ELECTRONICS & DEFENSE

Time Sensitive Networking

March 2023

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TSN & WR as Enablers for Next-Gen Architectures

"TSN + 10G + WR + low latency can deliver a single network solution to handle all flows in different mission-critical scenarios"

Highlights of the proposed Convergent Networking solution

IEEE 802.1 IEEE 802.3 TSN

a. **High capacity for data aggregation (1G, 10G, …)**

b. **Unprecedented traffic control with ns-level data delivery jitter by leveraging WR timing**

c. **Network- & Synchronization-level robustness**

d. **Seamless handling of critical & best-effort data**

e. **Standards-based solution (PTP HA, WR, IEEE 802.1Q, IEEE 802.3)**

f. **Reliable sub-ns reference to hundreds of nodes**

Examples of potential applications

- **ADG:** Timing & data robustness
- **RoE:** RF, consistent phase shifting, data acquisition
- **HEP:** RF, timing distribution, MPS interlock propagation
- **Avionics:** Timing, fly-by-wire, commands & control
- **Telecom:** Timing for the fronthaul, extend TSN to the edge over **5G** systems

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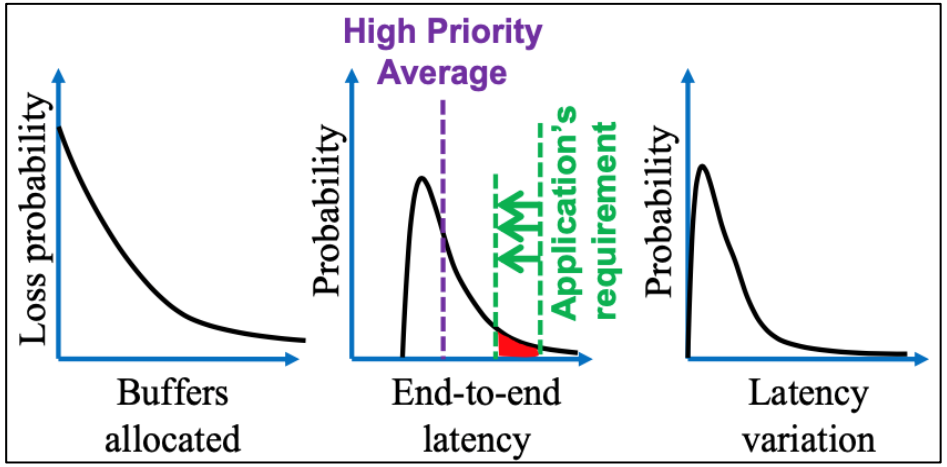
Best-Effort vs Deterministic Data Delivery

The usual performance of Ethernet networks

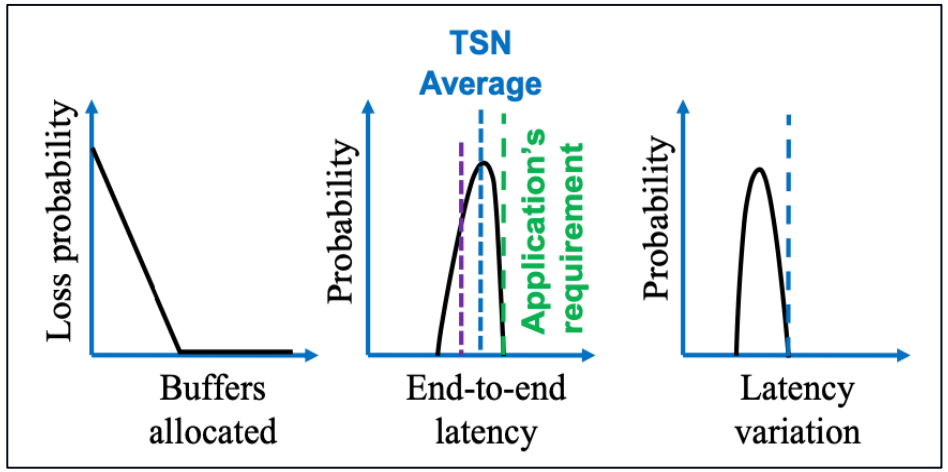


No implicit guarantees → Best-effort.

