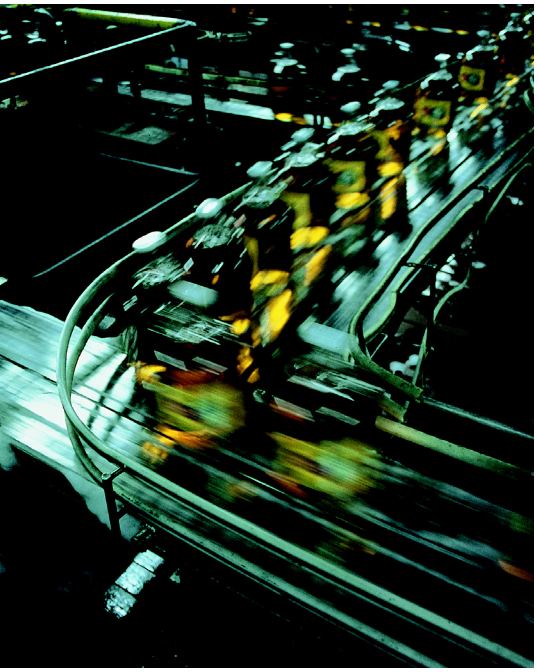

Deploying Scalable Time Distribution within a Converged Plantwide Ethernet Architecture

Design Guide

May 2019

Cisco Reference Design

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Preface

Converged Plantwide Ethernet (CPwE) is a collection of tested and validated architectures. The testing and validation follow the Cisco Validated Design (CVD) and Cisco Reference Design (CRD) methodologies. The content of CPwE, which is relevant to both operational technology (OT) and informational technology (IT) disciplines, consists of documented architectures, best practices, guidance, and configuration settings to help industrial operations and OEMs achieve the design and deployment of a scalable, reliable, secure, and future-ready plant-wide industrial network infrastructure. CPwE can also help industrial operations and OEMs achieve cost reduction benefits using proven designs that can facilitate quicker deployment while helping to minimize risk in deploying new technology. CPwE is brought to market through an ecosystem consisting of Cisco, Panduit, and Rockwell Automation emergent from the strategic alliance between Cisco Systems and Rockwell Automation.

Deploying Scalable Time Distribution within a Converged Plantwide Ethernet Architecture CRD (CPwE Time), which is documented in this Design Guide (DG), outlines several use cases for designing and deploying Scalable Time Distribution technology throughout a plant-wide Industrial Automation and Control System (IACS) network infrastructure. CPwE Time highlights the key IACS application requirements, technology, and supporting design considerations to help with the successful design and deployment of these specific use cases within the CPwE framework. CPwE Time was architected, tested, and verified by Cisco Systems and Rockwell Automation with assistance by Panduit.

Document Organization

This document is composed of the following chapters and appendices.

Chapter/Appendix	Description
CPwE Scalable Time Distribution Overview	Overview of CPwE Time.
CPwE Scalable Time Distribution Design Considerations	Describes primary design considerations when choosing how to implement CPwE Time in an IACS architecture.
CPwE Scalable Time Distribution Configuration	Describes how to configure CPwE Time within the CPwE architecture based on the design considerations and recommendations of the previous chapter.

Chapter/Appendix	Description
Test Hardware and Software	Lists the Cisco and Rockwell Automation hardware and software used in testing the CPwE Time solution.
References	Links to documents and websites that are relevant to Deploying Scalable Time Distribution within a Converged Plantwide Ethernet Architecture Design Guide.
Acronyms	List of all acronyms and initialisms used in this document.
About the Cisco Validated Design (CVD) Program	Describes the Cisco Validated Design (CVD) process and the distinction between CVDs and Cisco Reference Designs (CRDs).

For More Information

More information on CPwE Design and Implementation Guides can be found at the following URLs:

- Rockwell Automation site:
  - http://www.rockwellautomation.com/global/products-technologies/network-technology/architectures.page?
- Cisco site:
  - http://www.cisco.com/c/en/us/solutions/enterprise/design-zone-manufacturing/landing_ettf.html

Note This release of the CPwE architecture focuses on EtherNet/IP™, which uses the ODVA, Inc. Common Industrial Protocol (CIP™), and is ready for the Industrial Internet of Things (IIoT). For more information on EtherNet/IP and CIP Sync™, see odva.org at the following URL:

- http://www.odva.org/Technology-Standards/EtherNet-IP/Overview

CHAPTER 1

CPwE Scalable Time Distribution Overview

The prevailing trend in Industrial Automation and Control System (IACS) networking is the convergence of technology, specifically IACS operational technology (OT) with information technology (IT). Converged Plantwide Ethernet (CPwE) helps to enable IACS network and security technology and OT-IT persona convergence through the use of standard Ethernet, Internet Protocol (IP), network services, security services, time synchronization technologies, and EtherNet/IP. A real-time converged plant-wide IACS architecture helps to enable the Industrial Internet of Things (IIoT).

Business practices, corporate standards, policies, industry standards, and tolerance to risk are key factors in determining the degree of time synchronization required within a plant-wide IACS architecture. IACS networks differ from their IT counterparts in their need to support significantly lower latency (time delay between message sent and message received) and jitter (the variance of the latency) to help enable real-time IACS communications. Time synchronization helps to support time-critical data for the most demanding IACS applications.

Successful deployment of IIoT IACS applications within CPwE Architectures (Figure 1-1) depends on a network infrastructure design that addresses IACS application performance requirements. The content of CPwE, which is relevant to both OT and IT disciplines, consists of documented architectures and key tenets from OT and IT to help achieve real-time communications to support IIoT IACS applications. CPwE key tenets include:

- **Smart IIoT Devices**—controllers, I/O, drives, instrumentation, actuators and analytics
- **Zoning (segmentation)**—smaller connected LANs, functional areas and security groups
- **Managed Infrastructure**—managed industrial Ethernet switches (IES) and industrial firewalls
- **Resiliency**—robust physical layer and resilient or redundant topologies with resiliency protocols
- **Time-critical Data**—data prioritization and time synchronization via CIP Sync and IEEE-1588 Precision Time Protocol (PTP)
- **Wireless**—unified wireless LAN (WLAN) to enable mobility for personnel and equipment
- **Holistic Defense-in-Depth Security**—multiple layers of diverse technologies for threat detection and prevention, implemented by different persona (e.g., OT and IT) and applied at different levels of the plant-wide IACS architecture
- **Convergence-ready**—seamless plant-wide integration by trusted partner applications

The ODVA, Inc. CIP Sync technology uses the Common Industrial Protocol (CIP) application layer protocol and the IEEE 1588-2008 Precision Time Protocol (PTP) standard for time synchronization. CIP Sync and IEEE 1588-2008 are designed for local and plant-wide IACS applications requiring very high accuracies beyond those attainable with Network Time Protocol (NTP).

This *Deploying Scalable Time Distribution within a Converged Plantwide Ethernet Architecture Design Guide* (CPwE Time) outlines several use cases for designing and deploying IEEE 1588 PTP and CIP Sync technology throughout a plant-wide IACS network infrastructure. CPwE Time was architected, tested and verified by Cisco Systems and Rockwell Automation with assistance by Panduit.

CPwE Time Solution Use Cases

CPwE is the underlying architecture that provides standard network and security services for control and information disciplines, devices and equipment found in modern IACS applications. The CPwE architectures (Figure 1-1) were architected, tested and validated to provide design and implementation guidance, test results and documented configuration settings. This can help to achieve the real-time communication, reliability, scalability, security and resiliency requirements of modern IACS applications.

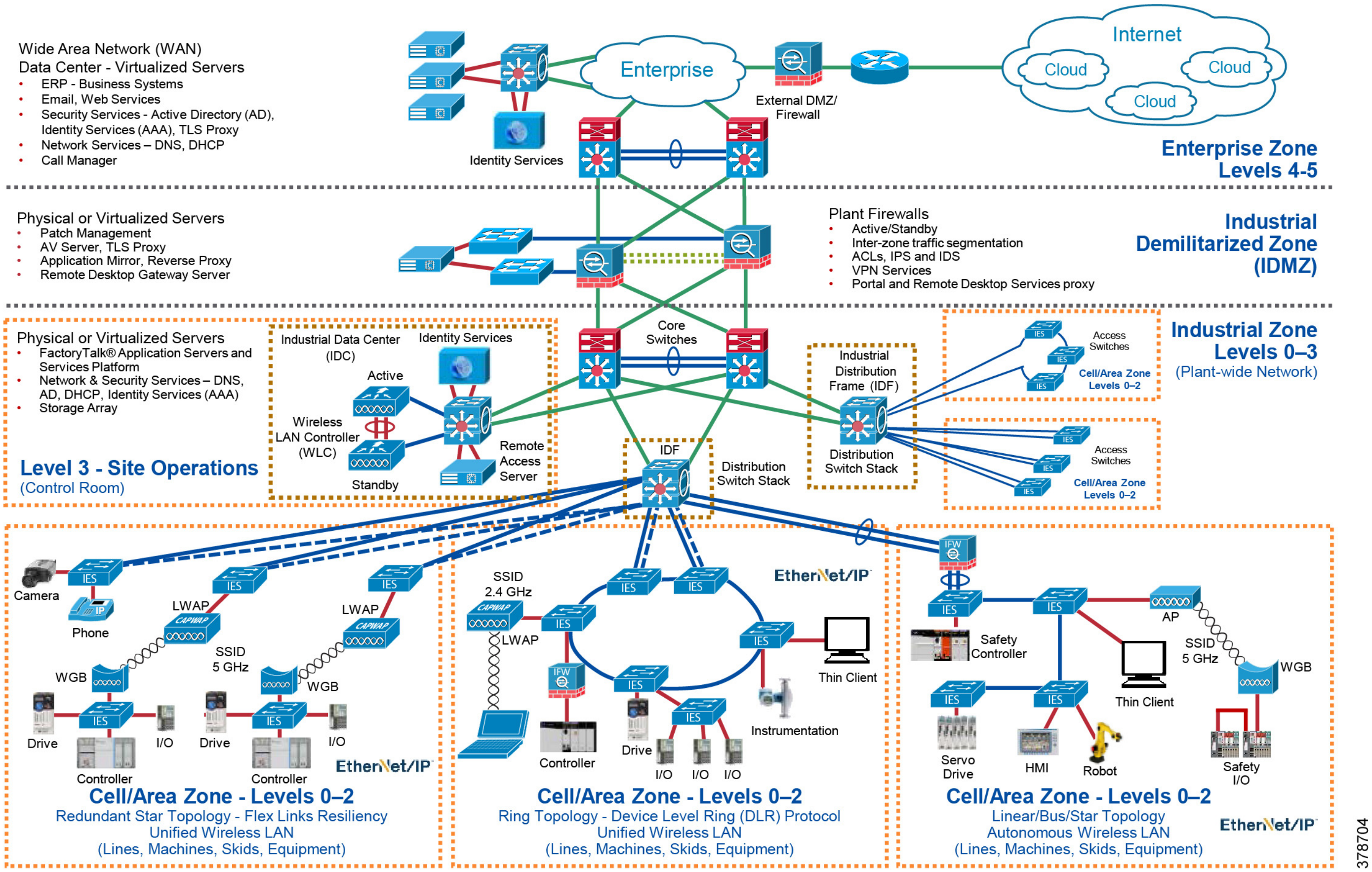
An IACS is deployed in a wide variety of discrete and process manufacturing industries such as automotive, pharmaceuticals, consumer packaged goods, pulp and paper, oil and gas, water/wastewater, mining and energy. IACS applications are composed of multiple control and information disciplines such as continuous process, batch and discrete, and hybrid combinations. One of the challenges facing industrial operations is the hardening of standard Ethernet and IP-converged IACS networking technologies to take advantage of the business benefits associated with IIoT.

This *Deploying Scalable Time Distribution within a Converged Plantwide Ethernet Architecture Design Guide* outlines the concepts, requirements and technology solutions for reference designs developed around a specific set of priority use cases. These use cases were architected and tested for solution functional verification with limited scale by Cisco Systems and Rockwell Automation with assistance by Panduit to help support time synchronization within a converged plant-wide EtherNet/IP IACS architecture.

The CPwE Time Design Guide includes:

- Time Synchronization Overview:
  - IEEE 1588 Precision Time Protocol (PTP)
  - ODVA, Inc. CIP Sync
- Time Synchronization Use Cases—the following represents a portion of the use cases:
  - Time stamping
  - First fault detection
  - Sequence of Events (SOE)
  - Distributed motion (not included in CPwE Time)
- Plant-wide Architectures for Reliable Time Synchronization:
  - Design, configuration and diagnostic considerations for plant-wide (Levels 0-3) IEEE 1588 PTP and CIP Sync deployments
  - Limited resiliency and reliability PoC testing
- Selection of Industrial Ethernet Switches (IES):
  - Layer 2 IES—Allen-Bradley® Stratix® 5700/5400
  - Layer 3 IES—Allen-Bradley Stratix 5410

Figure 1-1 CPwE Architectures



CPwE Time Architecture Overview

ODVA, Inc. CIP Sync technology for time synchronization is used across a broad range of IACS applications to synchronize control system clocks (Figure 1-2) and helps enable applications such as event sequencing and logging. For example:

- A sequence of events or first fault system can use timestamps to determine the order in which faults occurred in the system. This allows for the tracking of faults to establish the first in a chain of faults. These types of applications use dedicated alarm instructions in the Programmable Automation Controller (PAC) to record events or time stamping inputs in order to log the change of state for a point.
- An in-PAC chassis historian module logs historical data at Level 1 (skid/machine).
- High-speed applications can use timestamps to process inputs and outputs asynchronously from the control loop. For example, an application can use time-synchronized inputs and outputs to trigger a diverter without the application scan time matching the part cycle time.

