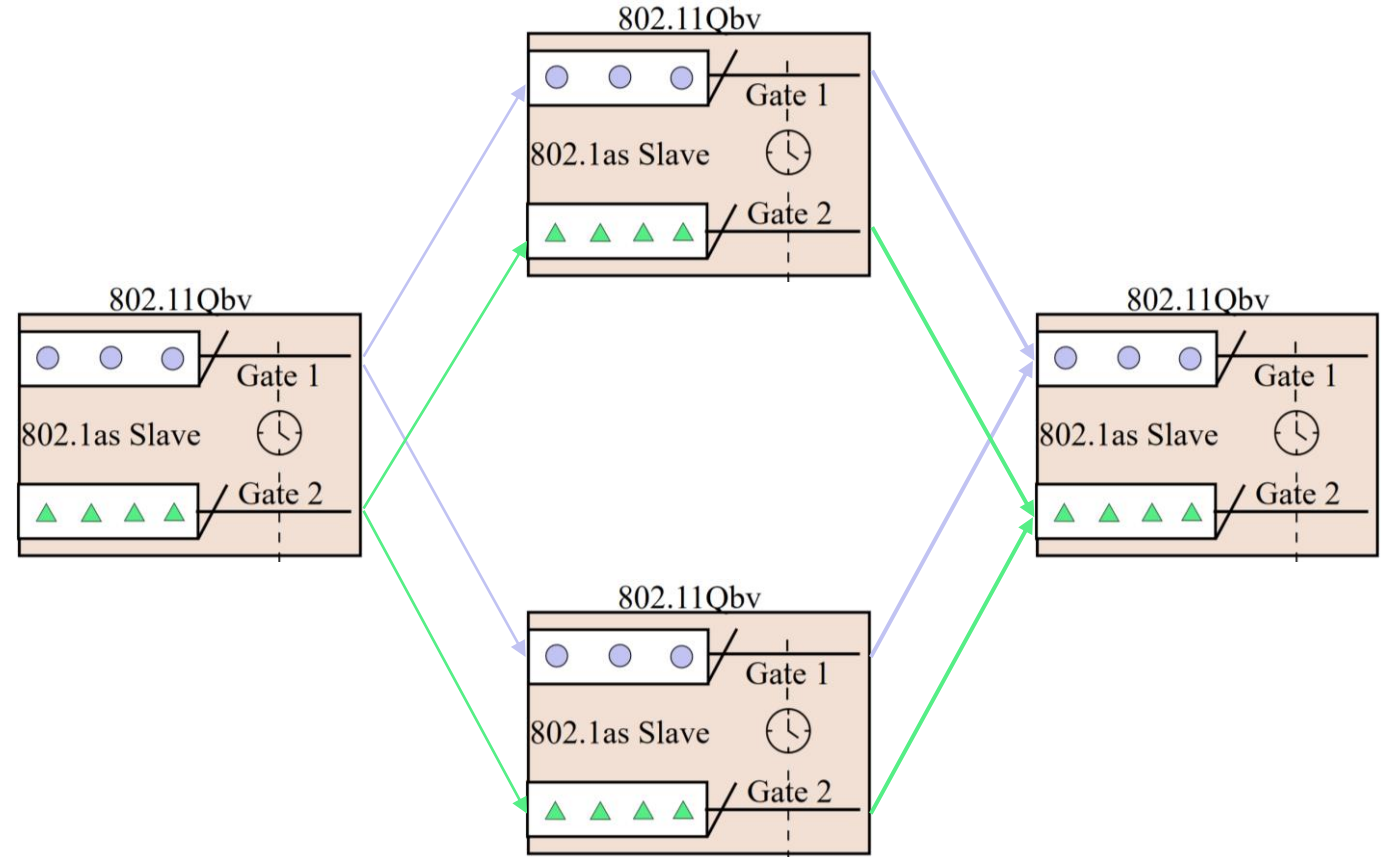
Intel 210AX chips at TSN-enabled Wi-Fi AP and STA with
over the air time synchronization, Qbv and traffic shaping

Wired TSN-Enabled Domain

Relyum FRER Topology for TSN Domain

Commercial TSN domain composed of Relyum TSN4 switches, capable of:

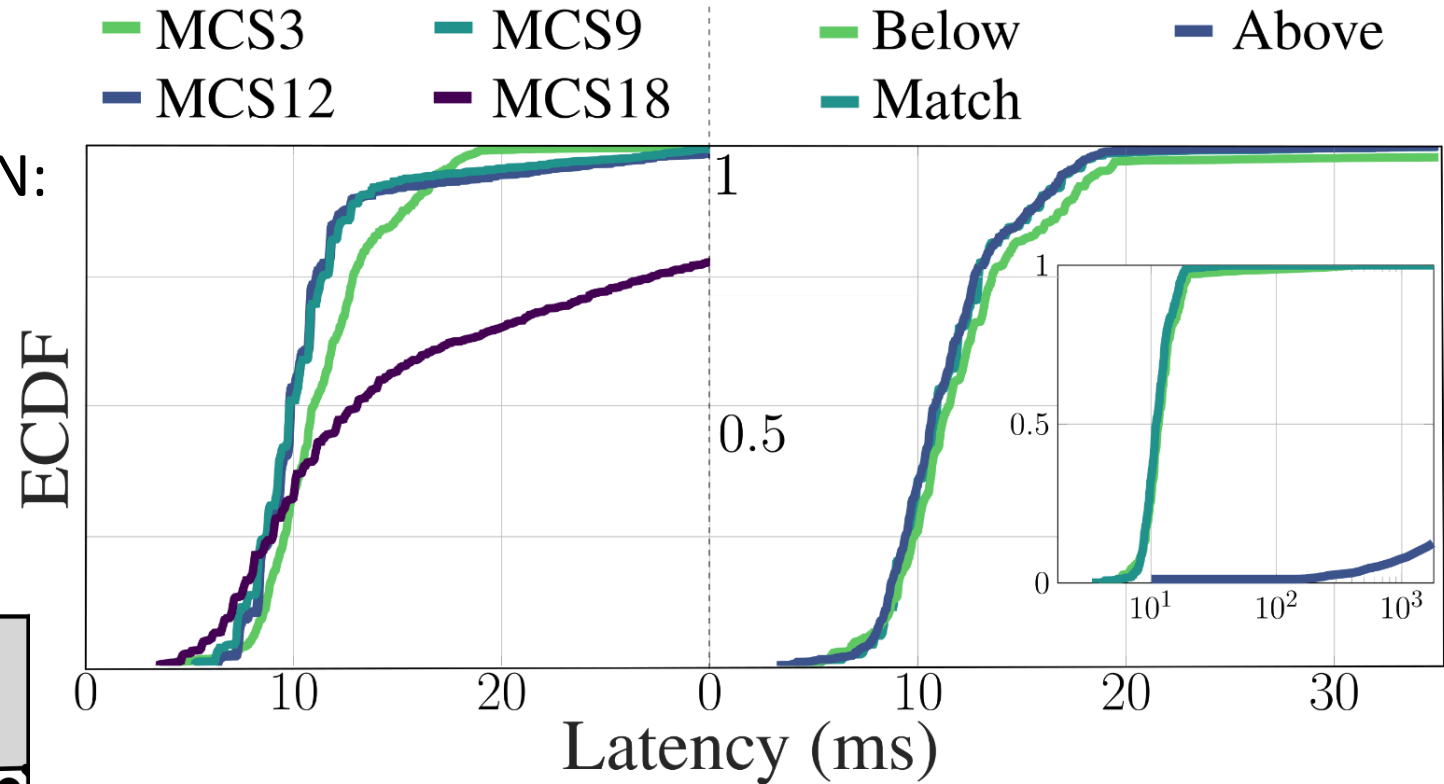
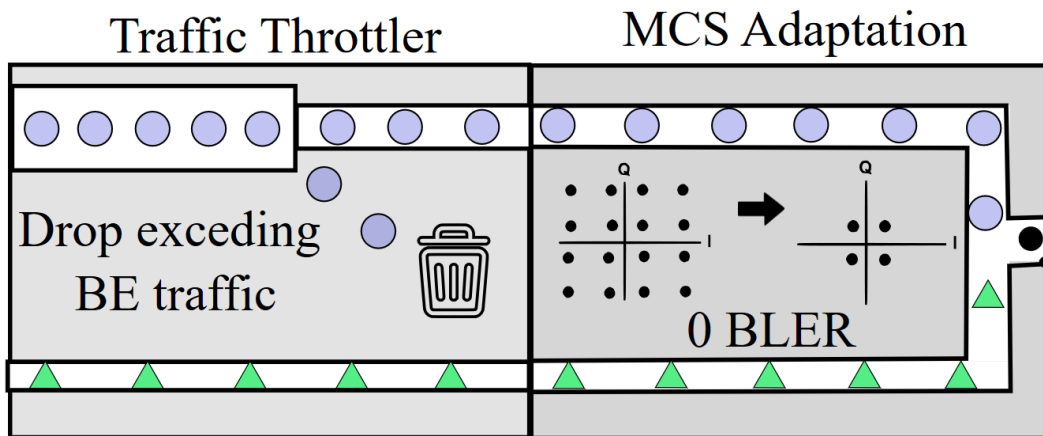
- IEEE 802.1Qbv
- Frame Replication and Elimination
- Latency <1 ms



