MODULAR OPEN
SYSTEMS APPROACH

Time-Sensitive Networking (TSN) in Military Ground Vehicle Architectures

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TSN in a Nutshell

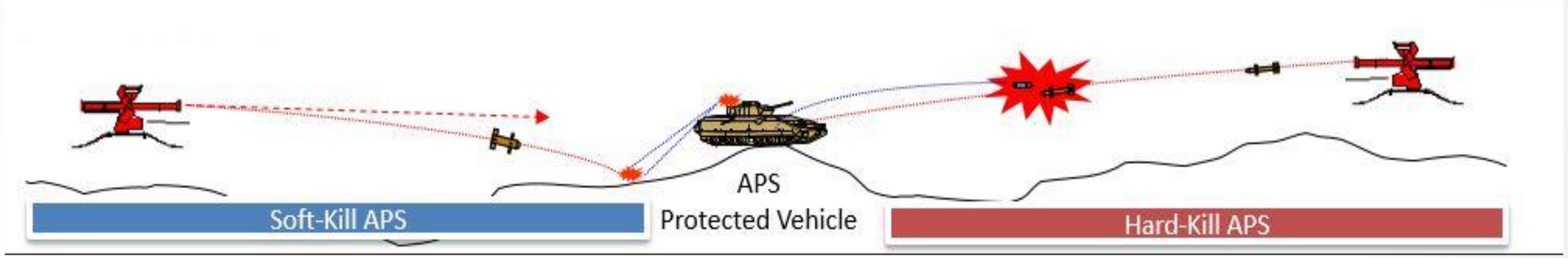
TSN is a collection of enhancements to traditional Ethernet which provide determinism and other features which make it a good candidate for being the next generation digital backbone for military ground vehicles and other cyber-physical systems

Why Are Deterministic Networks Important to Us?

Systems built on best-effort communications using VICTORY, DDS, UDP, TCP, and IP are great for non-safety related functions, experimental work, R&D, **but….**

- Traditional IP networks typically cannot synchronize hosts to the same level of accuracy, limiting coordination of activities between nodes
- Safety-boards are more likely to approve highly-predictable designs, and changes to designs when the system is deterministic (i.e., you will likely save $/schedule)
- Determinism is needed for proper support of motion control applications and hard real-time systems (e.g. fire-control, indirect driving)

Autonomous Maneuver ROGUE Anti-Ship Missile Using RTK [1]



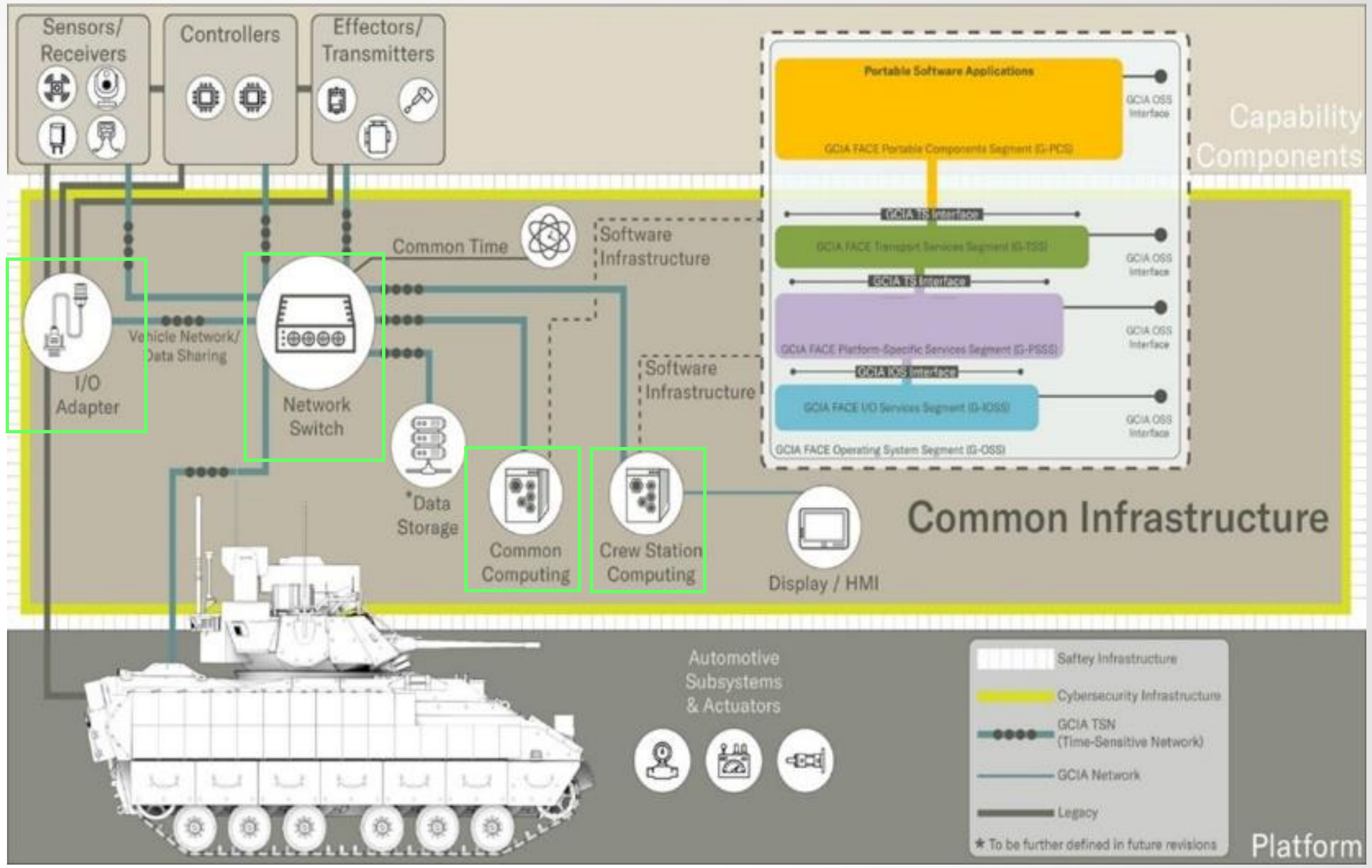
What Do You Mean Deterministic?

