

ELECTRONICS & DEFENSE

# Time Sensitive Networking

March 2023



# 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

## Examples of potential applications

IEEE  
802.1

IEEE  
802.3



TSN

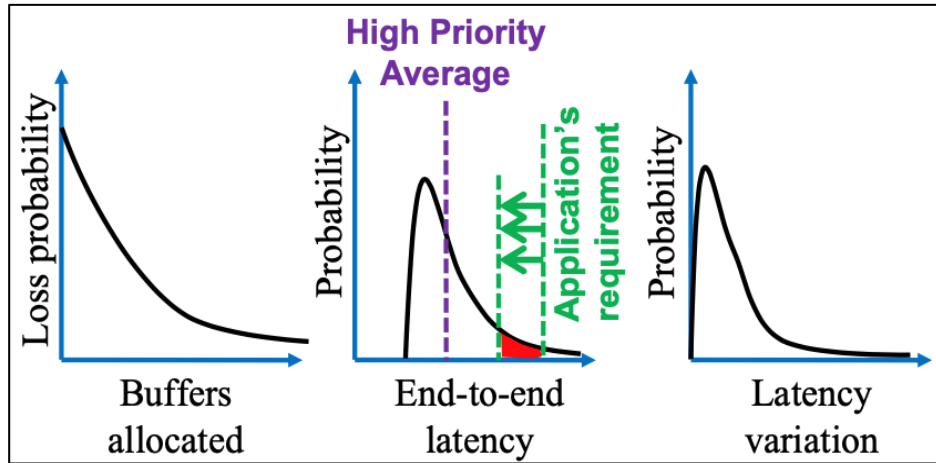
- a** High capacity for data aggregation (1G, 10G, ...)
- b** Unprecedented traffic control with ns-level data delivery jitter by leveraging WR timing
- c** Network- & Synchronization-level robustness
- d** Seamless handling of critical & best-effort data
- e** Standards-based solution (PTP HA, WR, IEEE 802.1Q, IEEE 802.3)
- f** Reliable sub-ns reference to hundreds of nodes

- **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

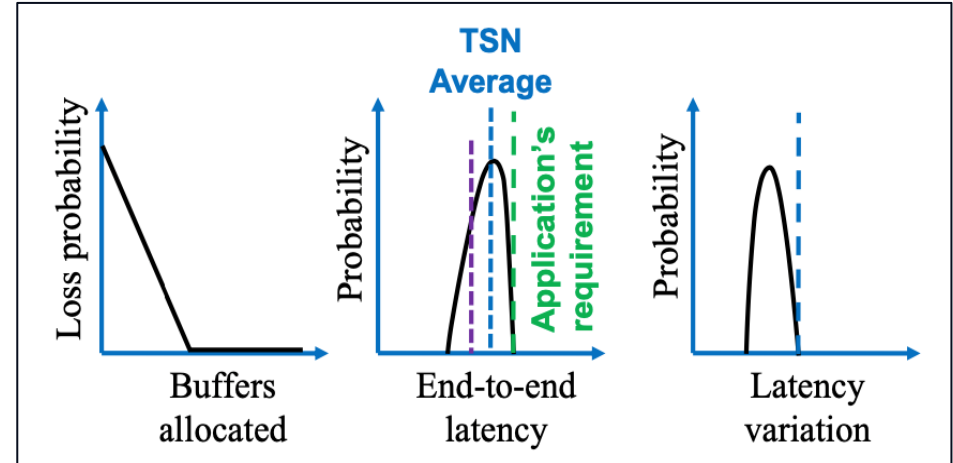


### No implicit guarantees → Best-effort.

- 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, ...



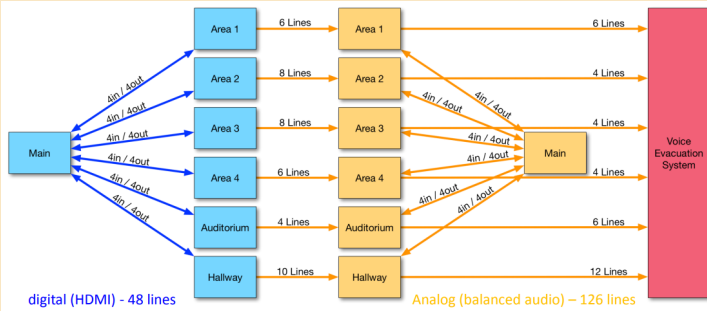
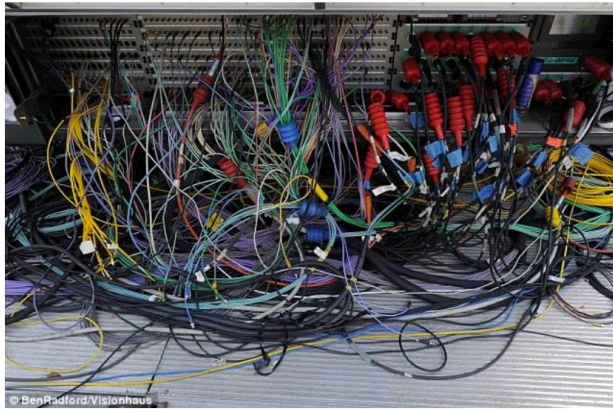
## Converged Networks

