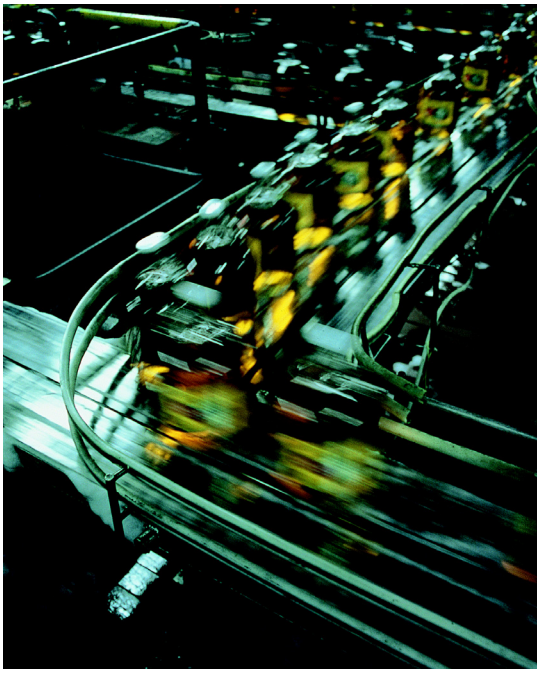


Deploying a Resilient Converged Plantwide Ethernet Architecture

Design and Implementation Guide

February 2018

Cisco Validated Design

Document Reference Number: ENET-TD010B-EN-P

Preface

Converged Plantwide Ethernet (CPwE) is a collection of tested and validated architectures that are developed by subject matter authorities at Cisco Systems and Rockwell Automation and that follow the Cisco Validated Design (CVD) program. 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 manufacturers with the design and deployment of a scalable, reliable, secure and future-ready plant-wide industrial network infrastructure. CPwE can also help manufacturers achieve the benefits of cost reduction using proven designs that help facilitate quicker deployment while helping to reduce risk in deploying new technology.

Resilient plant-wide network architectures play a pivotal role in helping to confirm overall plant 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 network architecture is made up of multiple technologies (logical and physical) deployed at different levels within plant-wide architectures. When selecting resiliency technology, various IACS application factors should be evaluated, including physical layout of IACS devices (geographic dispersion), resiliency performance, uplink media type, tolerance to data latency and jitter and future-ready requirements. Deploying a Resilient Converged Plantwide Ethernet Architecture CVD (CPwE Resiliency CVD), which is documented in this *Deploying a Resilient Converged Plantwide Ethernet Architecture Design and Implementation Guide (DIG)*, outlines several use cases for designing and deploying resilient plant-wide architectures for IACS applications. The CPwE Resiliency CVD was tested and validated by Cisco Systems, Panduit and Rockwell Automation.

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	Lists document references for CPwE, the core switch architecture, distribution switches, access layer switches, routing between zones, Network Time Protocol, and network infrastructure hardening.

Chapter/Appendix	Description
Test Hardware and Software	Provides information about the role, product and software version for hardware and software tested in this release.
Physical Infrastructure Network Design for CPwE Logical Architecture	Introduces key concepts and addresses common design elements for mapping the physical infrastructure to the CPwE Logical Network Design, key requirements and considerations, link testing, and wireless physical infrastructure considerations.
Physical Infrastructure Design for the Cell/Area Zone	Describes the Cell/Area Zone physical infrastructure for on-machine or process skid applications and the locations for the Cisco and Allen-Bradley® Stratix® Industrial Ethernet Switches (IES), including IES located in control panels and/or PNZS components.
Physical Infrastructure Design for the Industrial Zone	Describes the physical infrastructure for network distribution across the Industrial Zone (one or more Cell/Area Zones) through use of Industrial Distribution Frames (IDF), industrial pathways, and robust media/connectivity.
Physical Infrastructure Deployment for Level 3 Site Operations	Describes the physical infrastructure for Level 3 Site Operations, including Industrial Data Centers (IDCs) for compute, storage, and switching resources for manufacturing software and services.
Acronyms and Initialisms	List of acronyms and initialisms used in this document.
About Cisco Validated Design (CVD) Program	Describes the purpose of and steps for the Cisco Validated Design (CVD) process.

For More Information

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

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

Note This release of the CPwE architecture focuses on EtherNet/IP™, which uses the ODVA Common Industrial Protocol (CIP™) and is ready for the Industrial Internet of Things (IIoT). For more information on EtherNet/IP, 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 network technology convergence through the use of standard Ethernet, Internet Protocol (IP) and resiliency technologies, which help to enable the Industrial Internet of Things (IIoT).

Business practices, corporate standards, industry standards, policies and tolerance to risk are key factors in determining the degree of resiliency and application availability required within an IACS plant-wide architecture. 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 uptime.

An IACS is deployed in a wide variety of industries such as automotive, pharmaceuticals, consumer goods, pulp and paper, oil and gas, mining and energy. IACS applications are made up of multiple control and information disciplines such as continuous process, batch, discrete and hybrid combinations. A resilient network architecture can help to increase overall equipment effectiveness (OEE) of the IACS by reducing the impact of a failure and speed recovery from an outage which lowers mean-time-to-repair (MTTR).

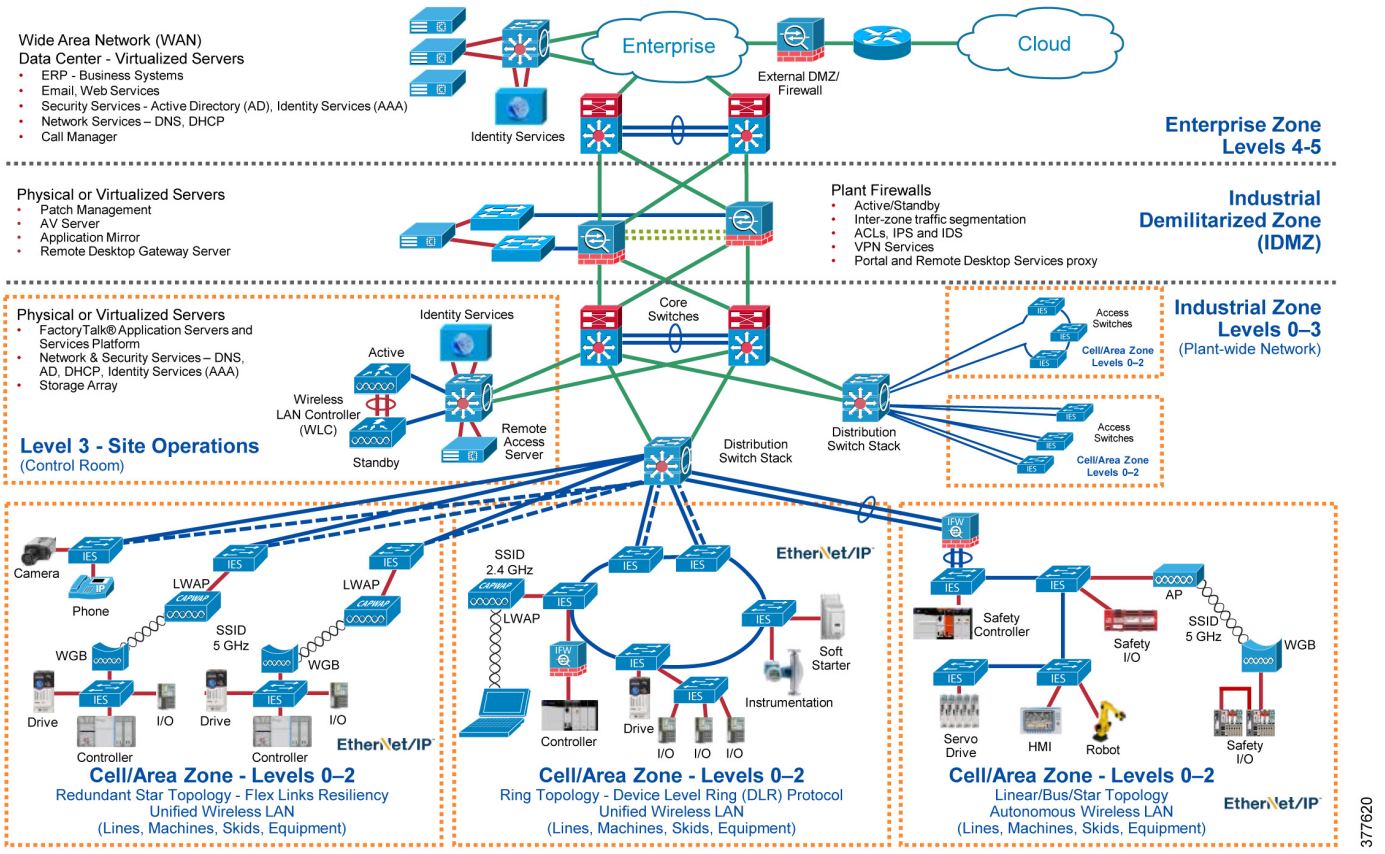
A holistic resilient plant-wide network architecture is made up of multiple technologies (logical and physical) deployed at different levels within the plant-wide architecture:

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

CPwE is the underlying architecture that provides standard network services for control and information disciplines, devices, and equipment found in modern IACS applications. The CPwE architectures (Figure 1-1) provide design and implementation guidance, test results and documented configuration settings that can help to achieve the real-time communication, reliability, scalability, security and resiliency requirements of modern IACS applications. CPwE is brought to market through a strategic alliance between Cisco Systems and Rockwell Automation.

Figure 1-1 CPwE Architectures



Converged Plantwide Ethernet Resiliency

The Deploying a Resilient Converged Plantwide Ethernet Architecture Cisco Validated Design (CVD), which is documented in this *Deploying a Resilient Converged Plantwide Ethernet Architecture Design and Implementation Guide (DIG)*, outlines the following key requirements and design considerations to help with successfully designing and deploying a holistic resilient plant-wide network architecture:

- Industrial Zone:
  - Core Switching
  - Aggregation/Distribution Switching
  - Active/Standby WLC
  - Robust Physical Infrastructure
- Cell/Area Zone:

  - Redundant Path Topology with Resiliency Protocol
  - Industrial Ethernet Switching
  - Robust Physical Infrastructure
- Level 3 Site Operations:
  - Virtual Servers
  - Security and Network Services
  - Robust Physical Infrastructure
- Industrial Demilitarized Zone (IDMZ):
  - Active/Standby Firewalls
  - Robust Physical Infrastructure

Note The Deploying a Resilient Converged Plantwide Ethernet Architecture DIG outlines resiliency use cases for switch-level topologies. For device-level resiliency use cases, see the *Deploying Device Level Ring within a Converged Plantwide Ethernet Architecture White Paper* at the following URLs:

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

CPwE Resiliency Use Cases

The CPwE architecture supports scalability which includes the degree of resiliency applied to a plant-wide network architecture. Scalable resiliency comes in many forms; that is, technology choices in topology and distribution switch. For this *Deploying a Resilient Converged Plantwide Ethernet Architecture DIG*, the following represents a portion of the use cases that were tested, validated and documented by Cisco Systems, Panduit and Rockwell Automation. For more details, see CPwE Resiliency Design Considerations.

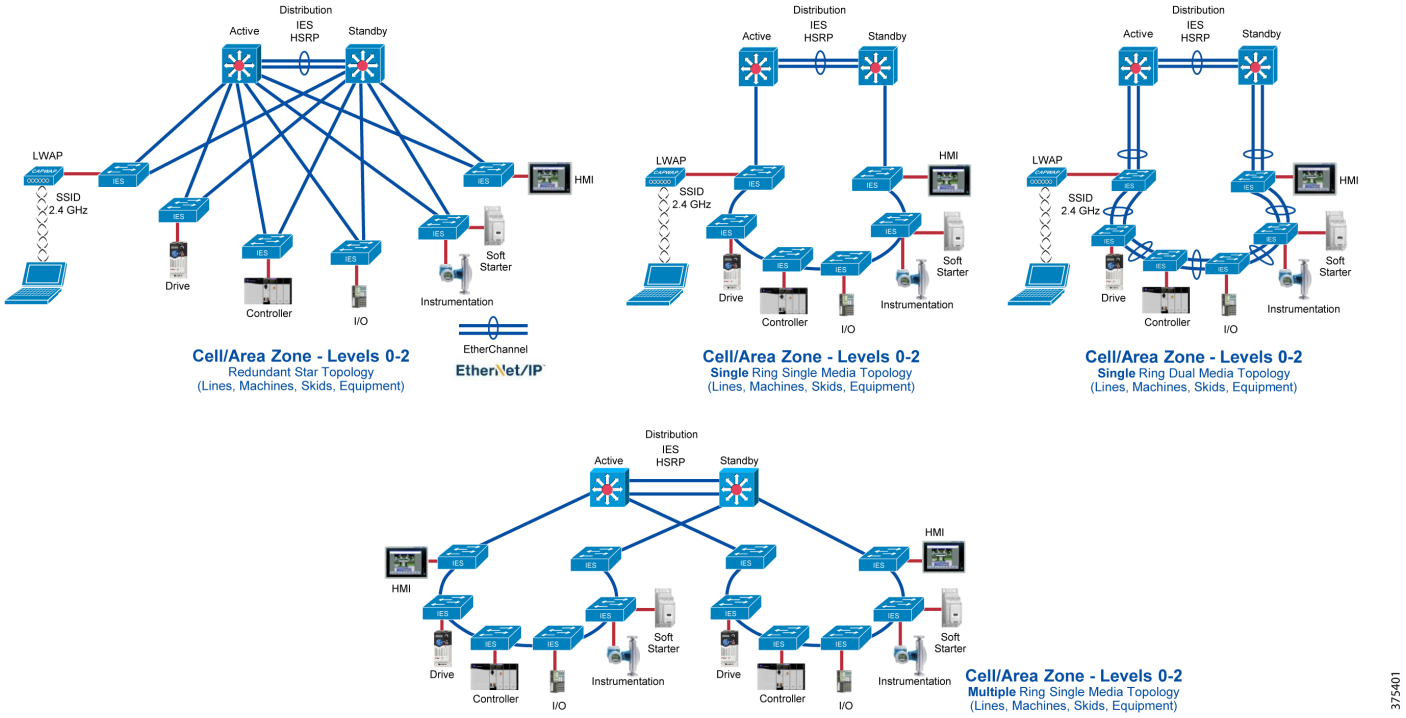
Allen-Bradley® Stratix® and Cisco Industrial Ethernet Switches (IES)

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)
- 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

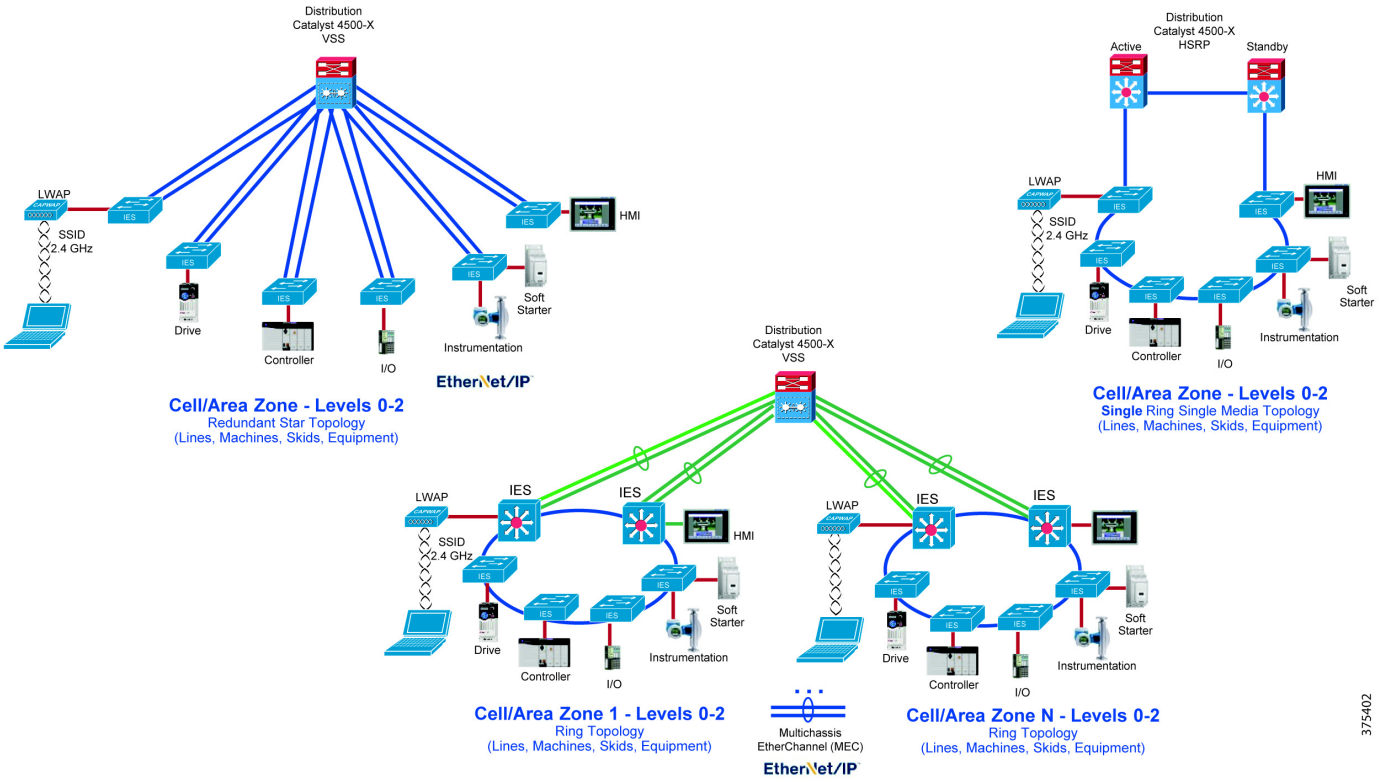


Catalyst 4500-X Aggregation/Distribution Switches

Refer to Figure 1-3.

- Virtual Switching System (VSS) virtualization technology that pools 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

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

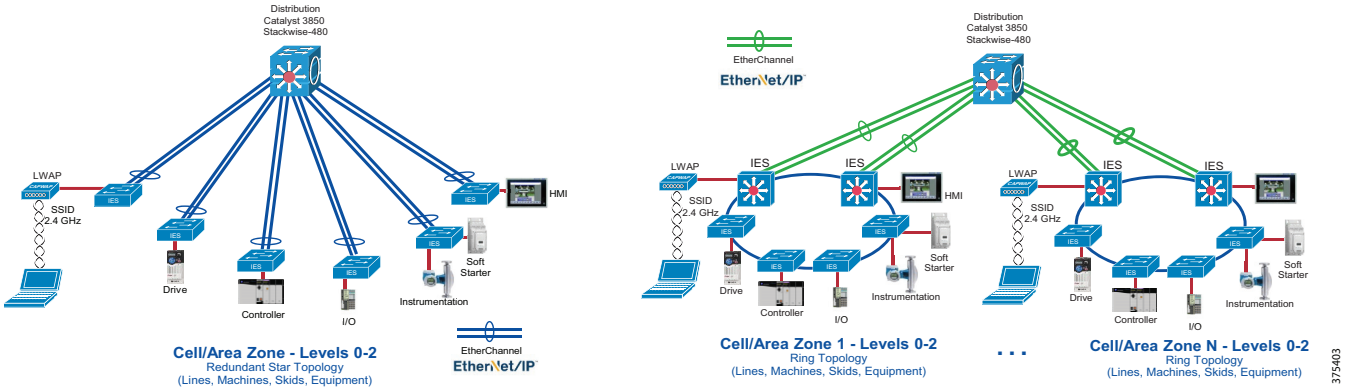


Catalyst 3850 StackWise-480 Aggregation/Distribution Switch

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

Figure 1-4 Catalyst 3850 Aggregation/Distribution Switch

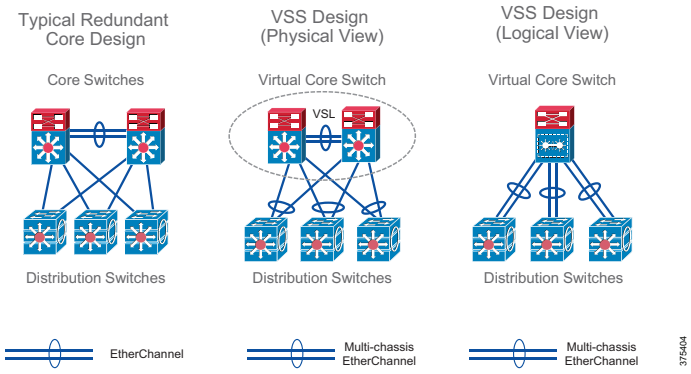


Catalyst 6800 Core Switches

Refer to Figure 1-5.

- VSS virtualization technology that pools two physical switch chassis into one virtual switch, with SSO

Figure 1-5 Core Switches - Traditional versus VSS Design



Wireless LAN Controller (WLC)

Refer to Figure 1-6.

- High availability (HA) in Cisco Wireless LAN Controllers (WLC) allows you to reduce the downtime of the wireless networks that occurs due to the WLC failure.
- In an HA architecture, one WLC is configured as the primary controller and another WLC as the secondary (standby-hot) controller. The standby-hot controller continuously monitors the health of the active controller through a direct wired connection over a dedicated redundancy port. Both the controllers share the same configuration.
- Unified WLAN architecture supports Stateful Switchover of Access Points (APs) and clients. Access points establish a Control and Provisioning of Wireless Access Points (CAPWAP) tunnel with the Active WLC and share a mirror copy of the AP database with the Standby WLC.

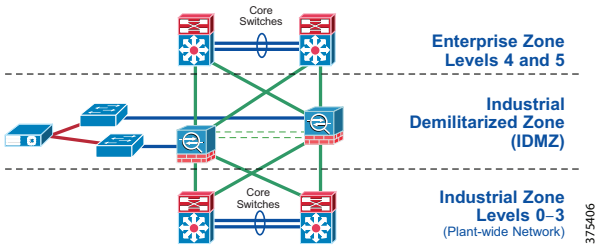
Figure 1-6 Active/Standby Wireless LAN Controllers (WLC)

Adaptive Security Appliance 5500-X Firewalls with FirePOWER

Refer to Figure 1-7.

- Active/Standby stateful failover mechanism enabling a standby Adaptive Security Appliance (ASA) to take over the functionality of a failed unit. When the active unit fails, the standby unit changes to the active state and the failed unit becomes standby when it comes up.
- When Stateful Failover is enabled, the active unit continually passes per-connection state information to the standby unit. After a failover occurs, the same connection information is available at the new active unit therefore allowing supported end-user applications to keep the same communication session.

Figure 1-7 Active/Standby Firewalls



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 and Rockwell Automation have collaborated with Panduit to include their building block approach for physical infrastructure deployment. This approach is reflected in Appendices C-F and helps customers address the physical deployment associated with converged plant-wide EtherNet/IP. As a result, users can achieve resilient, scalable networks that can support proven and flexible CPwE logical architectures designed to help optimize plant-wide IACS network performance.

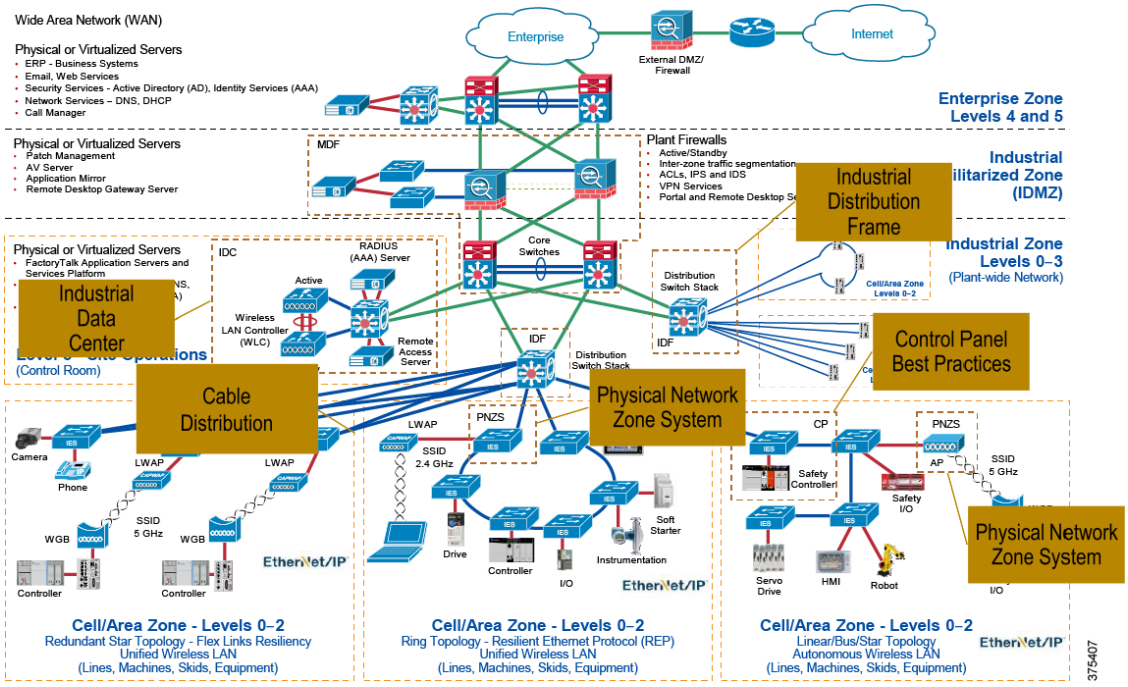
Refer to Figure 1-8.

For this *Deploying a Resilient Converged Plantwide Ethernet Architecture DIG*, 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
  - IES deployment within the Cell/Area Zone

- Physical Network Zone System:
  - IES and 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 1-8 Robust Physical Infrastructure for the CPwE Architecture



CHAPTER 2

CPwE Resiliency Design Considerations

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

Resiliency Architectural Framework

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

- Industrial Zone (core switching, distribution switching, and wireless infrastructure)
- Cell/Area Zone (access switching)
- Level 3 Site Operations (network and security services)
- Industrial Demilitarized Zone (IDMZ)

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.

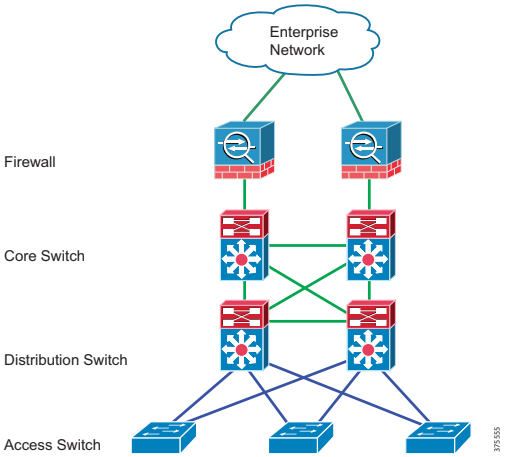
Network Reference Model

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. In essence though, 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

The CPwE Resiliency CVD introduces the following new distribution layer switches: Catalyst 4500-X, Catalyst 3850, IE 5000/ Stratix® 5410 and IE 4000/Stratix® 5400. 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:

- Virtual Switching System, page 2-3
- StackWise-480, page 2-5
- Hot Standby Redundancy Protocol, page 2-6

Virtual Switching System

Virtual Switching System Overview

Virtual Switching System (VSS) helps enable unprecedented functionality and availability of network design by integrating network and systems redundancy into a single device. The end-to-end network that is enabled with VSS capability helps allow the flexibility and availability that is described in this document. The Catalyst 4500-X is the distribution platform that is used within this document that supports VSS technology.

Note The Catalyst 4500-X with VSS can also be used in the core layer, depending on plant size.