Characteristics of a deterministic network:

1. Precision time synchronization (<1 µs timing deviation)
2. Deterministic data flow with guaranteed and bounded latency and jitter
3. Protection against misbehaving nodes
4. Reservation of resources
5. Each node in deterministic message paths provides items 1 - 4

GCIA and TSN

- GCIA supports MOSA at the hardware, software, and network level
- GCIA remedies deficiencies of prior MOSA approaches like VICTORY, specifically addressing safety-critical
- GCIA adopts a mix of 1 Gbps and 10 Gbps TSN (TSN enabled components highlighted in green)
- TSN requirements leveraged on End-Stations and Bridges



TSN Specifications Overview

Relevant TSN Profiles
Automotive In-Vehicle (P802.1DG); Industrial Automation (IEC/IEEE 60802); Aerospace Onboard (P802.1DP)

IEEE – 802.1Q Standard for LAN and MAN Bridges and Bridged Networks

Time-Synchronization
IEEE 802.1AS-2020

Management & Configuration
IEEE 802.1Qcc
IEEE 802.1Qcp
IEEE 802.1Qcw
IEEE 802.1CBcv

High Availability & Reliability
Frame Replication and Elimination (IEEE 802.1CB)
Per-Stream Filtering and Policing (IEEE 802.1Qci)

Bounded Low Latency
Scheduled Traffic (IEEE 802.1Qbv)
Rate-Constrained Traffic (IEEE 802.1Qav)

Note 1: Only high-level TSN specs are shown here, there are ~24 other subspecifications not shown
Note 2: IEEE-802.1Q**xy** specs will likely be merged into IEEE – 802.1Q in the future
Note 3: Standards that begin with a "P" are in draft