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

# Practical advantage of TSN Ethernet

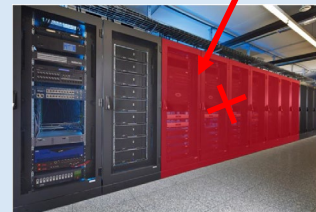
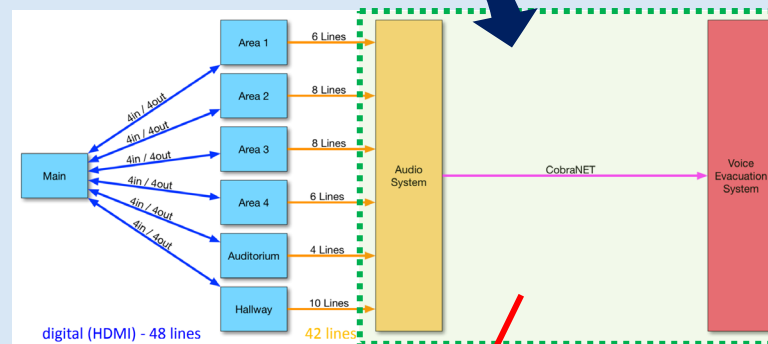
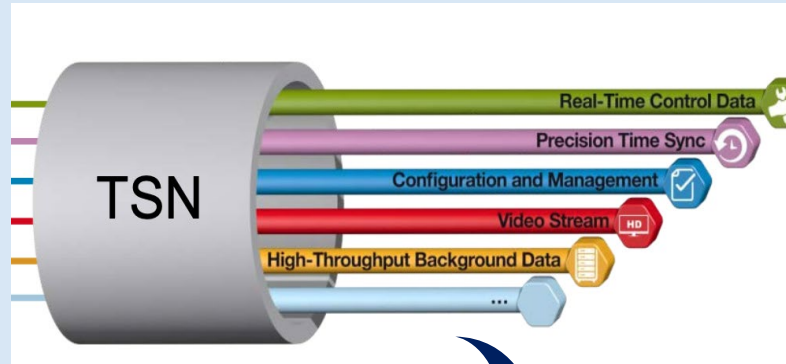
(Images: [Schindler. "Current deployments of AVB media networks"] & ["TSN. Enabling Technology for the automation model of the future", W. Schenk]. TSN/A Conf. 2017)