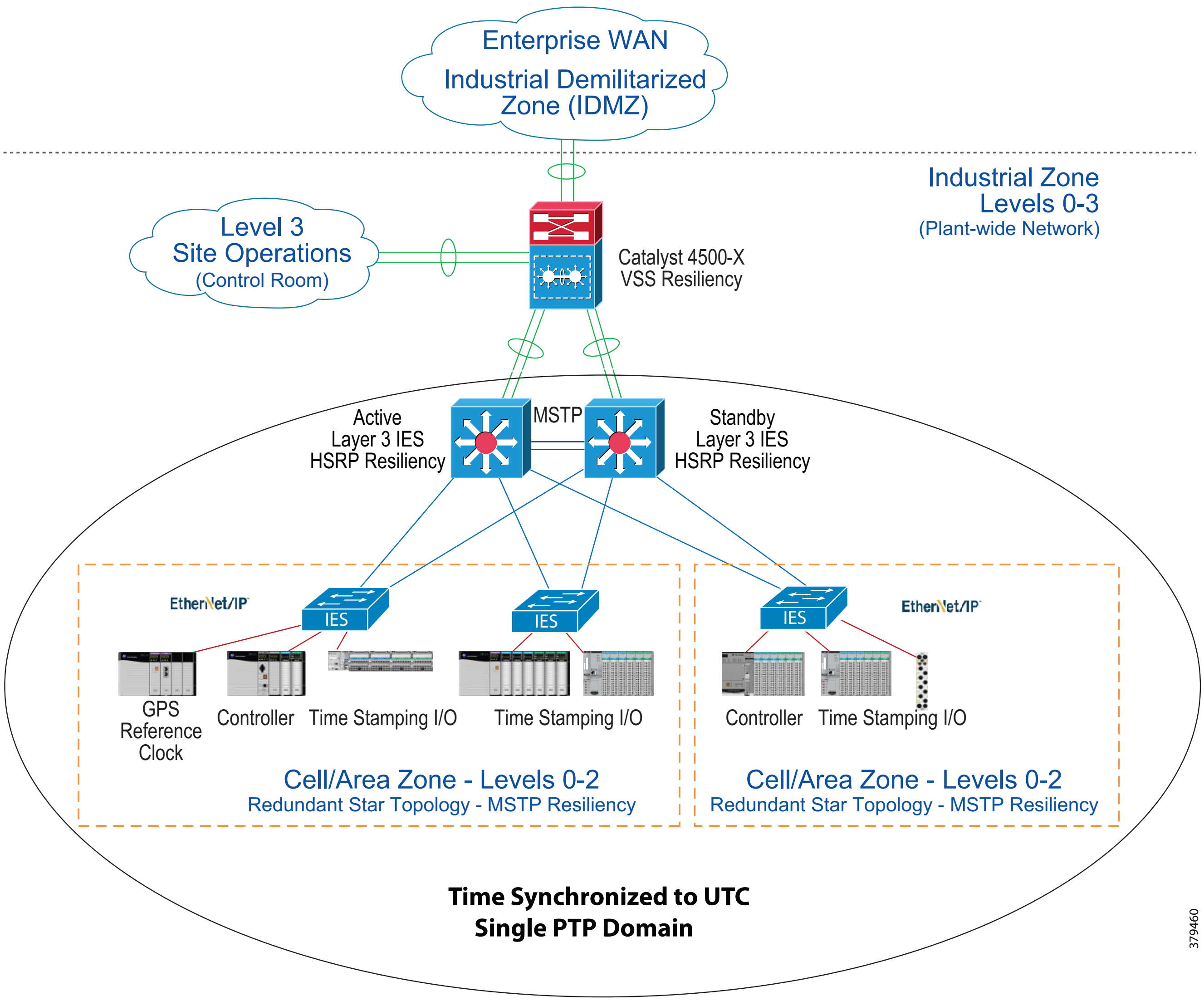
CIP Sync uses IEEE 1588 Precision Time Protocol (PTP) to synchronize clocks in the control system. In the PTP architecture, all clocks are synchronized to a single grandmaster clock. In turn, this clock must be synchronized to Coordinated Universal Time (UTC) to represent the time of day in the system.

Several approaches exist for setting time in the grandmaster clock that allow customers to meet different application requirements. For example, applications that only require rough correlation to UTC can use a handset grandmaster clock. In this case, the administrator simply sets the time in the grandmaster clock based on the time that is currently shown on another device such as their PC or smartphone. All clocks drift over time and need to be adjusted to accurately reflect UTC. Handset clocks do not have any inherent mechanism to compensate for drift. As such, the administrator will need to re-adjust the grandmaster time manually to ensure alignment with UTC time. This readjustment will need to be done on a regular basis to help prevent the two clocks from drifting too far apart.

Applications that require tight correlation to UTC can use a grandmaster clock with a built-in Global Navigation Satellite System (GNSS) receiver such as a Layer 3 IES or a dedicated PAC module (e.g., Allen-Bradley 1756-TIME module). These type of grandmaster clocks synchronize to the atomic clocks in the navigation satellites and automatically adjust their time to match UTC. However, the installation of these systems is complex and requires an antenna with an unobstructed view of the sky and low loss coaxial cable to connect to the receiver.

A final approach is the NTP-PTP flywheel feature available in some IES. This is a hybrid approach that uses Network Time Protocol (NTP) to synchronize and regulate the grandmaster clock to UTC. Correlation to UTC will not be as good as with a GNSS receiver; however, the flywheel does compensate for drift.

Figure 1-2 CPwE Time Architecture



In the CPwE Time solution (Figure 1-2), PTP time does not pass through the core and the PTP domain is bounded to the Cell/Area Zones connected to a single Layer 3 IES distribution pair. Within these bounds, the grandmaster clock will function as the reference for all PTP IACS devices in the plant-wide architecture. The preferred solution for the network topology is redundant star, however ring may work for some use cases. In either case, synchronization should be sufficient to support time stamping functionality of I/O modules that typically have a resolution of ±4µs to ±100µs. However, the accuracy of the timestamps to UTC will be limited by how well the grandmaster clock is correlated to UTC. Since PTP time does not synchronize across the core, correlation between PTP domains is also limited by how well the grandmaster in each of the PTP domains is correlated to UTC.

For more information on CIP Sync and CIP Sync applications, see *Integrated Architecture and CIP Sync Configuration*
https://literature.rockwellautomation.com/idc/groups/literature/documents/at/ia-at003_-en-p.pdf

CHAPTER 2

CPwE Scalable Time Distribution Design Considerations

Reference Clocks

Reference clocks are the master time source for a plant-wide Industrial Automation and Control System (IACS) architecture. They are high precision clocks that are synchronized to a time standard such as International Atomic Time (TAI) or Coordinated Universal Time (UTC). TAI uses a system of hundreds of atomic clocks to accurately track time using International System of Units (SI) seconds. The SI second is a fixed measurement and is not compensated for changes in the notional period of the Earth.

UTC is the time scale people use to track time of day. UTC is based on TAI time and the SI second, however it uses leap seconds to align clocks with solar time. Periodically, leap seconds are added to adjust UTC time to the solar day. As of December 2015, UTC is 37 seconds behind TAI. All clocks in the system should synchronize directly or indirectly with the reference clock to provide a consistent view of time across the IACS application network infrastructure.

Global Navigation Satellite Systems

Global Navigation Satellite Systems (GNSS) such as the Global Positioning System (GPS) can be used to provide accurate reference time for network systems, for instance, time-critical IACS applications. GNSS navigation systems function by measuring the time delay between a receiver and one or more satellites. For these navigation systems to function, they must have highly accurate atomic clocks in each satellite. GNSS timeservers use these signals to synchronize their internal clock to the atomic clocks in the satellites. This allows the GNSS timeserver to provide very accurate synchronization to UTC. GNSS-based solutions also automatically handle leap seconds. Most GNSS receivers can output time as an NTP server. Some timeservers such as the 1756-TIME, Allen-Bradley Stratix 5410, and Cisco IE 5000 industrial Ethernet switches (IES) can function as a PTP grandmaster clock.

Network Time Protocol

Network Time Protocol (NTP) servers are commonly used to provide a reference clock for enterprise and IACS applications. NTP-based systems have an advantage because they do not require complicated satellite receivers to provide reference time for the system. However, the fact that the IACS application is synchronizing to a reference clock across a network limits the accuracy of the solution. NTP-based solutions will maintain an approximate synchronization to UTC and handle events like leap seconds.

Internal Clock

Internal clocks are free running oscillators inside IACS devices like Programmable Automation Controllers (PACs). Internal clocks need to be manually set to UTC by an administrator, such as an authorized OT engineer (e.g., Control Systems Engineer). Furthermore, all clocks drift over time and internal clocks do not have an automated mechanism for correcting drift. If clock accuracy to UTC becomes unacceptable due to drift or leap seconds, the administrator must manually correct the time in the clock.

Reference Clock Location

The location of the reference clock can have an impact on how well IACS devices in the IACS application synchronize to each other and to UTC. The ability of IES and IACS devices to synchronize across the network is generally impacted by factors such as bandwidth, latency, and jitter. These are some of the driving factors for the location of the reference clock. Availability is another consideration which may influence the placement of the reference clock. The reference clock should be positioned within the plant-wide IACS architecture so that the time synchronization architecture can meet the application requirements.

Internet

Protocols like NTP allow systems to synchronize to reference clocks located anywhere in the world. These reference clocks are hosted by a number of different types of organizations and the quality of the time service may vary widely:

- Government entities
- Corporations
- Educational institutions

Generally, reference clock sources offered by these organizations are reliable based on the limits of the NTP protocol. However, there are risks associated with using internet-based reference clocks. Most of these services are provided on a volunteer basis and could be changed or discontinued at any time. Furthermore, many public NTP servers do not provide any security to authenticate or verify the integrity of the time sources. Because of this, IT administrators should consider if the use of internet-based reference clocks is appropriate for their application needs. In addition, accessing internet-based NTP servers from the Industrial Zone is problematic since the traffic must flow through both the Industrial Demilitarized Zone (IDMZ) and the enterprise edge firewalls.

Enterprise Zone

Placing the reference clock in the Enterprise Zone places it directly under the authority of the IT organization. IT departments commonly deploy reference clocks to reliably synchronize their computer and network systems to a common time using NTP. Like internet-based NTP servers, these internal servers could be used as the time reference for IACS applications. However, as with internet-based sources it is important to consider the path between the IACS network and the enterprise time servers. If the Industrial Zone is connected to the headquarters site using a low bandwidth, high latency, and high jitter wide area network (WAN) link the accuracy and stability of time could be impacted. Furthermore, these deployments generally will not support applications where the reference clock must feed PTP time directly into the IACS application.

The *Securely Traversing IACS Data across the Industrial Demilitarized Zone Design and Implementation Guide* discusses passing NTP through the IDMZ.
https://literature.rockwellautomation.com/idc/groups/literature/documents/td/enet-td009_-en-p.pdf

Industrial Zone

From an IACS application perspective, placing the reference clocks directly in the Industrial Zone should provide the best quality of time synchronization and accuracy to UTC. This approach also allows the reference clock to source PTP time directly into the IACS application without converting NTP to PTP. The tradeoff is that a reference clock such as a GNSS receiver must be installed in the Industrial Zone.

Network Time Protocol

Network Time Protocol (NTP) is the Internet Engineering Task Force (IETF) standard for synchronizing clocks across the Internet and TCP/IP networks in general. NTP uses a hierarchical system of clocks to synchronize time across disparate hosts on the network. There are three roles for clocks in the NTP architecture:

- Servers—NTP servers act as a time source for one or more NTP clients.
- Clients—NTP clients synchronize their clocks to one or more servers.
- Peers—NTP peers allow two clocks to synchronize to each other. In essence, peers are clients and servers to each other.

These roles are not exclusive and any clock in the plant-wide IACS architecture can act as one or more of these roles. For example, an NTP server is generally a client to servers higher up in the NTP hierarchy.

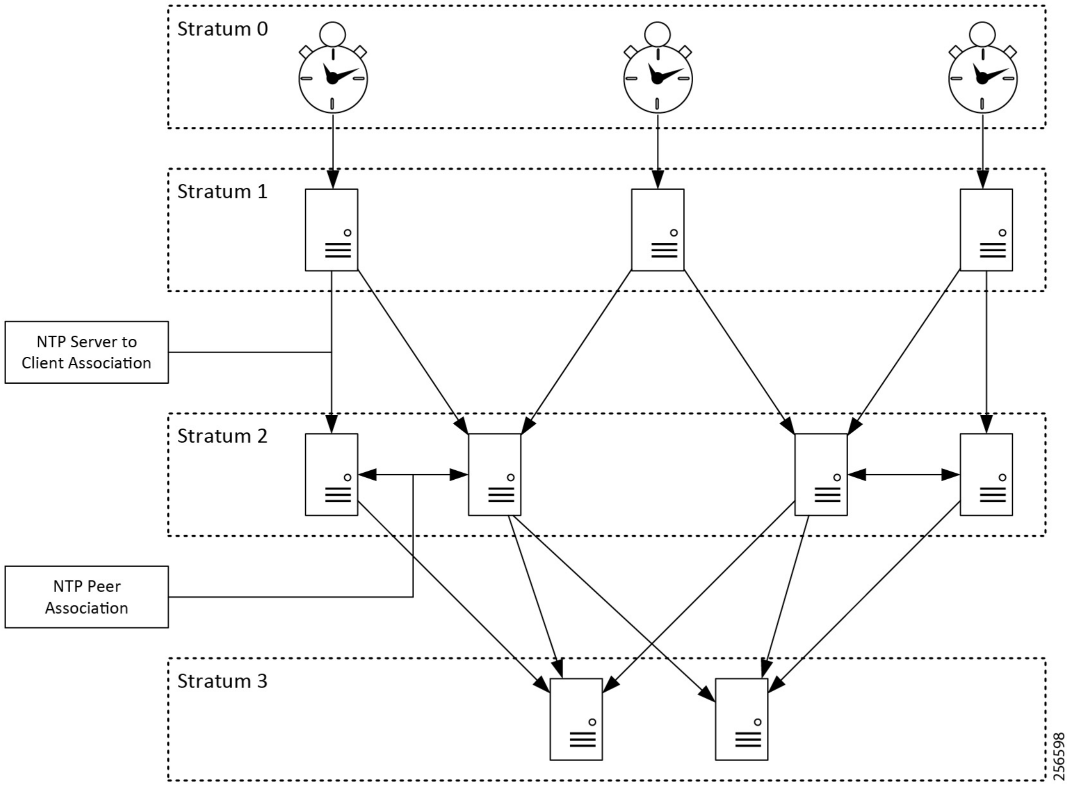
NTP has limited provisions for authenticating timeservers. Most implementations support symmetric keys for authentication. Some recent implementations support the autokey security protocol. NTP authentication is outside the scope for this guide.