Common Vehicle Communications Technologies

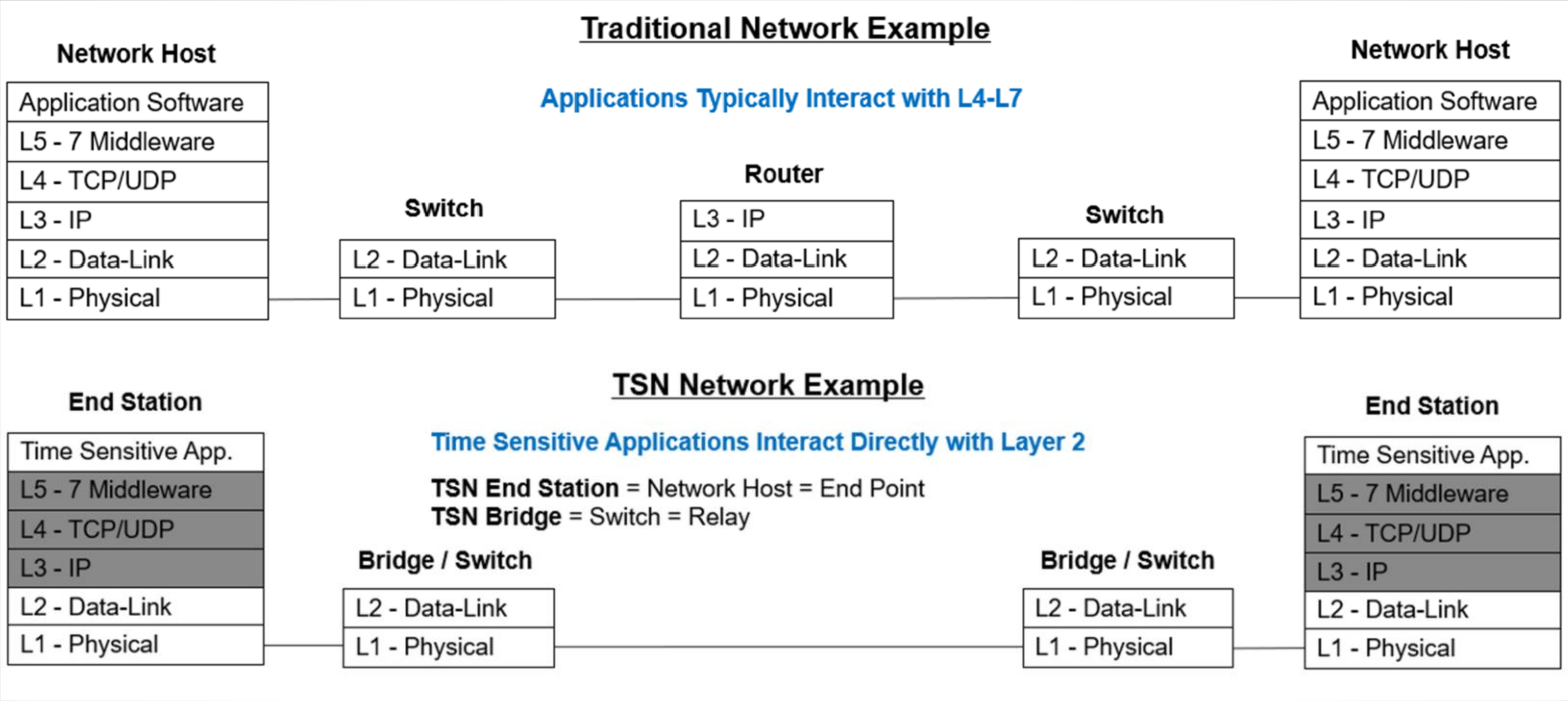
Standard	Approx. Standards Development	Approx. Max. Bandwidth	Benefits	Drawbacks
MIL-STD-1553	1973 - 1980	1 Mbps	Deterministic, Reliable	Expensive, Very Slow
RS-422	1975 - 2005	10 Mbps	Cheap, High-Integrity	Slow, Stagnant
CAN	1986 - Present	5 Mbps	Cheap, High-Integrity	Slow
IEEE 802.3 Ethernet	1973 - Present	400 Gbps	Very Fast	Non-Deterministic

TSN and the Open-Systems Interconnect (OSI) Model

Layer	Name	Functions	Protocol Data Unit (PDU)	Example
Layer 7	Application	APIs	Data	HTTP, SOAP, DDS
Layer 6	Presentation	Encoding, Encryption	Data	XML, DDS
Layer 5	Session	Inter-Process Sessions	Data	RPC, DDS
Layer 4	Transport	End-to-End Connection	Datagram, Segment	TCP, UDP
Layer 3	Network	Addressing, Routing	Packet	IP
Layer 2	Data-Link	Media Access Control, Addressing, Flow Control	Frame	Ethernet, CAN TSN
Layer 1	Physical	Electrical Signaling	Bits	1000BASE-X, 1000BASE-T

IMPORTANT!! This is a only a model and some protocols like TLS don't fit cleanly into a particular layer while others such as Data-Distribution Service (DDS) span multiple layers