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

- Reduced risk associated with a looped topology
- Better return on existing investments via increased bandwidth from the access layer
- Reduced operational expenses (OPEX) through increased flexibility in deploying and managing new services with a single logical device, such as network virtualization
- Reduced configuration errors and elimination of First Hop Redundancy Protocols (FHRPs), such as Virtual Router Redundancy Protocol (VRRP) and Hot Standby Redundancy Protocol (HSRP), resulting in faster convergence at Layer 3 and fewer consumed IP addresses

- Simplified management of a single configuration and fewer operational failure points

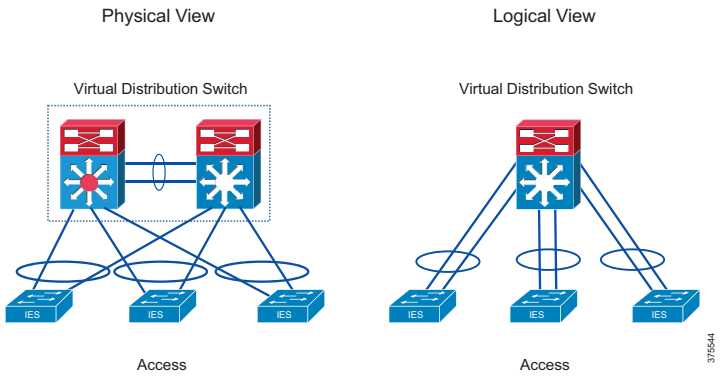
Note For more information on VSS design and implementation, see the "Configuring VSS" chapter of the *Catalyst 4500 Series Switch Software Configuration Guide, Release IOS XE 3.4.xSG and IOS 15.1(2)SGx* at the following URL:

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

Virtual Switching System Topology

Network operators increase network reliability by configuring switches in redundant pairs and by provisioning links to both switches in the redundant pair. Redundant network elements and redundant links can add complexity to network design and operation. Figure 2-2 shows how VSS simplifies the network by helping to reduce the number of network elements and hiding the complexity of managing redundant switches and links.

Figure 2-2 VSS in the Distribution Network



VSS combines a pair of switches into a single network element. VSS manages the redundant links, which act as a single port-channel for neighboring switches. It also simplifies network configuration and operation by reducing the number of Layer 3 routing neighbors and by providing a loop-free Layer 2 topology.

Active and Standby Chassis

When you create or restart a VSS, the peer chassis negotiate their roles. One chassis becomes the active chassis, and the other chassis becomes the standby.

The active chassis controls the VSS. It runs the Layer 2 and Layer 3 control plane protocols for the switching modules on both chassis. The active chassis also provides management functions for the VSS, such as module online insertion and removal (OIR) and the console interface.

The active and standby chassis perform packet forwarding for ingress data traffic on their locally hosted interfaces. However, the standby chassis sends all control traffic to the active chassis for processing.

Virtual Switch Link

For the two chassis of the VSS to act as one network element, they need to share control information and data traffic. The Virtual Switch Link (VSL) serves as a logical connection that carries critical system control information such as hot-standby supervisor programming, line card status, Distributed Forwarding Card (DFC) programming, system management, diagnostics and more, as shown in the physical view in Figure 2-2.

In addition, VSL is also capable of carrying user data traffic when necessary. Thus, the VSL has a dual purpose: supporting system control synchronization and being a data link. The VSL is implemented as an EtherChannel with up to eight links. The VSL gives control traffic higher priority than data traffic so that control messages are never discarded. Data traffic is load balanced among the VSL links by the EtherChannel load-balancing algorithm.

Redundancy and High Availability

In VSS mode, supervisor engine redundancy operates between the active and standby chassis, using SSO and Cisco Nonstop Forwarding (NSF). The peer chassis exchange configuration and state information across the VSL and the standby supervisor engine runs in hot standby mode.

The standby chassis monitors the active chassis using the VSL. If it detects failure, the standby chassis initiates a switchover and takes on the active role. When the failed chassis recovers, it takes on the standby role.

If the VSL fails completely, the standby chassis assumes that the active chassis has failed and initiates a switchover. After the switchover, if both chassis are active, the dual-active detection feature detects this condition and initiates recovery action.

In addition, unlike some other redundancy methods (such as the StackWise-480), the VSS devices can be geographically separated by great distances as long as the connecting media supports signal transmission over that distance.

StackWise-480

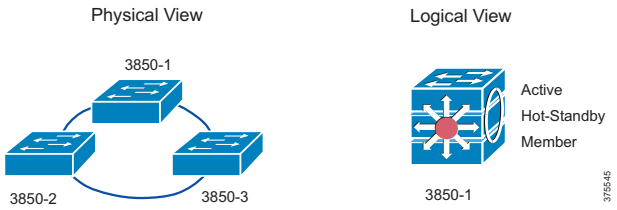
Cisco Catalyst 3000 switches define stacking architecture for enterprise networks to expand form factors, switching capacity and redundancy in the wiring closet. Cisco StackWise® Plus is a proven and widely deployed, cost-effective solution that helps deliver scale, performance, resiliency and operational simplicity. To build the next-generation modular stack product, Cisco made significant changes to the StackWise Plus hardware and software architecture for the Cisco Catalyst 3850 Switch. The new Cisco Catalyst 3850 Switch is built upon high-speed next-generation Cisco Unified Access Data Plane (UADP) Application-Specific Integrated Circuit (ASIC) technology and is combined with the feature-rich and powerful Cisco IOS XE software operating system.

Using the IOS XE 16.x train firmware, the switch includes a host of all new software advances, including MAC Security (MACsec) on all ports, Audio Video Bridging (AVB), Network as a Sensor/Network as an Enforcer (NaaS/NaaE), Multiprotocol Label Switching (MPLS), Fabric, mGig, Converged Access, mDNS Gateway, Wireshark, 40G uplinks, Cisco Expandable Power System (XPS), 8 queues, Modular Quality of Service CLI (MQC), Cisco Flexible NetFlow (FNF) on all ports, Cisco Application Visibility and Control (AVC), Cisco Unique Access Data Plane (UADP), Cisco Encapsulated Remote Switch Port Analyzer (ERSPAN), Trustsec, SSO, and UPOE.

The new StackWise-480 architecture allows you to build a high-speed stack ring with features and services scalability superior to StackWise Plus. To accommodate varying port density requirements, the hardware can support both 48- and 24-port switches in a single stack ring. The Cisco Catalyst 3850 Switch delivers uncompromised hardware-accelerated, rich integrated borderless network services and enterprise-class system resiliency.

Cisco StackWise-480 provides a robust distributed forwarding architecture through each stack member switch and a unified, fully centralized control and management plane to simplify operation in a large-scale network design. One switch in a stack ring is elected to be the active switch. The active switch controls the management plane of the entire stack from both the network and user perspective. The hot standby switch assumes the active role when it detects a failure of the primary active switch. Figure 2-3 illustrates the physical versus logical view of a system in stack configuration mode.

Figure 2-3 StackWise-480 Physical versus Logical Topology



The Cisco Catalyst 3850 Switches support a wide range of Layer 2 and Layer 3 stateful capabilities to provide resilient network communication. In real time, the Cisco IOS XE Software running on the active switch synchronizes its protocol state machines, software forwarding tables and system configuration to the Cisco IOS XE Software instance running on the standby switch.

Note For more details about the StackWise-480 architecture and capabilities of the Catalyst 3850, 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 a variety of platforms, including the Catalyst 4500-X, IE 5000/Stratix 5410 and IE 4000/Stratix 5400.

In the recommended hierarchical model, the distribution switches are the Layer 2/Layer 3 boundary and also 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.

Wireless Infrastructure

The Wireless LAN Controller (WLC) provides redundancy through the use of an active/hot-standby configuration. To provide the backup/failure performance, it is recommended to connect the active and standby WLCs via a 2x GE port aggregate link (EtherChannel) to the distribution switch.

A separate connection via a redundancy port is used to verify peer reachability and ensure quick failover.

Note For more information on wireless infrastructure resiliency options, see the *Deploying 802.11 Wireless LAN Technology within a Converged Plantwide Ethernet Architecture Design and Implementation Guide* at the following URLs:

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

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 connectible 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 looking at the overall IACS network design, the access switch provides the majority 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.

This *Deploying a Resilient Converged Plantwide Ethernet Architecture DIG* introduces the IE 4000/Stratix® 5400 as a new access switch option to supplement the existing IE 2000/Stratix® 5700 and IE 3000/Stratix® 8000. 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 2-19 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 2-1 summarizes these topology options.

Table 2-1 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 reduces 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 floor 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 this CVD.

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

Redundant Star Topology

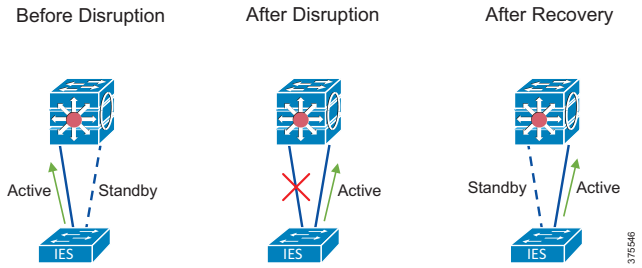
Resiliency Protocols

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 uplink interface and a backup uplink interface. Figure 2-4 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 of 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 2-4 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 ensure 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:

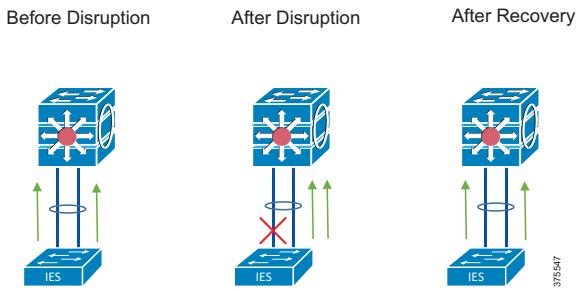
- http://www.cisco.com/c/en/us/td/docs/switches/lan/cisco_ie2000/software/release/15_2_2_e/configuration/guide/scg-ie2000/swflink.html

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 need to 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 2-5, 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 2-5 EtherChannel Basic Operation



LACP as defined in the IEEE 802.3ad standard. LACP 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. The CPwE Resiliency CVD 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 does 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** incorporated into IEEE 802.1D. STP will recover from a topology change in less than 60 seconds. Generally speaking, 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 a large number of 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, in general, 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 in particular, 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 very 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. The total number of failure samples for every use case is 250, which includes multiple failure points in the topology for links and switches.

Catalyst 4500-X with VSS

The following use cases represent Catalyst 4500-X in VSS mode as a distribution platform configured with Flex Links and EtherChannel protocols correspondingly. See Figure 2-6 and Figure 2-7 depicting topologies.

Figure 2-6 Catalyst 4500-X VSS with Flex Links Redundant Star Topology

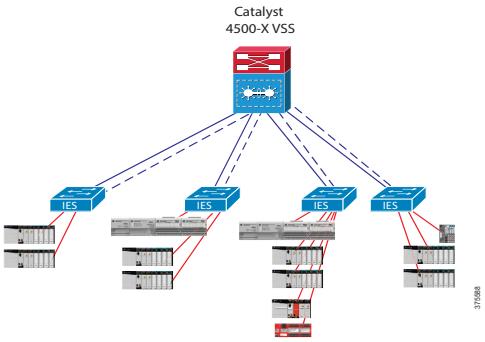


Figure 2-7 Catalyst 4500-X VSS with EtherChannel Redundant Star Topology

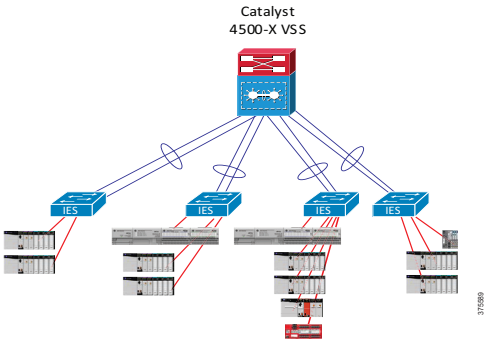


Table 2-2 and Table 2-3 summarize the convergence values observed during validation efforts and can be used to select the appropriate resiliency protocols based on application requirements. The results are based on CIP Class 1 (implicit) traffic flows (both unicast and multicast), and the unicast results 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 2-2 and Table 2-3 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, please refer to Appendix D: Physical Infrastructure Design for the Cell/Area Zone.

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

			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 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 2-3 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 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 4500-X with HSRP

The following use cases represent Catalyst 4500-X in HSRP mode as a distribution platform configured with Flex Links and MSTP protocols correspondingly. See Figure 2-8 and Figure 2-9 depicting topologies.

Figure 2-8 Catalyst 4500-X HSRP with Flex Links Redundant Star Topology

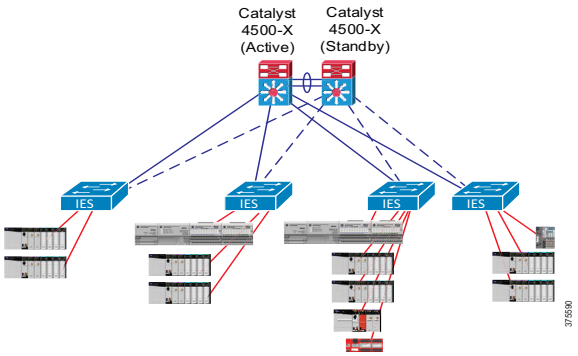


Figure 2-9 Catalyst 4500-X HSRP with MSTP Redundant Star Topology

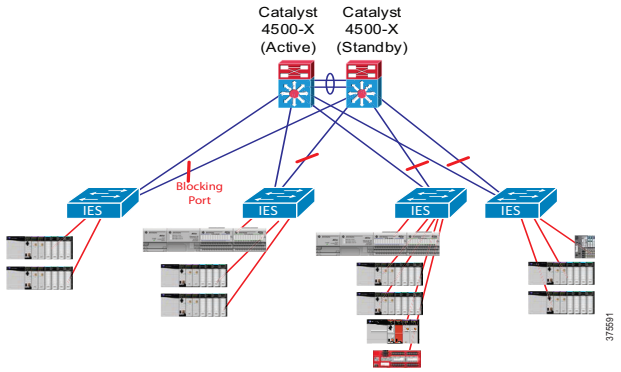


Table 2-4 and Table 2-5 summarize the convergence values observed during validation efforts and can be used to select the appropriate resiliency protocols based on application requirements.

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, please refer to Appendix D: Physical Infrastructure Design for the Cell/Area Zone.

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 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 2-5 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
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 4500-X as the distribution platform, Cisco, Panduit and Rockwell Automation recommend using VSS as the Layer 3 gateway resiliency protocol and Flex Links 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 2-10 and Figure 2-11 depicting topologies.

Figure 2-10 IE 5000/Stratix 5410 HSRP with Flex Links Redundant Star Topology

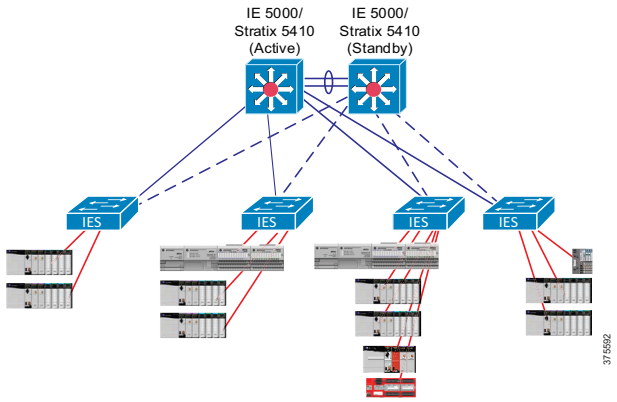


Figure 2-11 IE 5000/Stratix 5410 HSRP with MSTP Redundant Star Topology

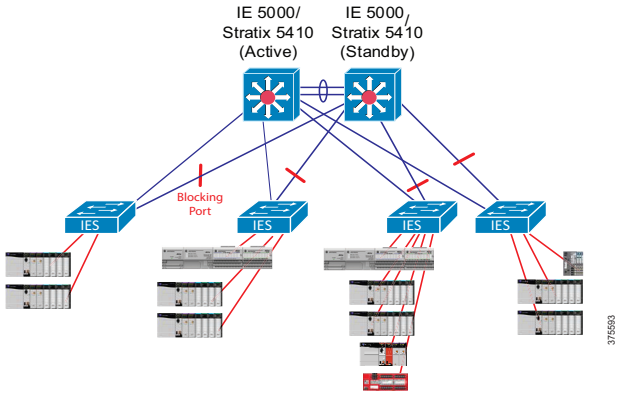


Table 2-6 and Table 2-7 summarize the convergence values observed during validation efforts and can be used to select the appropriate resiliency protocols based on application requirements.

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 network, please refer to Appendix D: Physical Infrastructure Design for the Cell/Area Zone.

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

			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
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 2-7 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
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 3850 with StackWise-480

The following use cases represent Catalyst 3850 in StackWise-480 as a distribution platform configured with Flex Links, EtherChannels and MSTP protocols correspondingly. See Figure 2-12, Figure 2-13 and Figure 2-14 depicting topologies.

Figure 2-12 Catalyst 3850 StackWise-480 with Flex Links Redundant Star Topology

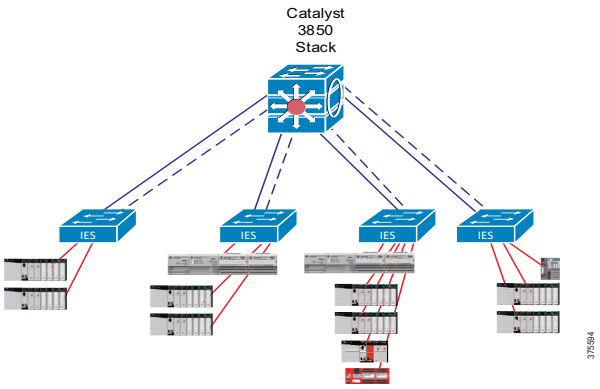


Figure 2-13 Catalyst 3850 StackWise-480 with EtherChannel Redundant Star Topology

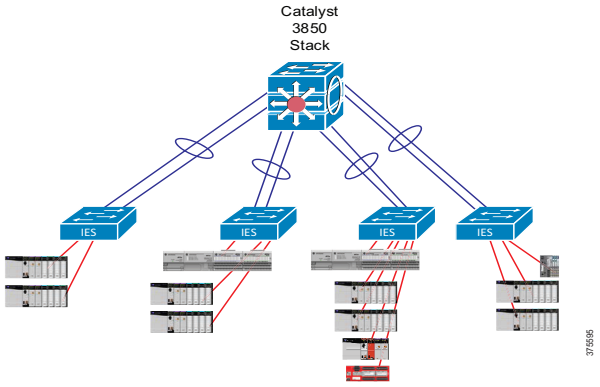


Figure 2-14 Catalyst 3850 StackWise-480 with MSTP Redundant Star Topology

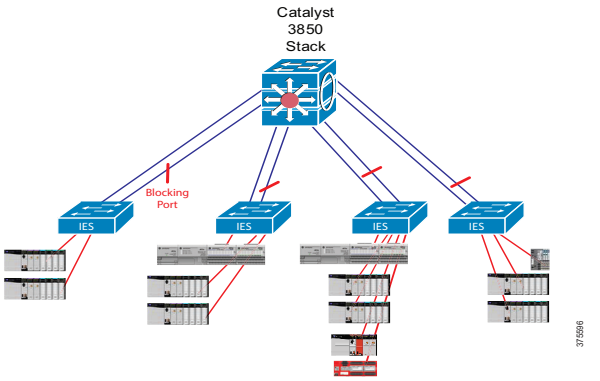


Table 2-8 and Table 2-9 summarize the convergence values observed during validation efforts and can be used to select the appropriate resiliency protocols based on application requirements

Note Link and switch disruption locations are defined in Table 2-8 and Table 2-9. To help prevent such events from occurring within your network, please refer to Appendix D: Physical Infrastructure Design for the Cell/Area Zone.

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

			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 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 2-9 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 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 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.

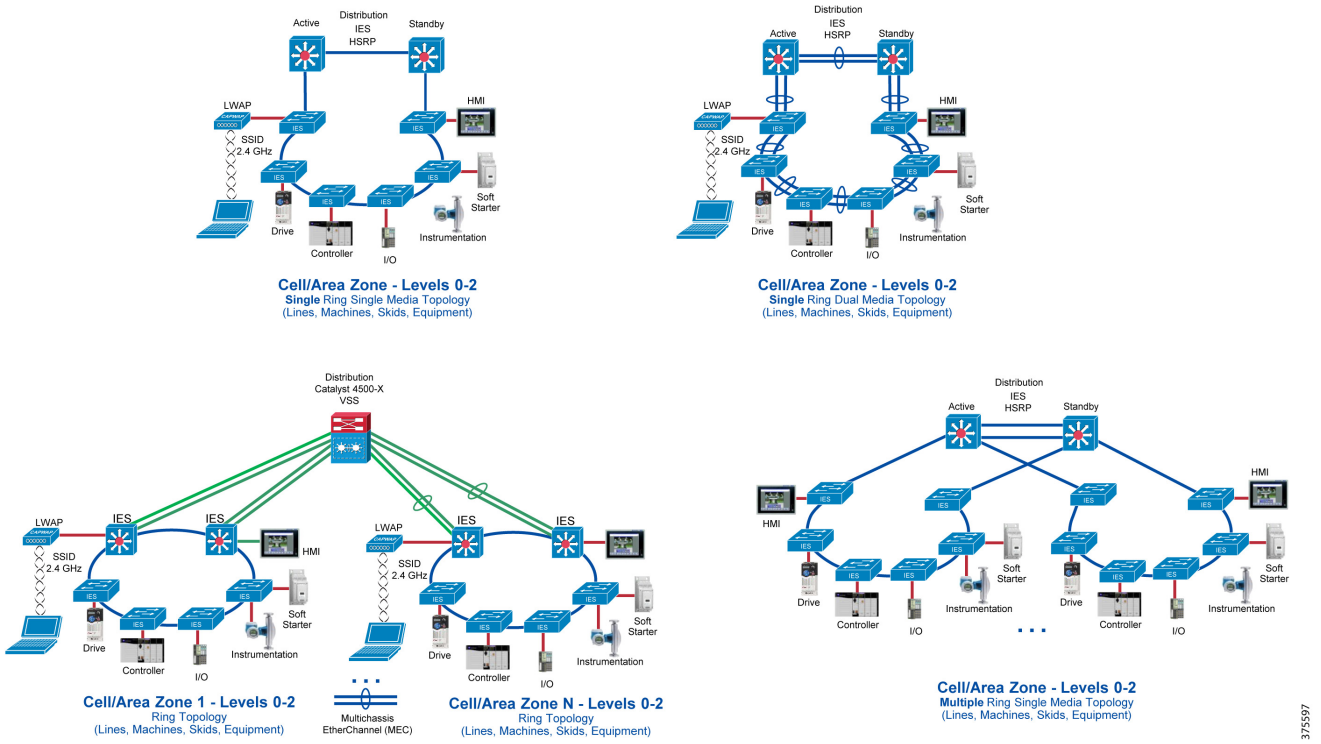
Ring Topology

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 2-15):

- 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, provided that 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; for example, 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, as well as 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 2-15 Ring Topology Options



Resilient Ethernet Protocol

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

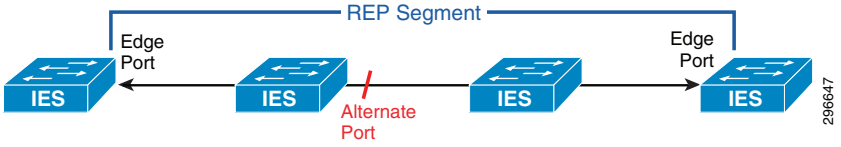
REP is a segment protocol that integrates easily into existing CPwE Cell/Area Zone LANs. Although REP disables STP on interfaces where REP is enabled, it can coexist with STP as part of the same Cell/Area Zone LAN. Since REP can also notify STP about potential topology changes, it allows for interoperability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

REP is a distributed and secure control plane protocol that does not rely on a master 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

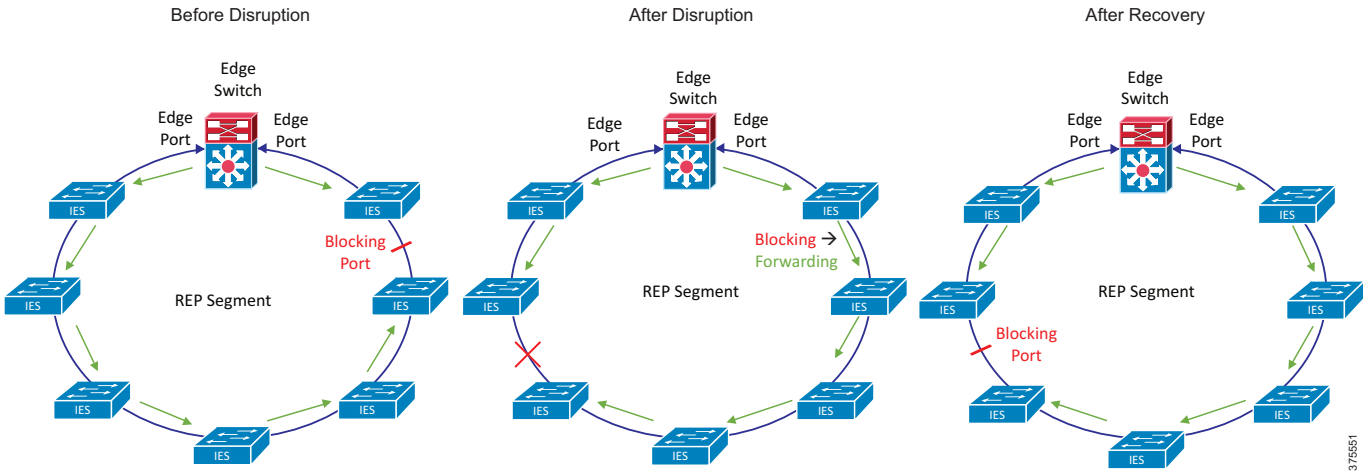
A REP segment, as shown in Figure 2-16, is a chain of switch ports connected to each other and configured with the same segment ID. Each end of a segment terminates on what is called the "edge port" of an edge switch. Note that each switch in a segment has exactly two REP-enabled ports.

Figure 2-16 REP Segment



With REP, in order to 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 2-17 shows the basic operation of REP to converge the network when a disruption occurs.

Figure 2-17 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:

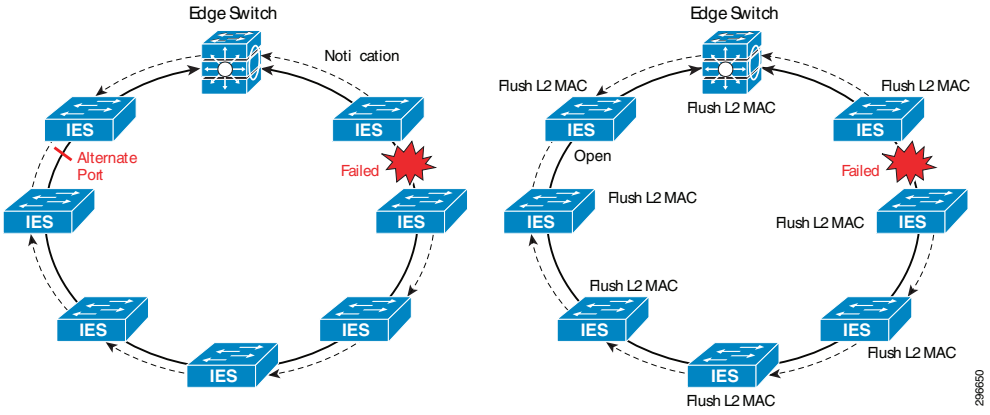
- Instruct the alternate port to unblock immediately because the segment is broken.
- Flush MAC table entries on all switches within the REP segment.