- *Unbounded end-to-end latency.*
- *Large latency variation (PDV).*
- *Congestion losses as a function of buffer size.*

"Open world" ⟶ TCP/IP, Internet-like traffic, …

Performance from a deterministic service



Implicit guarantees: E2E latency, BW, jitter, integrity

- *Bounded end-to-end latency.*
- *Bounded latency variation (PDV).*
- *Congestion losses minimized if usage below threshold.*

"Closed world" ⟶ Fieldbuses, critical systems, …

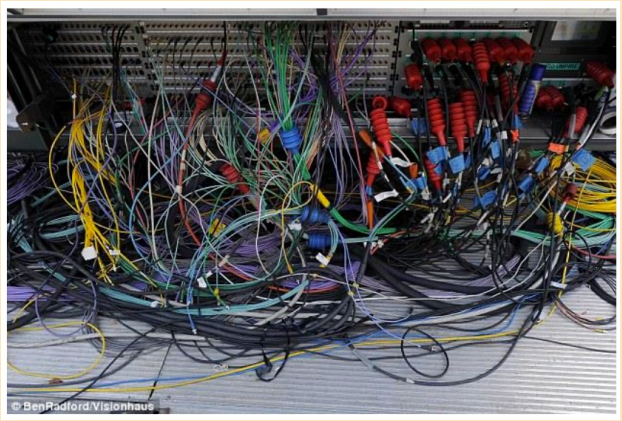
Converged Networks

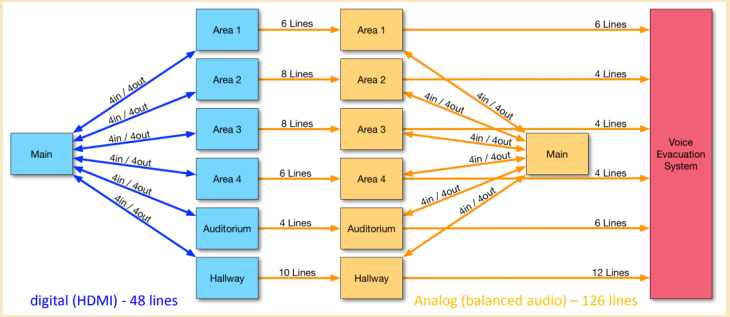
- ***Same physical network* for handling both flows (*Closed & Open World*).**
- **Open standards → *Ethernet (TSN).***

Practical advantage of TSN Ethernet

(Images: [Schindler. "Current deployments of AVB media networks"] & ["TSN. Enabling Technology for the automation model of the future", W. Schenk]. TSN/A Conf. 2017)

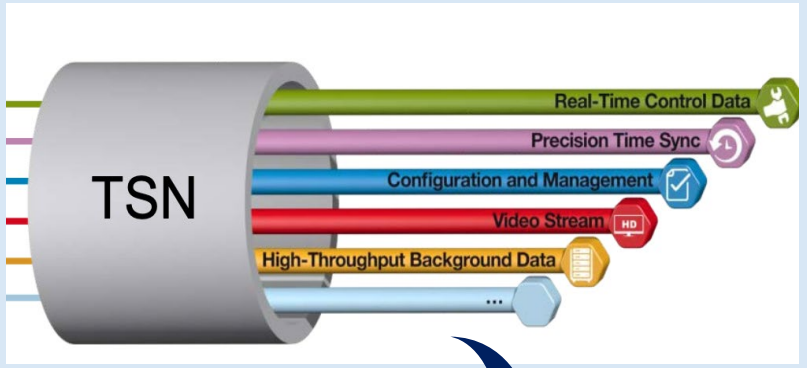
Regular, non-TSN system

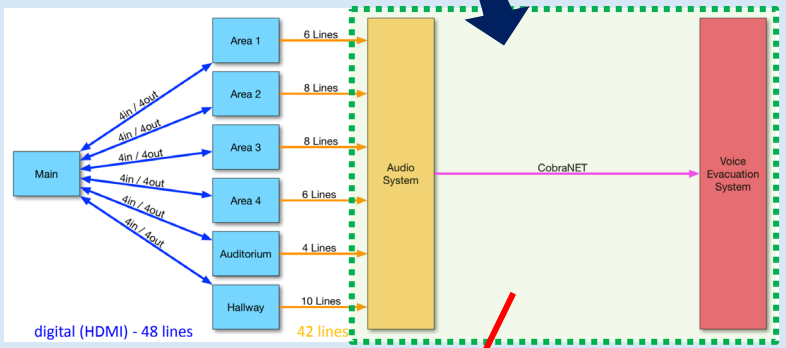


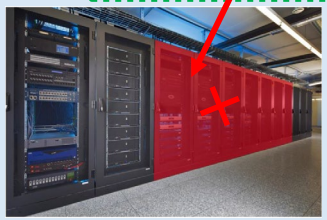


"Unmanageable, non-scalable clutter"

