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Time-Sensitive Networking:

Empowering next-generation network devices for Industry 4.0 and Industrial IoT

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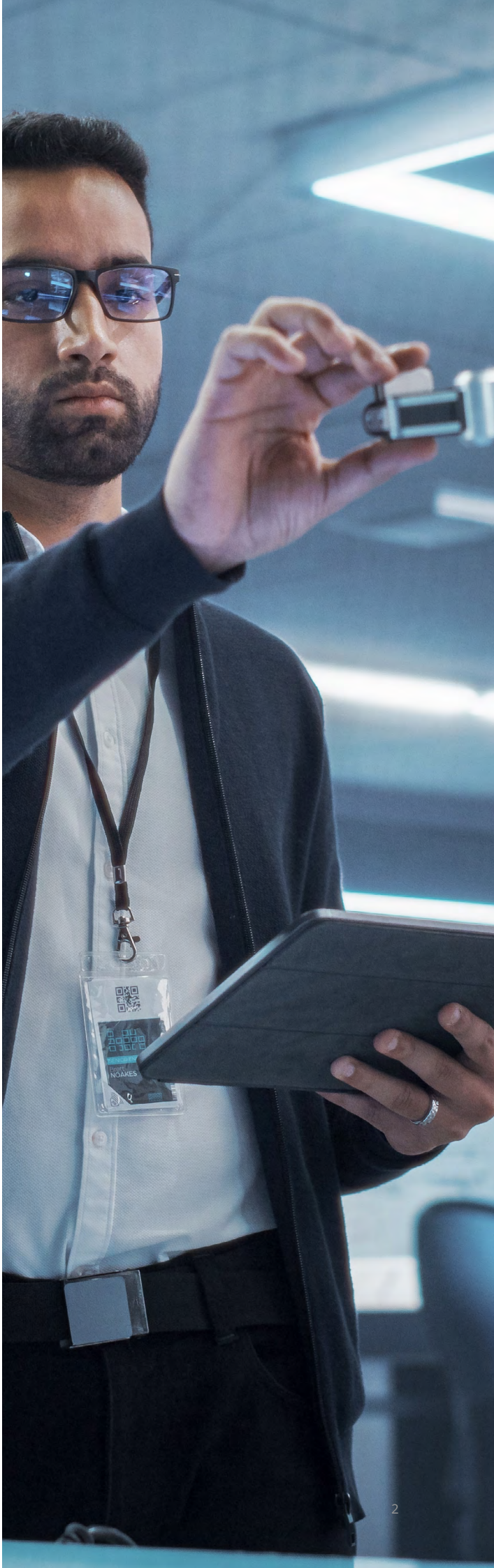
In an increasingly connected and automated world, the need for real-time, deterministic communication in industrial environments has become paramount. Time-Sensitive Networking (TSN) has emerged as a critical technology, enabling the convergence of operational technology (OT) and information technology (IT) networks. This white paper explores the significance of TSN in the development of new network devices, with a particular focus on its interworking capabilities for 5G and Wi-Fi. Luxoft has the expertise and experience to help build Time-Sensitive Network Devices — including routers, switches, firewalls, IoT (Internet of Things) devices, firmware, and the testing and control applications required.

The rising importance and **key features of TSN**

Network prioritization and Time Synchronization protocols have been around for decades — but often the easiest way to deal with high priority traffic was to simply increase the bandwidth and reduce the network latency in the original design. With the emergence of Industry 4.0 use cases are emerging that require fully deterministic and prioritized traffic — latency, arrival and bit-rate guarantees are fundamental to next-generation industrial control and automation, automotive, utilities and health care applications.

Determinism refers to the ability to guarantee consistent and predictable communication models. In TSN, determinism ensures on-time delivery of data frames to the destination. By eliminating or minimizing variations in message delivery time, determinist networks enable precise synchronization and coordination between devices.

