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APPLYING TIME-SENSITIVE NETWORKS TO COMMUNICATION FOR ENTERPRISE (C4E) NETWORKS

Discover how Time-Sensitive Networking (TSN) is reshaping enterprise communication by bridging IT and OT networks.

CONTENTS

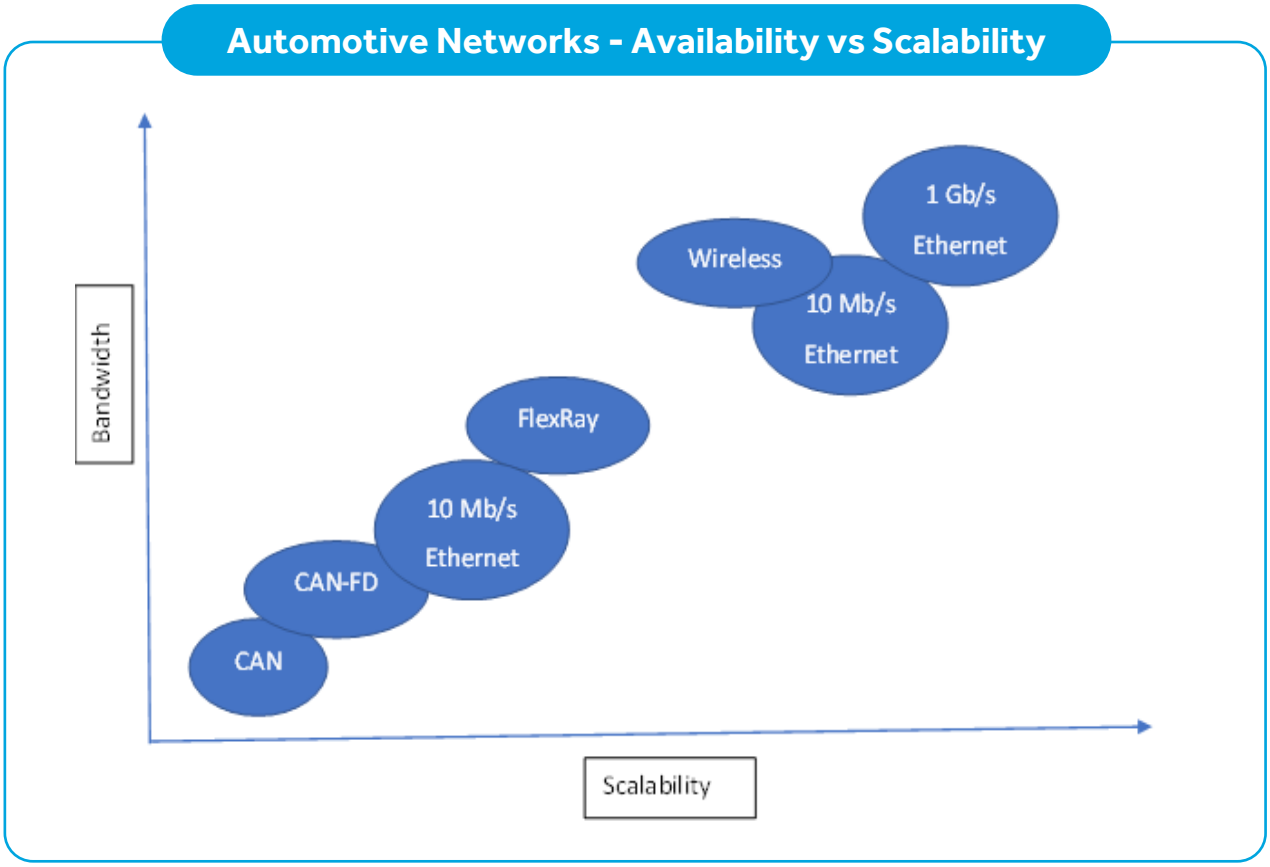
Abstract

This paper explores the critical role of Time-Sensitive Networking (TSN) in Communication for Enterprises (C4E) industries, addressing the convergence of OT and IT networks. TSN is a pivotal enhancement for Ethernet-based communications, and time stamped which in turn ensures the priority of frames frame handling at Layer 2 of the Open Systems Interconnection (OSI) Model. By enabling deterministic networking, TSN addresses critical industrial needs such as synchronization, latency management, and traffic prioritization. This white paper delves into the application of TSN across various sectors, the underlying standards, and its transformative potential for enterprise automation and communication. At Enterprise and Communication Networks, Data originates from an ethernet source, is encapsulated across various carrier's mediums, and decapsulated back to the ethernet destination. Hence, it's essential to distinguish the frame details and ensure proper queuing and guarantee of service (GoS) for the ethernet frame and packets. Here, the article explains the new happenings on TSN Networks and how its adopted in various enterprise domains.

Introduction

The adoption of TSN is revolutionizing industrial communication landscapes by bridging the gap between IT and OT networks. Initially developed for audio/video systems, TSN's transition to industrial applications provides enterprises with robust, interoperable communication solutions. With the exponential growth of Industry 4.0 technologies, businesses increasingly turn to TSN to manage the complexities of converged