Simplified Network Comparison



IMPORTANT: TSN IS BACKWARD COMPATIBLE SO BEST-EFFORT HOSTS CAN USE LEFTOVER BANDWIDTH

Selected TSN Feature Deep-Dive: IEEE-802.1AS Time-Synchronization

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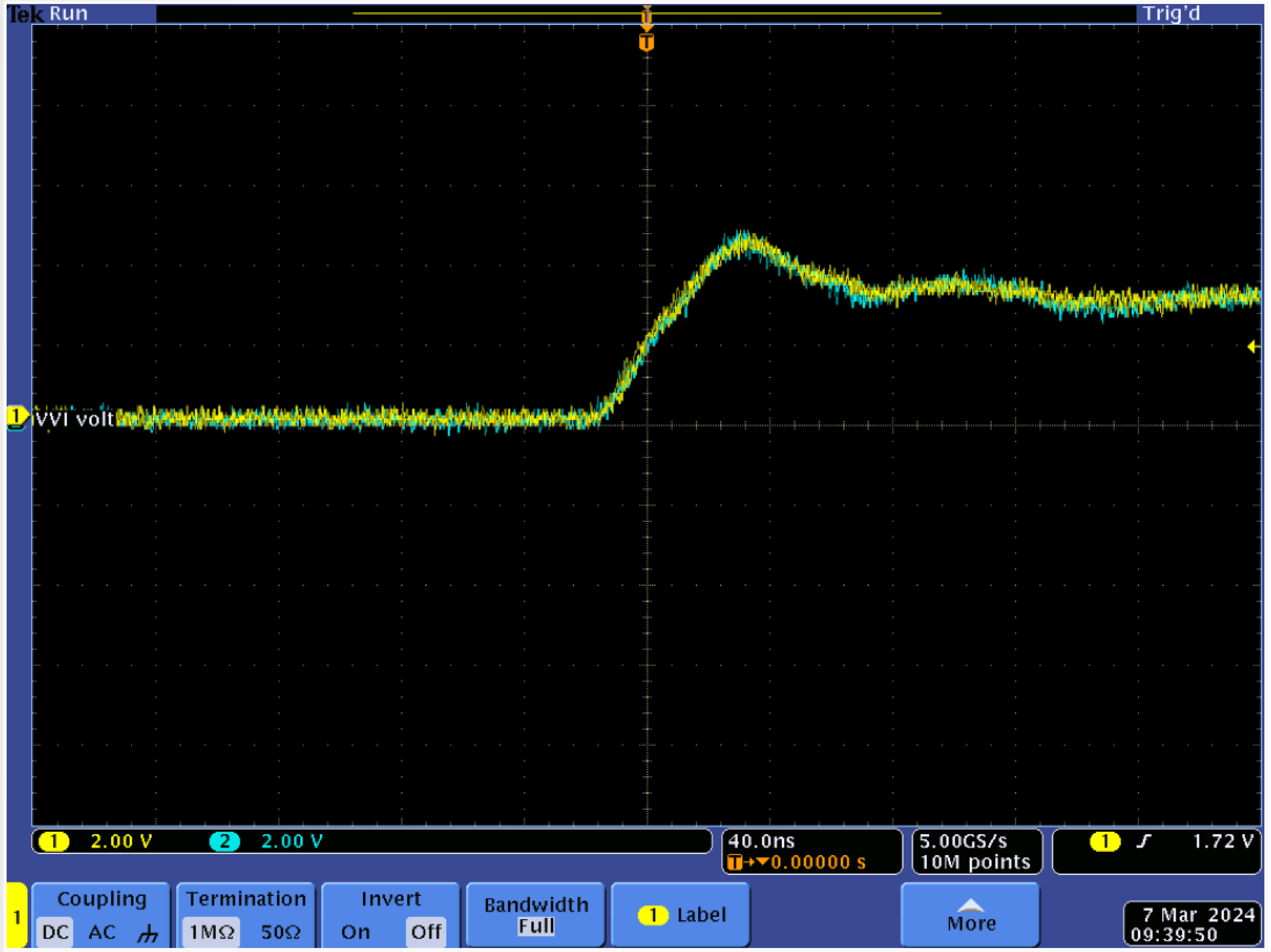
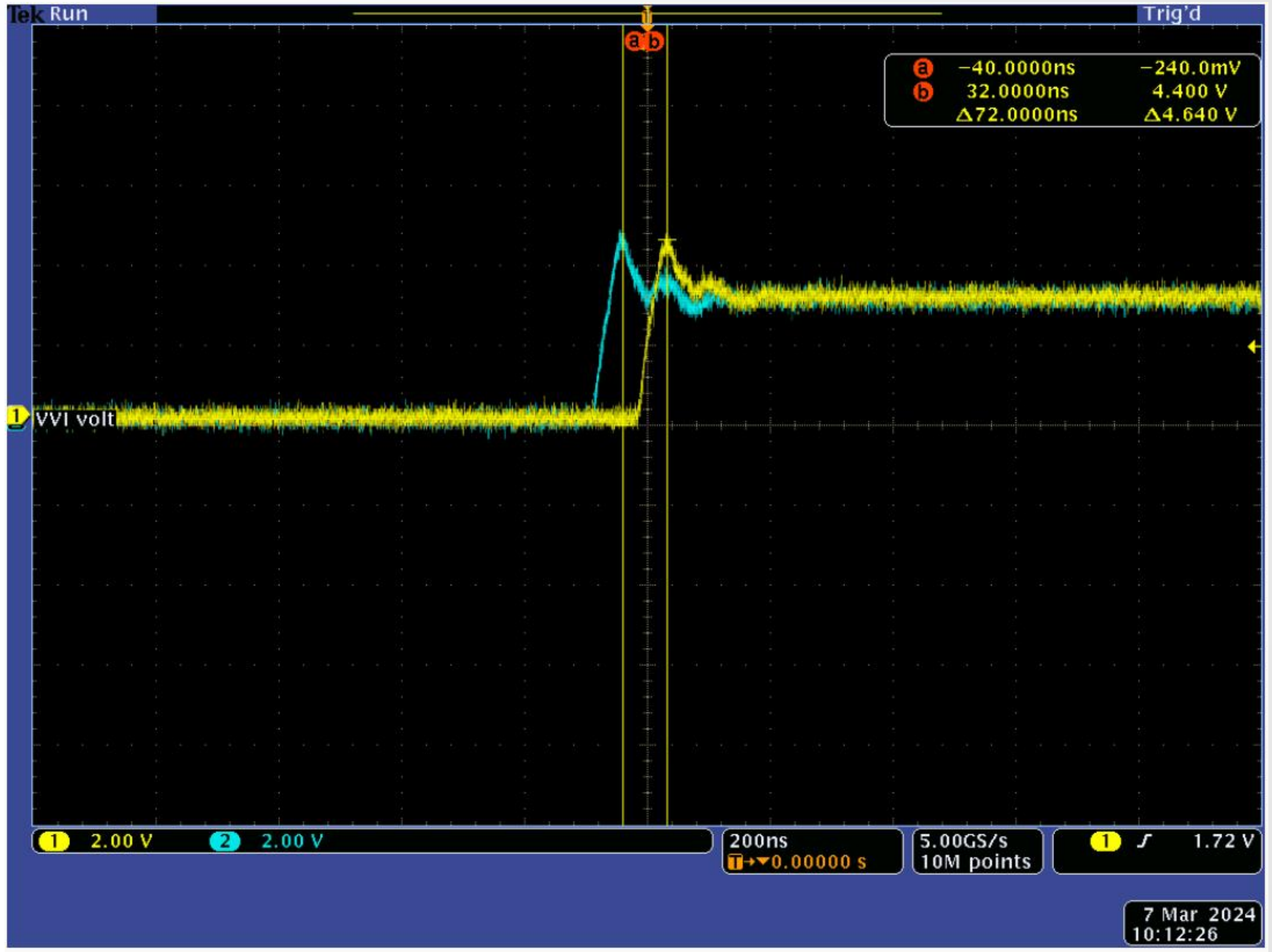
- Precision time-synchronization over the network
- Critical for distributed real-time control system
- Pulse-Per Second from Time-Sender (yellow) and Time-Receiver (blue) demonstrate accuracy



