

## Audio/Video and Hard Real-Time Capability for Advanced IMA Architectures

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### ABSTRACT

The design of complex integrated systems and avionics architectures relies on the system architect's capability to manage key system interfaces, and share computing and networking resources. The capability of Ethernet-based ARINC 664 avionics networks to handle critical traffic with  $\mu$ s-jitter and fixed latency can be expanded using the Layer 2 Quality Of Service (QoS) protocol enhancements described in SAE AS6802. All existing critical distributed functions using ARINC 664 Virtual Links (VLs) can operate without congestion and with prescribed maximum latencies.

This paper discusses basic considerations for how time triggered services based on AS6802 standard could enable integration of hard real-time and audio/video capabilities in advanced ARINC 664-based IMA architectures. In order to adapt those capabilities to existing design processes for ARINC 664 networks, time triggered services described in SAE AS6802 can be modeled as periodic ARINC664 traffic with  $\mu$ s-jitter and fixed latency.

Both standards integrated on one switch establish Ethernet as the deterministic unified Ethernet technology for time-, safety-, and mission-critical applications, capable of handling any low-jitter, low-latency and lossless applications. Finally, an overview is provided which shows how strict communication determinism influences platform complexity and design of IMA architectures.

### INTRODUCTION

Ethernet enjoys tremendous support in different commercial and industry applications. The use of Ethernet in multi-decade programs helps to minimize risks of technology and component obsolescence in aerospace and defense

applications. There are no other system integration technologies on the market with such continuing industry momentum and guaranteed growth. However, in the past, Ethernet application in critical embedded systems was limited by its capability for deterministic communication. This has changed with the introduction of different Ethernet modifications, and introduction of time-synchronization services, or creation of industry-specific Layer 2 QoS enhancements.

Full control of latency, jitter and message order is related to the synchronization of endsystems and network operation, and enables congestion-free and lossless communication at high bandwidth utilization. The synchronization capability simplifies sensor fusion and allows shorter processing of video data and precise vertical and horizontal pixel transfer synchronization from different sources. Video standards such as ARINC 818 (based on FibreChannel) enable synchronous transfer of video data [1]. On the other hand, Ethernet-based ARINC 664 networks are designed for deterministic system integration for IMA architectures [2] and they use asynchronous communication. Ethernet-based architectures impose limitations on mixing audio, video and critical controls, as mixing of different traffic classes with different jitter and latency requirements reduces bandwidth availability and makes system integration more complex. Also, any synchronization approach used in Ethernet networks should be proven and robust for critical flight applications.

Beyond the support for audio/video streaming in ARINC664 networks, the design of distributed hard real-time applications can also profit from minimized jitter and constant latency, as it simplifies design of distributed control loops. In cases where jitter, latency, and message order are well controlled, designers can separate functional (plain application functionality) and temporal behavior (control loop timing is

defined at the network level) [3]. This means that a function and its temporal behavior can be controlled separately and [4] and reduce the number of (unintended) system states, which is the key to system complexity reduction. In addition, with alignment or “synchronization” of interactions in a distributed system, system (computing and networking) resources can be used more effectively.

## AUDIO, VIDEO AND REAL-TIME TRAFFIC IN ETHERNET NETWORKS

Avionics video applications include infrared and other wavelength sensor applications such as optical cameras, radar, but also large data transfers for displays, HUDs, map loading and flight recorders and cabin video distribution systems. Audio transfers should also be managed for different audio sources, intercoms, voice recording and radios. Video applications require minimized latency and low jitter with minimal buffering of images. As a 25Hz image buffering adds 40ms latency in control loops for storing an image, in many cases critical video data is transferred and processes line-by-line with  $\mu$ s-jitter and latencies below 1ms. With 400 (at 25Hz) lines video FIFO buffering prior to processing adds less than 100  $\mu$ s of latency delay from sensing to data transfer to processing. Audio transfers have higher bound on latency and smaller packets, but it is important to prevent large latency jitter which distorts voice and audio signal. Dropping audio or video frames in critical flight phases can be critical for system safety; therefore the communication must be loss-sensitive (with minimal probability of drop-outs), or lossless.

