



TSN: Will Time-Sensitive Networking Take Over MIL-STD-1553?

Networking Solutions

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The landscape of communication technologies in defense and aerospace systems is at a pivotal point of evolution. Traditional systems have long relied on well-established technologies such as MIL-STD-1553 and ARINC 429 to ensure reliable, time-critical communications. However, the rapid advancement in operational speed demands and the need for more flexible, dynamic systems are challenging the viability of these legacy data buses.

On the other side of the spectrum, civil aviation has seen a rise in the adoption of Ethernet technologies like ARINC 664, although these standards come with significant initial investment costs and lack the flexibility required for future-proof solutions. This brings us to the question: can Time-Sensitive Networking (TSN) rise to the occasion and potentially take over MIL-STD-1553 in defense and aerospace applications?

What is STD-MIL-1553?

The half a century old standard MIL-STD-1553, a pivotal military standard, meticulously outlines the mechanical, electrical, and operational specifications of a serial data communication bus primarily for the U.S. Department of Defense. Originally devised for military purposes, it has transcended its initial scope and is presently widely embraced across both military and civilian realms, particularly in the realms of avionics, aircraft, and spacecraft data management.

MIL-STD-1553 is utilized in a wide array of products across various sectors, primarily within the aerospace and defense industries. Used as well for ground vehicle applications, such as tanks and armored vehicles, where reliable communication and data exchange are critical. Moreover, it is employed in certain industrial settings where stringent standards for data communication and reliability are essential, ensuring its relevance beyond purely military contexts.

What is TSN?

Time-sensitive networking (TSN) is a set of standards developed by the IEEE 802.1 task group in 2012. Its purpose is to provide deterministic and reliable communication over Ethernet networks. It enables precise timing and synchronization, low latency, and high availability, making it ideal for industrial automation, security, military and defense, automotive networks, and other time-critical applications. TSN ensures that data is transmitted within strict time constraints, allowing for real-time control and coordination of complex systems, thereby enhancing efficiency, reliability, and interoperability.

The Limitations of Legacy Systems

MIL-STD-1553 and ARINC 429 have been the backbone of military and aerospace communications for decades. These technologies have proven their reliability and robustness in various critical applications. However, their inability to evolve with the increasing demand for higher operating speeds and more dynamic configurability has exposed significant limitations.

1. **Speed Constraints:** MIL-STD-1553, for instance, operates at a maximum data rate of 1 Mbps, which is insufficient for modern applications that require faster data transfer rates.
2. **Static Configurations:** Once deployed, these systems lack the flexibility to be dynamically configured, making it challenging to adapt to new requirements or integrate with newer technologies.

The Emergence of Ethernet Technologies

In the civil aviation sector, Ethernet-based standards like ARINC 664 (part of the AFDX - Avionics Full-Duplex Switched Ethernet) have gained traction. These standards offer higher data rates and more flexibility compared to traditional avionics solutions. However, the adoption of such technologies comes with substantial upfront investments and complexities associated with ensuring compatibility and integration with existing systems.

TSN: A New Paradigm

Time-Sensitive Networking (TSN) emerges as a promising technology capable of addressing the limitations of legacy systems while offering the flexibility and high performance required for modern defense and aerospace applications. TSN is not a single standard but a suite of standards managed by the IEEE 802.1 task group, designed to provide deterministic and reliable communication over standard Ethernet networks.

Key Features of TSN

1. **Dynamic Configuration:** TSN supports dynamic setup and configuration of time-sensitive communication channels in real time, allowing for greater flexibility and adaptability in various operational scenarios.
2. **High Precision and Synchronization:** Utilizing the gPTP, TSN ensures precise clock synchronization between nodes with an accuracy under 1 μ sec. This is critical for maintaining the timing integrity required in defense and aerospace applications.
3. **Deterministic Communication:** TSN enables the establishment of deterministic communication channels with guaranteed parameters such as throughput, latency, and jitter. This ensures that the communication performance remains predictable and reliable, which is essential for mission-critical systems.

The Potential of TSN in Defense and Aerospace

The potential applications of TSN (Time-Sensitive Networking) in defense and aerospace are vast and transformative. The industry is exploring Ethernet backbones for future ground vehicles and aircraft that can handle not only traditional data and communication traffic but also precision control over Ethernet for weapons systems, autonomous vehicles, and other devices historically controlled via legacy data buses. In the military sector, TSN is being utilized in various cutting-edge applications.

For example, TSN technology is being employed in micro launchers designed to deploy small and nano-satellites for commercial and educational purposes, offering lower implementation costs and greater flexibility. Next-generation helicopters are also benefiting from TSN, as it allows them to handle increased traffic volumes and mixed-criticality functions, reducing network device costs and simplifying wiring harnesses.

Additionally, the NATO Generic Vehicle Architecture (NGVA) utilizes TSN for real-time data access in braking systems and video streaming, ensuring optimal performance and high-quality video in challenging environments.