## Regular, non-TSN system



**"Unmanageable, non-scalable clutter"**

## TSN-enhanced Ethernet

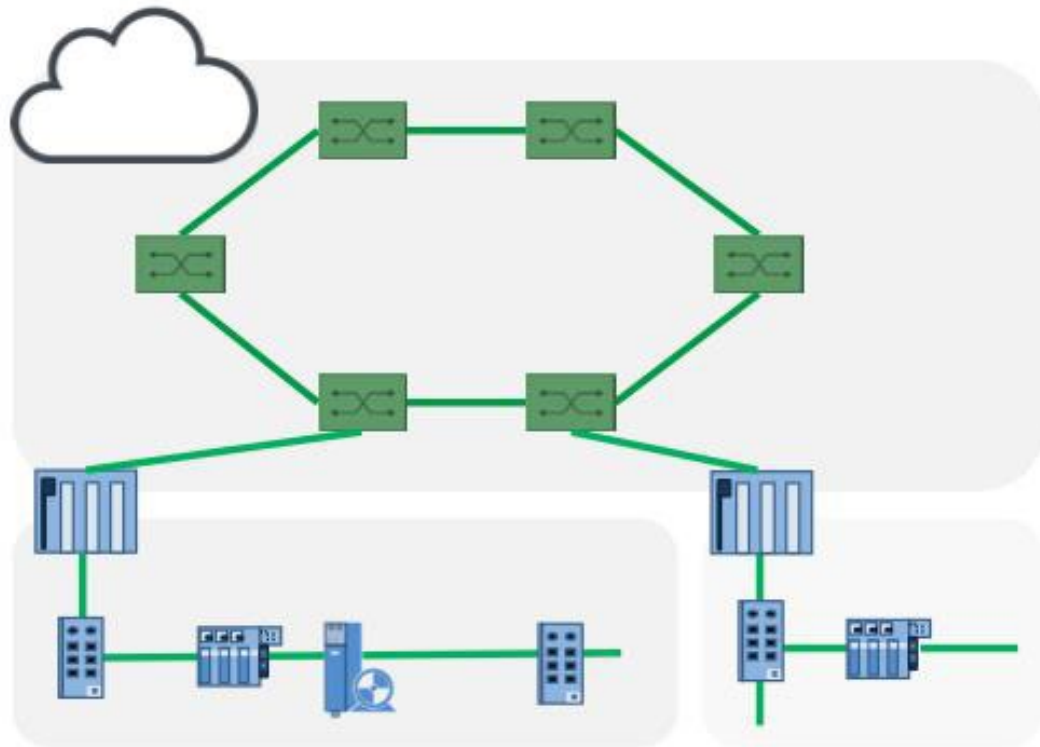


- Standardized, Ethernet-based foundation
- Open specification
- High interoperability & seamless integration
- Pervasiveness & availability from multiple vendors
- Widespread engineering community
  - **"Engineers learn about Ethernet at school..."**
- Streamlined integration & troubleshooting
- High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

**+ Determinism & Robustness**

# Motivation. Typical TSN networking scenario

## Example. Convergent TSN for industrial systems



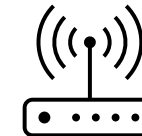
Plant level



Field level



**Potential extension to wireless**



TSN over WiFi

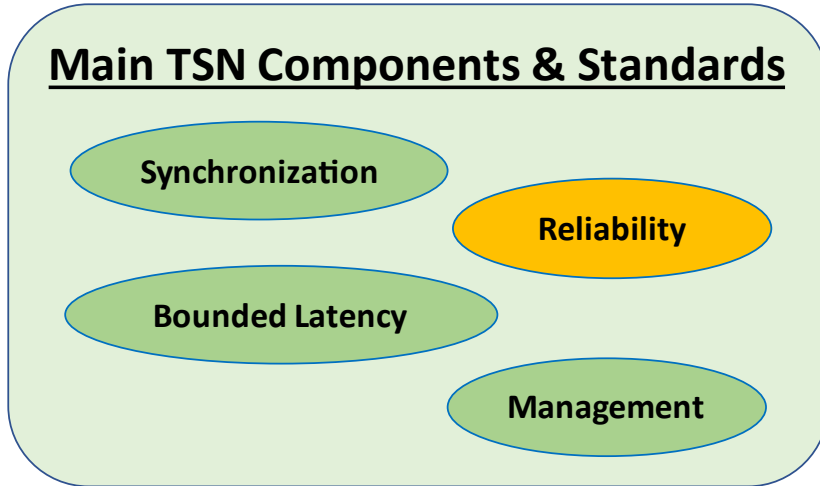


5G/Cellular

(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)



- **Minimize congestion losses**
- **Deterministic forwarding**

| Synchronization  | Bounded Low Latency   |
|--|---|
| <ul style="list-style-type: none"> <li>— IEEE 802.1AS-REV Profiles</li> <li>— <b>gPTP</b></li> </ul>   | <ul style="list-style-type: none"> <li>— Time-Aware Traffic Shaper: <b>802.1Qbv</b></li> <li>— Credit-Based Traffic Shaper: <b>802.1Qav</b></li> <li>— Frame Preemption: <b>802.1Qbu &amp; 802.3Qbr</b></li> <li>— Asynchronous Traffic Shaping: <b>802.1Qcr</b></li> </ul> |
| System Reliability   | Management  |
| <ul style="list-style-type: none"> <li>— <b>TSN Traffic Shapers</b></li> <li>— Path Control: <b>802.1Qca</b></li> <li>— Replication for Reliability: <b>802.1CB</b></li> <li>— Time-based Ingress Policing: <b>802.1Qci</b></li> </ul> | <ul style="list-style-type: none"> <li>— <b>Resource Reservation (802.1Qcc)</b></li> <li>— <b>User-configuration APIs, YANG Models, ...</b></li> <li>— <b>TSN Profiles</b></li> </ul>   |

| AV Bridging    | Automotive      | Industrial Automation | Onboard Avionics | Telecommunications                 |
|----------------|-----------------|-----------------------|------------------|------------------------------------|
| <b>802.1BA</b> | <b>P802.1DG</b> | <b>IEC/IEEE 60802</b> | <b>P802.1DP</b>  | <b>802.1CM</b><br>— (5G fronthaul) |