## REDUCING JITTER IN ETHERNET NETWORKS

In asynchronous Ethernet networks, jitter can be reduced by limiting the number of hops (number of switches on the path between two end systems), maximum bandwidth use, and prioritization schemes with very few high-priority data streams. In this case, the high priority traffic will have low latency and jitter, assuming the network workload and traffic profile does not change significantly during operation. With some form of temporal alignment or synchronization among endsystems, jitter and latency can be minimized for networks with comparable traffic load. Typically, as a result of lacking endsystem synchronization, asynchronous Ethernet networks enable microbursts, a rare situation where all end systems send at the same time and create the worst-case traffic scenario, influence maximum latency and reduce system designer's capability to control jitter under high workload and with mixed time-criticality traffic.

Ethernet is a family of standards, and not a monolithic standard such as MIL 1553 or ARINC 429. Therefore, different protocol services can be added, without altering the essence of IEEE 802.3 Ethernet standard [5]. For example, additional Layer 2 QoS enhancements like VLAN or ARINC

664 can be added to advance QoS or determinism required for specific applications. Packet switched Ethernet networks can also be enhanced to emulate circuit-switching behavior (e.g., in telecommunication applications protocols such as TDMoIP or pseudowire [6] with adaptive clock recovery are used), but this approach is too sensitive for critical flight applications.

SAE AS6802 is a critical embedded system Ethernet networking standard - a Layer 2 QoS enhancement, designed to emulate circuit switching behavior over packet-switched Ethernet networks ensure fault tolerant timing, startup and recovery in case of multiple faults. It can operate on Ethernet switches implementing also other Layer 2 QoS services.

## MICROSECOND-JITTER AND CONSTANT LATENCY IN IMA NETWORKS

### AVIONICS BACKBONE WITH AUDIO/VIDEO CAPABILITY

In commercial avionics, ARINC 664-P7 (Avionics Full Duplex Ethernet or AFDX) Layer 2 QoS enhancement has been added to standard Ethernet switches to enable redundant rate-constrained communication using virtual links (VLs) with defined maximum latency, packet size and message periodicity. VLs enable deterministic point-to-point communication among different endsystems in the network.

With a known network traffic profile, virtual link prioritization, defined switch buffer dimensioning, and advanced network calculus and configuration tools, very deterministic operation with respect to maximum latency can be ensured for all end-to-end virtual links (VLs) defined in AFDX networks. ARINC 664-P7 standard also describes traffic policing and shaping for ensuring planned AFDX network performance.

The capability of ARINC664 networks to handle voice and video with minimized jitter and constant latency is possible, but limited, primarily due to jitter control requirements and bandwidth use trade-offs.

While rate-constrained communication with ARINC664 is very deterministic in terms of maximum latency and prescribed jitter bounds (in  $N \times 100\mu$ s), the network operation is asynchronous and relies on statistical bandwidth multiplexing without endsystem synchronization, i.e., it offers limited control of jitter and message order, which is typically the property of TDMA-based communication systems and time-triggered networks.

Too stringent jitter control for few audio/video streams in ARINC664 would cause significantly lower average

bandwidth use (measured in single-digit percentage) for all networked functions.

In a complex multi-hop IMA network servicing communication needs of Nx(10-100) distributed critical functions and many audio/video streams, differing QoS requirements (low-jitter/fixed latency vs. variable, but defined maximum latency) could severely limit system integration, system modifications and upgrades. This leads to use of separate digital networks and communication standards for delivery of audio/video such as FibreChannel (ARINC 818).

Another approach to addressing this challenge in Ethernet networks is to integrate services compatible with ARINC 664, such as SAE AS6802, which allow emulation of perfectly bounded temporal behavior of ARINC 664 VLs, with constant latency and  $\mu$ s-jitter.

