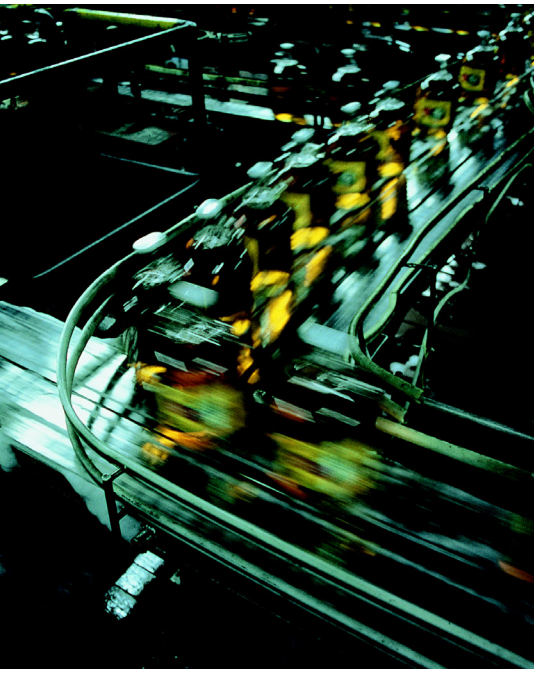


Deploying a Resilient Converged Plantwide Ethernet Architecture

Design and Implementation Guide

September 2020

Cisco Validated Design

Document Reference Number: ENET-TD010C-EN-P

Preface

Converged Plantwide Ethernet (CPwE) is a collection of architected, tested, and validated designs. 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 or site-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 a CPwE ecosystem consisting of Cisco, Panduit, and Rockwell Automation emergent from the strategic alliance between Cisco Systems and Rockwell Automation.

Resilient plant-wide or site-wide network architectures play a pivotal role in helping to confirm overall plant/site uptime and productivity. Industrial Automation and Control System (IACS) application requirements such as availability and performance drive the choice of resiliency technology. A holistic resilient plant-wide or site-wide network architecture is composed of multiple technologies (logical and physical) deployed at different levels within plant-wide or site-wide architectures. When selecting resiliency technology, various IACS application factors should be evaluated, including physical layout of IACS devices (geographic dispersion), recovery time performance, uplink media type, tolerance to data latency and jitter and future-ready requirements.

Deploying a Resilient Converged Plantwide Ethernet Architecture CVD (CPwE Resiliency), which is documented in this Design and Implementation Guide (DIG), outlines several use cases for designing and deploying resilient plant-wide or site-wide architectures for Industrial Automation and Control System (IACS) applications. CPwE Resiliency 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 Resiliency was architected, tested, and validated by Cisco Systems, Panduit, and Rockwell Automation.

Release Notes

This section summarizes the extensions to CPwE Resiliency in this September 2020 release:

- Test Hardware, Software, test results and reference architecture for Catalyst 9300 as distribution/aggregation switch
- Test Hardware, Software, test results and reference architecture for Catalyst 9500 as distribution/aggregation switch

- References to *Deploying Parallel Redundancy Protocol within a Converged Plantwide Ethernet Architecture*

This section summarizes the extensions that were added to the CPwE Resiliency February 2018 release:

- Test Hardware, Software, test results and reference architecture for Catalyst 3850 as distribution/aggregation switch
- Removal of Catalyst 3750X as distribution/aggregation switch
- References to *Deploying Device Level Ring within a Converged Plantwide Ethernet Architecture*

Document Organization

This document is composed of the following chapters and appendices:

Chapter/Appendix	Description
CPwE Resiliency Overview	Provides an overview of CPwE Resiliency and the uses cases used in this release.
CPwE Resiliency Design Considerations	Provides an overview of design considerations for integrating resiliency into an Industrial Automation and Control System (IACS) network based on the CPwE architecture.
CPwE Resiliency Configuration	Describes how to configure resiliency for the Industrial and Cell/Area Zone switches in the CPwE architecture based on the design considerations and recommendations of the previous chapters.
CPwE Resiliency Troubleshooting	Describes how to assess and verify the status of the resiliency protocols running on the Industrial and Cell/Area Zone switches.
References	Links to documents and websites that are relevant to Deploying a Resilient Converged Plantwide Ethernet Architecture Design and Implementation Guide.
Acronyms and Initialisms	List of acronyms and initialisms used in this document.
About 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:
  - https://www.rockwellautomation.com/en-us/capabilities/industrial-networks/network-architectures.html
- 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, CIP Sync™, and DLR, see odva.org at the following URL:

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

CHAPTER 1

CPwE Resiliency Overview

This chapter includes the following major topics:

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 convergence, including OT-IT persona convergence, by using standard Ethernet, Internet Protocol (IP), network services, security services, and EtherNet/IP. A reliable and secure converged plant-wide or site-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 resiliency and application availability required within an IACS plant-wide or site-wide architecture, such as non-resilient LAN, resilient LAN, or redundant LANs. A resilient network architecture within an IACS application plays a pivotal role in helping to minimize the risk of IACS application shutdowns while helping to maximize overall plant/site uptime.

A holistic resilient plant-wide or site-wide network architecture is composed of multiple technologies (logical and physical) deployed at different levels within the plant/site. When selecting a resiliency technology, various plant/site application factors should be evaluated, including the physical layout of IACS devices (geographic dispersion), recovery time performance, uplink media type, tolerance to data latency and jitter, and future-ready requirements:

- Robust physical infrastructure
- Topologies and protocols
- Switching and routing
- Wireless LAN Controllers (WLC)
- Firewalls
- Network and device management

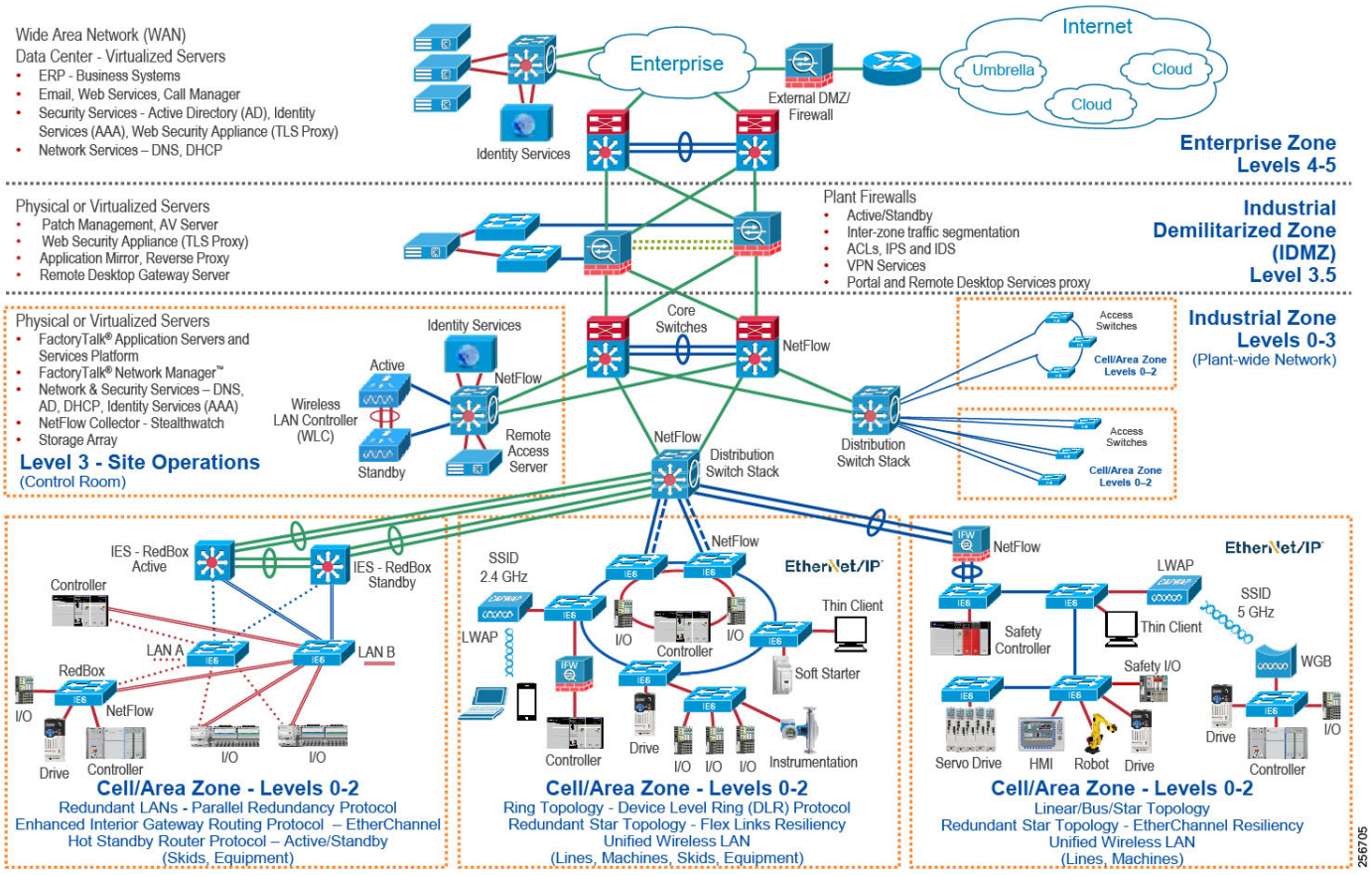
Deploying a Resilient Converged Plantwide Ethernet Architecture Design and Implementation Guide (DIG), outlines several use cases for designing and deploying resilient plant-wide or site-wide LAN architectures for IACS applications. CPwE Resiliency was architected, tested, and validated by Cisco Systems, Panduit and Rockwell Automation.

CPwE Overview

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. The content and key tenets of CPwE are relevant to both OT and IT disciplines. CPwE key tenets include:

- Smart IIoT devices—Controllers, I/O, drives, instrumentation, actuators, analytics, and a single IIoT network technology (EtherNet/IP) , facilitating both technology coexistence and IACS device interoperability, which helps to enable the choice of best-in-class IACS devices.
- Zoning (segmentation)—Smaller connected LANs, functional areas, and security groups.
- Managed infrastructure—Managed Allen-Bradley® Stratix® industrial Ethernet switches (IES), Cisco Catalyst® distribution/core switches, FactoryTalk® Network Manager™ software, and Stratix 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 (for example, OT and IT) and applied at different levels of the plant-wide or site-wide IACS architecture.
- Convergence-ready—Seamless plant-wide or site-wide integration by trusted partner applications.

Figure 1-1 CPwE Architectures



CPwE Resilient IACS Architectures Overview

An IACS is deployed in a wide variety of industries such as automotive, pharmaceuticals, consumer packaged goods, pulp and paper, oil and gas, mining, and energy. IACS applications are composed of multiple control and information disciplines such as continuous process, batch, discrete, and hybrid combinations. One of the challenges facing industrial operations is the industrial hardening of standard Ethernet and IP-converged IACS networking technologies to take advantage of the business benefits associated with IIoT. A resilient LAN architecture can help to increase the overall equipment effectiveness (OEE) of the IACS by helping to reduce the impact of a failure and speed recovery from an outage, which lowers Mean-Time-to-Repair (MTTR).

Protecting availability for IACS assets requires a scalable defense-in-depth approach where different solutions are needed to address various network resiliency requirements for OEM, plant-wide or site-wide architectures. This section summarizes the Cisco, Panduit and Rockwell Automation CPwE validated designs that address different aspects of availability for IIoT IACS applications.

- *Deploying Device Level Ring within a Converged Plantwide Ethernet Architecture Design and Implementation Guide* outlines several use cases for designing and deploying DLR technology with IACS device-level, switch-level, and mixed device/switch-level single and multiple ring topologies across OEM and plant-wide or site-wide resilient LAN IACS applications.

  - 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 Parallel Redundancy Protocol within a Converged Plantwide Ethernet Architecture Design and Implementation Guide* outlines several use cases for designing and deploying Parallel Redundancy Protocol (PRP) technology with redundant LANs across plant-wide or site-wide IACS applications.
  - Rockwell Automation site: https://literature.rockwellautomation.com/idc/groups/literature/documents/td/enet-td021_-en-p.pdf
  - Cisco site: https://www.cisco.com/c/en/us/td/docs/solutions/Verticals/CPwE/5-1/PRP/DIG/CPwE-5-1-PRP-DIG.html
- *Deploying a Fiber Optic Physical Infrastructure within a Converged Plantwide Ethernet Architecture Application Guide* helps designers and installers select and deploy fiber optic media in plant/site environments. It details fiber optic network infrastructure solutions that provide high-performance connectivity options that help increase the integrity and availability of a CPwE architecture at each level of the OEM, plant-wide or site-wide network.
  - Rockwell Automation site: https://literature.rockwellautomation.com/idc/groups/literature/documents/td/enet-td003_-en-p.pdf
  - Cisco site: https://www.cisco.com/c/en/us/td/docs/solutions/Verticals/CPwE/5-1/FOI/CPwE-5-1-FOI-AG.html
- *Physical Infrastructure for the Converged Plantwide Ethernet Architecture Application Guide* which helps customers address the physical deployment associated with converged plant-wide or site-wide EtherNet/IP architectures. As a result, users can achieve resilient, scalable EtherNet/IP networks that can support proven and flexible CPwE logical architectures designed to help optimize OEM, plant-wide or site-wide IACS network performance.
  - Rockwell Automation site: https://literature.rockwellautomation.com/idc/groups/literature/documents/td/enet-td020_-en-p.pdf
  - Cisco site: https://www.cisco.com/c/en/us/td/docs/solutions/Verticals/CPwE/5-1/Phy_Arch/CPwE_PhyArch_AppGuide.html
- *Deploying A Resilient Converged Plantwide Ethernet Architecture Design and Implementation Guide* outlines several use cases for designing and deploying resilient plant-wide or site-wide architectures for IACS applications, utilizing a robust physical layer and resilient LAN topologies with resiliency protocols.
  - Industrial Zone:
    - Core Switching
    - Aggregation/Distribution Switching
    - Robust Physical Infrastructure
  - Cell/Area Zone:
    - Redundant Path Topology with Resiliency Protocol
    - Industrial Ethernet Switching
    - Robust Physical Infrastructure

  - Rockwell Automation site: https://literature.rockwellautomation.com/idc/groups/literature/documents/td/enet-td010_-en-p.pdf
  - Cisco site: https://www.cisco.com/c/en/us/td/docs/solutions/Verticals/CPwE/4-0/Resiliency/DIG/CPwE_resil_CVD.html

CPwE Resiliency Solution Use Cases

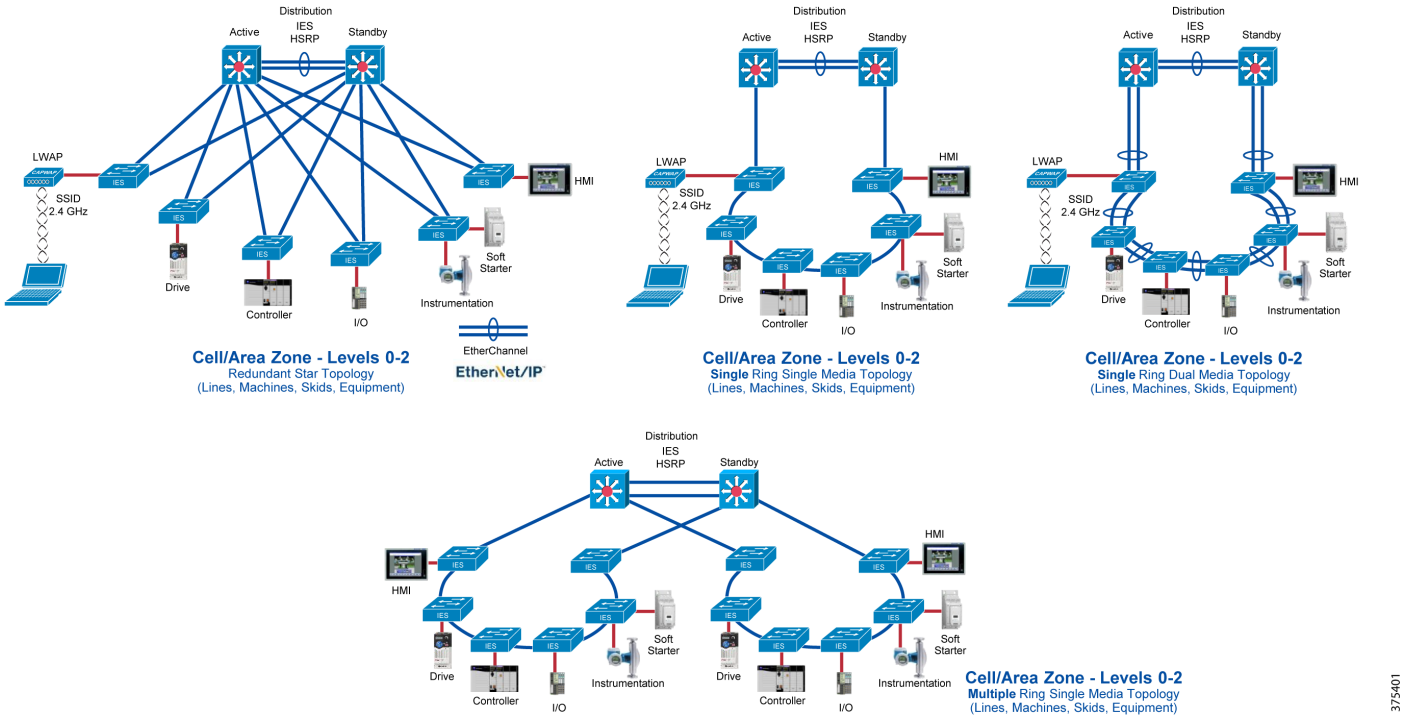
The CPwE Resiliency architecture supports scalability, which includes the degree of resiliency applied to a plant-wide or site-wide architecture. Scalable resiliency comes in many forms, such as technology choices in topology and distribution switches. This *Deploying a Resilient Converged Plantwide Ethernet Architecture Design and Implementation Guide* represents a portion of the use cases that were architected, tested, validated, and documented by Cisco Systems, Panduit, and Rockwell Automation. For more details, see CPwE Resiliency Design Considerations.

Allen-Bradley Stratix and Cisco Industrial Ethernet Switches (IES)

Refer to Figure 1-2.

- Form factor:
  - DIN rail/panel mount
  - 19” rack mount - 1 RU (rack unit)
- Hot Standby Routing Protocol (HSRP) first hop redundancy protocol
- Redundant star switch-level topology:
  - Flex Links resiliency protocol
  - MSTP resiliency protocol
- Ring switch-level topology:
  - Resilient Ethernet Protocol (REP)
  - Device Level Ring Protocol (see CPwE DLR)
  - Multiple Spanning Tree Protocol (MSTP) resiliency protocol
  - Single and dual media ring
    - EtherChannel for dual media ring only

Figure 1-2 IES Aggregation/Distribution Switch



Catalyst 9500 Aggregation/Distribution Switches

Refer to Figure 1-3.

- Cisco® Catalyst® 9000 platform StackWise® Virtual technology allows the clustering of two physical switches together into a single logical entity. The two switches operate as one; they share the same configuration and forwarding state. This technology allows for enhancements in all areas of network design, including high availability, scalability, management, and maintenance. StackWise Virtual also incorporates many other Cisco innovations, such as Stateful Switch Over (SSO), Non-Stop Forwarding (NSF), and Multi-chassis EtherChannel (MEC).
- Hot Standby Routing Protocol (HSRP) first hop redundancy protocol
- Redundant star switch-level topology:
  - Multi-chassis EtherChannel (MEC) port aggregation
  - Flex Links resiliency protocol
  - MSTP resiliency protocol
- Ring switch-level topology:
  - REP
  - MSTP resiliency protocol
  - Single and dual media ring

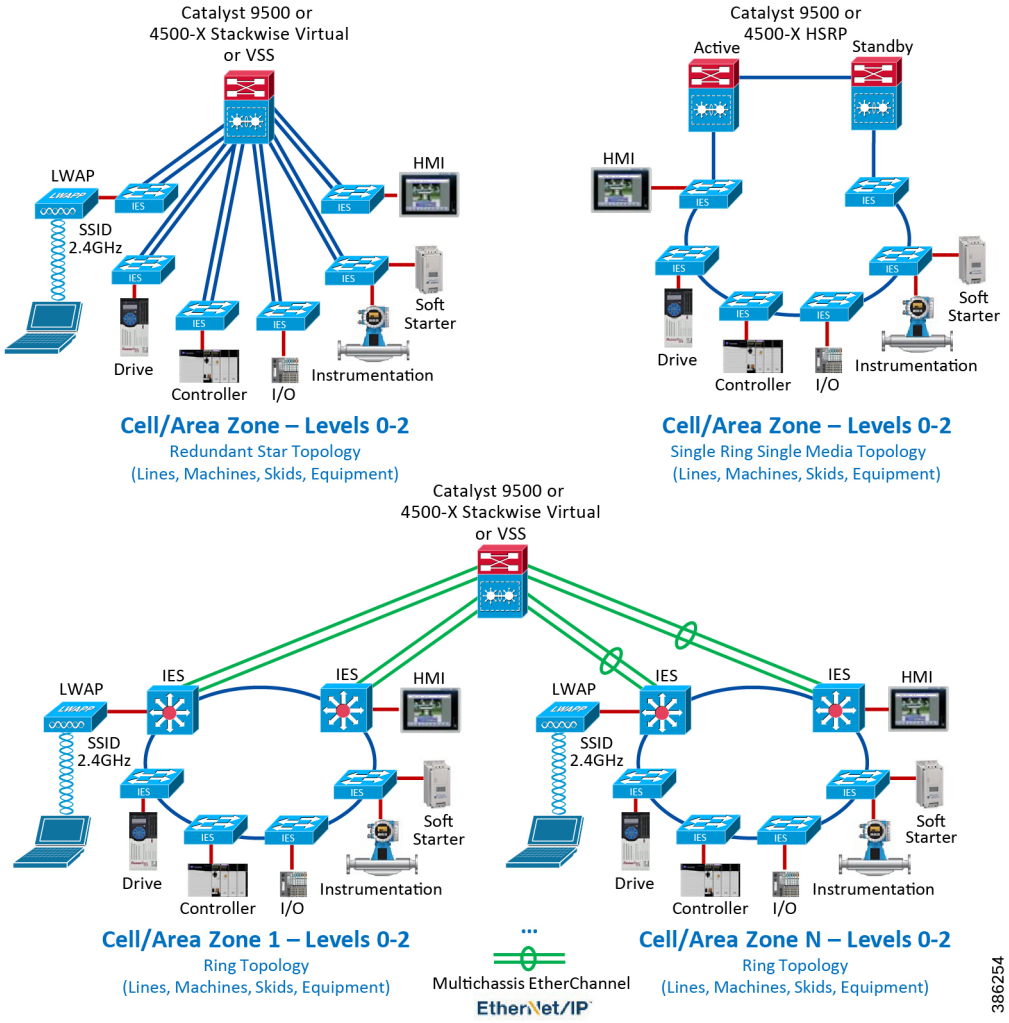
Catalyst 4500-X Aggregation/Distribution Switches

Refer to Figure 1-3.

- Virtual Switching System (VSS) virtualization technology that combines two physical switch chassis into one virtual switch, with Stateful Switch Over (SSO) and Non-stop forwarding (NSF)
- Hot Standby Routing Protocol (HSRP) first hop redundancy protocol
- Redundant star switch-level topology:
  - Multi-chassis EtherChannel (MEC) port aggregation
  - Flex Links resiliency protocol
  - MSTP resiliency protocol
- Ring switch-level topology:
  - REP
  - MSTP resiliency protocol
  - Single and dual media ring

Note Cisco, Panduit, and Rockwell Automation recommend migrating from Catalyst 4500-X to Catalyst 9500 series as the aggregation/distribution switch platform.

Figure 1-3 Catalyst 9500 or Catalyst 4500-X Aggregation/Distribution Switch



Catalyst 9300 StackWise-480 Aggregation/Distribution Switch

Refer to Figure 1-4.

- Switch stack, which is a set of up to eight stacking-capable switches, connected through their StackWise-480 ports, and united to form a logical unit
- Redundant star switch-level topology:
  - EtherChannel port aggregation
  - Flex Links resiliency protocol
  - MSTP resiliency protocol
- Ring switch-level topology:
  - REP
  - MSTP resiliency protocol

  - Single and dual media ring

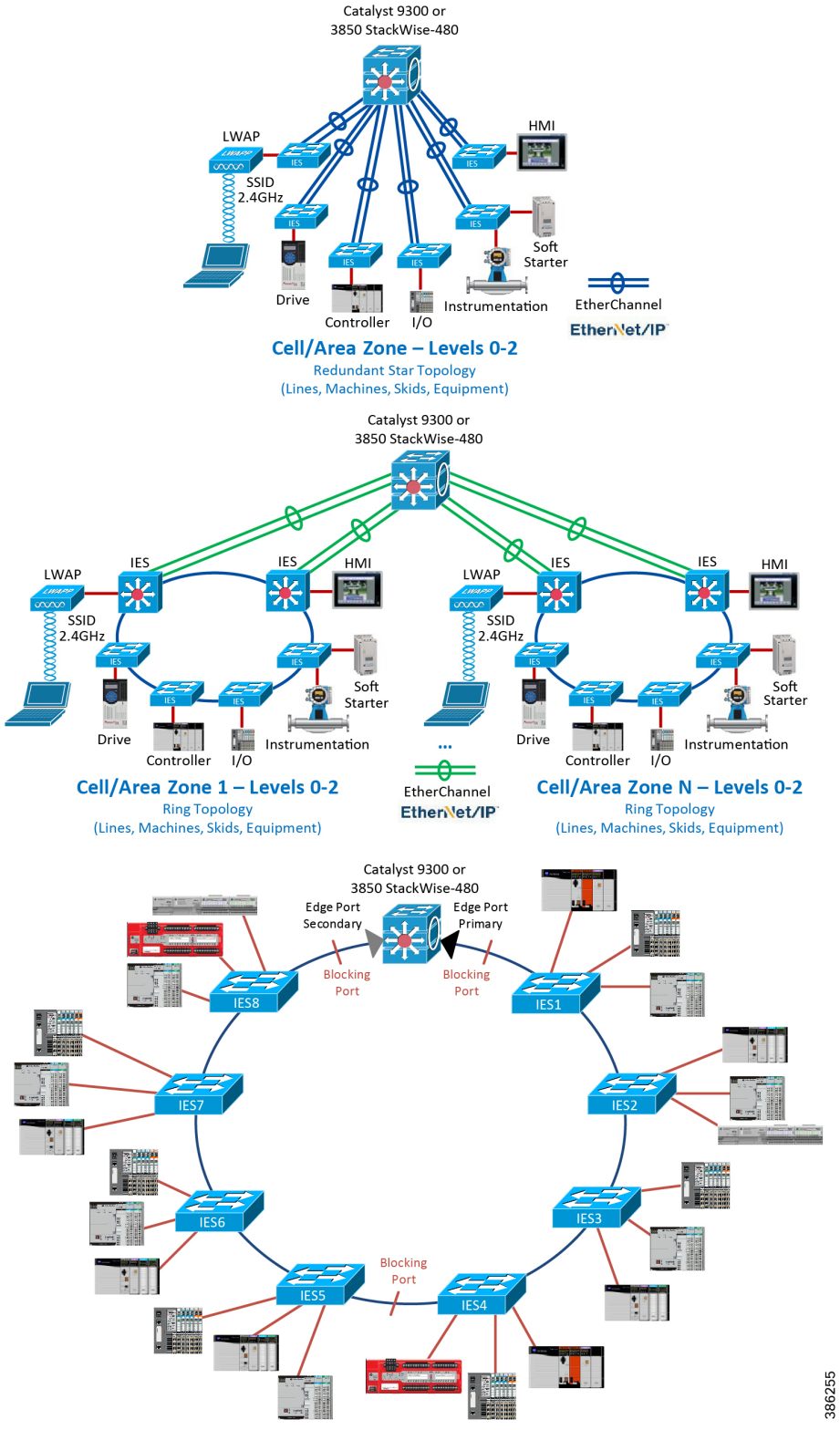
Catalyst 3850 StackWise-480 Aggregation/Distribution Switch

Refer to Figure 1-4.