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 master node. Note that 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 fast 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 2-18).

Figure 2-18 REP Link Fault Notifications



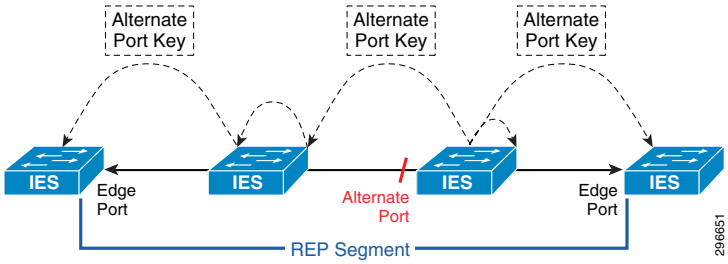
REP Distributed and Secure

REP is a distributed and secure control plane protocol that does not rely on a master node monitoring the health of the ring. REP provides an additional layer of security, which protects 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 2-19). 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 protects against potential security attacks; it also avoids problems with overlapping segment IDs due to misconfiguration.

Figure 2-19 Alternate Port Key Distribution



MSTP

For a description of MSTP, please refer to Multiple Spanning Tree Protocol, page 2-11.

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. CVD testing and validation for this use case produced convergence results that are acceptable to most IACS application resiliency requirements. See Table 2-10 and Table 2-11.

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 2-28.

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 significantly 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 2-20. 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 this CVD. 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 4500-X, IE 5000/Stratix5410 or IE 4000/Stratix5400 as a distribution platform configured in HSRP mode with REP. See Figure 2-20 depicting the topology.

A second use case uses a pair of Catalyst 4500-X switches in VSS mode acting as the distribution switches in a REP ring topology, as depicted in Figure 2-21.

A third use case is shown in Figure 2-22 using a Catalyst 3850 as a distribution platform configured with StackWise technology for the resiliency method and using REP.

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 2-20 Catalyst 4500-X, IE 5000/Stratix 5410 or IE 4000/Stratix 5400 HSRP with REP Ring Topology

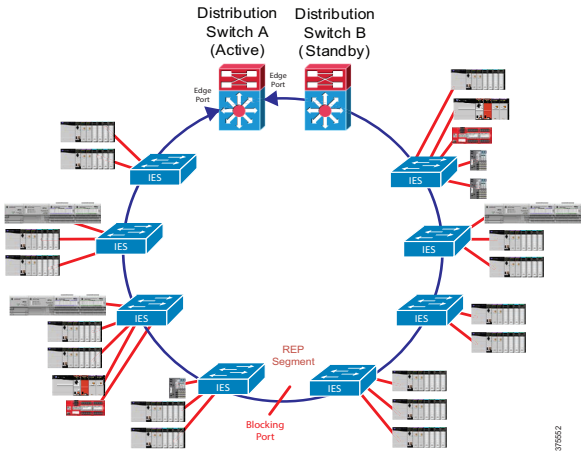


Figure 2-21 Pair of Catalyst 4500-X in VSS mode with REP Ring Topology

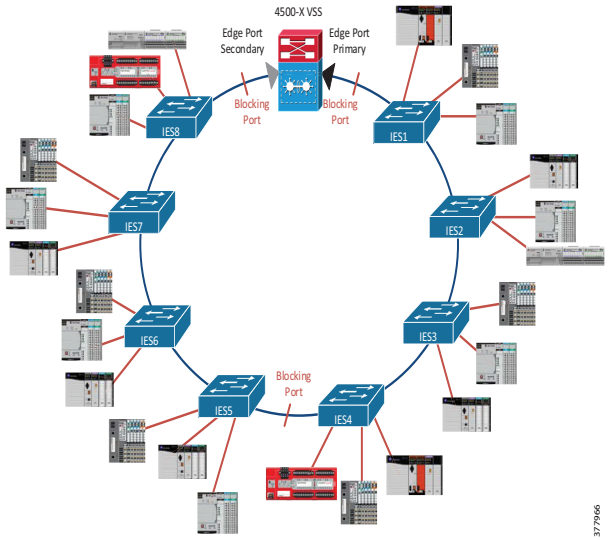


Figure 2-22 Catalyst 3850 StackWise with REP Ring Topology

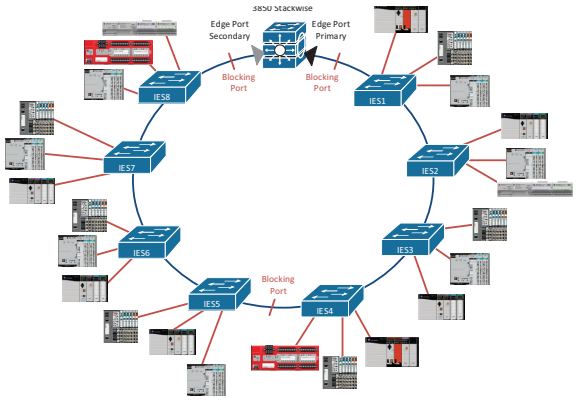


Table 2-10 and Table 2-11 summarize the convergence values observed during validation efforts, and can be used to select the appropriate resiliency protocols based on application requirements.

Note Link disruptions in Table 2-10 and Table 2-11 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, please refer to Appendix D: Physical Infrastructure Design for the Cell/Area Zone.

Table 2-10 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 4500-X	HSRP	Link	L2	4	45	112
			L3	4	56	186
		Switch	L2	16	56	90
			L3	16	461	1064

Table 2-10 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 4500-X	VSS (see note below)	Link	L2	8	66	192
			L3	--	--	--
		Switch	L2	--	--	--
			L3	--	--	--
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	24	426	952
Catalyst 3850	StackWise	Link	L2	16	78	260
			L3	16	82	266
		Switch	L2	18	81	168
			L3	18	86	170

Table 2-11 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 4500-X	HSRP	Link	L2	8	51	220
		Switch	L2	4	31	74
Catalyst 4500-X	VSS (see note below)	Link	L2	6	257	10352
		Switch	L2	--	--	--
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 3850	StackWise	Link	L2	16	75	294
		Switch	L2	16	70	138

Note

RESILIENCY RECOMMENDATION:

- With 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 3850 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 2-10 and Table 2-11.

- Based on the proof-of-concept test results with Catalyst 4500-X distribution switches in VSS mode with REP, Cisco, Panduit and Rockwell Automation do not recommend this configuration for ring topologies at this time.

Note For detailed results for link and switch disruptions 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 Multiple Ring Segments section below 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 2-23. 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 2-9). Because each connection between switches is a separate EtherChannel, the ring is also resilient to multiple link disruptions, provided that the two links within each EtherChannel are not both disrupted at the same time.
- **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 4500-X and IE 5000/Stratix5410 as a distribution platform configured in HSRP mode with EtherChannel and REP. See Figure 2-23.
- Catalyst 3850 as a distribution platform in StackWise-480 mode with EtherChannel and REP. See Figure 2-24.

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 2-23 Catalyst 4500-X or IE 5000/Stratix 5410 HSRP with REP Dual Media Ring Topology

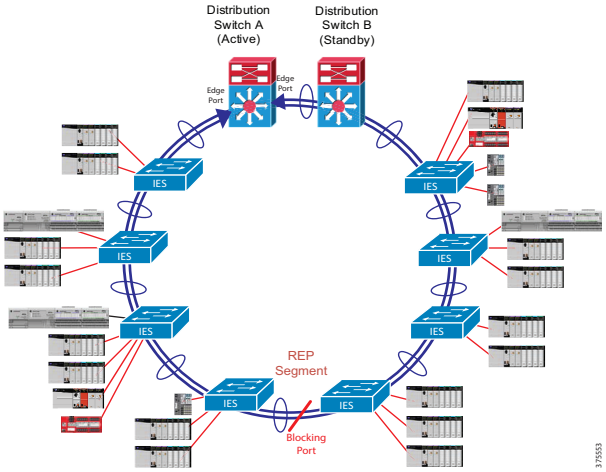


Figure 2-24 Catalyst 3850 StackWise with REP Dual Media Ring Topology

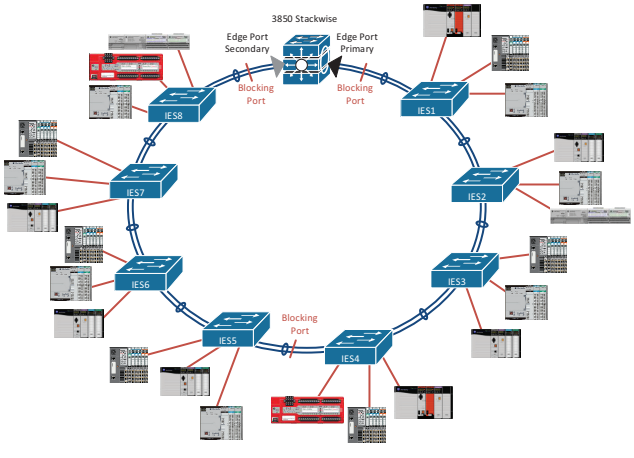


Table 2-12 and Table 2-13 summarizes the convergence values observed during validation efforts, and can be used to select the appropriate resiliency protocols based on application requirements.

Note Link disruptions in Table 2-12 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, please refer to Appendix D: Physical Infrastructure Design for the Cell/Area Zone..

Table 2-12 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 4500-X	HSRP	Link	L2	4	94	2204
			L3	4	170	2204
		Switch	L2	30	60	92
			L3	30	44	1036

Table 2-12 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
IE 5000/Stratix 5410	HSRP	Link	L2	4	31	74
			L3	4	34	74
		Switch	L2	28	29	30
			L3	22	454	950
Catalyst 3850	StackWise	Link	L2	4	304	850
			L3	4	301	868
		Switch	L2	16	78	286
			L3	12	91	374

Table 2-13 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 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 3850	StackWise	Link	L2	4	288	864
		Switch	L3	38	107	278

Note

RESILIENCY RECOMMENDATION:

- With 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 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 2-12 and 2-13.

Multiple Ring Segments

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 in an HSRP configuration
- Multiple REP segments with an HSRP pair of Layer 3 access switches in each segment connecting to a Catalyst 4500-X VSS pair or a Catalyst 3850 StackWise via Layer 3 (routed) links

Layer 2 Access Design with Multiple Ring Segments

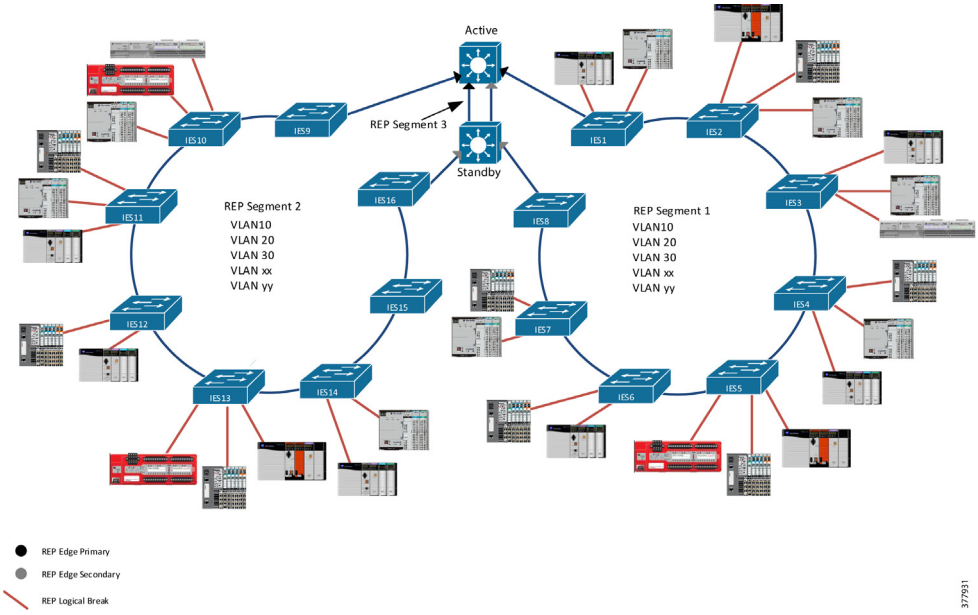
The following use case represents the requirement for configuring multiple REP segments using one pair of IE 5000/Stratix 5410 switches in an HSRP configuration.

Each REP segment will have 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).

This design requires an additional REP segment to be configured as the trunk between the two HSRP nodes. Preferably, this REP segment will be configured on two 10 Gigabit ports to accommodate a higher level of traffic.

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.

Figure 2-25 IE 5000/Stratix 5410 HSRP with Multiple REP Ring Topology



REP configuration is as follows:

- Primary REP edges are on the HSRP active gateway and secondary REP edges on the HSRP standby gateway for all segments connecting access switches
- A special “backbone” REP segment is configured as trunk between HSRP nodes using two ports on each switch
- 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).

Table 2-14 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
IE 5000/Stratix 5410	HSRP	Link	L2	4	47	316
			L3	10	51	168
		Switch	L2	18	87	206
			L3	18	465	940

Table 2-15 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
IE 5000/Stratix 5410	HSRP	Link	L2	4	47	316
		Switch	L2	4	83	170

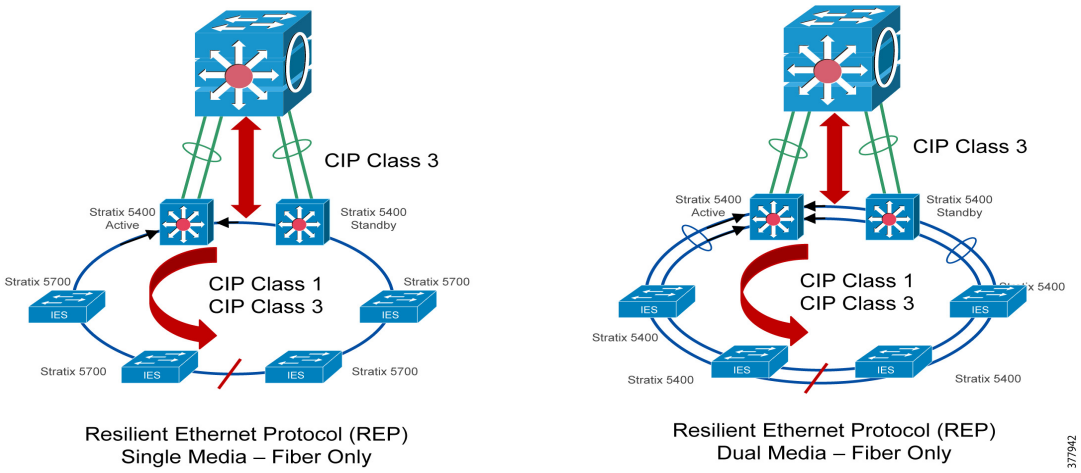
Layer 3 Access Design Overview

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 2-26, 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 3850 is used as the distribution platform using Stackwise-480 as the resiliency method.

Figure 2-26 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 2-28 on page 2-33. The Layer 3 access design throughput platforms (such as Catalyst 4500-X and Catalyst 3850) 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 4500-X VSS or Catalyst 3850 StackWise-480 is used as distribution platform. See Figure 2-27 on page 2-31 depicting the topology.

Figure 2-27 Catalyst 4500-X VSS or Catalyst 3850 StackWise-480 Distribution with IE 5000/Stratix 5410 Layer 3 Access and REP Ring

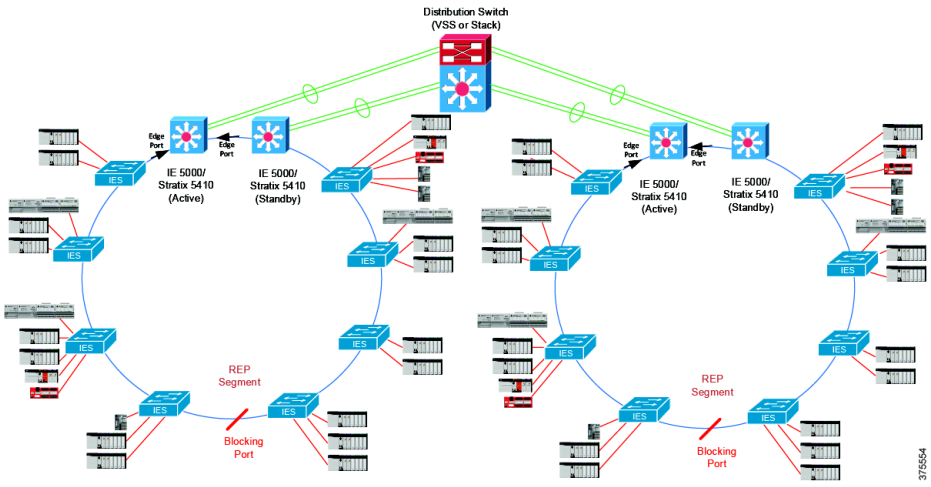


Table 2-16 and Table 2-17 summarize the convergence values observed during validation efforts, and can be used to select the appropriate resiliency protocols based on application requirements. For results for link disruptions within the access ring, refer to the Single Ring sections preceding this one.

Note Link and switch disruption locations are defined in Table 2-16 and Table 2-17. To help prevent such events from occurring within your network, please refer to Appendix D: Physical Infrastructure Design for the Cell/Area Zone.

Table 2-16 Multiple Ring Topology 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 2-17 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 4500-X as the distribution platform and IE 5000/Stratix 5410 as the Layer 3 access platform, Cisco, Panduit and Rockwell Automation recommend using VSS on the Catalyst 4500-X 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 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 on the Catalyst 3850 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

Figure 2-28 shows the summary of use cases performed with different distribution platform with resiliency recommendation. Please refer to the previous section for detailed information on the topology.

Figure 2-28 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 4500-X	HSRP	✓	✓	×	✓	○	×	✓
	VSS	×	✓	✓	✓	×	✓	○
Catalyst 3850	HSRP	○	○	×	○	○	×	○
	Stack	✓	✓	✓	✓	○	✓	✓
IE 5000 / Stratix 5410	HSRP	✓	✓	×	✓	✓	×	✓
IE 4000 / Stratix 5400	HSRP	×	×	×	✓	×	×	○

** See summary of recommendations for multi-ring topology

✓	Validated and recommended
✓	Validated
○	Not tested
×	Invalid / Not recommended

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Redundant Star Topology Recommendation Summary

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

Catalyst 4500-X with VSS

With Catalyst 4500-X as the distribution platform, Cisco, Panduit and Rockwell Automation recommend using VSS as the Layer 3 gateway resiliency protocol and Flex Links as the Layer 2 resiliency protocol for redundant star topology. See Figure 2-6 on page 2-12.

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 2-10 on page 2-15.

Catalyst 3850 with StackWise-480

With 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. See Figure 2-12 on page 2-17.

Ring Topology Recommendation Summary

The following is the resiliency recommendation summary for ring topology.

Single Ring (Single Media)

With 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. See Figure 2-20 on page 2-23.

Single Ring (Dual Media)

With Catalyst 4500-X or IE 5000/Stratix 5410 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 on page 2-27.

Multiple Ring Segments

With Catalyst 4500-X 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 VSS on the Catalyst 4500-X 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 2-27 on page 2-31.

With Catalyst 3850 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 3850 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 2-27 on page 2-31.

Level 3 Site Operations

Network Services

For information on deploying network services in Level 3, see the *Securely Traversing Data across the Industrial Demilitarized Zone Design and Implementation Guide* at the following URLs:

Rockwell Automation site:

- http://literature.rockwellautomation.com/idc/groups/literature/documents/td/enet-td009_-en-p.pdf

Cisco site:

- http://www.cisco.com/c/en/us/td/docs/solutions/Verticals/CPwE/3-5-1/IDMZ/Design and Implementation Guide/CPwE_IDMZ_CVD.html

Security Services

For information on deploying security services, including the Cisco Identity Services Engine (ISE), see the *Deploying Identity Services within a Converged Plantwide Ethernet Architecture Design and Implementation Guide* at the following URLs:

Rockwell Automation site:

- http://literature.rockwellautomation.com/idc/groups/literature/documents/td/enet-td008_-en-p.pdf

Cisco site:

- http://www.cisco.com/c/en/us/td/docs/solutions/Verticals/CPwE/3-5-1/ISE/Design and Implementation Guide/CPwE_ISE_CVD.html

IDMZ

For information on deploying the Industrial Demilitarized Zone (IDMZ), see the *Securely Traversing Data across the Industrial Demilitarized Zone Design and Implementation Guide* at the following URLs:

Rockwell Automation site:

- http://literature.rockwellautomation.com/idc/groups/literature/documents/td/enet-td009_-en-p.pdf

Cisco site:

- http://www.cisco.com/c/en/us/td/docs/solutions/Verticals/CPwE/3-5-1/IDMZ/Design and Implementation Guide/CPwE_IDMZ_CVD.html

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 4500-X VSS Configuration

By default, the Catalyst 4500-X switch is configured to operate in standalone mode (the switch works independently). The VSS combines two standalone switches into one virtual switch, operating in virtual switch mode.

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

VSS is configured and activated as shown in the following sections.

Note The following configurations are needed for a manual conversion to VSS. Starting in IOS XE version 3.6.0E (IOS 15.2(2)E), the Catalyst 4500-X also supports an automated conversion process called Easy VSS. For more details on Easy VSS, please see *Configuring Easy VSS* at the following URL:

- http://www.cisco.com/c/en/us/td/docs/switches/lan/catalyst4500/XE3-6-0E/15-22E/configuration/guide/xe-360-config/vss.html#pgfId-1480723

Assigning Virtual Switch Domain and Switch Numbers

The same virtual switch domain number must be configured on both switches of the VSS. The virtual switch domain is a number between 1 and 255. In addition, the switch should be given a unique number under the virtual switch domain. The virtual switch domain configuration for each switch is shown below:

```
switch virtual domain 10
 switch 1

switch virtual domain 10
 switch 2
```

Configuring VSL Port-Channel

The VSL is configured with a unique port-channel on each switch. During the conversion, the VSS configures both port-channels on the VSS Active switch. The VSL configuration for each switch is shown below:

```
int port-channel 5
 switchport
 switch virtual link 1

int port-channel 10
 switchport
 switch virtual link 2
```

Configuring VSL Ports

The VSL member ports are added to the port-channel as shown in the configuration below:

```
int range gig7/3 - 4
 switchport mode trunk
 channel-group 5 mode on

int range gig4/45 - 46
 switchport mode trunk
 channel-group 10 mode on
```

Converting the Switch to Virtual Switch Mode

To convert to VSS mode, enter the *switch convert mode virtual* command on each switch, as shown below. After confirming the action, the system will create a converted configuration file and save it to the boot flash, then reboot the switch.

```
switch convert mode virtual
```

This command will convert all interface names to naming convention *interface-type switch-number/slot/port*, save the running config to startup-config and reload the switch.

After the reboot, the switch is in virtual switch mode. Verify the switch state using the *show switch virtual* command.

The following are guidelines for configuring VSS:

1. The VSL port-channel must have more than one port in the channel, preferably distributed on more than one module. If the VSL consists of only one link, its failure causes a Dual-Active operation of the VSS. Also, all VSL links configured on one module may cause a Dual-Active operation, if the module goes down.
2. After SSO, much of the processing power of the VSS active supervisor engine is consumed in bringing up a large number of ports simultaneously in the VSS standby switch. As a result, some links might be brought up before the supervisor engine has configured forwarding for the links, causing traffic to those links to be lost until the configuration is complete. This condition is especially disruptive if the link is a MEC link and it is running in "ON" mode. This is why it is recommended that MEC ports always have either LACP or PAgP configured in active mode.

3. The VSS configurations in the startup-config file must match on both switches; that is, the domain must match, the switch ID must be unique and the VSL ports' information must match the physical connection.
4. SSO and NSF are configured as default on VSS. Cisco NSF is supported by the Enhanced Interior Gateway Routing Protocol (EIGRP) protocol for routing and by CEF for forwarding. EIGRP depends on Cisco Express Forwarding (CEF) to continue forwarding packets during switchover while the routing protocols rebuild the Routing Information Base (RIB) tables. Once the routing protocols have converged, CEF updates the Forwarding Information Base (FIB) table and removes stale route entries. CEF, in turn, updates the line cards with the new FIB information. NSF must be explicitly enabled under the EIGRP process, and once enabled, EIGRP NSF capabilities are exchanged by EIGRP peers in hello packets. The NSF-capable device notifies its neighbors that an NSF restart operation has started by setting the restart (RS) bit in a hello packet. When an NSF-aware device receives notification from an NSF-capable neighbor that an NSF-restart operation is in progress, the NSF-capable and NSF-aware devices immediately exchange their topology tables. The NSF-aware device sends an end-of-table (EOT) update packet when the transmission of its topology table is complete.
5. The virtual switch domain number must be unique for each VSS in your network (the domain number is incorporated into various identifiers to be sure that these identifiers are unique across the network).

