Kennedy Space Center Timing and Countdown Interface to Kennedy Ground Control Subsystem

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Kennedy Ground Control System (KGCS) engineers at the National Aeronautics and Space Administration (NASA) Kennedy Space Center (KSC) are developing a time-tagging process to enable reconstruction of the events during a launch countdown. Such a process can be useful in the case of anomalies or other situations where it is necessary to know the exact time an event occurred. It is thus critical for the timing information to be accurate. KGCS will synchronize all items with Coordinated Universal Time (UTC) obtained from the Timing and Countdown (T&CD) organization. Network Time Protocol (NTP) is the protocol currently in place for synchronizing UTC. However, NTP has a peak error that is too high for today's standards. Precision Time Protocol (PTP) is a newer protocol with a much smaller peak error. The focus of this project has been to implement a PTP solution on the network to increase timing accuracy while introducing and configuring the implementation of a firewall between T&CD and the KGCS network.

Nomenclature

NASA	=	National Aeronautics and Space Administration
KSC	=	Kennedy Space Center
KGCS	=	Kennedy Ground Control System
PLC	=	Programmable Logic Controller
UTC	=	Coordinated Universal Time
T&CD	=	Timing and Countdown
NTP	=	Network Time Protocol
PTP	=	Precision Time Protocol
IEEE	=	Institute of Electrical and Electronics Engineers
GPS	=	Global Positioning System
TTL	=	Time to Live
NIC	=	Network Interface Card

I. Introduction

The Engineering Directorate at the National Aeronautics and Space Administration (NASA) Kennedy Space Center (KSC) is responsible for creating a new command and control system to checkout and launch future rockets and spacecraft. The Kennedy Ground Control System (KGCS) plays a unique role in the checkout of launch vehicles. KGCS duties include health management of the Programmable Logic Controllers (PLCs) on the launch pads, as well as the development of a process that will enable reconstruction of the events during a launch countdown.

To obtain reconstruction data, KGCS will time-tag and store selected field measurement values from the different subsystem end-items. To ensure accuracy, KGCS will synchronize all items with Coordinated Universal Time (UTC) obtained from the Timing and Countdown (T&CD) organization. UTC is the time standard used across the world. Timing centers across the globe have agreed to keep their time scales closely synchronized to this standard [1]. KGCS currently synchronizes with UTC using Network Time Protocol (NTP). However, NTP has a peak error greater than 1 millisecond (ms), and can even reach 100 ms in a congested network. Precision Time

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Protocol (PTP) is a newer protocol with a peak error less than a microsecond [2]. The outcome of this internship was the completion of a prototype network design that allows a PTP timing signal to pass unimpeded from a grandmaster clock to the KGCS network through a firewall.

II. Precision Time Protocol

Also known as the IEEE[2] 1588 protocol, PTP was created by Agilent Technologies and was passed as a standard by the IEEE in 2002. An improved version became available in 2008, called PTPv2 or IEEE 1588-2008. This is the most recent version of the protocol, and has several advantages over the original, including the capability to achieve sub nanosecond-range accuracy, reduced network bandwidth, a revised messaging system, and faster synchronization [2].

PTP acts as a master to slave protocol. This means that in order for two PTP devices to communicate, they must decide which device's clock has the higher priority – the device with the higher priority will act as the master and send its own time to the slave. A device that is receiving and/or transmitting a PTP signal must have its priority set to a number between 1 and 255. When two PTP devices connect, the device with the lower number will act as the master, and the device with the higher number will act as the slave.

Once the master and slave are set, the master clock sends a sync message to the slave that is time-stamped on both ends to calculate the time offset [3]. Once the slave receives this message, it sends a delay request message back to the master clock. The master clock sends a delay response back to the slave upon receiving the delay request signal. The delay request and delay response signals are used in conjunction to determine the latency of the network between the master and slave. Once the slave knows the time offset as well as the delay, it is able to synchronize itself to the master clock.