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# An overview of the main TSN components (I)

## *Selected components for minimum TSN functionality*

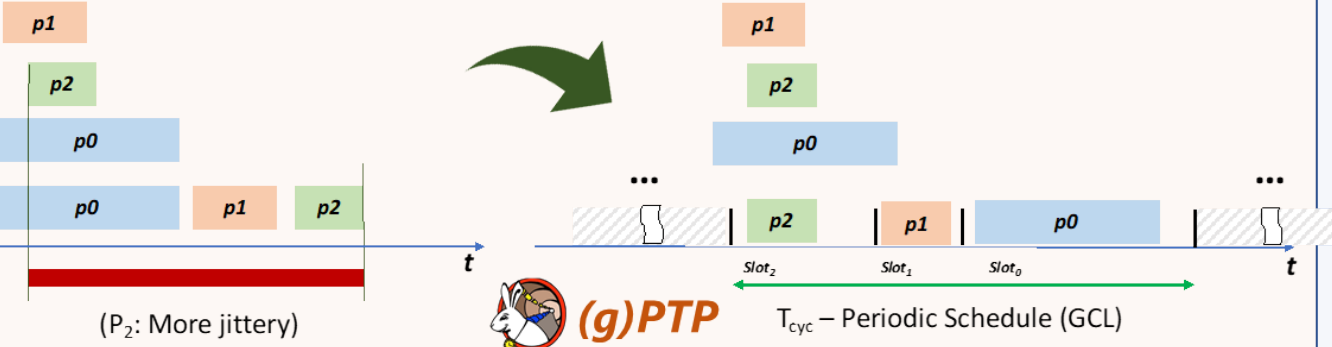
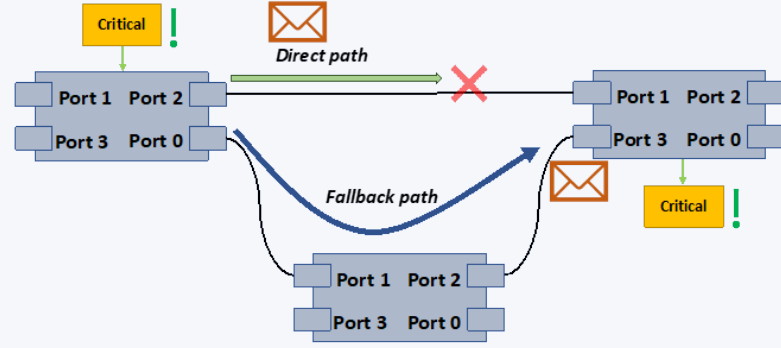
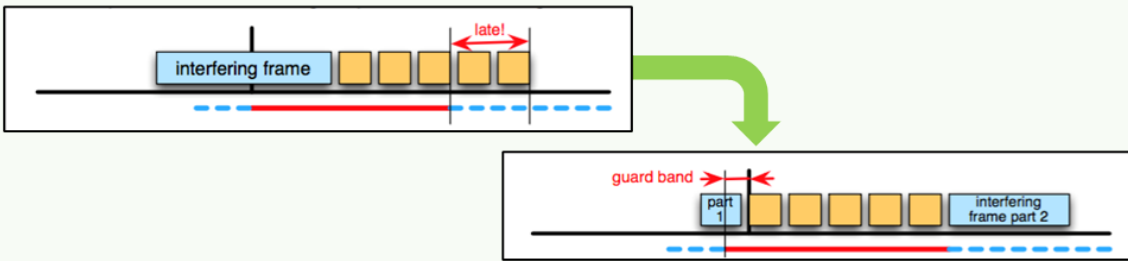
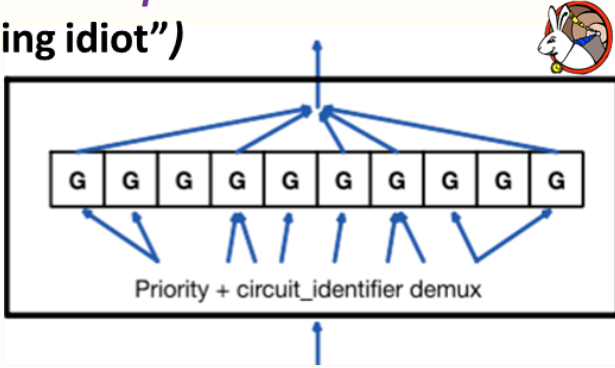
- **Main set of components to implement a functioning TSN system**