Note For more information on VSS configuration, see the *Catalyst 4500 Series Switch Software Configuration Guide, Release IOS XE 3.4.xSG and IOS 15.1(2)SG*x at the following URL:

- http://www.cisco.com/c/en/us/td/docs/switches/lan/catalyst4500/15-1-2/XE_340/configuration/guide/config/vss.html#wp1020417

Note For VSS-Enabled Campus best practices configuration examples, see the *VSS-Enabled Campus Best Practice Configuration Example* at the following URL:

- http://www.cisco.com/c/en/us/td/docs/solutions/Enterprise/Campus/VSS30dg/campusVSS_DG/VSS-dg_appa-configs.html

Catalyst 3850 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 in case of 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 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 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 as a result of the behavior mentioned above. 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 3850 StackWise-480 configuration, see *Stack Manager and High Availability Configuration Guide, Cisco IOS XE Release 3SE (Catalyst 3850 Switches)* at the following URL:

- http://www.cisco.com/c/en/us/td/docs/switches/lan/catalyst3850/software/release/3se/ha_stack_manager/configuration_guide/b_hastck_3se_3850_cg.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 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 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 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, as well as 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:

```
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 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 web page). 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 similar to 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 a different 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, ensure 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 very 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 a different 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, ensure 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 2-20 on page 2-23 and Figure 2-23 on page 2-27.
- **Single Ring with StackWise or VSS**—Configure edge ports on different switches in the stack or the VSS pair. See Figure 2-21 on page 2-24, Figure 2-22 on page 2-24 and Figure 2-24 on page 2-27.
- **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 2-25 on page 2-29.

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

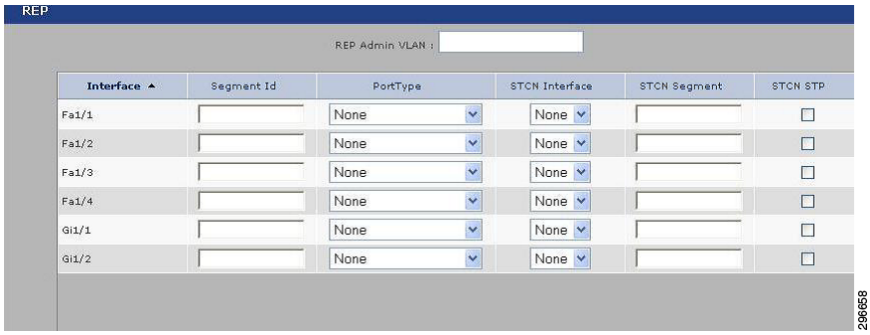
```
rep segment 1 edge primary
rep stcn segment 2-3
```

- **Multiple Rings (Layer 3 Access)**—Configure edge ports in each segment on the active HSRP switch in each ring. This is similar to the single ring configuration since each REP segment is not directly connected to others. See Figure 2-27 on page 2-31.

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:

VSS Troubleshooting

To investigate problems with VSS, the primary command for confirming the configuration is *show switch virtual* run on the active switch, as shown below:

```
SW1#sh switch virtual

Executing the command on VSS member switch role = VSS Active, id = 1

Switch mode                  : Virtual Switch
Virtual switch domain number : 10
Local switch number          : 1
Local switch operational role: Virtual Switch Active
Peer switch number           : 2
Peer switch operational role : Virtual Switch Standby

Executing the command on VSS member switch role = VSS Standby, id = 2

Switch mode                  : Virtual Switch
Virtual switch domain number : 10
Local switch number          : 2
Local switch operational role: Virtual Switch Standby
Peer switch number           : 1
Peer switch operational role : Virtual Switch Active
```

StackWise-480 Troubleshooting

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

```
3850-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
```

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, as well as 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 Release 3SE (Catalyst 3850 Switches)* at the following URL:

- http://www.cisco.com/c/en/us/td/docs/switches/lan/catalyst3850/software/release/3se/system_management/configuration_guide/b_sm_3se_3850_cg/b_sm_3se_3850_cg_chapter_01110.html

HSRP Troubleshooting

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

```
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), as well as 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 below:

```
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 below:

```
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 below:

```
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 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 which device and port 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 shown below:

```
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, as well as 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)

- *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 Design and Implementation Guide:*
  - 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 Design and Implementation Guide:*
  - 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

- *Deploying Identity Services within a Converged Plantwide Ethernet Architecture Design and Implementation Guide*:
  - Rockwell Automation site:
    - http://literature.rockwellautomation.com/idc/groups/literature/documents/td/enet-td008_-en-p.pdf
  - Cisco site:
    - http://www.cisco.com/c/en/us/td/docs/solutions/Verticals/CPwE/3-5-1/ISE/DIG/CPwE_ISE_CVD.html
- *Securely Traversing IACS Data Across the Industrial Demilitarized Zone Design and Implementation Guide*:
  - Rockwell Automation site:
    - http://literature.rockwellautomation.com/idc/groups/literature/documents/td/enet-td009_-en-p.pdf
  - Cisco site:
    - http://www.cisco.com/c/en/us/td/docs/solutions/Verticals/CPwE/3-5-1/IDMZ/DIG/CPwE_IDMZ_CVD.html
- *Deploying Industrial Firewalls within a Converged Plantwide Ethernet Architecture Design and Implementation Guide*:
  - Rockwell Automation site:
    - http://literature.rockwellautomation.com/idc/groups/literature/documents/td/enet-td002_-en-p.pdf
  - Cisco site:
    - http://www.cisco.com/c/en/us/td/docs/solutions/Verticals/CPwE/5-0/Firewalls/DIG/CPwE-5-IFS-DIG.html
- *Deploying Device Level Ring within a Converged Plantwide Ethernet Architecture White Paper*:
  - Rockwell Automation site:
    - http://www.rockwellautomation.com/global/products-technologies/network-technology/architectures.page?
  - Cisco site:
    - http://www.cisco.com/c/en/us/solutions/enterprise/design-zone-manufacturing/landing_ettf.html

Core Switch Architecture

- *Virtual Switching Systems Release 15.1SY Supervisor Engine 2T Software Configuration Guide*:
  - http://www.cisco.com/c/en/us/td/docs/switches/lan/catalyst6500/ios/15-1SY/config_guide/sup2T/15_1_sy_swcg_2T/virtual_switching_systems.html

- *Virtual Switching Systems (Supervisor Engine 6T Software Configuration Guide, Release 15.3SY)*:
  - http://www.cisco.com/c/en/us/td/docs/switches/lan/catalyst6500/ios/15-3SY/config_guide/sup6T/15_3_sy_swcg_6T/virtual_switching_systems.pdf

Distribution Switches

- *Catalyst 4500 Series Switch Software Configuration Guide*:
  - http://www.cisco.com/c/en/us/td/docs/switches/lan/catalyst4500/15-1-2/XE_340/configuration/guide/config.html
- *Cisco Catalyst 3850 Switch Deployment Guide*:
  - http://www.cisco.com/c/en/us/products/collateral/switches/catalyst-3850-series-switches/deployment_guide_c07-727067.html
- *Industrial Ethernet 5000 Software Configuration Guide:*
  - http://www.cisco.com/c/en/us/td/docs/switches/lan/cisco_ie5000/software/release/15-2_2_eb/configuration/guide/scg-ie5000.html
- *Stratix Managed Switches User Manual*:
  - http://literature.rockwellautomation.com/idc/groups/literature/documents/um/1783-um007_-en-p.pdf

Access Layer Switches

- *Industrial Ethernet 4000 Software Configuration Guide*:
  - http://www.cisco.com/c/en/us/td/docs/switches/lan/cisco_ie4000/software/release/15-2_2_ea/configuration/guide/scg-ie4000.html
- *Industrial Ethernet 3000 Software Configuration Guide*:
  - http://www.cisco.com/c/en/us/td/docs/switches/lan/cisco_ie3000/software/release/15-2_2_e/configuration/guide/scg_ie3000.html
- *Industrial Ethernet 2000 Software Configuration Guide*:
  - http://www.cisco.com/c/en/us/td/docs/switches/lan/cisco_ie2000/software/release/15_2_2_e/configuration/guide/scg-ie2000.html
- *Stratix Managed Switches User Manual*:
  - http://literature.rockwellautomation.com/idc/groups/literature/documents/um/1783-um007_-en-p.pdf

Routing Between Zones

- *Enhanced Interior Gateway Routing Protocol White Paper*:
  - http://www.cisco.com/c/en/us/support/docs/ip/enhanced-interior-gateway-routing-protocol-eigrp/16406-eigrp-toc.html
- *OSPF Design Guide*:
  - http://www.cisco.com/c/en/us/support/docs/ip/open-shortest-path-first-ospf/7039-1.html

Network Time Protocol

- *Network Time Protocol: Best Practices White Paper*:
  - http://www.cisco.com/c/en/us/support/docs/availability/high-availability/19643-ntpm.html

Network Infrastructure Hardening

- *Cisco Guide to Harden Cisco IOS Devices*:
  - http://www.cisco.com/c/en/us/support/docs/ip/access-lists/13608-21.html

APPENDIX B

Test Hardware and Software

Table B-1 lists the test hardware and software for the Deploying a Resilient Converged Plantwide Ethernet (CPwE) CVD.

Table B-1 Test Hardware and Software

Role	Product	Software Version	Notes
Access switch	Cisco Industrial Ethernet 2000 Series Switch/Allen-Bradley Stratix 5700	15.2(3)EA	--
Access switch	Cisco Industrial Ethernet 3000 Series Switch/Allen-Bradley Stratix 8000	15.2(3)EA	--
Access switch	Cisco Industrial Ethernet 4000 Series Switch/Allen-Bradley Stratix 5400	15.2(2)EA (Cisco), 15.2(2)EA1 (RA)	--
Distribution switch	Cisco Industrial Ethernet 5000 Series Switch/Allen-Bradley Stratix 5410	15.2(2)EB	Hot Standby Routing Protocol (HSRP)
Distribution switch	Catalyst 3850	03.03.05.SE	Switch stack
Distribution switch	Catalyst 4500-X	03.08.00.E	Virtual Switching System (VSS) and Hot Standby Routing Protocol (HSRP)
Distribution switch	Cisco Industrial Ethernet 4000 Series Switch/Allen-Bradley Stratix 5400	15.2(2)EA (Cisco), 15.2(2)EA1 (RA)	Hot Standby Routing Protocol (HSRP)
Core switch	Catalyst 6800	15.1(1)SY4	Virtual Switching System (VSS)
Rockwell Software	RSLinx® Classic	3.73.00	--
Rockwell Software	Studio 5000 Logix Designer®	V26	--
Allen-Bradley Controller	ControlLogix® (1756-L75)	26.013	--
Allen-Bradley Safety Controller	GuardLogix® Safety (1576-L73S)	26.013	--
Allen-Bradley EtherNet/IP Adapter	ControlLogix® EtherNet/IP (1756-ENT2T/EN2TR)	5.0.28	--
Allen-Bradley Safety Controller	GuardLogix Safety (1756-L7SP)	26.013	--
Allen-Bradley Controller	CompactLogix™ (1769-L36ERM)	26.013	--
Allen-Bradley Controller	CompactLogix (1769-L18ERM)	26.013	--
Allen-Bradley I/O Adapter	FLEX™ I/O EtherNet/IP (1794-AENT)	4.003	--
Allen-Bradley I/O Adapter	POINT I/O™ EtherNet/IP (1734-AENT/AENTR)	3.012	--
Allen-Bradley Safety I/O Adapter	CompactBlock™ Guard I/O™ (1791ES-IB8XOBV4)	1.9	--

APPENDIX C

Physical Infrastructure Network Design for CPwE Logical Architecture

Successful deployment of a Converged Plantwide Ethernet (CPwE) logical architecture depends on a solid physical infrastructure network design that addresses environmental, performance, and security challenges with best practices from Operational Technology (OT) and Information Technology (IT). Panduit collaborates with industry leaders such as Rockwell Automation and Cisco to help customers address deployment complexities that are associated with plant-wide Industrial Ethernet. As a result, users achieve resilient, scalable networks that support proven and flexible logical CPwE architectures that are designed to optimize industrial network performance. This Appendix provides an overview of the key recommendations and best practices to simplify design and deployment of a standard, highly capable industrial Ethernet physical infrastructure.

This physical infrastructure network design includes four appendices: Appendix C, Appendix D, Appendix E and Appendix F.

Appendix C (this Appendix)—Introduces key concepts and addresses common design elements for the other appendices, specifically:

Appendix D—"Physical Infrastructure Design for the Cell/Area Zone"Describes the Cell/Area Zone physical infrastructure for on-machine or process skid applications and the locations for the Cisco and Allen-Bradley® Stratix™ Industrial Ethernet Switches (IES), including IES located in control panels and/or PNZS components.

Appendix E—"Physical Infrastructure Design for the Industrial Zone"—Describes the physical infrastructure for network distribution across the Industrial Zone (one or more Cell/Area Zones) through use of Industrial Distribution Frames (IDF), industrial pathways, and robust media/connectivity.

Appendix F—"Physical Infrastructure Deployment for Level 3 Site Operations"—Describes the physical infrastructure for Level 3 Site Operations, including Industrial Data Centers (IDCs) for compute, storage, and switching resources for manufacturing software and services.

Mapping Physical Infrastructure to the CPwE Logical Network Design

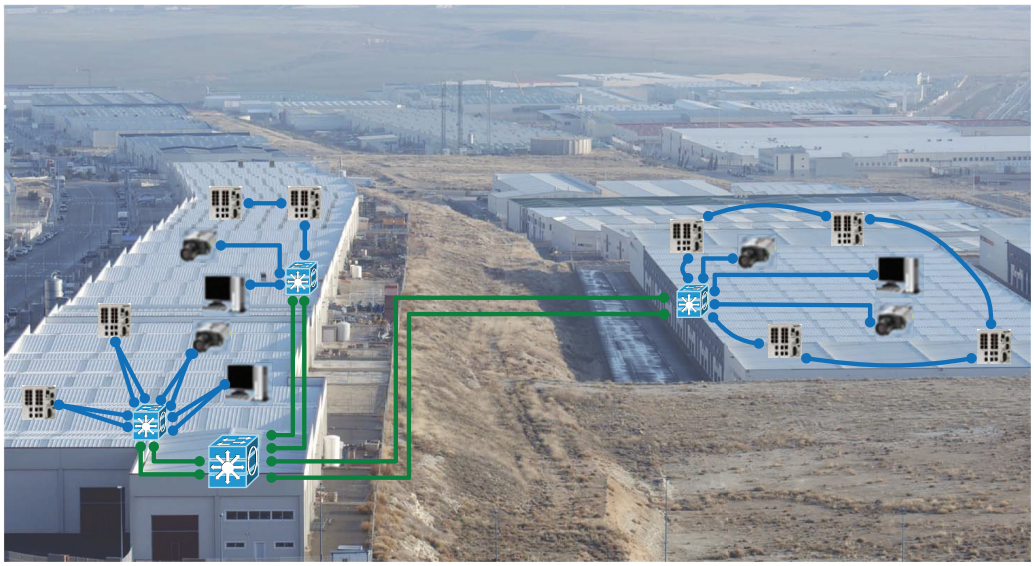
Network designers are being challenged to implement a reliable, secure, and future-ready network infrastructure across the varied and harsh environments of industrial plants. The networking assets must be placed across the plant floor with consideration of difficult environmental factors such as long distances, temperature extremes, humidity, shock/vibration, chemical/climatic conditions, water/dust ingress and electromagnetic threats. These factors introduce threats that can potentially degrade network performance, affect network reliability, and/or shorten asset longevity. Figure C-1 shows the CPwE logical framework mapped to a hypothetical plant footprint.

Mapping CPwE Logical to Physical

The physical impact on network architecture includes:

- **Geographic Distribution**—The selection of IES and overall logical architecture is also heavily influenced by the geographic dispersion of IACS devices, switches, and compute resources, and the type and amount of traffic anticipated between IACS devices and switches. Figure C-1 shows the network architecture superimposed over the building locations and the campus-type connectivity between buildings that may require the long-reach capabilities of single-mode fiber.

Figure C-1 Network Overlay on Building Locations



- **Brownfield or Legacy Network**—Additional design considerations are necessary to transition from or work alongside a legacy network. Existing installations have many challenges, including bandwidth concerns, poor grounding/bonding, inadequate media pathways, and limited space for new areas to protect networking gear. Additional cabling and pathways are often needed during the transition to maintain existing production while installing new gear.
- **Greenfield or New Construction**—Critical deadlines must be met within short installation time frames. In addition, installation risk must be minimized. Mitigating these concerns requires a proven, validated network building block system approach that uses pre-configured, tested, and validated network assets built specifically for the application.

Physical Infrastructure Building Block Systems

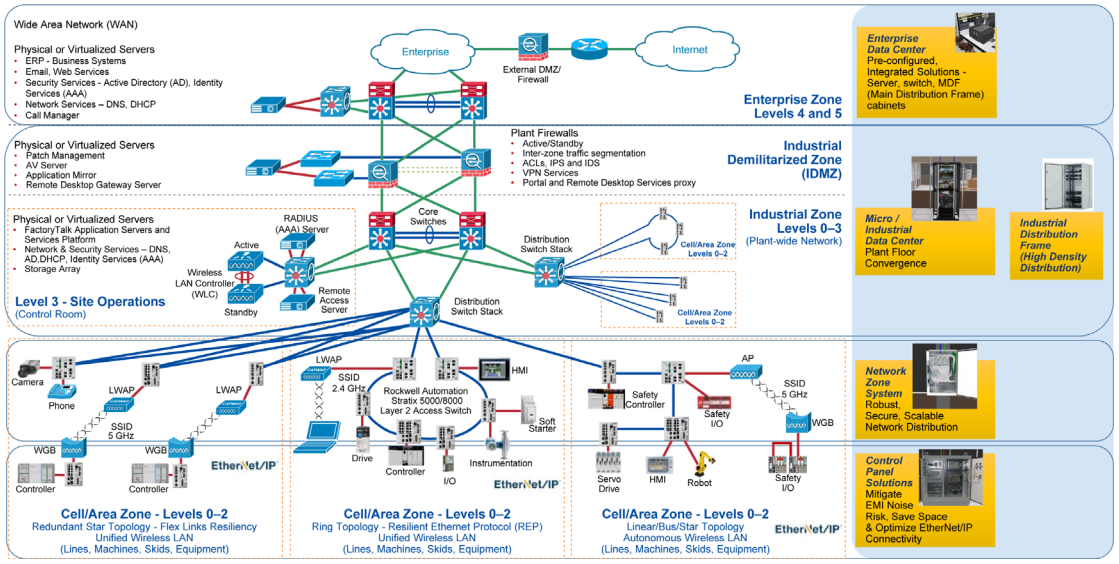
Industrial physical infrastructure cabling systems and enclosures are often designed and built without attention to detail. Poorly deployed industrial networks frequently fail because growth, environmental impact, incompatibility and poor construction were not anticipated. A better approach is to specify tested, validated industrial network *building block systems* that are built for industrial network deployment. A standardized approach to industrial network design speeds deployment and reduces risk, leading to a cost-effective solution. Also, as the network is expanded, the consistency of standardized, validated systems is rewarded with lower maintenance and support costs.

Industrial physical infrastructure network building block systems comprised of integrated active gear can be deployed at most levels of the CPwE logical architecture. An industrial network building block system simplifies deployment of the network infrastructure required at each level of CPwE by containing the specified switching, routing, computing and/or storage elements required for a given zone housed in an enclosure, cabinet, or rack complete with cabling, cable management, identification, grounding, and power. These building block systems can be ordered pre-configured with all the components and parts to be assembled on site or as an integrated, ready-to-install solution.

Figure C-2 shows various building block systems as they relate to the CPwE architecture. At the Level 3 Site Operations or IDMZ, the building block system may consist of a network, compute, and storage system and may be delivered as both pre-configured and integrated. The integrated solution is basically an appliance compute system, such as an IDC, which is described in more detail in Appendix F: “Physical Infrastructure Deployment for Level 3 Site Operations”. In the Cell/Area Zone, a Physical Network Zone System (PNZS)

with a DIN-mount IES can be deployed as a building block system. These building block systems can be both pre-configured and integrated. Building block systems in the Industrial Zone are addressed in Appendix F: "Physical Infrastructure Deployment for Level 3 Site Operations". The Cell/Area Zone building block systems are described in Appendix E: "Physical Infrastructure Design for the Industrial Zone".

Figure C-2 Various CPwE Building Block Systems



Key Requirements and Considerations

The following are key considerations for helping to ensure the success of CPwE logical architecture:

- **Reach**—The distance the cable must travel to form the connections between the IACS device and IES ports. Distance includes all media between ports, including patch cables.
- **Industrial Characteristics**—Environmental factors that act upon networking assets and cabling infrastructure installed in the plant.
- **Physical Infrastructure Life Span**—IACS and the plant network backbone can be in service 20 years or more. Therefore, cabling, connectivity, and the PNZS must survive the expected lifespan. During its lifespan, changes and upgrades to the IACS served by the network can occur. As a result, the physical infrastructure and logical aspects of the network must be engineered to adapt.
- **Maintainability**—Moves, Adds, and Changes (MACs) have dependencies and may affect many Cell/Area Zones. Also, changes must be planned and executed correctly because errors can cause costly outages. Proper cable management practices, such as use of patch panels, secure bundling and routing, clear and legible permanent identification with accurate documentation, and revision control are vital to effective network maintenance and operation and rapid response to outages.
- **Scalability**—In general, the explosive growth of EtherNet/IP™ and IP connections strains legacy network performance. In addition, rapid IACS device growth causes network sprawl that can threaten uptime and security. A strong physical infrastructure design accounts for current traffic and anticipated growth. Forming this forecast view of network expansion simplifies management and guides installation of additional physical infrastructure components when necessary.

- **Designing for High Availability**—PNZSs can either be connected in rings or redundant star topologies to achieve high availability. Use of an uninterruptable power supply (UPS) for backup of critical switches prevents network downtime from power bumps and outages. New battery-free UPS technologies leverage ultra-capacitors with a wide temperature range and a long lifetime for IACS control panel and PNZSs. Intelligent UPS backup devices with EtherNet/IP ports and embedded CIP™ (ODVA Common Industrial Protocol) object support allow for faceplates and alarm integration with IACS to improve system maintainability and uptime.
- **Network Compatibility and Performance**—Network compatibility and optimal performance are essential from port to port. This measurement includes port data rate and cabling bandwidth. Network link performance is governed by the poorest performing element within a given link. These parameters take on greater importance when considering the reuse of legacy cabling infrastructure.
- **EMI (Noise) Mitigation**—The risks from high frequency noise sources (such as variable frequency drives, motors, power supplies and contractors) causing networking disruptions must be addressed with a *defense-in-depth* approach that includes grounding/bonding/shielding, well-balanced cable design, shielded cables, fiber-optics and cable separation. The importance of cable design and shielding increases for copper cabling as noise susceptibility and communication rates increase. Industry guidelines and standards from Open DeviceNet Vendors Association (ODVA), Telecommunications Industry Association (TIA), and International Electrotechnical Commission (IEC) provide guidance into cable spacing, recommended connectors and cable categories to enable optimum performance.
- **Grounding and Bonding**—Grounding and bonding is an essential practice not only for noise mitigation but also to help enable worker safety and prevent equipment damage. A well-architected grounding/bonding system, whether internal to control panels, across plants, or between buildings, helps to greatly enhances network reliability and helps to deliver a significant increase in network performance. A single, verifiable grounding network is essential to avoid ground loops that degrade data transmission. Lack of good grounding and bonding practices risks loss of equipment availability and has considerable safety implications.
- **Security**—A security incident can cause outages resulting in high downtime costs and related business costs. Many industry security practices and all critical infrastructure regulations require physical infrastructure security as a foundation. Network security must address not only intentional security breaches but inadvertent security challenges. One example of an inadvertent challenge is the all-too-frequent practice of plugging into live ports when attempting to recover from an outage. A successful security strategy employs logical security methods and physical infrastructure practices such as lock-in/block-out (LIBO) devices to secure critical ports, keyed patch cords to prevent inappropriate patches, and hardened pathways to protect cabling from tampering.
- **Reliability Considerations**—Appropriate cabling, connectivity, and enclosure selection is vital for network reliability, which must be considered over the design life span, from installation through operational phase(s) to eventual decommissioning/replacement. Designing in reliability protocols helps prevent or minimizes unexpected failures. Reliability planning may also include over-provisioning the cabling installation. Typically, the cost of spare media is far less than the labor cost of installing new media and is readily offset by avoiding outages.
- **Safety**—During the physical infrastructure deployment of IES, it is important to consider compliance with local safety standards to avoid electrical shock hazards. IT personnel may occasionally require access to industrial network equipment and may not be familiar with electrical and/or other hazards contained by PNZSs deployed in the industrial network. Standards such as National Fire Protection Association (NFPA) 70E provide definitions that help clarify this issue. Workers are generally categorized by NFPA-70E as qualified or unqualified to work in hazardous environments. In many organizations, IT personnel have not received the required training to be considered qualified per NFPA-70E. Therefore, network planning and design must include policies and procedures that address this safety issue.

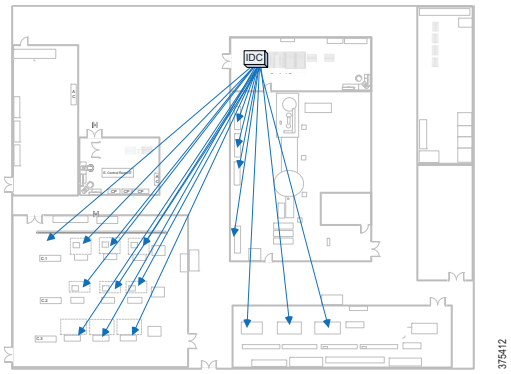
- **Wireless**—The deployment of wireless in the PNZS requires design decisions on cabling and installation considerations for access points (APs) and Wireless Local Area Networks (WLANs). The PNZS backbone media selection and the selection of cabling for APs using Power over Ethernet (PoE) are critical for future readiness and bandwidth considerations. Another planning aspect in the wireless realm involves legacy cabling connected to current wireless APs. Many wireless APs deployed today are 802.11 a/b/g/n. As higher performance wireless standards such as 802.11ac are considered, it is important to understand that in some cases, existing cabling may not support increased uplink bandwidths necessary to support higher bit rate APs.
- **PoE**—PoE is a proven method for delivering commercial device power over network copper cabling. DC power, nominally 48 volts, is injected by the network switch. PoE switch capabilities have evolved to help deliver higher levels of power over standards-compliant Ethernet copper cabling. In time, the scope of PoE will expand to become a viable power source for other elements of industrial networks. Accordingly, consideration of conductor gauge and bundling density will grow in importance.

The above considerations are addressed in this Appendix with various design, installation, and maintenance techniques, such as PNZS architecture and cabling methods (structured and point-to-point). The following sections describe these methodologies.

Physical Zone Cabling Architecture

A common approach to deploying industrial Ethernet networks was to cable infrastructure as a home run from the IES back to a centralized IT closet switch, to an IDC, as shown in Figure C-3. This was a reasonable approach because fewer cable runs existed and the Ethernet network was for IACS information only. As industrial networks grew in size and scope, with Ethernet becoming pervasive in many layers of the network (control and information), this home run methodology became difficult to scale and developed into a more expensive choice. Adding a new IES to the edge of the IACS may require a major cable installation to help overcome obstacles, route in pathways, and so on. In addition, this growth in home run networks has led to significant network cabling sprawl, impacting the reliability of the network. A better approach is a PNZS cabling architecture.

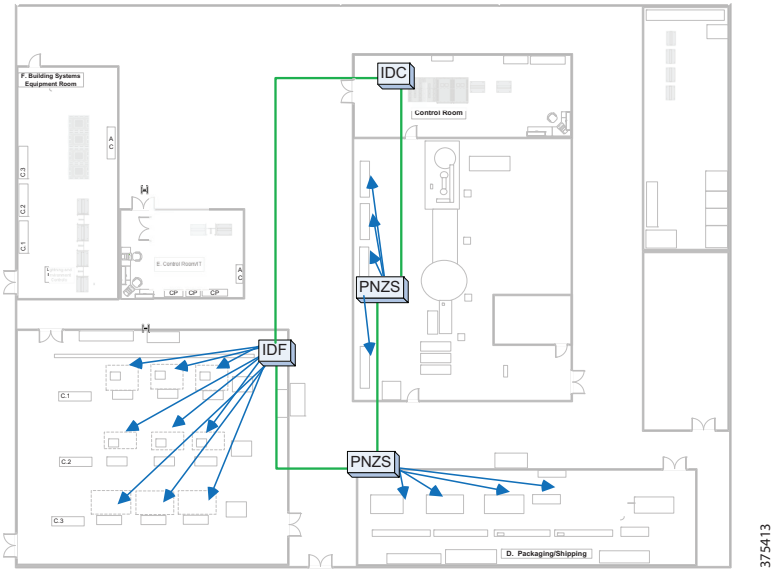
Figure C-3 Example of 'Home Run' Cabling from Control Panels and Machines back to IT Closet



PNZS cabling architectures are well proven in Enterprise networks across offices and buildings for distributing networking in a structured, distributed manner. These architectures have evolved to include active switches at the distributed locations. For an IACS application as depicted in Figure C-4, PNZS architecture helps mitigate long home runs by strategically locating IES around the plant to connect equipment more easily. The IES switches are located in control panels, IDF enclosures, and in PNZS enclosures. IDF enclosures house higher density 19" rack-mounted IES and related infrastructure while PNZSs house DIN rail-mounted IES and related infrastructure. PNZS architectures can leverage a robust, resilient fiber

backbone in a redundant star or ring topology to link the IES in each enclosure location. Shorter copper cable drops can then be installed from each IDF or PNZS to control panels or on-machine IACS devices in the vicinity rather than back to a central IT closet.

Figure C-4 Example Use of PNZS and IDFs to Efficiently Distribute Cabling Using a Physical Zone Cabling Architecture



TIA/EIA and related ISO/IEC standards support PNZS cabling architectures. A specific example of cabling support appears in Work Area Section 6.1 of TIA 568-C.1: *"Work area cabling is critical to a well-managed distribution system; however, it is generally non-permanent and easy to change."* These standards define work areas to be the locations where end device connections are made. For office buildings, the work area can be desks in offices and cubicles. In industrial settings, the work area is often in harsh areas on the machine or process line within Cell/Area Zones. These standards require structured cabling that eases management and enables performance by connecting equipment with patch cords to horizontal cabling terminated to jacks.