Some clients implement the Simple Network Time Protocol (SNTP). SNTP is a simplified version of the NTP daemon (computer program that runs as a background process) and generally has lower precision than the full NTP protocol.

NTP Hierarchy

The clock hierarchy (Figure 2-1) is divided into “stratum” where lower stratum numbers are closer to the reference clock. The reference clock is identified as the stratum 0 clock and is frequently a receiver for a GNSS such as a GPS, but could also be a radio receiver, atomic clock, or another precision time source. The stratum 0 clock is directly connected to the stratum 1 server and cannot be directly accessed across the network. The stratum 2 servers are the first to synchronize across the network using the NTP protocol. They are clients to several stratum 1 servers and are frequently peers to other stratum 2 servers. The stratum 3 servers are clients to the stratum 2 servers and may be peers to other stratum 3 servers and so on.

Figure 2-1 NTP Hierarchy



Generally, the ability of a client (e.g., IACS device) to synchronize its clock to the reference depends on its stratum level. Clocks with lower stratum numbers will be more tightly synchronized with the reference clock. NTP clocks will have limited accuracy to UTC. They are generally a better fit for IACS applications that can tolerate offsets to UTC of tens, if not hundreds, of milliseconds or even seconds.

However, there are a number of factors that can affect how precisely a client will synchronize to the reference clock.

- Network latency and jitter
- Asymmetric networks
- Number of hops between clocks
- Quality of the internal oscillator
- Operating system capabilities

The NTP clock algorithm supports associating with multiple servers. It will use the multiple inputs to provide better time synchronization of the local clock. The clock algorithm also sanity checks the associated servers. Clock updates from servers that are inconsistent with the pool are invalidated and discarded. Sanity checking reduces the risk of a bad clock source skewing in the NTP client.

Recommendations

Deploy two to four NTP servers in the Enterprise Zone to function as the central clocks for enterprise applications. Depending on the application requirements, these NTP servers could either be directly connected to reference clocks or synchronized to public servers on the Internet. If the decision is made to synchronize to public sources, each of these servers should be synchronized to two to four public sources. There should be some diversity in the public sources, so that a bad clock can be identified and removed from the clock pool. In addition, the Enterprise Zone servers should be peers to each other. Large organizations will likely have additional stratums of NTP servers within the organization to cascade time to the NTP clients. In cases where high accuracy NTP time is needed in the Industrial Zone, consider deploying a stratum 1 server within the Industrial Data Center (IDC) as part of Level 3 Site Operations.

Access to public NTP servers should be controlled at the enterprise edge firewalls. The goal is to have all NTP clients in the organization synchronize to the internal NTP servers. As such, access to public servers should be limited to the internal top-level NTP servers. Moreover, access should be limited to specific public servers that are trusted by the organization. Ideally, use authentication with any external NTP servers to reduce the risk of time synchronization being compromised.

Use NTP to synchronize the clocks in the switches, routers, firewalls, and other network infrastructure deployed in the IDMZ and Industrial Zone(s). Synchronizing time for these network devices is important so that syslogs from multiple network devices can be analyzed together to help troubleshoot system level faults.

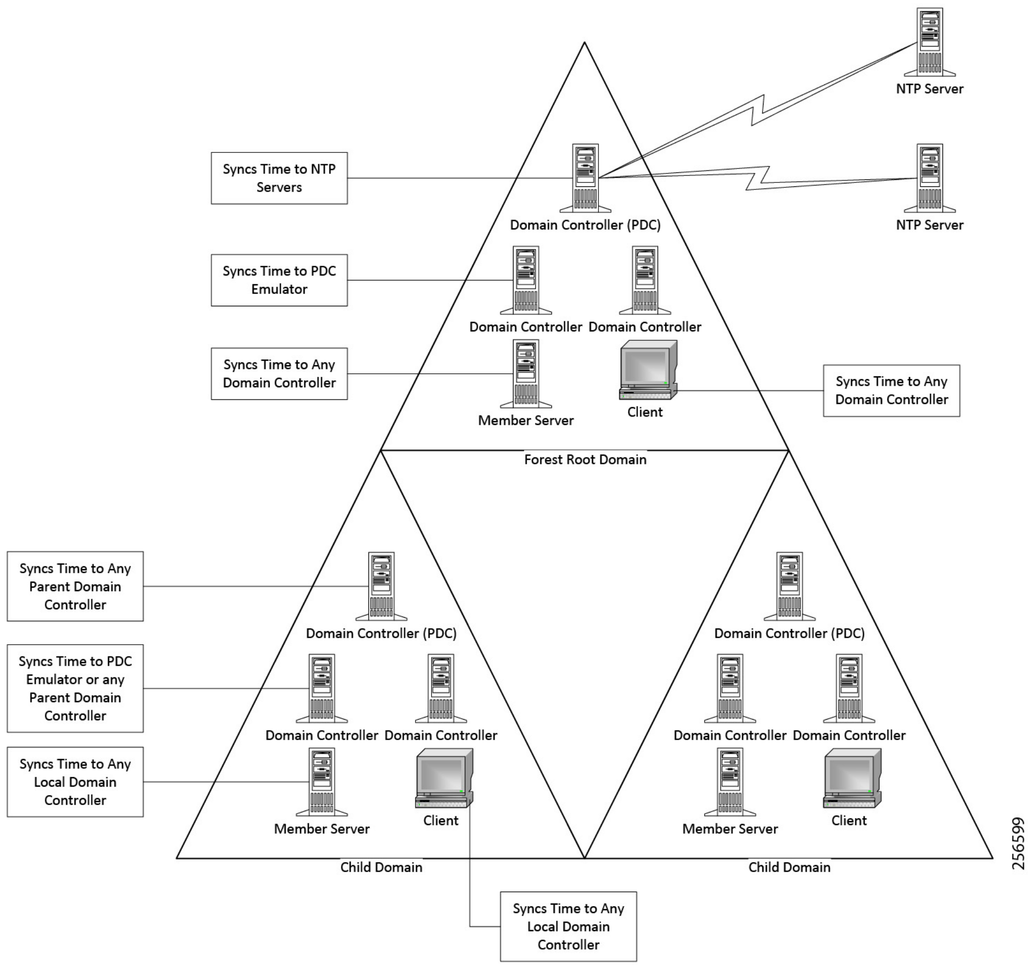
Windows Domain Time

Windows Active Directory Domain Services require the domain members to synchronize their clocks with a common reference to support Kerberos authentication. The forest structure forms the basis for the time hierarchy in the Windows time model. A domain controller in the forest root is configured with the primary domain controller (PDC) emulator flexible single master operation (FSMO) role. This domain controller synchronizes its clock to one or more reliable NTP servers. The remaining domain controllers in the forest root domain synchronize their clocks to the PDC emulator. Any member servers or workstations in the forest root domain synchronize their clocks to any domain controller in the domain.

Each child domain also has a PDC emulator. The PDC Emulator in the child domains synchronizes its clock to any domain controller in the parent domain. The remaining domain controllers in the child domain synchronize their clocks to the local PDC emulator or any domain controller in the parent domain. Any member servers or workstations in the child domain will synchronize their clocks to the domain controllers in the local domain.

The same pattern continues for any additional child domains. Using the forest hierarchy for time synchronization ensures that all computer clocks in the domain synchronize within the limits of the Windows Time service.

Figure 2-2 Windows Time Hierarchy



Windows uses a customized version of NTP to maintain clock synchronization called MS-NTP. MS-NTP extends the NTP protocols to support authentication via Netlogon RPC. MS-NTP uses different versions of the NTP protocol depending on the version of the operating system.

Table 2-1 Windows NTP Versions

Operating System	NTP Version
Windows 2000	SNTP
Windows XP and Windows Server 2003 or later	NTP v3
Windows 10 (build 1607) and Server 2016	NTP v4

Windows Time Service

Microsoft® designed the Windows Time Service to synchronize all clocks in the forest within five minutes to support Kerberos authentication. It is possible for the Windows Time Server to maintain accuracy better than five minutes, however there is no guarantee or requirement to support higher precision time.

Recommendations

- Configure the PDC emulator in the root domain to synchronize to two to four reliable NTP time sources.
- Windows domain controllers, member servers, and workstations should synchronize their clocks to the domain to ensure successful authentication.
- Enforce Windows time settings through group policy objects (GPO) to ensure correct configuration across the domains.
- Non-domain members should synchronize their time to a reliable NTP time source.
- Internet-based NTP servers may be considered acceptable given the relatively low accuracy of the Windows Time Service

Windows Time Service for High-accuracy Environments

Microsoft introduced an updated Windows Time Service in Windows Server 2016 and Windows 10 (build 1607). The new time service supports clock synchronization as accurate as 1 ms across the domain. The domain can consist of a mix of older and newer Windows Time Services, however only the Windows 10 and Server 2016 systems will achieve higher accuracy time. To achieve this level of accuracy Microsoft has developed a number of design restrictions based on the required accuracy. In the Microsoft model, the domain controllers act as time sources for the member servers and workstations. Therefore, the domain controllers need to be running Windows Server 2016 to support high-accuracy time. The member servers and workstations need to be running Windows Server 2016 or Windows 10 to achieve high-accuracy time.

https://docs.microsoft.com/en-us/windows-server/identity/ad-ds/get-started/windows-time-service/accurate-time

Recommendations

Microsoft has published requirements for maintaining 1 second, 50 millisecond, and 1 millisecond time synchronization across the forest. These requirements for the high accuracy Windows Time Service place some constraints on the Active Directory Domain Services design. The Active Directory Domain Services design for CPwE uses a single domain across the Enterprise and Industrial Zones. Assuming that this is also the forest root domain, it could be possible to achieve time synchronization with an accuracy that is close to 1 ms. This is assuming that the network infrastructure meets the requirements of the solution.

https://support.microsoft.com/en-us/help/939322/support-boundary-to-configure-the-windows-time-service-for-high-accura

It is important to consult with the IACS software vendor to ensure it is compatible with the latest versions of Windows server and workstation. For compatibility information for specific FactoryTalk® applications, see the Rockwell Automation® Product Compatibility and Download Center: https://compatibility.rockwellautomation.com/Pages/home.aspx

Precision Time Protocol

The Precision Time Protocol (PTP) is defined by the IEEE 1588 standard and it is designed to provide nanosecond accuracy to clocks of IACS devices and IES in a network. PTP is designed specifically for industrial, networked measurement, and control systems. It is optimal for use in distributed IACS applications because it requires minimal bandwidth and little processing overhead.

The protocol operates in a hierarchical manner, establishing master-slave relationships among devices, where slaves will synchronize their clocks with a master clock. The IACS devices and IES maintain time synchronization by sending and receiving PTP event messages containing information that allows them to correct time differences between master and slaves.

The process that builds the clock hierarchy, determining what devices will be assigned as master or slave, is done by using the Best Master Clock Algorithm (BMCA). When a PTP-capable clock joins the network, it will listen to PTP messages called PTP announce messages. These messages will contain information such as time source, clock quality, and priority numbers. The BMCA runs continuously and uses the announce messages information to make these assignments and adjustments as necessary.

CIP Sync

There are a number of different solutions that utilize IEEE 1588 for time synchronization. This CPwE Time reference design focuses on IACS applications that use the ODVA, Inc. CIP Sync standard. CIP Sync is an extension of the Common Industrial Protocol (CIP) that establishes object models for the synchronization of time within an IACS application. CIP Sync can be used for various applications including sequence of events and distributed motion control (not included in CPwE Time) applications. CIP Sync uses the IEEE 1588 default profile and end-to-end transparent clocks.

EtherNet/IP devices are not required to implement the CIP Sync standard. It is important to select IACS devices (e.g., communications adapters and I/O modules) that support CIP Sync during the design, sizing, and selection phase of a project. Furthermore, it is important to verify the specifications for time stamping I/O modules to ensure that they meet the IACS application requirements. Integrated Architecture® Builder is a Rockwell Automation product that provides a means to select Rockwell Automation IACS devices and IES that support CIP Sync.

More information on Rockwell Automation Integrated Architecture Builder can be found at the following URL:
http://www.rockwellautomation.com/global/support/integrated-architecture-builder.page

Best Master Clock Algorithm

The Best Master Clock Algorithm (BMCA) is used to determine which IACS device or IES in a PTP domain has the best clock and should be the grandmaster clock for the IACS application. To accomplish this, the BMCA uses an ordered set of attributes to select the grandmaster clock, as shown in Table 2-2.

Table 2-2 BMCA Criteria

Order	Attribute	Description
1	priority1	User configurable value that overrides the election process
2	Clock Class	Measure of the clock's quality
3	Clock Accuracy	Measure of the clock's accuracy to UTC
4	Clock Variance	Measure of the clock's stability
5	priority2	User configurable value that prioritizes otherwise equal clocks
6	Clock Identity	Unique clock identifier set by the manufacturer
7	Steps Removed	Closest clock to the grandmaster

The BMCA will always select the "best" grandmaster available on the network. However, in most cases it may be beneficial to use the priority1 and priority2 values to weight the election and force specific devices to become the grandmaster.

Clock Types

Ordinary Clock

An ordinary clock has a single PTP port. It functions as a node in the PTP topology and can be selected by the BMCA as a master or slave within the PTP domain. Ordinary clocks are the most common clock type in a PTP system because they are used as end nodes in the system. Typical examples of ordinary clocks in an IACS application are a Programmable Automation Controller (PAC) or an I/O device.

Grandmaster Clock

The grandmaster clock is the primary source of time in the PTP domain. Grandmaster clocks should have high quality oscillators and be synchronized to UTC.

Boundary Clock

A boundary clock is a multiport device (e.g., IES) that becomes a slave on one port. As a slave clock, the boundary clock synchronizes its internal clock to the master. The boundary clock then becomes a master to IACS devices connected to the other ports on the IES. Other clocks connected to these ports will become slaves to the boundary clock and synchronize to the boundary clock's internal clock.

Transparent Clock

Transparent clocks compensate for latency across the network by inserting delay corrections into the PTP packets. There are two types of transparent clocks defined in the IEEE 1588 specification:

- End-to-end transparent clocks compensate for latency across a network by measuring how long IACS devices and IES in the network take to process and forward the PTP packets. These measurements are added to the correction field in the PTP packets.