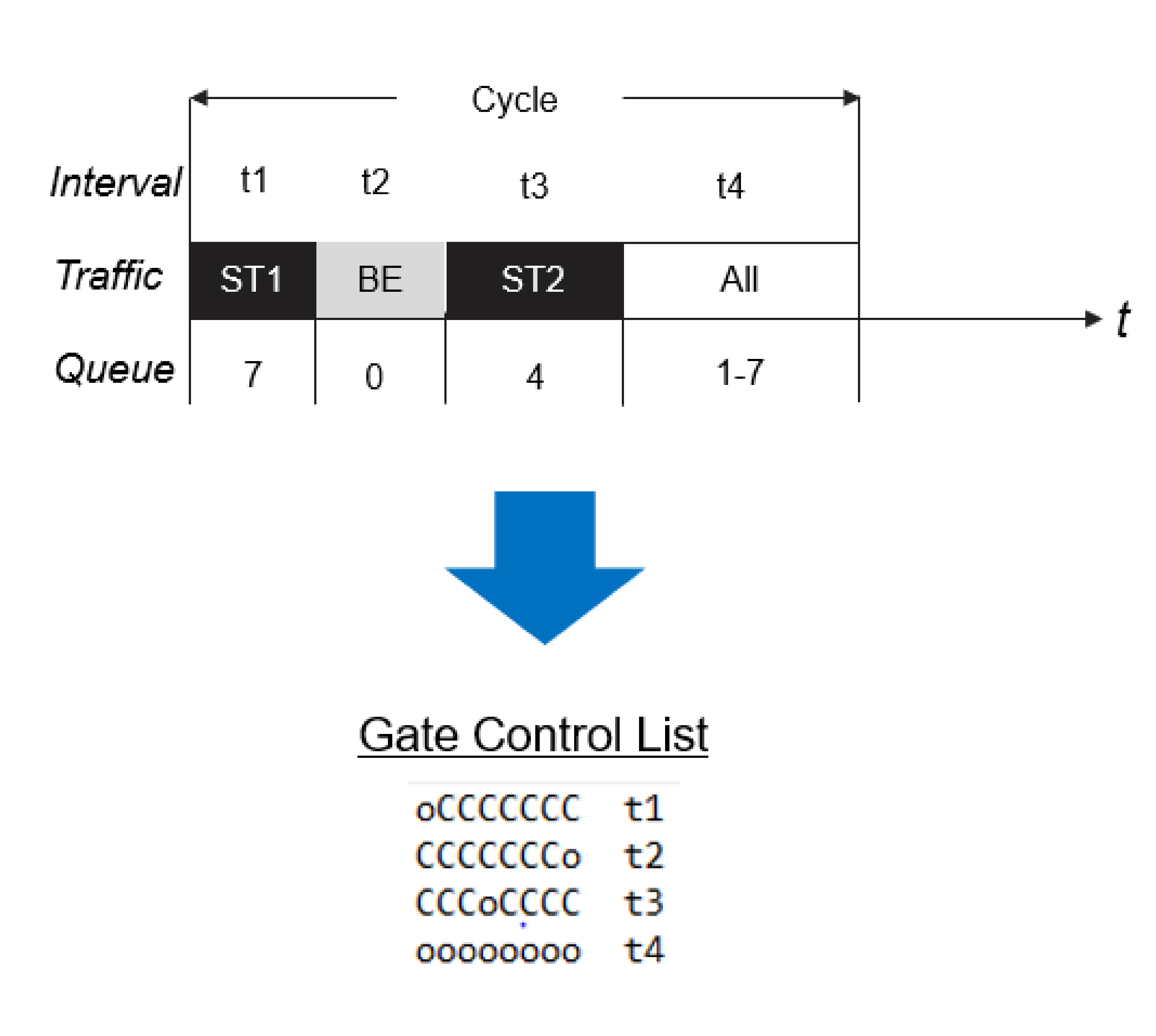
PPS Outputs (802.1AS running) Zoomed In View