Structured and Point-to-Point Cabling Methods

Networked IACS devices can be connected in two ways for both copper conductor and optical fiber:

- Structured
- Point-to-Point or Direct Attached

The preferred approach to deploy an industrial network is a standards-based (TIA-1005) structured cabling approach. Structured cabling has its roots in Enterprise and data center applications and can be very reliable, maintainable and future-ready. Although point-to-point connectivity was the practice for slower proprietary networks for over 25 years, as networks move to higher-performing industrial Ethernet networks, weaknesses occur. In general, point-to-point is less robust than structured cabling because testable links don't exist, spare ports cannot be installed, and the use of stranded conductors means reduced reach. However, good use cases exist for point-to-point connectivity, such as connecting devices to a switch in a panel or short single-connection runs. See Appendix F: “Physical Infrastructure Deployment for Level 3 Site Operations” for more detail on this topic.

A PNZS cabling architecture addresses the following key considerations:

- **Reach**—Media selection is a significant aspect of network reach. Standards-compliant copper installations have a maximum link length of 100 m (328 feet). A fiber backbone can reach 400 m to 10 km along with the downlinks. PNZS cabling architecture has a unique ability to extend the practical reach of copper links beyond the 100 m home run copper cabling limitation. For an all-copper installation, the uplink can travel up to 100 m while the downlink can reach another 100 m for a total of 200 m.
- **Industrial Characteristics**—Media selection can be more granular and cost-effective in a PNZS architecture because only the necessary harsh environment drops from IES to IACS end devices are run in hardened media and connectivity.
- **Physical Network Infrastructure Life Span**—A PNZS cabling infrastructure has a longer potential life span than home run cabling. Where it may be too expensive to install state-of-the-art cabling to each IACS device in a home run scenario, a physical zoned architecture can have high-bandwidth uplinks in the backbone and downlinks/IES can be upgraded as needed, extending the effective life span of a PNZS cabling infrastructure.
- **Maintainability**—MACs are faster, easier, and less expensive with a PNZS architecture because only shorter downlink cables are installed, removed, or changed. A home run change requires greater quantities of cable and installation/commissioning labor.
- **Scalability**—A main feature for a PNZS architecture is the ability to help scale because spares are automatically included in the design with a structured cabling approach.
- **Designing for High Availability**—PNZSs can be connected in either a resilient ring or redundant star topology to achieve higher availability.
- **Network Compatibility and Performance**—A key feature of a PNZS-deployed IES is the ability to place the machine/skid IES in a dedicated enclosure with power always on. This helps eliminate network degradation to rebuild address tables caused by powering up/down IES in a control panel for production runs.
- **Grounding and Bonding**—A PNZS enclosure must have a grounding system with a ground bar tied to the plant ground network. In addition to addressing worker safety considerations, an effective grounding/bonding strategy s maximum transmission quality for the network.
- **Security**—PNZSs typically have a keyed lock to control access to the equipment housed within. In addition, port blocking and port lock-in accessories can secure IES ports, preventing problems that may be caused by inadvertent connections made when recovering from an outage.
- **Reliability Considerations**—A PNZS architecture with a structured cabling system helps deliver high reliability because it provides testable links. Built-in spare ports can resolve outages rapidly.
- **Safety**—An IES in a PNZS enclosure separates personnel from hazardous voltages in a control panel connected to the IES.
- **Wireless**—APs can be connected to IES in a PNZS architecture.
- **PoE**—IES can have PoE-powered ports. Typical applications for PoE include cameras, APs, and other IP devices that can use PoE power. PNZS cabling architectures can help easily support the addition of PoE devices from the IES while minimizing cost and complexity of a home run.

M.I.C.E. Assessment for Industrial Characteristics

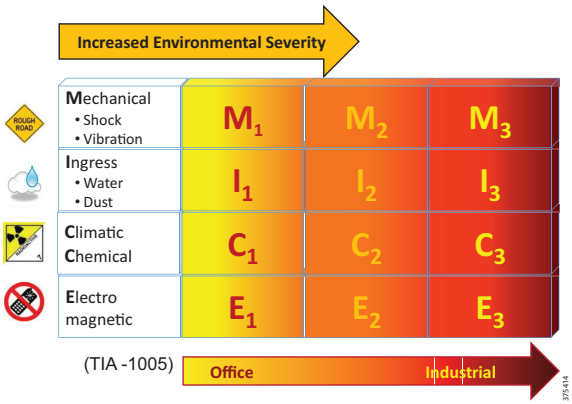
Cabling in IACS environments frequently is exposed to caustic, wet, vibrating, and electrically noisy conditions. During the design phase, network stakeholders must assess the environmental factors of each area of the plant where the network is to be distributed. A systematic approach to make this assessment, called Mechanical Ingress Chemical/Climatic Electromagnetic (M.I.C.E.), is described in TIA-1005A and other standards ANSI/TIA-568-C.0, ODVA, ISO/IEC24702 and CENELEC EN50173-3.

M.I.C.E. assessment considers four areas:

- **Mechanical**—Shock, vibration, crush, impact
- **Ingress**—Penetration of liquids and dust
- **Chemical/Climatic**—Temperature, humidity, contaminants, solar radiation
- **Electromagnetic**—Interference caused by electromagnetic noise on communication and electronic systems

M.I.C.E. factors are graded on a severity scale from 1 to 3, where 1 is negligible, 2 is moderate and 3 is severe (see Figure C-5). Understanding exposure levels helps to enable the appropriate connectivity and pathways are specified to guarantee long-term performance. For example, exposure to shock, vibration, and/or UV light may require use of armored fiber cabling suitable for outdoor environments.

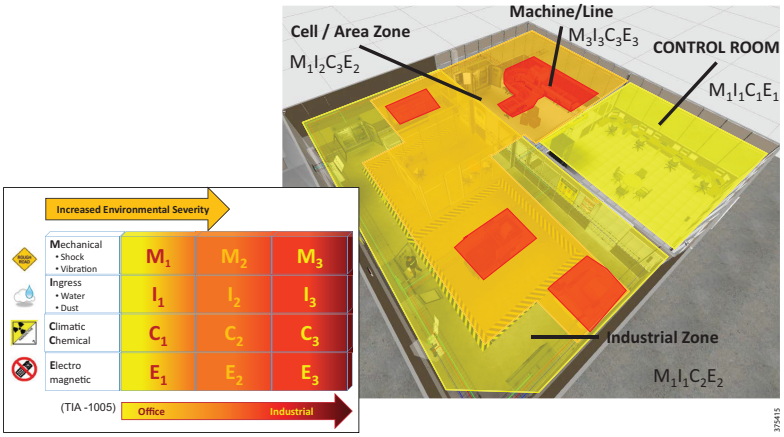
Figure C-5 TIA-1005A MICE Criteria



It is important to understand that M.I.C.E. rates the environment, not the product. The result of a M.I.C.E. evaluation is used as a benchmark for comparing product specifications. Each product used in the system design should at least be equal to or exceed the M.I.C.E. evaluation for that space.

M.I.C.E diagramming allows the design to balance component costs with mitigation costs to build a robust, yet cost-effective system. The process starts by assessing the environmental conditions in each Cell/Area Zone within the Industrial Zone. A score is determined for each factor in each area. For example, the Machine/Line is a harsh environment with a rating of M3I3C3E3. Since the E factor, electromagnetic, is high, the likely cabling would be optical fiber. Since the other factors, M, I and C, are high as well, the cabling would require armor and a durable jacket. Figure C-6 shows an example of M.I.C.E. diagramming.

Figure C-6 Sample Environmental Analysis Using the M.I.C.E. System



Cable Media and Connector Selection

Many considerations exist for media selection, such as reach, industrial characteristics, life span, maintainability, compatibility, scalability, performance, and reliability, all of which depend on the construction of the cable. The four main options for the cable construction are:

- **Media**—Copper (shielded or unshielded, solid or stranded) or optical fiber
- **Media Performance**—For copper, Cat 5e, Cat 6, Cat 6A, Cat 7; for fiber-optic cable, OM1, OM2, OM3, OM4, single-mode
- **Inner Covering/Protection**—A number of media variants are designed to allow copper and fiber-optic cable to survive in harsh settings. These include loose tube, tight buffer, braided shield, foil, aluminum-clad, and all-dielectric conduited.
- **Outer Jacket**—TPE, PVC, PUR, PE, LSZH

In addition, regulations and codes may govern the use of cabling in certain areas based on characteristics such as flammability rating, region deployed (such as low-smoke zero-halogen in Europe) and voltage rating (600 v). Table C-1 shows some general cable characteristics.

Table C-1 General Cable Characteristics

Parameter	Copper Cable	Multimode Fiber	Single-mode Fiber
Reach (maximum)	100 m	2,000 m (1 Gbps) 400 m (10 Gbps)	10 km (1 Gbps) 10 km (10 Gbps)
Noise Mitigation Option	Foil shielding	Noise immune*	Noise immune*
Data Rate (Industrial)	100 Mbps (Cat 5e) 1 Gbps (Cat 6) 10 Gbps (Cat 6a)	1 Gbps 10 Gbps	1 Gbps 10 Gbps
Cable Bundles	Large	Small	Small
Power over Ethernet (PoE) capable	Yes	Yes, with media conversion	Yes, with media conversion

*Fiber-optic media is inherently noise immune; however, optical transceivers can be susceptible to electrical noise.

Fiber and Copper Considerations

When cabling media decisions are made, the most significant constraint is reach (see Table C-1). If the required cable reach exceeds 100 m (328 feet), then the cable media choice is optical fiber cable. Copper Ethernet cable is limited to a maximum link length of 100 m. However, other considerations may be important for distances less than 100 m, such as EMI, for which fiber-optic cable is preferred due to its inherent noise immunity. Another consideration is the fact that switch uplinks connected with optical fiber help to provide faster convergence after a switch power interruption, lessening the duration of the network outage. In a comparison of data rates, copper and fiber are similar for typical industrial applications (see Table C-1); however, other higher performing optical fiber cables are available for very high demand networks.

Network life span is a significant consideration for media performance. For instance, installing a network with Cat 5e cabling is not recommended if growth is expected within 10 years, especially if the network will be transporting video. If the expectation is 10 or more years of service, a higher performance category cabling (such as Cat 6a) should be considered.

Optical Fiber Cable Basics

Single-mode and multimode are the two fiber types. Multimode fiber has glass grades of OM1 to OM4. When selecting any optical fiber, the device port must first be considered and must be the same on both ends, (that is, port types cannot be mixed). In general, the port determines the type of fiber and glass grade. If the device port is SFP, it is possible to select compatible transceivers and the optimal transceiver for the application. Also, considerations for number of strands, mechanical protection, and outer jacket protection exist. See Appendix F: "Physical Infrastructure Deployment for Level 3 Site Operations" for a more detailed explanation of optical fiber.

Optical Fiber Link Basics

The optical fiber link (that is, channel) is formed with a patch cord from the device to an adapter. Adapters hold connector ends together to make the connection and are designed for a single fiber (simplex), a pair (duplex), or as a panel containing many adapter pairs. One end of the adapter holds the connector for the horizontal cable that extends to an adapter on the opposite end. A patch cord from the end adapter connects to the device on the opposite end, completing the link. A variety of connectors and adapters exist in the field where Lucent Connector (LC) is the predominate choice due to the SFP and performance. However, many legacy devices may have older-style Subscriber (SC) or Straight Tip (ST) connectors. See Appendix F: "Physical Infrastructure Deployment for Level 3 Site Operations" for a more detailed explanation of connectors and adapters.

Copper Network Cabling Basics

Copper network cabling performance is designated as a category (that is, Cat). Higher category numbers indicate higher performance. Currently, the predominant choice is Cat 6 (especially for video applications) where higher categories are beginning to be deployed. The copper conductor is typically 23 American wire gauge (AWG), although smaller diameter 27 AWG may be used in some cases for patching. Larger gauge wires are available and the conductor can be stranded or solid. Typically, a solid conductor is used to help achieve maximum reach for the horizontal cable/permanent links, while a stranded conductor is used for patching or flex applications. Different strand counts are available in stranded Ethernet cable, and higher strand counts are for high flex applications. Another consideration is EMI shielding. A variety of shielding possibilities can be employed to suppress EMI noise with foil and/or braided outer jacket or pairs with foil. Mechanical protection and outer jacket protection also need to be considered when selecting copper network cables. See Appendix E: "Physical Infrastructure Design for the Industrial Zone" for a more detailed explanation of copper network cabling.

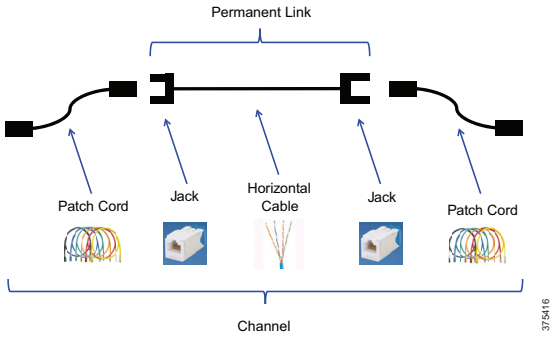
Copper Network Channel Basics

A structured copper network channel is formed with a patch cord plugged into the device and the other end of the patch cord plugged into a jack in a patch panel. The jack is terminated to solid copper horizontal cable that extends to a jack on the other end. A patch cord is plugged into the jack, and the other end of the patch cord is plugged into the device, completing the channel (see Figure C-7). Two predominant, proven connectors or jacks exist for copper industrial networks:

- **RJ45**—Part of validated and tested patch cord or field terminable
- **M12**—Over-molded patch cord or field terminable

The RJ45 plug and jack have been adapted for industrial networks, where they can be deployed in a DIN patch panel. If the connector is located inside a protected space or enclosure, standard RJ45 connectivity is preferred. The plug could be part of a tested and validated patch cord or a durable field-attachable plug. The RJ45 bulkhead versions are available for quick connect/disconnect and versions that are sealed from ingress of liquids and particulates. The M12 is a screw-on sealed connector well suited for splashdown and harsh environments and can be a two-pair D-Code or a four-pair X-Code. See Appendix E: "Physical Infrastructure Design for the Industrial Zone" for a detailed explanation of copper network cabling and connectivity.

Figure C-7 Simplified Example of Copper Structured Cabling



Cable Management

Proper cable management helps to provide a converged network with high system performance, availability, and reliability across all zones of the CPwE architecture. Cable management impacts MACs, signal performance and cable life in infrastructure locations that range from harsh industrial areas to air conditioned, protected areas. Cable management features include:

- **Bend Radius Control**—Maintaining the cable bend radius (that is, change in direction) within specifications minimizes signal attenuation for both fiber and copper. All bends should be controlled from port to port with slack spools, pathway waterfalls, enclosure spools or features built into products. Cable runs through conduit must maintain bend radius, and some conduit fittings may not be appropriate.
- **Panel, Rack, and Cabinet Cable Routing and Protection**—Cable routing and protection is essential in server cabinets, switch racks, enclosures, control panels, etc. For cabinets and racks, cables must be managed both horizontally (such as D rings) and vertically (such as cabinet fingers). Network cables in enclosures and control panels should be routed in duct and may need shielding from noise. Standard distribution fiber cabling may need to be routed through a corrugated loom tube or conduit for protection.
- **Slack Management**—Slack cabling should be properly coiled and secured to prevent tangling, snagging, and poor appearance.

- **Bundling**—Cable ties specific for network cables, such as hook and loop or elastomeric cable ties, should be used only to prevent cable deformation that can lead to signal loss.
- **Identification**—Identification can be accomplished with printed labels and color coding of cables, cable ties, labels and icons. Intuitive and standard methods reduce errors for moves/adds/changes and aid in troubleshooting by helping to identify cabling and upgrade planning.

Cable inside PNZS architecture, freestanding enclosures, and control panels are addressed in Appendix E: "Physical Infrastructure Design for the Industrial Zone". See Appendix F: "Physical Infrastructure Deployment for Level 3 Site Operations" for information about cable management for an IDF and routing to the Cell/Area Zone. See Appendix F: "Physical Infrastructure Deployment for Level 3 Site Operations" for information on network cable management for switches, servers, storage, and other gear.

Network Cabling Pathways

Pathways for cables are critical for distributing copper and fiber cabling securely across the plant floor while protecting it from physical infrastructure threats. The TIA-1005 standard, the *ODVA Media Planning and Installation Manual*, and other guides provide recommendations on pathways, including cable spacing and installation guidance to minimize risks from environmental threats. Several options of routing cables via pathways simplify deployment using best practices for a variety of environments across the plant. Figure C-8 describes some of these options.

Figure C-8 Pathway Considerations

Installation Consideration	J-Hook 	Wyr-Grid® 	FiberRunner® 
Cable Protection Environment	Mild	Moderate	Moderate to harsh
Cable Density	Light to medium	Medium to heavy	Light to heavy
Applicable in Constrained Spaces	Yes	No	No
Installation Complexity	Simple	Moderate	Moderate to strong
Ease of Moves, Adds, Changes	Simple	Moderate	Moderate

375450

The simplest and lowest-cost pathways are J-Hooks. J-Hooks can be mounted to a wall, beam, or other surface. Network cables are held in place by the hook feature and are often secured with a cable tie. The J-Hook hook feature is designed to achieve proper bend radius control when transitioning down. J-Hook systems should be used with cables with enough rigidity to have an acceptable bend between spans and are suitable for a small bundle. Standard fiber distribution cable is not suitable for J-Hooks unless supported by corrugated loom tube.

When routing large or many cable bundles, a tray or wire basket can be installed overhead to form a solid and continuous pathway. Since cabling is exposed to the plant environment, cable jackets must be specified for the environment. An enclosed tray, such as a fiber tray, provides a high level of environmental protection for light to heavy cable densities. For the highest protection with few network cables, conduit is the preferred choice and care must be taken to maintain the proper bend radius.

Grounding and Bonding Industrial Networks

A proper grounding and bonding system is essential for personnel safety, equipment protection, equipment operation, and reliable network communication. An appropriately designed grounding and bonding system is intentional (designed and specified), visually verifiable (such as green and yellow cable jacket), and consists of adequately sized conductors to safely handle expected electrical currents and dissipate electrical noise.

Earthing, Grounding, and Bonding

The terms earthing, grounding, and bonding are often interchanged; however, each has a specific meaning:

- **Earthing**—Connecting to earth or a conductive body that is connected to earth
- **Grounding**—The point at which all bonded conductors come together at earth
- **Bonding**—Electrically connecting all exposed metallic items not designed to carry electricity, such as enclosures, trays, racks, cable armor, etc., to a ground

Figure C-9 Earthing, Grounding, and Bonding

Grounding for Safety

Cable trays, enclosures, communication/control cable, chassis, or metallic surfaces can be inadvertently energized by a power cable short or lightning, potentially leading to shock that causes injury or equipment damage. A dedicated grounding conductor safely directs the hazardous stray electrical current to ground.

Ground Loop

A ground loop is an unwanted current in a conductor connecting two points that should be at the same potential. Ground loops result from multiple ground connections to earth, creating a potential difference.

Grounding and Bonding for Network Communication

Stray electrical noise and ground loops can disrupt electronic equipment, especially Ethernet gear. Varying methods exist to suppress these elements. Unshielded Twisted Pair (UTP) Ethernet cable has limited noise cancellation. Shielded Twisted Pair (STP) cable is more effective because it has a metallic sheath that is bonded to dissipate the electrical noise. The challenge is to maintain equipotential, and an equalizing potential conductor (EPC) may be necessary. Network cable protected by a grounded noise shield or shielded duct is designed to dissipate electrical noise in an enclosure. Also, a flat, wide bonding strap bonded to the enclosure door and side panels dissipates noise more effectively than standard cable (skin effect of high frequency noise). The goal is to implement a single ground reference throughout.

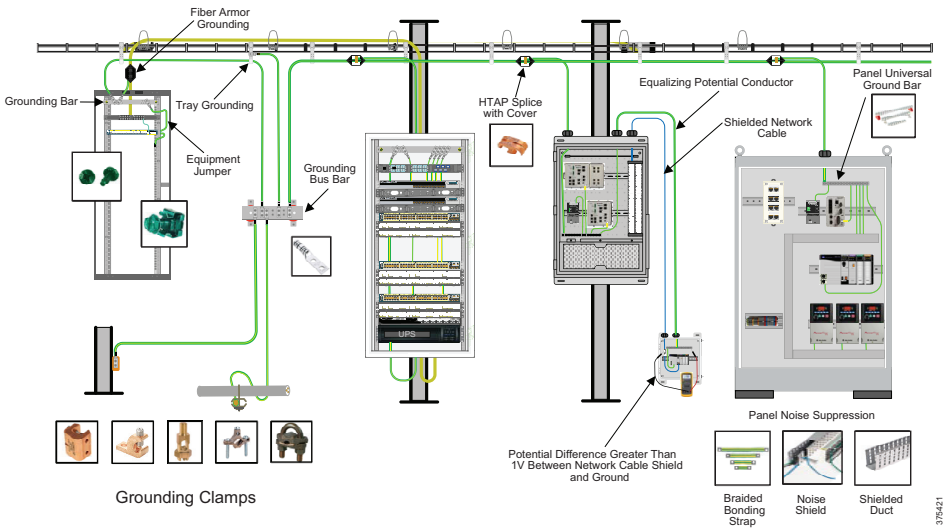
Equalizing Potential Conductor

If a potential difference exists between the cable shield and equipment ground greater than one volt, a ground loop can form, disrupting transmission. An EPC restores ground and limits potential differences between network segments. (See Figure C-10).

Applicable Grounding and Bonding Standards

- NEC Article 250 and 645.15
- IA 607-B and 1005
- BICSI
- Industrial Grounding Network

Figure C-10 Industrial Grounding Network



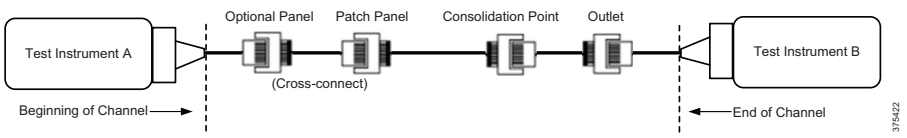
Link Testing

Link testing verifies baseline performance and assists in efficient network maintenance over its life span. Two forms of link testing are utilized:

- **Static**—Typically used at installation and commissioning phases and some maintenance tasks
- **Dynamic**—Network monitoring solution that resides on the network and provides real-time performance data and analytics

Static link testing (see Figure C-11) involves test instrumentation attached to each link.

Figure C-11 TIA568 Static Link Testing Set Up



This step is important at installation and commissioning of the network to confirm that any challenges relating to media installation are uncovered before the network moves into the operational phase. Performance measurements are made and recorded for each link. This baseline performance information is archived and can greatly speed diagnosis and correction. Finally, having the installer provide link test data as part of acceptance criteria can greatly reduce the likelihood of billing disputes if the test data is included as acceptance criteria.

Dynamic link testing solutions reside in the network and provide real-time monitoring and analysis of network performance. Dynamic solutions should include discovery and visualization functions in addition to staple functions such as bandwidth indication. Visualization is especially important as a maintenance adjunct to expedite correction of challenges as they are discovered. Many networks are mixture of various manufacturers' equipment, therefore, it is advisable to choose a vendor-neutral solution.

A key advantage of dynamic link testing is that many conventional tools are unable to detect some forms of network interruptions, especially intermittent challenges and/or challenges that manifest only under actual network operation. Dynamic monitoring solutions provide daily around-the-clock performance data and analysis, permitting trending and other forms of long-term analytics that can weed out difficult challenges. Another advantage of dynamic solutions is gaining the ability to detect and respond quickly to issues such as duplicate IP addresses, device or cable moves, connection or applications faults, and unauthorized connections.

Channel

All segments in the cabling system must be subject to link loss testing. A segment consists of media and connectivity, such as connectors, adapters, splice points, and so on, joining different segments of the network. The link testing measurement includes the insertion loss of connectors at the panels (termination bulkheads) on either end of the link, but does not include the attenuation of any short jumpers attached to terminating electronics or to the performance of the connector at the equipment interface. Although the channel is defined as all of the components in the permanent link and additional jumpers attached to terminating electronics, only the permanent link is measured against the standard's expectations.

ISO/IEC and TIA standards define the permanent link as the permanent fiber cabling infrastructure over which the active equipment must communicate. This does not include equipment patch cords to connect the active network devices in control panels or the patch cords in other switch patching areas. ISO/IEC and TIA standards define specific permanent link testing to verify the performance of the fixed (permanent) segments of installed cabling as accurately as possible.

The permanent link segment constitutes the cabling infrastructure: the fiber cabling and the connectivity that joins patch panel to patch panel, and the connectivity residing in the patch panels. A permanent link does not include any patch cords to the line-terminating electronics. Testing of a permanent link should be completed before any patch cords are connected to the panels.

Unless otherwise stated, all permanent link loss testing should be performed with a handheld power meter/source. This equipment measures link attenuation, which is the most important performance parameter when installing components.

For backbone cabling, permanent link testing is recommended for all links at both specified wavelengths. Multimode fibers must be tested in one direction at 850nm (the SX operating window) and at 1300nm to account for fiber attenuation differences due to wavelength and to reveal potential issues associated with installation. Similarly, for LX applications, window testing should first be performed at the application operating wavelength and the second window at the higher wavelength (1550nm).

Significant differences in link test results between these windows can aid in troubleshooting failing links. Link failures predominately at the first window may indicate challenges with connector systems, while second window failures may indicate fiber macrobend sites in the installed cabling; that is, large-radius bends in the cable that can cause incremental attenuation.

To verify that fiber links are tested and cleaned properly according to the standards, Panduit provides the following best practices documents:

- **Field Testing Multimode 10 Gbps Fiber Permanent Links**—This document provides information on testing the fiber permanent links used to connect Stratix switches. This document also outlines the Panduit recommended procedures for testing multimode and single-mode structured cabling system links.
- **Visual Inspection and Cleaning of Multimode and Single-mode Structured Cabling System Interconnect Components**—This document outlines the Panduit recommended procedures for visual inspection and cleaning of multimode and single-mode structured cabling system interconnect components (connectors and adapters).

Wireless Physical Infrastructure Considerations

Secure and robust wireless access networks have become a necessity in industrial environments. As these networks are being stretched to maximum capacity with various new trends, it is important to consider during the planning and design stages specific tasks that must be accomplished wirelessly. It is also important to have a forecast of future growth. Currently, two main client applications are served wirelessly: mobility and workgroup bridge (WGB) communications. This section discusses important topics relating to the physical infrastructure and deployment of wireless APs.

Site Survey

The first step to the design and successful operation of a WLAN network is the site survey. The survey characterizes and identifies the RF environment over the entire coverage area to confirm that performance requirements of the wireless APs are met. The survey can be conducted using measured data from APs arranged throughout the coverage area, or may be predictive where a computer model of the detailed coverage area is created and performance is determined.

Wireless Spectrum

The 5 GHz frequency band is recommended for industrial wireless applications. Because of the limited number of channels and a much higher chance of interference, the 2.4 GHz band is not recommended for critical IACS applications, such as machine control. However, 2.4 GHz band can be used for personnel access and low throughput, non-critical applications. Use only channels 1, 6, and 11 in the 2.4 GHz band. Use of non-standard channels or more than three channels in a 2.4 GHz band will cause adjacent channel interference and lower throughput.

The guidelines constantly change, therefore it is important to refer to the local regulatory authority and product documentation for the most recent compliance information and channel availability for a particular country.

Many sources of interference are intermittent, and new sources may appear over time. It is important to proactively monitor for radio interference in the industrial environment, before and after the deployment. Properly defined and enforced spectrum policy on site is critical for interference prevention.

Wireless Coverage

The AP coverage area where the desired data rate can be supported depends on many factors and can only be determined during the site survey. Changes in the environment and interference levels also dynamically change the coverage.

For EtherNet/IP applications, confirm that minimum levels of parameters such as Received Signal Strength Indication (RSSI) and Signal to Noise Ratio (SNR) are met. For CIP Sync™ traffic, the cell coverage area should be designed to sustain a 54 Mbps data rate.