- Switch stack, which is a set of up to nine stacking-capable switches, connected through their StackWise-480 ports, and united to form a logical unit
- Redundant star switch-level topology:
  - EtherChannel port aggregation
  - Flex Links resiliency protocol
  - MSTP resiliency protocol
- Ring switch-level topology:
  - REP
  - MSTP resiliency protocol
  - Single and dual media ring

Note Cisco, Panduit, and Rockwell Automation recommend migrating from Catalyst 3850 to Catalyst 9300 series as the aggregation/distribution switch platform.

Figure 1-4 Catalyst 9300 or Catalyst 3850 Aggregation/Distribution Switch

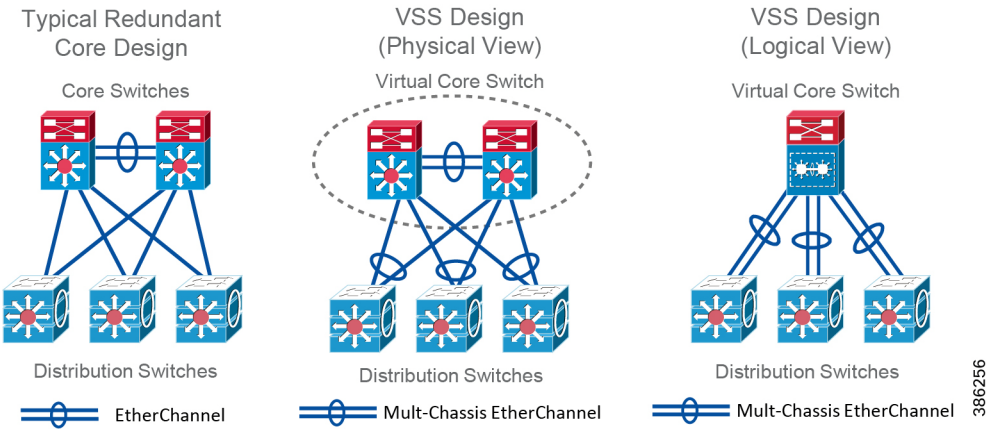


Core Switches

Large-scale architectures typically use modular chassis-based core switches, such as Cisco Catalyst 9600 and 6800 platforms. In addition to having redundant hardware components, core switches are configured as resilient pairs utilizing StackWise Virtual or VSS technology.

Refer to Figure 1-5.

Figure 1-5 Core Switches—Traditional versus VSS Design



Medium and small-scale architectures can use fixed-size switch platforms as a core, such as Cisco Catalyst 9500 with StackWise Virtual technology, or use a collapsed core/distribution model.

Robust Physical Infrastructure

Successful deployment of CPwE logical architectures depends on a robust physical infrastructure network design that addresses environmental and performance challenges with best practices from Operational Technology (OT) and Information Technology (IT). For this *Deploying a Resilient Converged Plantwide Ethernet Architecture DIG*, Cisco, Panduit, and Rockwell Automation have collaborated to reference the building block approach Panduit uses for physical infrastructure deployment. This approach is reflected in *Physical Infrastructure for the Converged Plantwide Ethernet Architecture Application Guide*, which helps customers address the physical deployment associated with converged plant-wide or site-wide EtherNet/IP:

- Rockwell Automation site:
  https://literature.rockwellautomation.com/idc/groups/literature/documents/td/enet-td020_-en-p.pdf
- Cisco site:
  https://www.cisco.com/c/en/us/td/docs/solutions/Verticals/CPwE/5-1/Phy_Arch/CPwE_PhyArch_AppGuide.html

As a result, users can achieve resilient, scalable networks that can support proven and flexible CPwE logical architectures designed to help optimize plant-wide or site-wide IACS network performance.

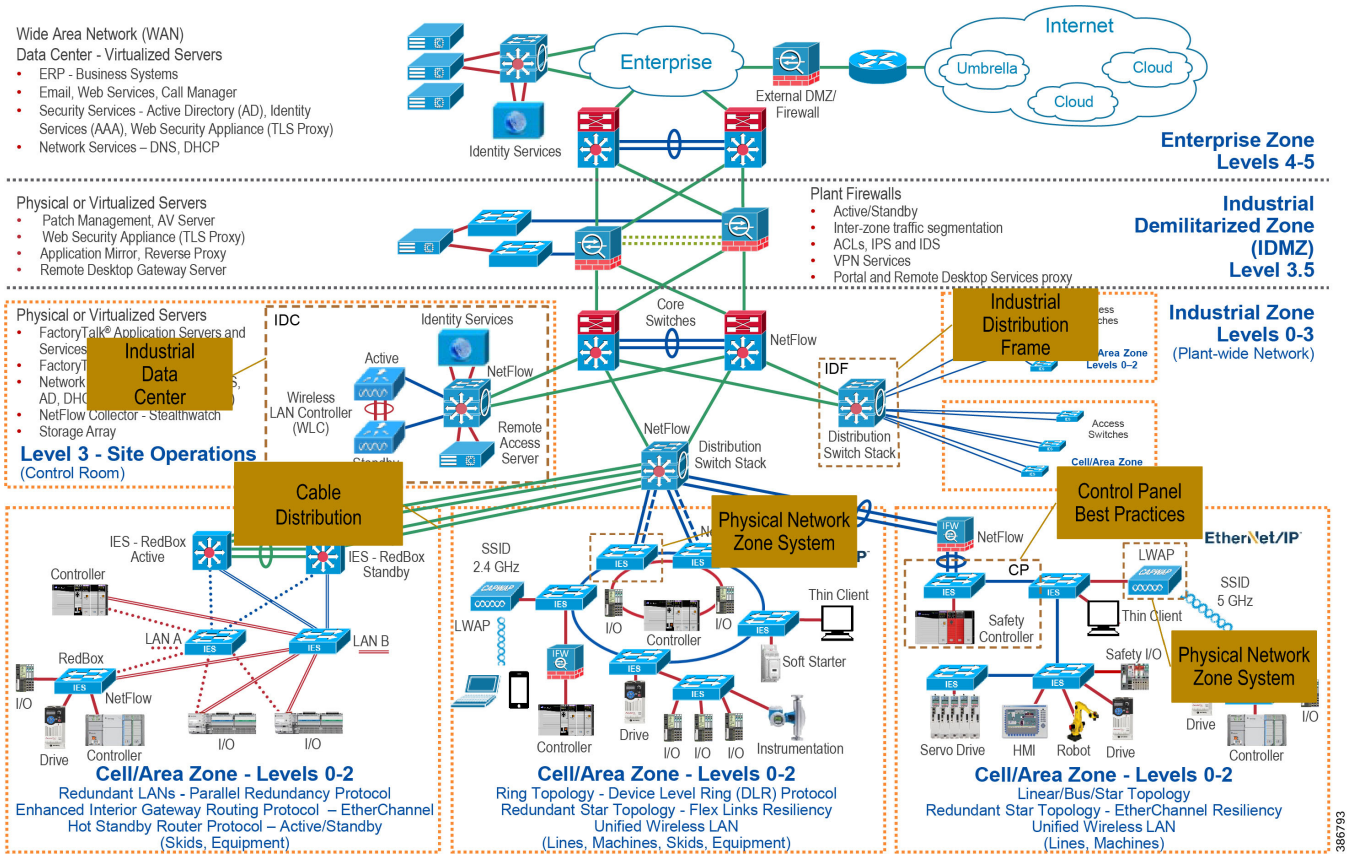
Refer to Figure 1-6.

For the *Physical Infrastructure for the Converged Plantwide Ethernet Architecture Application Guide*, the following use cases were documented by Panduit:

- Robust physical infrastructure design considerations and best practices
- Control Panel:

  - Electromagnetic interference (EMI) noise mitigation through bonding, shielding and grounding
  - Industrial Ethernet Switch (IES) deployment within the Cell/Area Zone
- Physical Network Zone System:
  - IES and Access Point (AP) deployment within the Cell/Area Zone
- Cable distribution across the Industrial Zone
- Industrial Distribution Frame (IDF):
  - Industrial aggregation/distribution switch deployment within the Industrial Zone
- Industrial Data Center (IDC):
  - Physical design and deployment of the Level 3 Site Operations

Figure 1-6 Panduit Robust Physical Infrastructure for the CPwE Architecture



CHAPTER 2

CPwE Resiliency Design Considerations

This chapter provides an overview of design considerations for integrating resiliency into an Industrial Automation and Control System (IACS) network based on the CPwE architecture and includes:

Test Hardware and Software

Table 2-1 Network Hardware and Software

Role	Product	Software Version			Notes
		2015 DIG Release	2018 DIG Release	2020 DIG Release	
Access switch	Cisco Industrial Ethernet 2000 Series Switch/Allen-Bradley Stratix 5700	15.2(3)EA	15.2(6)E1	15.2(7)E (Cisco) 15.2(6)E1 (RA)	
Access switch	Cisco Industrial Ethernet 3000 Series Switch/Allen-Bradley Stratix 8000	15.2(3)EA	Not tested	Not tested	
Access switch	Cisco Industrial Ethernet 4000 Series Switch/Allen-Bradley Stratix 5400	15.2(2)EA (Cisco), 15.2(2)EA1 (RA)	15.2(6)E1	15.2(7)E (Cisco) 15.2(6)E1 (RA)	
Distribution switch	Cisco Industrial Ethernet 5000 Series Switch/Allen-Bradley Stratix 5410	15.2(2)EB	15.2(6)E1	Not tested	Hot Standby Routing Protocol (HSRP)
Distribution switch	Catalyst 3850	Not tested	03.03.05.SE	Not tested	StackWise-480
Distribution switch	Catalyst 9300	Not tested	Not tested	16.12.1 (see note [1])	StackWise-480
Distribution switch	Catalyst 9500	Not tested	Not tested	16.9.3 (see note [1])	StackWise Virtual and HSRP
Distribution switch	Catalyst 4500-X	Not tested	03.08.00.E	Not tested	Virtual Switching System (VSS) and HSRP
Distribution switch	Cisco Industrial Ethernet 4000 Series Switch/Allen-Bradley Stratix 5400	15.2(2)EA (Cisco), 15.2(2)EA1 (RA)	15.2(6)E1	15.2(7)E (Cisco) 15.2(6)E1 (RA)	HSRP)

1. 16.12 is a Long-Term Maintenance version of code. 16.12.1 and 16.9.3 were the versions available for the 9300 and 9500 platforms when the testing for this release was initiated. Cisco, Panduit, and Rockwell Automation recommend using the most recent CCO versions of Long-Term maintenance code for their deployments and to check the release notes for fixes and updates that are included in each release, especially regarding key features and functions upon which they may be relying.

Table 2-2 IACS Hardware and Software

Role	Product	Software Version
Rockwell Software	RSLinx® Classic software	3.73.00
Rockwell Software	Studio 5000 Logix Designer® software	V26
Allen-Bradley Controller	ControlLogix® controller (1756-L75)	26.013
Allen-Bradley Safety Controller	GuardLogix® Safety controller(1576-L73S)	26.013
Allen-Bradley EtherNet/IP Adapter	ControlLogix® EtherNet/IP adapter (1756-ENT2T/EN2TR)	5.0.28
Allen-Bradley Safety Controller	GuardLogix Safety controller (1756-L7SP)	26.013
Allen-Bradley Controller	CompactLogix™ controller (1769-L36ERM)	26.013
Allen-Bradley Controller	CompactLogix controller (1769-L18ERM)	26.013
Allen-Bradley I/O Adapter	FLEX I/O™ EtherNet/IP adapter (1794-AENT)	4.003
Allen-Bradley I/O Adapter	POINT I/O™ EtherNet/IP adapter (1734-AENT/AENTR)	3.012
Allen-Bradley Safety I/O Adapter	CompactBlock™ Guard I/O™ adapter 1791ES-IB8XOBV4)	1.9

Note The 2015 CPwE Resiliency release has been tested with the IACS hardware and software listed above. The 2018 and 2020 releases have been tested with Ixia-generated traffic representing the IACS data.

Resiliency Architectural Framework

Within the CPwE architecture, resiliency is key to helping prevent network outages and related plant/site downtime. Resiliency should be incorporated into as many levels of the IACS network as possible, including:

- Industrial Zone (core switching and distribution switching)
- Cell/Area Zone (Levels 0-2 IES access switching)

The following sections describe the choices that are available to design a resilient industrial network, along with recommendations based on testing conducted by Cisco Systems, Panduit, and Rockwell Automation.

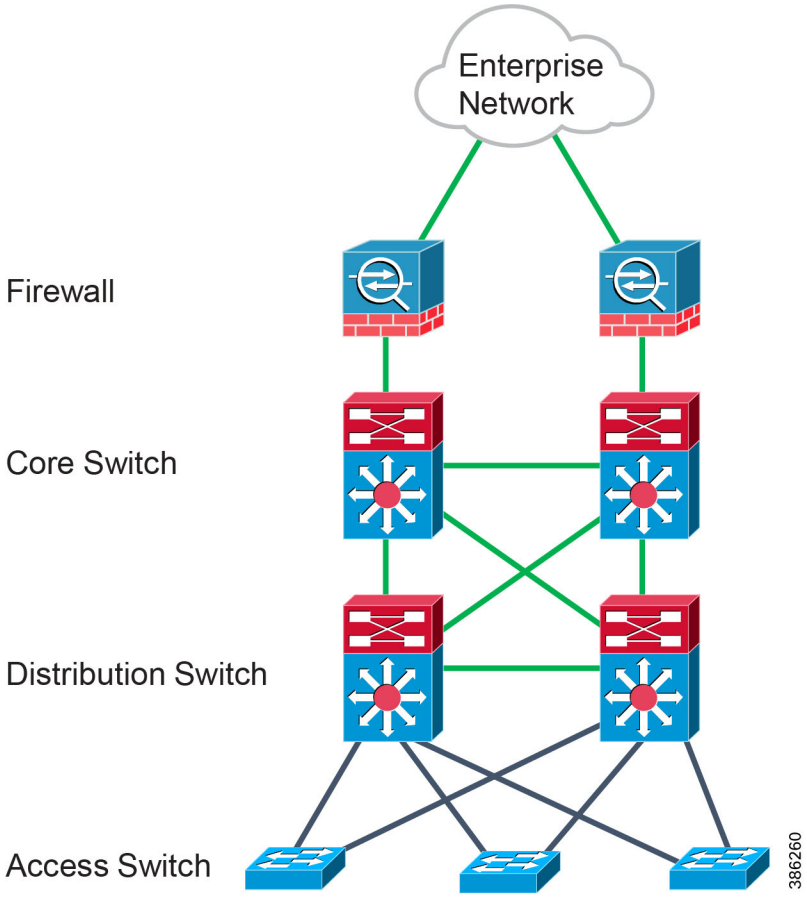
Network Reference Model

The CPwE logical framework reflects the basic functions of an IACS, which is the key model for this CPwE Resiliency solution architecture. However, as identified earlier, the goal of this architecture is to integrate the knowledge and expertise from both an IACS perspective and an IT perspective. An important and relevant model for network architectures is the Cisco Enterprise Campus network, which incorporates key networking concepts and models. The CPwE solution architecture comprises many of the concepts and models of the Enterprise Campus solution architecture, but not the entire scope of that solution since not all concepts are relevant to IACS networks. Essentially, the IACS network can be viewed as a specialized Campus network.

This section briefly introduces the Campus network and some of the key concepts of its solution architecture. The Cisco Enterprise Campus network combines a high-availability core infrastructure of intelligent switching and routing with an overlay of productivity-enhancing technologies, including IP communications, mobility and advanced security. This Design and Implementation Guide refers to the Campus network

documentation and the concept of access, distribution and core. Figure 2-1 shows a hierarchical design model that has proven to be effective in a Campus environment consisting of three main layers: access, distribution and core.

Figure 2-1 Campus Network Hierarchical Model



- The access layer provides the first layer of access to the IACS network. Layer 2 (OSI model) switching, security and QoS reside at this layer. Access layer switches aggregate IACS devices.
- The distribution layer aggregates the access layer switches and provides security and access level network policy enforcement. Layer 3 protocols are used at this layer to provide load balancing, fast convergence and scalability.
- The core is the backbone of the network. This layer is designed to be fast converging, highly reliable and stable. This layer aggregates the distribution switches and often integrates connectivity to the IDMZ in this CPwE solution architecture. Designed with Layer 3 protocols, the core helps provide load balancing, fast convergence and scalability. Often, in small-to-medium topologies, the core and distribution layers are consolidated into a single collapsed core/distribution layer. For large topologies, the core is required for scalability, throughput and to interconnect multiple distribution switches to other services (such as security firewalls).

This three-layer design provides high availability with redundant hardware, redundant software features, redundant network connections/paths and automatic procedures for reconfiguring network paths when failures occur.

Note For more information on the Enterprise Campus network, see the following URLs:

- *Enterprise Campus Architecture: Overview and Framework*: http://www.cisco.com/en/US/docs/solutions/Enterprise/Campus/campover.html
- *Campus Network for High Availability Design Guide*: http://www.cisco.com/en/US/docs/solutions/Enterprise/Campus/HA_campus_DG/hacampusdg.html

Note For more information on the Industrial Zone design and topology options, see the "Solution Design--Manufacturing and Demilitarized Zones" chapter of the *Converged Plantwide Ethernet (CPwE) Design and Implementation Guide* at the following URLs:

Rockwell Automation site:

- http://literature.rockwellautomation.com/idc/groups/literature/documents/td/enet-td001_-en-p.pdf

Cisco site:

- http://www.cisco.com/en/US/docs/solutions/Verticals/CPwE/CPwE_DIG.html

This release of the CPwE Resiliency DIG introduces the following new distribution layer switches: Catalyst 9500 and Catalyst 9300. The following sections describe the resiliency options available for the distribution layer.

Industrial Zone

Resiliency Protocols

The following section describes the resiliency protocol available for the distribution layer:

- StackWise Virtual, page 2-4
- StackWise-480, page 2-7
- Hot Standby Redundancy Protocol, page 2-8

StackWise Virtual

StackWise Virtual Overview

Cisco Catalyst 9000 platform StackWise Virtual technology allows the clustering of two physical switches together into a single logical entity. The two switches operate as one; they share the same configuration and forwarding state. This technology allows for enhancements in all areas of network design, including high availability, scalability, management, and maintenance. Figure 2-2 graphically represents the StackWise Virtual feature, which allows you to manage two Cisco Catalyst 9000 Switches as a single switch.

Note For more information on StackWise Virtual design and implementation, see the “Configuring Cisco StackWise Virtual” chapter of the *Catalyst 9500 Switches High Availability Guide IOS XE* at the following URL:

- https://www.cisco.com/c/en/us/td/docs/switches/lan/catalyst9500/software/release/16-9/configuration_guide/ha/b_169_ha_9500_cg/configuring_cisco_stackwise_virtual.html

Note The Catalyst 9500 with StackWise Virtual can also be used in the core layer, depending on plant/site size.

The virtualization of two physical chassis into a single logical switch with StackWise Virtual fundamentally alters the design of the campus topology. One of the most significant changes is that StackWise Virtual enables the creation of a loop-free topology. In addition, the StackWise Virtual incorporates many other Cisco innovations such as SSO and MEC, which substantially enhance application response time. Key business benefits of StackWise Virtual include the following:

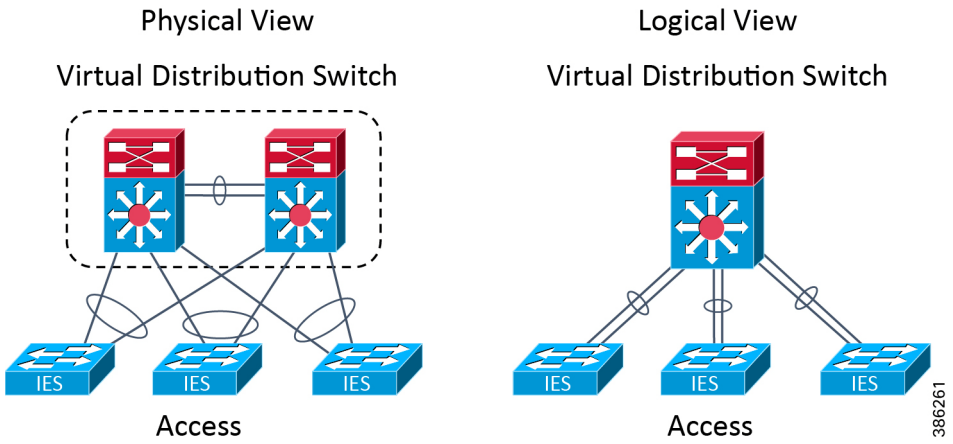
- Reduced risk associated with a looped topology
- Non-stop business communication by using a redundant chassis with SSO
- Better return on existing investments via increased bandwidth from the access layer
- Reduced configuration errors and elimination of First Hop Redundancy Protocols (FHRP), such as Hot Standby Routing Protocol (HSRP), GLBP, and VRRP
- Simplified management of a single configuration and fewer operational failure points

StackWise Virtual Topology

StackWise Virtual (SV) architecture combines two switches into a single logical network entity from the network control plane and management perspectives. It uses Cisco IOS Stateful Switchover (SSO) technology and Non-Stop Forwarding (NSF) extensions to routing protocols, to provide seamless traffic failover when one of the devices fails over. To neighboring devices, a StackWise Virtual domain appears as a single logical switch or router. Within a StackWise Virtual domain, one device is designated as the SV active switch, and the other is designated as the SV standby switch (Figure 2-2). All control plane functions are centrally managed by the SV active switch, including:

- Management (Simple Network Management Protocol [SNMP], Telnet, Secure Shell [SSH] Protocol, and so on)
- Layer 2 protocols (Bridge Protocol Data Units [BPDUs], Protocol Data Units [PDUs], Link Aggregation Control Protocol [LACP], and so on)
- Layer 3 protocols (routing protocols, and so on)
- Software data path

Figure 2-2 StackWise Virtual in the Distribution Network



StackWise Virtual Link

A StackWise Virtual domain consists of two Cisco Catalyst 9000 Switches. In order to bond the two switches together into a single logical node, special signaling and control information must be exchanged between the two switches in a timely manner. To facilitate this information exchange, a dedicated link is used to transfer both data and control traffic between the peer switches. This link is referred to as the StackWise Virtual link

Centralized Management

The fundamental design of a StackWise Virtual domain allows the centralized management of all network and device resources. This includes Layer 3 protocols such as Open Shortest Path First (OSPF), Enhanced Interior Gateway Routing Protocol (EIGRP), and Border Gateway Protocol (BGP) and Layer 2 protocols such as Spanning Tree Protocol (STP), Unidirectional Link Detection Protocol (UDLD), Flow Control, and LACP. A single switch in the StackWise Virtual domain is elected as the central management point for the entire system when accessed via management IP or console. The switch acting as the single management point is referred to as the SV active switch. The peer chassis is referred to as the SV standby switch. The SV standby switch is also considered a hot-standby switch since it is ready to become the active switch and take over all functions if something happens to the active switch.

StackWise Virtual Link Initialization

The initialization process must determine which switch will become the active switch for the StackWise Virtual domain. To determine the active and standby roles, the StackWise Virtual link must be initialized and brought online for control plane communication. Because this determination affects the behavior of each switch, the roles must be negotiated early during the switch bootup cycle. As a result, the system must bring the StackWise Virtual link and its associated ports online before initializing the rest of the system. Communication between the two switches is facilitated with internal messaging that is sent across the StackWise Virtual link. Because the link is implemented as an EtherChannel interface, it is resilient to single-link failures. The system must bring the StackWise Virtual link online before activating the StackWise Virtual domain.

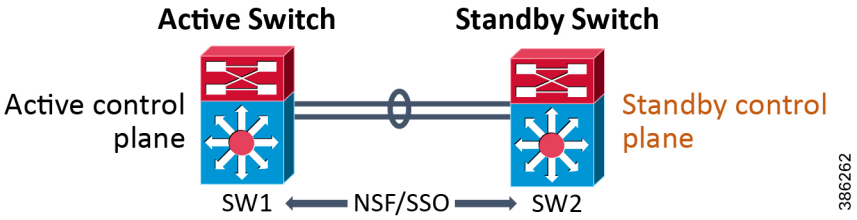
StackWise Virtual Link Redundancy

StackWise Virtual provides the signaling path used for synchronizing the two switch control planes, and the data path for any user data traffic needing to pass between the two switches. Therefore, the StackWise Virtual link is bundled as an EtherChannel interface, allowing for redundant interfaces and higher bandwidth capacity.