TSN-enhanced Ethernet







- Standardized, Ethernet-based foundation
- Open specification
- High interoperability & seamless integration
- Pervasiveness & availability from multiple vendors
- Widespread engineering community
  - → "***Engineers learn about Ethernet at school…***"
- Streamlined integration & troubleshooting
- High capacity for data aggregation

+ ***Determinism & Robustness***

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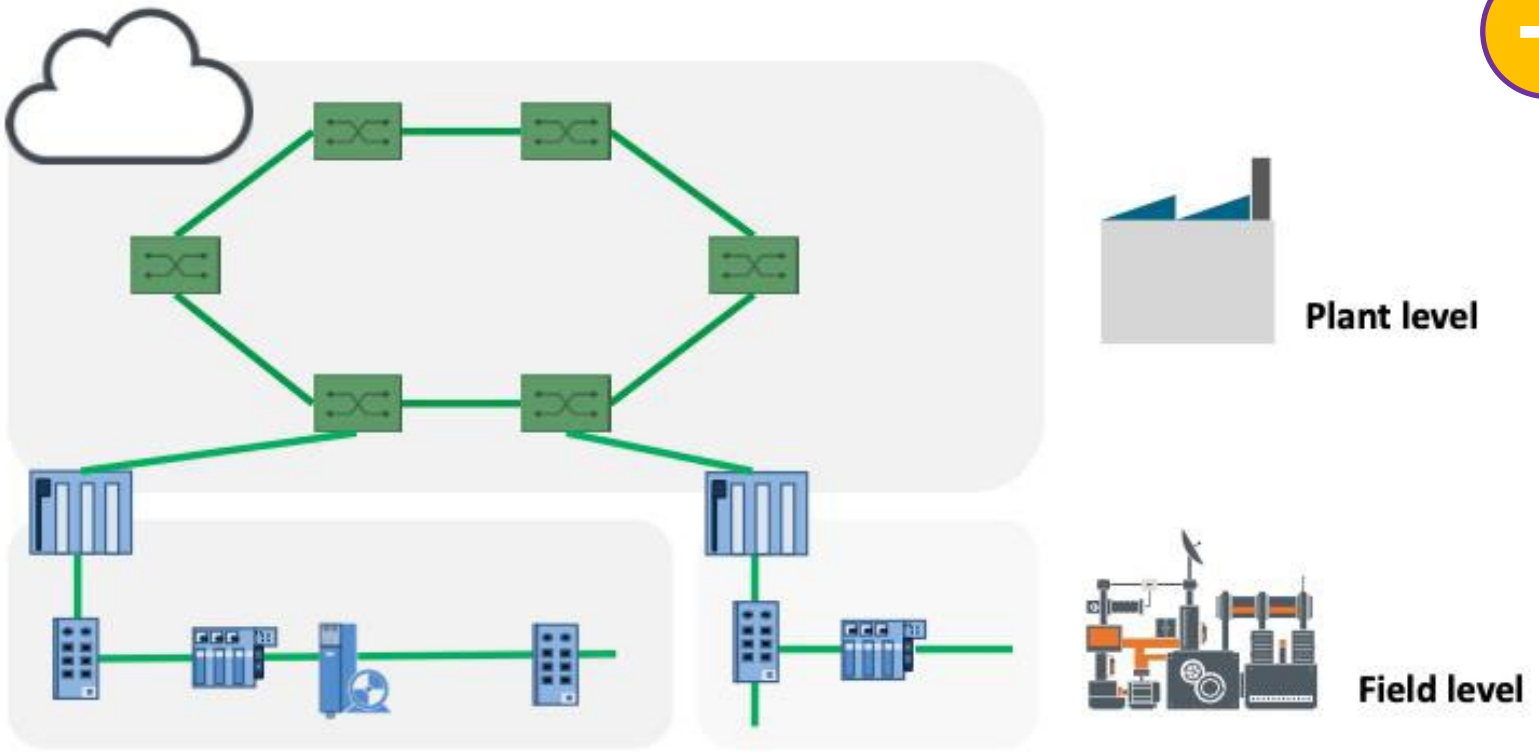
Motivation. Typical TSN networking scenario