  Transparent clocks do not become nodes in the PTP hierarchy and are therefore neither master or slave clocks. Transparent clocks sit in-line between the master and slave clocks and provide time correction between these devices.

- Peer-to-peer transparent clocks are not compatible with end-to-end transparent clocks, they are not used in CIP Sync applications, and are out of scope for this CPwE Time Design Guide.

IES Clock Modes

GMC-BC

The GMC-BC mode allows an IES to function as the grandmaster in the IACS application. In GMC-BC mode, there are two options to synchronize the grandmaster to UTC: the NTP to PTP feature and the GNSS receiver. The Allen-Bradley Stratix 5400/5410 and Cisco IE 4000/5000 IES support the NTP to PTP feature. The Allen-Bradley Stratix 5410 and Cisco IE 5000 IES also support the GNSS receiver.

The IES GNSS receiver allows the switch to synchronize to one of several different satellite constellations:

- GPS/NAVSTAR—Global Positioning System
- GLONASS—Global'naya Navigatsionnaya Sputnikovaya Sistema
- BeiDou—BeiDou Navigation Satellite System

Note The GNSS receiver is only enabled on Allen-Bradley Stratix 5410 IES Series B and Cisco IE 5000 IES Version ID (VID) 05 hardware or later.

Note The GNSS receiver requires IOS 15.2(6)E0a or later.

Note The GNSS receiver only functions as a grandmaster clock in a PTP system. It cannot be used as a stratum 0 clock for NTP.

The NTP to PTP feature allows the IES to use an NTP server as the reference clock for the PTP domain. In this mode, the IES synchronizes its clock to one or more NTP servers. How well the switch synchronizes to UTC will depend on the quality of the NTP implementation.

Boundary Clock

The IES boundary clock mode has three different transfer functions that change how the boundary clock adjusts for packet delay variation (PDV) as shown in Table 2-3. PDV is a measure of the difference in the one way end-to-end delay of packets in a network flow and is a more precise description of what is commonly referred to network “jitter”.

Table 2-3 Boundary Clock Transfer Functions

Transfer Function	PDV Filtering	Time Convergence
Default (Linear)	Low	Average
Feedforward	None	Fast
Adaptive	High	Slow

The feedforward transfer function can be used in applications that require very accurate time synchronization. Because the feedforward transfer does not filter PDV, it should only be implemented in networks where the IES include PTP support in hardware.

The adaptive filter can be used in applications with high PDV such as 802.11 wireless LANs. It can also be used in applications where the network consists of non-PTP aware switches and high PDV.

Note The adaptive filter does not meet the time performance requirements specified in ITU-T G.8261.

Forward Mode

Forward mode disables hardware support for PTP. This IES will continue to forward PTP traffic and can prioritize PTP traffic with QoS. However, the IES will not function as a boundary clock or a transparent clock.

IES that do not include hardware support for PTP effectively function in forward mode. This includes some Allen-Bradley Stratix 5700 and Cisco IE 2000 SKUs as well as the expansion modules on Allen-Bradley Stratix 8000 and Cisco IE 3000 IES.

E2E Transparent

E2E transparent mode enables the end-to-end transparent clock in the IES. In this mode, the IES will compensate for the time it takes for the IES to process and forward the PTP packets. The ODVA, Inc. DLR IACS devices also utilize an end-to-end transparent clock.

Note The Allen-Bradley Stratix and Cisco IE IES only support PTP on a single VLAN in E2E transparent mode. No other VLANs on the switch can carry any PTP traffic.

Time Scales

The PTP protocol supports two timescales:

- The PTP timescale uses TAI time and requires that the PTP grandmaster send the UTC offset (number of leap seconds) to the slave clocks so they can record timestamps in UTC.
- The arbitrary (ARB) timescale can be any administrative timescale and may or may not require a UTC offset to convert to the UTC time.

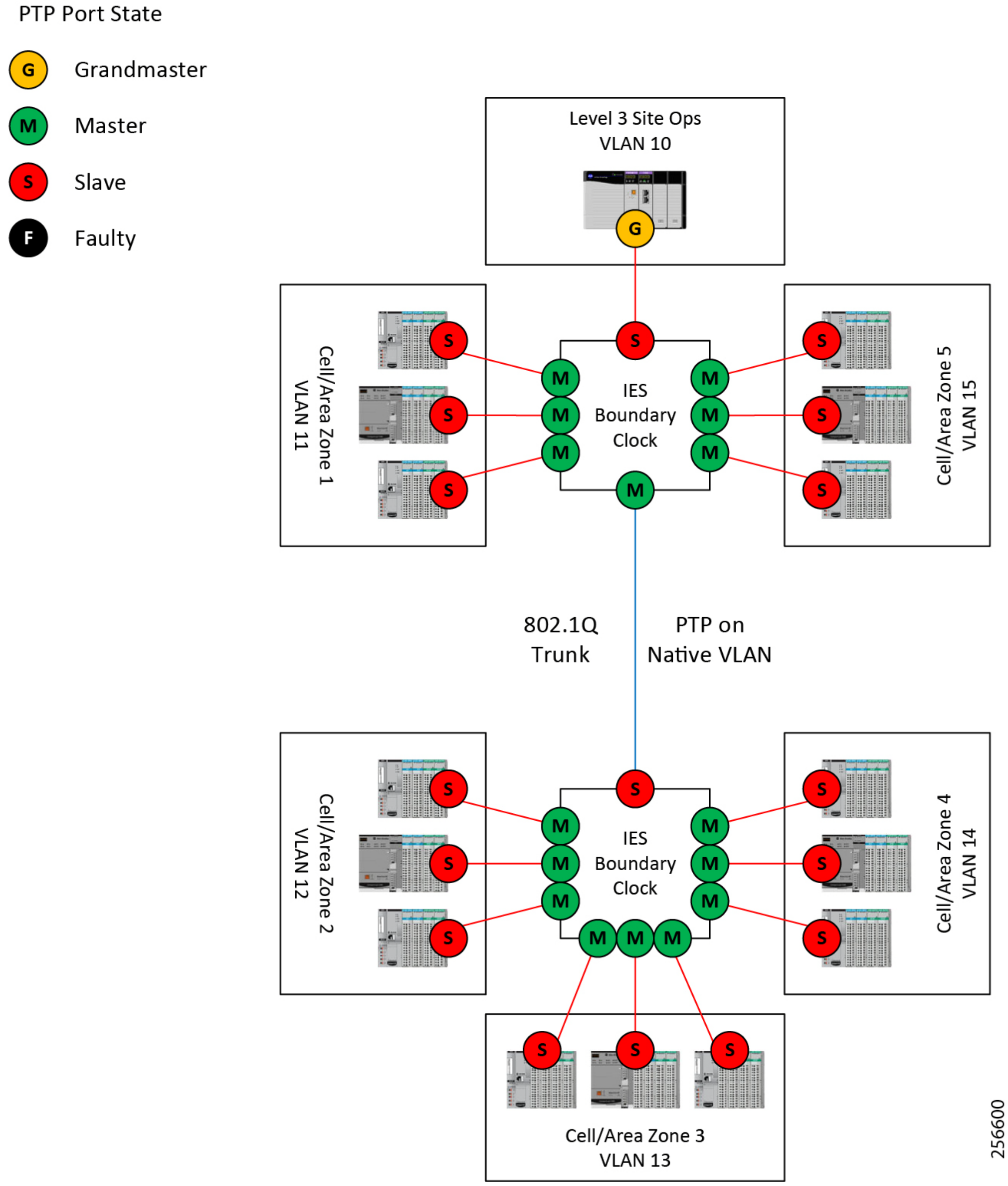
Differences in timescales can result in a significant disruption if the grandmaster clock fails and the new grandmaster uses a different timescale or offset to UTC. During the transition between grandmasters, the slave clocks may report timestamps that are seconds off from each other.

Passing PTP Time through Boundary Clocks

Figure 2-3 shows a simplified topology consisting of two IES in boundary clock mode and six VLANs. VLAN 10 at the top of Figure 2-3 contains the grandmaster that is connected to an access port configured for VLAN 10. The switch becomes a slave to the master on this port and synchronizes its internal clock to the grandmaster. Three of the ports on this switch are configured as access ports on VLAN 11 and are connected to PTP IACS devices in Cell/Area Zone 1. The boundary clock on the IES will become the master on these ports and the IACS devices in VLAN 11 will become slaves to the IES boundary clock.

In this design, the slave clocks in the IACS devices do not need to be on the same VLAN as the grandmaster to maintain time synchronization. Likewise, the IACS devices in Cell/Area Zone 5 are connected to access ports on the same IES and are synchronized to the clock in the boundary clock even though they are on VLAN 15.

Figure 2-3 PTP Multi-VLAN with Trunking



An 802.1q trunk connects the two IES. Trunks are used to allow multiple VLANs to pass across a single Ethernet link. The IES boundary clock can only send and receive PTP on a single VLAN on the trunk. By default, PTP is passed on the native VLAN of the trunk. The native VLAN is used to build the master/slave relationship between the two IES. Like the top IES, the bottom IES will synchronize its clock to its master. Moreover, the IACS devices in VLANs 12, 13, and 14 will synchronize their clocks to the boundary clock in the lower IES.

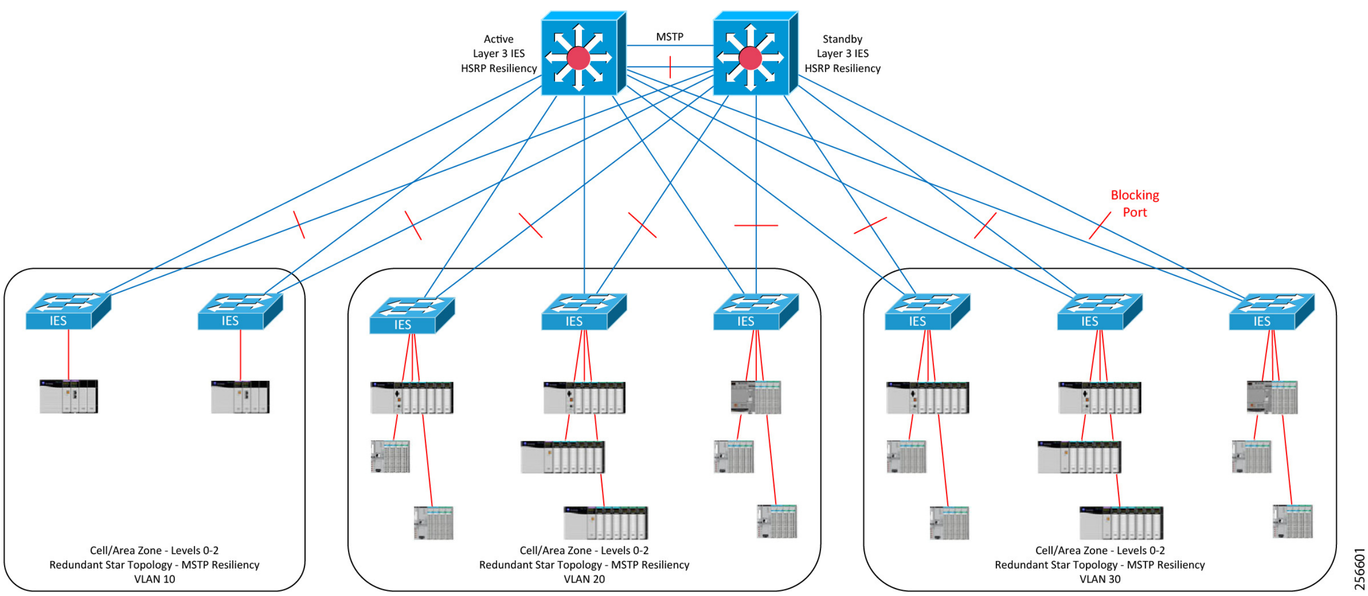
This method allows all IACS devices in a multi-VLAN environment to synchronize their clocks to a single grandmaster clock and have a common time reference for all Cell/Area Zones in the plant-wide IACS architecture.

Reference Architecture 1—Redundant Star Topology

This architecture is based on the Allen-Bradley Stratix 5410 IES. It is configured with HSRP active/standby, and a Redundant Star Topology which includes the MSTP resiliency protocol. This is published in the *Deploying a Resilient Plantwide Ethernet Architecture (CPwE Resiliency) Design and Implementation Guide*. The CPwE Time solution differs in how the two distribution switches are connected together. The traditional redundant star topology features an EtherChannel to provide bandwidth and resiliency between the two distribution switches. This architecture replaces the EtherChannel with two 10 Gigabit Ethernet links running MSTP. Network convergence testing was not performed on this architecture and the convergence times may be higher than what is published in the CPwE Resiliency DIG.

Note The Allen-Bradley Stratix IES and Cisco Catalyst switches do not support PTP over EtherChannels.