networks requiring time sensitivity. TSN enables synchronized operations, real-time data exchange, and prioritized traffic handling, which is crucial for ensuring operational efficiency and reliability in mission-critical environments. By leveraging IEEE-defined TSN standards, organizations can achieve scalable and deterministic networking solutions, fostering seamless integration of IT-OT systems and ensuring readiness for future technological advancements.

Most industry OT-IT network architects still use proprietary industrial ethernet protocols such as Powerlink, Device net, CC-Link IE, Profinet, Ether Cat, Modbus TCO, and most frequently used OPC-UA for OT-IT Networks, enabling and managing communication within industrial equipment. However, with the advancement in rolling Private 5G networks at enterprises, there has been an increase in the adoption of Automotive Ethernet use cases. These business units increasingly turn toward converged networks with a holistic integration of Information and Operational Technologists, who are all set to change the status of the industrial communication landscape and create a bright foundation for the convergence of IT and OT networks.

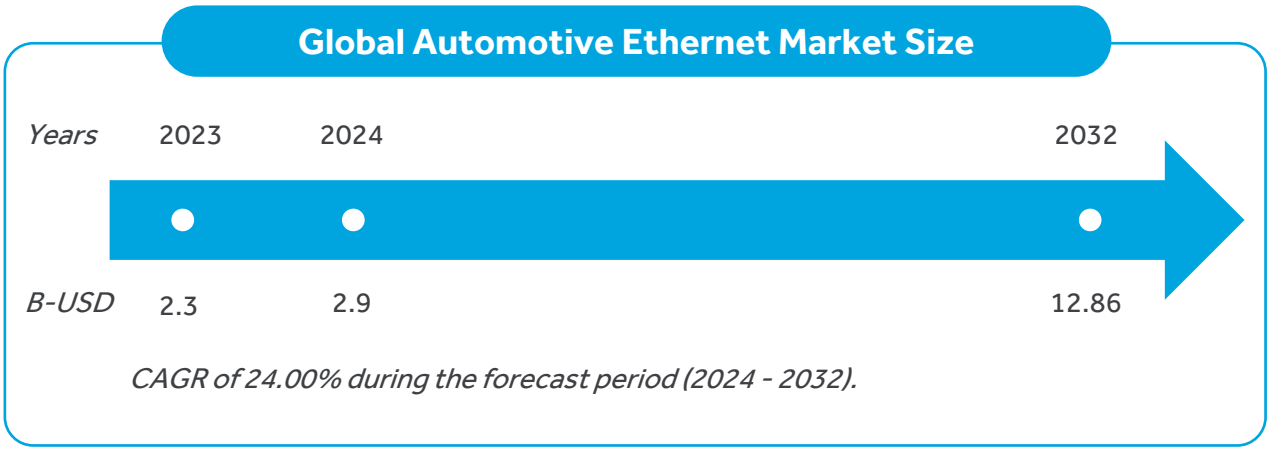


Brief History

The TSN enhancement to the Ethernet protocol was initially developed for audio/video equipment and was originally known as the AVB Bridging set of standards. The term TSN Networks emerged as industrial equipment manufacturers began adopting this technology. By incorporating industrial-grade robustness and reliability into the Ethernet system, TSN offers an IEEE-standard communication technology that ensures interoperability between industrial devices conforming to standards, regardless of the IT-OT vendor. Ethernet, known for its efficiency, has established a strong presence in the IT industry and expanded into OT infrastructure.