Example. Convergent TSN for industrial systems



Potential extension to wireless

TSN over WiFi

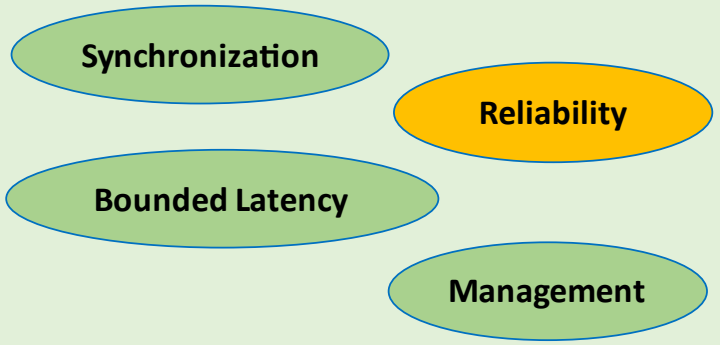
5G/Cellular

(Image: "The goals of integration of TSN into PROFINET", X. Schmidt, TSN/A Conf. 2017)

Towards fully deterministic Ethernet with TSN

The Four Pillars of Time-Sensitive Networking (TSN)

Main TSN Components & Standards



→ ***Minimize congestion losses***

→ ***Deterministic forwarding***

Synchronization

- IEEE 802.1AS-REV Profiles
- ***gPTP***

Bounded Low Latency

- Time-Aware Traffic Shaper: ***802.1Qbv***
- Credit-Based Traffic Shaper***: 802.1Qav***
- Frame Preemption: ***802.1Qbu & 802.3Qbr***
- Asynchronous Traffic Shaping: ***802.1Qcr***

System Reliability

- ***TSN Traffic Shapers***
- Path Control: ***802.1Qca***
- Replication for Reliability: ***802.1CB***
- Time-based Ingress Policing: ***802.1Qci***

Management

- ***Resource Reservation (802.1Qcc)***
- ***User-configuration APIs, YANG Models, …***
- ***TSN Profiles***

AV Bridging	Automotive	Industrial Automation	Onboard Avionics	Telecommunications
802.1BA	P802.1DG	IEC/IEEE 60802	P802.1DP	802.1CM — *(5G fronthaul)*

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An overview of the main TSN components (I)

Selected components for minimum TSN functionality

- **Main set of components to implement a functioning TSN system**
  - Provide traffic shaping elements coupled with modules for management, synchronization, and robust forwarding
  - Select from the IEEE "*letter soup*" to provide the essential TSN bridging functionality:

Standard	Area	Title
IEEE 802.1AS- Rev, IEEE 1588	Timing & Synchronization	*Enhancements and Performance Improvements*
IEEE 802.1Qbu & IEEE 802.3br	Forwarding and Queuing	*Frame preemption and Interspersing Express Traffic*
IEEE 802.1Qbv	Forwarding and Queuing	*Enhancements for Scheduled Traffic – Time-Aware Traffic Shaping*
IEEE 802.1Qca	Path Control and Reservation	*Path Control and Reservation*
IEEE 802.1Qcc	Stream Reservation (SRP)	*Enhancements and Performance Improvements*
IEEE 802.1Qci	Time Based Ingress Policing	*Per-Stream Filtering and Policing*
IEEE 802.1CB	Seamless Redundancy	*Frame Replication & elimination for Reliability*

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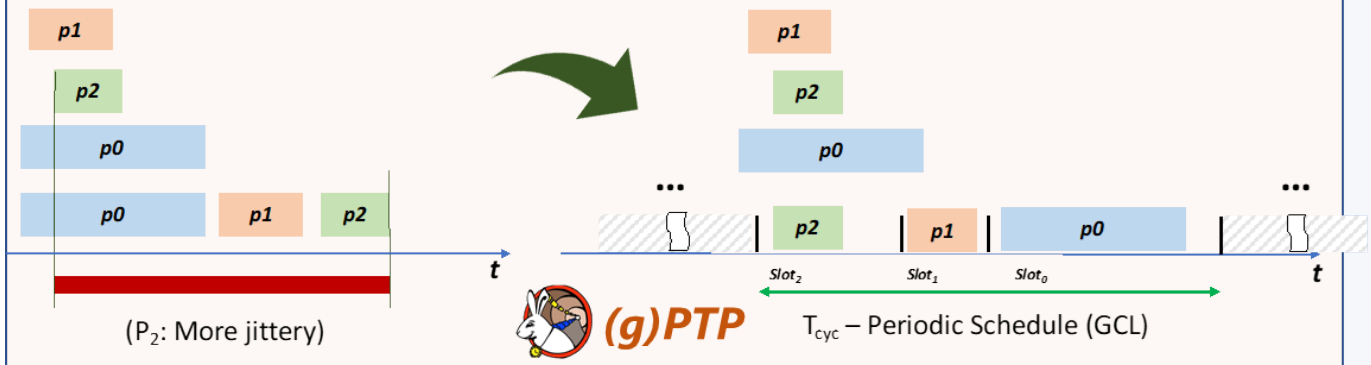
An overview of the main TSN components (II)