The Ground Combat System Common Infrastructure Architecture (GCIA) aims to utilize open standards like Time Sensitive Networking (TSN) to enable real-time, deterministic communication over Ethernet. TSN upgrades standard Ethernet by allowing the logical

segmentation of both deterministic and best-effort network traffic on the same physical media. Through TSN integration, the GCIA standard seeks to enhance the coordination and performance of vehicle systems, providing a robust framework that not only bolsters cybersecurity but also supports cutting-edge automotive technologies.

The Common Remotely Operated Weapons Station (CROWS) technology benefits significantly from TSN. By leveraging TSN, CROWS achieves streamlined communication, utilizing a shared channel for both real-time control and high-bandwidth data transmission. This integration ensures more efficient and reliable operations, crucial for advanced combat scenarios.

Benefits Over MIL-STD-1553

1. **Increased Data Rates:** TSN can leverage the high data rates of Ethernet, far surpassing the 1 Mbps limit of MIL-STD-1553.
2. **Scalability and Flexibility:** Unlike MIL-STD-1553, TSN can be dynamically configured and scaled to meet the evolving needs of defense and aerospace systems.
3. **Interoperability:** As an open standard supported by major semiconductor suppliers like Intel, TSN can coexist with existing Ethernet technologies, facilitating smoother integration and interoperability with current systems.

Implementation and Profiles

TSN uses a profiles approach, which defines specific sets of features, options, configurations, and protocols appropriate for particular applications. Some TSN profiles are already well-defined, while others are still under development.

Technical Implementation of TSN

The foundation of TSN's deterministic communication capability lies in its precise clock synchronization using IEEE 1588v2 PTP. This protocol allows nodes to synchronize their local clocks to a master clock, ensuring all nodes operate on a common time reference and traffic shaping protocols, Quality of Service protocols, and Fault-Tolerance. This synchronization is critical for coordinating time-sensitive operations across the network.

1. **Master Clock Selection:** One node is designated as the master clock, and all other nodes synchronize to it. The selection can be static or determined dynamically through a Best Master Clock Algorithm (BMCA).
2. **Using several levels of synchronization,** such as Boundary Clocks and Transparent Clocks, can improve the synchronization accuracy up to 10 nanoseconds.

QoS

QoS (Quality of Service) is a well-established mechanism used by networking devices, such as bridges and routers, to prioritize different types of network traffic, especially under congestion conditions. This prioritization ensures that critical data gets through even when the network is busy. On the other hand, TSN is designed to guarantee the timely delivery of time-sensitive data across a network by allocating specific resources for these high-priority flows.

Unlike traditional QoS, which prioritizes all traffic based on its assigned priority level, TSN flows are managed separately and do not compete with non-TSN traffic, regardless of the priority

assigned to the latter. This separation ensures that TSN traffic can maintain its strict timing requirements without being affected by other network traffic.

Deterministic Communication Channels

Once clocks are synchronized, TSN can establish deterministic communication channels with guaranteed performance parameters. These channels are defined by specific requirements for throughput, latency, and jitter, which are essential for ensuring reliable communication in defense and aerospace applications.

Resource Reservation

Equipment along the communication path reserves the necessary buffers and bandwidth and configures queue priorities to meet the defined parameters.

Dynamic Setup and Tear Down: Channels can be dynamically established and terminated based on operational needs, allowing for efficient resource utilization and adaptability.

Challenges and Considerations

While TSN offers significant advantages, its implementation in defense and aerospace systems also presents certain challenges and considerations.

1. Integration with Legacy Systems: Ensuring seamless integration with existing MIL-STD-1553 and ARINC 429 systems requires careful planning and compatibility testing.
2. Security: As with any Ethernet-based technology, ensuring the security of TSN networks is paramount. Robust encryption and authentication mechanisms must be implemented to protect sensitive communications.
3. Standardization and Certification: Ongoing efforts to standardize TSN profiles for specific defense and aerospace applications are crucial for widespread adoption. Certification processes must also be established to ensure compliance with stringent industry requirements.

Conclusion

Time-Sensitive (TSN) represents a transformative technology with the potential to revolutionize communication systems in defense and aerospace. By offering dynamic configuration, high precision, and deterministic communication capabilities, TSN addresses the limitations of legacy systems like MIL-STD-1553 and ARINC 429.

As the industry continues to evolve, the adoption of TSN could lead to more flexible, scalable, and high-performance communication infrastructures, paving the way for future innovations in military and aerospace applications.

The journey toward TSN dominance is underway, and its success will depend on continued advancements in technology, standardization efforts, and the ability to integrate seamlessly with existing systems. In February 2024, a draft of TSN Profile for Automotive In-Vehicle Ethernet Communications was published. This is important because the in-vehicle communication is mostly based on CANBUS, which is not so far away from the 1553 topology.

As the draft for IEEE P802.1DP - TSN profiles for aerospace gains traction, it demonstrates significant motivation from the aerospace market, indicating that these industries are already adapting TSN to meet their requirements, potentially replacing outdated technologies.