Global Automotive Ethernet Market Overview

The global automotive Ethernet market is experiencing rapid growth driven by advancements in vehicle connectivity and autonomous technologies. Ethernet's high bandwidth and low latency make it the backbone of modern automotive communication systems. The market is valued at USD 2.3 billion in 2024 and is projected to grow at a CAGR of 24.00%, reaching USD 12.86 billion by 2032. This growth is fueled by the increasing adoption of ADAS (Advanced Driver Assistance Systems), zonal architectures, and next-generation infotainment systems. TSN's integration into automotive Ethernet networks is critical in addressing autonomous vehicles' stringent performance and reliability requirements, ensuring seamless data transmission between sensors, controllers, and actuators. By replacing legacy protocols like CAN and FLEXRAY, TSN offers a unified and future-ready communication standard for the automotive industry.



Core Features of TSN

Time-sensitive networking (TSN) is characterized by its ability to deliver reliable, real-time communication within complex network environments. By addressing the specific demands of time-critical applications, TSN introduces groundbreaking features that transform traditional Ethernet into a deterministic communication framework. These core features form the backbone of TSN's functionality:

1

Synchronization of Network Devices

TSN ensures precise timing and coordination across all connected network devices, which is essential for applications requiring high precision and real-time operations. Accurate synchronization minimizes timing discrepancies, enabling seamless data exchange.

2

Latency Management and Bounded Delay

TSN provides mechanisms to control and guarantee latency, ensuring time-critical data packets reach their destinations without delay. This feature is vital for industrial and automotive systems where even microseconds matter.

3

Traffic Prioritization and Queuing

By classifying and prioritizing network traffic, TSN ensures that critical operations receive precedence over non-essential tasks. This feature enhances the efficiency of resource utilization within converged networks.

4

Guaranteed Bandwidth Allocation

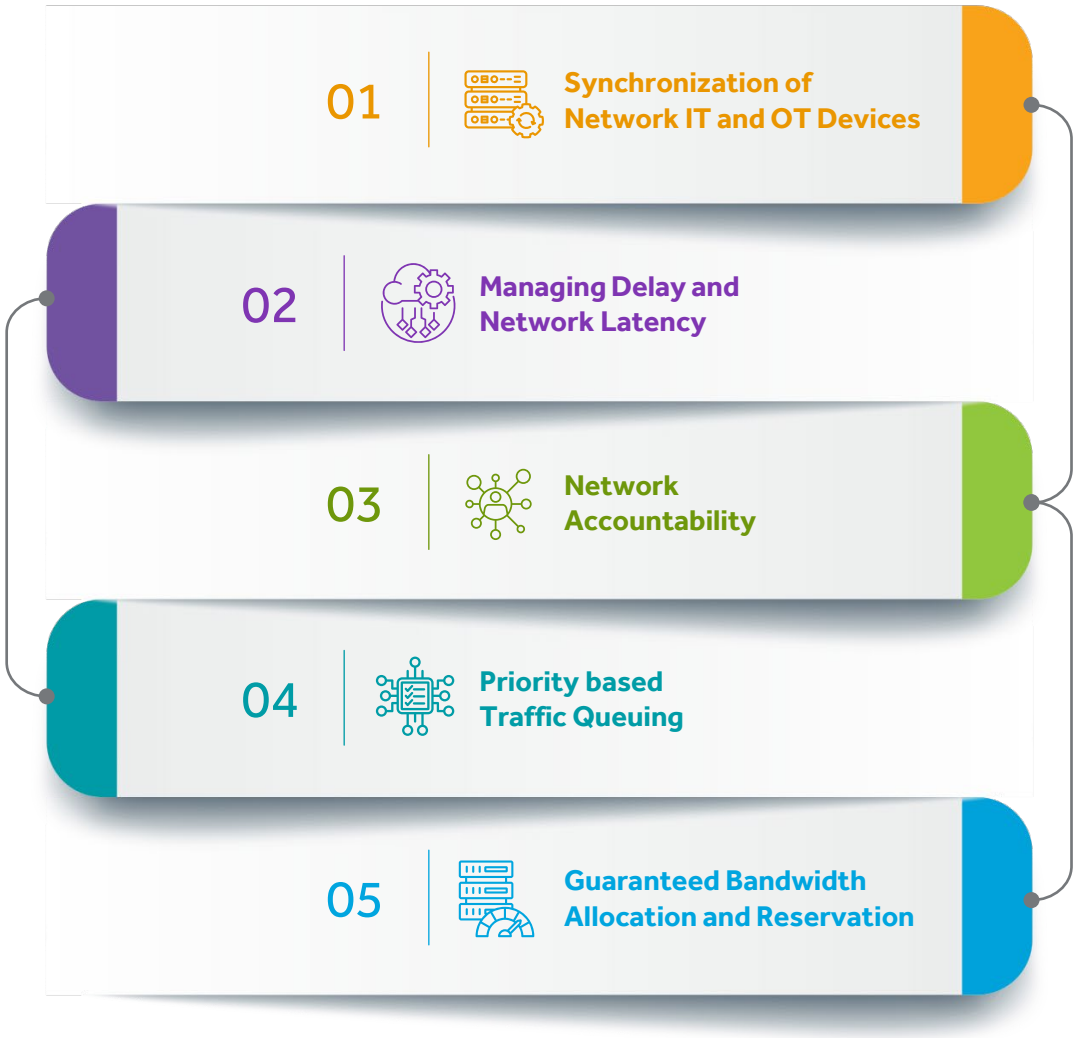
TSN reserves specific bandwidth for critical operations, providing uninterrupted communication for high-priority applications. This guarantees performance reliability even during peak network loads.