SYSTEM DETERMINISM

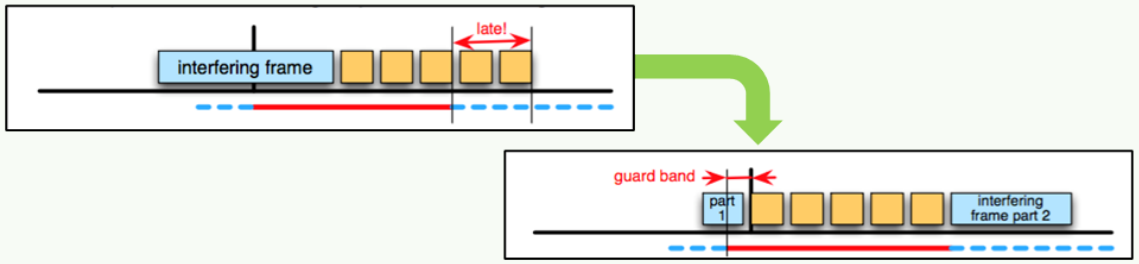
▪ 802.1Qbv – Time-aware traffic shaper

→ *TDMA-like processing for TSN flows in accordance with priority*



▪ 802.1Qbu & 802.3br – Frame preemption

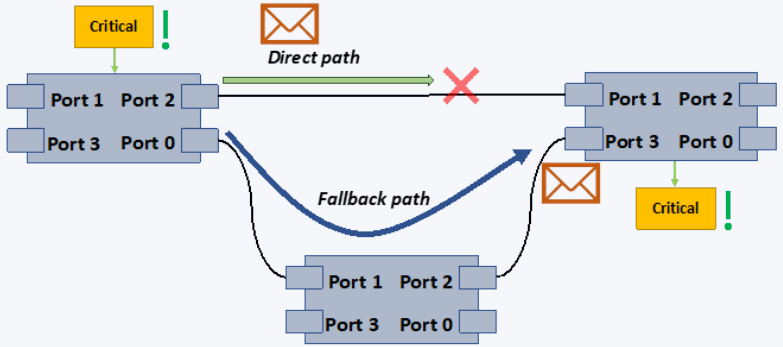
→ *Reduce PDV for critical flows, preserve bandwidth*



ROBUSTNESS

▪ 802.1CB – Seamless redundancy

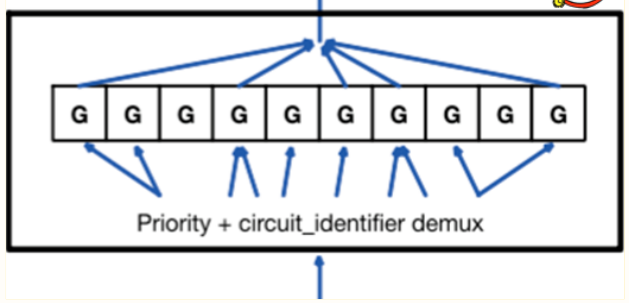
→ *Redundant transmissions of critical data*