PPS Outputs (after 10 minutes of 802.1AS not-running)

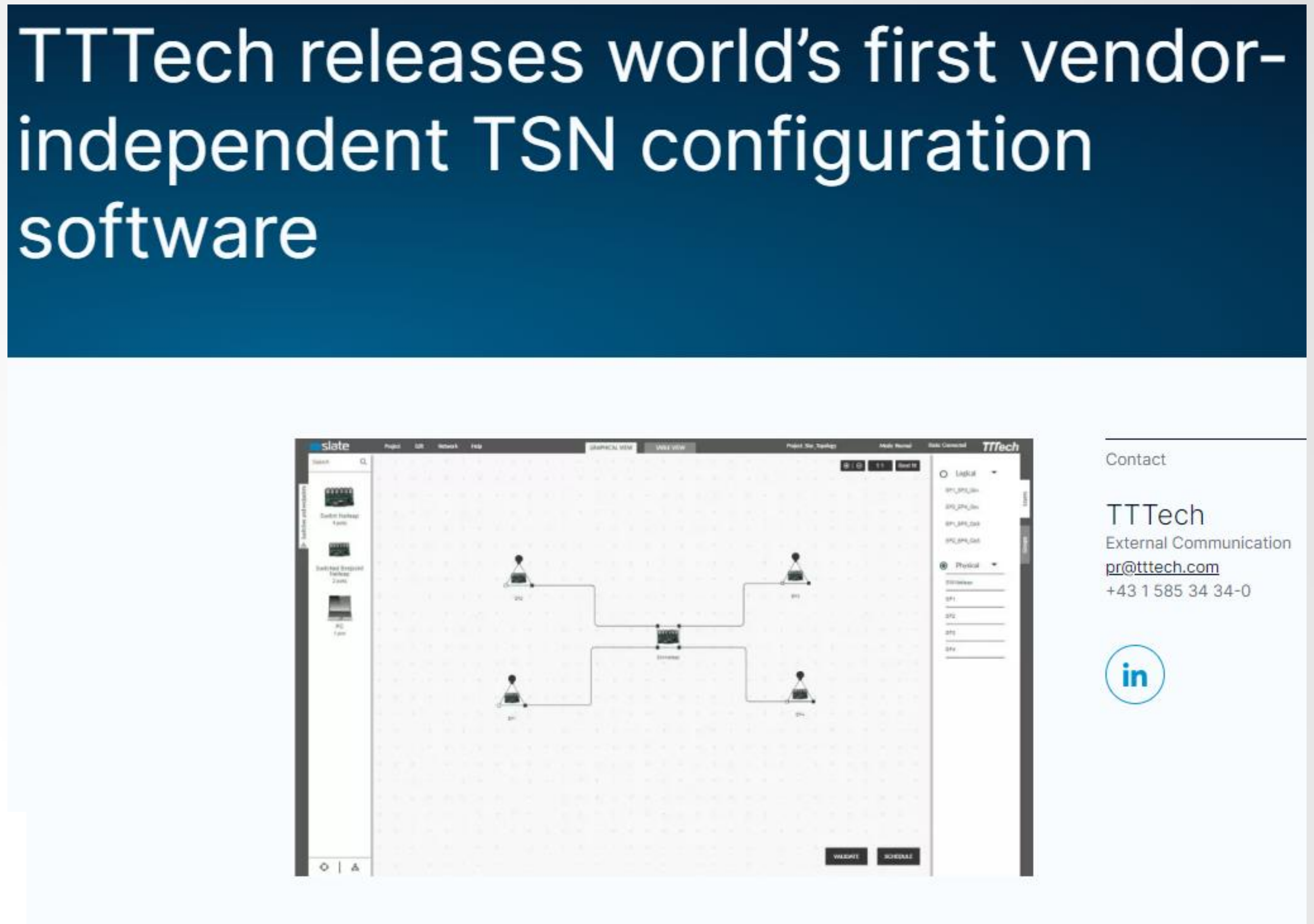
Selected TSN Feature Deep-Dive: IEEE-802.1Qbv Scheduled-Traffic