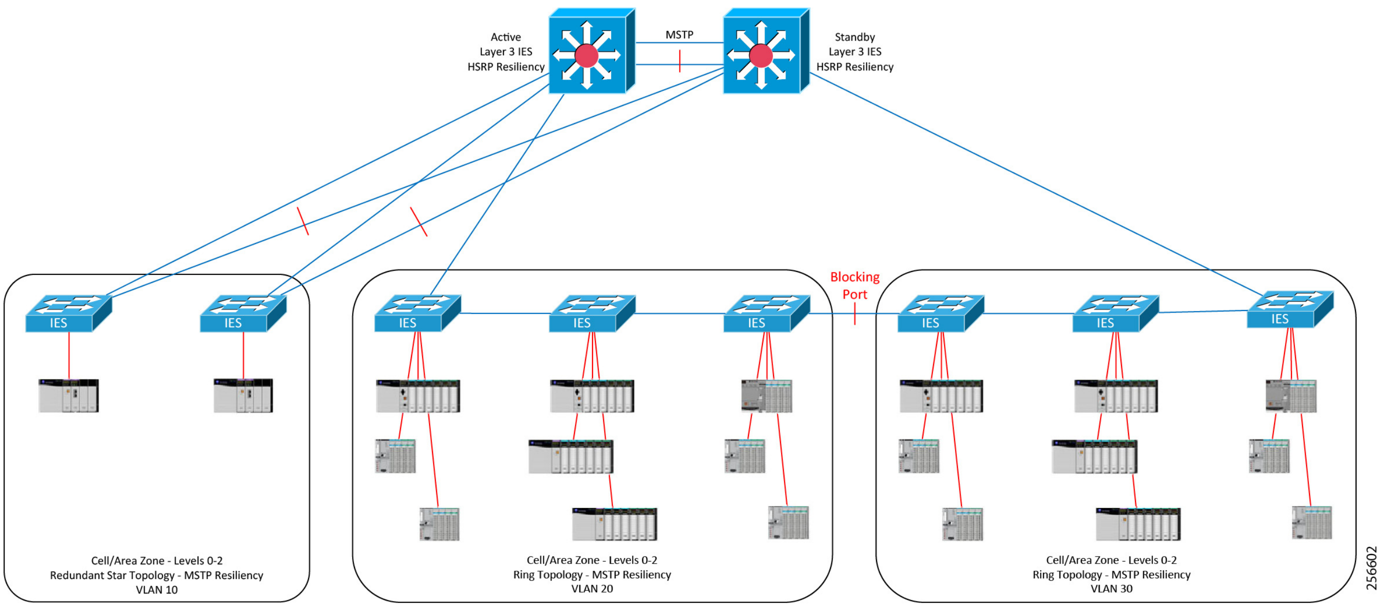
Figure 2-4 MSTP Redundant Star Topology



Reference Architecture 2—Ring Topology

The CPwE Time solution also supports MSTP ring topologies using the modified distribution switch architecture as decribed in Reference Architecture 1—Redundant Star Topology. As with the redundant star topology, MSTP was used for the resiliency protocol and was not tested for topology convergence performance. It is important to note that ring topologies cascade boundary clocks and will likely reduce clock accuracy in the IACS application. In the CPwE Time solution, rings were only tested with six IES plus the two IES distribution switches.

Figure 2-5 MSTP Ring Topology



PTP and MSTP Topologies Overview

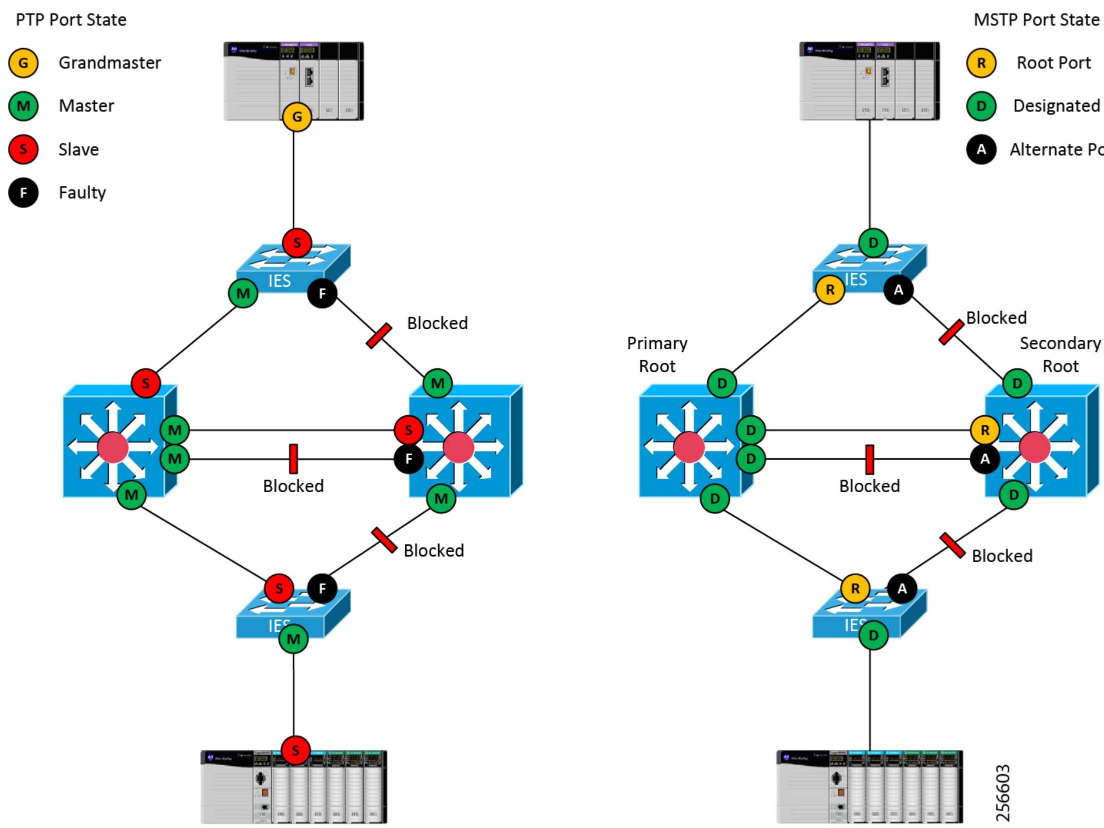
In most cases, the loss of the active uplink from an access switch to the distribution will introduce both a Layer 2 MSTP topology change and a PTP topology change. It is important to manage how the PTP topology converges to limit the impact on time synchronization within the Cell/Area Zone.

The following sections describe what happens to PTP and MSTP topologies during normal steady state operation and the convergence event.

PTP and MSTP Topologies (Steady State)

Figure 2-6 shows a simple topology using two IACS devices: two access switches and two distribution switches. The access and distribution switches are all configured for boundary clock mode. In addition, the IACS device at the top of Figure 2-6 is the IACS application grandmaster. The drawing on the left shows the PTP topology with a cascading series of master and slave ports down to the IACS device at the bottom. The drawing on the right shows the same topology from a MSTP perspective. It is important to note that the MSTP alternate root ports are in the "faulty" PTP port state.

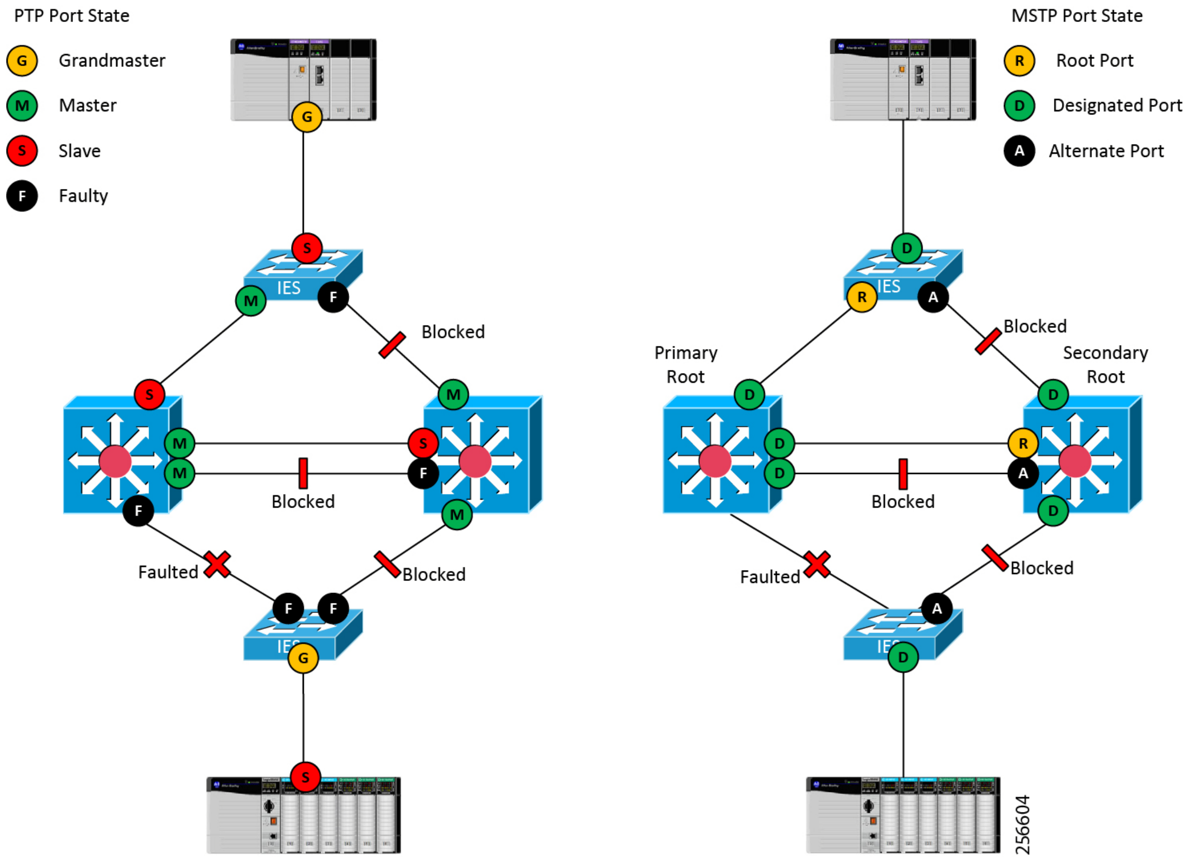
Figure 2-6 PTP and MSTP Topologies during Steady State



PTP and MSTP Topologies (Convergence Event)

In Figure 2-7, the link between the lower IES and the primary root bridge has faulted. This results in a condition where both uplinks from the lower IES are in the PTP fault state. This triggers a BMCA election within the Cell/Area Zone. One of the goals of this architecture is to manage this election to reduce the impact of the PTP topology change on IACS devices in the Cell/Area Zone. This is accomplished by weighting the BMCA so the IES in the Cell/Area Zone becomes the new grandmaster within the local Cell/Area Zone.

Figure 2-7 PTP and MSTP Topologies during Convergence

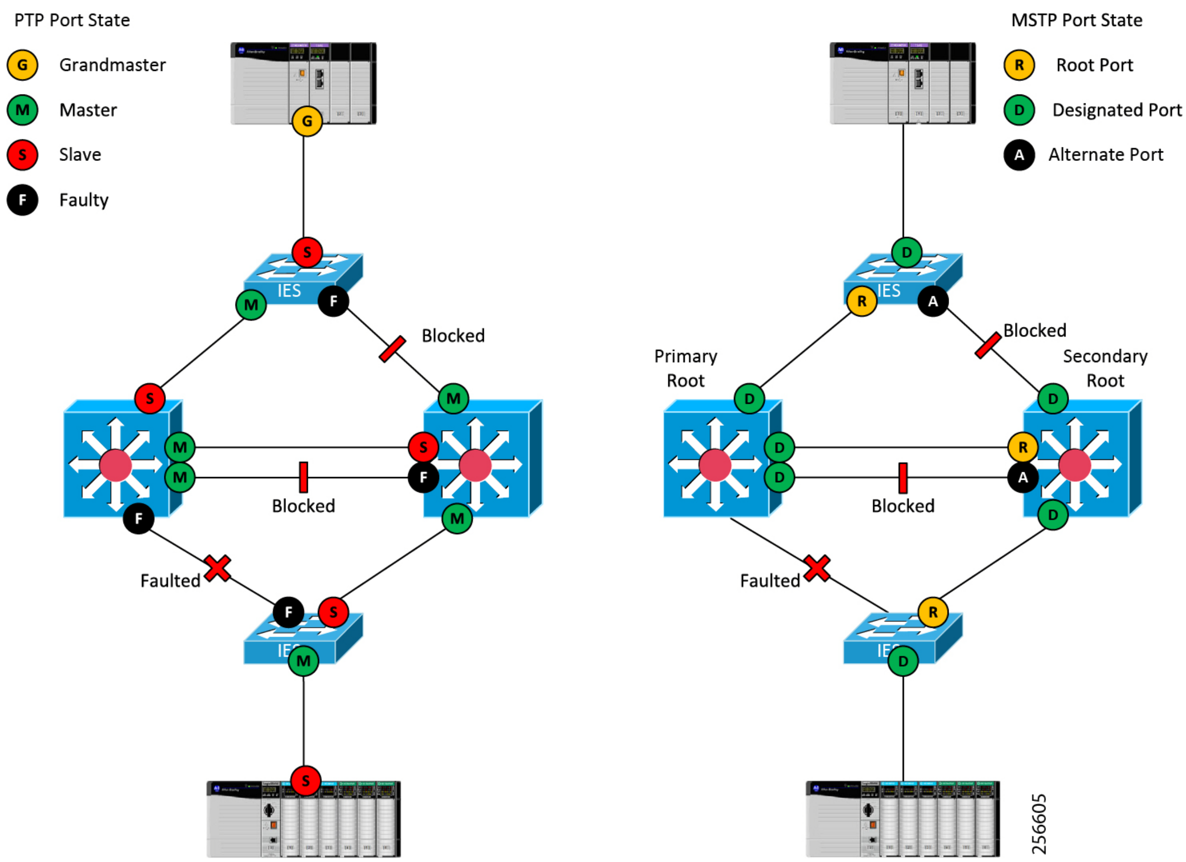


In Figure 2-8 MSTP has converged and the alternate root on the lower IES has become the new root port. This reestablishes a path to the IACS application grandmaster at the top of the topology. A BMCA election is triggered and the PTP topology is restored to its original state.

The crux of the CPwE Time solution is to use the boundary clock in the Cell/Area Zone IES to ride through the topology change. The Cell/Area Zone IES is configured to become the new grandmaster during the PTP convergence and is also configured to maintain the IACS application grandmaster PTP time properties such as the PTP timescale and the UTC offset during the Layer 2 topology change.

The solution weights the BMCA algorithm to better control the selection of the grandmaster both during normal operation and during a system fault. This architecture uses the PTP priority1 and priority2 values to divide the PTP topology into four tiers, each with its own role in maintaining time synchronization in the architecture.