5

Redundancy and Reliability

TSN enhances network resilience by implementing seamless failover mechanisms and redundancy protocols. These capabilities ensure continuous operation, even during network disruptions or failures.

Recently, some Enterprise businesses that are quickly adopting TSN (Time-Sensitive Networks) are mining, utilities, automotive, rail networks, and aeronautical networks. While Ethernet-based technology is the most widespread networking technology, it inherently operates on a best-effort basis to deliver packets across a network. TSN - Ethernet standards that enable deterministic networking technology are their features are highlighted here:



TSN eliminates the need for physically separating critical and non-critical communication networks across IT and OT networks. It allows same-channel data communication across Operations Networks and IT enterprise networks that revolve around IIoT using the same communication network at Enterprises. TSN can be implemented in industrial devices by integrating switched endpoints, switches, and associated network system software. The advantage is that FPGA can be reconfigured based on new TSN Standards without much rework and effort.

Ethernet is the most adopted and widely accepted networking technology implemented, and it operates on a best-effort-based delivery mechanism to transfer packets across a network. It complies with Ethernet and Time-Sensitive Networking standards which enables Ethernet to become a deterministic networking technology.

Ethernet Standards

The Institute of Electrical and Electronics Engineers (IEEE) has introduced IP-based automotive Ethernet 100BASE-T1 (P802.3bw), Multi-Gigabit Ethernet (IEEE 802.3ch), 1000BASE-T1 (802.3bp) and 10BASE-T1S (IEEE 802.3cg) standards. Most recently, the IEEE introduced the Multi-Gigabit Ethernet (IEEE 802.3ch) standard, which can operate at 2.5Gbps, 5Gbps and 10Gbps with PAM4 encoding scheme. To ensure the interoperability of hardware and the safe, predictable operation of the vehicle in diverse environments and operating conditions, strict constraints are placed on signal levels, noise, and clock characteristics. The testing techniques specified by the standards, although well-established for stationary Ethernet networks, have created new design challenges for many automotive engineers accustomed to working with slower serial buses like CAN and LIN.