High Availability

Central to the high-availability model of a StackWise Virtual domain are the concepts of NSF and SSO. To take advantage of the existing innovations in NSF and SSO technologies, StackWise Virtual has implemented a high-availability model that uses this redundancy framework for an interchassis environment.

Figure 2-3 Interchassis NSF and SSO in a StackWise Virtual Environment



In an SSO system, “high-availability-aware” protocols and features may synchronize events and state information from the active switch to the hot-standby switch. From a redundancy framework viewpoint, the active switch acts as a server, whereas the standby switch acts as the client. Information that is "high availability aware" will be statefully synchronized between these entities. In the event of a failover, the standby switch does not need to relearn this information, reducing the outage time. As Figure 2-3 shows, the primary switch (SW1 in the figure) assumes the active role, whereas the secondary switch (SW2) assumes the hot-standby role.

Note For more information on StackWise Virtual design and implementation, see the “Configuring Cisco StackWise Virtual” chapter of the Catalyst 9500 Switches High Availability Guide IOS XE at the following URL:

https://www.cisco.com/c/en/us/td/docs/switches/lan/catalyst9500/software/release/16-9/configuration_guide/ha/b_169_ha_9500_cg/configuring_cisco_stackwise_virtual.html

Note Catalyst 4500-X platform uses VSS technology, which is similar in functionality to StackWise Virtual. For more information on VSS design and implementation in Catalyst 4500-X, see the “Configuring VSS” chapter of the Catalyst 4500 Series Switch Software Configuration Guide at the following URL:

https://www.cisco.com/c/en/us/td/docs/switches/lan/catalyst4500/15-1-2/XE_340/configuration/guide/config/vss.html

StackWise-480

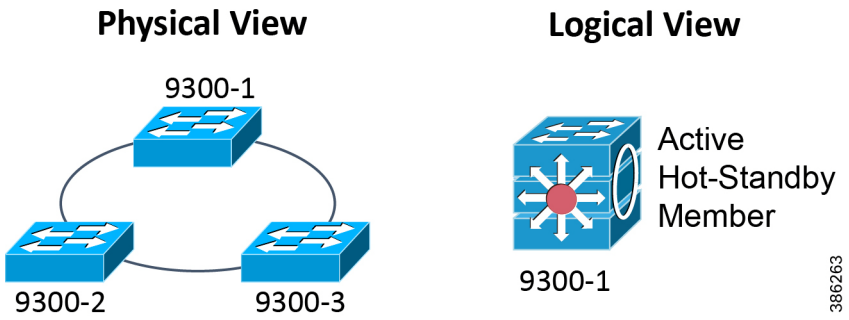
The StackWise-480/320 architecture allows stacking of up to eight switches in a ring topology to achieve either 480G or 320G of stack bandwidth. The stacking architecture expands form factor, switching capacity, port density, and redundancy and provides a single control plane. This architecture provides resiliency, scalability, and central management. The latest Cisco Catalyst 9300 Series Switches support StackWise-480/320. This technology is flexible, modular, evolutionary, and it delivers Cisco IOS XE feature capabilities with hardware acceleration to every port in the stack.

Up to a maximum of eight switches can be stacked together physically in a ring topology to form a single, unified, virtual stack system. A Cisco Catalyst 9300 Series Switch, when deployed in StackWise-480/320 mode, is designed to deliver deterministic and nonblocking switching performance to a maximum port

density of 448 ports with a distributed data plane, single control plane, and management plane. The switching performance delivers hardware-accelerated, integrated borderless network services such as PoE, PoE+, Cisco UPOE, Quality of Service (QoS), Access Control Lists (ACLs), Flexible NetFlow, Cisco Encrypted Traffic Analytics (ETA), streaming telemetry, and many more services on every port.

Depending on the requirement of each switch in the stack, a Cisco Catalyst 9300 Series Switch provides the flexibility for mixed-mode support between different models in a single stack ring. You can mix switches with different model variants (PoE, Cisco UPOE, data, Multigigabit) and different network modules in the stack.

Figure 2-4 StackWise-480 Physical versus Logical Topology



Next-generation Cisco Catalyst 9300 Series Switches have been designed to meet the future demands in wiring closet networks. Stackwise-480/320 provides maximum port density at the access layer, along with platform, software, and network resiliency at the access layer. As more technologies are integrated into the system, the Cisco Catalyst 9300 Series offers operational simplicity, scalability, performance, and adaptability for future protocols. The software architecture of Cisco StackWise-480/320 technology delivers superior performance and best-in-class resiliency along with the flexibility of a UADP ASIC. This document is primarily focused on the StackWise architecture for the Cisco Catalyst 9300 Series switches.

Note For more details about the StackWise-480 architecture and capabilities of the Catalyst 9300, see the Cisco Catalyst 9300 Stackwise System Architecture White Paper at the following URL:

https://www.cisco.com/c/en/us/products/collateral/switches/catalyst-9300-series-switches/white-paper-c11-741468.html

Note Catalyst 3850 platform also supports StackWise-480 technology. For more details, see the Cisco Catalyst 3850 Series Switches StackWise-480 Architecture White Paper at the following URL:

http://www.cisco.com/c/en/us/products/collateral/switches/catalyst-3850-series-switches/white-paper-c11-734429.html

Hot Standby Redundancy Protocol

Default gateway redundancy (also known as first hop redundancy) allows a highly available network to recover from the failure of the device acting as the default gateway for the end stations on a physical segment. Cisco developed HSRP to address this need, and the IETF subsequently ratified Virtual Router Redundancy

Protocol (VRRP) as the standards-based method of providing default gateway redundancy. HSRP is supported on various platforms, including the Catalyst 4500-X, IE 5000/Stratix 5410, IE 4000/Stratix 5400, Catalyst 3850, and Catalyst 9300/9500.

In the recommended hierarchical model, the distribution switches are the Layer 2/Layer 3 boundary and act as the default gateway for the entire Layer 2 domain that they support. Some form of redundancy is required because this environment can be large, and a considerable outage could occur if the device acting as the default gateway failed.

HSRP, which provides a robust method of backing up the default gateway, can provide sub-second failover to the redundant distribution switch when tuned properly. HSRP is the recommended protocol because it is a Cisco-owned standard that allows for the rapid development of new features and functionality for HSRP before VRRP.

Note Cisco, Panduit, and Rockwell Automation recommend that the Spanning Tree Protocol (STP) root be configured to be the same as the primary HSRP peer. Therefore, if the STP root and primary HSRP peer are not synchronized due to a switch disruption, a manual switchover to restore the original peer as primary should be initiated during the next maintenance window.

Cell/Area Zone

Common Industrial Protocol Messaging

Before discussing resiliency and design recommendations in the Cell/Area Zone, a clear understanding of the different types of Common Industrial Protocol (CIP) traffic that may traverse this area of the IACS network is required, since each of these has its own unique convergence requirements:

- **Class 1 (Implicit)**—Class 1 connections do not use a reliable transport method so they are less tolerant of excessive latency and disruptions in the IACs network. Examples include I/O and produced/consumed connections. Another name for a Class 1 message is *implicit* messaging. Once the Class 1 connection is established the producer sends an "implicit" message every requested packet interval (RPI).

Note Recommendations given in this document focus on Class 1 (implicit) traffic since this type of traffic is more sensitive to IACS network disruptions.

- **Class 3 (Explicit)**—Class 3 connections use a reliable transport method so they are more tolerant of excessive latency and disruptions in the IACS network. Examples include MSG instructions and going online with a Programmable Automation Controller (PAC). Another name for a Class 3 message is *explicit* messaging. Explicit messages are triggered on demand or in other terms the data is explicitly requested.

Note For more information on convergence requirements for different types of CIP messaging, see the "CPwE Solution - Design Cell/Area Zone" chapter of the *Converged Plantwide Ethernet (CPwE) Design and Implementation Guide* at the following URLs:

Rockwell Automation site:

- http://literature.rockwellautomation.com/idc/groups/literature/documents/td/enet-td001_-en-p.pdf

Cisco site:

- http://www.cisco.com/en/US/docs/solutions/Verticals/CPwE/CPwE_Design and Implementation Guide.html

Access Layer Switching

The access layer is the first tier or edge of the CPwE architecture. It is the place where IACS network devices (such as PCs, servers, controllers, I/O devices, and drives) attach to the wired portion of the IACS network. The wide variety of possible types of connectable devices and the various necessary services and dynamic configuration mechanisms, make the access layer one of the IACS feature-rich parts of the CPwE architecture.

The access layer provides the intelligent demarcation between the network infrastructure and the devices that leverage that infrastructure. As such, it provides a security, QoS, and policy trust boundary. When reviewing the overall IACS network design, the access switch provides most of these access layer services and is a key element in enabling multiple IACS network services. The Cell/Area Zone can be considered an access layer network specialized and optimized for IACS networks.

CPwE Resiliency uses the IE 4000/Stratix 5400 and IE 2000/Stratix 5700 access layer industrial Ethernet switches (IES). The IE 4000/Stratix 5400 is available as an all Gigabit Ethernet switch to support advanced applications. In addition, all IE 4000/Stratix 5400 variants support four gigabit uplink ports, which allow it to be used in both single and dual media rings (see Ring Topology, page 2-26 for more details on these designs). The IE 4000/Stratix 5400 can also be used as a distribution switch for smaller scale deployments.

A large variety of Cell/Area Zone IACS network topologies must be considered to address a wide range of industrial applications. Table 2-3 summarizes these topology options.

Table 2-3 Cell/Area Topology Option Comparison

Type	Advantages	Disadvantages
Redundant Star	• Resiliency from multiple connection failures • Faster convergence to connection loss • Consistent number of hops (typically two in a flat design) provides predictable and consistent performance and real-time characteristics • Fewer bottlenecks in the design reduce chances of segment over-subscription	• Additional wiring (and relevant costs) required to connect Layer 2 access switches directly to a Layer 3 distribution switch • Additional configuration complexity (for example, Spanning Tree with multiple blocks)
Ring	• Resiliency from loss of one network connection • Less cabling complexity in certain plant/site layouts	• Additional configuration complexity (for example, Spanning Tree with a single block) • Longer convergence times • Variable number of hops makes designing predictable performance more complex
Linear/Star	• Easy to design, configure, and implement • Least amount of cabling (and associated cost)	• Loss of network service in case of connection failure (no resiliency) • Creates bottlenecks on the links closest to Layer 3 device, and varying number of hops make it more difficult to produce reliable performance.

Note Since linear/star topologies are inherently not resilient, they are not discussed in this *Deploying a Resilient Converged Plantwide Ethernet Architecture DIG.*

Cisco, Panduit and Rockwell Automation recommend using fiber media for all links between switches in the Industrial Zone. Fiber media provides faster link loss detection and faster convergence when compared to the copper Gigabit links. Only fiber inter-switch links were tested as part of CPwE Resiliency.

The following sections describe the redundant star and ring resiliency options available for the access layer.

Redundant Star Topology

Resiliency Protocols

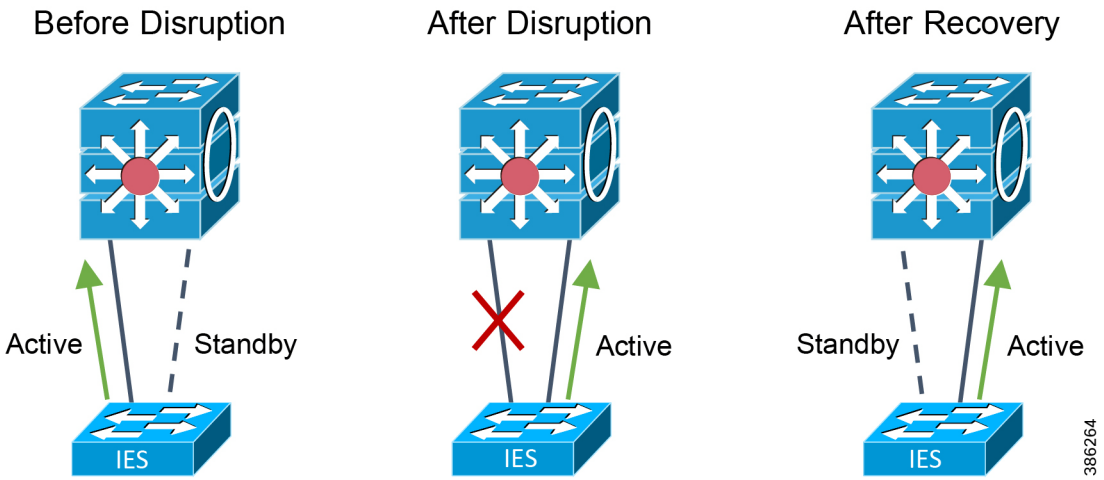
Flex Links

Flex Links is a Cisco proprietary resiliency protocol that is an alternative to STP and EtherChannel in redundant star networks. It is used to connect an access switch to a distribution switch. With Flex Links, you define an active and backup uplink interface. Figure 2-5 shows the process by which Flex Links converge a redundant star topology. To begin, the active interface is in the up condition. The interface that is up sends and receives frames just like any other Ethernet port. The backup interface begins in the standby state. The standby interface establishes a link to the other side of the connection (that is, it is up/up by both switches).

However, the interface in the standby state does not send or receive any packets. Only the interface that is up sends and receives all the traffic to and from the switch. When a failure is detected on the forwarding link, the MAC address and multicast entries are transferred to the standby link. When the failed interface is restored, it becomes the standby link.

Note Flex Links, which is configured only on the access switch, does not require any additional configuration on the distribution switch.

Figure 2-5 Flex Links Basic Operation



Flex Links can be used to replace STP or EtherChannel in specific topologies, namely when the access switch has dual links to the distribution switch.

Note Flex Links does not function in a ring topology.

Flex Links contains two features to improve the recovery of multicast traffic, if present in the network:

1. A switch with Flex Links receives Internet Group Management Protocol (IGMP) queries from the querier and thus assigns that port as the mrouter port. To accelerate multicast convergence, Flex Links will also confirm that the standby port is listed as an mrouter port. However, since that port is blocked, multicast data traffic will not be sent or received on that port.

2. "Leaking" IGMP reports out of the blocked port improves multicast convergence. When the upstream or distribution switch receives these reports on this port, the port is added to the snooping table and multicast traffic is sent in that direction. The Flex Links protocol on the access switch blocks the incoming traffic on the standby port. When a failure occurs and the standby link is unblocked, the port is already an mrouter port and the upstream switch is already forwarding multicast traffic on that interface.

Flex Links has the following key advantages:

- **Ease of use**—Simple protocol to manage resilient uplinks between two switches
- **Performance**—Fast convergence of unicast and multicast traffic, with built-in features to improve multicast convergence
- **Compatibility with STP**—As Flex Links blocks one port, STP does not identify a loop and inappropriately block any ports
- **Interoperability**—Although Flex Links is proprietary, the fact that it does not communicate or negotiate with other switches means that the protocol can be used in mixed vendor environments

Flex Links has the following key disadvantages:

- **Not standards-based**—Protocol is Cisco proprietary, so it can only be configured on devices operating Cisco IOS
- **Bandwidth—**Does not take advantage of the available bandwidth (only one link forwarding traffic)
- **Not configurable via Device Manager web interface on IES (must be configured via CLI)**

Note For more information about Flex Links, see *Configuring Flex Links* at the following URL:

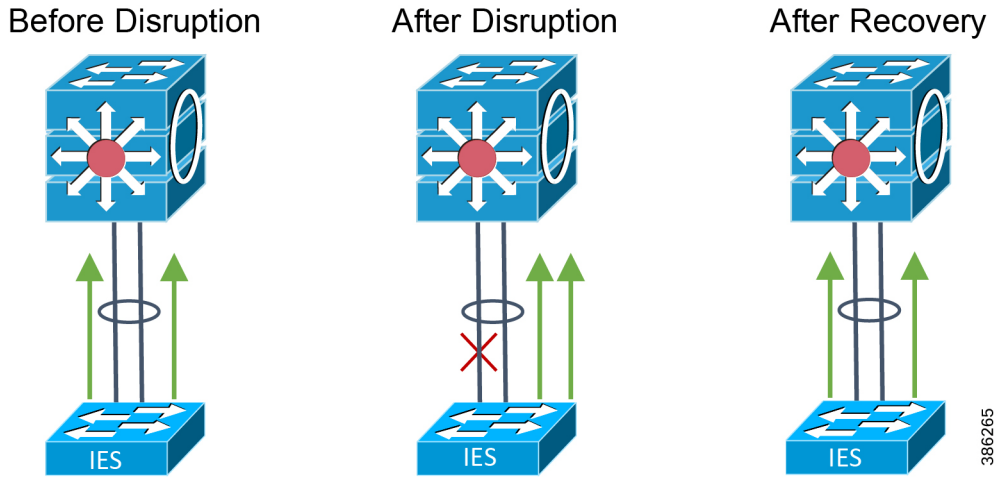
- http://www.cisco.com/c/en/us/td/docs/switches/lan/cisco_ie2000/software/release/15_2_2_e/configuration/guide/scg-ie2000/swflink.html

EtherChannel

Strictly speaking, EtherChannel and Link Aggregation Control Protocol (LACP) are not resiliency protocols. They are designed to provide additional bandwidth between two devices by aggregating multiple Ethernet connections into a higher bandwidth virtual connection. However, these protocols must quickly recover from the loss of one or more channel members. This fast recovery from a failure of an individual channel member can be used to provide link redundancy between two devices.

EtherChannel bundles multiple Ethernet links between two switches into a single logical link and balances the traffic load across the physical links. As shown in Figure 2-6, when a physical link is lost, the EtherChannel load-balancing algorithm stops using the lost link and uses the other available links. When the link is restored, EtherChannel resumes balancing the load across the available link. In this way, EtherChannel can be used as a resiliency protocol when multiple links exist between two switches. To be used as a resiliency protocol, the switches must have redundant links between each other, such as in the redundant star topology.

Figure 2-6 EtherChannel Basic Operation



LACP as defined in the IEEE 802.3ad standard facilitates the automatic creation of EtherChannels by exchanging LACP packets between Ethernet ports. As interoperability is a key requirement for the CPwE solution, Cisco, Panduit, and Rockwell Automation recommend the use of LACP to establish EtherChannel links between switches when multiple physical links exist. CPwE Resiliency design guidance below assumes the use of LACP.

EtherChannel has the following key advantages:

- **Bandwidth**—EtherChannel uses all available links simultaneously, adding bandwidth to uplink capacity
- **Standards-based**—As LACP is defined in an IEEE standard, infrastructure from various vendors can be configured in a topology and interoperate
- **Configurable via Device Manager web interface on IES**

EtherChannel has the following key disadvantage:

- **Performance**—Although EtherChannel uses multiple links and converges quickly when a link-loss is detected, it does not converge as quickly on average as Flex Links

Note For more on EtherChannel, see the "Configuring EtherChannels" chapter of the *Software Configuration Guide, Cisco IOS Release 15.2(2)E (Industrial Ethernet 2000 Switch)* at the following URL:

- http://www.cisco.com/c/en/us/td/docs/switches/lan/cisco_ie2000/software/release/15_2_2_e/configuration/guide/scg-ie2000/swethchl.html

Multiple Spanning Tree Protocol

Spanning Tree Protocol (STP) is a Layer 2 protocol designed to run on bridges and switches. Its main purpose is to avoid loops when redundant paths exist by deterministically blocking appropriate interfaces. If a link failure occurs in such a network, STP is responsible for establishing a new path for data traffic.

STP is arguably the only standard network protocol commonly available from a wide range of vendors and across any type of topology. It is a reasonable expectation that products from two or more network infrastructure vendors would inter-operate when running STP. Cisco, Panduit and Rockwell Automation know of no tests to verify the interoperability of STP between vendors.

STP is an IEEE standard that has gone through several revisions since its conception. These revisions are summarized as follows:

1. **Original Spanning Tree Protocol** is incorporated into IEEE 802.1D. STP will recover from a topology change in less than 60 seconds. STP is too slow to use in IACS networks.
2. **Rapid Spanning Tree Protocol (RSTP)** known as IEEE 802.1w is now incorporated into IEEE 802.1D-2004, which helps reduce the convergence time.
3. **Multiple Spanning Tree Protocol (MSTP)** known as IEEE 802.1s now incorporated into IEEE 802.1Q-2003, which extends the RSTP to work with multiple VLANs.

The standards are backward compatible with each other but may lose some of the performance advantages. For example, a ring of switches operating with both STP and RSTP, will default to using STP and thereby lose the performance advantages of RSTP. We recommend that when using STP, the switches in a topology are all operating the same STP protocol.

Cisco, Panduit and Rockwell Automation used MSTP for validation, since it is enabled by default by standard IES and Stratix macros. Using MSTP, multiple VLANs can be mapped to the same Spanning Tree instance, which reduces the number of Spanning Tree instances required to support many Virtual LANs (VLANs). MSTP runs on top of RSTP, which provides for rapid convergence by eliminating the forward delay and quickly transitioning root ports and designated ports to the forwarding state.

The key advantages of STP include the following:

- **Plug-and-Play**—STP sends packets to determine whether loops exist in the topology. If a loop is inadvertently created and STP has not been disabled, it will detect the loop and block a port to "close" the loop. For this feature, Cisco, Panduit and Rockwell Automation recommend that STP be enabled in a topology unless specific conflicts exist.
- **Consistency**—In the same topology, STP will always choose the same link to block.
- **Adaptability**—STP will function on any redundant topology.
- **Standards-based**—Since STP is defined in various IEEE standards, infrastructure from various vendors can be configured in a topology and inter-operate.

Key disadvantages of STP in general include the following:

- **Performance**—All variants of STP converge more slowly than other protocols. Cisco, Panduit and Rockwell Automation did not find that MSTP converges fast enough to avoid application outages on a consistent basis to recommend it for anything other than information/process applications.
- **Fallback issues**—STP is the lowest common denominator of the STP variants. It is supported by most hardware vendors and serves as the fallback if two devices are using incompatible STP implementations. If this situation occurs, STP may be unknowingly in effect due to incompatibility between the other STP variants, causing long network recovery when failures occur.

Note For more information on MSTP and related technologies, see *Understanding Multiple Spanning Tree Protocol (802.1s)* at the following URL:

- http://www.cisco.com/c/en/us/support/docs/lan-switching/spanning-tree-protocol/24248-147.html

The following section describes the redundant star options available for the access layer with their results.

Catalyst 9500 and Catalyst 4500-X with StackWise Virtual or VSS

The following use cases represent Catalyst 9500 in StackWise Virtual mode or Catalyst 4500-X in VSS mode as a distribution platform configured with Flex Links, EtherChannel, and Spanning Tree (MSTP) protocols correspondingly. See Figure 2-7, Figure 2-8, and Figure 2-9 depicting topologies.