- 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     | <i>Enhancements and Performance Improvements</i>                       |
| IEEE 802.1Qbu & IEEE 802.3br | Forwarding and Queuing       | <i>Frame preemption and Interspersing Express Traffic</i>              |
| IEEE 802.1Qbv                | Forwarding and Queuing       | <i>Enhancements for Scheduled Traffic – Time-Aware Traffic Shaping</i> |
| IEEE 802.1Qca                | Path Control and Reservation | <i>Path Control and Reservation</i>                                    |
| IEEE 802.1Qcc                | Stream Reservation (SRP)     | <i>Enhancements and Performance Improvements</i>                       |
| IEEE 802.1Qci                | Time Based Ingress Policing  | <i>Per-Stream Filtering and Policing</i>                               |
| IEEE 802.1CB                 | Seamless Redundancy          | <i>Frame Replication &amp; elimination for Reliability</i>             |

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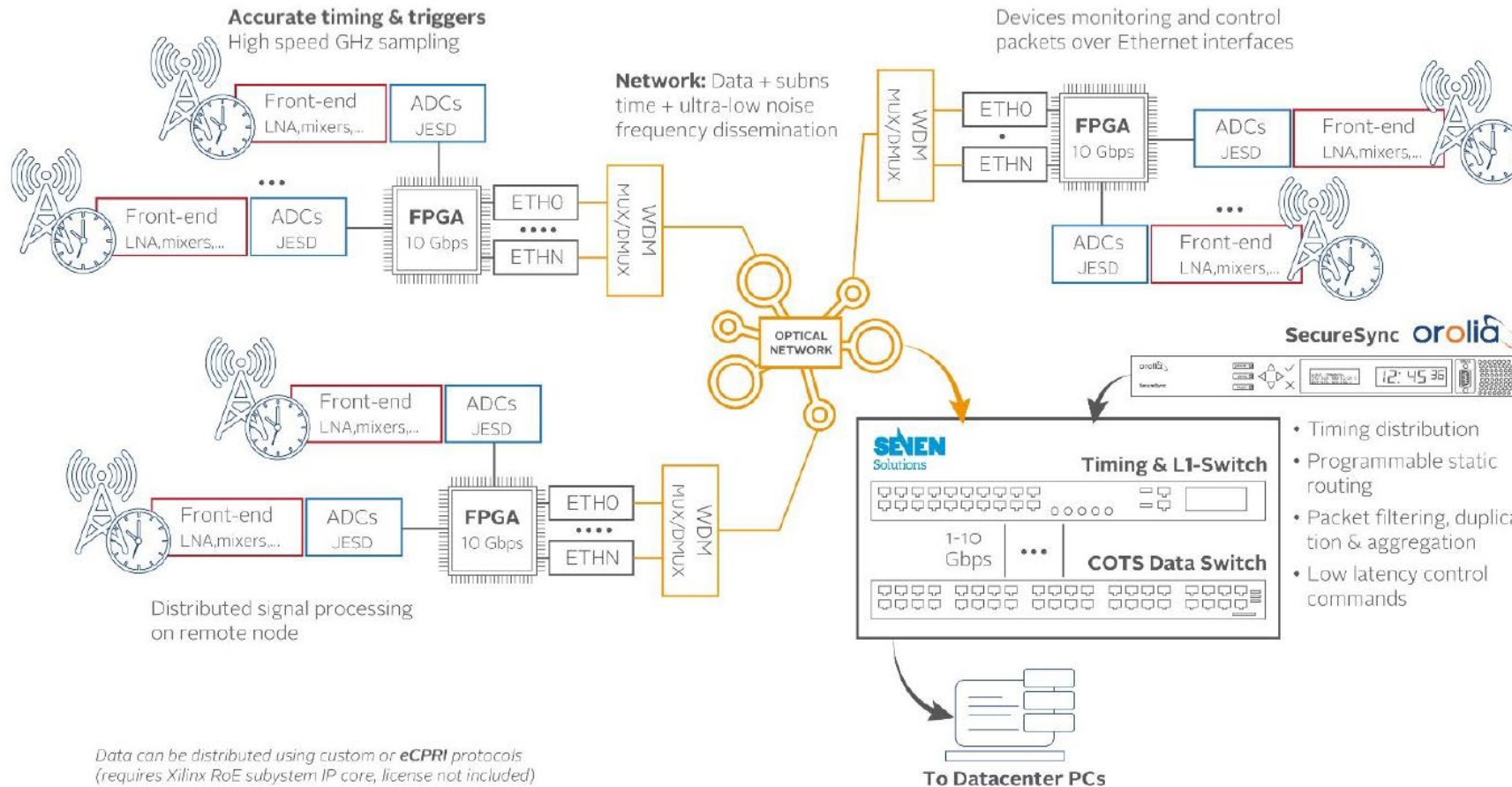
# An overview of the main TSN components (II)