Coral of TSN Standards

TSN leverages many IEEE standards to manage and address various issues and add-on network functionalities. These standards, some active and others under development, ensure robust and deterministic networking for critical applications. Below is a summary of key TSN standards:

Ethernet Standards	Feature
802.1AS	Rev Timing and Synchronization for Time-Sensitive Applications
802.1AS-2011	Timing and Synchronization for Time-Sensitive Applications in Bridged Local Area Networks
802.1Qav	Forwarding and Queuing Enhancements for Time-Sensitive Streams
802.1Qbv	Enhancements for Scheduled Traffic
802.1Qbu	Frame Pre-emption
802.3br	Interspersing Express Traffic
802.1Qat	Stream Reservation Protocol (SRP)
802.1Qca	Path Control and Reservation
802.1Qcc	Enhancements and Performance Improvements
802.1CB	Seamless Redundancy
802.1Qci	Per-Stream Filtering and Policing
802.1Qch	Cyclic Queuing and Forwarding
802.1CM	Time-Sensitive Networking for Front-haul
802.1Qcr	Asynchronous Traffic Shaping
802.1CS	Local Registration Protocol
1722-2011	Layer 2 Transport Protocol for Time-Sensitive Applications in a Bridged Local Area Network
1722-Rev	Enhance the Stream Transport Protocol
1733-2011	Layer 3 Transport Protocol for Time-Sensitive Applications in Local Area Networks
1722.1-2013	Device Discovery, Enumeration, Connection Management and Control Protocol

Seamlessly integrating TSN capabilities into Communications for Enterprise (C4E) businesses can help deliver the significant necessary network improvements

OT and TSN Networks

TSN capabilities can enable the co-existence of different types of traffic on the same network depending on its operational needs. Enabling such OT connectivity and network devices to be successfully deployed and managed and ensuring interoperability and conformance with the IEEE-defined TSN standards is essential and is the most critical piece toward Private 5G Networks (P5G) from an IR 4.0 Network Integration. C4E Network Automation from an IR 4.0 automation consisting of real-time detection, monitoring, tracking and closed-loop decision making, IoT Sensor integration and Enabling Automation for C4E domains - such as Intelligent Factory Automation and Scada/IoT Utilities Sensor Integration, Aero IoT Sensor integration, Rail Scada/IoT Sensor Integration, AGV Automation, Automotive Sensor Integration. TSN offers deterministic, real-time communication that allows different OT/IT equipment to work seamlessly.

Network Traffic Management

As OT/IT networks grow and ends up as a complex infrastructure, implementing network traffic management and prioritizing system resources to ensure that critical data gets delivered on time make the network ultra-reliable and more secure with network traffic management (NTM). NTM analyses and directs network traffic to the best resources based on priorities to ensure that critical data is delivered on time. NTM helps to optimize network performance and security and avoid network congestion. Generally, the TSN specification is implemented in industrial devices within their SoC FPGA/Accelerator subsystems. It integrates with the Processor Systems and FPGA into a single device and ensures tight integration of TSN Hardware and embedded software. At network level communication, TSN applies deterministic communication based on network schedules distributed to devices via standard interfaces, with IIoT and IL4.0 dominance and increased rollout in C4E industries. TSN offers better and more reliable real-time connections than proprietary or industrial ethernet technologies. Like the seamless enterprise IT world of Ethernet connectivity from a laptop or PC to server and network devices, adopting TSN ethernet to OT/IT infrastructure connectivity toward integration and alignment with worldwide IEEE standards. TSN ensures more considerable adoption benefits - Ensures compatibility at network levels between various vendor devices, thus avoiding vendor lock-in and naturally scaling with ethernet connectivity and allowing networks and systems to be converged separately earlier.