III. Early Timing Prototype

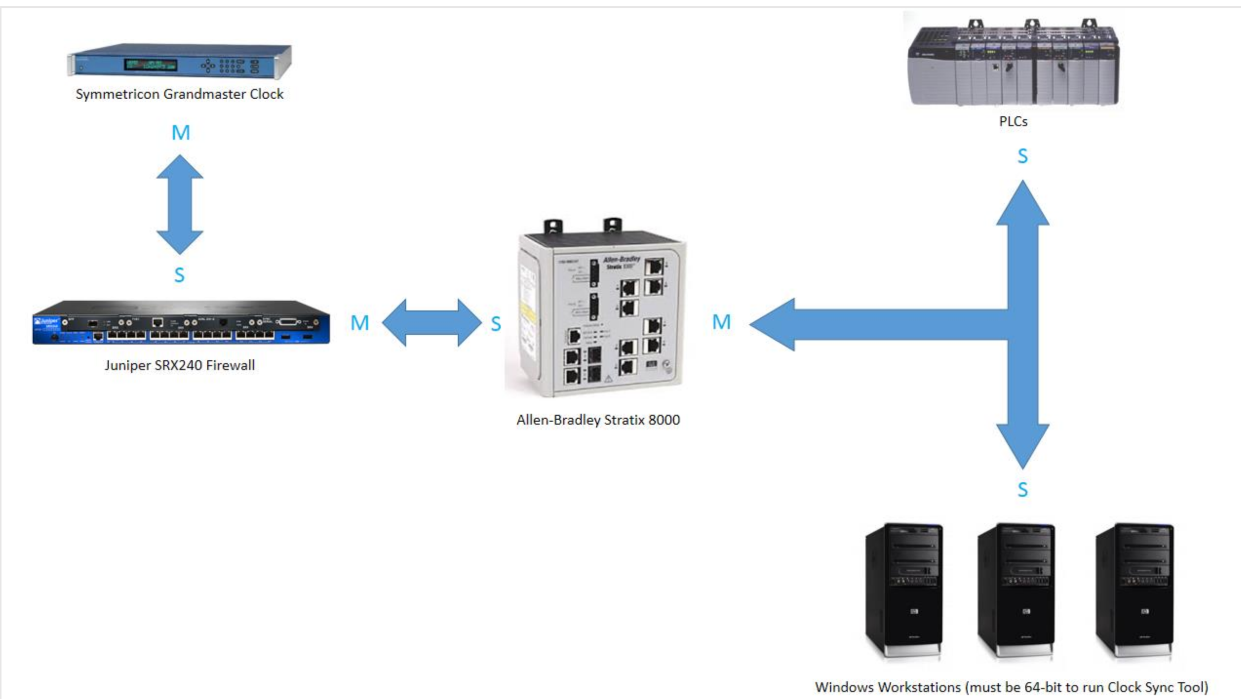

Figure 1 - Original Timing Prototype

[2] Institute of Electrical and Electronics Engineers

The diagram above shows the early design for the timing prototype. The timing signal would be obtained from a Symmetricon Grandmaster Clock[3], and passed through a Juniper SRX240 Firewall to an Allen-Bradley Stratix 8000 Boundary Clock. This boundary clock would distribute the timing signal throughout the KGCS network.

A. Symmetricon Grandmaster Clock

The Grandmaster Clock is simply the origin of the UTC time signal. It is controlled by T&CD and is capable of transmitting a timing signal via PTP as well as NTP. Where PTP is concerned, it has the highest priority in the network and will always act as the master. Grandmaster clocks are designed to be highly precise. Great accuracy is most imperative here since all clocks in the KGCS network will be synced to the signal created by this device. If the grandmaster clock has the wrong time, all of KGCS will have the wrong time. To help achieve this accuracy, Symmetricon designed this clock to obtain its time using the Global Positioning System (GPS) [4].

B. Juniper SRX240 Firewall

Due to the large scale of KSC's timing network, it has become useful for KGCS to isolate its own timing network. Therefore, a firewall was put in place between the grandmaster clock and the KGCS network. Once configured properly, the firewall will ensure that only PTP or NTP timing signals are permitted to pass through the firewall. This increases local security, guarding the KGCS network in case the security of T&CD is compromised. Juniper's SRX240 firewall can be configured to set specific ports on the firewall to be trusted or untrusted. Setting configuration rules allows the user to control what type of information that enters an untrusted port is allowed to leave the firewall through the trusted ports. In this case, the grandmaster clock was connected to an untrusted port and the boundary clock was connected to a trusted port. Much of the configuration for the firewall was completed by Shania Sanders in the fall of 2014 [5]. For the initial proof of concept, the firewall was configured to allow all data to pass through.

C. Allen-Bradley Stratix 8000 Boundary Clock

In a PTP network, a boundary clock is essentially a device that acts as both a master and a slave. The Stratix 8000 Boundary Clock is an Allen-Bradley product that acts like a network switch[4] with a robust internal clock. In this prototype, the Stratix would be used to distribute the timing signal from the firewall to the rest of the KGCS network. Unlike a simple Ethernet hub[5], which would simply pass the PTP signal to anything else connected to it, a boundary clock syncs its own clock to the master, and acts as a master to any devices on the other side. This has several uses. If the connection to the grandmaster clock is lost for any reason, the boundary clock's own internal clock will still function to provide time to the rest of the network. In addition, since the firewall is not "PTP-smart"[6], devices within the network might have trouble syncing to the grandmaster clock through the firewall. Having a PTP-smart boundary clock assures that as long as the boundary clock can sync to the grandmaster clock, all other devices within the network will be able to sync correctly.