RF Parameters

Spatial Division Multiplexing has limited benefit for the real-time EtherNet/IP traffic. Multiple spatial streams make communication less reliable, dependent on higher SNR, and more susceptible to multipath fading. Single spatial stream is more suitable for EtherNet/IP control communication. In this case, 20 MHz channel width (no channel bonding) is recommended with IACS applications.

It is not always desirable to use the maximum transmit power in the Cell/Area Zone. Limiting transmit power creates smaller coverage Cell/Area Zone size with less signal propagation outside the intended area and less chance for distant clients to join the AP.

Note For more information, see the *Deploying 802.11 Wireless LAN Technology within a Converged Plantwide Ethernet Architecture Design and Implementation Guide* at the following URLs:

- http://www.cisco.com/c/en/us/td/docs/solutions/Verticals/CPwE/NovCVD/CPwE_WLAN_CVD.html
- http://literature.rockwellautomation.com/idc/groups/literature/documents/td/enet-td006_-en-p.pdf

Location of Wireless Access Points

The location of wireless APs is determined by means of wireless coverage and performance modeling software. These findings are then validated during the commissioning phase. On occasion, thorough initial testing of the WLAN during the commissioning phase reveals that the location of the AP has to be moved slightly to accommodate building layouts, obstacles, and so on that were not taken into account. Typically, these interferences were changed or moved after the time of software modeling. The structured cabling used to connect the AP to the IES port can be designed taking into account the need for change by the use of patch cords connecting the AP to fixed equipment outlets (EO) that are connected to the horizontal cable run. This concept is introduced in TIA Technical Services Bulletin (TSB) 162-A, *Telecommunications Cabling Guidelines for Wireless Access Points*.

TSB-162-A bases initial design on the deployment of APs on a square grid model, and emphasizes that after initial design, software prediction of performance should be carried out to determine any deviation of AP locations from this grid. Frequently, in larger plant floor deployments, vertical structural beams that support the roof and give strength to the overall building are used, and these form a potential array of supporting locations for APs. These beams also can provide convenient support locations for the PNZS enclosure located in the Cell/Area Zone.

Cabling for Wireless Access Points

From the original release of IEEE 802.11 standards for WLAN, IEEE 802.11-1997 was released in 1997 and supported data rates of up to 2 Mbps, the IEEE has been developing and technology has developed WLAN systems capable of increasingly higher data rates. Through progression of 802.11b, 802.11g, 802.11a and 802.11n, the most recent standard to be released is IEEE 802.11ac. Up until IEEE 802.11n, backhaul data rates were less than 1 Gbps, which indicates that Cat 5e or 6 cabling could be used. With the release of IEEE 802.11ac, however, Generation 2 APs (often referred to as the second wave) will experience the backhaul rate

increasing to over 1 Gbps. Therefore, it will be necessary to deploy Cat 6A cabling that will support data rates of up to 10 Gbps and is recommended for new deployments. Some references have been made to the use of two Cat 6A cables for each AP, thereby increasing reliability and availability in the event of channel failure. The IEEE standards development groups are establishing lower data rates that can support Wave 2 data rates, focusing on the use of 2.5 and 5 Gbps and using existing Cat 5e and 6 cabling. The standards are still in development at the time of writing and will need to be reviewed closer to the time of WLAN design and deployment.

Since the original release of IEEE 802.11 standards for WLAN, new technology includes WLAN systems capable of -increasingly higher data rates. The current standard is IEEE 802.11ac. Until the previous standard, IEEE 802.11n, backhaul data rates were less than 1 Gbps, therefore Cat 5e or 6 cabling could be used. With the release of IEEE 802.11ac, however, second-generation APs (often referred to as the second wave) will experience the backhaul rate increasing to over 1 Gbps. As a result, it will be necessary to deploy Cat 6A cabling, which supports data rates of up to 10 Gbps and is recommended for new deployments. Two Cat 6A cables can be used for each AP, thereby increasing reliability and availability in the event of channel failure. The IEEE standards development groups establishing lower backhaul data rates that can support second wave APs, focusing on the use of 2.5 and 5 Gbps and using existing Cat 5e and 6 cabling. The standards are still in development at the time of writing and will need to be reviewed closer to the time of WLAN design and deployment.

Power over Ethernet

Copper cabling used for the backhaul for the AP can also be used to supply power to the AP with PoE. PoE has been developed by the IEEE standards bodies, and currently two versions exist:

- IEEE 802.3af, delivering up to 12.95 watts at the end of a maximum-length channel
- IEEE 802.3at, delivering up to 25.5 watts at the end of a maximum-length channel.

The detailed design of the cabling must be considered since higher data rate APs typically require a higher power feed, and on occasions may require more power than would be available from one PoE source. In this case, two cables would be required and power combining would be used in the AP.

Access Points in Harsh Environments

APs used in plant floor deployments are frequently located in harsh, or even outdoor, environments. In these cases, the APs must be placed into a protective enclosure. Consideration of the design of the enclosure must be made, since the proximity of additional material associated with an enclosure made from metal can affect the radiation pattern and hence the coverage behavior of the AP. In addition, the antennas must be located outside of the enclosure or the enclosure must include an RF-transparent window.

APPENDIX D

Physical Infrastructure Design for the Cell/Area Zone

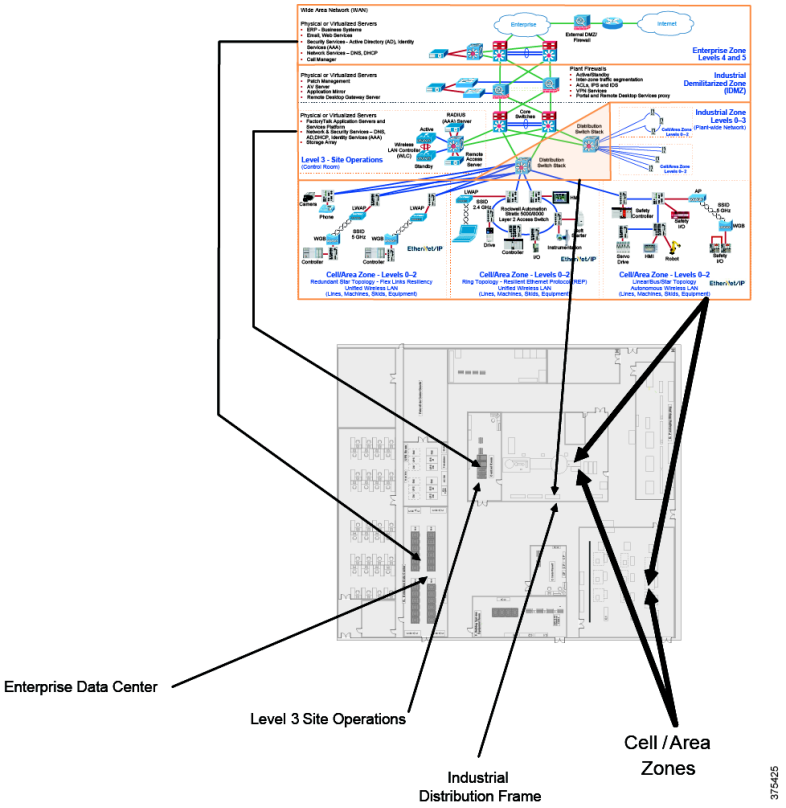
Successful deployment of a Converged Plantwide Ethernet (CPwE) logical architecture depends on a robust network infrastructure design, starting with a solid physical layer that addresses the environmental, performance, and security challenges with best practices from both Operational Technology (OT) and Information Technology (IT). Through collaboration on technology and physical network infrastructure, Panduit teams work with Rockwell Automation and Cisco to help customers develop a scalable, robust, secure, future-ready plant-wide industrial automation and control system (IACS) physical network infrastructure. The rapid growth in both IACS devices leveraging EtherNet/IP, and non-IACS devices leveraging IP for security, mobility, etc., creating a structured, physical layer deployment.

This Appendix addresses the following key recommendations/best practices to simplify design and deployment of a robust industrial Ethernet physical layer focused on the Cell/Area Zone - Levels 0-2 of the CPwE reference architecture:

Logical to Physical Mapping

A Cell/Area Zone consists of machines, skids and equipment to be monitored, managed, and controlled. A Cell/Area Zone consists of Level 0 sensors and actuators, Level 1 controllers, and Level 2 local supervisory function (see Figure D-1). This Appendix discusses aspects of the physical infrastructure deployment in the Cell/Area Zone.

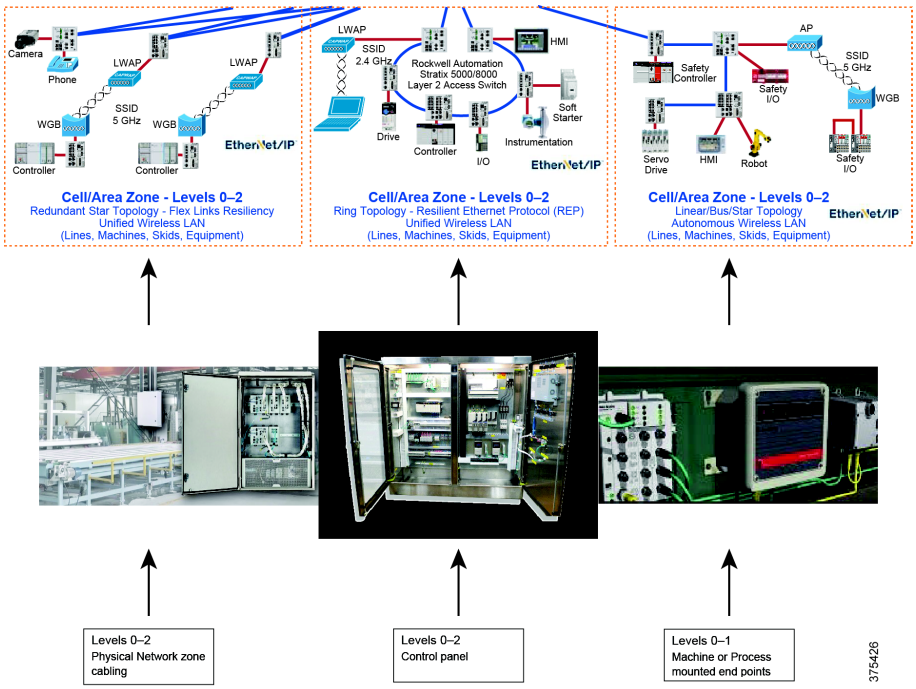
Figure D-1 CPwE Logical Architecture to Physical Plant Floor



The Cell/Area Zone differs from much of the upper level network in several important areas. Cell/Area Zone requirements affect both the equipment and media deployed in these areas as follows:

- The environment encountered by both equipment and cabling is usually at its most harsh, therefore network cables and connectors, and equipment must withstand these conditions.
- Local cabling architectures in the Cell/Area Zone can take on different forms. For example, the three types shown include Redundant Star, Ring and Linear/Bus topologies.
- Although standards-based structured cabling is almost exclusively used at higher levels within the plant and enterprise networks, frequently in Cell/Area Zone Levels 0 - 2 a point to point cabling method is often encountered. Although variations can exist, this cabling most typically involves the use of stranded Ethernet copper cabling field terminated with RJ45 or M12 plugs. This allows direct connections between pieces of equipment.
- Physical Cisco and Allen-Bradley Stratix IES deployment can range from switches located inside dedicated a PNZS or control panels to machine mounted IP67-rated switches.
- Wireless deployments in plant floor or plant environments may be subject to various factors in the environment that cause reflection or signal attenuation and competition for frequency spectrum. A thorough site survey and spectrum analysis is required.

Figure D-2 Cell/Area Zone Logical to Physical Mapping



Key Requirements and Considerations

Many aspects of the Cell/Area Zone serve an important role and must be considered in the design and implementation of the network:

- **Availability**—The design of a robust and reliable infrastructure achieves service levels demanded of current and future networks. The use of standards-based cabling together with measured, validated performance confirms reliable data throughput. Use of redundant logical and physical networks assures highest availability.
- **Reliability**—The harshest environments are often encountered in the Cell/Area Zone. In addition to extreme mechanical and environmental exposure, network cabling is often subject to excessive levels of EMI. Solution choices must be made between unshielded, balanced twisted-pair cabling or shielded, balanced twisted-pair cabling, together with appropriate attention paid to grounding and bonding. In situations where satisfactory performance cannot be achieved, fiber-optic solutions can provide an option for highly reliable, error-free communications.
- **Future ready**—Consideration of higher performance cabling categories enables the data communications to fully meet current and future Cell/Area Zone requirements. Choices in media between copper and fiber cabling assure higher data rate transport requirements.
- **Security**—Network security is critical to its uptime and availability. Physical layer security products, such as jack blockouts and plug lock-ins help limit access to and help prevent inadvertent or malicious removal or installation of patch cords to help achieve service level goals.
- **Scalability**—The use of a physical zone topology together with structured copper and fiber cabling chosen for high data throughput and building block type pre-configured solutions enable a network infrastructure comprised of modular components that scale to meet the increasing data communications needs of discrete and process-orientated IACS applications.

Physical Network Design Considerations

In the Cell/Area Zone physical network design, several key areas should be considered for physical network design. This section uses terminology associated with media in the Cell/Area Zone; however, these media types are described in more detail later in this Appendix.

- **Physical media**—copper and fiber connectivity:
- **On Machine**—Device Level
- **Cell/Area Zone Cabling**—Control Panel
- **Cell/Area Zone Cabling**—Redundant Star
- **Resilient Ethernet Protocol (REP) Ring**—Zone Deployment

PNZS for housing IES as networks scale to larger node counts.

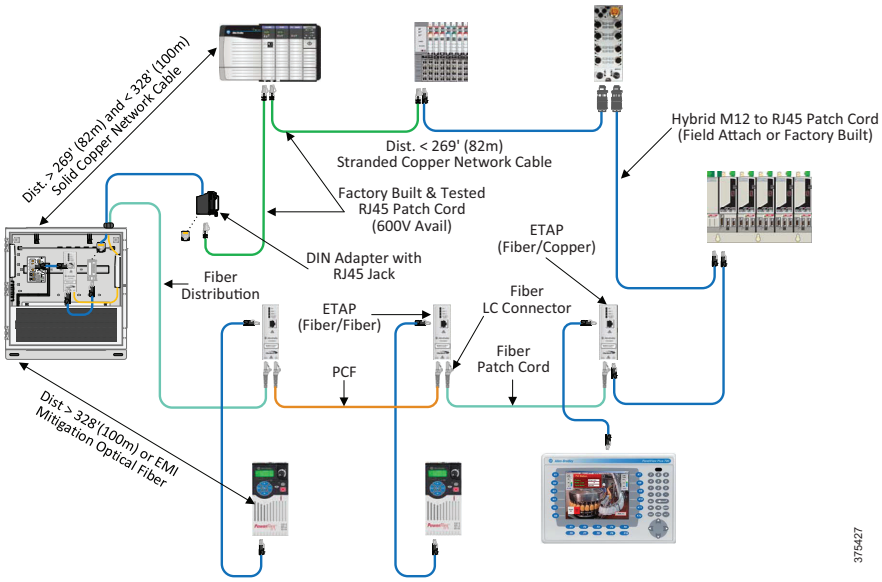
IDF system for distribution switch infrastructure deployments for the Industrial Zone.

Physical Media

On Machine - Device-Level

Cabling on the machine is often subjected to the harshest environment in the entire network. The M.I.C.E. criteria, which are described in Appendix D: "Physical Infrastructure Design for the Cell/Area Zone" are used to characterize different environment types and guide media and connectivity selection. The image in Figure D-3 shows the topology often used at Level 0 and 1 where I/O devices are connected in a device-level ring topology using the ODVA Device Level Ring (DLR) protocol to provide a redundant path connecting all devices to an IES. If a cable connecting two adjacent devices fails, the ring supervisor detects this fault and forwards traffic in the other direction, maintaining the connection of all devices to the network.

Figure D-3 Device-level Ring Topology



Frequently, Cell/Area Zone installations use IP67-rated connector options. Copper cabling using M12 connectivity (see Figure D-4 and Figure D-5) or IP67-rated RJ45 connectivity is applicable in many environments and in many applications.

Optical fiber is also used in the Cell/Area Zone. Here, field installation is prevalent, and personnel less familiar with single-mode (OS type) or multimode (OM type) find that larger glass diameter Polymer Coated Fiber (PCF) using Hard Clad Silica technology offers easier installation.

Figure D-4 Example of M12 Connectivity - Field Terminable M12 D-code Plug

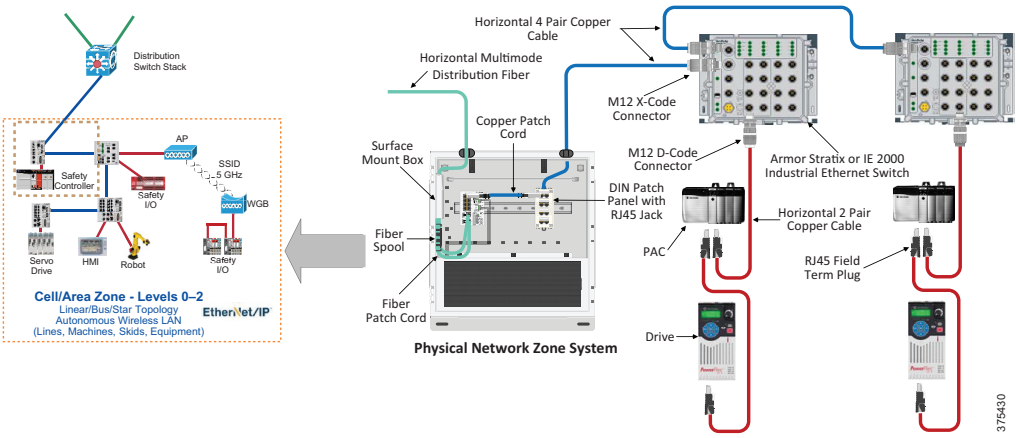
Figure D-5 Example of M12 Connectivity - RJ45 to M12 D-code Adapter)

Cell/Area Zone Cabling - Control Panel

The control panel is typically connected to functional areas within the Cell/Area Zone. Network connections can be made from the control panel to the machine, (for example, to an IES or I/O block located on the machine). On the other side, network connections are made to PNZS or IDF where typically other network connections converge and consolidate before being routed to higher levels within the Converged Plantwide Ethernet architecture.

Figure D-6 illustrates a detailed view of the Cell/Area Zone linear/bus/star topology. In this example, the control panel contains an IES (such as Stratix™ 5400) to connect devices such as Human Machine Interface (HMI), Programmable Automation Controller (PAC), and Variable Frequency Drives (VFD). The uplinks are connected to the PNZS.

Figure D-6 Linear Connectivity Deployment Example



The control panel environment exposes industrial Ethernet cabling to EMI risks from VFD drives, contactors, power supplies, and other sources. The use of shielded cabling, EMI noise shields and shielded patch cords, as shown in Figure D-7, reduce risk of noise coupling causing equipment downtime or damage. 600V rated cabling is useful to comply with standards such as UL508A requirements for control panels with higher voltages (such as 480VAC). Consult your local standards to specify media that addresses safety guidelines in control panels.

Figure D-7 Schematic of Control Panel

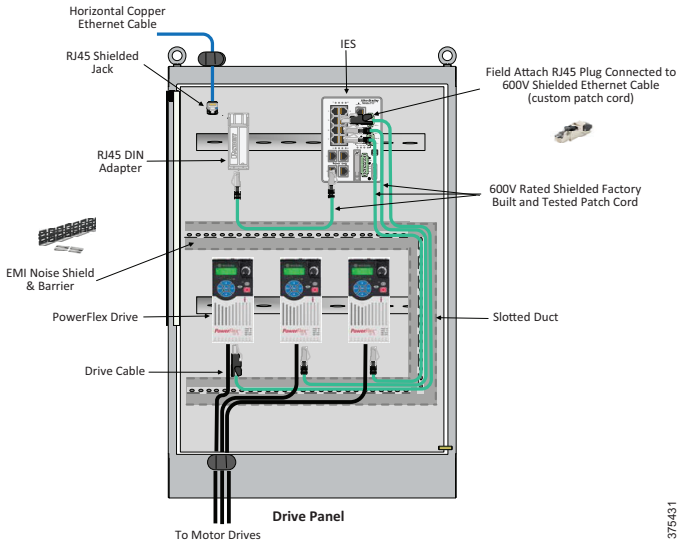
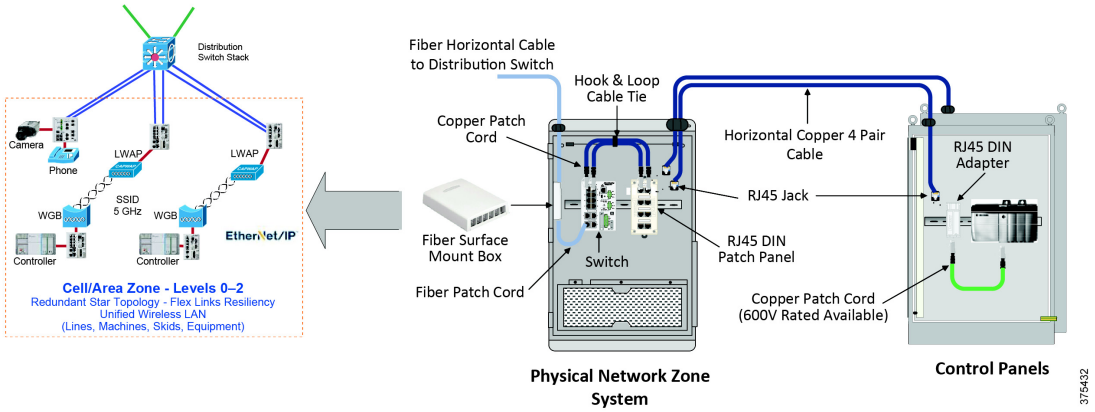


Figure D-8 illustrates the cabling configuration for the control panel to a PNZS. In this figure, horizontal copper cable downlinks to devices are routed from the PNZS into the control panel. Entry can be made in a variety of ways, such as through a metal conduit that is attached to the control panel enclosure by means of a conduit gland, or through a cable transit. For uplink connections, individual fibers are terminated and the connectors installed into adapters contained in the surface mount box. The fibers are managed and installed onto slack spools located inside or close to the surface mount box for protection of the fibers. Fiber patch cords are used to connect from the front face of the adapters in the surface mount box to the IES. The IES uplinks typically use SFP pluggable transceivers that in turn are provisioned with duplex LC type connections.

Figure D-8 Redundant Star Topology



Cell/Area Zone Cabling - Redundant Star Switch-level Topology

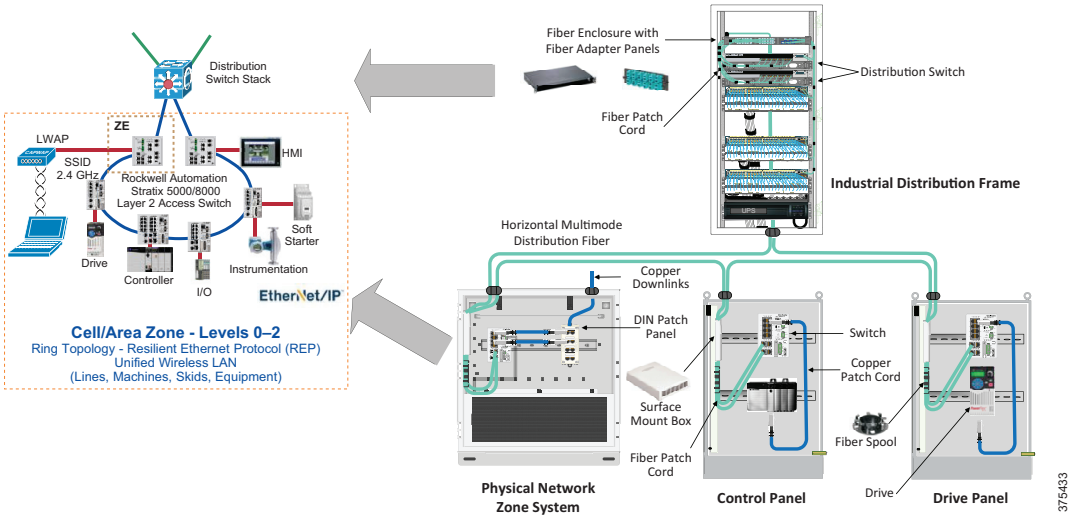
The IES shown in Figure D-8 provides network connections to individual applications. A number of individual applications can be connected to the IES (for example, video surveillance camera, voice over IP phone) and then connected to the higher level network. This connection to the network from the IES switch is critical because damage to the connection causes failure to multiple applications. For this reason, it is often necessary to create multiple redundant uplink paths to support traffic, if the primary connection fails. The IES, depending on the model, is provisioned with redundant uplink ports. Two cable runs can be made to a higher level, such as distribution switching. The connection route from the IES to the distribution switch should be different for the main cable and redundant cable runs. If this is not accomplished, the level of redundancy is compromised. For example, if both runs are routed in the same pathway, then catastrophic damage to the pathway would likely sever both cable runs.

A PNZS provides environmental protection for the IES and serves as a consolidation point for multiple network connections. The PNZS contains physical infrastructure that is required to make network connections to the switch and can be pre-configured; that is, supplied with all the required physical infrastructure components assembled into the PNZS or integrated where the active IES is supplied along with the physical infrastructure to constitute a ready to go building block system. The PNZS solution is described in more detail later in this Appendix.

Cell/Area Zone Cabling - Switch-Level Ring Topology

The implementation of the switch-level ring topology within the Cell/Area Zone is similar to the linear/ star topology described previously. However, for the switch-level ring topology, a further industrial Ethernet cable is added that connects the last IES in the linear network back to the distribution switch, which closes the ring to form a redundant path topology. If one industrial Ethernet cable or IES fails, communication is converged in the other direction around the ring to make sure that all other switches are still connected to the network. The switch-level ring topology is highlighted in Figure D-9.

Figure D-9 Switch-level Ring Topology in the Cell/Area Zone



Cabling Jacketing Materials

Communications and control networks are expected to operate consistently and reliably in all types of environments that are characterized by the M.I.C.E. criteria that are described in Appendix D: "Physical Infrastructure Design for the Cell/Area Zone". In harsh environments, industrial networked communications systems are required to be extremely durable. If exposed to harsh environments, physical deterioration in cabling infrastructure can occur and failure in mission critical data transmission components can lead to defective network performance and safety issues, ultimately leading to loss of data transfer, costly downtime, or catastrophic failure. Cable jackets that are used in industrial environments, and guidance for the choice of jacketing material are indicated in Table D-1.

Table D-1 Overview of Different Jacketing Types

Function	PVC	TPE	PUR
Oil Resistance	Good	Very Good	Very Good
Abrasion Resistance	Good	Very Good	Excellent
High Flex Applications	Good	Excellent	Excellent
Smoke Rating	CM	CM CMX Outdoor	Zero Halogen (IEC 60332-1)
Relative Cost	$	$$$	$$$

Cable and Connector Ingress Protection

IEC 60529A specifies the degree to which an item can withstand the effects of particle or liquid entry. Ingress Protection, IP rating, is the rating that is based on these tests for the component. In the case of particle ingress, 0 represents the lowest level of ingress and 6 represents the highest level. In the case of liquid ingress, 0 represents the lowest level of ingress and 8 represents the highest level.