| SYSTEM DETERMINISM  | ROBUSTNESS  |
|---|---|
| <p>▪ <b>802.1Qbv – Time-aware traffic shaper</b></p> <p>→ TDMA-like processing for TSN flows in accordance with priority</p>  <p>(P<sub>2</sub>: More jittery) <span style="color: orange;">(g)PTP</span> T<sub>cyc</sub> – Periodic Schedule (GCL)</p> | <p>▪ <b>802.1CB – Seamless redundancy</b></p> <p>→ Redundant transmissions of critical data</p>    |
| <p>▪ <b>802.1Qbu &amp; 802.3br – Frame preemption</b></p> <p>→ Reduce PDV for critical flows, preserve bandwidth</p>  <p style="color: orange;">(g)PTP</p>   | <p>▪ <b>802.1Qci – Time-based ingress policing</b></p> <p>→ Enforce <i>reception</i> within allocated slot (“babbling idiot”)</p>  <p style="color: orange;">(g)PTP</p> |



# 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

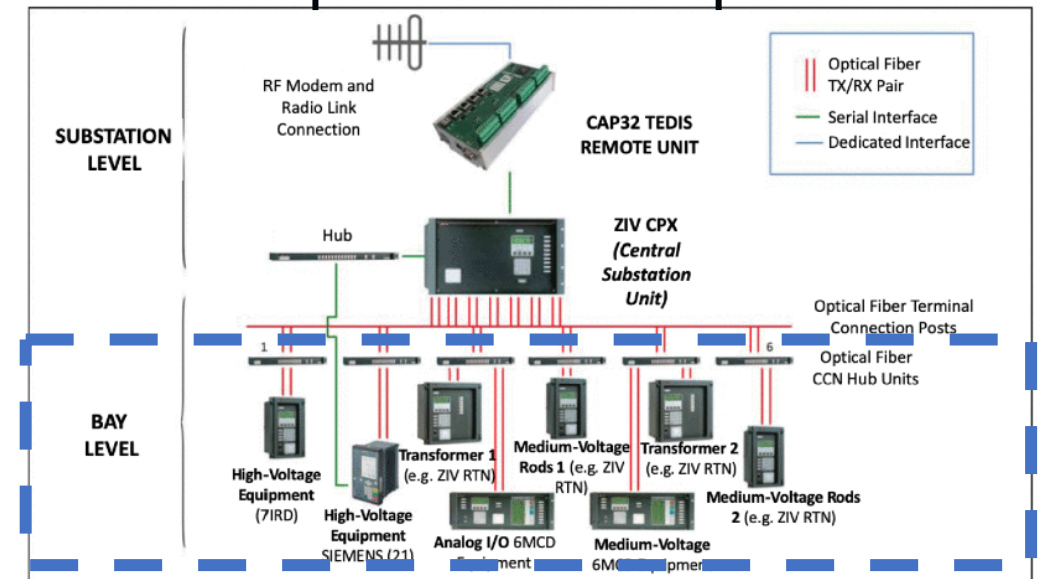
GOOSE

Ordinary data

- Critical events
- Latency ~ 30  $\mu$ s

- Medium priority
- IEC 61850

- Best effort
- Video, monitoring



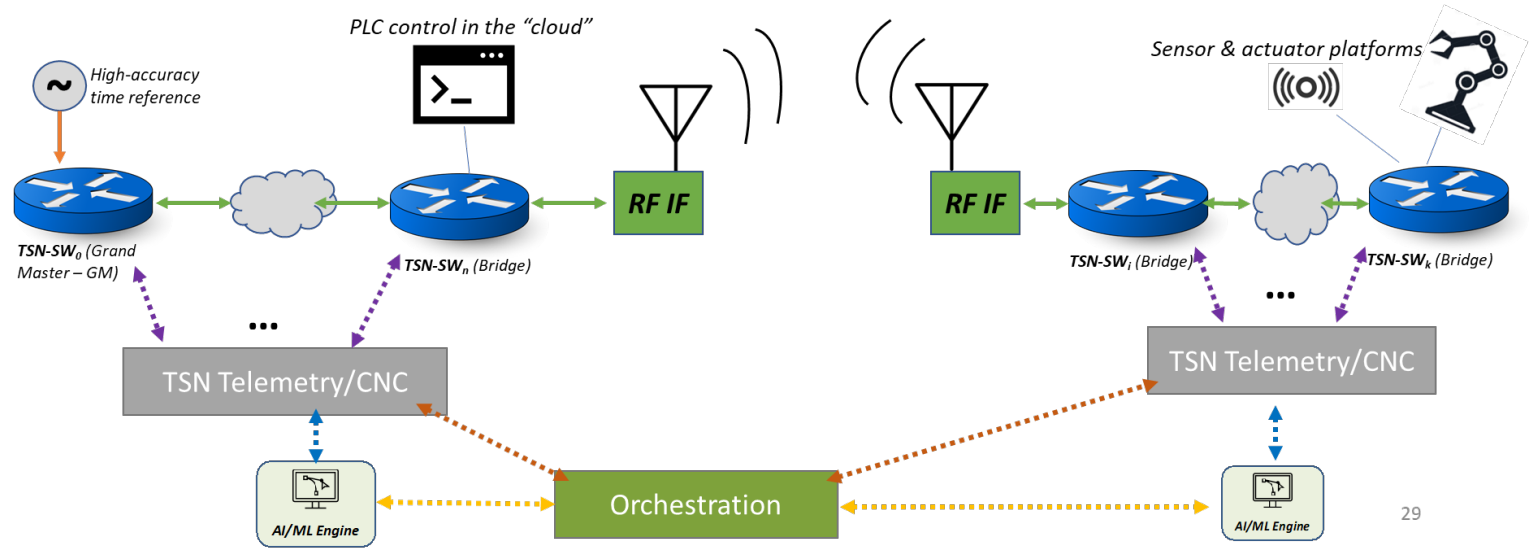
# Telecommunications. TSN & 5G

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

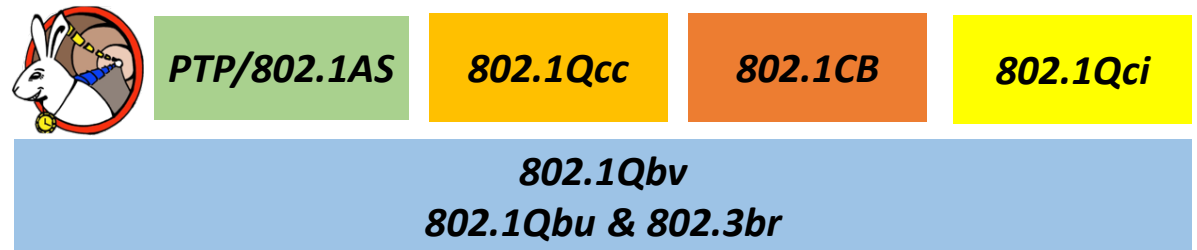
- End-to-end timing distribution (wired and wireless)
- Large geographic span for deterministic data
- Implement closed sensor-controller loops with guaranteed delivery, and determinism

## → Cloudification of control systems

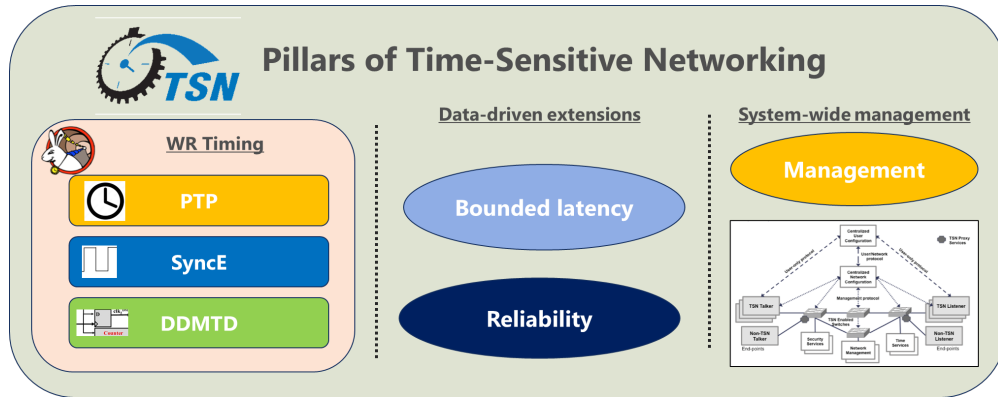
- Control servers on premise
- AGVs, vehicles, IoT devices on-site
- Determinism for control & sensor traffic through TSN & Timing (PTP/gPTP/WR)