D. Wireshark

Another capability of the Stratix was that it allowed one of its ports to be set to port-mirroring. A port that is set to port-mirroring simply mirrors the traffic entering or leaving another port on the switch. This allows a "port-sniffing" tool such as Wireshark to see this traffic. This is very useful for debugging an Ethernet network. For example, if a given packet is not being received by an end-item, Wireshark can be used to trace the packet to determine where the signal is being lost.

E. PLC's and Workstations

To test that the PTP signal could sync end-items properly, several devices were used as PTP-slaves following the Stratix boundary clock. Allen-Bradley PLCs were used, as well as a Windows Server 2008 machine and a Windows 7 machine. These devices needed to be PTP-smart in order to correctly act as a slave and sync to a master. The

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[3] Controlled by T&CD.

[4] A network switch connects devices in a computer network, receiving, processing, and forwarding data to the destination device.

[5] An Ethernet hub is a device for connecting Ethernet devices together and making them act as a single network segment.

[6] i.e. the firewall does not act as a master/slave or follow the protocol for interacting with a PTP signal; it simply receives the signal and passes it on as it would any IP packet.

PLCs have built-in PTP capability, but the Windows machines require software to function in this way. Two types of software were tested to provide this functionality: the Domain Time II client[7] and the Studio 5000 Clock Sync Tool[8].

IV. Issues with the Early Prototype

PTP was designed to be a single-network solution, and the protocol recommends the avoidance of routing PTP signals[9] to guarantee the high accuracy the protocol claims. For this reason, the default time-to-live (TTL) for PTP packets is set to 1 on most PTP devices. TTL defines the number of router "hops" a packet can go through before the packet is dropped. When a router obtains a packet and passes it on to another network, it decreases the TTL of the packet by 1; if the TTL reaches zero, the packet is dropped and does not travel further.

This TTL issue was problematic for the KGCS timing prototype because of the existence of the firewall. Wireshark sniffing on the Stratix 8000 revealed that while PTP packets reached the boundary clock perfectly when the grandmaster clock was connected directly to the boundary clock, once the firewall was introduced the PTP packets disappeared. This was originally believed to be caused by an error in the firewall configuration. However, this would even occur when the firewall was configured to pass all packets. Upon careful inspection[10], it was discovered that the TTL of PTP packets from both the grandmaster clock and the boundary clock were set to 1. As a result, whenever these packets would attempt to pass through the firewall, the firewall would decrement the TTL to zero, causing the packet to be dropped.

After communicating this issue to T&CD, they were able to increase the TTL of the grandmaster clock's PTP signals to 5[11]. These packets were then able to be seen reaching the boundary clock, even in the presence of the firewall. However, this was not enough, since the boundary clock also needs to send delay request messages back to the grandmaster clock. Unfortunately, Allen-Bradley does not allow the TTL of their products to be changed. Thus, the Stratix 8000 had to be replaced.