Figure 2-7 Catalyst 9500 StackWise Virtual or Catalyst 4500-X VSS with Flex Links Redundant Star Topology

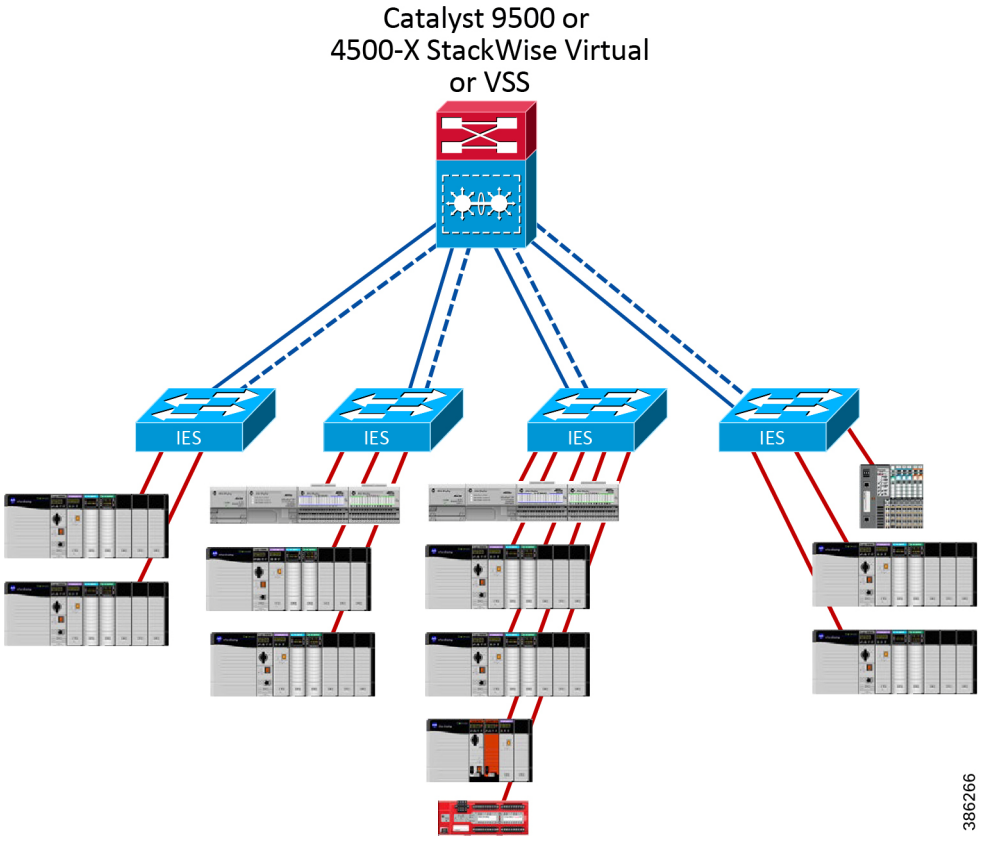


Figure 2-8 Catalyst 9500 StackWise Virtual or Catalyst 4500-X VSS with EtherChannel Redundant Star Topology

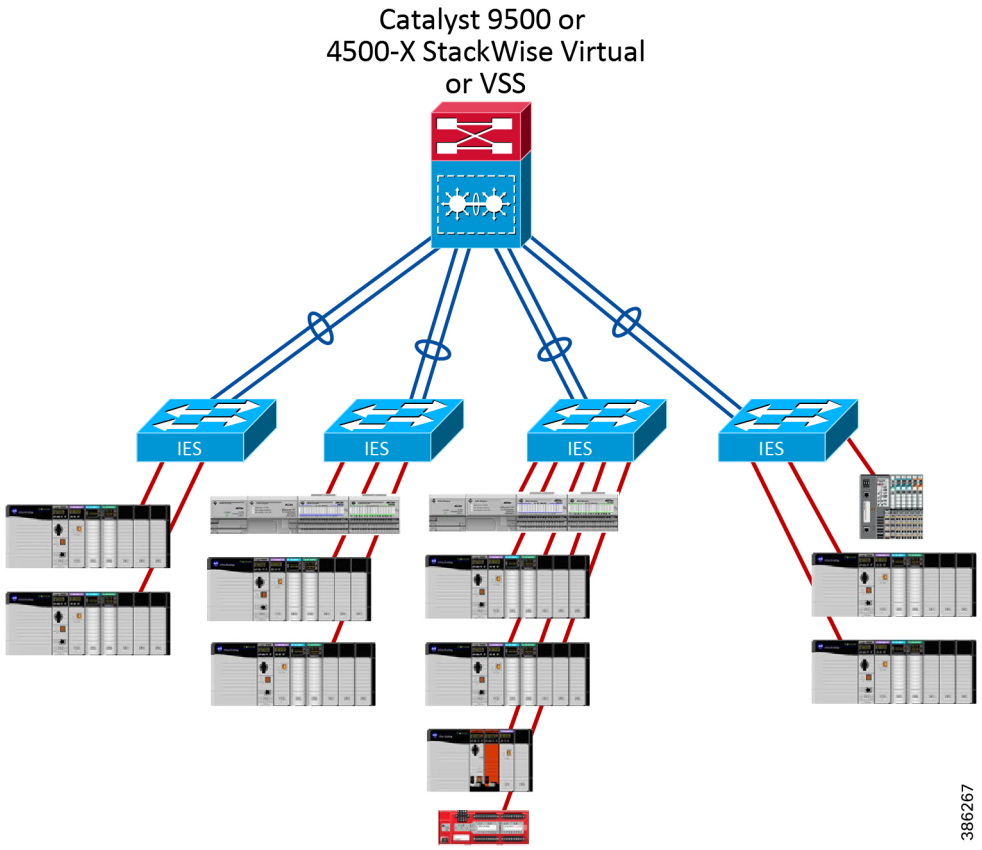


Figure 2-9 Catalyst 9500 StackWise Virtual or Catalyst 4500-X VSS with MSTP Redundant Star Topology

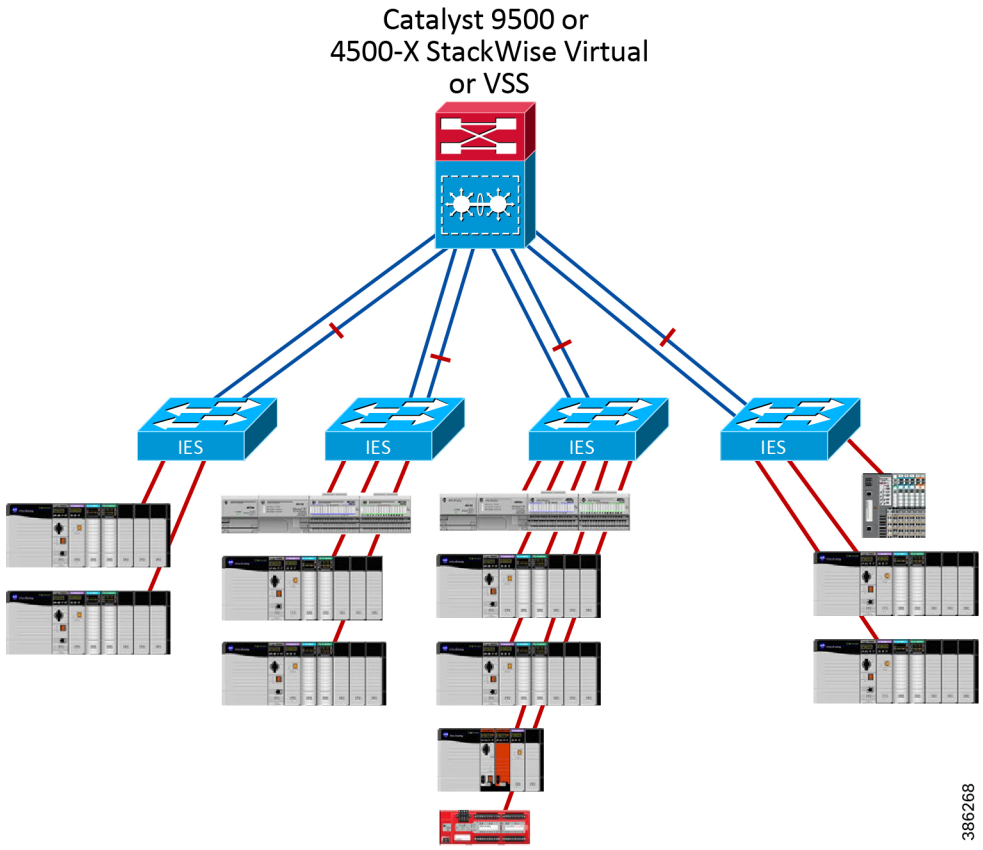


Table 2-4 and Table 2-5 summarize the convergence values observed during validation efforts and can be used to select the appropriate resiliency protocols based on application requirements. The results are based on CIP Class 1 (implicit) traffic flows (both unicast and multicast), and the unicast results are further divided into traffic that remains within the VLAN (Layer 2) and traffic that travels across VLANs (Layer 3).

Note Link disruptions in Table 2-4 and Table 2-5 refer to links within the Cell/Area Zone. Switch disruptions refer to the distribution switches only. To help prevent such events from occurring within your IACS network, refer to "Physical Infrastructure Design for the Cell/Area Zone" in *Physical Infrastructure for the Converged Plantwide Ethernet Architecture Application Guide* (https://www.cisco.com/c/en/us/td/docs/solutions/Verticals/CPwE/5-1/Phy_Arch/CPwE_PhyArch_AppGuide.html).

Table 2-4 Redundant Star Topology Resiliency Protocol Selection Criteria (Unicast)

Distribution Platform	Recommended Resiliency Method	Disruption Type	Flex Links Convergence (msec)				EtherChannel Convergence (msec)				MSTP Convergence (msec)			
			Traffic Type	Min	Avg	Max	Traffic Type	Min	Avg	Max	Traffic Type	Min	Avg	Max
Catalyst 9500	StackWise Virtual	Link	L2	14	142	386	L2	4	140	322	L2	44	188	362
			L3	12	142	386	L3	4	142	322	L3	12	188	352
		Switch	L2	52	212	704	L2	20	41	76	L2	62	135	200
			L3	54	212	700	L3	20	41	76	L3	62	135	196

Table 2-4 Redundant Star Topology Resiliency Protocol Selection Criteria (Unicast)

Catalyst 4500-X	VSS	Link	L2	4	68	272	L2	4	84	180	L2	N/A	N/A	N/A
			L3	4	21	80	L3	4	138	266	L3	N/A	N/A	N/A
		Switch	L2	18	126	230	L2	34	53	76	L2	N/A	N/A	N/A
			L3	20	30	40	L3	34	53	76	L3	N/A	N/A	N/A

Table 2-5 Redundant Star Topology Resiliency Protocol Selection Criteria (Multicast)

			Flex Links Convergence (msec)				EtherChannel Convergence (msec)				MSTP Convergence (msec)			
Distribution Platform	Recommended Resiliency Method	Disruption Type	Traffic Type	Min	Avg	Max	Traffic Type	Min	Avg	Max	Traffic Type	Min	Avg	Max
Catalyst 9500	StackWise Virtual	Link	L2	14	141	386	L2	4	141	322	L2	56	3040	11516
		Switch	L2	12	31	58	L2	20	41	76	L2	372	1911	3448
Catalyst 4500-X	VSS	Link	L2	4	21	82	L2	4	102	210	L2	N/A	N/A	N/A
		Switch	L2	20	30	42	L2	35	45	76	L2	N/A	N/A	N/A

Catalyst 9500 and Catalyst 4500-X with HSRP

The following use cases represent Catalyst 9500 or Catalyst 4500-X in HSRP mode as a distribution platform configured with Flex Links and MSTP protocols correspondingly. See Figure 2-10 and Figure 2-11 depicting topologies.

Figure 2-10 Catalyst 9500 or Catalyst 4500-X HSRP with Flex Links Redundant Star Topology

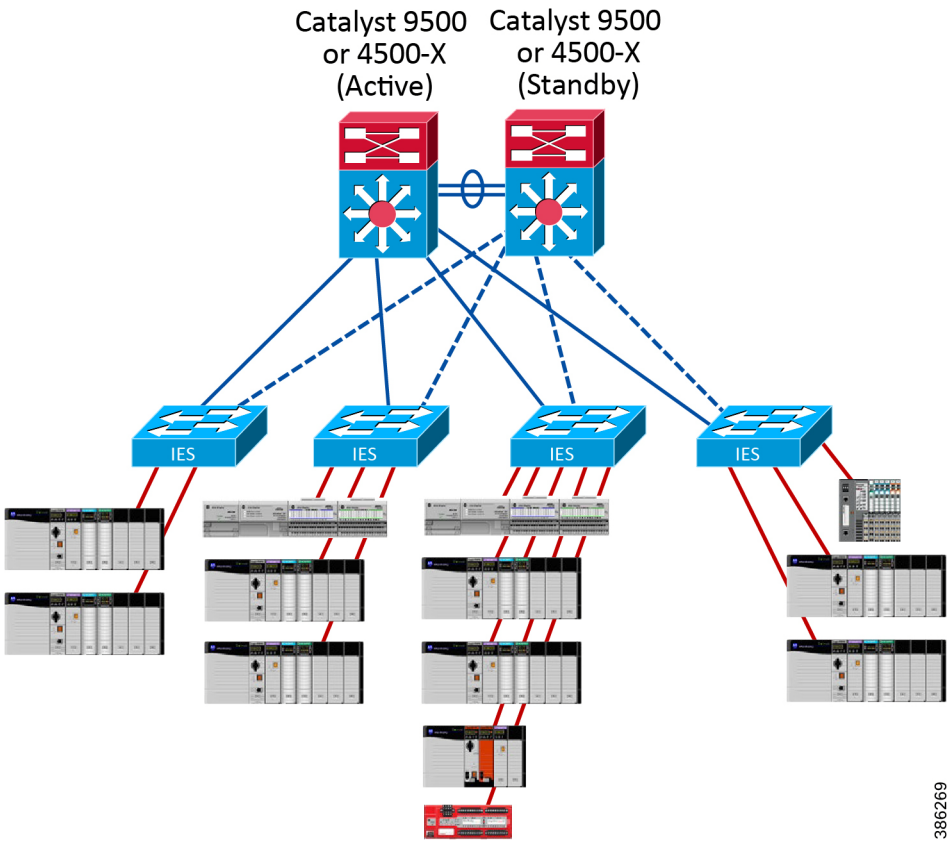


Figure 2-11 Catalyst 9500 or Catalyst 4500-X HSRP with MSTP Redundant Star Topology

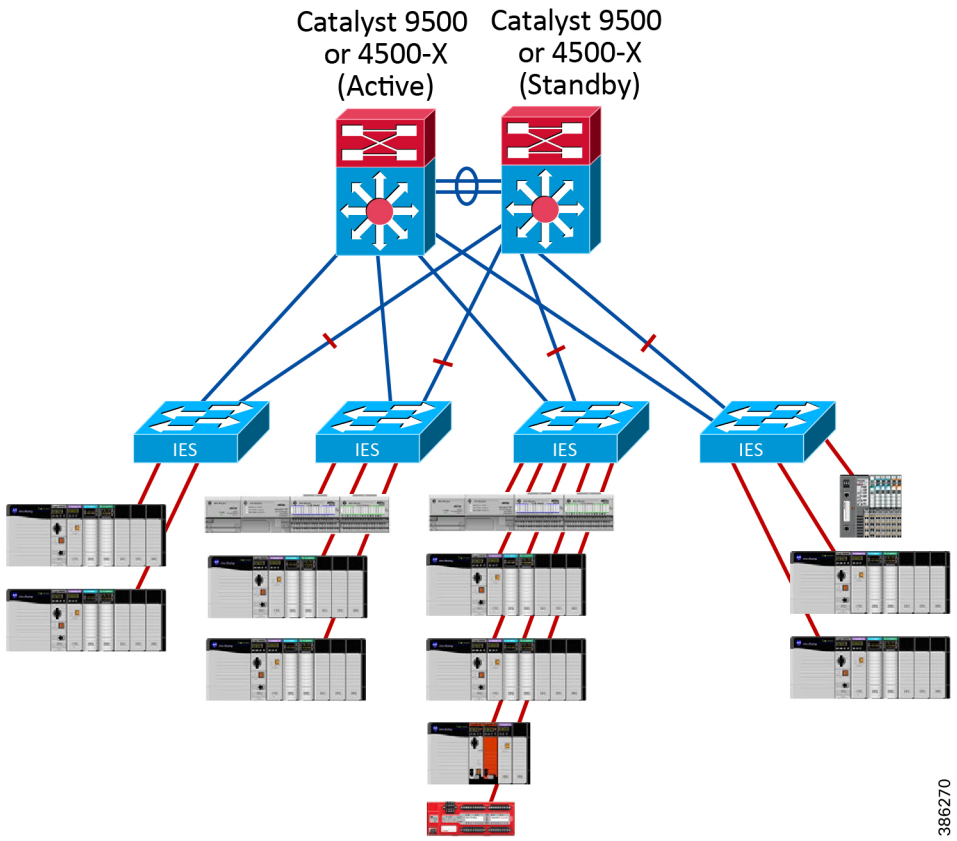


Table 2-6 and Table 2-7 summarize the convergence values observed during validation efforts and can be used to select the appropriate resiliency protocols based on application requirements.

Note Link disruptions in Table 2-6 and Table 2-7 refer to links within the Cell/Area Zone. Switch disruptions refer to the distribution switches only. To help prevent such events from occurring within your IACS network, refer to "Physical Infrastructure Design for the Cell/Area Zone" in *Physical Infrastructure for the Converged Plantwide Ethernet Architecture Application Guide* (https://www.cisco.com/c/en/us/td/docs/solutions/Verticals/CPwE/5-1/Phy_Arch/CPwE_PhyArch_AppGuide.html).

Table 2-6 Redundant Star Topology Resiliency Protocol Selection Criteria (Unicast)

Distribution Platform	Recommended Resiliency Method	Disruption Type	Flex Links Convergence (msec)				EtherChannel Convergence (msec)				MSTP Convergence (msec)			
			Traffic Type	Min	Avg	Max	Traffic Type	Min	Avg	Max	Traffic Type	Min	Avg	Max
Catalyst 9500	HSRP	Link	L2	20	38	124	L2	N/A	N/A	N/A	L2	40	74	120
			L3	12	38	129	L3	N/A	N/A	N/A	L3	12	73	120
		Switch	L2	16	35	74	L2	N/A	N/A	N/A	L2	46	152	2912
			L3	16	496	910	L3	N/A	N/A	N/A	L3	44	442	2912

Table 2-6 Redundant Star Topology Resiliency Protocol Selection Criteria (Unicast)

Catalyst 4500-X	HSRP	Link	L2	6	23	70	L2	N/A	N/A	N/A	L2	4	132	2198
			L3	6	25	68	L3	N/A	N/A	N/A	L3	4	145	2198
		Switch	L2	18	36	46	L2	N/A	N/A	N/A	L2	138	162	178
			L3	22	518	830	L3	N/A	N/A	N/A	L3	171	521	1024

Table 2-7 Redundant Star Topology Resiliency Protocol Selection Criteria (Multicast)

			Flex Links Convergence (msec)				EtherChannel Convergence (msec)				MSTP Convergence (msec)			
Distribution Platform	Recommended Resiliency Method	Disruption Type	Traffic Type	Min	Avg	Max	Traffic Type	Min	Avg	Max	Traffic Type	Min	Avg	Max
Catalyst 9500	HSRP	Link	L2	20	36	120	L2	N/A	N/A	N/A	L2	40	76	120
		Switch	L2	12	29	56	L2	N/A	N/A	N/A	L2	48	157	2920
Catalyst 4500-X	HSRP	Link	L2	6	22	58	L2	N/A	N/A	N/A	L2	22	2788	43384
		Switch	L2	17	2705	9810	L2	N/A	N/A	N/A	L2	68	4720	12788

Note **RESILIENCY RECOMMENDATION**:

- With Catalyst 9500 or Catalyst 4500-X as the distribution platform, Cisco, Panduit and Rockwell Automation recommend using StackWise Virtual/VSS as the Layer 3 gateway resiliency protocol and EtherChannel as the Layer 2 resiliency protocol for redundant star topology.

IE5000/Stratix 5410 with HSRP

The following use cases represent IE 5000/ Stratix 5410 in HSRP mode as a distribution platform configured with Flex Links and MSTP protocols correspondingly. See Figure 2-12 and Figure 2-13 depicting topologies.

Figure 2-12 IE 5000/Stratix 5410 HSRP with Flex Links Redundant Star Topology

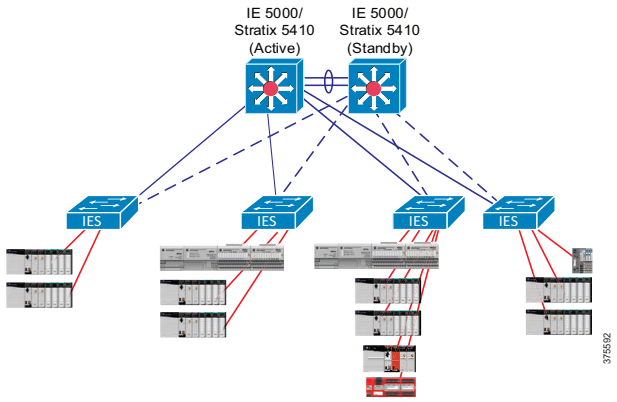


Figure 2-13 IE 5000/Stratix 5410 HSRP with MSTP Redundant Star Topology

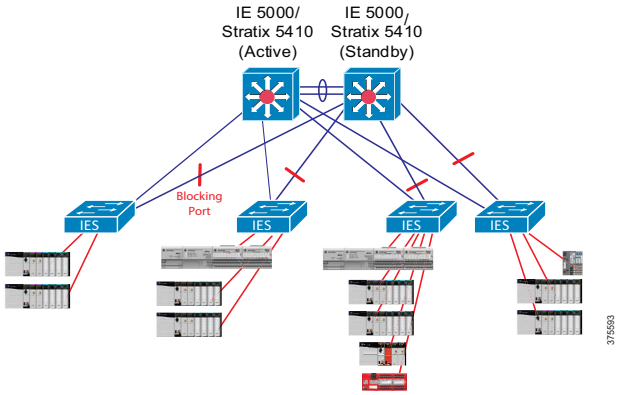


Table 2-8 and Table 2-9 summarize the convergence values observed during validation efforts and can be used to select the appropriate resiliency protocols based on application requirements.

Note Link disruptions in Table 2-8 and Table 2-9 refer to links within the Cell/Area Zone. Switch disruptions refer to the distribution switches only. To help prevent such events from occurring within your network, refer to "Physical Infrastructure Design for the Cell/Area Zone" in *Physical Infrastructure for the Converged Plantwide Ethernet Architecture Application Guide* (https://www.cisco.com/c/en/us/td/docs/solutions/Verticals/CPwE/5-1/Phy_Arch/CPwE_PhyArch_AppGuide.html).

Table 2-8 Redundant Star Topology Resiliency Protocol Selection Criteria (Unicast)

Distribution Platform	Recommended Resiliency Method	Disruption Type	Flex Links Convergence (msec)				EtherChannel Convergence (msec)				MSTP Convergence (msec)			
			Traffic Type	Min	Avg	Max	Traffic Type	Min	Avg	Max	Traffic Type	Min	Avg	Max
IE 5000/Stratix 5410	HSRP	Link	L2	8	31	92	L2	N/A	N/A	N/A	L2	68	123	294
			L3	8	37	92	L3	N/A	N/A	N/A	L3	68	122	296
		Switch	L2	12	41	90	L2	N/A	N/A	N/A	L2	107	113	767
			L3	12	296	888	L3	N/A	N/A	N/A	L3	436	695	977

Table 2-9 Redundant Star Topology Resiliency Protocol Selection Criteria (Multicast)

Distribution Platform	Recommended Resiliency Method	Disruption Type	Flex Links Convergence (msec)				EtherChannel Convergence (msec)				MSTP Convergence (msec)			
			Traffic Type	Min	Avg	Max	Traffic Type	Min	Avg	Max	Traffic Type	Min	Avg	Max
IE 5000/Stratix 5410	HSRP	Link	L2	8	24	48	L2	N/A	N/A	N/A	L2	66	2506	13522
		Switch	L2	6	278	9902	L2	N/A	N/A	N/A	L2	171	3986	9460

Note **RESILIENCY RECOMMENDATION**:

- With IE 5000/Stratix 5410 as the distribution platform, Cisco, Panduit and Rockwell Automation recommend using HSRP as the Layer 3 gateway resiliency protocol and Flex Links as the Layer 2 resiliency protocol.
- In this configuration, the distribution switch failure may cause high convergence time for multicast traffic and connection timeouts for IACS applications that use multicast.

Catalyst 9300 or Catalyst 3850 with StackWise-480

The following use cases represent Catalyst 9300 or Catalyst 3850 with StackWise-480 as a distribution platform configured with Flex Links, EtherChannels and MSTP protocols correspondingly. See Figure 2-14, Figure 2-15 and Figure 2-16 depicting topologies.

Figure 2-14 Catalyst 9300 or Catalyst 3850 StackWise-480 with Flex Links Redundant Star Topology

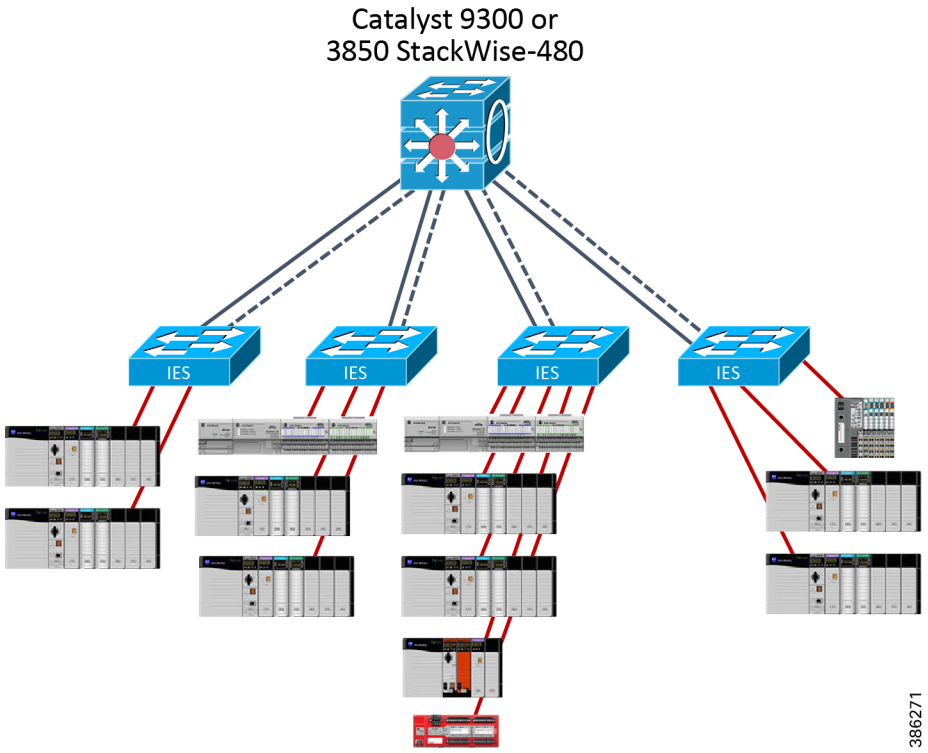


Figure 2-15 Catalyst 9300 or Catalyst 3850 StackWise-480 with EtherChannel Redundant Star Topology

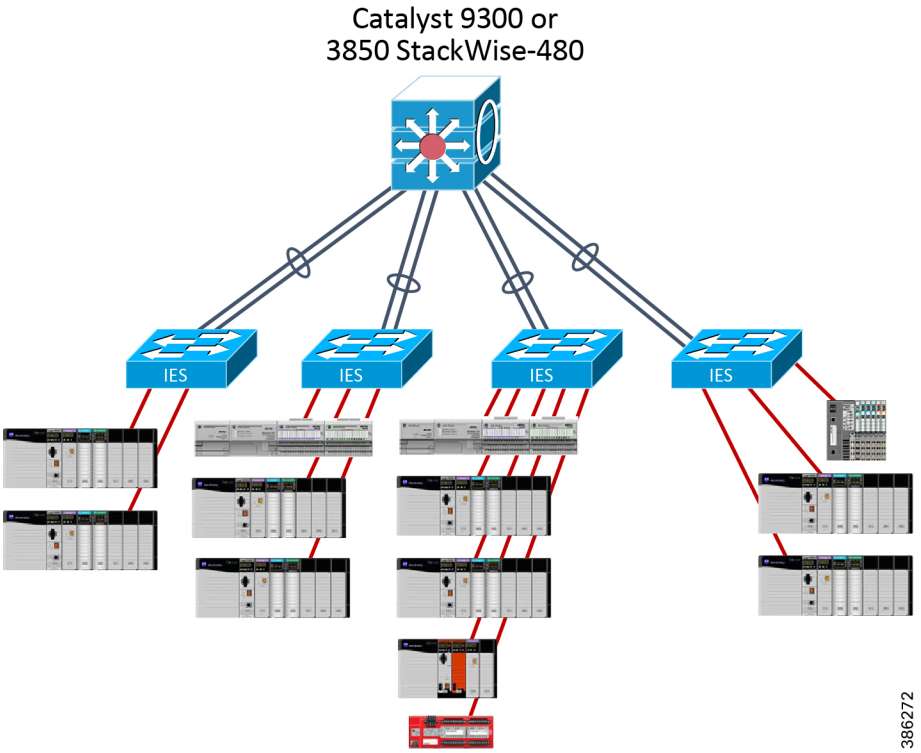


Figure 2-16 Catalyst 9300 or Catalyst 3850 StackWise-480 with MSTP Redundant Star Topology

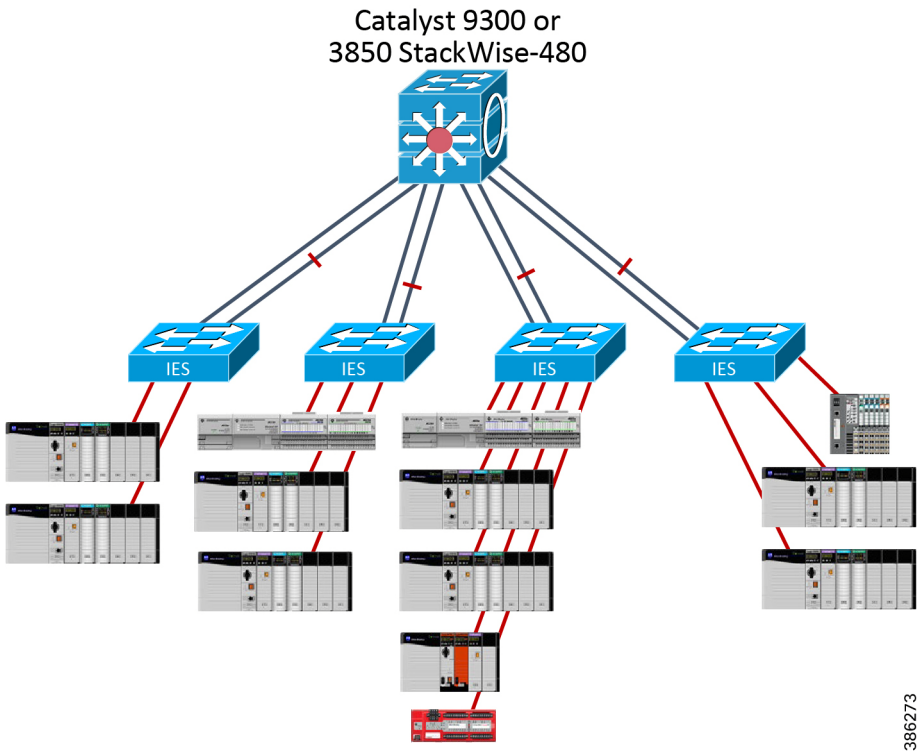


Table 2-10 and Table 2-11 summarize the convergence values observed during validation efforts and can be used to select the appropriate resiliency protocols based on application requirements.