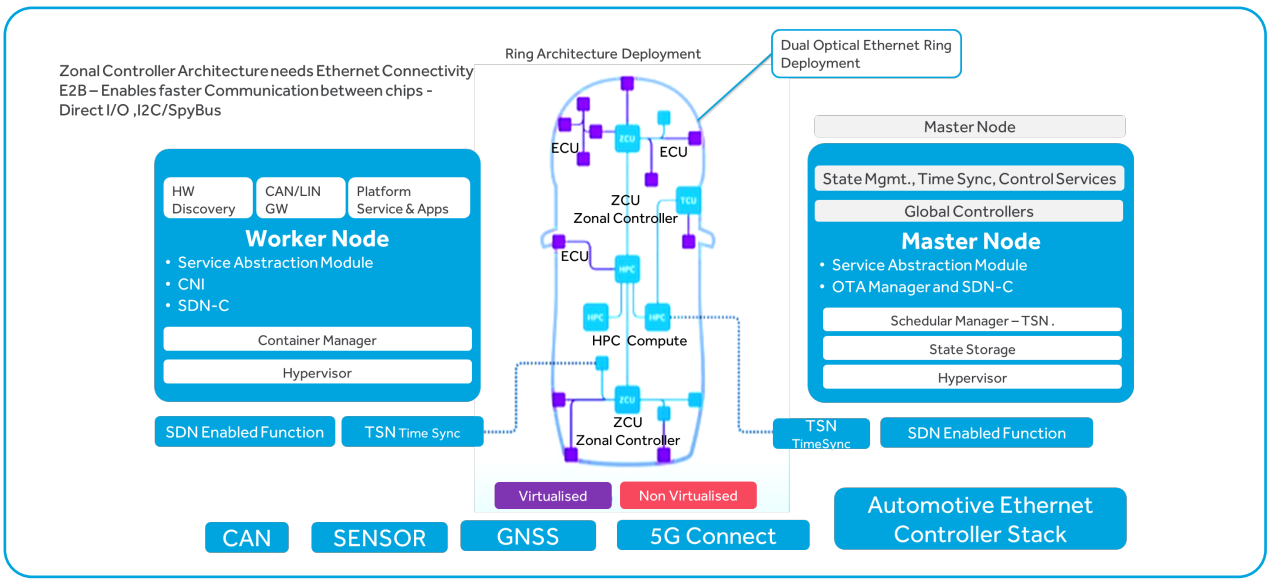
Applications of TSN in C4E Industries

1. Automotive

There is an increasing demand forecast for the adoption of Automotive Ethernet systems in the automotive industry in the coming years. Some of the key features driving the need for TSN Networks in this industry include:

- **High data rates:** Enable high-speed, high-volume data communication management.
- **Low latency:** Provides minimal delay for real-time systems, such as AD/ADAS feature enablement and quick decision-making capabilities powered by machine learning.
- **LIDAR and RADAR inputs:** Supports 2D, 3D, and video-based decision-making.
- **Lane Assist Programs:** Enhances driver safety and convenience.
- **V2X feature enablement:** Facilitates vehicle-to-everything communication for improved connectivity.
- **High reliability:** Offers robust noise immunity for uninterrupted communication.
- **Lightweight, space-efficient, and cost-effective cabling:** Reduces overall vehicle weight and cost.
- **Standardization:** Based on well-established standards from reputable standards bodies.
- **Zonal controller integration:** Streamlines autonomous driving architecture.
- **Replacement of legacy protocols:** Phases out protocols like CAN and FlexRay for internal automotive communications.
- **Deterministic communication:** Ensures seamless and predictable performance for infotainment systems.

Unlike non-automotive Ethernet, automotive Ethernet cables use PAM3/PAM4 modulation to achieve high data rates and reliability. Here's an example of the adoption of TSN Ethernet implementation at automotive domain.