- Requires 802.1AS to Synchronize End-Stations and Bridges
- Schedule is configurable based on a number of time-slots repeated on a cycle (AdminCycleTime)
- During the cycle, gate operations (open/close) are applied at configurable time intervals (Gate Control List)
- Egress ports and queues on TSN end-stations and bridges are gated
- Scheduled Traffic (ST) does not encounter any buffering
- Leftover bandwidth can be allocated for Best-Effort (BE) and other traffic

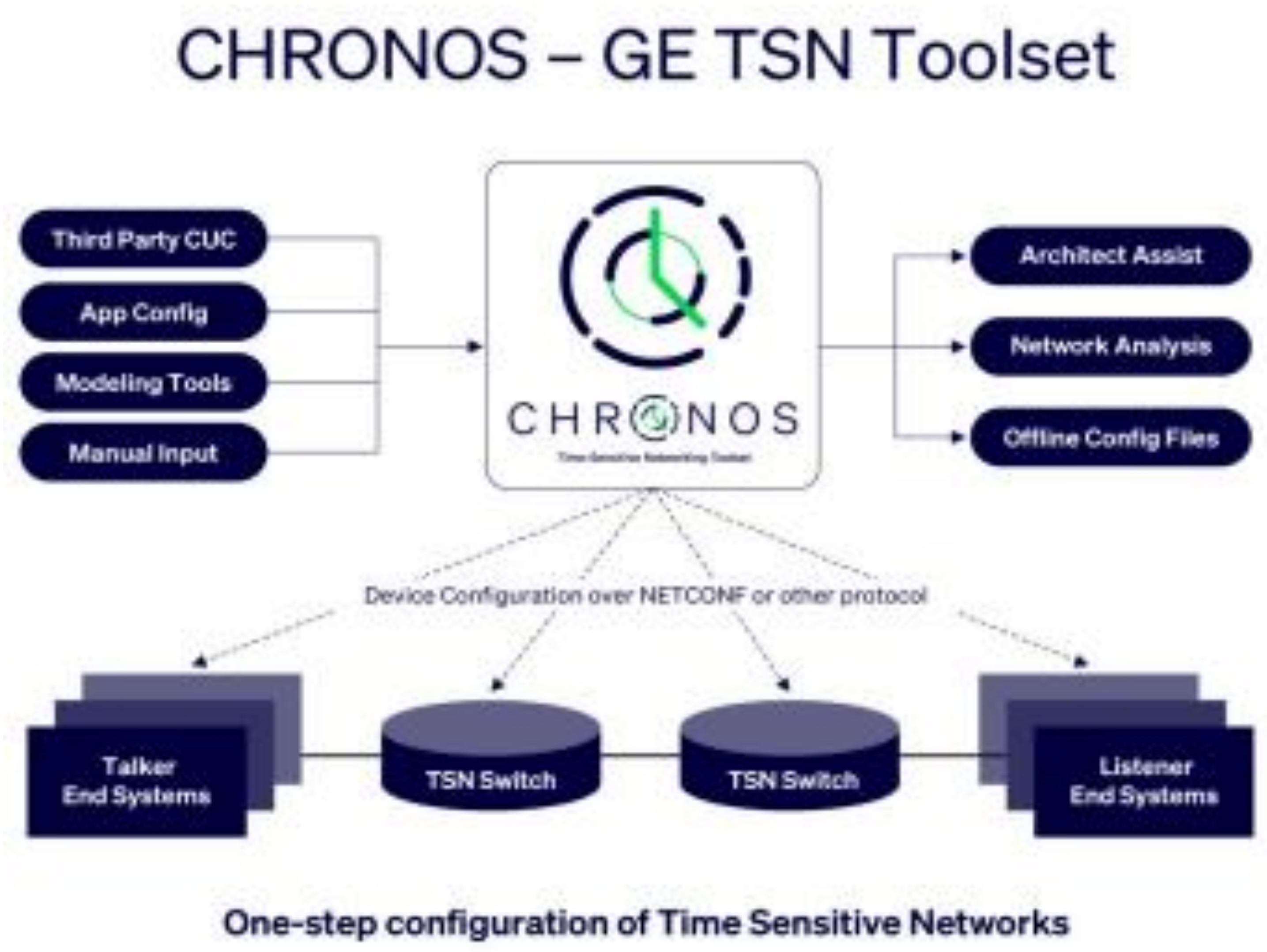


TSN Tools

- Designers will likely need tools to use TSN effectively
- Multiple options for tools (e.g. OnTime, GE, TTTech)
- A healthy ecosystem of tools built up around a open-standard is important - MOSA "Establish an Enabling Environment" Principle



TTTech Slate TSN Configuration Tool [2]



GE Chronos TSN Tool [3]