Note Link and switch disruption locations are defined in Table 2-10 and Table 2-11. To help prevent such events from occurring within your network, refer to "Physical Infrastructure Design for the Cell/Area Zone" in *Physical Infrastructure for the Converged Plantwide Ethernet Architecture Application Guide* (https://www.cisco.com/c/en/us/td/docs/solutions/Verticals/CPwE/5-1/Phy_Arch/CPwE_PhyArch_AppGuide.html).

Table 2-10 Redundant Star Topology Resiliency Protocol Selection Criteria (Unicast)

Distribution Platform	Recommended Resiliency Method	Disruption Type	Flex Links Convergence (msec)				EtherChannel Convergence (msec)				MSTP Convergence (msec)			
			Traffic Type	Min	Avg	Max	Traffic Type	Min	Avg	Max	Traffic Type	Min	Avg	Max
Catalyst 9300	StackWise-480	Link	L2	10	35	92	L2	4	56	104	L2	4	414	2858
			L3	10	35	94	L3	4	56	106	L3	4	427	11634
		Switch	L2	66	136	276	L2	18	372	1036	L2	52	140	316
			L3	66	140	282	L3	18	376	1036	L3	54	141	317
Catalyst 3850	StackWise-480	Link	L2	14	49	124	L2	4	62	112	L2	52	203	526
			L3	14	49	124	L3	4	62	112	L3	52	205	526
		Switch	L2	12	48	172	L2	4	1871	7448	L2	62	2990	6382
			L3	10	47	172	L3	4	1870	7449	L3	60	2989	6382

Table 2-11 Redundant Star Topology Resiliency Protocol Selection Criteria (Multicast)

			Flex Links Convergence (msec)				EtherChannel Convergence (msec)				MSTP Convergence (msec)			
Distribution Platform	Recommended Resiliency Method	Disruption Type	Traffic Type	Min	Avg	Max	Traffic Type	Min	Avg	Max	Traffic Type	Min	Avg	Max
Catalyst 9300	StackWise-480	Link	L2	10	34	92	L2	4	56	104	L2	4	1429	26506
		Switch	L2	12	31	58	L2	4	372	1036	L2	1000	5646	19658
Catalyst 3850	StackWise-480	Link	L2	14	47	112	L2	4	62	112	L2	58	3433	11460
		Switch	L2	12	30	58	L2	4	1871	7448	L2	1526	25283	48124

Note **RESILIENCY RECOMMENDATION**:

- With Catalyst 9300 or Catalyst 3850 as the distribution platform, Cisco, Panduit, and Rockwell Automation recommend using StackWise-480 as the Layer 3 gateway resiliency protocol and Flex Links as the Layer 2 resiliency protocol.
- If EtherChannel is used as a Layer 2 resiliency protocol, distribution switch failures in the stack may cause high convergence times. The impact on IACS applications should be evaluated.

Ring Topology

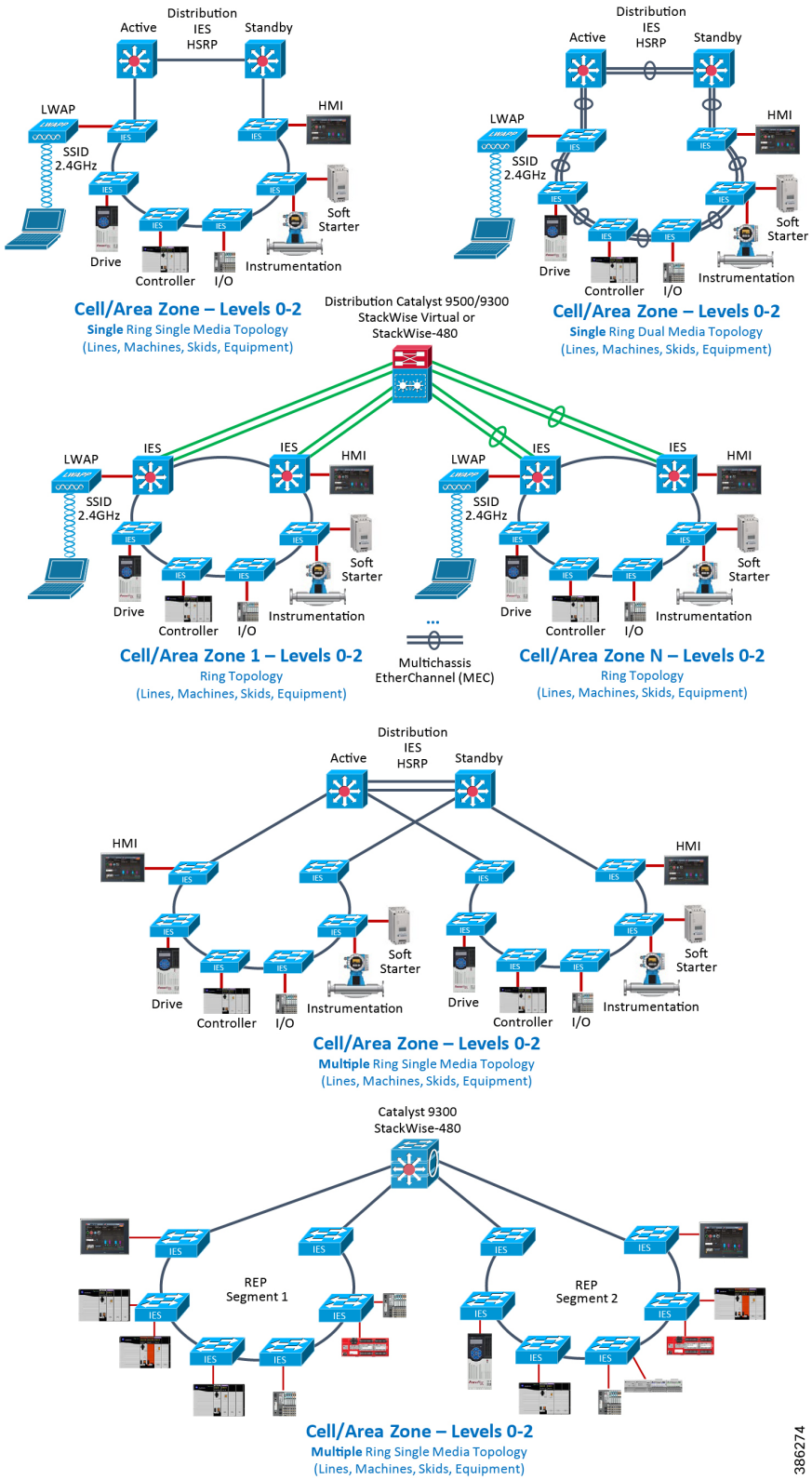
Resiliency Protocols and Topology Design Options

This section describes resiliency protocol and topology options for an access ring design. Several options are available when implementing a ring topology in the access layer (see Figure 2-17):

- Single ring with single media is the simplest choice in terms of implementation. All access switches are connected in a linear fashion, with each end of the line connected to the distribution switch. Multiple VLANs can exist in the ring segment. This design can sustain a single disruption within the ring and still maintain connectivity between all switches. It is supported with all IES platforms.
- Single ring with dual media uses the same design as the previous ring, but connects each switch with an EtherChannel, rather than a single link. Therefore, a single link disruption within the ring is converged by EtherChannel, and only a disruption of both links between two switches or a switch failure triggers the underlying resiliency protocol for recovery. This design can sustain multiple disruptions throughout the ring and still maintain connectivity between all switches, if at least one link is still active in each EtherChannel connection. Since dual links between each access switch are required, and Gigabit fiber media is recommended, only access switches with four or more Gigabit fiber ports support this design; such as the IE 4000/Stratix 5400 switches.
- For multiple rings (with single or dual media), two design options exist:
  - In the Layer 3 Access design, each of the rings contains two Layer 3 access switches that provide redundant gateways for routed traffic and handle Layer 2 resiliency. Routed traffic is then aggregated by the distribution switches, which provide routed connectivity to the core and handle Layer 3 resiliency. Multiple VLANs can exist in each ring segment; however, VLANs cannot be spanned across multiple rings because of the routed links in between.

– In the Layer 2 Access design, each of the rings attaches to the same pair of distribution switches that participate in a Layer 2 resiliency protocol, provide routed connectivity to the core, and handle Layer 3 resiliency. Multiple VLANs can exist in each ring segment and can span across segments.

Figure 2-17 Ring Topology Options



Resilient Ethernet Protocol

Resilient Ethernet Protocol (REP) is a technology implemented on Cisco distribution switches, Cisco IE, and Rockwell Automation Stratix IES. REP is designed to provide fast network and application convergence in a media or network failure, without a negative impact on most network applications.

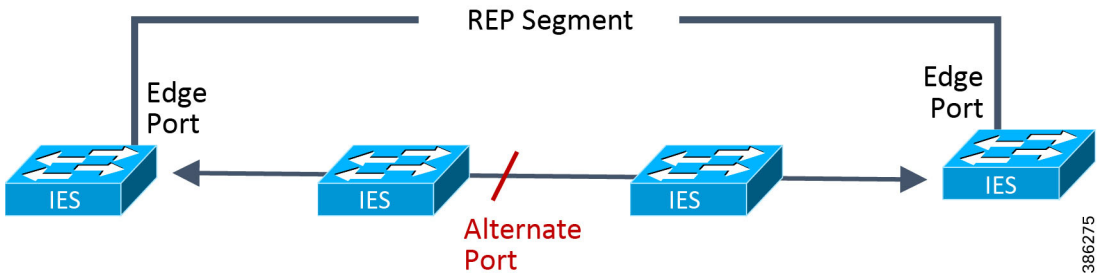
REP is a segment protocol that integrates easily into existing CPwE Cell/Area Zone LANs. Although REP disables STP on interfaces where REP is enabled, it can coexist with STP as part of the same Cell/Area Zone LAN. Since REP can also notify STP about potential topology changes, it allows for interoperability between the two.

REP is a distributed and secure control plane protocol that does not rely on a primary switch controlling the status of the ring. Therefore, failures can be detected locally, either through loss of signal (LOS) or loss of connectivity to a neighboring switch. By default, REP automatically elects an alternate port (the switch port being blocked). Any REP port within the REP topology can initiate a switchover to unblock the alternate port.

REP Operation

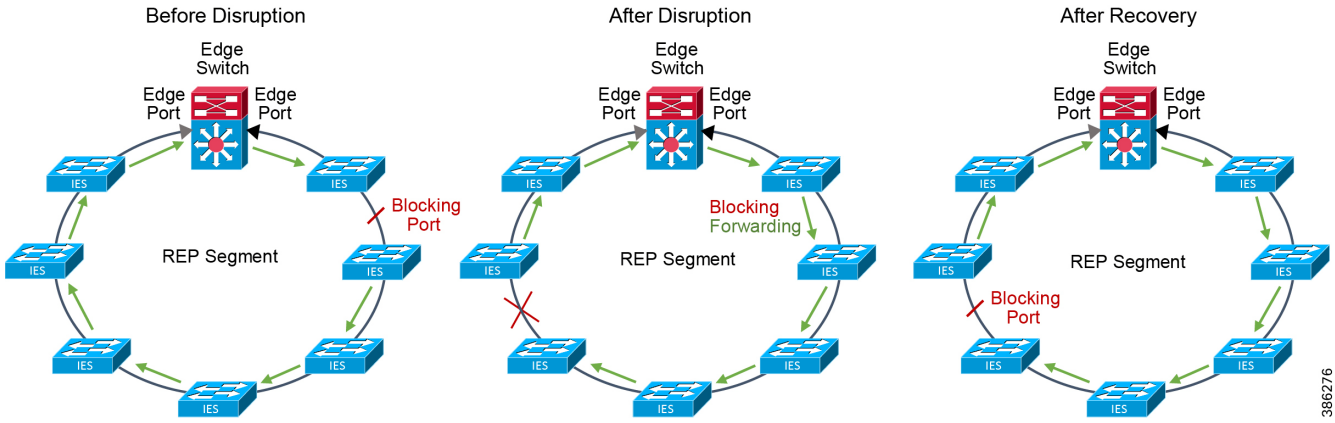
A REP segment, as shown in Figure 2-18, is a chain of switch ports connected to each other and configured with the same segment ID. Each end of a segment terminates on what is called the "edge port" of an edge switch. Each switch in a segment has exactly two REP-enabled ports.

Figure 2-18 REP Segment



With REP, to help prevent a loop in the network, one switch port (the alternate port) is always blocked in any given segment. The blocked port helps achieve loop-free traffic within the segment by requiring traffic flow to exit only one of the edge ports. Therefore, when a failure occurs in the segment, REP opens the alternate port so traffic can reach the edge of the segment. Figure 2-19 shows the basic operation of REP to converge the network when a disruption occurs.

Figure 2-19 REP Basic Operation



REP Fault Detection

REP, which relies primarily on LOS to detect a fiber link failure, can always learn the location of the failure within the ring. When a failure occurs, the failed ports immediately send link failure notifications to all REP peers. The failure notification has two purposes:

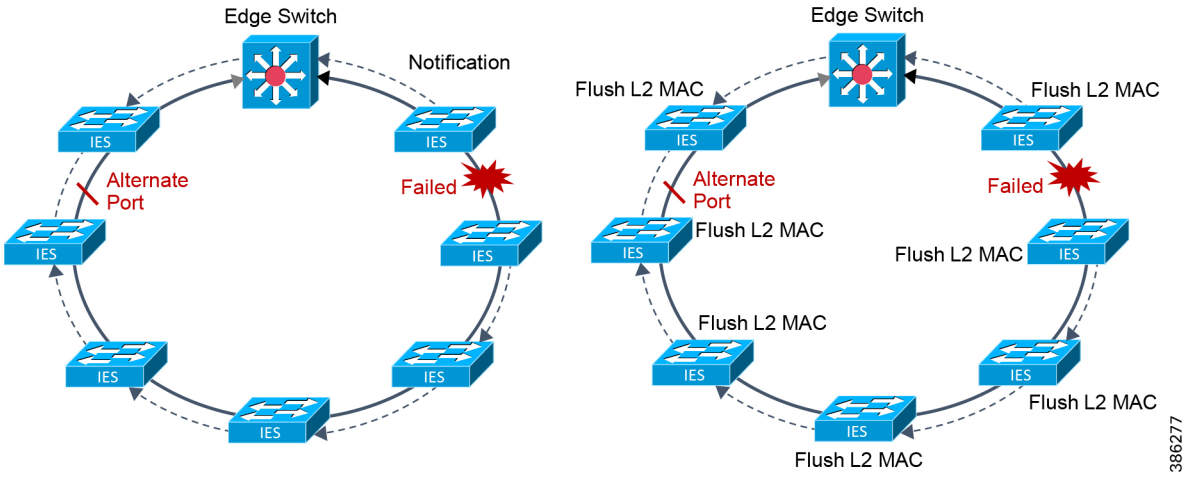
- Instruct the alternate port to unblock immediately because the segment is broken.
- Flush MAC table entries on all switches within the REP segment.

A REP node maintains neighbor adjacencies and continuously exchanges hello packets with its neighbors. In scenarios where LOS is not detected, the loss of a REP adjacency also triggers a switchover. Neighbor adjacency awareness is unique to REP and has advantages over alternate polling mechanisms that require centralized management from a primary node. The Unidirectional Link Detection Protocol (UDLD) can be enabled on REP interfaces to detect unidirectional failures. The UDLD is enabled by default after the IES Express Setup.

Fast and reliable failure notification is critical for accomplishing rapid convergence for an IACS application. To achieve this, REP propagates the notifications using the following two methods:

- **Fast Notification—**Using a Multicast MAC address, the notification is forwarded in hardware so that each node in the segment is notified immediately without software involvement from any node.
- **Reliable Notification—**Distributed through the REP Adjacency Protocol and can be retransmitted if lost. The protocol uses sequence numbering and relies on packet acknowledgment. Upon receiving the notification, each REP node flushes MAC address entries learned on these REP ports and the alternate port then begins forwarding traffic. Because REP sends the notification through a reserved multicast address, the MAC addresses flushing can proceed in parallel on each REP node (Figure 2-20).

Figure 2-20 REP Link Fault Notifications



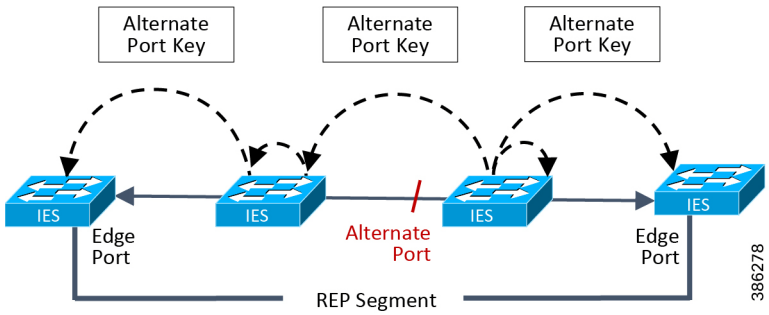
REP Distributed and Secure

REP is a distributed and secure control plane protocol that does not rely on a primary node monitoring the health of the ring. REP provides an additional layer of security, which helps protect the reliability and availability of the REP segment with the use of a 9-byte word generated by the alternate port and that is unique to that REP segment. The primary edge port is responsible only for initiating topology collection. Failure can be detected locally either through LOS or loss of neighbor adjacency. Any REP port can initiate a switchover as long as it has acquired a secure key to unblock the alternate port.

The secure key consists of a 9-byte length word that identifies each port. It is a combination of the port ID and a random number generated when the port activates. The alternate port key is secure because it is distributed only within a specific segment.

The REP alternate port generates and distributes its key to all other ports within the segment (Figure 2-21). Each port on the segment can use that key to unblock the alternate port. With this mechanism, users or attackers cannot unblock the alternate port unless they learn the key. This mechanism helps protect against potential security attacks; it also avoids problems with overlapping segment IDs due to misconfiguration.

Figure 2-21 Alternate Port Key Distribution



MSTP

For a description of MSTP, please refer to Multiple Spanning Tree Protocol, page 2-13.

As with redundant star topologies, Cisco, Panduit and Rockwell Automation do NOT recommend that MSTP should exist in a ring topology except for information/process applications that do not require fast convergence.

Single Ring (Single Media)

Note The recommendations for this use case only apply to a single REP segment connection to the distribution switch. CPwE Resiliency testing and validation for this use case produced convergence results that are acceptable to most IACS application resiliency requirements. See Table 2-16 and Table 2-17.

The recommendations for this use case do not apply to architectures that require connection of multiple REP segments to the same distribution switch. If multiple access rings are required, refer to Multiple Ring Segments, page 2-46.

In a single access ring design consisting of any IES model with up to 50 switches, REP should generally be used for resiliency, since it provides better reaction time following a disruption than other protocols. The REP segment should be configured with the edges co-located on the primary distribution switch, as shown in Figure 2-22. All other ports in the ring should be configured as members of the segment.

Note Only 1 Gbps fiber links between switches in a ring topology were tested as part of CPwE Resiliency. The fiber media provides faster convergence to meet the requirements of most IACS applications. For applications that can perform appropriately with RPI settings of 100 ms or greater, such as Motor Control Centers (MCC) applications, a Fast Ethernet (100 Mbps) copper inter-switch links may provide sufficient convergence in a REP topology.

- The first use case represents Catalyst 9500, Catalyst 4500-X, IE 5000/Stratix 5410, or IE 4000/Stratix 5400 as a distribution platform configured in HSRP mode with REP (Figure 2-22).
- A second use case represents Catalyst 9300 or Catalyst 3850 switches configured with StackWise-480 technology acting as the distribution switch in a REP ring topology (Figure 2-23).

Note Multiple VLANs can exist in a ring topology. Use cases have been validated for Layer 2 traffic within a VLAN and for Layer 3 traffic between VLANs in the same ring.

Figure 2-22 Catalyst 9500, Catalyst 4500-X, IE 5000/Stratix 5410, or IE 4000/Stratix 5400 HSRP with REP Ring Topology

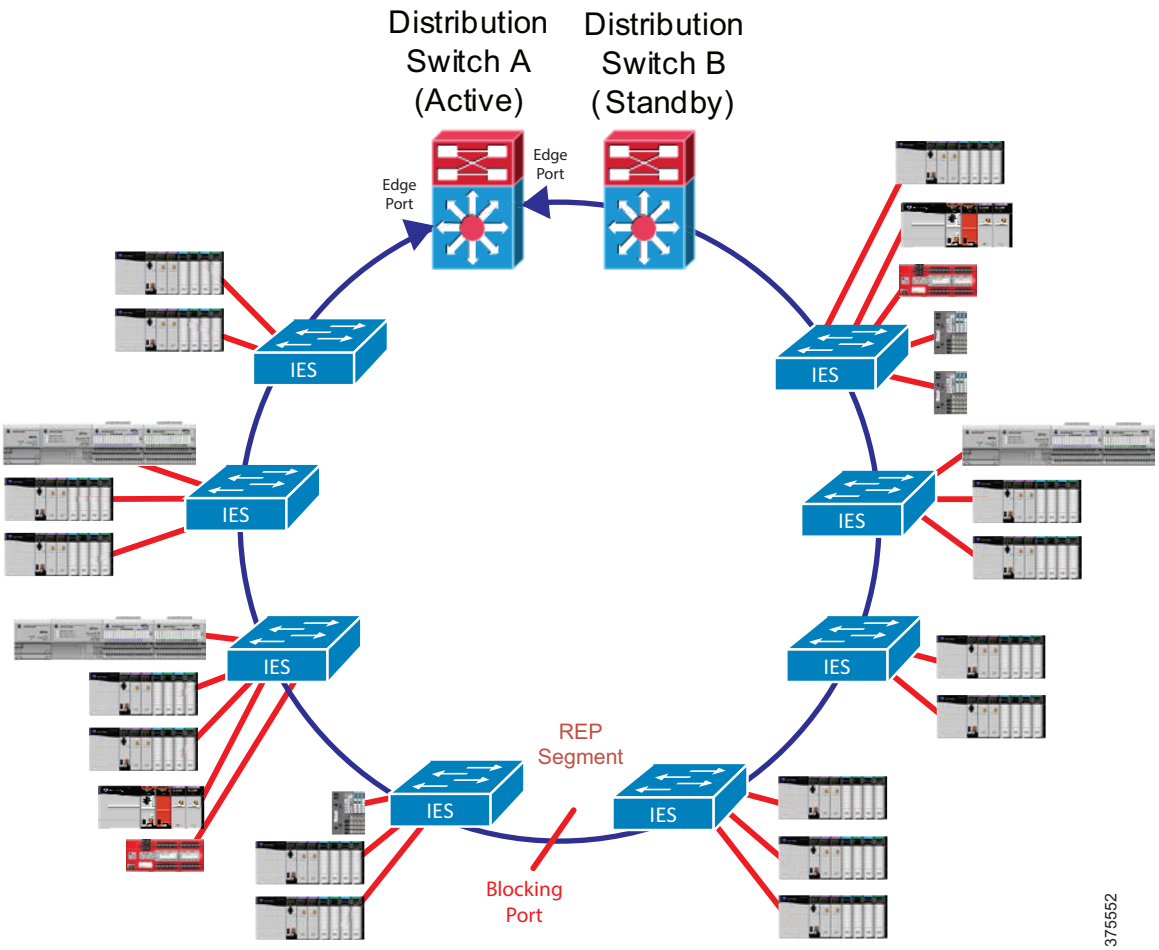


Figure 2-23 Catalyst 9300 or Catalyst 3850 StackWise-480 with REP Ring Topology

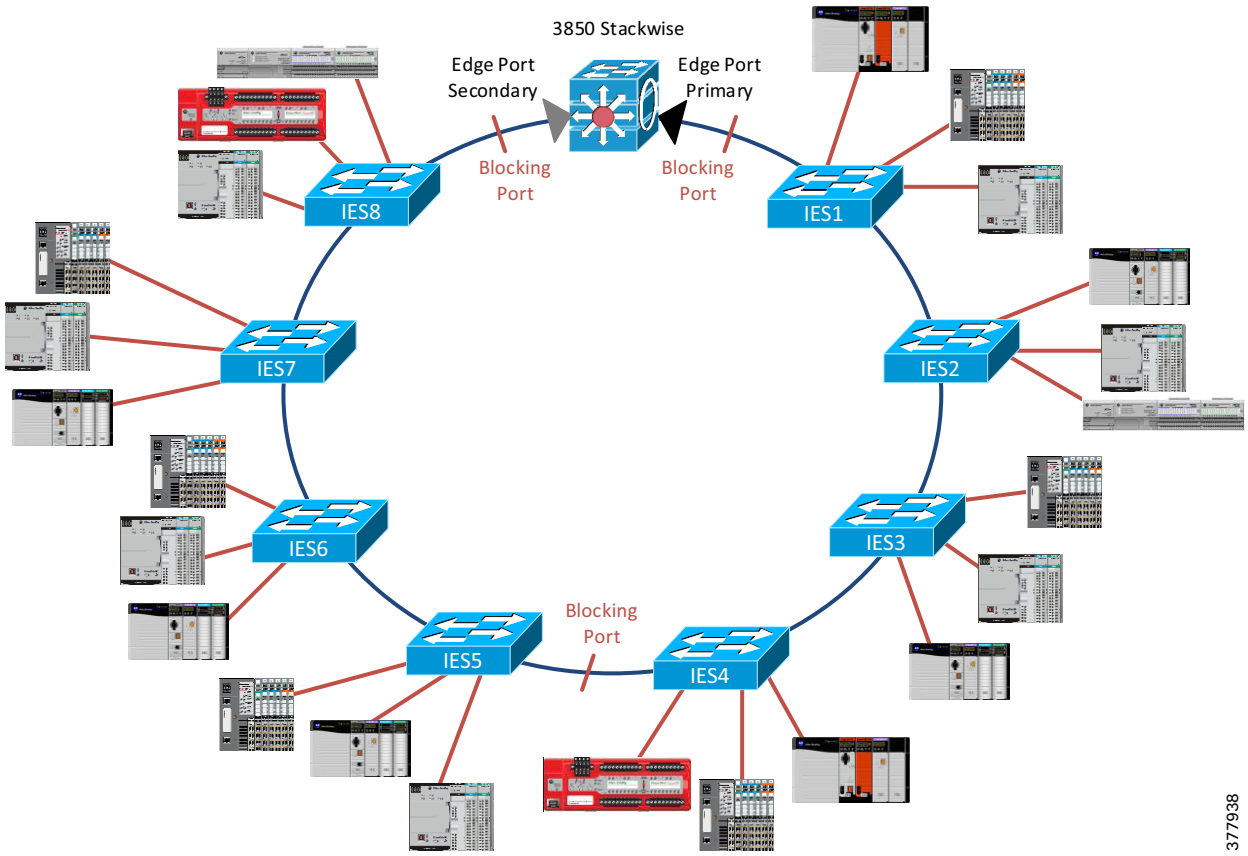


Table 2-12 and Table 2-13 summarize the convergence values observed during validation efforts and can be used to select the appropriate resiliency protocols based on application requirements.