▪ 802.1Qci – Time-based ingress policing

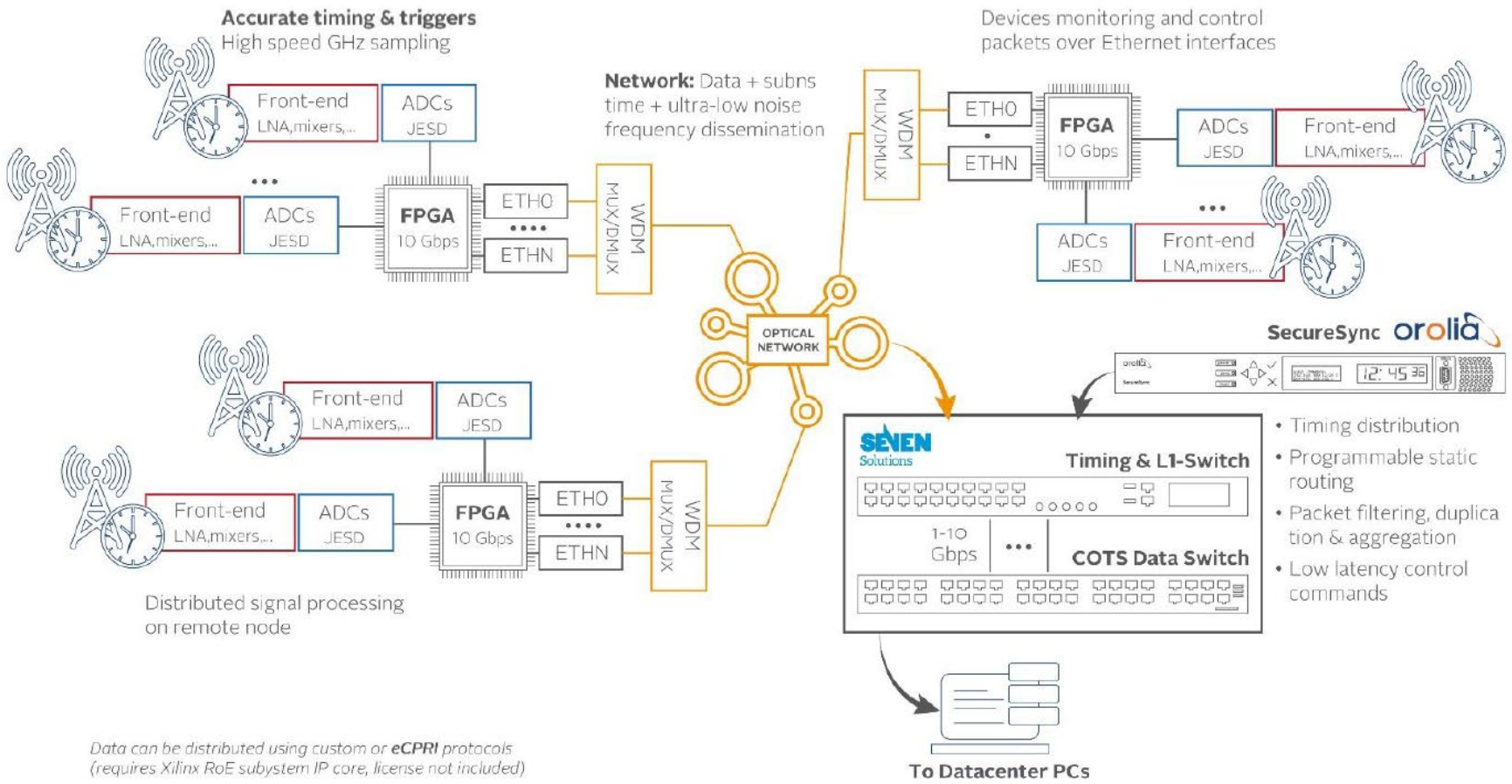
→ *Enforce reception within allocated slot*
("babbling idiot")

(g)PTP



TSN & WR for Radio over Ethernet

Joint distribution of resilient, HA timing (WR) & deterministic, robust data (TSN)



Distributed Radar, telescopes, ultrasound sensors and communication transmitters/receivers (cognitive radio systems, phase arrays, etc.)

- **Data and timing over same network**
  - Sub-ns triggers
  - **Programmable frequency distribution with low jitter & Phase Noise**
  - **10s/100s of kms.**
- HATI (OEMs), WR appliances
- Interoperability
- Resilience:
  - WR FOCA/BMCA, Failover
  - TSN: Redundancy, Preemption, Frame filtering
- **Value proposition**: scalability, improved performance, easy deployment, reducing costs (less cabling, maintenance)