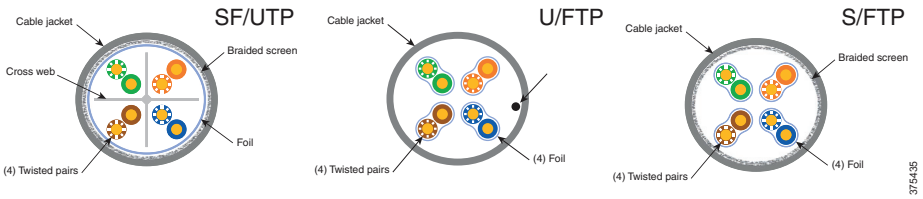
The IP69K rating is for applications where high pressure and high temperature washdown is used to sanitize equipment such as food and beverage. The IP69K test specification was initially developed for road vehicles, especially those that need regular intensive cleaning, but has been widely adopted in the food and beverage industries as a test of product ability to withstand sanitary washdown.

Ethernet Copper Cable Types - Unshielded and Shielded

When choosing a shielded cable type, several options should be considered. Figure D-10 shows the three major categories of shielded cables.

- Screened UTP cable includes an overall foil around the pairs
- STP cable includes a shield around each individual pair
- Screened STP cable includes an overall shield, or braid, around all pairs with an additional foil around each individual shield

Figure D-10 Cross Section of Shielded Twisted Pair Cabling Type

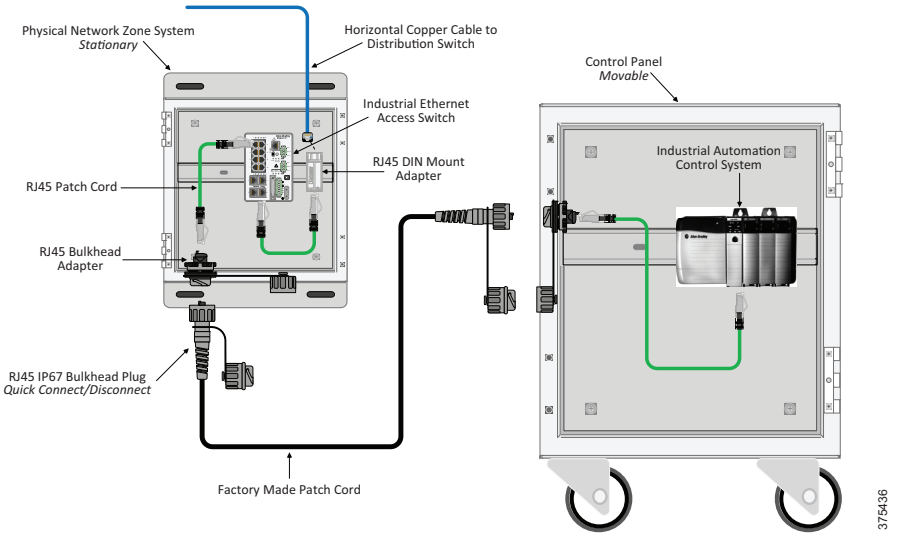


Connector Types

Ethernet connectivity makes almost exclusive use of the 4- or 8-pin version of the RJ45 connector. When using 4 pins, pins 1, 2, 3 and 6 two-way data traffic is supported up to and including data rates of 100 Mbps. Four-pair twisted pair cable that is connected to all eight pins of the connector supports higher data rates (such as 1 Gbps) when the channel is rated to Category 5e or higher.

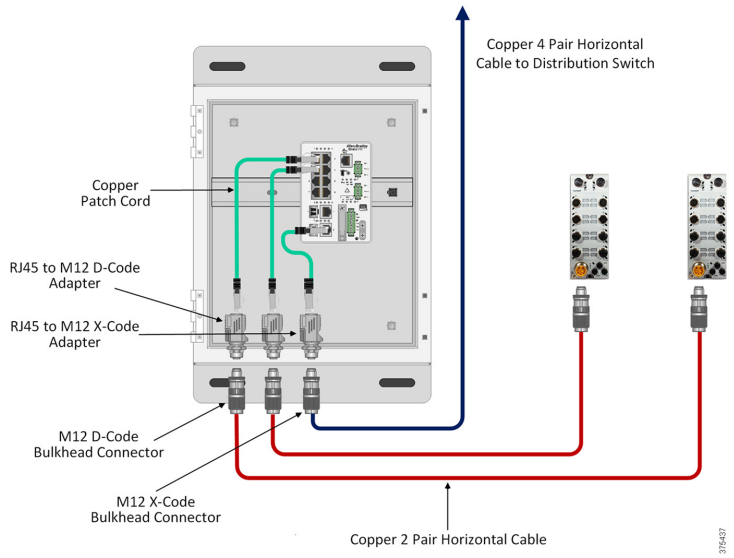
The RJ45 used in Enterprise type environments, such as in the office or data center areas, is rated as being suitable to meet the requirements of IP20. An external housing is required to be fitted around the RJ45 plug and jack if the connector system is to meet higher IP ratings. Various housing types exist, defined in IEC standard 61076-3-106. Variant 1 in this standard is the type that is adopted by the ODVA for EtherNet/IP connectivity. An example of Variant 1 is shown in Figure D-11.

Figure D-11 Quick Connect Variant 1 Example



In addition to the RJ45 connection types described above, other connector form factors that provide IP65/IP67 ingress protection that are used for twisted-pair cabling. Figure D-12 shows the M12 form factor. ODVA adopted four and eight pin versions in support of EtherNet/IP. Different pin and keying arrangements are possible with these connector types. Specifically, EtherNet/IP uses the D-code for the 4-pin and X-code for the 8-pin connector types. The M12 D-code connector system conforms to IEC 61076-2-101; the M12 X-code connector system conforms to IEC 61076-2-106.

Figure D-12 M12 Industrial Bulkhead to Device



Fiber Options for the Plant Floor - Cell/Area Zone

Appendix F: "Physical Infrastructure Deployment for Level 3 Site Operations" describes the OS and OM fiber types that are used to connect from the Industrial Zone through to the PNZS in great detail. Fiber that is used in the Cell/Area Zone is often required to be easy to install. Electrical contractors are frequently employed to connect control panels to and in the vicinity of the machine using field termination methods. Although these connections generally center on copper cabling, *electrician friendly* fiber-optic media does exist for use in the Cell/Area Zone. One excellent example is PCF.

Polymer Coated Fiber

Polymer Coated Fiber (PCF) cables are used in applications demanding high mechanical performance. These fibers are the best choice for industrial data links and IACS applications, and for utility applications that require high mechanical integrity and reliability at the fiber level. Ideal applications include control panel, robotics, and DLRs because they make exact patch cord lengths to help minimize bends, loops, and slack. The PCF coating also facilitates easy field terminations and makes possible the vision of electrician friendly field fiber terminations. See the *NECA/FOA 301-2009 Standard for Installing and Testing Fiber-optics* for fiber-optic installation safety guidelines.

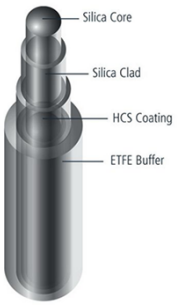
PCF is an optical fiber with a core of pure silica glass (typical diameter of 200 µm), and an optical cladding that is constructed of special plastic (typical diameter of 230 µm). PCF fibers are step or graded index types. The terms *step* and *graded* refer to the radial profile of the dielectric constant of the fiber core. The dielectric constant is uniform as a function of radius with step indexed fibers. A *step* difference exists between the dielectric constants of the core and the cladding. By contrast, for *graded* index fiber, the dielectric constant

of the core is at maximum in the center of the core and reduces away from the center of the core. This profile decreases mode dispersion in the multimode fiber and helps to increase the maximum reach (link distance) supported.

Manufacturers have introduced PCF with a smaller core diameter (to map to OM1 and OM2 type fiber) and a correspondingly larger cladding diameter. Panduit has introduced PCF types that are available in 50 µm and 62.5 µm core diameters. This cable has greater durability than standard fiber cable, is quick to deploy and is easy to terminate in the field. These two characteristics make this cable a preferred fiber solution when mechanical integrity and reliability are a necessity.

Panduit offers PCF cable that has a graded-index (GI) core that is composed of pure silica (50 µm or 62.5 µm), a silica cladding layer (200 µm), a silica hard coating layer (230 µm),\ and a High-Density Polyethylene (HDPE) primary coating (500 µm). An example of the fiber construction and key characteristics is shown in Figure D-13.

Figure D-13 Polymer Coated Fiber Construction and Key Characteristics



Core Diameter	62.5 ±3µm	50 ±3µm
Cladding Diameter	200 ±4µm	200 ±4µm
Coating Diameter	228 ±10µm	230 ±10µm
Buffer Diameter	500 ± 30µm	500 ± 30µm
Core/Coating Offset	<5µm	<5µm
Index Profile	Graded Index	Graded Index
NA (Numerical Aperture)	0.275 ± 0.02	0.20 ± 0.02
Attenuation @ 850 nm	<3.5 dB/km	<2.8 dB/km
Attenuation @ 1300 nm	<1.2 dB/km	<1.0 dB/km
Bandwidth-Length @850nm	>200 MHz*km	>400 MHz*km
Bandwidth-Length @1300nm	>500 MHz*km	>400 MHz*km
Operating Temperature	-65 to +125 deg	-65 to +125 deg
Proof Test Level	>150kpsi	>150kpsi

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Deployments can be made using a combination of cable types that take into account the rigors of the industrial environment. As the run approaches the localized harsh environment, from the IDF or PNZS towards the control panel, armored or dielectric conduited fiber offer options. PCF is a good option to consider in the control panel to machine and on-machine application where field terminations are desirable.

Physical Layer Design for WLAN

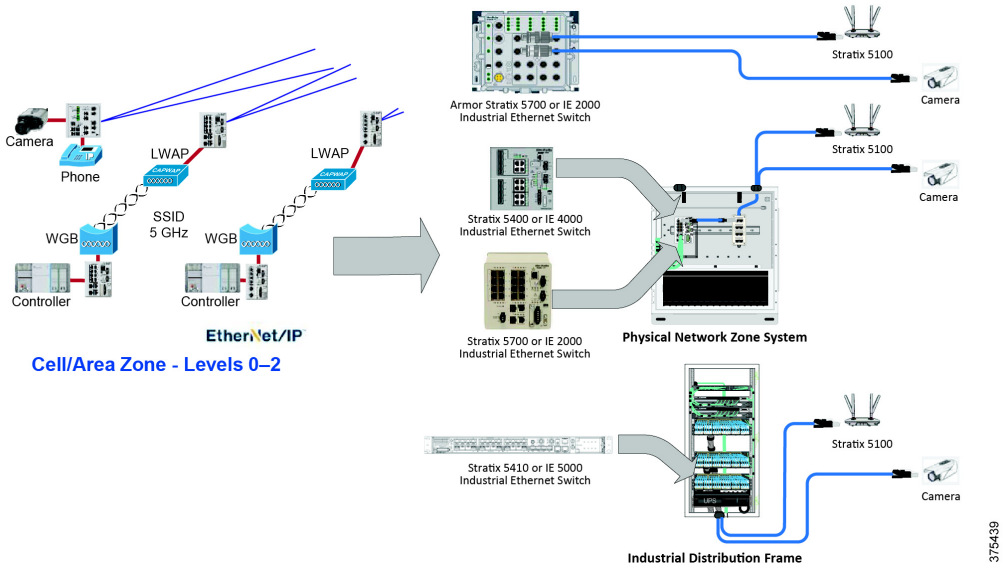
Wireless networks are increasingly being used for critical IACS applications in the Cell/Area Zone. The physical layer provides wired connections to wireless APs that are located in the plant. Wired connections can be made from APs to switch ports that are located in any of the pre-configured building blocks that are used throughout the plant. Wired connections also can be made to either of the WLAN architectures. Typically, wireless APs or WGBs are connected to the PNZS. In some plant deployments, connections for the APs may be direct to the IDF, as is typical in a Level 0-3 deployment, or directly to the IDC. The industrial WLC is commonly located in Level 3 Site Operations.

Note For more information, see the *Deploying 802.11 Wireless LAN Technology within a Converged Plantwide Ethernet Architecture Design and Implementation Guide* at the following URLs:

- http://www.cisco.com/c/en/us/td/docs/solutions/Verticals/CPwE/NovCVD/CPwE_WLAN_CVD.html
- http://literature.rockwellautomation.com/idc/groups/literature/documents/td/enet-td006_-en-p.pdf

Figure D-14 shows a cabling configuration for an AP (or other device such as PoE camera) where power is supplied to the AP via PoE.

Figure D-14 Cabling Configuration for Wireless Access Point and Other Devices



Uplink fiber termination into the control panel is made into a fiber adapter that is mounted in the surface mount box and connected to the switch by means of a fiber patch cord. Fiber patch cords connect both to internal devices and the Fiber DIN Rail Patching Solution. Downlink copper cables are installed, connected inside the Fiber DIN Rail Patching Solution and proceed out of the control panel to the device. Usually, but not always the cable is terminated with a plug, rather than a jack.

Deployment Points

A number of topics relate to the physical layer and deployment of WAPs and are listed as follows:

- **Location of Wireless Access Points**:

  Industrial environments are highly dynamic with RF reflectors and absorbers present in abundance. The location of WAPs is determined using wireless coverage and performance modeling software, which is then validated during the commissioning phase. On occasion thorough initial testing of the WLAN during the commissioning phase revealed that the location of the AP has to be moved slightly to accommodate building layouts, obstacles, and so on that were not taken into account or changed after software modeling. The structured cabling to connect the AP to the IES can be designed to accommodate some installation variability. Use patch cords to connect APs to fixed Equipment Outlets (EO) that in turn connect to the horizontal cable run. This concept is introduced in the TIA Technical Services Bulletin (TSB): T*SB-162-A Telecommunications Cabling Guidelines for Wireless Access Points*.

  The above referenced TSB bases initial design deployment of APs on a square grid model. It emphasizes software performance prediction and then determines any deviation of AP locations from this grid. Frequently, in larger plant wireless deployments, vertical structural beams that support the roof are used to support APs. These beams form an array of support locations for APs. These beams also can provide convenient support locations for the PNZS (containing IES) found in the Cell/Area Zone area.

- **Cabling Used for Wireless Access Points**:

  The original release of IEEE 802.11 standards for WLAN, IEEE 802.11-1997, supported data rates of up to 2 Mbps. From that starting point, IEEE have developed technology that pushes WLAN systems to ever higher data rates. The most recent standard to be released is IEEE 802.11ac. Through progression of 802.11b, 802.11g, 802.11a, 802.11n, backhaul data rates were less than 1 Gbps meaning that Category 5e or 6 cabling could be used. With the advent of IEEE 802.11ac, however, Generation 2 APs (the Second

Wave) have backhaul rates over 1 Gbps. This wireless performance increases makes it necessary to utilize Category 6A cabling for 802.11ac backhaul connections. Category 6A supports data rates of up to 10 Gbps. Category 6A cabling is recommended for new deployments. Some references have been made to the use of two Category 6A cables to be used for each AP, thereby increasing reliability and availability in the event of channel failure. The IEEE task groups are working on lower data rates which can support Wave 2 wireless data rates. Development focuses on 2.5 and 5 Gbps wired data rates and avoiding Category 6A cable runs. If successful, this effort could permit the use of existing Category 5e and 6 cabling. The standards are still in development at the time of writing. Companies considering near term utilization of 802.11ac APs should monitor this development.

PNZS

The PNZS is a network building block of the IACS industrial Ethernet network following a physical zone topology. The PNZS, contrasted against the control panel, has relatively low power versus control panels, though it may still involve single phase utility voltages, such as 120 or 240 Vac. The supplied power is used, by means of a step-down transformer, DC power supply, etc., to power an IES. The PNZS serves as a consolidation point in the CPwE architecture, providing communications to a localized group of control panels in the Cell/Area Zone. An example of a PNZS is shown in Figure D-15.

Figure D-15 PNZS

Control Panel Network Infrastructure Considerations

Today's control panels are more connected into the network than in years past. Control panels involve the proximity of power cabling with low voltage data cabling. Electrical noise that is generated by power cabling can be radiated or conducted to data cables. Power cable interference effects such as transients and cabling imbalance can corrupt data, leading to less reliable operation or even cause shutdown of motion control machinery. Another distinguishing factor is that space within the control panel is at a premium. Therefore, connections between active equipment present severe location and routing difficulties. In some situations, increasing the distance between the two cable types reduces the level of radiation noise picked up by the data cable. However, increasing distance to decrease noise is diametrically opposite to the trend within the control panel industry to reduce the envelope size as much as possible.

Some of the factors and components arrangements adopted into the control panel industry are described in more detail in Appendix (NEED CROSS-REF).

- **Spatial and Noise Optimization**—Considerations for cable segregation, thermal management, cable entry, EMI, cable bend radius and space for future expansion must be addressed when attempting to reduce the size of control panels.
- **Noise Shield and Shielded Duct**—Noise Shield and Shielded Duct can be used to separate noisy motors or drive cables from sensitive Ethernet or control cables. Both products are effective EMI barriers and provide an equivalent of six inches of air space.

- **600 V-Rated Cable and Patch Cords**—Typical enterprise-rated cables are rated up to 300V. For higher voltage applications, 600V-rated cables and patch cords are available.
- **Physical Security Products**—Block-out devices prevent unauthorized access to existing network infrastructure from the data center to the plant floor.

Panduit List of Materials

Table D-2 is a sample bill of material for best-in-class physical layer solutions for the Cell/Area Zone from Panduit.

Table D-2 Sample Bill of Materials

Part Number	Description
PNZS	
Z23N-SGABD5	24"x36" integrated system with 16 downlinks, expandable up to 48, Stratix 5400 and UPS
FSPD508-50	12-Fiber OM2 Dielectric multimode Armored Distribution 50 m
FLCDMCXAQY	LC Opticam® OM3/OM4 fiber-optic connector
Control Panel	
IFC6C04BBL-CEG	Shielded Cat6 stranded cable, PVC jacket, CM
CADIN1IG	DIN rail mount adapter, international gray
ISTPHCH1MBL	600 volt rated, Category 5e patch cord, 1 meter long
ICAM12DRJS	Bulkhead mounted RJ45 to M12 adapter
ISPS688FA	Field attached shielded RJ45 plug
IAEBH6	Bulkhead Jack Cat6 UTP RJ45 with cap
IAPNG5EWH	IndustrialNet™ Data Access Port, Category 5e, White
Machine or Skid	
ISFCH5C02ATL-XG	Industrial Copper Cable, Cat5e, 2-pair, 24/7 AWG stranded, SF/UTP, CM, 600V, Teal, 1000ft/305m reel, High Flex, Sun and Oil Resistant
ISFCH5C04ATL-XG	Industrial Copper Cable, Cat5e, 4-pair, 24/7 AWG stranded, SF/UTP, CM, 600V, Teal, 1000ft/305m reel, High Flex, Sun and Oil Resistant
ISPS55E44MFA	Field attached shielded M12 plug
JP2SBC50-L20	J Hook with screw-on beam clamp for use with flanges up to ½"
WG12BL10	12" wide x 10' long pathway section that is used to carry cables horizontally throughout the system.
IUTPSP10BL	Industrial Patch Cord Cat6 UTP RJ45 with caps, 10 Feet
ISX6004AYL-LED	Industrial Copper Cable, Cat6, 4-pair, 24/7 AWG Stranded, S/FTP, PUR, Yellow, 500 m RL

APPENDIX E

Physical Infrastructure Design for the Industrial Zone

This Appendix provides recommendations and best practices to simplify industrial network physical infrastructure design and deployment for the CPwE Industrial Zone, switching infrastructure, and industrial compute. The CPwE Industrial Zone consists of the Distribution Layer that converges Level 3 Site Operations, with one or more Cell/Area Zones consisting of IACS controllers, and connections to the edge IACS devices. This portion of the network encompasses Levels 0-3 of the CPwE architecture below the Core Switches.

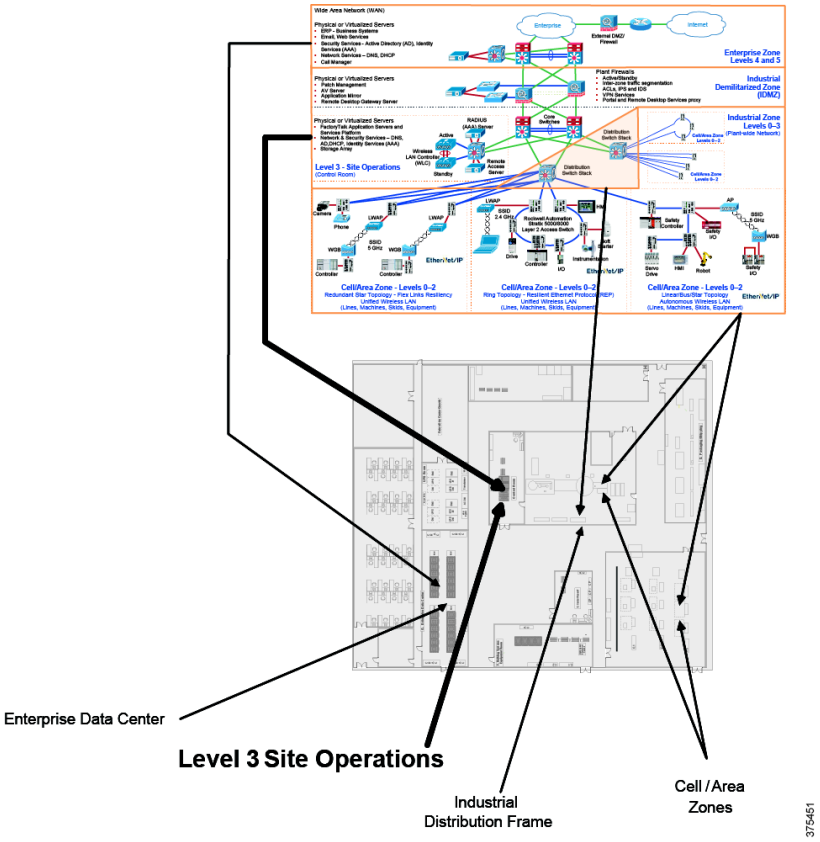
Level 3 Site Operations is discussed in Appendix F: "Physical Infrastructure Deployment for Level 3 Site Operations" Levels 0-2 or the Cell/Area Zone is addressed in Appendix E: "Physical Infrastructure Design for the Industrial Zone". This Appendix primarily focuses on the plant backbone network distribution and network cabling that ties all the levels together. Five main elements are essential to consider for deployment:

In addition, this Appendix provides:

Logical to Physical Mapping

The Industrial Zone forms the connectivity between Level 3 Site Operations, the Cell/Area Zones (Levels 0-2), and the space in between (see Figure E-1). This zone covers all plant-wide networking below the IDMZ to the IACS edge devices.

Figure E-1 Mapping CPwE Logical to Physical



Industrial Plant Network Backbone and Distribution Switching Overview

In the CPwE architecture, Levels 0-3 are tied together with an Industrial Zone network backbone and distribution switches. The physical network routes critical traffic to coordinate IACS controllers, collect production data and connect to the IDMZ. With the high growth of EtherNet/IP devices for IACS, video, security, and so on, the importance of a structured, hardened physical layer has increased. Longevity and scalability are achieved using proven, validated designs for enclosures, media, connectivity, grounding, pathways and identification. Although machines/lines/skids may produce independently, IACS-critical functions are often tied together at the network distribution layer. Poor design and implementation of the distribution layer can impede decision making and affect the IACS application. These operational functions include inventory transactions, material issues, regulatory data and machine control.

Network distribution switches in the Industrial Zone can be rack mount or DIN mount. Though environmentally-hardened switches are available, most switches that are used for this function are protected by an industrial enclosure. Selecting industrial Ethernet switches as part of a pre-configured or integrated solution that includes the proper enclosure and accompanying cabling infrastructure achieves rapid, low-cost deployment. These pre-configured or integrated solutions are known as physical network building block systems. One type of physical network building block system is an IDF, which is a 19-inch rack-style system. Another type is a PNZS with a DIN mount switch that can either be an Allen-Bradley Stratix 5400 or Cisco IE-4000 IESs.

The cabling for distribution switch uplink and downlink ports is typically fiber to allow for longer reach required from the Level 3 Site Operations and to IES in PNZS or control panels. The topology depends on availability requirements. Special considerations exist for hardening and bandwidth that are specific to harsh environments (for example, cable jacket design, stranded vs. solid conductor, connector protection, enclosure liquid ingress, and EMI).

Key Requirements and Considerations

Key requirements cover the physical deployment of the Industrial Zone backbone and distribution switching. This section includes requirements for housing network gear, cabling, pathways, cable management, and security. In addition to the common key requirements and considerations that are addressed in Appendix D: "Physical Infrastructure Design for the Cell/Area Zone", the network distribution layer has these unique requirements and challenges:

- **Reach**—Cable reach is challenging for the distribution network, especially for large plants.
- **Industrial Characteristics**—Environmental impacts, as assessed by M.I.C.E. (see Appendix D: "Physical Infrastructure Design for the Cell/Area Zone") are varied because the distribution layer has network connectivity to different types of environments.
- **Physical Network Infrastructure Life Span**—The physical infrastructure for the distribution layer has a longer life span compared to other parts of the industrial network, as long as 20 years. Therefore, cabling, connectivity, and enclosures must survive the expected life span.
- **Maintainability**—MACs in the distribution layer have dependencies, and a change affects many Cell/Area Zones. Changes must be planned and executed correctly because an error can disrupt or halt IACS applications. Therefore, proper cable management, such as bundling, identification, access, etc., is vital to the network distribution layer.
- **Scalability**—Major changes lower in the architecture have significant impact on the distribution layer because the distribution layer aggregates and routes traffic. Designs must account for traffic growth and additional cabling for equipment.
- **Designing for High Availability**—A key aspect of high availability is redundancy. Redundancy can be implemented in many ways, with varying degrees of protection. Different strategies at the distribution layer exist to handle redundancy. Another key element is continuous switch power to support network communication after a power outage or short power bump.
- **Network Compatibility and Performance**—Network compatibility and optimal performance are essential from port to port. This includes port data rates and cabling bandwidth. Network performance is governed by the poorest performing element. As distribution switches are upgraded, the cabling should meet increased performance requirements.
- **Grounding and Bonding**—The distribution layer travels long distances (that is, between buildings). Therefore, there may be ground voltage differences between locations. A single, verifiable grounding network is essential to avoid ground loops that can degrade data.
- **Security**—A security threat at the distribution layer can cause a widespread outage, leading to high downtime costs. The distribution network requires security hardening to prevent unauthorized access to ports and gear.
- **Reliability Considerations**—Cabling, connectivity, and enclosure selection are essential for reliability. Network reliability must be considered for the life cycle, starting with the installation/commissioning phase through the operational phase to help prevent or minimize failures.

- **Ease of Deployment/Cost**—A building block system approach can facilitate ease of deployment and lower cost. Ease of deployment and cost are impacted by part selection and topology. In addition, part selection can impact required skill level and expertise, affecting ease of deployment for parts such as the RJ45 jack, LC fiber connector or M12 connector.
- **PoE and Wireless**—Specialized functions such PoE and wireless have additional requirements that impact the physical layer.

Industrial Network Building Block Systems

Industrial network building block systems, such as the IDF and PNZS, are purpose-built for various CPwE needs. The building block system approach speeds deployment and reduces deployment risk because the building block system design is pre-engineered and validated for thermal, cable management, identification, and grounding. For the IACS plant backbone, which is part of the Industrial Zone, specific physical network building block systems include the PNZS and the IDF. These building block systems are described below. For more information about building block systems, see Appendix D: "Physical Infrastructure Design for the Cell/Area Zone".

Industrial Distribution Frame

A cabinet with a Rack Unit (RU) frame is preferred when network designs include rack-mount gear. Deployment of Enterprise-grade computer or network cabinets leads to premature network switch failure because cabinets are typically open to the environment, accumulating dusts, liquids, and other contaminants over time. The predominant enclosure choice is a double-hinged 26 RU design (see Figure E-2) and is commonly referred to as an IDF. An IDF is designed for 19-inch RU style switches and other gear, such as a UPS, and is typically wall or column mounted. An IDF may come pre-configured with cabling, duct, cable ties, and so on, leading to consistent equipment deployment, minimizing engineering effort and reducing installation time. The advantage of a pre-configured IDF is best-in-class cable management, thermal performance, and proven installation.