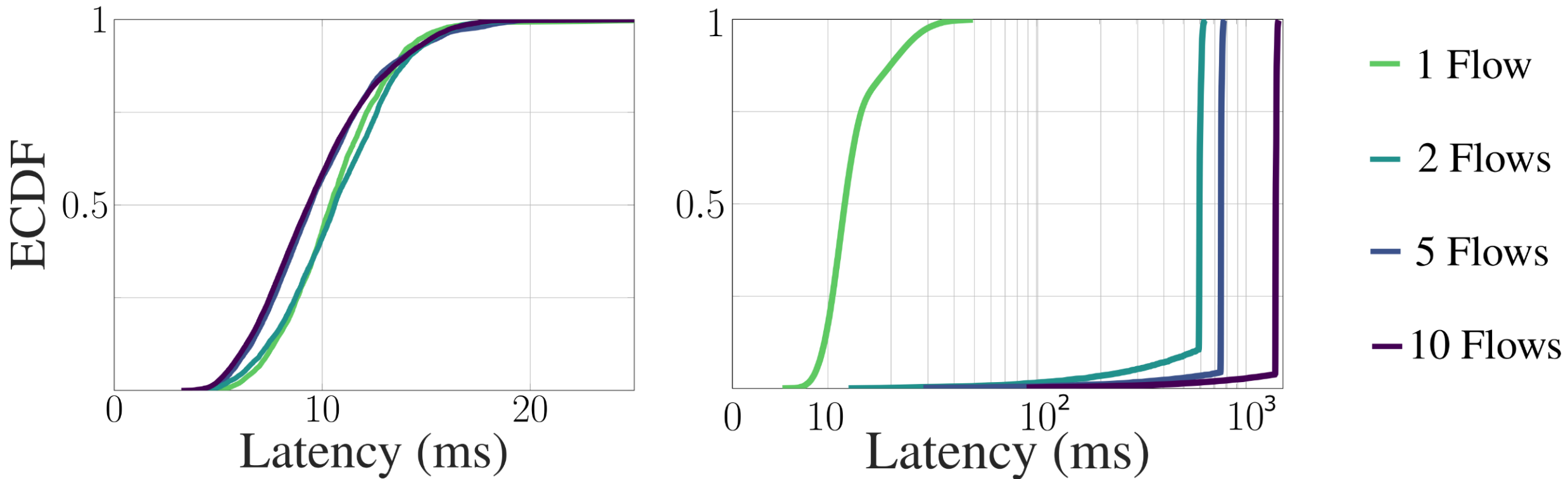
3GPP TSN Enhanced Domain (v1)

OpenAir Interface based 5G SA network with enhancements for TSN:

- Dynamic Traffic Throttler
- MCS Adaptation



First E2E latency & jitter results

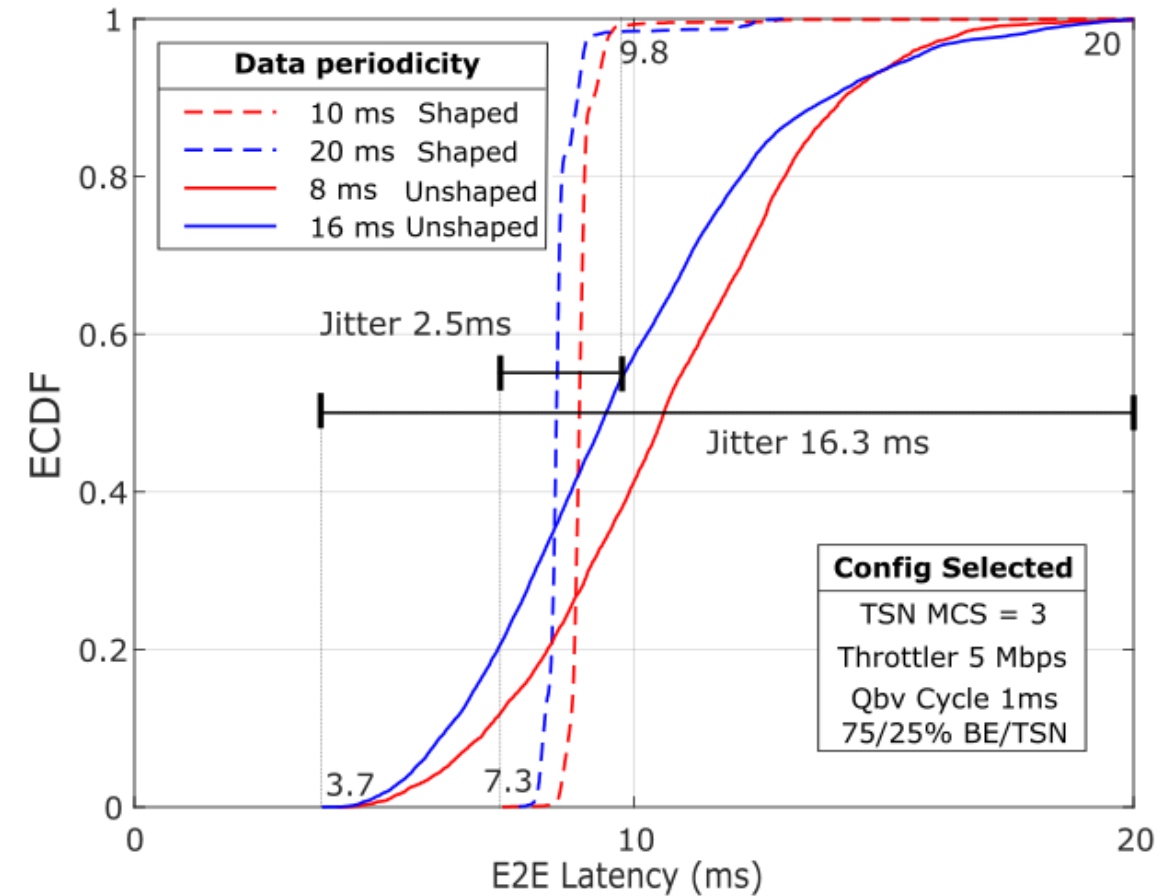
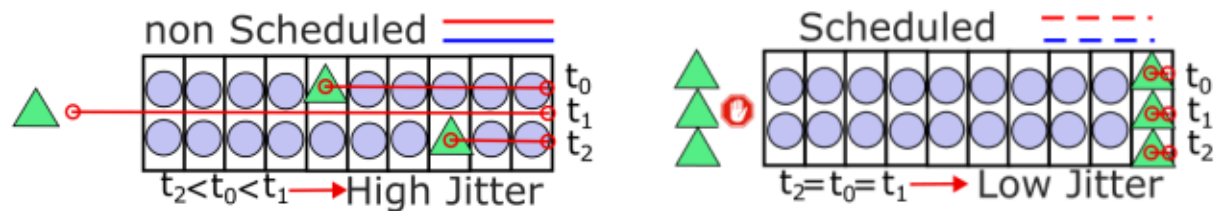


Tackling 3GPP impact in the E2E latency & jitter

OpenAir Configurations Tested on E2E

| MCS | 3 (QPSK) | 9 (4QAM) | 12 (4QAM) | 16 (16QAM) |
|-----------|------------|----------|------------|------------|
| BLER | 0.00 | 0.05 | 0.08 | 0.2 |
| THR | 5 Mbps | 10 Mbps | 20 Mbps | 30 Mbps |
| LAT nSCHE | 3.7-20 ms | 3.8-27ms | 3.7-26.2ms | 3.1-55ms |
| LAT SCHE | 7.3-9.8 ms | 6.6-12ms | 6.4-11.7ms | 7.2-22ms |

Frame Reservation (Improvement)



Thank You