V. Final Timing Prototype

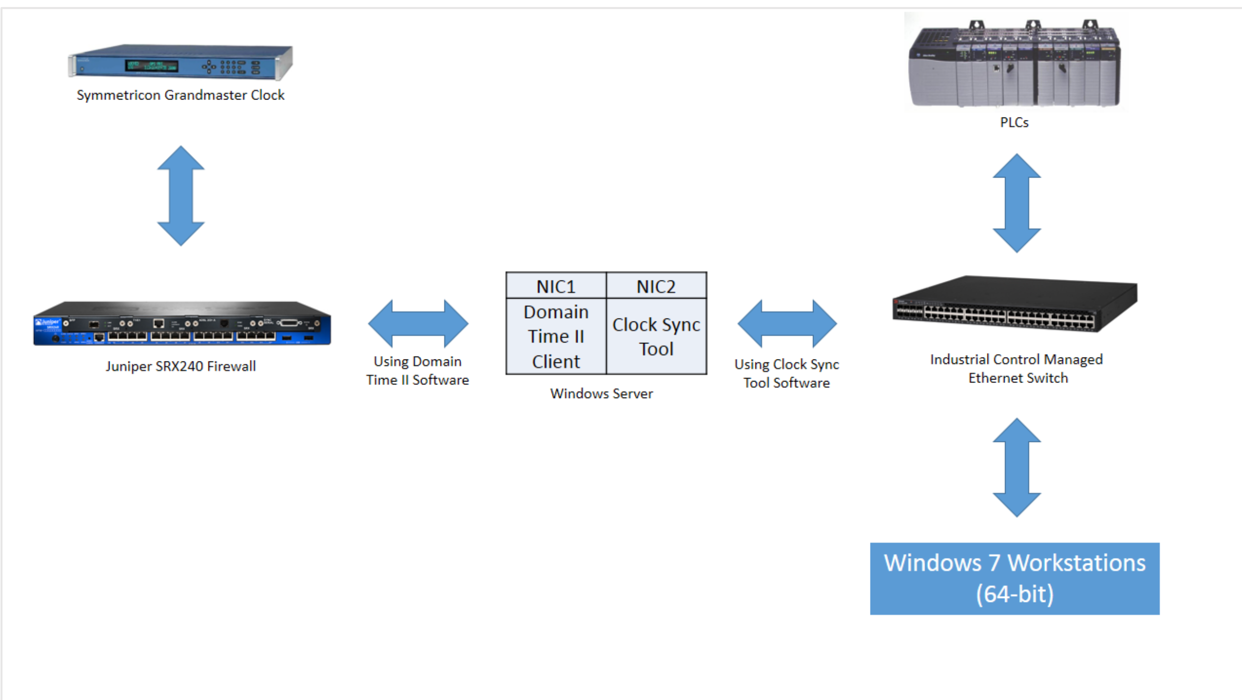

Figure 2 - Final Timing Prototype

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[7] Developed by Greyware
[8] Developed by Allen-Bradley
[9] i.e. sending PTP signals between different networks
[10] i.e. meticulous examination of Wireshark data
[11] Setting the TTL to 2 would have been sufficient, but 5 was selected in case more routing is required in the future.

The final timing synchronization prototype is shown above. The Stratix 8000 was replaced by a Windows Server 2008 machine with two network interface cards (NICs) – one for receiving the timing signal from the firewall, and another for sending a timing signal to the KGCS network. Due to differing limitations on the Domain Time II client software and the Clock Sync Tool software, the final solution used both products, each assigned to one of the NICs.

The Domain Time II Client does not support functionality as a boundary clock, or even as a PTP master. Therefore, it could not be used to send a PTP signal from the server to the KGCS network. However, it functions very well as PTP slave software, easily allowing the user to set the TTL of outgoing multicast packets like PTP. Using this software and increasing the TTL quickly allowed the server to sync to the grandmaster, even in the presence of the firewall.

The Clock Sync Tool had the opposite restraint. Being an Allen-Bradley product, it would not allow the user to change the TTL of the packets. This prohibited it from being used to obtain the PTP signal from the grandmaster clock in the presence of the firewall. On the other hand, this software can be configured to act as a master as well as a slave. Thus, it will be used to send timing signals from the server to the KGCS network. **Note:** The Clock Sync Tool only runs correctly on 64-bit Windows. 32-bit Windows cannot be used for this configuration.

Since the server used only had two Ethernet ports, an Industrial Control Managed Ethernet Switch was placed between the server and the rest of the KGCS network. This switch is not a router, and can pass PTP packets without fear of the TTL being decreased.

VI. Accomplishments

The work involved for this internship consisted of debugging the early prototype to discern the cause of error, assisting the development of the final network solution, and testing the final prototype. I monitored the network using Wireshark and communicated with Juniper until it was discovered that the reason the PTP packets were not making it through the firewall was because they had a TTL of 1. I then analyzed the Domain Time II and Clock Sync Tool software products to determine which could allow a TTL greater than 1 and found the capabilities and limitations of each. Once it was clear that each software had a clear purpose in the prototype, I helped design the final network solution that used two NICs and both software solutions. I tested the capability of this final prototype and verified its validity by successfully syncing the server to the grandmaster clock through the firewall.

VII. Conclusion

The goal of this internship, to pass a PTP signal from a grandmaster clock through a firewall to the KGCS network, was a success. The next task will be to further configure the firewall. More strict rules must be added so that the firewall only allows PTP and NTP timing signals through. In addition, although PTP is now working, Greyware[12] highly recommends the implementation of a backup NTP source in case the server fails to sync to the PTP signal from the grandmaster clock.

VIII. Acknowledgments

I would like to thank Reggie Martin and Elias Victor for their continued support and patience, and for giving me the opportunity to develop new skills. I would also like to thank Kurt Leucht and Caylyne Shelton for ensuring this internship was a challenging and enjoyable experience.

IX. References

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