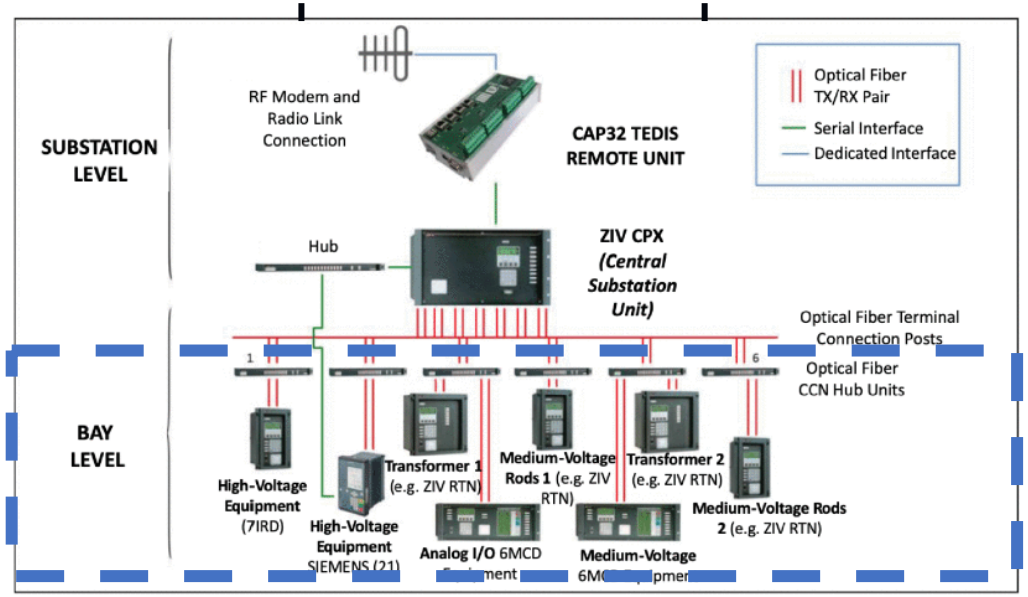
Industrial applications

DAIS - Distributed Artificial Intelligent System

- Develop intelligent, secure, and trustworthy systems for industrial applications
- Facilitate ***integration of AI engines within monitoring tools***
- Facilitate management and configuration of ***TSN networks***

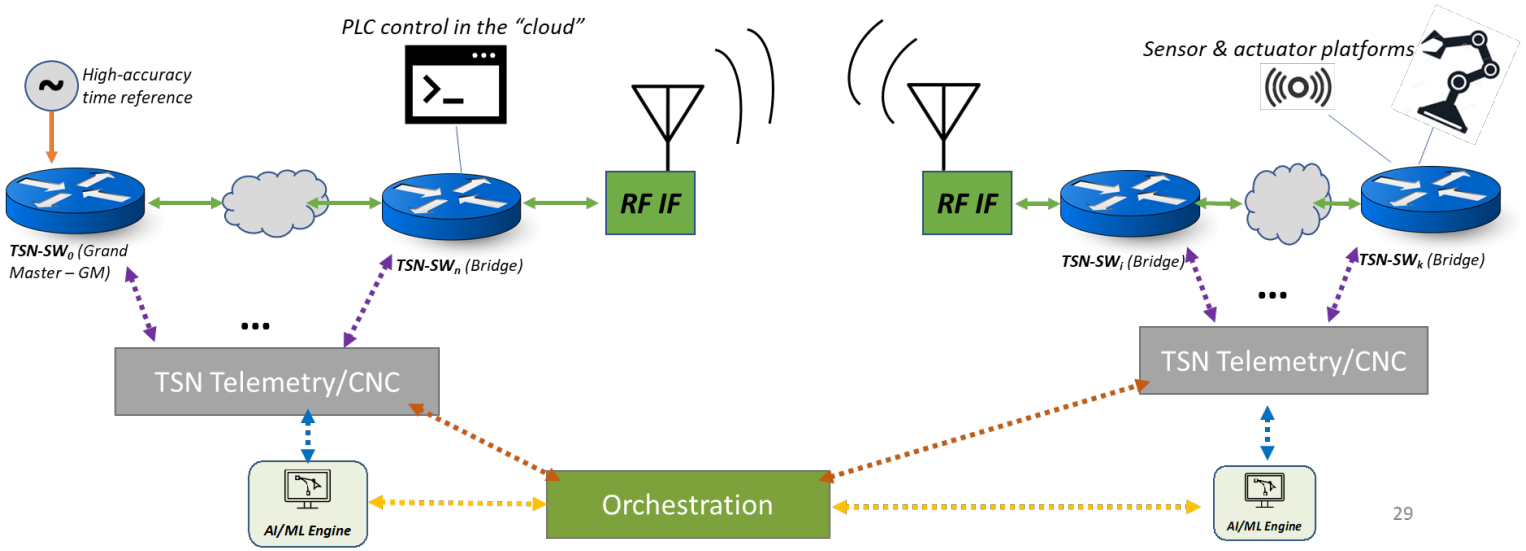
TSN for the Smart Grid

Analog triggers	**GOOSE**	**Ordinary data**
– Critical events – Latency ~ 30 µs	– Medium priority – IEC 61850	– Best effort – Video, monitoring