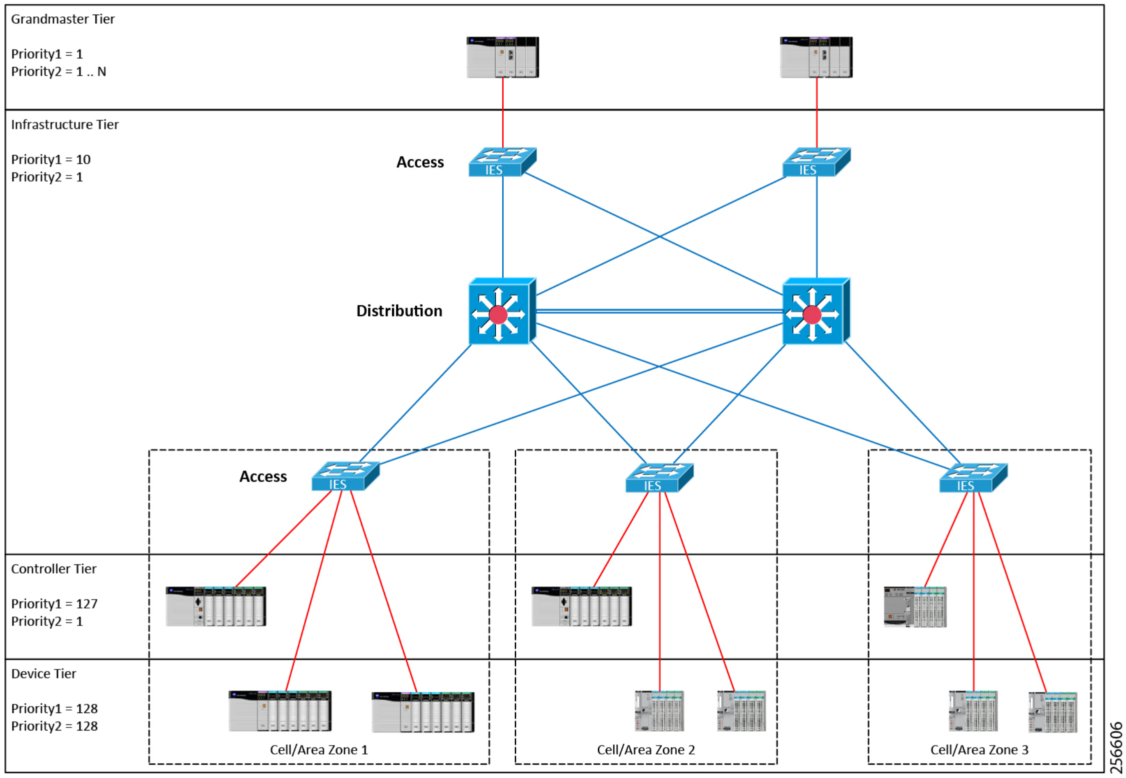
Figure 2-8 PTP and MSTP Topologies after Convergence



Recommended PTP Clock Hierarchy and Configuration

Figure 2-9 depicts recommended PTP clock hierarchy and configuration for both reference architectures shown in Figure 2-4 and Figure 2-5. It is designed to minimize the impact of Layer 2 topology changes on the PTP topology.

Figure 2-9 PTP Clock Hierarchy and Configuration



PTP Clock Hierarchy

This section describes the PTP clock hierarchy shown in Figure 2-9.

Grandmaster Tier

The grandmaster tier contains the designated grandmasters for the PTP domain. It is recommended to select an IACS device to be the primary grandmaster for the PTP domain. This device should have an accurate and reliable clock and ideally be synchronized to UTC using a reference clock. The primary grandmaster should be protected from faults such as power failures to improve stability of the PTP domain. It is also recommended to designate a secondary grandmaster which should use the same PTP timescale and UTC offset to minimize impact to the IACS application when the secondary grandmaster becomes the grandmaster. However, failing over from a primary grandmaster to a secondary grandmaster and vice versa may cause disruptions to time synchronization.

The IACS devices in the grandmaster tier should have the priority1 value set low so that they win the BMCA election. The priority2 value should be used to differentiate between the primary and secondary grandmasters with the primary having the lowest priority2 value.

It is recommended to provide power protection to the IACS devices in the grandmaster tier since a grandmaster failure is a system-wide event.

Infrastructure Tier

The infrastructure tier consists of the IES that allows the IACS devices to synchronize to the grandmaster. This architecture supports both redundant star and ring topologies with multiple VLANs. However, ring topologies require multiple cascaded boundary clocks that may reduce the accuracy of IACS devices further away from the grandmaster. PTP relies on the underlying infrastructure to build the PTP clock hierarchy. Moreover, a disruption to the underlying Layer 2 topology will cause a disruption to the PTP clock hierarchy. This can cause the loss of synchronization between IACS devices within the local Cell/Area Zone.

The infrastructure tier is designed to reduce the impact of topology changes on clock synchronization in the Cell/Area Zone. This is accomplished by weighting the BMCA algorithm so that the IES becomes the grandmaster during the event. Furthermore, the IES is configured to maintain the time properties, such as timescale and UTC offset of the grandmaster, since changes to the PTP timescale can introduce disruptions in time synchronization.

The IES should be configured as boundary clocks using the feedforward transfer function. The IES should have the priority1 value set so they become grandmaster if the IACS devices in the grandmaster tier are unreachable. In addition, the **ptp time-property persist infinite** command should be applied to all IES boundary clocks. Finally, it is recommended to set the PTP sync fault limit to 10,000 on all PTP-enabled IES interfaces.

Note Use caution when setting the sync limit below 50,000. This setting should only be used in IACS applications where the grandmaster has a very high-precision clock and where all the IES have hardware support for PTP enabled.

It is recommended to provide power protection to the infrastructure tier to improve overall IACS application reliability. OT engineers should consider installing the IES in separate enclosures with dedicated DC power supplies and backup batteries. If the IES are installed in the control panel with the IACS hardware, the OT engineer should consider using a dedicated DC power supply for the IES. These power supplies should be on a separate power disconnect so power can be removed from the IACS hardware while maintaining the network. This approach can help limit the number of Layer 2 and PTP topology changes experienced by the IACS application and help the overall stability of time.

Controller Tier

The controller tier is designed to reduce time synchronization issues when the IES is down, such as when the control panel is powered on as IACS devices take different number of times to start up. Some IACS devices like Programmable Automation Controllers (PAC) feature battery backed real-time clocks and will continue to keep time when the power is disconnected. These IACS devices should have their priority1 value set so they become grandmaster until connectivity to the network is restored. This reduces the chance of a device without a real-time clock becoming grandmaster and setting an arbitrary time, like January 1 1970 00:00:00. Some IACS devices such as FactoryTalk Historian ME modules may fault if they detect an IACS application time that is significantly earlier than the time logged for existing data points.

Device Tier

The device tier contains all other PTP-aware IACS devices. Most of these IACS devices exclude battery backed real-time clocks and will revert to some known epoch on startup, such as January 1 1970 00:00:00. Therefore, they should not be relied on as a grandmaster clock. Their priority1 and priority2 values should be set so they will not become the grandmaster. The device tier is likely to contain most of the IACS devices in the plant-wide IACS architecture. The overhead of configuring the system can be reduced by using the default priority1 and priority2 value of 128 for the IACS devices in the device tier.

Recommended PTP Clock Configuration

In the PTP architecture shown in Figure 2-9, two 1756-TIME modules are used in the grandmaster tier. The 1756-TIME modules use GPS receivers to synchronize their clocks to UTC. The primary grandmaster has its priority1 set to 1 and its priority2 set to 1. The secondary grandmaster has its priority1 set to 1 and its priority2 set to 2.

A mix of Allen-Bradley Stratix 5700, 5400, and 5410 IES are used in the infrastructure tier. All IES in the infrastructure tier have their priority1 set to 10 and their prioirty2 set to 1.

The controller tier consists of a mix of ControlLogix® 5380, 5570, and 5580 PACs. The PACs have their priority1 value set to 127 and their priority2 value set to 1.

The remainder of the IACS devices in the IACS application consist of various I/O platforms and have their priority1 and priority2 values at the default of 128.

Summary of Recommendations

- Grandmaster Tier
  - Select a specific device to be a reliable grandmaster for the IACS application.
  - Protect the grandmaster from faults such as power disruptions to increase stability of the IACS application.
  - Synchronize the grandmaster to UTC.
- Infrastructure Tier
  - Use IES in boundary clock mode to propagate time between VLANs.
  - Use the feedforward transfer function and the sync limit to improve synchronization across the IACS application.
  - Use the **time properties persist** command to help ride through the loss of the grandmaster.
  - Isolate and provide battery backed power to the IES to reduce Layer 2 and PTP topology changes.
  - Use a redundant star topology to reduce time error in the IACS application.
  - Do not send PTP traffic over EtherChannels.
- Controller Tier
  - Configure IACS devices with real-time clocks, such as PACs, to become the grandmaster if the network is down.
- Device Tier
  - Use the default priority1 and 2 values to simplify configuration.

CHAPTER 3

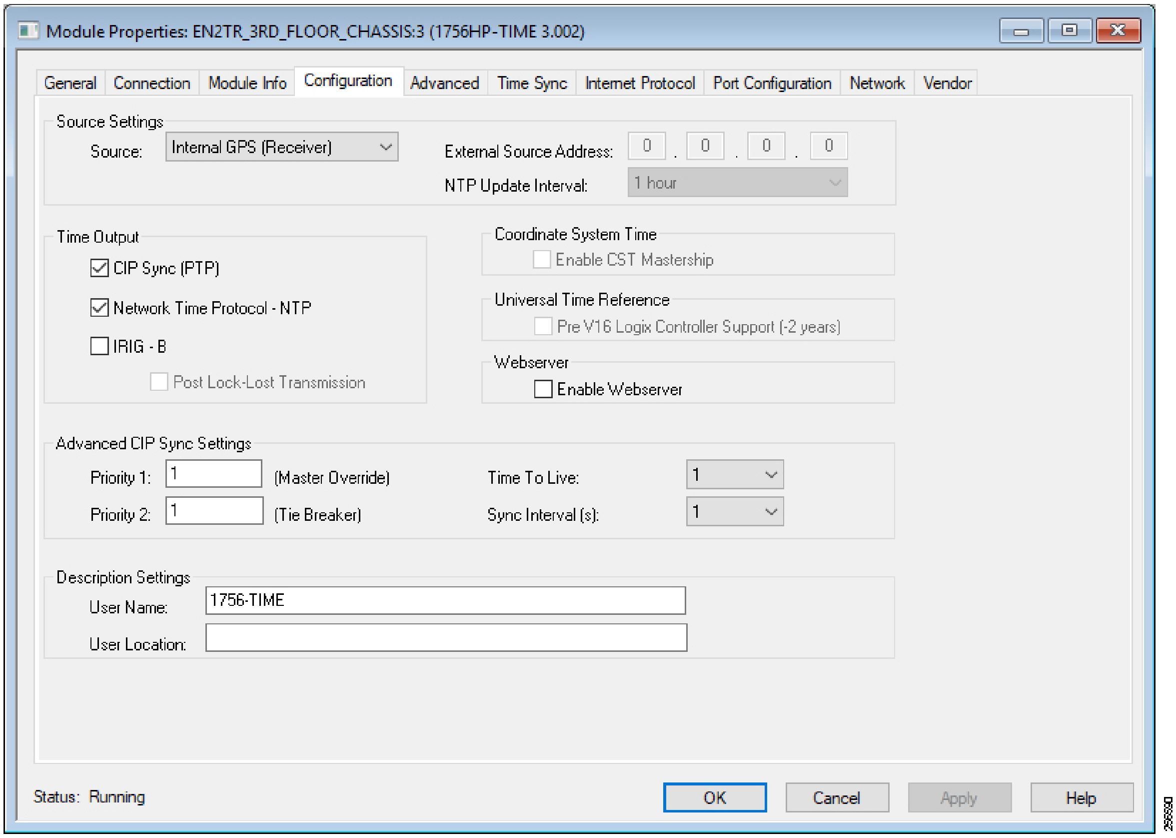
CPwE Scalable Time Distribution Configuration

Configuring IACS Devices

1756-TIME

The 1756-TIME module is a reference clock that synchronizes to the GPS constellation. The module is capable of outputting time as an NTP server or PTP grandmaster and is configured using the Studio 5000 Logix Designer® Add-on Profile (AOP). The module must be owned by a PAC. Once the module is added to the I/O tree, the AOP can be opened to configure the module.

Figure 3-1 1756-TIME Configuration

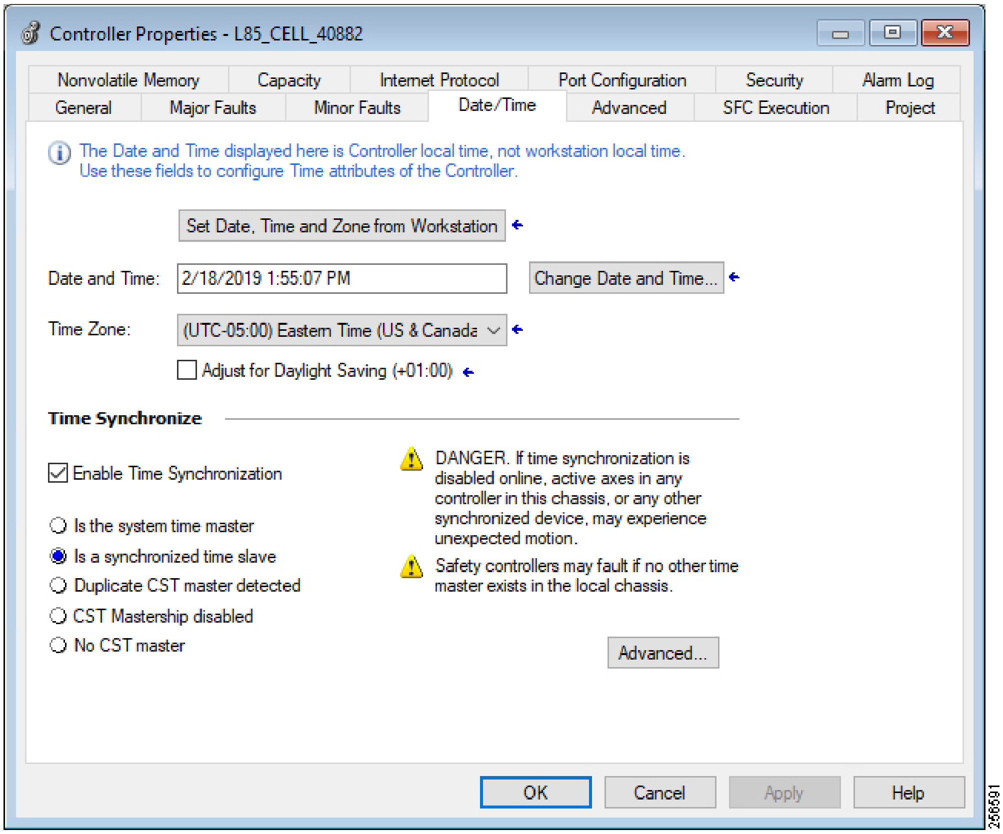


The module should be configured to use the internal GPS receiver as the source and output CIP Sync time. The priority1 and priority2 values should be set so the module becomes the primary or secondary grandmaster as desired. Optionally, the NTP server can be enabled so the module becomes a stratum 1 NTP server.

