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OPEN STANDARD APPROACH FOR REAL TIME CONTROL OVER ETHERNET

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ABSTRACT

Curtiss-Wright has developed an open-standard approach for real time control over Ethernet, incorporating VICTORY .specifications. The paper presents definitions for Real Time, traditional perceptions of Ethernet for real-time usage, solutions for real time, a comparison to MIL-STD-1553, and suggestions for additional specifications to include in VICTORY.

INTRODUCTION

Real-Time control of low-latency systems has been traditionally served using application specific buses, such as CAN, MIL-STD-1553, and RS-485. The significant movement toward an Ethernet infrastructure in industrial and vehicle electronics has largely replaced these legacy buses; however, Ethernet has not been applied in an open-standards manner to handle real-time control.

Curtiss-Wright has developed an advanced, open system architectural approach to Vehicle Electronics, based on our vast experience in providing military electronics to many programs for ground, sea, and air platforms. Additionally, for the past several years we have been performing research into network centric approaches specifically for Heavy Brigade Combat Team (HBCT) Vehicle Electronics. This experience has provided CW with a unique understanding of key architectural concepts which provide for highly successful implementation of specific Vehicle Electronics suites to meet Ground Combat System program and platform requirements.

Specifically, the notion of bridging legacy protocols to an Ethernet data bus was investigated and demonstrated. This paper builds upon that experience to show open-systems, non-proprietary approach to real-time control using industry standard Ethernet. The paper will provide comparisons of deterministic legacy buses versus Ethernet, highlighting the areas in which Ethernet has been traditionally perceived to be incapable of deterministic real-time control. The paper will illustrate the methods to architect the real-time control system leveraging modern Ethernet standards, such as Quality-of-Service and IEEE-1588 Precision Time Protocol. An investigation into the suitability of commonly used Operating Systems for real-time control over Ethernet will be presented.

Correlation of these approaches to the VICTORY Architecture and Specifications will be provided, illustrating the capability of the VICTORY databus to achieve real-time control of C4ISR/EW and Platform Systems without the use proprietary electronics or software.

Upon completion of our presentation, the audience will have an understanding of the applicability of Ethernet to Real-time control, how it can be used to replace legacy vehicle buses such as MIL-STD-1553, and how it fits within the VICTORY Architecture.

REAL TIME DEFINITIONS

The IEEE POSIX Standard definition of a real-time system is "*A real-time system is one in which the correctness of a result not only depends on the logical correctness of the calculation but also upon the time at which the result is made available.*" Key to this is the timing aspect, something which has been traditionally thought of as not possible on Ethernet without significant (often proprietary) modifications.

The time aspect to this requires the following considerations:

- Control Frequency – the fundamental rate at which the real-time control system operates
- Control Window – the window of time during which to perform control actions
- Jitter – the amount of acceptable variation in the control action timing during the Control Window from one control period to the next

Key to all of this is the actual scale of the real-time control system. Control systems which have frequencies of 1 Hz and wide windows of 1 second with a jitter of +/- 500ms is very forgiving, and at a very different scale from a control system operating at 10KHz with 10 us windows allowing +/- 1 us of jitter. The types of buses and approaches need can vary significantly based on these.

TRADITIONAL ETHERNET PERCEPTIONS

Unlike buses such as CAN, MIL-STD-1553, and RS-485, which provide hard time division multiplexing, Ethernet was conceived to be a higher capacity yet uncertain bus, without guarantee of delivery as tradeoff for its additional capacities and speeds. Ethernet implemented on the shared coax of 10Base-2 and physical hubs of 10Base-T would suffer collisions, with no guarantee of when or if a retransmit would succeed. Furthermore, without an embedded clock in the Ethernet signal (unlike recoverable or discrete clocks of other buses), synchronization between nodes on the network for real-time control is extremely difficult. This perception of Ethernet as originally conceived has previously precluded Ethernet from being a reasonable real-time control network. In addition, the various Ethernet Stacks – including the commonly used IP and TCP/UDP layers above it – are considered problematic for real-time control.

These tradition perceptions of Ethernet are no longer accurate, and can be overcome by the solutions presented below.

SOLUTIONS

Real-time control systems fundamentally require two things:

- Guarantee of Action
- Determinism of Action Timing

Modern Ethernet, using star topologies and switches (instead of hubs) mitigates the collision issues of the past, removing the major impediment to guarantee of action. The addition of Precision Time Protocol v2 (IEEE 1588-2008) mitigates the other issue by providing a robust method to distribute time across the network to nanosecond levels, allowing the synchronization of nodes.

A conceptual approach for real-time control over Ethernet is as shown in Figure 1.