REP configuration for a single ring is as follows:

- For HSRP use cases, both primary and secondary REP edges are on the HSRP active gateway
- For StackWise-480 use cases, the primary REP edge and the secondary REP edge are on different switches in the stack

Note Link disruptions in Table 2-12 and Table 2-13 refer to links within the Cell/Area Zone. Switch disruptions refer to the distribution switches only. To help prevent such events from occurring within your network, refer to "Physical Infrastructure Design for the Cell/Area Zone" in *Physical Infrastructure for the Converged Plantwide Ethernet Architecture Application Guide* (https://www.cisco.com/c/en/us/td/docs/solutions/Verticals/CPwE/5-1/Phy_Arch/CPwE_PhyArch_AppGuide.html).

Table 2-12 Single Ring (Single Media) Topology Resiliency Protocol Selection Criteria (Unicast)

Distribution Platform	Recommended Resiliency Method	Disruption Type	REP Convergence (msec) Traffic Type	Min	Avg	Max
Catalyst 9500	HSRP	Link	L2	L3	4	34
			L3	4	34	82
		Switch	L2	29	194	238
			L3	20	44	864
Catalyst 4500-X	HSRP	Link	L2	4	45	112
			L3	4	56	186
		Switch	L2	16	56	90
			L3	16	461	1064
IE 5000/Stratix 5410	HSRP	Link	L2	8	31	68
			L3	8	31	68
		Switch	L2	18	31	50
			L3	18	430	896
IE 4000/Stratix 5400	HSRP	Link	L2	4	33	78
			L3	4	33	78
		Switch	L2	16	32	40
			L3	4	154	516
Catalyst 9300	StackWise-480	Link	L2	18	116	314
			L3	4	92	486
		Switch	L2	18	119	378
			L3	4	154	516

Table 2-13 Single Ring (Single Media) Topology Resiliency Protocol Selection Criteria (Multicast)

Distribution Platform	Recommended Resiliency Method	Disruption Type	REP Convergence (msec) Traffic Type	Min	Avg	Max
Catalyst 9500	HSRP	Link	L2	12	13	290
		Switch	L2	40	185	348
Catalyst 4500-X	HSRP	Link	L2	8	51	220
		Switch	L2	4	31	74
IE 5000/Stratix 5410	HSRP	Link	L2	6	27	66
		Switch	L2	14	29	48
IE 4000/Stratix 5400	HSRP	Link	L2	18	29	40
		Switch	L2	14	31	38
Catalyst 9300	StackWise-480	Link	L2	6	104	298
		Switch	L2	16	109	350

Note **Resiliency Recommendation**:

- With Catalyst 9500, Catalyst 4500-X, IE 5000/Stratix 5410, or IE 4000/Stratix 5400 as the distribution platform, Cisco, Panduit, and Rockwell Automation recommend using HSRP as the Layer 3 gateway resiliency protocol and REP as the Layer 2 resiliency protocol. This allows for fast convergence of the traffic within the Cell/Area Zone and failover for traffic leaving the Cell/Area Zone.
- With Catalyst 9300 in StackWise-480 mode as the distribution platform, Cisco, Panduit, and Rockwell Automation recommend using this platform in ring topologies only for applications that can tolerate maximum times as shown in the Table 2-12 and Table 2-13.
- At the time of this publication, REP is not supported with the Catalyst 9500 configured with StackWise Virtual mode.

Note For detailed results on link and switch disruptions in ring topologies with MSTP, see the "Complete Test Data" appendix of the *Converged Plantwide Ethernet (CPwE) Design and Implementation Guide* at the following URLs:

Rockwell Automation site:

- http://literature.rockwellautomation.com/idc/groups/literature/documents/td/enet-td001_-en-p.pdf

Cisco site:

- http://www.cisco.com/en/US/docs/solutions/Verticals/CPwE/CPwE_DIG.html

Single Ring (Dual Media)

Note These recommendations only apply to a single ring design with dual media links between switches. If multiple access rings are required, refer to the following Multiple Ring Segments section for recommendations.

If the access ring is constructed entirely from IE 4000/Stratix 5400, which has four SFP gigabit uplinks available, then an alternative to the previous design is a dual media ring. In this design, the access switches have two links between each switch that are grouped into an EtherChannel, as shown in Figure 2-24. REP is still recommended for resiliency and is configured as in the single media case. Multiple network disruption scenarios are accommodated by this design:

- **Single Link Disruption**—The EtherChannel itself provides the resiliency for a single link disruption, migrating traffic from the disrupted link to the remaining link automatically (see description of EtherChannel in Redundant Star Topology, page 2-11). Because each connection between switches is a separate EtherChannel, the ring is also resilient to multiple link disruptions if the two links within each EtherChannel are not both disrupted simultaneously.
- **EtherChannel Disruption**—While unlikely, if both links within one of the EtherChannels fail simultaneously, causing the entire EtherChannel to go down, REP (or MSTP) is responsible for recovering the network in the same way as the single media ring, providing a backup mechanism for the EtherChannel resiliency.
- **Switch Disruption**—Since a switch disruption (access or distribution switch) causes all links within its connected EtherChannels to be disrupted as well, REP (or MSTP) is responsible for recovering the network in the same way as the single media ring.

The following use cases have been tested with dual-media ring topology:

- Catalyst 9500, Catalyst 4500-X, or IE 5000/Stratix5410 as a distribution platform configured in HSRP mode with EtherChannel and REP. See Figure 2-24.
- Catalyst 9300 or Catalyst 3850 as a distribution platform in StackWise-480 mode with EtherChannel and REP. See Figure 2-25.

Note Multiple VLANs can exist in a ring topology with dual media. Use cases have been validated for Layer 2 traffic within a VLAN and for Layer 3 traffic between VLANs in the same ring.

Figure 2-24 Catalyst 9500, Catalyst 4500-X, or IE 5000/Stratix 5410 HSRP with REP Dual Media Ring Topology

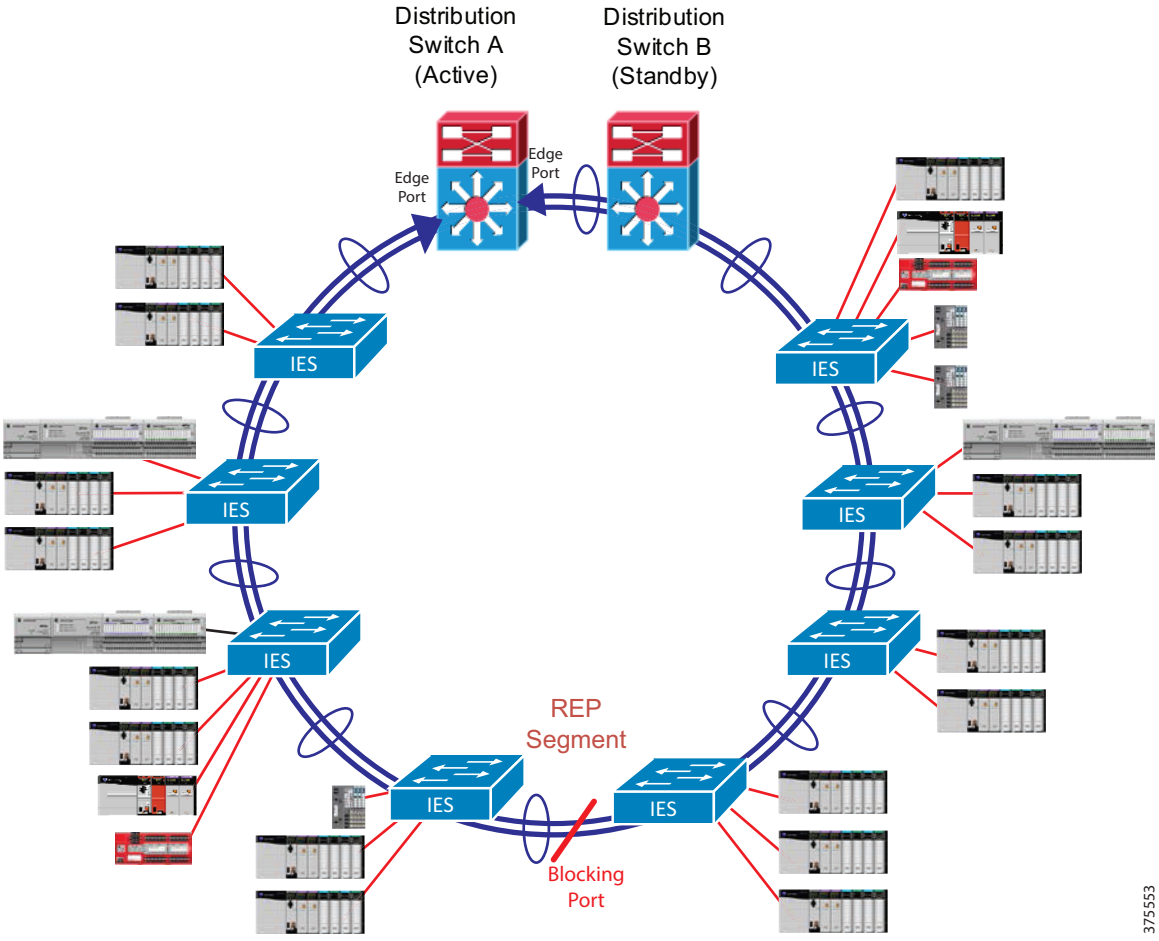


Figure 2-25 Catalyst 9300 or Catalyst 3850 StackWise with REP Dual Media Ring Topology

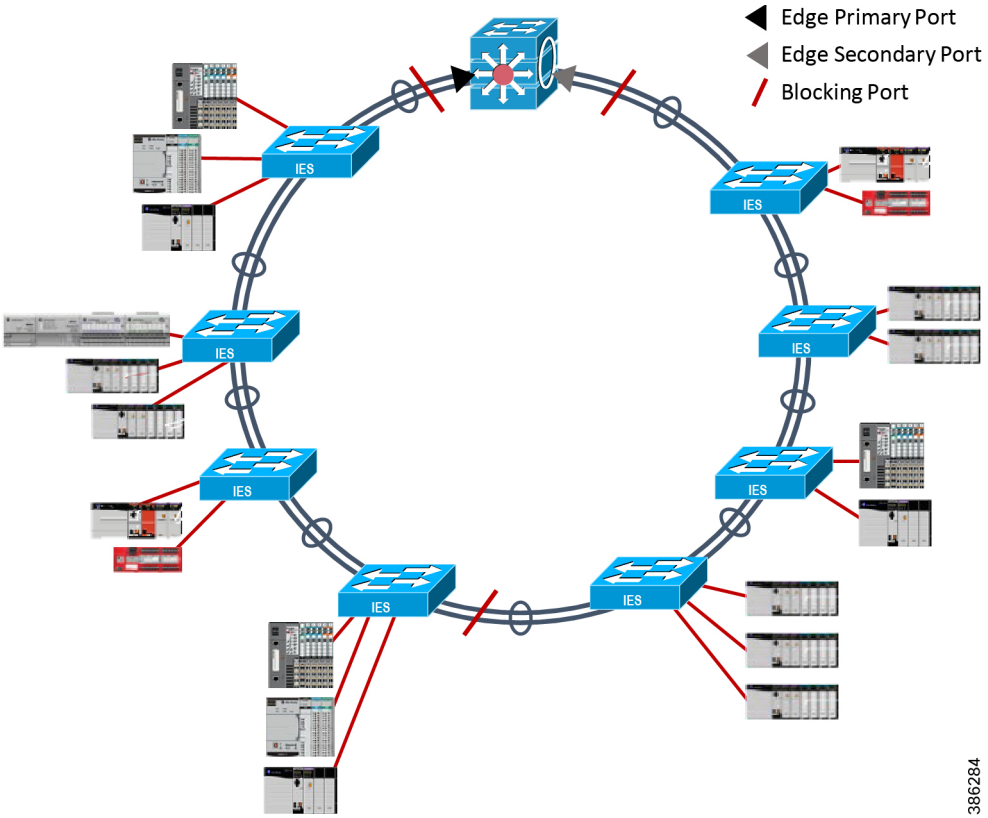


Table 2-14 and Table 2-15 summarizes the convergence values observed during validation efforts, and can be used to select the appropriate resiliency protocols based on application requirements.

Note Link disruptions in Table 2-14 and Table 2-15 refer to links within the Cell/Area Zone. Switch disruptions refer to the distribution switches only. To help prevent such events from occurring within your network, refer to "Physical Infrastructure Design for the Cell/Area Zone" in *Physical Infrastructure for the Converged Plantwide Ethernet Architecture Application Guide* (https://www.cisco.com/c/en/us/td/docs/solutions/Verticals/CPwE/5-1/Phy_Arch/CPwE_PhyArch_AppGuide.html).

Table 2-14 Single Ring (Dual Media) Topology Resiliency Protocol Selection Criteria (Unicast)

Distribution Platform	Recommended Resiliency Method	Disruption Type	REP Convergence (msec)			
			Traffic Type	Min	Avg	Max
Catalyst 9500	HSRP	Link	L2	4	38	84
			L3	4	40	82
		Switch	L2	18	68	154
			L3	46	442	896
Catalyst 4500-X	HSRP	Link	L2	4	94	2204
			L3	4	170	2204
		Switch	L2	30	60	92

Table 2-14 Single Ring (Dual Media) Topology Resiliency Protocol Selection Criteria (Unicast) (continued)

Distribution Platform	Recommended Resiliency Method	Disruption Type	REP Convergence (msec)			
			Traffic Type	Min	Avg	Max
			L3	30	44	1036
IE 5000/Stratix 5410	HSRP	Link	L2	4	31	74
			L3	4	34	74
		Switch	L2	28	29	30
			L3	22	454	950
Catalyst 9300	StackWise-480	Link	L2	4	98	256
			L3	4	97	296
		Switch	L2	18	83	192
			L3	6	119	505
Catalyst 3850	StackWise-480	Link	L2	4	304	850
			L3	4	301	868
		Switch	L2	16	78	286
			L3	12	91	374

Table 2-15 Single Ring (Dual Media) Topology Resiliency Protocol Selection Criteria (Multicast)

Distribution Platform	Recommended Resiliency Method	Disruption Type	REP Convergence (msec)			
			Traffic Type	Min	Avg	Max
Catalyst 9500	HSRP	Link	L2	16	68	146
		Switch	L3	12	62	194
Catalyst 4500-X	HSRP	Link	L2	4	77	2205
		Switch	L3	30	70	172
IE 5000/Stratix 5410	HSRP	Link	L2	4	39	98
		Switch	L3	2	44	64
Catalyst 9300	StackWise-480	Link	L2	4	90	272
		Switch	L3	38	94	212
Catalyst 3850	StackWise-480	Link	L2	4	288	864
		Switch	L3	38	107	278

Note

Resiliency Recommendation:

- With Catalyst 9500 or IE 5000/Stratix 5410 as the distribution platform in a dual-media ring, Cisco, Panduit and Rockwell Automation recommend using HSRP as the Layer 3 gateway resiliency protocol and EtherChannel (with REP) as the Layer 2 resiliency protocol. This allows for fast convergence of the traffic within the Cell/Area Zone and failover for traffic leaving the Cell/Area Zone.
- With Catalyst 9300, Catalyst 4500-X, or Catalyst 3850 as the distribution platform, due to higher REP convergence times, Cisco, Panduit, and Rockwell Automation recommend using these platforms in dual-media rings only for applications that can tolerate maximum times as shown in the Table 2-14 and Table 2-15.

Multiple Rings

Two design options exist for the multiple ring topology: Layer 2 Access design and Layer 3 Access design. With REP as a ring resiliency protocol, the following use cases have been considered for the CPwE architecture:

- Multiple REP segments with Layer 2 access switches connecting to a pair of the distribution IE 5000/Stratix 5410 switches with HSRP
- Multiple REP segments with Layer 2 access switches connecting to the distribution Catalyst 9300 StackWise-480
- Multiple REP segments with an HSRP pair of Layer 3 access switches in each segment connecting to a Catalyst 9500 StackWise Virtual pair, Catalyst 4500-X VSS pair, or a Catalyst 9300 or 3850 StackWise-480 via Layer 3 (routed) links

Layer 2 Access with Multiple Rings

The following use cases represent the requirement for configuring multiple REP segments using one pair of Catalyst 9500 or IE 5000/Stratix 5410 switches with HSRP. See Figure 2-26 and Figure 2-27.

Figure 2-26 Catalyst 9500 HSRP with REP Ring Topology

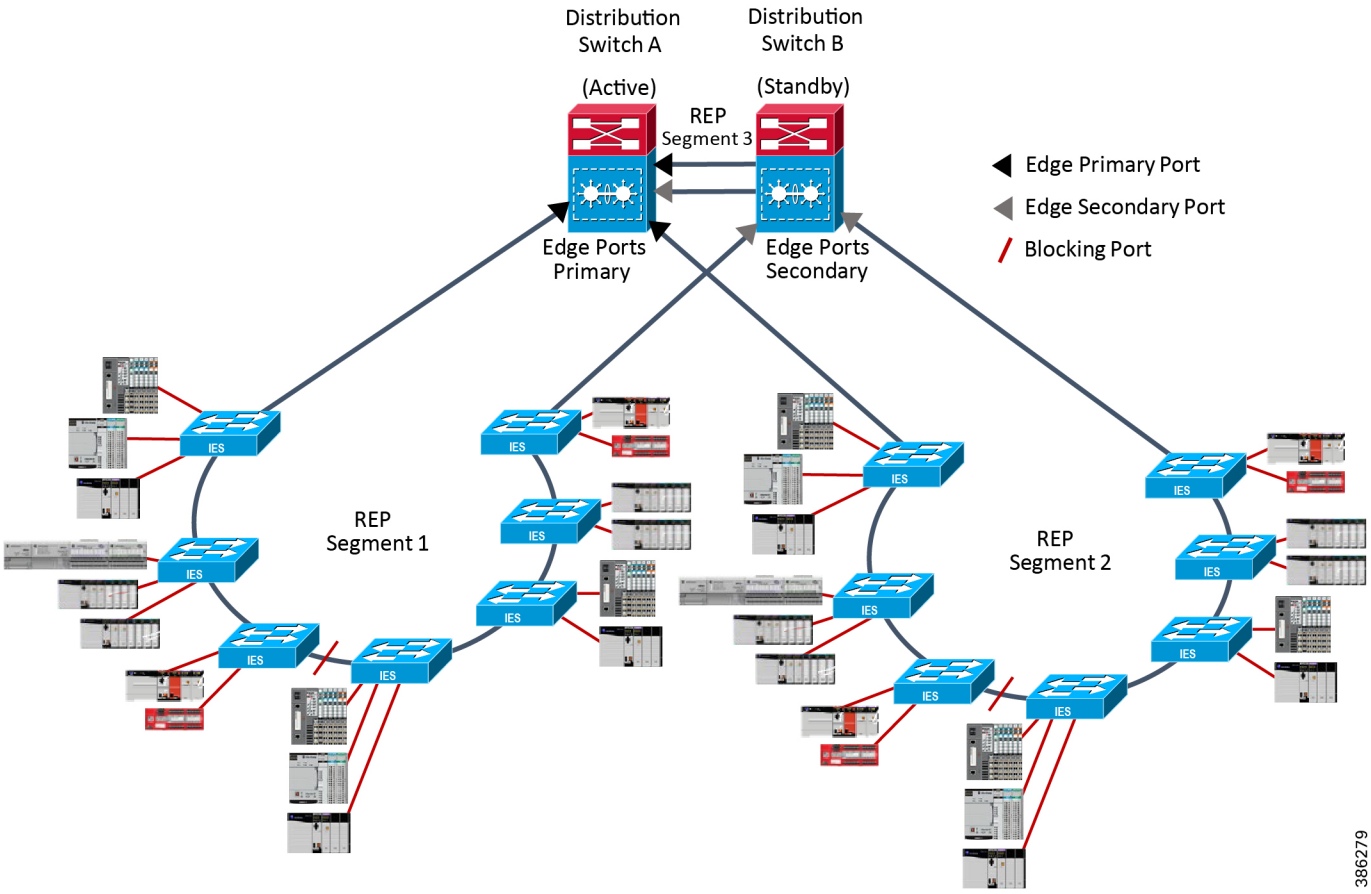
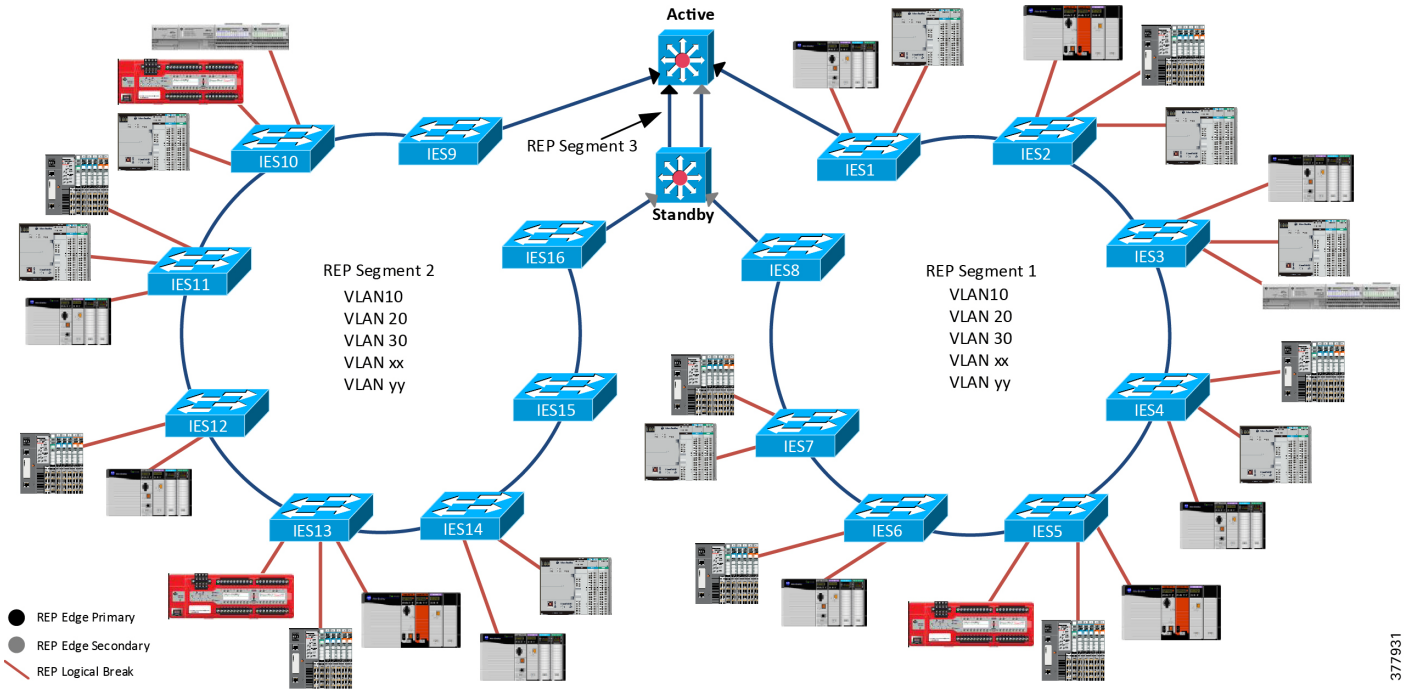


Figure 2-27 IE 5000/Stratix 5410 HSRP with Multiple REP Ring Topology



REP configuration for multiple rings with HSRP is as follows:

- Each REP segment has a segment edge on each of the HSRP nodes (that is, the primary REP segment edge on the active HSRP node and the secondary REP segment edge on the standby HSRP node).
- A special “backbone” REP segment is configured as trunk between HSRP nodes using two ports on each switch. Preferably, this REP segment will be configured on two 10 Gigabit ports to accommodate a higher level of traffic.
- Both primary and secondary edge ports of the “backbone” segment are on the active HSRP gateway.
- All REP segment edges are configured to send Segment Topology Change Notifications (STCN) to all other REP segments.