U.S. Army Ground Vehicle TSN Use-Case Projection

Characteristic	Current	Future	Driving Use-Case
Node Count	3 – 50	200	Fully Integrated, Optionally Manned, Combat Vehicle
Topology	Hybrid Star, Mesh, Tree		Fault-Tolerant Systems
# of Bridge Hops	0	5	Highly Integrated Combat Vehicle
Network Redundancy	Optional Independent A/B networks		Fault-Tolerant Systems
Media Type	Copper		Cost and low maintainability of fiber
Data-Rates	1 Gbps	10 Gbps	>10 Gbps unlikely without fiber
Maximum Link Utilization	90% worst case configured		
Configuration & Management	Mandatory TSN MIBS		
Traffic Types	Safety-Significant & Best-Effort		All ground vehicle types

TSN Profile Comparison

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IEEE Standard	Description	P802.1DG	P802.1DP - Synchronous	P802.1DP - Asynchronous	60802
802.1AS	Time Synchronization	Optional	Yes	No	Yes
802.1CB	Redundancy	No	Yes	Yes	Optional
802.1Qav	Rate Constrained	Yes	Yes	Yes	Optional
802.1Qbv	Scheduled Traffic	Optional	Yes	No	Yes
802.1Qbu	Pre-Emption	Optional	No	No	Optional
802.1Qci	Filtering & Policing	Yes	Yes	Yes	Yes
802.1Qcc	Configuration	No	Yes	Yes	Yes

NOTE: All but IEC/IEEE 60802 are drafts

Military Ground Vehicle Profile Preliminary Observations

- Network configuration for weapon-systems, including military ground vehicles, will likely be statically configured
- It would be a tremendous amount of work to develop a separate profile for military ground vehicles and it would probably only fracture the ecosystem (better to adopt/adapt)
- A Military Ground Vehicle Profile would most likely align with the P802.1DP Aerospace Profile
- Fault-tolerance will likely be needed on some but not all network links
- P802.1DP does not support frame-preemption (IEEE-802.1Qbu) and this might be beneficial, so we are looking trying to determine cost/benefit

Future Work

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- NAMC MOSA COI recently kicked-off a work group to explore TSN profiles
- Continued work in S&T programs to test TSN specifications and equipment
- Determine how time-sensitive applications should interact with TSN (e.g. FACE, DDS-TSN)
- Explore TSN conformance/qualification process
- Evaluate TSN tools for network design, analysis, and configuration

Modular Open Systems Approach (MOSA) COI

OBJECTIVE

- Develop the USG baseline architecture by enhancing PEO GCS Common Infrastructure Architecture (GCIA) based on Modular Open Systems Approach (MOSA) to guide the Optionally Manned Fighting Vehicle (OMFV) system development.
- The effort is directed by the Army Acquisition Executive to achieve transformational capabilities for OMFV via Modular, Open and Scalable Architecture, and by using applicable open standards.
- The effort will be executed by the Government, with input from industry and academia. The output of this MOSA COI will be incorporated the OMFV program and proliferated across the Ground Combat and Tactical Vehicle portfolios. Final architecture decisions will be made by the Government.

PRIMARY GOALS

- Guide the development of MOSA compliant open OMFV system
- A common hardware (AKA vetronics) and software infrastructure
  - Avoid redundant or stove-pipe system development and integrations
  - Avoid non-standard/non-commercial connectors, cables (as appropriate), and wires
  - Enforce sharing resources (e.g., processing) and data across shared network
  - Enforce the use of configurable and manageable switching technologies
    - For handling low-latency constraints and safety-critical functions
- Enable platform upgrades to a more autonomous system
  - To facilitate shared data to the AI based systems and other capabilities
- Avoid costly long-term supply chain lock
- Reduce future integration cost and development effort
- Enable efficient testing and qualification procedures
  - Optimize on validations, qualifications and test (Cost, Schedule and efforts)

If you are interested in joining the MOSA COI, please click the button below for the application and submission instructions.

MOSA COI APPLICATION (PDF, 165.33 KB)

NAMC MOSA COI [4]

Overall Takeaway

- High-performance, scalable deterministic networks are an important tool to help us build safe, highly-integrated, next generation vehicles with advanced capabilities

- TSN is a promising candidate for fulfilling the safety-critical and best-effort networking needs of ground vehicles using one unified communication infrastructure

- TSN is complex and more work is needed to understand it and come up with implementation guidance

- Need to rightsize 10 Gbps TSN requirements

- If you are interested in TSN come talk to us

References

1. ROGUE Anti-Ship Missile System. Adapted from “Marines adopt Army autonomous software for ROGUE Fires” retrieved from https://www.usarmygvsc.com/marines-adopt-army-autonomous-software-for-rogue-fires/ U.S. Army/Public Domain
2. TTTech Slate Product Launch, https://www.tttech.com/tttech-releases-worlds-first-vendor-independent-tsn-configuration-software
3. GE Chronos TSN Tool, https://www.geaerospace.com/sites/default/files/ge-aerospace-chronos.pdf
4. NAMC MOSA COI, https://www.namconsortium.org/membership/communities-interest

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