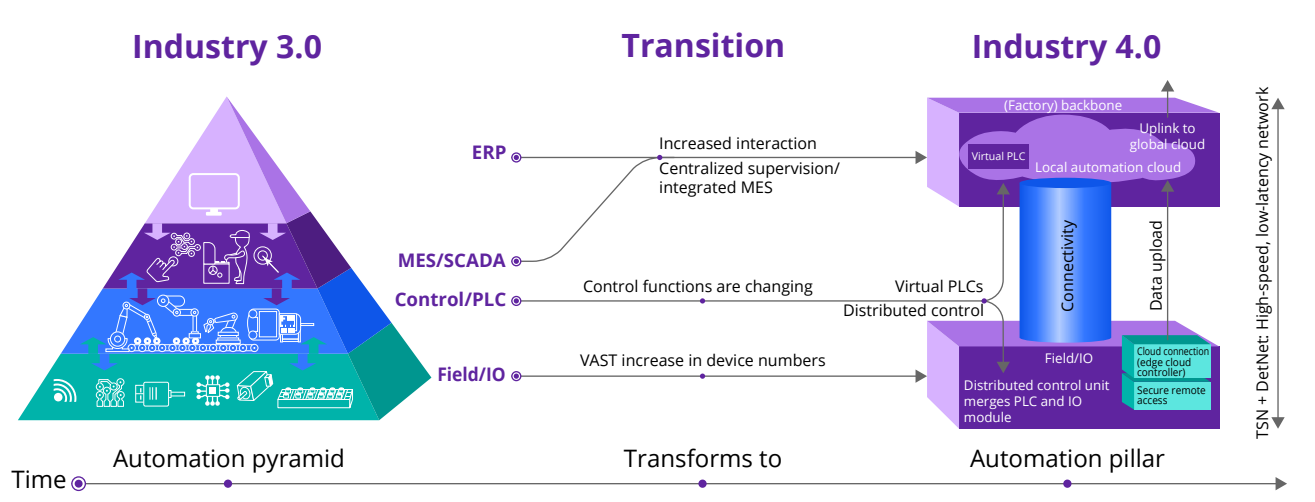


TSN also allows the prioritization of distinct types of traffic based on their importance or time-criticality. By assigning priorities to different traffic streams, TSN ensures that critical traffic receives preferential treatment and is delivered with minimal delay.

Latency refers to the time delay between sending a message from the source and receiving it at the destination. In TSN, low and bounded latency is crucial to supporting real-time communication.

TSN allows for the allocation of specific bandwidth or bit rates to different traffic streams or flows. By reserving a dedicated amount of network capacity, TSN ensures that critical data flows can transmit at their required bit rates without being affected by other non-time-critical traffic. This guarantees that the necessary bandwidth is available to meet the real-time requirements of critical applications, thereby maintaining their performance and reliability.

In industrial automation, TSN ensures precise synchronization and time coordination for critical processes in industrial automation, enabling real-time control systems and seamless integration of machines and devices.



Source: Kleineberg, Oliver, and Axel Schneider. “Time-Sensitive Networking-for dummies.” (2018).