This configuration allows for VLANs to exist on multiple REP segments without creating network loops (MAC address flapping).

The following use case represents the requirement for configuring multiple REP segments using Catalyst 9300 with StackWise-480. See Figure 2-28.

- The primary REP edge and the secondary REP edge for each segment are on different switches in the stack

Figure 2-28 Catalyst 9300 StackWise-480 Mode with Multiple REP Ring Topology

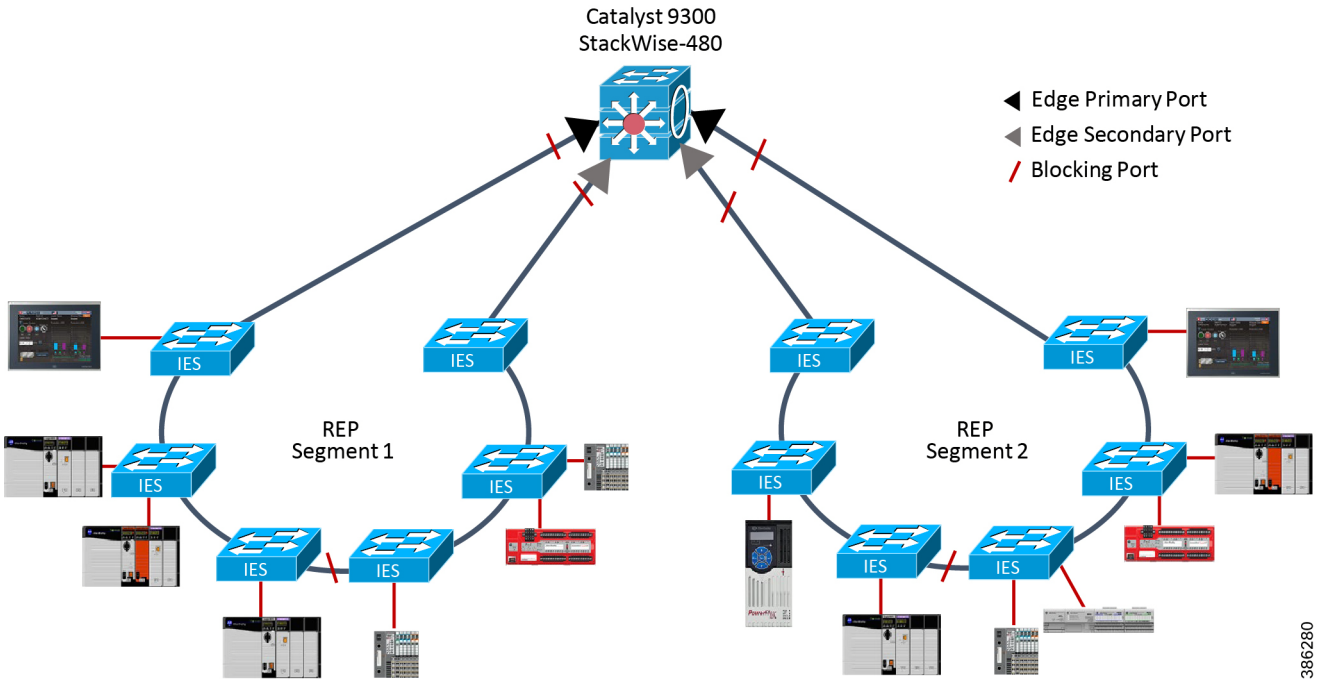


Table 2-16 and Table 2-17 summarize the convergence values observed during validation efforts and can be used to select the appropriate resiliency protocols based on application requirements.

Note Multiple VLANs can exist in each REP segment. In addition, any or all VLANs can span across multiple REP segments if necessary. The preferred approach, however, is to configure a VLAN in only one REP segment to avoid Layer 2 traffic crossing between segments. This use case has been validated for Layer 2 traffic within a VLAN and for Layer 3 traffic between VLANs in the same ring and between VLANs in different rings.

Note Link disruptions in Table 2-16 and Table 2-17 refer to links within the Cell/Area Zone. Switch disruptions refer to the distribution switches only. To help prevent such events from occurring within your network, refer to "Physical Infrastructure Design for the Cell/Area Zone" in *Physical Infrastructure for the Converged Plantwide Ethernet Architecture Application Guide* (https://www.cisco.com/c/en/us/td/docs/solutions/Verticals/CPwE/5-1/Phy_Arch/CPwE_PhyArch_AppGuide.html).

This configuration allows for VLANs to exist on multiple REP segments without creating network loops (MAC address flapping).

Table 2-16 Multiple Ring (Single Media) Topology Resiliency Protocol Selection Criteria (Unicast)

Distribution Platform	Recommended Resiliency Method	Disruption Type	REP Convergence (msec)			
			Traffic Type	Min	Avg	Max
Catalyst 9500	HSRP	Link	L2	4	34	78
			L3	4	34	82
		Switch	L2	29	194	238
			L3	20	44	864
IE 5000/Stratix 5410	HSRP	Link	L2	4	47	316
			L3	10	51	168
		Switch	L2	18	87	206
			L3	18	465	940
Catalyst 9300	HSRP	Link	L2	18	116	314
			L3	4	92	486
		Switch	L2	18	119	378
			L3	4	154	516

Table 2-17 Multiple Ring (Single Media) Topology Resiliency Protocol Selection Criteria (Multicast)

Distribution Platform	Recommended Resiliency Method	Disruption Type	REP Convergence (msec)			
			Traffic Type	Min	Avg	Max
Catalyst 9500	HSRP	Link	L2	12	13	290
		Switch	L2	40	185	348
IE 5000/Stratix 5410	HSRP	Link	L2	4	47	316
		Switch	L2	4	83	170
Catalyst 9300	HSRP	Link	L2	6	104	298
		Switch	L2	16	109	350

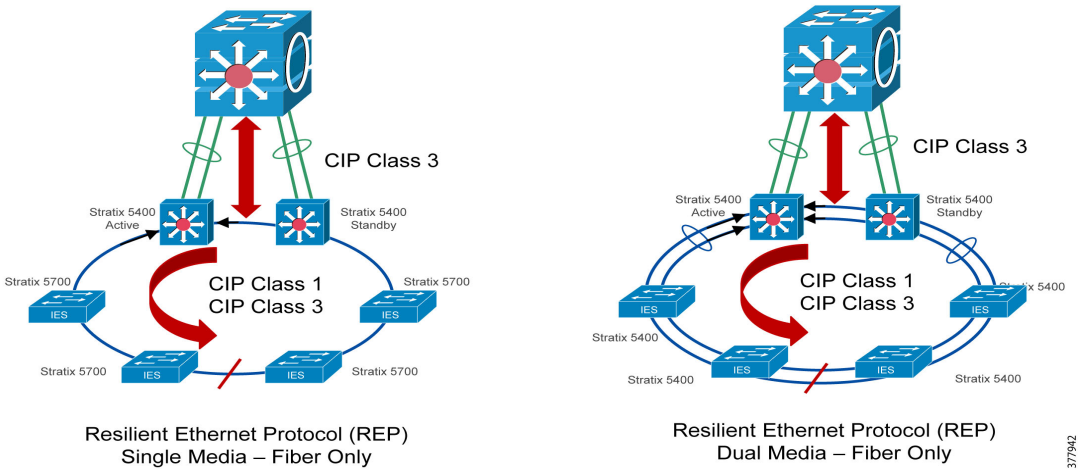
Layer 3 Access Design Overview

In Layer 3 Access Design, two Layer 3-enabled access switches provide resiliency for the ring and a gateway for routing traffic upstream, while the distribution switches provide consolidation of routed traffic from the multiple ring segments into the core.

Many end users prefer to keep real-time (CIP Class 1) Industrial Automation and Control System (IACS) traffic within the Cell/Area Zone, with only non-real-time (CIP Class 3) traffic traversing the Distribution Layer. Loss of IACS traffic during ring convergence is critical and therefore simplifying the Layer 2 ring has benefits. Using REP (single or dual media) with all IES switches, shown in Figure 2-29, provides an optimal ring setup with the fastest convergence times.

The following examples show an all IES ring with Stratix 5400/IE4K as the Layer 3 access platform configured in HSRP mode with REP. In this example, the Catalyst 9300 or Catalyst 3850 switches are used as the distribution platform using Stackwise-480 as the resiliency method.

Figure 2-29 Layer 3 Access Design Topology



Layer 3 Access with Multiple Ring Segment

Layer 3 Access Design can also be used in a multiple ring topology, as shown in Figure 2-30 on page 2-45. The Layer 3 access design throughput platforms (such as Catalyst 9500 and Catalyst 9300) handle routing of traffic from multiple rings and provide Layer 3 resiliency. This approach is highly scalable and customizable based on the network requirements.

Note Multiple VLANs can be set up within a single ring but only one ring per VLAN.

The following use cases represent IE5000/Stratix 5410 or IE4K/Stratix 5400 as Layer 3 access platform configured in HSRP mode with REP. Here Catalyst 9500/4500-X with StackWise Virtual/VSS or Catalyst 9300/3850 with StackWise-480 is used as distribution platform. See Figure 2-30 on page 2-43 depicting the topology.

Figure 2-30 Catalyst Distribution Switches with IE 5000/Stratix 5410 Layer 3 Access and REP Ring

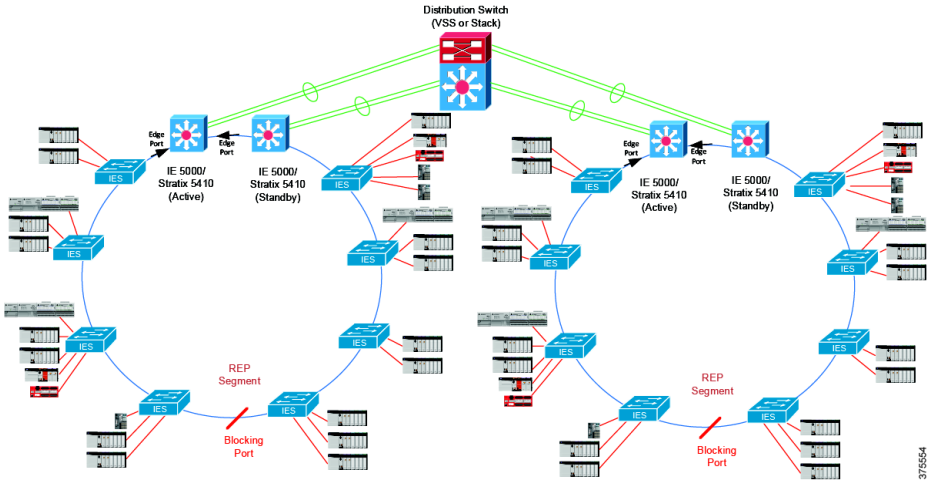


Table 2-18 and Table 2-19 summarize the convergence values observed during validation efforts and can be used to select the appropriate resiliency protocols based on application requirements. For results for link disruptions within the access ring, refer to the Single Ring sections preceding this one.

Note Catalyst 9300 and Catalyst 9500 platforms have not been tested for the Layer 3 Access use case for this release of the DIG.

Note Link and switch disruption locations are defined in Table 2-18 and Table 2-19. To help prevent such events from occurring within your network, refer to "Physical Infrastructure Design for the Cell/Area Zone" in *Physical Infrastructure for the Converged Plantwide Ethernet Architecture Application Guide* (https://www.cisco.com/c/en/us/td/docs/solutions/Verticals/CPwE/5-1/Phy_Arch/CPwE_PhyArch_AppGuide.html).

Table 2-18 Multiple Ring Topology (Layer 3 Access) Resiliency Protocol Selection Criteria (Unicast)

Distribution Platform	Recommended Resiliency Method	Layer 3 Access Platform	Recommended Resiliency Method	Disruption Type	Convergence (msec)			
					Traffic Type	Min	Avg	Max
Catalyst 4500-X	VSS	IE 5000/Stratix 5410	HSRP	Link (Layer 3 Access to Distribution)	L2	N/A	N/A	N/A
					L3	79	94	106
				Layer 3 Access Switch	L2	8	41	60
					L3	16	1208	2186
				Distribution Switch	L2	N/A	N/A	N/A
					L3	18	34	50
Catalyst 3850	StackWise-480	IE 5000/Stratix 5410	HSRP	Link (Layer 3 Access to Distribution)	L2	N/A	N/A	N/A
					L3	12	50	120
				Layer 3 Access Switch	L2	20	31	44
					L3	20	958	2142
				Distribution Switch	L2	N/A	N/A	N/A
					L3	16	275	964

Table 2-19 Multiple Ring Topology Resiliency Protocol Selection Criteria (Multicast)

Distribution Platform	Recommended Resiliency Method	Layer 3 Access Platform	Recommended Resiliency Method	Disruption Type	Convergence (msec)		
					Min	Avg	Max
Catalyst 4500-X	VSS	IE 5000/Stratix 5410	HSRP	Link (Layer 3 Access to Distribution)	N/A	N/A	N/A
				Layer 3 Access Switch	4	44	60
				Distribution Switch	N/A	N/A	N/A
Catalyst 3850	StackWise-480	IE 5000/Stratix 5410	HSRP	Link (Layer 3 Access to Distribution)	N/A	N/A	N/A
				Layer 3 Access Switch	20	31	44
				Distribution Switch	N/A	N/A	N/A

Note **Resiliency Recommendations:**

- With Catalyst 9500 or Catalyst 4500-X as the distribution platform and IE 5000/Stratix 5410 as the Layer 3 access platform, Cisco, Panduit, and Rockwell Automation recommend using StackWise Virtual/VSS for distribution switch resiliency, Multi-Chassis EtherChannel for Layer 3 link resiliency, HSRP on the

IE 5000/Stratix 5410 as the Layer 3 gateway resiliency protocol and REP as the Layer 2 resiliency protocol (as recommended with a single ring). This allows for fast convergence of the traffic within the Cell/Area Zone and failover for traffic leaving the Cell/Area Zone.

- With Catalyst 9300 or Catalyst 3850 as the distribution platform and IE 5000/Stratix 5410 as the Layer 3 access platform, Cisco, Panduit, and Rockwell Automation recommend using StackWise-480 for distribution switch resiliency, EtherChannel for Layer 3 link resiliency, HSRP on the IE 5000/Stratix 5410 as the Layer 3 gateway resiliency protocol and REP as the Layer 2 resiliency protocol (as recommended with a single ring). This allows for fast convergence of the traffic within the Cell/Area Zone and failover for traffic leaving the Cell/Area Zone.

Summary of Resiliency Recommendations

Table 2-20 shows the summary of use cases performed using different distribution platforms with resiliency recommended. Refer to the previous section for detailed information on the topology.

Table 2-20 Redundant Star and Ring Topology Use Case Summary

		Redundant Star			Ring			
Distribution switch	L2 Protocol L3 Protocol	MSTP	Flex Links	EtherChannel	REP (Single)	REP (Multi) L2 Access	REP (Multi) L3 Access	REP (Dual Media)
Catalyst 9500	HSRP	✓	✓	x	✓	✓	○	✓
	StackWise Virtual	✓	✓	✓	✓	x	○	x
Catalyst 9300	HSRP	○	○	x	○	○	○	○
	StackWise-480	✓	✓	✓	✓	✓	○	✓
Catalyst 4500-X	HSRP	✓	✓	x	✓	○	x	✓
	VSS	x	✓	✓	✓	x	✓	x
Catalyst 3850	HSRP	○	○	x	○	○	○	○
	StackWise-480	✓	✓	✓	✓	○	✓	✓
IE 5000/Stratix 5410	HSRP	✓	✓	x	✓	✓	x	✓
IE 4000/Stratix 5400	HSRP	x	x	x	✓	x	x	○

✓	Validated and Recommended
✓	Validated
○	Not tested
x	Invalid/not recommended

Redundant Star Topology Recommendation Summary

The following is the resiliency recommendation summary for redundant star topology.

Catalyst 9500 with StackWise-Virtual

With Catalyst 9500 as the distribution platform, Cisco, Panduit, and Rockwell Automation recommend using StackWise Virtual as the Layer 3 gateway resiliency protocol and EtherChannel as the Layer 2 resiliency protocol for redundant star topology. See Figure 2-8.

IE 5000/Stratix 5410 with HSRP

With IE 5000/Stratix 5410 as the distribution platform, Cisco, Panduit, and Rockwell Automation recommend using HSRP as the Layer 3 gateway resiliency protocol and Flex Links as the Layer 2 resiliency protocol. See Figure 2-12.

Catalyst 9300 with StackWise-480

With Catalyst 9300 as the distribution platform, Cisco, Panduit, and Rockwell Automation recommend using StackWise-480 as the Layer 3 gateway resiliency protocol and Flex Links as the Layer 2 resiliency protocol. See Figure 2-14.

Ring Topology Recommendation Summary

The following is the resiliency recommendation summary for ring topology.

Single Ring (Single Media)

With Catalyst 9500, IE 5000/Stratix 5410, or IE 4000/Stratix 5400 as the distribution platform, Cisco, Panduit, and Rockwell Automation recommend using HSRP as the Layer 3 gateway resiliency protocol and REP as the Layer 2 resiliency protocol. See Figure 2-22.

Single Ring (Dual Media)

With Catalyst 9500, IE 5000/Stratix 5410, or IE 4000/Stratix 5400 as the distribution platform, Cisco, Panduit, and Rockwell Automation recommend using HSRP as the Layer 3 gateway resiliency protocol and EtherChannel (with REP) as the Layer 2 resiliency protocol. See Figure 2-23.

Multiple Ring Segments

With Catalyst 9500 as the distribution platform and IE 5000/Stratix 5410 or IE4000/Stratix 5400 as the Layer 3 access platform, Cisco, Panduit and Rockwell Automation recommend using StackWise Virtual on the Catalyst 9500 for distribution switch resiliency, Multi-Chassis EtherChannel for Layer 3 link resiliency, HSRP on the IE 5000/Stratix 5410 as the Layer 3 gateway resiliency protocol and REP as the Layer 2 resiliency protocol (as recommended with a single ring). See Figure 2-30.

With Catalyst 9300 as the distribution platform and IE 5000/Stratix 5410 or IE4000/Stratix 5400 as the Layer 3 access platform, Cisco, Panduit and Rockwell Automation recommend using StackWise-480 on the Catalyst 9300 for distribution switch resiliency, EtherChannel for Layer 3 link resiliency, HSRP on the IE 5000/Stratix 5410 as the Layer 3 gateway resiliency protocol and REP as the Layer 2 resiliency protocol (as recommended with a single ring). See Figure 2-30.

CHAPTER 3

CPwE Resiliency Configuration

This chapter describes how to configure resiliency in the CPwE architecture based on the design considerations and recommendations of the previous chapters. It covers the configuration of the Industrial and Cell/Area Zone switches. The included configurations have been validated during the testing effort.

This chapter includes the following major topics:

Industrial Zone

Distribution Switching

Catalyst 9500 StackWise Virtual Configuration

By default, the Catalyst 9500 switch is configured to operate in standalone mode (the switch works independently). StackWise Virtual combines two standalone switches into one virtual switch, operating in virtual switch mode.

Note The LAN Base license does not support StackWise Virtual. You must upgrade to IP Base or higher to support this feature.

StackWise Virtual is configured and activated as shown in the following sections.

Note For more information on StackWise Virtual configuration, see the *High Availability Configuration Guide, Cisco IOS XE Fuji 16.9.x (Catalyst 9500 Switches)* at the following URL: https://www.cisco.com/c/en/us/td/docs/switches/lan/catalyst9500/software/release/16-9/configuration_guide/ha/b_169_ha_9500_cg/configuring_cisco_stackwise_virtual.html

Prerequisites for Cisco StackWise Virtual

- All switches in a Cisco StackWise Virtual solution must be of the same switch model.
- All switches in a Cisco StackWise Virtual solution must be running the same license level.
- All switches in a Cisco StackWise Virtual solution must be running the same software version.

Assigning Virtual Switch Domain and Switch Numbers

The same virtual switch domain number must be configured on both switches of the StackWise Virtual stack. The virtual switch domain is a number between 1 and 255. The following is the virtual switch domain configuration for each switch:

Enter the commands for **both** switches (9500-A and 9500-B).

Define the **Domain**:

```
9500-A#conf t
9500-A(config)#stackwise-virtual
9500-A(config-stackwise-virtual)#domain 10
9500-A(config-stackwise-virtual)#exit
```

Define the **Virtual link**:

```
9500-A(config)#int HundredGigE1/0/49
9500-A(config-if)#stackwise-virtual link 1
9500-A(config)#int HundredGigE1/0/51
9500-A(config-if)#stackwise-virtual link 1
9500-A(config-if)#exit
9500-A(config)#reload
```

Define the **Dual-active-detection link**:

Configuring StackWise Virtual **Fast Hello Dual-Active-Detection Link**

```
9500-A(config)#int TwentyFiveGigE1/0/48
9500-A(config-if)#stackwise-virtual dual-active-detection
9500-A(config-if)#exit
9500A(config)#reload
```

Dual-Active Detection

If the standby switch detects a complete loss of the StackWise Virtual link, it assumes that the active switch has failed and will take over as the active switch. However, if the original Cisco StackWise Virtual active switch is still operational, both the switches will now be Cisco StackWise Virtual active switches. This situation is called a dual-active scenario. This scenario can have adverse effects on network stability because both the switches use the same IP addresses, SSH keys, and STP bridge IDs. Cisco StackWise Virtual detects a dual-active scenario and takes recovery action. The dual-active-detection link is the dedicated link used to mitigate this.

If a StackWise Virtual link fails, the Cisco StackWise Virtual standby switch cannot determine the state of the Cisco StackWise Virtual active switch. To confirm that switchover occurs without delay, the Cisco StackWise Virtual standby switch assumes that the Cisco StackWise Virtual active switch has failed and initiates switchover to take over the Cisco StackWise Virtual active role. The original Cisco StackWise Virtual active switch enters recovery mode and brings down all the interfaces except the StackWise Virtual link and the management interfaces.

Dual-Active-Detection Link with Fast Hello

To use the dual-active fast hello packet detection method, you must provision a direct Ethernet connection between the two Cisco StackWise Virtual switches. You can dedicate up to four links for this purpose.

The two switches periodically exchange special dual-active hello messages containing information about the switch state. If all SVLs fail and a dual-active scenario occurs, each switch recognizes that there is a dual-active scenario from the peer's messages. This initiates recovery actions as described in the Recovery Actions section. If a switch does not receive an expected dual-active fast hello message from the peer before the timer expires, the switch assumes that the link is no longer capable of dual-active detection.

Dual-Active Detection with enhanced PAgP

Port aggregation protocol (PAgP) is a Cisco proprietary protocol used for managing EtherChannels. If a StackWise Virtual MEC terminates on a Cisco switch, you can run PAgP protocol on the MEC. If PAgP is running on the MECs between the StackWise Virtual switch and an upstream or downstream switch, StackWise Virtual can use PAgP to detect a dual-active scenario. The MEC must have at least one port on each switch of the StackWise Virtual setup.

Enhanced PAgP is an extension of the PAgP protocol. In virtual switch mode, ePAgP messages include a new type length value (TLV) which contains the ID of the StackWise Virtual active switch. Only switches in virtual switch mode send the new TLV.

When the StackWise Virtual standby switch detects SVL failure, it initiates SSO and becomes StackWise Virtual active. Subsequent ePAgP messages sent to the connected switch from the newly StackWise Virtual active switch contain the new StackWise Virtual active ID. The connected switch sends ePAgP messages with the new StackWise Virtual active ID to both StackWise Virtual switches.

If the formerly StackWise Virtual active switch is still operational, it detects the dual-active scenario because the StackWise Virtual active ID in the ePAgP messages changes.

Catalyst 9300 StackWise-480 Configuration

The active switch has the saved and running configuration file for the switch stack. The standby switch automatically receives the synchronized running configuration file. Stack members receive synchronized copies when the running configuration file is saved into the startup configuration file. If the active switch becomes unavailable, the standby switch takes over with the current running configuration.

Once a stacked switch configuration comes up and elects active and standby switches within the stack, some additional configuration is required to assure stability if there are disruptions within the stack.

Stack Member Priority

By default, all switches within the stack have a priority of 1 (configurable up to 15). The desired active switch should be configured with a higher priority than other switches in the stack to help prevent changes whenever a re-election occurs.

Note The re-election process only occurs following a reset of the entire switch stack. If Switch 1 (active) is disrupted and Switch 2 (standby) becomes active, Switch 1 will rejoin the stack as the standby and will not preempt Switch 2 from being active.

Switch priority is set using the following command (in EXEC mode):

```
switch 1 priority 15
```

Stack MAC Address Persistence

A stacked switch configuration uses a single MAC address for its bridge ID and router MAC. By default, if the active switch in a stack is disrupted, the MAC address of the standby switch replaces the old one once it becomes active. This can result in traffic disruptions since a new MAC address must be learned within the network. To avoid this situation, use the following command to help prevent the stack MAC address from changing when new switches become active:

```
stack-mac persistent timer 0
```

Stack Member Renumbering

The stack member number (1 to 9) identifies each member in the switch stack. The member number also determines the interface-level configuration that a stack member uses. A new, out-of-the-box switch (one that has not joined a switch stack or has not been manually assigned a stack member number) ships with a default stack member number of 1. When it joins a switch stack, its default stack member number changes to the lowest available member number in the stack.