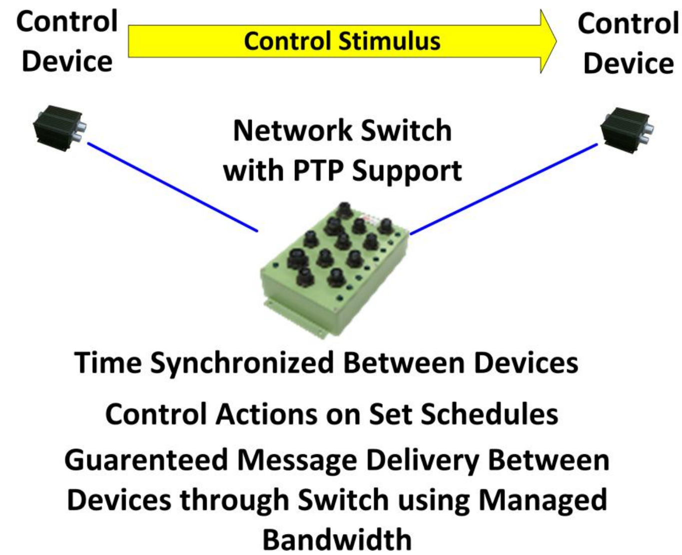

Figure 1: Real-Time Ethernet Approach

This architectural approach relies on a number of different mechanisms, as described below:

Synchronization, Sampling, and Triggering

With the use of Precision Time Protocol, the control devices can have highly synchronized clocks, allowing for actions during set Control Windows. Sampling of events and triggering of actions can be programmed for certain schedules or numbers of ticks since last events. This essentially replaces the clocks of previously used deterministic buses.

Quality of Service

Although the use of switches and star topologies mitigates various Ethernet collision issues, it does not mitigation the threat of network congestion. Quality of Service can be used to set aside a portion of the network bandwidth, ensuring that messages get through when desired. Assured Forwarding as defined in DiffServ Quality of Service is a good mechanism to set aside an isochronous control channel for real-time control messages, as is Expedited Forwarding. The switch and control devices will all need to have proper implementations of DiffServ in order to implement the guaranteed channel, and assure determinism in the system.

By imposing an end-to-end master / slave relationship, additional determinism can be achieved. This designates a single node as the master, and forces all other nodes to communicate as slaves with the master in well-defined exchanges, such as the master always opening a network socket to the slaves to read/write control, instead of allowing the slaves to asynchronously write back to the master.

RTOS and RT Schedulers

Regardless of which bus is used (Ethernet or other), the operating system must implement some sort of real-time behavior mechanisms, whether as a full-fledged RTOS or with an RT scheduler priority. Either way, the various stacks which handle Ethernet packets up to TCP/UDP/IP need to be well-defined and prioritized so that control messages will be available at the next Control Window.

Furthermore, just as with any underlying RT network, the operating system needs to ensure that the real-time control application can run when triggered by synchronization events at the expected Control Frequency within the Jitter bounds. This is a general consideration, and well understood, and is independent of the use of Ethernet to transmit control messages.

PERFORMANCE VERSUS MIL-STD-1553

The performance of MIL-STD-1553 is well understood and provides a baseline for comparison:

- Throughput: ~500kbits/s
- Time Synchronization: Broadcast messages support time synchronization to about +/- 1ms
- Time Stamping: Hardware is provided for time-stamping to the individual RT clock
- Time scheduling: Message schedule is predefined by system designers
- Determinism: Master/slave protocol ensures determinism
- Latency: Determined by the system design
- Jitter: Determined by the system design

In comparison, real-time Ethernet as described previously provides:

- Throughput: 500Mbits/s readily achievable on GbE
- Time Synchronization: Uses IEEE 1588 time synchronization protocol
- Time Stamping: Uses IEEE 1588 time synchronization protocol
- Time scheduling: Message schedule is predefined by system designers
- Determinism: Quality of Service on modern networks ensures determinism, additional imposed Master / slave system design
- Latency: Determined by the system design (choice of cycle time and message schedule)
- Jitter: Determined by the system design

At minimum, replacing MIL-STD-1553 networks can be achieved, with the understanding that the fundamental control frequency of MIL-STD-1553 was less than the bitrate of 500Kbps (i.e. less than 500KHz).

ANALYSIS VERSUS VICTORY

The above architecture correlates with the VICTORY Architecture (1.2) in the following ways:

- VICTORY specifies support for Quality of Service
- VICTORY recommends support for Precision Time Protocol v2

VICTORY does not, however, specify the following:

- Specific Real-Time control Quality of Service allocations
- Specific Real-Time control components and message definitions

Nothing in the Real-time control over Ethernet approach contradicts VICTORY Specifications, nor are any required elements part of any proprietary standards. It is recommended that the missing items be added to the VICTORY Specification given the potential applications for real-time control.

CONCLUSIONS

Real-Time Control over Ethernet using Open Standards is achievable, including replacement of existing MIL-STD-1553 buses. The VICTORY Databus can be used for this application without need for a separated or proprietary implementation for real-time applications.

Proper system design based using the described approach and open standards allows system designers to maintain an open standard approach to real-time control over Ethernet, with the potential to utilize COTS based hardware and software for system implementation, ensuring interoperability, longevity, and low risk for the vehicle's real-time control implementation.

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