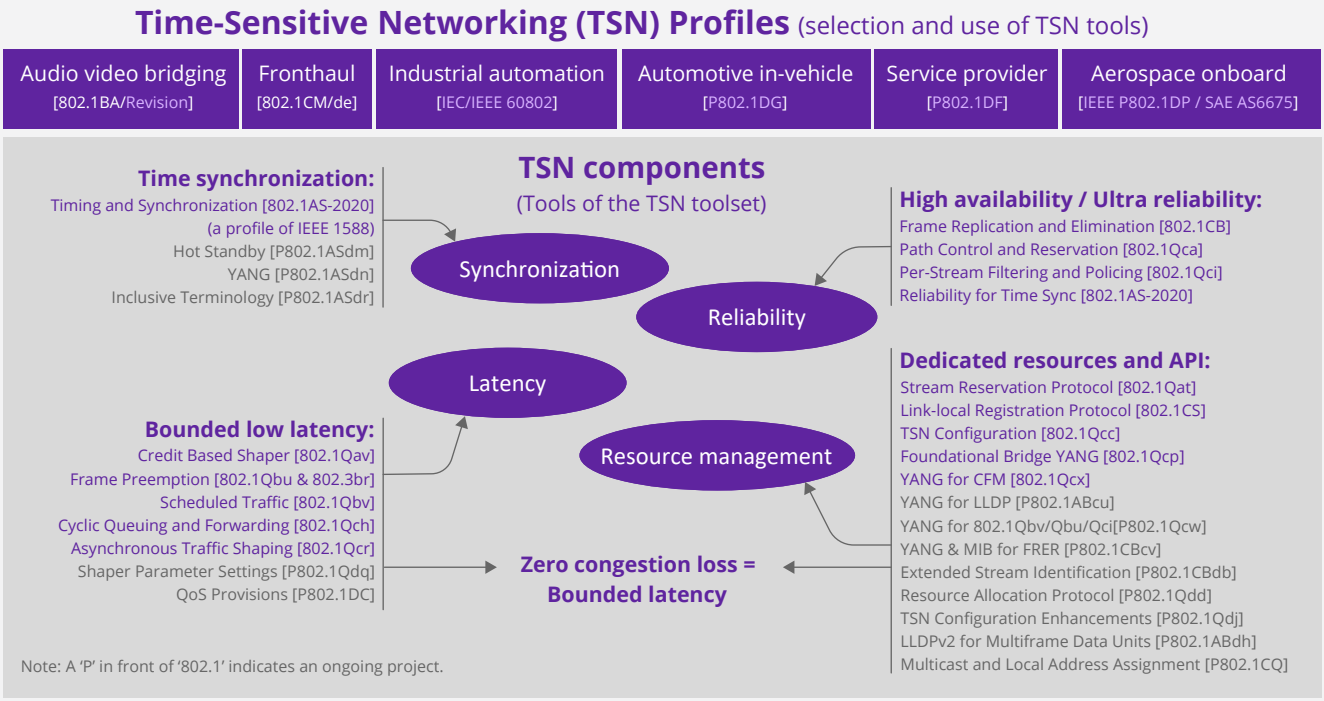
For the automotive industry, TSN facilitates reliable and time-critical communication between various components in connected and autonomous vehicles, supporting functions such as advanced driver assistance systems (ADAS), infotainment, and vehicle-to-everything (V2X) communication.

Within the utilities industry, TSN enables synchronized communication in energy and power systems, optimizing the management and control of smart grids, renewable energy generation and distribution systems. And in health care, TSN plays a crucial role in real-time telemedicine, remote patient monitoring and surgical procedures, ensuring the transmission of critical data with low latency and high reliability.

The integration of TSN
with 5G and Wi-Fi technologies

TSN relies on a set of standards developed by the Institute of Electrical and Electronics Engineers (IEEE) 802.1 working group. These standards include time synchronization, traffic scheduling, and frame pre-emption mechanisms, among others. To align TSN with mobile internetworking, such as industrial 5G devices, efforts are underway to integrate TSN capabilities into the 5G ecosystem.

TSN standards are in continuous development. The standards that define the key concepts are finalized; others are work in progress, and some are on the to-do list.



https://www.ieee802.org/1/files/public/docs2021/admin-TSN-summary-1121-v01.pdf

Standardization and evolution of TSN

By combining TSN and 5G, industrial applications can benefit from ultra-reliable, low-latency communication (URLLC) services provided by 5G networks. TSN can enable synchronized and deterministic communication within a 5G network slice dedicated to industrial use cases, ensuring end-to-end reliability and real-time responsiveness. Industry groups like the 5GACIA [3] are driving new and more expansive use cases all the time.

Additionally, TSN complements Wi-Fi networks by providing determinism and synchronization capabilities. This integration allows Wi-Fi to meet the demanding requirements of industrial applications, further expanding the range of use cases for TSN.

These complex TSN standards are continually evolving to address emerging challenges and requirements in diverse industries. Ongoing efforts focus on enhancing interoperability, scalability and time synchronization precision. Furthermore, advancements in TSN aim to enable seamless integration with emerging technologies such as machine learning, edge computing, and the Industrial Internet of Things (IIoT).