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# TSN & WR timing. TSN for Next-Gen Architectures



## Main Highlights

Furnish RF and accurate timing for critical systems

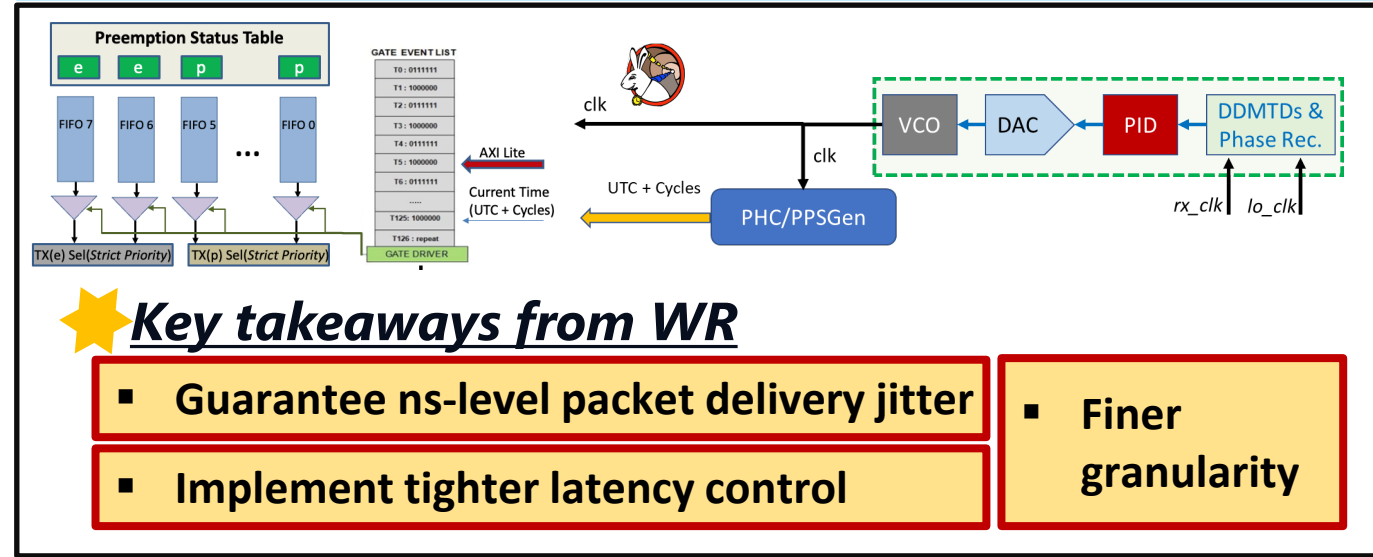
Low-latency transport for critical commands

Standards-based solution

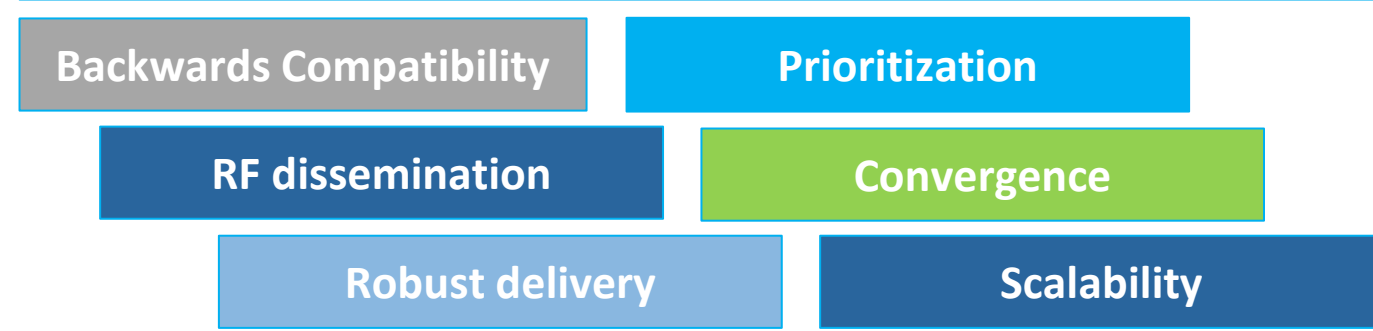
Joint data & Timing interface

Convergent data, timing, and control

## Enhanced Deterministic Forwarding



## Sub-ns Timing



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BY TRUST**

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