Telecommunications. TSN & 5G

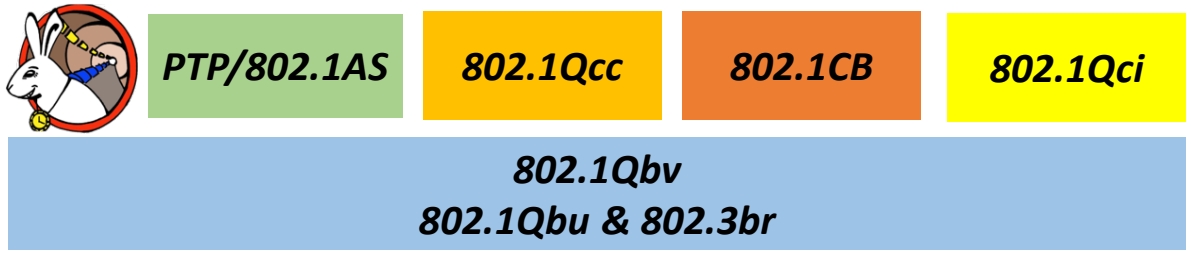
TSN from the fronthaul to the edge with integrated SDN-style management



- End-to-end timing distribution (wired and wireless)
- Large geographic span for deterministic data
- Implement closed sensor-controller loops with guaranteed delivery, and determinism

→ ***Cloudification of control systems***

- **Control servers on premise**
- **AGVs, vehicles, IoT devices on-site**
- **Determinism for control & sensor traffic through TSN & Timing (PTP/gPTP/WR)**



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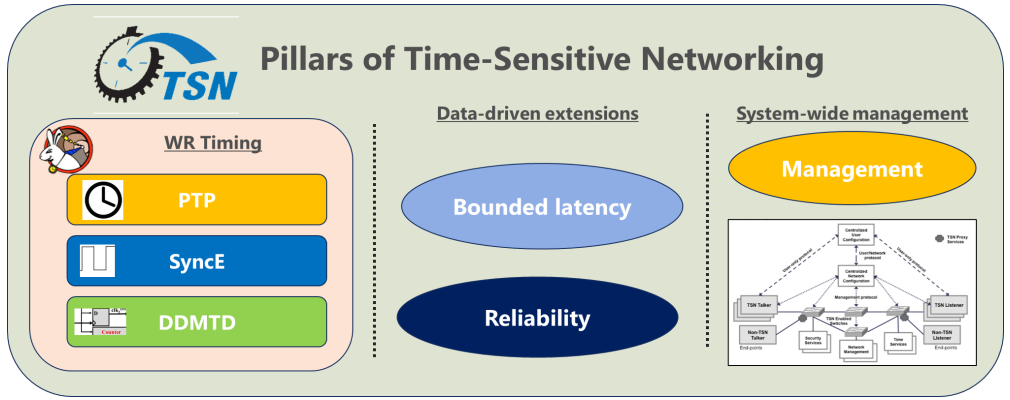
TSN & WR timing. TSN for Next-Gen Architectures



Main Highlights

Furnish RF and accurate timing for critical systems

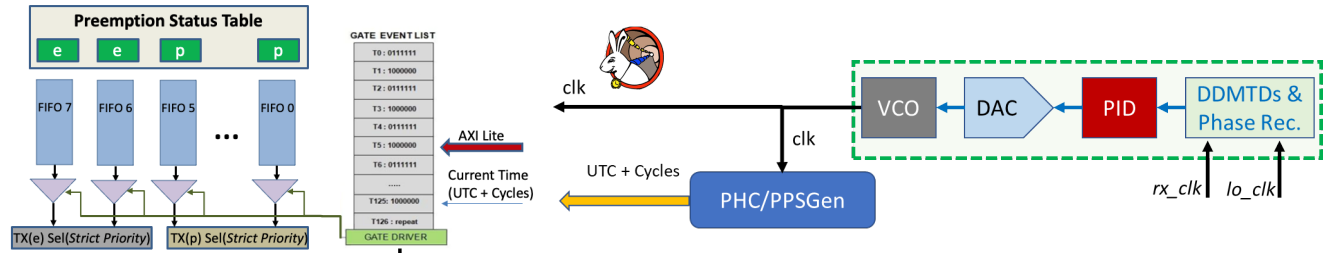
Low-latency transport for critical commands

Standards-based solution

Joint data & Timing interface

Convergent data, timing, and control

Enhanced Deterministic Forwarding



Key takeaways from WR

- Guarantee ns-level packet delivery jitter
- Implement tighter latency control
- Finer granularity

Sub-ns Timing

Backwards Compatibility

Prioritization

RF dissemination

Convergence

Robust delivery

Scalability

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- d **Seamless handling of critical & best-effort data**
- e **Standards-based solution (PTP HA, WR, IEEE 802.1Q, IEEE 802.3)**
- f **Reliable sub-ns reference to hundreds of nodes**

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