There are two approaches for minimizing jitter via synchronization, assuming the reliable fault-tolerant system time base is available:

1. SYNCHRONIZATION OF END SYSTEM ONLY: With applications scheduling their data transmissions based on the global time base, microburst probability can be reduced. This relaxes “worst-case” calculations of network peakloads due to microbursts, improves bandwidth use and reduces jitter in comparison to plain asynchronous communication. In this case all functions can use only rate-constrained ARINC 664, but applications must be aware of system communication scheduling which avoids clashes among data transfers.

2. SYNCHRONIZATION OF END SYSTEMS AND NETWORK SWITCHES WITH TRAFFIC SCHEDULING: Prevents peakloads due to microbursts, assures fixed latency and  $\mu$ s-jitter, enables lossless communication, independent of the network workload for synchronous time-triggered streams, and protects TDMA bandwidth sharing for synchronous and asynchronous Ethernet traffic. With end-system and network switch synchronization, communication jitter can be reduced below 1  $\mu$ s, and latency can be minimized and held constant due to exact communication schedule timing. Network operation is autonomous and cannot be influenced by applications.

Both approaches are supported by Layer 2 QoS enhancements defined by SAE AS6802 time-synchronization services designed for critical flight applications. By adding those services to an ARINC 664 switch, it would be possible to expand the capability to integrate audio/video and hard real-time controls with existing ARINC 664 VLs in complex IMA networks (see [Figure 1](#)). The SAE AS6802 standard supports integration of synchronization, synchronous communication capability and strict isolation of synchronous and asynchronous network traffic in complex networks. This integration can be accomplished without significant

modifications in ARINC 664 network design process workflow.

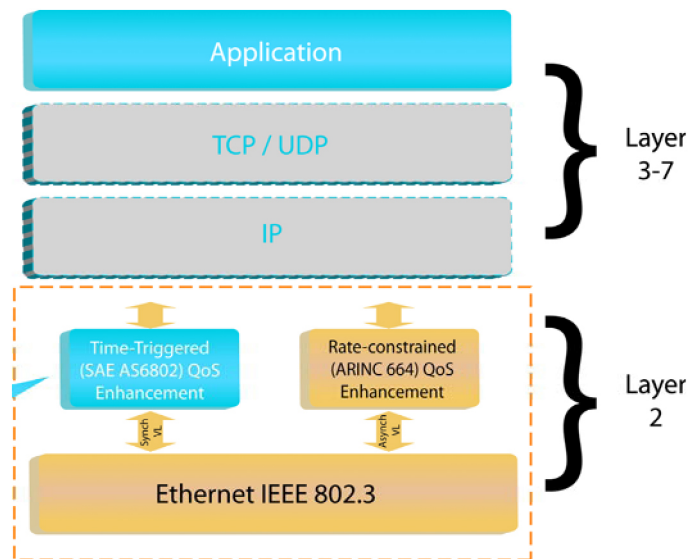


**Figure 1. SAE AS6802 Layer 2 QoS service (switch service!) for ARINC 664 network**

In addition, synchronization of local clocks supports design of distributed hard real-time functions that require unambiguous control of key system interfaces, isolation and integration of audio and video streams on an IMA platform. Furthermore, synchronization that is robust, fault-tolerant and compliant with ARINC664 network operation has essential implications for system architecture design and sharing of all computing and networking resources (see the chapter “Impact on System Architectures”).

## SAE AS6802 LAYER 2 QOS ENHANCEMENTS

Layer 2 Quality-Of-Service (QoS) enhancements standardized as TTEthernet (SAE AS6802) [7] guarantee deterministic computing and networking performance for time-, mission-, and safety-critical systems. With SAE AS6802, Ethernet gains strictly deterministic synchronous communication capability and can emulate circuit-switching communication with fixed latency, sub- $\mu$ s-jitter and predictable message order, in complex packet-switched Ethernet networks. SAE AS6802 provides fault-tolerant synchronization, synchronous communication, robust TDMA partitioning, and supports design of double, triple and quadruplex redundant systems.

SAE AS6802 services do not depend on Ethernet bandwidth or distance - they can operate at 0.1 to 10Gbit/s (or higher), and can be used in large Ethernet networks. Ethernet switches with SAE AS6802 fully support synchronous and asynchronous communication. This allows packet-switching