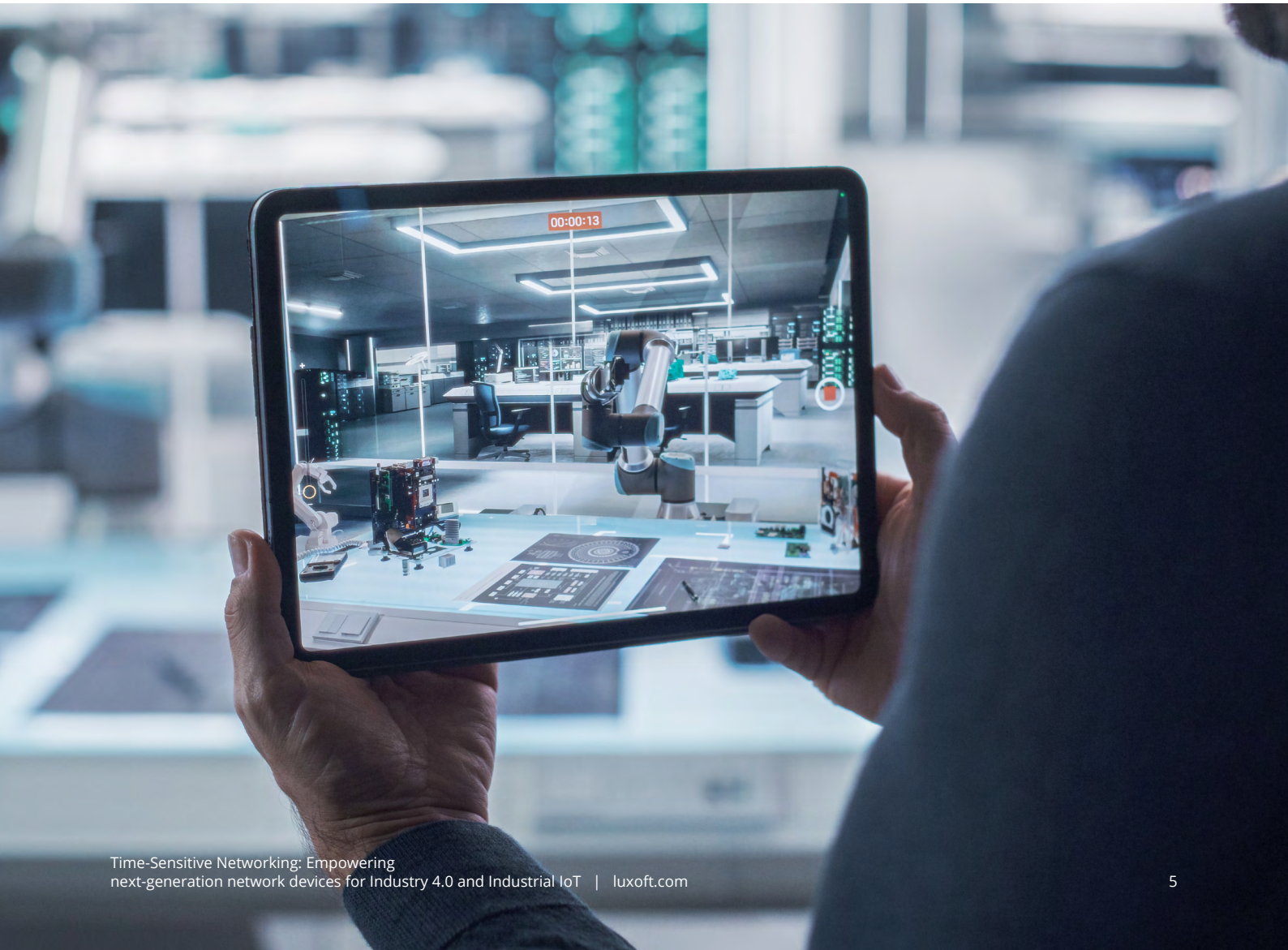
TSN integrated control centers can be instrumental in managing and applying time, latency, and bit-rate priority policies across private and public 5G networks for IoT devices and applications. These control centers act as central management systems specifically designed to handle TSN capabilities.

This integration enables centralized control and monitoring of devices and systems through a virtualized PLC (Programmable Logic Controller) or EDGE cloud.

The centralized architecture model is often used for TSN, which aligns with the strategy of Control and User Plane Separation (CUPS) instantiated in 5G.

TSN over Wi-Fi 6/6E and 5G is an area of active research and development, with many organizations and standards bodies working to make it a reality.

By combining TSN, 5G and Wi-Fi 6, a centralized network management model can be established for wired-wireless TSN networks.