Logix PAC

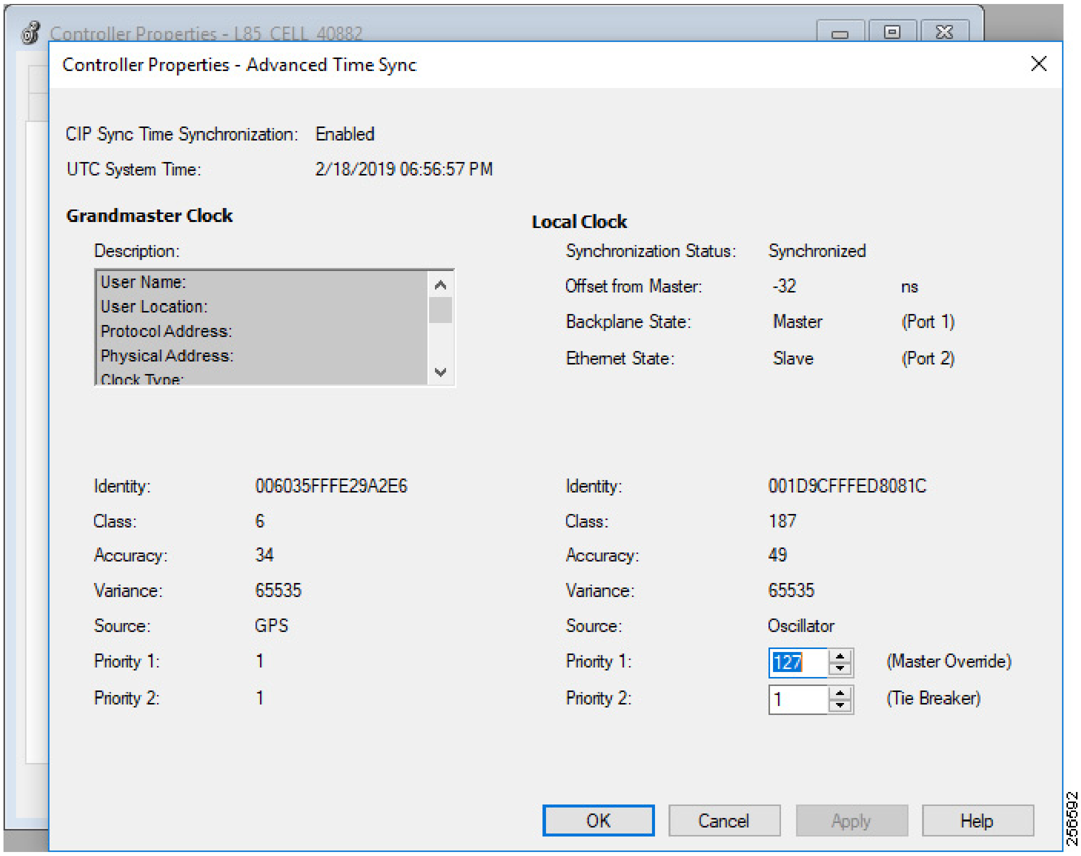
The Logix PAC® system is configured by editing the controller properties in Studio 5000 Logix Designer. On the **Date/Time** tab, the **Enable Time Synchronization** checkbox must be selected to configure the controller for time synchronization. If the controller will be used as the reference clock, the **Set Date, Time and Zone from Workstation** button can be used to set the controller's real-time clock based on the configuration of the computer running Studio 5000 Logix Designer.

Figure 3-2 PAC Date and Time Configuration



The **Advanced** button allows you to configure the priority1 and priority2 values of the controller. These values will vary depending on if the controller is designated to be a member of the grandmaster tier or controller tier.

Figure 3-3 PAC PTP Advanced Configuration



Communication Adapters

It is important to configure the communication adapters to support CIP Sync. Some Rockwell Automation platforms, such as the 5069-AEN2TR, have CIP Sync enabled by default. Other platforms, such as the 1756-EN2T family, require manual configuration to enable CIP Sync. Refer to vendor documentation for instructions on configuring your communications adapter.

I/O Points

CIP Sync applications require configuring the individual I/O points for time stamping. The time stamping features of the module will vary from module to module. In addition, the configuration of the I/O points may vary depending on the module selected and the application. Refer to vendor documentation for instructions on configuring your I/O points.

Industrial Ethernet Switches

There are three options for configuring PTP in the IES:

- Command line

- Device Manager
- Studio 5000 Logix Designer

The configuration choice will depend on the IES platform selected and preferences of the installer. The Allen-Bradley Stratix IES support all three configuration methods, while the Cisco IE IES only support command line and Device Manager. However, not all the PTP configuration options used in this CPwE Time solution are available in the Device Manager or Studio 5000 Logix Designer. These configuration options must be done via the command line interface.

Note Use caution when setting the sync limit below 50,000. This setting should only be used in IACS applications where the grandmaster has a very high-precision clock and all the IES have hardware support for PTP enabled.

Command Line

Step 1 Configure the IES for boundary clock mode:

`IES(config)#`**`ptp mode boundary`**

Step 2 Configure the boundary clock to use the feedforward transfer function:

`IES(config)#`**`ptp transfer feedforward`**

Step 3 Configure the time properties to persist infinitely:

`IES(config)#`**`ptp time-property persist infinite`**

Step 4 Configure the priority1 value for the infrastructure tier:

`IES(config)#`**`ptp priority1 2`**

Step 5 Configure the priority2 value for the infrastructure tier:

`IES(config)#`**`ptp priotiry2 10`**

Step 6 Configure the interfaces to use a sync limit of 10,000:

`IES(config-if)#`**`ptp sync limit 10000`**

The sync limit should be configured on all boundary clock interfaces. This can either be done individually or with the **interface range** configuration command.

Device Manager

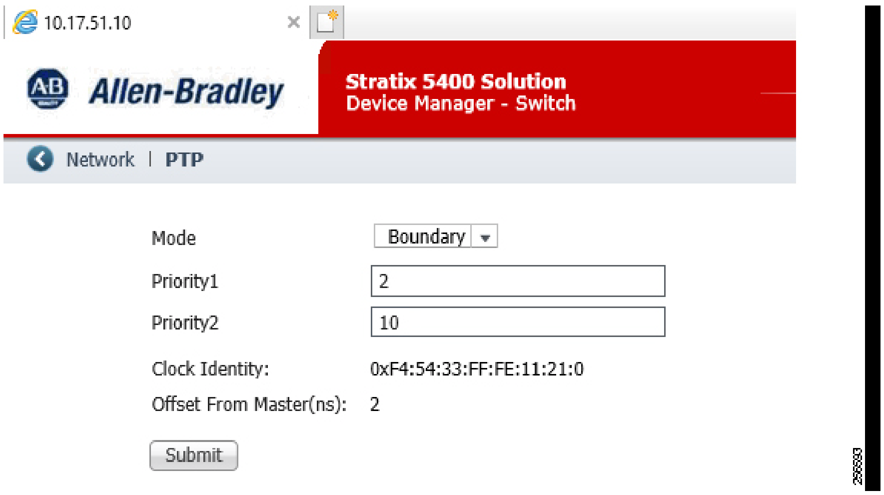
PTP is configured in the Device Manager by selecting the PTP option under the Configure menu.

Step 1 Configure the IES for boundary clock mode.

Step 2 Configure the priority1 value for the infrastructure tier.

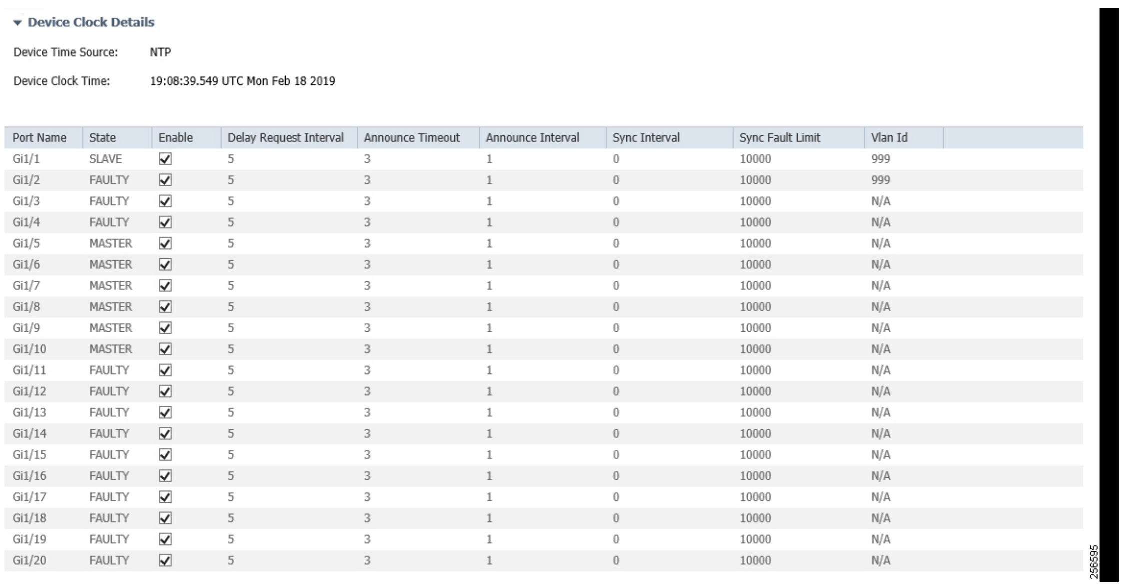
Step 3 Configure the priority2 value for the infrastructure tier.

Figure 3-4 Stratix Device Manager PTP Clock Configuration



Step 4 Configure the interfaces to use a sync fault limit of 10,000.

Figure 3-5 Stratix Device Manager PTP Port Configuration



Device Clock Details

Device Time Source: NTP

Device Clock Time: 19:08:39.549 UTC Mon Feb 18 2019

Port Name	State	Enable	Delay Request Interval	Announce Timeout	Announce Interval	Sync Interval	Sync Fault Limit	Vlan Id
Gi1/1	SLAVE	☑	5	3	1	0	10000	999
Gi1/2	FAULTY	☑	5	3	1	0	10000	999
Gi1/3	FAULTY	☑	5	3	1	0	10000	N/A
Gi1/4	FAULTY	☑	5	3	1	0	10000	N/A
Gi1/5	MASTER	☑	5	3	1	0	10000	N/A
Gi1/6	MASTER	☑	5	3	1	0	10000	N/A
Gi1/7	MASTER	☑	5	3	1	0	10000	N/A
Gi1/8	MASTER	☑	5	3	1	0	10000	N/A
Gi1/9	MASTER	☑	5	3	1	0	10000	N/A
Gi1/10	MASTER	☑	5	3	1	0	10000	N/A
Gi1/11	FAULTY	☑	5	3	1	0	10000	N/A
Gi1/12	FAULTY	☑	5	3	1	0	10000	N/A
Gi1/13	FAULTY	☑	5	3	1	0	10000	N/A
Gi1/14	FAULTY	☑	5	3	1	0	10000	N/A
Gi1/15	FAULTY	☑	5	3	1	0	10000	N/A
Gi1/16	FAULTY	☑	5	3	1	0	10000	N/A
Gi1/17	FAULTY	☑	5	3	1	0	10000	N/A
Gi1/18	FAULTY	☑	5	3	1	0	10000	N/A
Gi1/19	FAULTY	☑	5	3	1	0	10000	N/A
Gi1/20	FAULTY	☑	5	3	1	0	10000	N/A

Several of the configuration items required for this CPwE Time solution can only be configured using the command line interface.

Step 5 Configure the boundary clock to use the feedforward transfer function:

```
IES(config)#ptp transfer feedforward
```

Step 6 Configure the time properties to persist infinitely:

```
IES(config)#ptp time-property persist infinite
```

Studio 5000 Logix Designer

PTP is configured in the Time Sync Configuration section of the Allen-Bradley Stratix AOP.

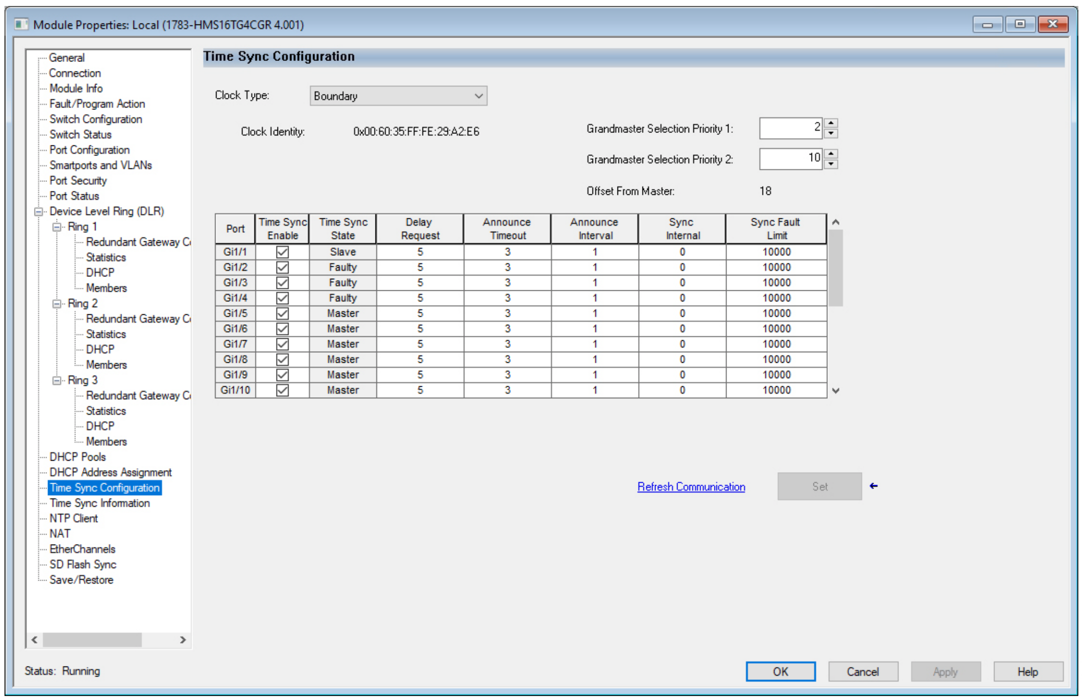
Step 1 Configure the IES for boundary clock mode.