Stack members in the same switch stack cannot have the same stack member number. Every stack member, including a standalone switch, retains its member number until you manually change the number or unless the number is already being used by another member in the stack.

Switches that are removed from one stack and put into another might have non-contiguous numbering because of the preceding behavior mentioned. If desired, the following command manually configures a stack member with a new number (the change will only take effect once that switch is reloaded):

```
switch <CURRENT VALUE> renumber <NEW VALUE>
```

Note For more information on the Catalyst 9300 StackWise-480 configuration, see *Stack Manager and High Availability Configuration Guide, Cisco IOS XE Fuji 16.9.x (Catalyst 9300 Switches)* at the following URL: https://www.cisco.com/c/en/us/td/docs/switches/lan/catalyst9300/software/release/16-9/configuration_guide/stck_mgr_ha/b_169_stck_mgr_ha_9300_cg/managing_switch_stacks.html

Hot Standby Routing Protocol Configuration

Hot Standby Routing Protocol (HSRP) is enabled and configured on the SVI of each distribution switch. The following sections describe how to configure HSRP features.

Note HSRP may be configured on Catalyst 9500, Catalyst 4500-X, IE 5000/Stratix 5410, and IE 4000/Stratix 5400. HSRP can only be configured via the switch CLI, not via the Device Manager web interface.

Virtual IP Address

HSRP is enabled by configuring an instance, specified by an ID value, and the virtual IP that will be shared between the HSRP peers. Generally, the primary HSRP peer should be configured with the lower physical IP address so that it will win elections for protocols that do not rely on the virtual IP, such as IGMP. In addition, the primary HSRP peer should also be the STP root switch (for reasons discussed earlier in this document). The following is a typical configuration for the HSRP primary peer, though different IP addresses may be used if desired:

```
interface Vlan10
 ip address 10.17.10.2 255.255.255.0
 standby 1 ip 10.17.10.1
```

The following is a typical configuration for the HSRP standby peer:

```
interface Vlan10
```

```
ip address 10.17.10.3 255.255.255.0
standby 1 ip 10.17.10.1
```

Priority

Priority is used to determine which HSRP peer should be active during initial setup (and if preemption is enabled). By default, HSRP peers have a priority of 100. The desired active peer should be configured with a higher priority (max 254) so that it consistently wins the election. HSRP priority is configured as follows:

```
standby 1 priority 254
```

HSRP Timers

HSRP relies on two timers: hello interval refers to the frequency that hello packets are sent to the other peer, and hold time refers to the amount of time to wait before declaring the other peer down. The hold time should be configured to be greater than or equal to three times the hello interval to help prevent unnecessary flapping between the peers. Cisco, Panduit and Rockwell Automation recommend configuring the following timer values on both HSRP peers to balance network stability with sub-second convergence:

```
standby 1 timers msec 200 msec 750
```

Startup Delay

The HSRP process itself must be delayed on startup to help prevent a new HSRP peer from assuming too quickly that it is the only peer in the network and taking on the active role. The following command specifies the minimum delay after HSRP is enabled before it attempts to establish a peer relationship and a longer delay following a reload:

```
standby delay minimum 30 reload 60
```

Cell/Area Zone

Access Layer Switching

Redundant Star Topology

Flex Links

Flex Links are simple to configure. On the active interface, the backup interface is specified using a single command, with multicast fast convergence enabled to allow consistent convergence results for all types of network traffic. The feature is enabled using the following command on the access switch (CLI only):

```
interface GigabitEthernet1/1
 switchport backup interface Gi1/2 multicast fast-convergence
```

Note If STP is enabled on the distribution switches connected to the access switch running Flex Links, a switch disruption could cause STP to converge, resulting in traffic loss for up to 30 seconds to transition the port through the listening and learning states before forwarding traffic. To help prevent this loss and allow the port to immediately forward traffic after a convergence event, enable the following command on the downlinks facing the access switch: *spanning-tree portfast edge trunk*.

EtherChannel

To configure an EtherChannel using LACP in active mode between the access and distribution switches, configure a port-channel interface on each switch, and then configure the links as members of the port-channel. This configuration is performed using the following commands:

```
interface Port-channel2
!
interface GigabitEthernet1/0/3
 channel-group 2 mode active
interface GigabitEthernet2/0/3
 channel-group 2 mode active
```

Ring Topology

Resilient Ethernet Protocol

This section describes the basic configurations necessary to implement REP in a single or multiple ring topology in a Cell/Area Zone. It is assumed that Express Setup and other Smart Port macro configurations for IES have already been applied, so the details of those configurations are not covered in this document (refer to the IES user manuals for these details). This section covers the following topics:

- General REP recommendations
- Native VLAN implementation for REP control messages.
- REP administrative VLAN implementation for fast failure notifications.
- REP segment and edge configuration.

The general considerations for configuring REP are:

- First configure the edge port in the REP segment, and then configure the contiguous ports in the segment.
- REP and STP or REP and Flex Links cannot be enabled on the same IES port.
- All trunk ports in the segment must be configured with the same set of allowed VLANs.
- Be careful when configuring REP through a switch management connection (for example, SSH or webpage). Because REP blocks all VLANs until another REP interface sends a message to unblock it, you might lose connectivity to the switch if you enable REP in a management session that accesses the switch through the same interface. As an alternative, you may use a direct Ethernet connection to IES or a serial console connection.
- REP is supported on EtherChannels, but not on an individual port that belongs to an EtherChannel. In a dual-media ring topology, REP must be configured on a logical EtherChannel interface (PortChannel).

Native VLAN Implementation

REP uses the native VLAN configured on the trunk interfaces of a network segment to establish and maintain connectivity across the segment, as well as reliably informing all nodes of any topology changes using Link Status Layer (LSL) frames. This behavior is like other Layer 2 control plane protocols such as Cisco Discovery Protocol (CDP) and VLAN Trunking Protocol (VTP).

Best practices for configuring the native VLAN on the trunk interfaces include the following:

- The native VLAN on a trunk is **1** by default. For security purposes, select another VLAN as the native VLAN.
- When selecting the native VLAN, use a VLAN that is separate from the one carrying IACS traffic as the best practice.

- When pruning unused VLANs from the trunk, be sure to include the native VLAN (along with the IACS VLAN) as allowed.

If the native VLAN has not already been configured on the uplink ports using a Smart Port macro (Device Manager or CLI), it can be configured using the following command in interface configuration mode:

```
switchport trunk native vlan <VALUE>
```

In addition, confirm that the VLAN has been added to the global database using the following commands in global configuration mode:

```
vlan <VALUE>
name Native_VLAN
```

Admin VLAN for REP

In addition to the reliable notifications sent on the native VLAN after a topology change, REP also uses Hardware Flood Layer (HFL) notifications that are immediately sent out as multicast frames by the switch hardware. Because these frames are hardware switched by each device in the path, rather than relayed hop-by-hop, they can be received across the segment quickly. This behavior allows REP to converge quickly following a failure and limit IACS device timeouts for many applications.

A REP administrative VLAN is configured globally on each switch within a segment to control the VLAN onto which the HFL frames are forwarded. In addition, since HFL frames are flooded as data traffic only on ports belonging to that VLAN, the scope of this traffic can be confined to the Cell/Area Zone LAN. Best practices for configuring the REP administrative VLAN include the following:

- As with the native VLAN, for security purposes change the REP administrative VLAN (via CLI or Device Manager) to another value from its default of 1. Similarly, do not choose the VLAN carrying IACS traffic.
- Be sure to include the administrative VLAN as allowed when pruning unused VLANs from the trunk.

Note If the administrative VLAN is not allowed across the entire REP ring, both within and outside the segment, the HFL frames will be dropped and network convergence will be dependent on the slower LSL mechanism. While LSL frames are considered control traffic and are therefore relayed across the trunk regardless of pruning, HFL frames are considered data traffic and must be explicitly allowed across the trunk.

- Since the administrative VLAN has similar constraints to the native VLAN, it makes sense to assign the two as the same VLAN. In addition, most Cell/Area Zones will be separated by Layer 3 (distribution switch) domains, so constraining the HFL flooding does not need to be a significant consideration.

To configure the REP administrative VLAN, use the following command in global configuration mode:

```
rep admin vlan <VALUE>
```

In addition, confirm that the VLAN has been added to the global database using the following commands in global configuration mode:

```
vlan <VALUE>
name REP_Admin_VLAN
```

REP Edge Configuration

REP is configured on both IES and distribution switches simply by enabling it on each interface that will be part of the segment and including a segment ID to identify to which segment the port belongs. Primary and secondary edge ports are configured at each end of the segment. The purpose of the primary edge port is to initiate topology discovery and communicate special configurations for the segment. The secondary edge port has no special function beyond terminating the segment.

To configure a port as a member of the REP segment, use the following command in interface configuration mode:

```
rep segment <ID>
```

To configure a port as an edge port (typically on a distribution switch), use the following command in interface configuration mode:

```
rep segment <ID> edge (primary)
```

The “primary” keyword is optional and allows for manual selection of the primary edge. If the primary keyword is used, the other edge port becomes the secondary edge port (no keyword required). To configure the secondary edge port, omit the primary keyword as shown:

```
rep segment <ID> edge
```

If neither edge port has this designation, REP will elect one as the primary edge based on the port ID.

Depending on the ring topology, REP edge ports should be placed as follows:

- **Single Ring with HSRP**—Configure edge ports in the segment on the same distribution switch (the active HSRP peer). See Figure 2-22 on page 2-32 and Figure 2-24 on page 2-36.
- **Single Ring with StackWise-480**—Configure edge ports on different switches in the stack. See Figure 2-23 on page 2-33.
- **Multiple Rings (Layer 2 Access)**—For all segments connecting access switches, configure primary REP edges on the HSRP active gateway and secondary REP edges on the HSRP standby gateway.

  A special "backbone" REP segment should also be configured between HSRP nodes using two ports on each distribution switch. Both primary and secondary edge ports of the "backbone" segment should be on the active HSRP gateway. See Figure 2-26 on page 2-39.

  In this topology, all REP segment edges must be configured to send Segment Topology Change Notifications (STCN) to all other REP segments, for example:

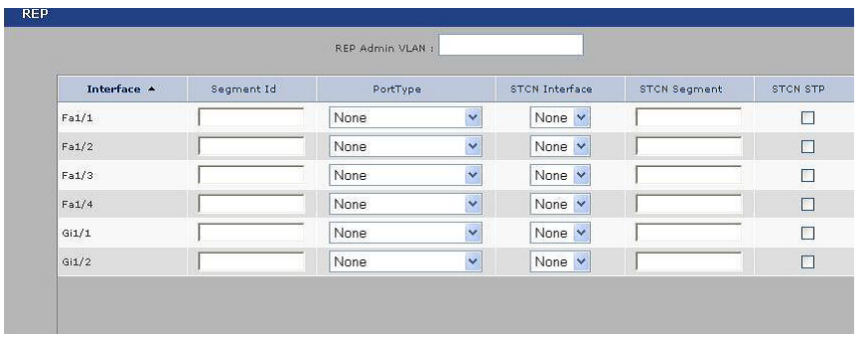
  ```
  rep segment 1 edge primary
  rep stcn segment 2-3
  ```

- **Multiple Rings (Layer 3 Access)**—Configure edge ports in each segment on the active HSRP switch in each ring. This is like the single ring configuration since each REP segment is not directly connected to others. See Figure 2-30 on page 2-43.

Device Manager Configuration

The IES Device Manager provides a graphical user interface to configure REP, including REP admin VLAN, segment ID, port types and STCN.

Figure 3-1 Device Manager Configuration for REP



For detailed description of the REP parameters in the Device Manager, see the *Stratix Managed Switches User Manual* at the following URL:

- http://literature.rockwellautomation.com/idc/groups/literature/documents/um/1783-um007_-en-p.pdf

CHAPTER 4

CPwE Resiliency Troubleshooting

This chapter, which describes how to assess and verify the status of the resiliency protocols running on the Industrial and Cell/Area Zone switches, includes the following major topics:

StackWise Virtual Troubleshooting

To investigate problems with StackWise Virtual, the commands for confirming the configuration are shown below.

To verify your StackWise Virtual configuration, use the show commands in Table 4-1.

Table 4-1 Commands for Verifying StackWise Virtual Configuration

Command	Description
show stackwise-virtual switch *number <1-2>*	Displays information of a particular switch in the stack.
show stackwise-virtual link	Displays StackWise Virtual link information.
show stackwise-virtual bandwidth	Displays the bandwidth available for the Cisco StackWise Virtual.
show stackwise-virtual neighbors	Displays the Cisco StackWise Virtual neighbors.
show stackwise-virtual dual-active-detection	Displays StackWise Virtual dual-active-detection information.
show stackwise-virtual dual-active-detection pagp	Displays ePAgP dual-active-detection information.

StackWise-480 Troubleshooting

To investigate problems with StackWise, the primary command for confirming the configuration is *show switch detail*, as shown below:

```
9300-stack#show switch detail
Switch/Stack Mac Address : 8890.8d52.5100 - Local Mac Address
Mac persistency wait time: Indefinite
                                                     H/W   Current
Switch#   Role    Mac Address     Priority Version  State
-----------------------------------------------------------
*1       Active   8890.8d52.5100     15     V01     Ready
 2       Standby  8890.8d6c.0580     1      V01     Ready



         Stack Port Status             Neighbors
Switch#  Port 1     Port 2           Port 1   Port 2
--------------------------------------------------------
  1         OK        DOWN              2       None
  2       DOWN          OK            None       1

9300-stack#
```

This command shows the following information about the configuration:

- Switch/Stack MAC Address
- MAC persistence setting (should be Indefinite)
- The switch numbers, MAC addresses, priority values, and current states
- The status of the stack ports on each switch and the neighbor to which each port is connected

Note For additional StackWise-480 troubleshooting tips, see "Troubleshooting the Software Configuration" in *System Management Configuration Guide, Cisco IOS XE Everest 16.5.1a (Catalyst 9300 Switches)* at the following URL: https://www.cisco.com/c/en/us/td/docs/switches/lan/catalyst9300/software/release/16-5/configuration_guide/sys_mgmt/b_165_sys_mgmt_9300_cg/troubleshooting_the_software_configuration.html

HSRP Troubleshooting

To investigate problems with HSRP, the primary command for confirming the configuration is *show standby*, as shown in the following:

```
SwitchA#sh standby
Vlan10 - Group 1
  State is Active
    5 state changes, last state change 04:12:59
  Virtual IP address is 10.17.10.1
  Active virtual MAC address is 0000.0c07.ac01 (MAC In Use)
    Local virtual MAC address is 0000.0c07.ac01 (v1 default)
  Hello time 200 msec, hold time 750 msec
    Next hello sent in 0.016 secs
  Preemption disabled
  Active router is local
  Standby router is 10.17.10.3, priority 100 (expires in 0.672 sec)
  Priority 254 (configured 254)
```

```
    Group name is "hsrp-Vl10-1" (default)
```

The settings shown in this output are as follows:

- **State**—Indicates whether the switch is Active (current gateway), Standby (backup gateway), or Init (not yet synchronized with HSRP peer)
- **Virtual IP Address**
- **Active virtual MAC Address**
- **Hello and Hold Times**—Shows the configured hello and hold timers
- **Preemption**—Indicates whether the feature is enabled or disabled
- **Active and Standby Routers**—Shows the physical IP address of the router (or indicates that it is local) and the configured priority value on the remote switch
- **Priority**—Shows the configured priority value on the local switch

For comparison, the output of *show standby* on the standby switch is shown in the following:

```
SwitchB#sh standby
Vlan10 - Group 1
  State is Standby
    9 state changes, last state change 04:11:31
  Virtual IP address is 10.17.10.1
  Active virtual MAC address is 0000.0c07.ac01 (MAC Not In Use)
    Local virtual MAC address is 0000.0c07.ac01 (v1 default)
  Hello time 200 msec, hold time 750 msec
    Next hello sent in 0.016 secs
  Preemption disabled
  Active router is 10.17.10.2, priority 254 (expires in 0.608 sec)
  Standby router is local
  Priority 100 (default 100)
  Group name is "hsrp-Vl10-1" (default)
```

Note For additional HSRP troubleshooting tips, see *Understanding and Troubleshooting HSRP Problems in Catalyst Switch Networks* at the following URL:

- http://www.cisco.com/c/en/us/support/docs/ip/hot-standby-router-protocol-hsrp/10583-62.html

Flex Links Troubleshooting

To investigate problems with Flex Links, the primary command for confirming the configuration is *show interface switchport backup*, as shown in the following:

```
Switch# show interface switchport backup

Switch Backup Interface Pairs:

Active Interface        Backup Interface        State
------------------------------------------------------------------------
FastEthernet1/1         FastEthernet1/2         Active Up/Backup Standby
```

Adding the *detail* keyword to the end of this command provides more information about the configuration, including preemption, bandwidth, and MAC address move parameters. These are generally not used when configuring Flex Links as part of the CPwE architecture.

EtherChannel Troubleshooting

To investigate problems with EtherChannel, the primary command for confirming the configuration is *show etherchannel summary*, as shown in the following:

```
IE2K-30#show etherchannel summary
Flags:  D - down        P - bundled in port-channel
        I - stand-alone s - suspended
        H - Hot-standby (LACP only)
        R - Layer3      S - Layer2
        U - in use      f - failed to allocate aggregator

        M - not in use, minimum links not met
        u - unsuitable for bundling
        w - waiting to be aggregated
        d - default port


Number of channel-groups in use: 1
Number of aggregators:           1

Group  Port-channel  Protocol    Ports
------+-------------+-----------+-----------------------------------------------
2      Po2(SU)         LACP      Gi1/1(P)    Gi1/2(P)
```

Each configured EtherChannel is shown in this output, along with their status (as indicated by the flags next to the port-channel number), protocol (LACP or Cisco Port Aggregation Protocol [PAgP]), and member port status (also indicated by flags). Confirm that all links are up, that the protocol matches on both sides, and that the overall EtherChannel status is up. If it is not up, use the flags to determine the reason why the links or port-channel are down and check the logging buffer for any related messages.

Note For additional Etherchannel troubleshooting tips, see *Troubleshooting Etherchannel* at the following URL:

- http://www.cisco.com/c/en/us/support/docs/lan-switching/ethernet/12006-chapter22.html#treth

REP Troubleshooting

REP has two basic commands that can be used to troubleshoot any problems with an incomplete segment:

```
show rep topology
show interfaces rep
```

The first command, *show rep topology*, gives an overall view of the segment, including the locations of the primary and secondary edge ports and alternate (blocking) port. It shows all ports that belong to the segment in a linear fashion, which helps to pinpoint the device and port that might be causing an issue. Typical output for a fully functional segment looks like the following:

```
IES-13#show rep topology
REP Segment 10
BridgeNamePortNameEdgeRole
---------------- ---------- ---- ----
D3750X  Gi1/1/1PriOpen
IES-11  Gi1/1      Open
IES-11  Gi1/2      Open
IES-10  Gi1/2      Open
IES-10  Gi1/1      Open
```

```
IES-12  Gi1/1       Open
IES-12  Gi1/2       Open
IES-13  Gi1/2       Open
IES-13  Gi1/1       Alt
IES-14  Gi1/1       Open
IES-14  Gi1/2       Open
IES-15  Gi1/2       Open
```

More detailed information about port status and identifiers can be found by adding *detail* to the command, as shown in the following output:

```
IES-13#show rep topology detail
REP Segment 10
D3750X, Gi1/1/1 (Primary Edge)
Open Port, all vlans forwarding
Bridge MAC: 0007.7d5c.6300
Port Number: 019
Port Priority: 000
Neighbor Number: 1 / [-50]
IES-11, Gi1/1 (Intermediate)
Open Port, all vlans forwarding
Bridge MAC: 4c00.8254.de80
Port Number: 001
Port Priority: 000
Neighbor Number: 2 / [-49]
IES-11, Gi1/2 (Intermediate)
Open Port, all vlans forwarding
Bridge MAC: 4c00.8254.de80
Port Number: 002
Port Priority: 000
Neighbor Number: 3 / [-48]
<output omitted>
```

Finally, by adding *archive* to the command, the output that would have resulted before the last event (for example, a failure) within the segment is displayed.

A more detailed view of REP-enabled ports on a particular switch within the segment is provided by the *show interfaces rep* command. Typical output for a switch with two REP-enabled uplinks is represented in the following:

```
IES-13#show interfaces rep
Interface             Seg-id Type    LinkOp         Role
-----------------------------------------------------
GigabitEthernet1/1    10             TWO_WAY Alt
GigabitEthernet1/2    10             TWO_WAY Open
```

Most of the fields are self-explanatory, but the LinkOp field indicates whether a full REP adjacency has been formed with the device connected to that port. When the port is first configured for REP, it will begin in a WAIT state. Next, it will send a Hello packet to the neighbor and change its state to ONE_WAY.

If the adjacency fails, the port will likely remain in either this or another failed state (for example, NO_NEIGHBOR). Reasons for a failed adjacency could include the opposite port not being configured for REP, REP traffic not being allowed on the trunk, or the REP process failing on the connected switch. Once a full adjacency is established, the state is changed to TWO_WAY.

Once again, adding *detail* to the command will give a much more detailed view of the REP port characteristics, as shown below:

```
IES-13#show interfaces rep detail
GigabitEthernet1/1 REP enabled
Segment-id: 10 (Segment)
PortID: 0001F84F575EBA00
Preferred flag: No
Operational Link Status: TWO_WAYf
```

```
Current Key: 0001F84F575EBA0011DD
Port Role: Alternate
Blocked VLAN: 1-4094
Admin-vlan: 900
Preempt Delay Timer: disabled
LSL Ageout Timer: 5000 ms
Configured Load-balancing Block Port: none
Configured Load-balancing Block VLAN: none
STCN Propagate to: none
LSL PDU rx: 1563198, tx: 1830473
HFL PDU rx: 1139, tx: 948
BPA TLV rx: 551026, tx: 1078849
BPA (STCN, LSL) TLV rx: 0, tx: 0
BPA (STCN, HFL) TLV rx: 0, tx: 0
EPA-ELECTION TLV rx: 22649, tx: 25342
EPA-COMMAND TLV rx: 0, tx: 0
EPA-INFO TLV rx: 422937, tx: 422832

GigabitEthernet1/2 REP enabled
Segment-id: 10 (Segment)
PortID: 0002F84F575EBA00
Preferred flag: No
Operational Link Status: TWO_WAY
Current Key: 0001F84F575EBA0011DD
Port Role: Open
Blocked VLAN: <empty>
Admin-vlan: 900
Preempt Delay Timer: disabled
LSL Ageout Timer: 5000 ms
Configured Load-balancing Block Port: none
Configured Load-balancing Block VLAN: none
STCN Propagate to: none
LSL PDU rx: 1330531, tx: 2110526
HFL PDU rx: 1087, tx: 0
BPA TLV rx: 28423, tx: 1601021
BPA (STCN, LSL) TLV rx: 0, tx: 0
BPA (STCN, HFL) TLV rx: 0, tx: 0
EPA-ELECTION TLV rx: 32022, tx: 22649
EPA-COMMAND TLV rx: 0, tx: 0
EPA-INFO TLV rx: 429606, tx: 429756
```

Significant fields from this output include:

- **PortID**—The full REP port identifier, formed by appending the port priority and port number to the bridge MAC address (these values can be seen in the output of *show rep topology detail*).
- **Current Key**—Indicates the key for the current alternate port in the segment. All segment ports should have synchronized keys.
- **Blocked VLAN**—Any VLANs blocked by this port for load balancing purposes.
- **Admin**—VLAN-configured REP administrative VLAN.
- Statistics for LSL and HFL packets and other REP-related messaging.

This debug command shows failure detection and HFL/LSL packets sent to inform the segment of the failure:

```
debug rep failure-recovery
```

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 802.11 Wireless LAN Technology within a Converged Plantwide Ethernet Architecture:*
  - Rockwell Automation site:
    http://literature.rockwellautomation.com/idc/groups/literature/documents/td/enet-td006_-en-p.pdf
  - Cisco site:
    http://www.cisco.com/c/en/us/td/docs/solutions/Verticals/CPwE/NovCVD/CPwE_WLAN_CVD.html
- *Deploying Network Address Translation within a Converged Plantwide Ethernet Architecture:*

  - Rockwell Automation site: http://literature.rockwellautomation.com/idc/groups/literature/documents/td/enet-td007_-en-p.pdf
  - Cisco site: http://www.cisco.com/c/en/us/td/docs/solutions/Verticals/CPwE/3-5-1/NAT/DIG/CPwE_NAT_CVD.html

- *OEM Networking within a Converged Plantwide Ethernet Architecture*:
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APPENDIX B

Acronyms and Initialisms

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

Table B-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 B-1 Acronyms and Initialisms (continued)

Term	Description
DACL	Downloadable Access Control List
DAN	Double Attached Node
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

Table B-1 Acronyms and Initialisms (continued)

Term	Description
LBS	Location Based Services
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
PRP	Parallel Redundancy Protocol
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

Table B-1 Acronyms and Initialisms (continued)

Term	Description
RAS	Remote Access Server
RD	Route Descriptor
RDG	Remote Desktop Gateway
RDP	Remote Desktop Protocol
RDS	Remote Desktop Services
RedBox	PRP redundancy box
REP	Resilient Ethernet Protocol
RPI	Request Packet Interval
RTT	Round Trip Time
SA	Security Association
SaaS	Software-as-a-Service
SAN	Single Attached Node
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
VDAN	Virtual Double Attached Node
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 C

About Cisco Validated Design (CVD) Program

Converged Plantwide Ethernet (CPwE) is a collection of architected, tested, and validated designs 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 ensure 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:

1. Requirements are gathered from a broad base of customers to devise a set of use cases that will fulfill these business needs.
2. 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).
3. 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.
4. 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, CPwE also provides Cisco Reference Designs (CRDs) that follow the CVD process, but that focus on reference designs developed around specific set 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 Cisco Validated Designs:

http://www.cisco.com/c/dam/en/us/td/docs/solutions/CVD/overview/cvd_overview.pdf

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