Interworking of TSN
with 5G and Wi-Fi networks

The integration of TSN and 5G, Wi-Fi 6/6E also enables collaboration between different access technologies and scheduling mechanisms, optimizing channel access and resource allocation.

Wi-Fi 7 is the next generation of Wi-Fi, which aims to include Time-Sensitive Networking capabilities to support low latency and ultra-reliability in license-exempt spectrum bands, enabling many new IoT scenarios. When the specification is finally released in 2024 a primary change will be the adoption of the 802.1 TSN standards. While still in development, it promises to offer faster connections, lower latency and the ability to manage more connections. It is expected to be up to four times faster than Wi-Fi 6 and could offer previously unattainable data rates. Wi-Fi 7 will employ new technologies to reduce latency, increase network capacity and boost efficiency.

Overall, the integration of TSN, 5G and Wi-Fi in a control center or centralized policy allows for efficient and coordinated management of industrial communication systems, enabling real-time control and monitoring of devices and processes. It ensures low-latency, reliable communication, and optimized resource allocation for improved performance and productivity across all areas of a large campus or industrial facility.

As the TSN standard evolves, it is mandatory for device manufacturers and software developers to stay abreast of the latest developments and best practices. Hiring experts with experience in TSN development, such as Luxoft, can provide the necessary expertise and insights to navigate this complex landscape effectively. The days when time synchronization and deterministic networks were for extreme cases only have passed.

Another particularly important aspect of TSN is cybersecurity. TSN does not directly contain cybersecurity mechanisms as this is out of scope for basic Ethernet. The most vulnerable component is time synchronization. A common and effective attack on the time synchronization is denial of service (DoS) that can affect the clock synchronization on all devices.

As any delay (jitter) introduced in the network can cause latency issues, designing a secure network architecture is crucial for TSN. This includes segmenting networks with zones and conduits, implementing firewalls, and ensuring proper network isolation to prevent unauthorized access or lateral movement by attackers without affecting the critical information flow.

Besides designing a network securely, the IEEE 802.1Qci-2017 standard, which is part of the TSN standards toolbox, specifies a set of supervision functions on TSN switch ports known as per-stream filtering and policing. These functions allow the switch to monitor the behavior of end devices and enforce quality of service (QoS) policies. Per-stream filtering and policing enable the switch to examine the traffic characteristics of individual streams or flows and react to predefined rules. The switch can monitor whether a device is behaving correctly or consuming an excessive amount of bandwidth. If a misbehavior is detected, the switch can prune or limit the traffic associated with the misbehaving device.

It is important to note that cybersecurity is an ongoing process, and organizations should continuously monitor, assess, and improve their security measures to adapt to evolving threats. Engaging with Luxoft cybersecurity experts and conducting regular risk assessments can provide valuable insights into the specific vulnerabilities and mitigation strategies for TSN deployments.

TSN management
in the 5G and Wi-Fi era

Time-Sensitive Networking is a critical technology that empowers the development of next-generation network devices in the era of Industry 4.0 and Industrial IoT. With its deterministic communication capabilities and integration potential with 5G and Wi-Fi, TSN enables real-time control, synchronization and coordination across various industrial applications. As the TSN standard continues to evolve, it is imperative to collaborate with experts, like Luxoft, who possess the expertise and experience required to harness its full potential and tame its complexity.

References

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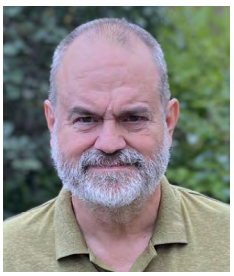
About **the authors**



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Ken leads Luxoft's global Technology, Media and Telecom Solutions team. He has 40 years' experience in delivering high technology IT and engineering software and services solutions to telecommunications and financial services industry clients all over the world.

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Mihai has more than 10 years' experience in industrial networking software development and Agile project management. He's responsible for managing the service delivery for a large client account, building firmware for the next-generation industrial networking solutions.

Mihai holds a PhD in Electronics and Telecommunications (Image processing and signal recovery) from Politehnica University of Bucharest and he leads the Luxoft Industrial Automation Chapter branch for Romania. He is a promoter of Agile engineering practices, and a certified Scrum Master and product owner.

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