Step 2 Configure the priority1 value for the infrastructure tier.

Step 3 Configure the priority2 value for the infrastructure tier.

Step 4 Configure the interfaces to use a sync fault limit of 10,000.

Figure 3-6 Stratix Studio 5000 Logix Designer PTP Configuration



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Step 5 Configure the boundary clock to use the feedforward transfer function:

```
IES(config)#ptp transfer feedforward
```

Step 6 Configure the time properties to persist infinitely:

```
IES(config)#ptp time-property persist infinite
```

APPENDIX A

References

This appendix includes the following major topics:

Converged Plantwide Ethernet (CPwE)

- Design Zone for Manufacturing-Converged Plantwide Ethernet: http://www.cisco.com/c/en/us/solutions/enterprise/design-zone-manufacturing/landing_ettf.html
- Industrial Network Architectures-Converged Plantwide Ethernet: http://www.rockwellautomation.com/global/products-technologies/network-technology/architectures.page
- *Converged Plantwide Ethernet (CPwE) Design and Implementation Guide*:
  - Rockwell Automation site: http://literature.rockwellautomation.com/idc/groups/literature/documents/td/enet-td001_-en-p.pdf
  - Cisco site: http://www.cisco.com/c/en/us/td/docs/solutions/Verticals/CPwE/CPwE_DIG.html
- *Deploying A Resilient Converged Plantwide Ethernet Architecture Design and Implementation Guide*:
  - Rockwell Automation site: https://literature.rockwellautomation.com/idc/groups/literature/documents/td/enet-td010_-en-p.pdf
  - Cisco site: http://www.cisco.com/c/en/us/td/docs/solutions/Verticals/CPwE/REP/CPwE_REP_DG.html
- *Deploying Identity and Mobility Services within a Converged Plantwide Ethernet Architecture Design and Implementation Guide*:
  - Rockwell Automation site: https://literature.rockwellautomation.com/idc/groups/literature/documents/td/enet-td008_-en-p.pdf
  - Cisco site: https://www.cisco.com/c/en/us/td/docs/solutions/Verticals/CPwE/3-5-1/ISE/DIG/CPwE_ISE_CVD.ht ml
- *Cloud Connectivity to a Converged Plantwide Ethernet Architecture*:

  - Rockwell Automation site: https://literature.rockwellautomation.com/idc/groups/literature/documents/td/enet-td017_-en-p.pdf
  - Cisco site: https://www.cisco.com/c/en/us/td/docs/solutions/Verticals/CPwE/5-1/Cloud/DIG/CPwE_Cloud_Connect_CVD.html
- *Securely Traversing IACS Data Across the Industrial Demilitarized Zone Design and Implementation Guide*:
  - Rockwell Automation site: http://literature.rockwellautomation.com/idc/groups/literature/documents/td/enet-td009_-en-p.pdf
  - Cisco site: https://www.cisco.com/c/en/us/td/docs/solutions/Verticals/CPwE/3-5-1/IDMZ/DIG/CPwE_IDMZ_CVD.html
- *Deploying Industrial Firewalls within a Converged Plantwide Ethernet Architecture Design and Implementation Guide*:
  - Rockwell Automation site: http://literature.rockwellautomation.com/idc/groups/literature/documents/td/enet-td002_-en-p.pdf
  - Cisco site: https://www.cisco.com/c/en/us/td/docs/solutions/Verticals/CPwE/5-0/Firewalls/DIG/CPwE-5-IFS-DIG.html
- *Deploying Network Security within a Converged Plantwide Ethernet Architecture*
  - Rockwell Automation site: https://literature.rockwellautomation.com/idc/groups/literature/documents/td/enet-td019_-en-p.pdf
  - Cisco site: https://www.cisco.com/c/en/us/td/docs/solutions/Verticals/CPwE/5-1/Network_Security/DIG/CPwE-5-1-NetworkSecurity-DIG.html
- *Deploying Device Level Ring within a Converged Plantwide Ethernet Architecture*
  - Rockwell Automation site: https://literature.rockwellautomation.com/idc/groups/literature/documents/td/enet-td015_-en-p.pdf
  - Cisco site: https://www.cisco.com/c/en/us/td/docs/solutions/Verticals/CPwE/5-1/DLR/DIG/CPwE-5-1-DLR-DIG.html
- *Deploying Industrial Data Center within a Converged Plantwide Ethernet Architecture*
  - Rockwell Automation site: https://literature.rockwellautomation.com/idc/groups/literature/documents/td/enet-td014_-en-p.pdf
  - Cisco site: https://www.cisco.com/c/en/us/td/docs/solutions/Verticals/CPwE/5-1/IDC/DIG/CPwE-5-1-IDC-DIG.html
- *OEM Networking within a Converged Plantwide Ethernet Architecture*
  - Rockwell Automation site: https://literature.rockwellautomation.com/idc/groups/literature/documents/td/enet-td018_-en-p.pdf
  - Cisco site: https://www.cisco.com/c/en/us/td/docs/solutions/Verticals/CPwE/5-1/OEM/DIG/CPwE-5-1-OEM-CRD.html

Other References

- *Stratix Managed Switches User Manual*
  - http://literature.rockwellautomation.com/idc/groups/literature/documents/um/1783-um007_-en-p.pdf

APPENDIX B

Test Hardware and Software

Table B-1 lists the Cisco and Rockwell Automation components used in testing the CPwE Time solution.

Table B-1 Cisco and Rockwell Automation Components

Component	Series	Version
Allen-Bradley Stratix 5410	B	15.2(6)E0a
Allen-Bradley Stratix 5400		15.2(6)E0a
Allen-Bradley Stratix 5700		15.2(6)E0a
1756-TIME	B	3.004
1756-L85E	B	30.011
1756-L75	B	30.012
1756-EN2TR	C	10.01
1756-IB16IEF	A	1.011
1756-OB16IEF	A	2.011
5069-L340DERM	A	30.011
5069-AEN2TR	A	3.011
5069-IB16F	A	2.012
5069-OB16F	A	2.012
Studio 5000 Logix Designer		v30

APPENDIX C

Acronyms

Table C-1 lists the acronyms and initialisms commonly used in CPwE documentation.

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Table C-1 Acronyms and Initialisms

Term	Description
1:1	One-to-One
AAA	Authentication, Authorization, and Accounting
AD	Microsoft Active Directory
AD CS	Active Directory Certificate Services
AD DS	Active Directory Domain Services
AES	Advanced Encryption Standard
ACL	Access Control List
AH	Authentication Header
AIA	Authority Information Access
AMP	Advanced Malware Protection
ASDM	Cisco Adaptive Security Device Manager
ASIC	Application Specific Integrated Circuit
ASR	Cisco Aggregation Services Router
BYOD	Bring Your Own Device
CA	Certificate Authority
CDP	CRL Distribution Points
CIP	ODVA, Inc. Common Industrial Protocol
CLI	Command Line Interface
CoA	Change of Authorization
CoS	Class of Service
CPwE	Converged Plantwide Ethernet
CRD	Cisco Reference Design
CRL	Certificate Revocation List
CSR	Certificate Signing Request
CSSM	Cisco Smart Software Manager
CTL	Certificate Trust List
CUR	Coarse Update Rate
CVD	Cisco Validated Design

Table C-1 Acronyms and Initialisms (continued)

Term	Description
DACL	Downloadable Access Control List
DC	Domain Controller
DHCP	Dynamic Host Configuration Protocol
DIG	Design and Implementation Guide
DLR	Device Level Ring
DMVPN	Dynamic Multipoint Virtual Private Network
DNS	Domain Name System
DPI	Deep Packet Inspection
DSRM	Directory Services Restoration Mode
EAP	Extensible Authentication Protocol
EAP-TLS	Extensible Authentication Protocol-Transport Layer Security
EIGRP	Enhanced Interior Gateway Routing Protocol
EMI	Enterprise Manufacturing Intelligence
EoIP	Ethernet over IP
ERP	Enterprise Resource Planning
ESP	Encapsulating Security Protocol
ESR	Embedded Services Router
FIB	Forwarding Information Base
FIFO	First-In First-Out
FPGA	Field-Programmable Gate Array
FQDN	Fully Qualified Domain Name
FVRF	Front-door Virtual Route Forwarding
GNSS	Global Navigation Satellite Systems
GRE	Generic Routing Encapsulation
HMAC	Hash Message Authentication Code
HMI	Human-Machine Interface
HSRP	Hot Standby Router Protocol
IACS	Industrial Automation and Control System
ICS	Industrial Control System
IDMZ	Industrial Demilitarized Zones
IES	Industrial Ethernet Switch (Allen-Bradley Stratix, Cisco IE)
IGMP	Internet Group Management Protocol
IIoT	Industrial Internet of Things
IKE	Internet Key Exchange
I/O	Input/Output
IoT	Internet of Things
IP	Internet Protocol
IPDT	IP Device Tracking
ISAKMP	Internet Security Association and Key Management Protocol
ISP	Internet Service Provider
ISE	Cisco Identity Services Engine
ISR	Integrated Service Router
IT	Information Technology
LBS	Location Based Services

Table C-1 Acronyms and Initialisms (continued)

Term	Description
LWAP	Lightweight Access Point
MAB	MAC Authentication Bypass
MAC	Media Access Control
MDM	Mobile Device Management
ME	FactoryTalk View Machine Edition
mGRE	Multipoint Generic Routing Encapsulation
MLS	Multilayer Switching QoS
MMC	Microsoft Management Console
MnT	Monitoring Node
MPLS	Multiprotocol Label Switching
MQC	Modular QoS CLI
MSE	Mobile Service Engine
MSS	Maximum Segment Size
MTTR	Mean Time to Repair
MTU	Maximum Transmission Unit
NAC	Network Access Control
NAT	Network Address Translation
NDES	Network Device Enrollment Service
NHRP	Next Hop Routing Protocol
NOC	Network Operation Center
NPS	Microsoft Network Policy Server
NSP	Native Supplicant Profile
NTP	Network Time Protocol
OCSP	Online Certificate Status Protocol
OEE	Overall Equipment Effectiveness
OEM	Original Equipment Manufacturer
OT	Operational Technology
OTA	Over-the-Air
OU	Organizational Unit
PAC	Programmable Automation Controller
PAN	Policy Administration Node
PAT	Port Address Translation
PCS	Process Control System
PEAP	Protected Extensible Authentication Protocol
PKI	Public Key Infrastructure
pps	Packet per second
PSK	Pre-Shared Key
PSN	Policy Service Node
PTP	Precision Time Protocol
QoS	Quality of Service
RA	Registration Authority
RADIUS	Remote Authentication Dial-In User Service
RAS	Remote Access Server
RD	Route Descriptor

Table C-1 Acronyms and Initialisms (continued)

Term	Description
RDG	Remote Desktop Gateway
RDP	Remote Desktop Protocol
RDS	Remote Desktop Services
REP	Resilient Ethernet Protocol
RPI	Request Packet Interval
RTT	Round Trip Time
SA	Security Association
SaaS	Software-as-a-Service
SCEP	Simple Certificate Enrollment Protocol
SE	FactoryTalk View Site Edition
SHA	Secure Hash Standard
SIG	Secure Internet Gateway
SPW	Software Provisioning Wizard
SSID	Service Set Identifier
STP	Spanning-Tree Protocol
SYN	Synchronization
TAI	International Atomic Time
TCN	Topology Change Notification
TCP	Transmission Control Protocol
TLS	Transport Layer Security
UDP	User Datagram Protocol
UTC	Coordinated Universal Time
VLAN	Virtual Local Area Network
VM	Virtual Machine
VNC	Virtual Network Computing
VPN	Virtual Private Network
VRF	Virtual Route Forwarding
VSS	Virtual Switching System
WAN	Wide Area Network
wIPS	wireless Intrusion Prevention Service
WLAN	Wireless LAN
WLC	Cisco Wireless LAN Controller
WSA	Cisco Web Security Appliance
ZFW	Zone-Based Policy Firewall

APPENDIX D

About the Cisco Validated Design (CVD) Program

Converged Plantwide Ethernet (CPwE) is a collection of tested and validated architectures developed by subject matter authorities at Cisco and Rockwell Automation with assistance by Panduit which follows the Cisco Validated Design (CVD) program.

CVDs provide the foundation for systems design based on common use cases or current engineering system priorities. They incorporate a broad set of technologies, features, and applications to address customer needs. Each one has been comprehensively tested and documented by engineers to help achieve faster, more reliable, and fully predictable deployment.

The CVD process is comprehensive and focuses on solving business problems for customers and documenting these solutions. The process consists of the following steps:

- Requirements are gathered from a broad base of customers to devise a set of use cases that will fulfill these business needs.
- Network architectures are designed or extended to provide the functionality necessary to enable these use cases, and any missing functionality is relayed back to the appropriate product development team(s).
- Detailed test plans are developed based on the architecture designs to validate the proposed solution, with an emphasis on feature and platform interaction across the system. These tests generally consist of functionality, resiliency, scale, and performance characterization.
- All parties contribute to the development of the CVD guide, which covers both design recommendations and implementation of the solution based on the testing outcomes.

Within the CVD program, Cisco also provides Cisco Reference Designs (CRDs) that follow the CVD process but focus on reference designs developed around specific sets of priority use cases. The scope of CRD testing typically focuses on solution functional verification with limited scale.

For more information about the CVD program, please see the Cisco Validated Designs at the following URL::

https://www.cisco.com/c/en/us/solutions/enterprise/validated-design-program/index.html

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