Ref. Architecture for TSN Ethernet in SDV

2. Mining

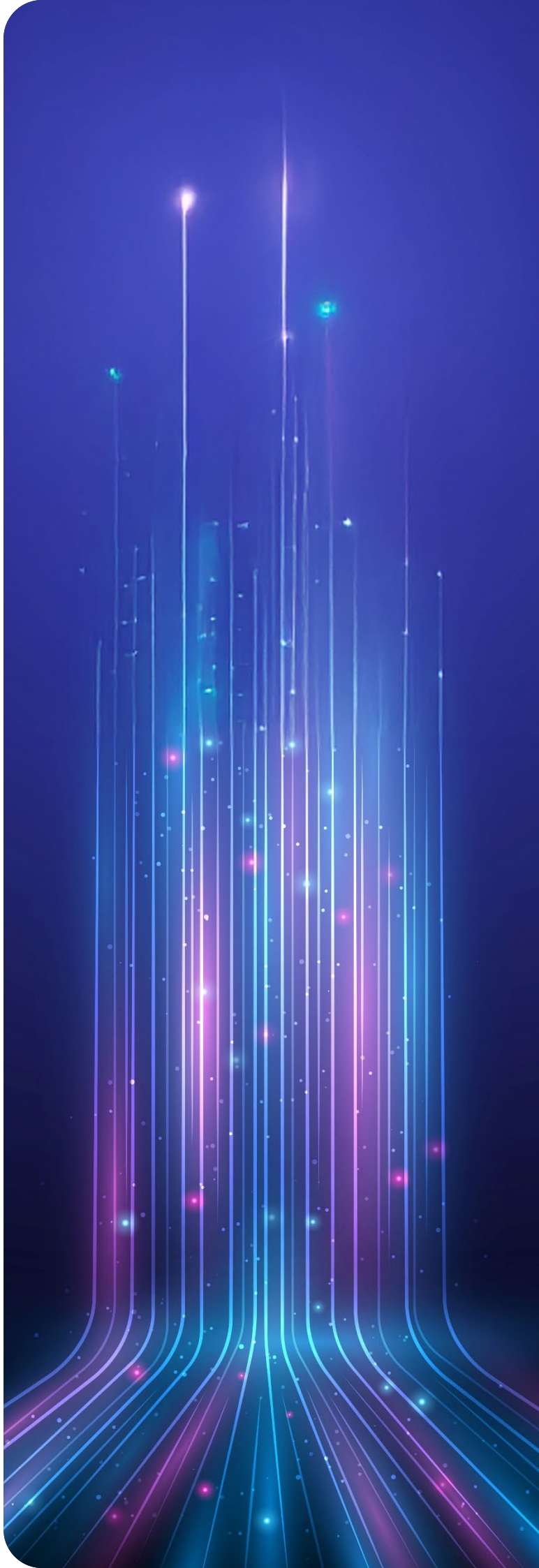
- Real-time data analytics using IoT sensors and RF drones.
- TSN's low-latency capabilities improve underground communication and safety.
- Scheduling algorithms manage delay constraints in multi-hop communication networks.

3. Utilities and Energy

- Integration with IEC 61850 for power substation automation and prepaid meter deployment
- Enhanced cybersecurity and synchisation protocols for smart grids.
- Precise-Time Protocols ensure accurate time synchronization across equipment.

4. Aerospace and Rail Networks

- Integration of TSN in SCADA systems for seamless operations.
- Real-time data sharing between IoT sensors for predictive maintenance.



Conclusion

TSN represents a cornerstone of modern high-speed communication, facilitating seamless integration of IT and OT infrastructures. By adopting TSN, industries can achieve real-time, reliable, and secure communication tailored to diverse operational needs. Cyient's dedicated Center of Excellence for Communications is at the forefront of applying TSN to regulated and multi-domain industries, empowering businesses to embrace digital transformation and innovation.

About the Author

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Joe has 28 years of experience in the IT & Telecom Domain including Network Engineering & Communication Service Providers Business verticals. He has been associated with CTO Office-based functioning and heading early technology adoption into solution conceptualization, design & development and taking it to global T1 & T2 customers. He has built about 14+ platforms & products for customers and internal developments for NG-OSS/BSS, Green Energy Management Platform, Radio Network Emulators, Cloud Car & Software Defined Vehicle. He led various customer projects as the chief architect, where he was involved in architecture inception definition, development & rollout of telecom products for T1 & T2 customers across the globe. His expertise is in areas of homegrown and COTS tools in areas of Telecom B/OSS, SDN NFV, Disaggregation of Telecom & Automotive domains - Softwarisation, Containerisation & Virtualisation of Wireless & Wireline Systems, Telco Cloud, Edge Networks, 5G & 6G ORAN Radio Networks, Network Automation - Resource & Service Orchestration, RT & Non-RT RIC Controller, Interface Specs Packet Core implementations & Automotive domain - Cloud Car & Software Defined Vehicle. He is a senior member at IEEE ; member at ACM and a contributing member to various technical forums such as FB-TIP, ORAN Alliance, TSDSI-SDO, TMF, ETSI, LF-ONAP, Akrino ,OAI, SOAFEE, CENT-OS & Ubuntu Automotive SIG & an invited speaker at many of these forums.

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