Often, an IDF has both access and distribution switching. Combining access and distribution switches consolidates sensitive network equipment in a protective and cooled enclosure in a cost-effective manner, controlling security access and simplifying mounting. An IDF contains many switches but is usually sized for two Cisco distribution switches (for example, 3850 fiber-based) and up to three Cisco access switches (for example, 2960-X copper-based) along with a UPS.

This section addresses the distribution switch considerations of an IDF. The details for an IDF with access switching are covered in Appendix E: "Physical Infrastructure Design for the Industrial Zone".

Figure E-2 Pre-configured Industrial Distribution Frame

An IDF may contain multiple distribution switches to aggregate IES from PNZSs or control panels. Distribution switches in an IDF facilitate VLANs and optimize traffic routing. The distribution switch connects to Level 3 Site Operations, a master distribution frame (MDF), or a core switch in an IDC. The distribution switch uplink cabling is a fiber-optic cable to handle the longer distances from the Industrial Zone to the IDMZ. By-products of this media choice are faster switch convergence after a network drop-out and higher bandwidth. In addition, the downlinks from the IDF to the PNZSs or control panel are best served with fiber, primarily for faster IES convergence in the event of a network drop-out to help to minimize production downtime and help to protect against EMI.

The following are specific key requirements and considerations for an IDF:

- **Reach**—An IDF can significantly increase cable reach, especially when deploying fiber uplinks and downlinks.
- **Industrial Characteristics**—A properly designed IDF mitigates M.I.C.E. hazards because IDF enclosures are IP67-rated with cooling capabilities. IDFs are isolated from Industrial Zone hazards, such as vehicle traffic, and are frequently located on outside walls, at a safe elevation on building columns, in mezzanines or a telecommunication room, and so on. IDF horizontal cabling, on the other hand, traverses harsh areas to reach its destination. The cabling must survive the harshest regions while maintaining end-to-end continuity. Cabling routed in underground troughs or tunnels must be hardened to withstand severe conditions and rodent damage. In these applications, close attention must be paid to cabling outer jacket, and an armor exterior such as aluminum clad or dielectric conduited should be considered. Since fiber-optic cable is inherently noise immune, fiber deployments remove EMI impacts.
- **Physical Network Infrastructure Life Span**—Network switches have an upgrade interval of three to five years. Cabling infrastructure should meet higher performance capabilities for future active equipment upgrades without the necessity of re-cabling the network.
- **Maintainability**—Cable management can be a challenge for an IDF. These enclosures host high port count switches and therefore must accommodate sizable cable bundles. Pre-configured solutions address these challenges by providing patching and routing to easily handle the mass of cable. Strain relief and bundling should be applied to horizontal cables routed to the IDF due to the tight quarters and bundle articulation when the cabinet is opened. Cable slack must be kept to a minimum because excessive slack cable leads to entanglement and snags, especially when opening an IDF. Installers sometimes use the enclosure to store slack cable. This practice can impede proper airflow and heat dissipation and makes the enclosure door difficult to close. Fiber-optic cables should be routed through corrugated loom tube for protection. The exception to this rule is dielectric conduited media, for which corrugated loom

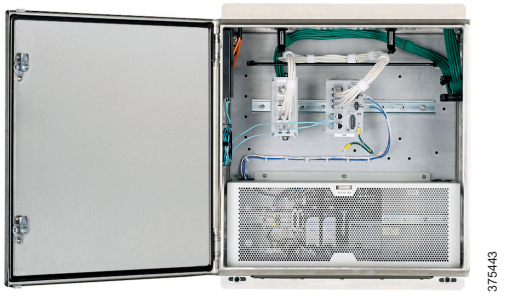
protection is unnecessary. Labeling and color coding cables facilitate MACs. Exact and shortest length patch cords can minimize cable sprawl. Small-diameter Ethernet patch cords, available in Category 5e and Category 6, reduce space occupied by cabling.

- **Scalability**—An IDF is the highest-density network distribution system. Growth is usually a feature for a proper IDF design. Network ports should be scaled to serve nodes today and for the next 10 years. For cable management and cable access with some growth, the enclosure should be sized to have at least three free RUs for every RU occupied by network switches.
- **Designing for High Availability**—Redundant switch uplinks must be present along with redundant star or ring topology downlinks to the IES.
- **Network Compatibility and Performance**—As distribution switches are upgraded, the cabling infrastructure must deliver compatible performance without re-cabling.
- **Grounding and Bonding**—All active network gear must be grounded to prevent worker injury and equipment damage. Further, laboratory tests have shown demonstrably better bit error rates when grounding and bonding practices are optimal. Typically, a network switch has a screw hole and pad for bonding. The best practice is to attach a grounding jumper to the switch grounding screw hole/pad with the opposite end connected to the enclosure grounding bar. When selecting grounding jumpers, it is important to consider that a low impedance path to ground delivers the best performance in managing EMI threats. In most cases, a braided grounding strap rather than a wire is the prudent choice. The grounding bar must be tied to the building grounding network. See Appendix D: "Physical Infrastructure Design for the Cell/Area Zone" for more details.
- **Security**—Part of a defense-in-depth strategy, the physical security surrounding an IDF requires a number of layers of protection. The most effective physical layer measures include enclosure locks to prevent unauthorized access, keyed patch cords to avoid inadvertent patches, and port lock-in/block-out devices to prevent incorrect connections to unused ports.
- **Reliability Considerations**—Deploying a structured cabling approach enhances reliable communication. In a structured cabling environment, the horizontal (permanent link) cable is not touched, bundles are segregated and secured to ease handling, cable managers such as D-rings are selected to route cables with better access, power cables are secured at both device and power outlet ends to prevent power loss, and cabling and connectivity are selected to withstand the manufacturing environment.
- **Ease of Deployment/Cost**—Design, procurement, installation, and maintenance are some of the costs to consider. When compared to designing and building enclosures for network assets, a building block system approach leads to lower total costs with faster, proven installation.

PNZS with Distribution/Aggregation Switch

Smaller-footprint applications, where the need is to aggregate a few IES on the plant floor, can employ a DIN mount distribution/aggregation switch, such as a Stratix 5400 or Cisco IE-4000, to connect to the plant backbone. This can be a suitable choice for a modular line or Cell/Area Zone that potentially can be moved in whole (that is, networking is self-contained). These switches are more hardened against a hotter, harsher environment than the rack-mount Enterprise grade switches. DIN-mount IES should be protected using an appropriately specified PNZS. A DIN distribution switch can be deployed in a PNZS in the same manner as a DIN-mounted IES (see Figure E-3). In most cases, external cooling may not be required, reducing cost and minimizing A/C maintenance when compared to an Enterprise switch deployment. Cabling and connectors are the same as those used with Enterprise switches. Cable management and connectivity include DIN mount patch panel, DIN adapter for RJ45 jacks, and slack and strain relief features mounted to backplane or DIN. In addition, a barrier may be included to separate higher voltages from the DC power to the switches. See Appendix E: "Physical Infrastructure Design for the Industrial Zone" for more information.

Figure E-3 Zone Enclosure with a DIN Mount Distribution/Aggregation Switch



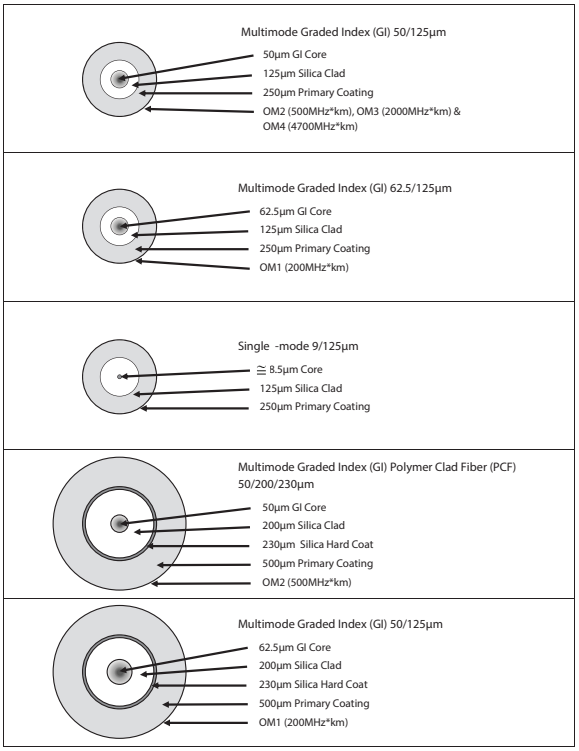
Optical Fiber Overview

An optical fiber link consists of a transceiver, connector/adapter, and cable. The transceiver converts electrical data packets into light pulses that are transmitted through a glass fiber, which are converted to electrical signals by the receiving transceiver. A fiber connection usually has two fiber cables, one to transmit and the other to receive (that is, duplex). For IACS applications, optical fiber has many advantages over copper channels, such as immunity to electrical noise, faster switch convergence after an interrupt, long reach, and higher bandwidth potential (with state-of-the-art fiber). The various considerations for selecting fiber are described below.

Physical Media

Fiber-optic cable is constructed of a core, cladding, coating, and jacket (see Figure E-4). The geometry of each of these components determines the index grade, or Optical Multimode. The two basic types of optical fiber are single-mode (referred to as OS) and graded index multimode (referred to as OM). Single-mode optical fiber supports data communications over long distances (for example, kilometers) and requires the use of higher-cost laser transceivers. On the other hand, graded index multimode fiber supports data communications up to 550 m but makes use of lower-cost transceivers, helping to lead to a lower-cost fiber deployment.

Figure E-4 Cross-Section of Fiber Construction Types



Although several transceiver types are available, most IES use a transceiver referred to as SFP. Most commonly, the connectivity is a duplex LC connector.

The term "graded index" refers to the dielectric constant of the silica material used in the core. "Graded" means that the dielectric constant is profiled as a function of radial distance from the center of the core to reduce slightly before the cladding material is reached. This parameter decreases the dispersion (a measure of the delay in time of arrival) between different modes within the fiber and helps to increase the maximum distance the fiber can support at a specified data rate.

Within multimode, two basic families of core size exist: 62.5 µm and 50 µm. They are defined as Optical Multimode (OM) and are described by four levels: OM1 through OM4. OM1 has a 62.5 µm core and is considered legacy cable. OM2, OM3, and OM4 have a 50 µm core and are deployed more typically. Single-mode (OS) cable used in these applications typically has a core diameter of around 8.5 µm and a cladding diameter of 125µm. The designations for each are as follows:

- **OM1**—62.5/125µm graded index multimode (200 MHz.km)
- **OM2**—50/125µm graded index multimode (500 MHz.km)
- **OM3**—50/125µm graded index multimode (2,000 MHz.km)
- **OM4**—50/125µm graded index multimode (4,700 MHz.km)
- **OS1**—9/125µm single-mode

The values in parentheses are referred to as the effective modal bandwidth (EMB) of the fiber. The EMB represents the capacity of the fiber to transmit a certain amount of information over a specific distance and is expressed in MHz per km.

Optical Fiber Cable Outer Covering

This section discusses basic optical fiber outer covering types and performance. Figure E-5 is a M.I.C.E. chart categorizing each cable type by increasing environmental severity. The fiber type listed in the first column, Distribution, has limited protection and bend radius control but is the most cost-effective. The fiber type in the second column, Indoor/Outdoor (Dielectric), has better protection against chemical/climatic effects. The fiber type in the third column, Indoor Armored, has an aluminum clad to protect against crush along with chemical/climatic hazards. The fiber type in the fourth column, Gel-Free Outside Plant (that is, OSP) Armored, has robust protection for all M.I.C.E. levels. Figure E-5 also indicates the type and designation of the compatible SFP module.

Figure E-5 Recommended Fiber-optic Cable Types with Common SFP Modules for Plant-wide Network Applications

Increasing Severity

SFP Module	Rockwell Automation SFP Part Number	Core Diameter	Maximum Distance per Standards	Fiber Type per MICE Level			
				$M_1I_1C_1E_3$	$M_1I_1C_2E_3$	$M_2I_2C_2E_3$	$M_2I_2C_2E_3$
				Distribution 	Indoor/Outdoor (Dielectric) 	Indoor Armored 	Gel -Free Outside Plant Armored 
100BASE-FX	1783-SFP100FX	62.5µm	2km	FSDR6^^Y	FSN6R^^Y	FSPR6^^Y	FSWN6^^
		50µm	2km	FSDR5^^Y	FSNR5^^Y	FSPR5^^Y	FSWN5^^
100BASE-LX	1783-SFP100LX	9µm	10km	FSDR9^^Y	FSNR9^^Y	FSPR9^^Y	FSWN9^^
1000BASE-SX	1783-SFP1GSX	62.5µm	275m	FSDR6^^Y	FSNR6^^Y	FSPR6^^Y	FSWN6^^
		50µm	550m	FSDR5^^Y	FSNR5^^Y	FSPR5^^Y	FSWN5^^
		10 Gig 50µm	550km	FODRX^^Y	FONRX^^Y	FOPRX^^Y	FOWNX^^
1000BASE-LX/LH	1783-SFP1GLX	9µm	10km	FSDR9^^Y	FSNR9^^Y	FSPR9^^Y	FSWN9^^
1000BASE-LX/LH	GLC-ZX-SM-RGD	9µm	40km	FSDR9^^Y	FSNR9^^Y	FSPR9^^Y	FSWN9^^

Panduit part numbers listed above for bulk cable
^^ - fiber count.
See http://www.panduit.com/ or additional part numbers not listed here and more information

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Fiber Connectors and Adapters

Connectors are the physical interface between the cabling media and devices. A number of connector types are used in fiber-optic physical infrastructure. This section discusses three of those connector types:

- **Lucent (LC) Connectors**—Used in data center environments and some IACS devices. They have a small footprint that allows them to be used on high port density IES and on devices, minimizing real estate. The LC connector interface presents a SFF demountable interface for connection to SFP transceivers. The standard construction of the LC connector consists of a spring-loaded, 1.25 mm diameter zirconia ceramic ferrule housed in a thermoplastic connector back shell. The dimensions for this connector are defined in both domestic (TIA-604 FOCIS-10) and international (IEC 61754-20) standards. The LC connector footprint is approximately half the size of an SC connector and has a back shell to accommodate standard 1.6 mm to 3.0 mm diameter cable designs.
- **Subscriber (SC) Connectors**—Snap-in connectors that are widely used in single-mode systems for their performance. These connectors are used in the data communication and telecommunication industries. SC connectors are losing ground to LC and other connector types due to their larger size, which is not suitable for high-density applications.

- **Straight Tip (ST) Connectors**—Bayonet-style connectors that create secure multimode connections. ST connectors are used for inline connections; however, some equipment uses this type of connector because of the stability in the connection. ST connectors were once one of the most popular types of connectors.

Of these three connector types, the LC connector is becoming the most used type due to its high performance and small size, allowing the highest connection densities to be obtained with the smallest footprint. The characteristics of the three connector types are summarized in Table E-1.

Table E-1 Fiber-optic Connector Comparison Summary

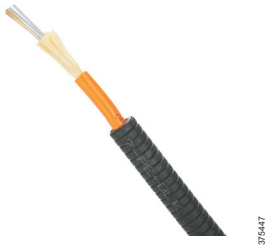
	LC	SC	ST
Connector Name *	Lucent or Little	Square or Subscriber	Straight Tip
Coupling Type	Snap	Snap (Push - Pull)	Bayonet
Connector Outside Dimensions, mm	4.5 x 4.5	9.0 x 8.3	Diameter 8.6
Ferrule Size, mm	1.25	2.5	2.5
TIA Standard	TIA-604 / FOCIS - 10	TIA-604 / FOCIS - 3	TIA-604 / FOCIS -2
IEC Standard	IEC 61754-20	IEC 61754-4	IEC 61754-2
Duplex Type	Yes, with clip	Yes. Connector can mate	No

*- Connector names vary

Dielectric Conduited Fiber Armored Cable for Plant Backbone

Dielectric Conduited Fiber (DCF) cable (see Figure E-5) may be the best option for plant backbone fiber. Its high crush resistance (six times greater than that of non-armored cable), self-supporting property (that is, can be hung from low-cost J-Hooks) and light weight for easy handling make it the best choice for this application. DCF cable is constructed of a rugged plastic conduit that is extruded over a standard tight buffered fiber distribution cable. The fiber specifications of DCF are the same as non-armored fiber OM1, OM2, and OS1/OS2 fiber cabling. The armored plastic dielectric properties remove the grounding and bonding requirements that govern standard armored metal-clad cable. For more information on DCF, see Appendix E: "Physical Infrastructure Design for the Industrial Zone".

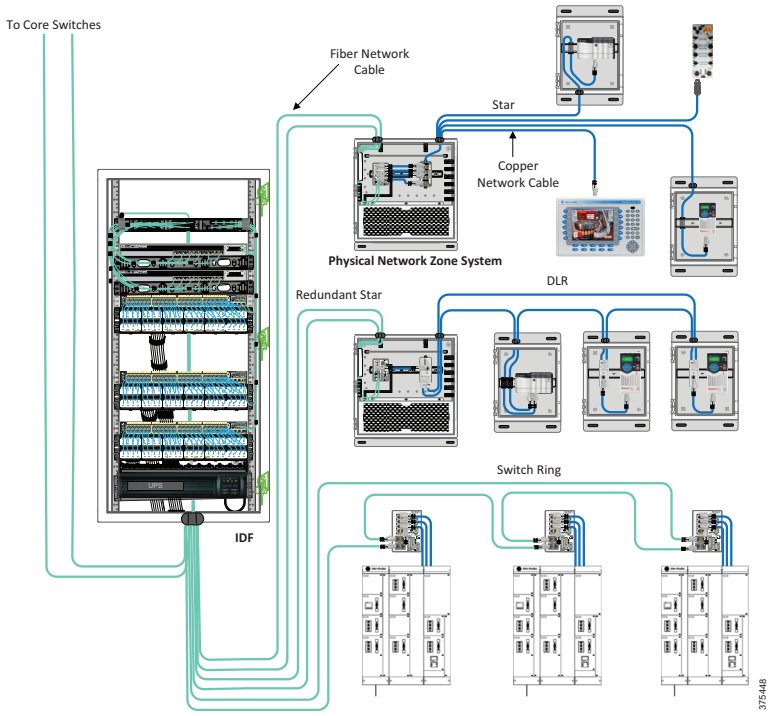
Figure E-6 Dielectric Conduited Fiber Cable (DCF)



Physical Network Design Considerations

Figure E-7 illustrates a simplified Industrial Zone physical deployment between Levels 0-3. Depending on the plant size, the Level 3 Site Operations could connect to the Cell/Area Zone(s) through Core Switches. The links between the core switches in the Level 3 Site Operations and the distribution switch in the IDF use fiber-optic cabling. The distribution layer also connects to control panels that have IES with fiber network cabling.

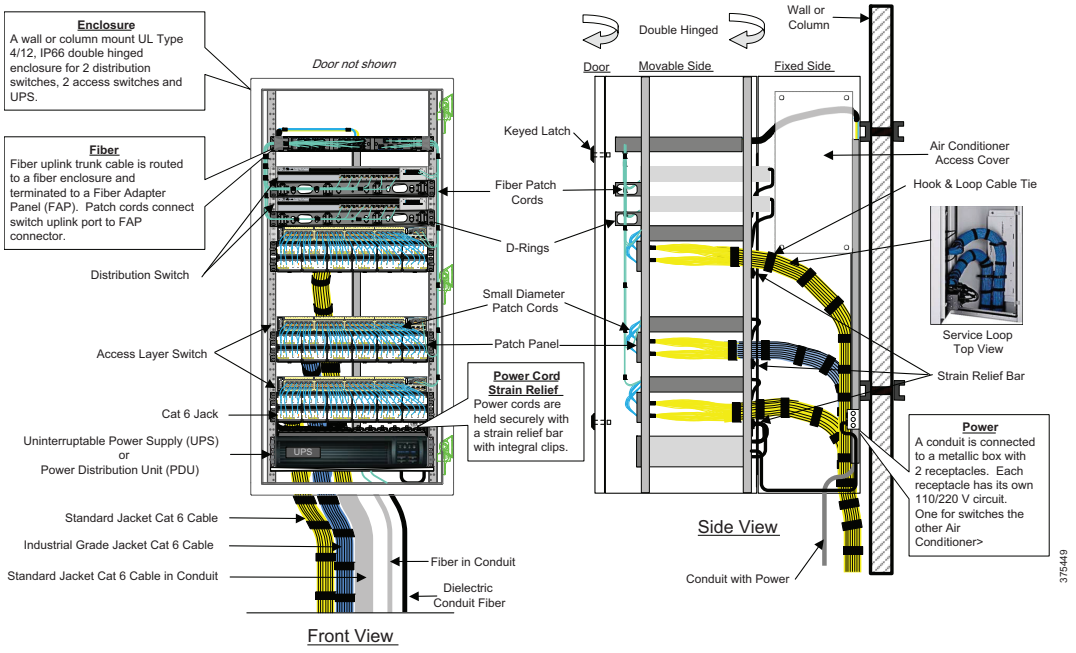
Figure E-7 Physical Industrial Network Backbone



IDF Physical Deployment Details

Figure E-8 illustrates IDF physical connectivity, detailing the enclosure cabling, jacks, patch cords, cable management, power, network switches, and cable ties. In general, an IDF is assembled in a similar manner as other RU cabinets and racks. The biggest challenge is to compensate for back articulation, thermal management, tight quarters, and cable sprawl from MACs. Following the best practices described below facilitates maintenance and long life.

Figure E-8 Typical IDF Deployment



Horizontal Cable Service Loop

The horizontal cabling is extended when opening a double-hinged IDF; therefore, a cable service loop is necessary for both fiber and copper. Planned and managed cable slack is required to fully open the enclosure. Although allowing service slack is important, too much extra cabling consumes excess space and can act as a spring when closing the enclosure. Also, the cable length increases from the first to the last copper port across the patch panel. The IDF stationary section uses hook & loop ties in the back to secure cabling. The copper cabling is also secured with hook & loop ties to strain relief bars on the movable side to minimize tugging on the jack when opening the enclosure. Fiber horizontal cable is channeled through duct and loom tube and then into a fiber enclosure for protection.

Thermal Management

The IDF can operate with an ambient temperature of up to 25º C (77º F) without air conditioning. Adding an air conditioner allows the IDF to operate up to 50º C (122º F) ambient air temperature. All cable should be neatly bundled and secured to prevent cabling from impeding airflow.

Connectivity and Patching

The IDF may have both copper and fiber cabling. Typically, all cable enters from the bottom of an IDF to prevent liquid ingress. The holes in the enclosure for the cabling should have a fitting or grommet to prevent chaffing.

For fiber-optic cable, the best practice is to terminate the horizontal fiber cable into a fiber enclosure. The fiber enclosure is similar to an Enterprise enclosure, containing slack spools and strain relief to secure fiber strands, along with Fiber Adapter Panels (FAP). Patching is performed with fiber patch cords from the enclosure FAP to the switch uplink ports.

Copper downlinks from the switch are connected to a patch panel via a patch cord. The best practice is to have switches adjacent to patch panels. This helps to minimize cable sprawl, makes ports more visible, and helps to minimize entanglement. A short (8-inch) small-diameter patch cord (28 AWG) is recommended for easier handling and less space consumption.

Panduit List of Materials

Table E-2 is a sample list of materials for best in class physical layer solutions for the Industrial Zone.

Table E-2 Sample List of Materials

Part Number	Description
Z23N-SGABD5	24"x36" integrated system with 16 downlinks, expandable up to 48, Allen-Bradley Stratix 5400 and Cisco IE 4000 IES and UPS
FSPD508-50	12-Fiber OM2 Dielectric multimode Armored Distribution 50m
FLCDMCXAQY	LC Opticam OM3/OM4 fiber-optic connector
Control Panel	
IFC6C04BBL-CEG	Shielded Cat 6 stranded cable, PVC jacket, CM
CADIN1IG	DIN rail mount adapter, international gray
ISTPHCH1MBL	600 volt rated, Cat 5e patch cord, 1 meter long
ICAM12DRJS	Bulkhead mounted RJ45 to M12 adaptor
ISPS688FA	Field attached shielded RJ45 plug
IAEBH6	Bulkhead Jack Cat 6 UTP RJ45 with cap
IAPNG5EWH	IndustrialNet Data Access Port, Cat 5e, White
Machine & Robot	
ISFCH5C02ATL-XG	Industrial Copper Cable, Cat5e, 2-pair, 24/7 AWG stranded, SF/UTP, CM, 600V, Teal, 1000ft/305m reel, High Flex, Sun and Oil Resistant
ISFCH5C04ATL-XG	Industrial Copper Cable, Cat5e, 4-pair, 24/7 AWG stranded, SF/UTP, CM, 600V, Teal, 1000ft/305m reel, High Flex, Sun and Oil Resistant
ISPS55E44MFA	Field attached shielded M12 plug
JP2SBC50-L20	J-Hook with screw-on beam clamp for use with flanges up to ½"
WG12BL10	12" wide x 10' long pathway section used to carry cables horizontally throughout the system.
IUTPSP10BL	Industrial Patch Cord Cat 6 UTP RJ45 with caps, 10 feet
ISX6004AYL-LED	Industrial Copper Cable, Cat6, 4-pair, 24/7 AWG Stranded, S/FTP, PUR, Yellow, 500m RL

APPENDIX F

Physical Infrastructure Deployment for Level 3 Site Operations

The Level 3 Site Operations Area provides the switching, compute, and storage resources needed to efficiently operate a plant-wide IACS architecture. This area is the foundation for data collection and application hosting in the industrial setting. Level 3 equipment may be physically housed in an industrial data center, in a rack in the control room, or several other locations on the premise. Level 3 Site Operations applications range from MES measures such as Overall Equipment Effectiveness (OEE), lot traceability preventive maintenance schedules, process monitoring/management, safety/security dashboards, and productivity key performance indicators (KPIs). Continuity of service is imperative as these functions are used for daily decision-making on an ever-increasing basis. Manufacturing downtime is readily measured in minutes and in thousands of dollars from missed customer commitments. Reliable and secure network support for these applications keeps operations running and business communication running smoothly.

The successful deployment of Level 3 Site Operations depends on a robust network infrastructure built on a rock solid physical layer that addresses the environmental, performance, and security challenges present when deploying IT assets (servers, storage arrays, and switching) in industrial settings. The Level 3 Site Operations is a key convergence point for IT and OT. Many businesses obtain these functions in a pre-engineered package, Industrial Data Center (IDC). IDC systems include the proper IT assets housed in an appropriate cabinet with patching, power, grounding/bonding, identification and physical security considerations already addressed a plug and play solution.

The Level 3 Site Operations Area presented in this Appendix is a model for integrating a scalable, modular, logical network and compute systems into the physical infrastructure. Some benefits of this approach are listed below:

- Improves network availability, agility, scalability and security
- Reduces operational costs, including energy costs, with improved efficiencies
- Can help to simplify resource provisioning
- Lays the foundation for consolidation and virtualization
- Helps to create a path to future technology requirements such as 10/40GbE

This Appendix includes the following major topics:

Key Requirements and Considerations

Industrial network deployments have evolved over the years from a network gateway layout to a converged plant-wide architecture. CPwE architecture provides standard network services to the applications, devices, and equipment found in modern IACS applications and integrates them into the wider enterprise network. The CPwE architecture provides design and implementation guidance to achieve the real-time communication and deterministic requirements of the IACS as well as to help provide the scalability, reliability and resiliency required by those systems.

In support of industrial network performance, many physical infrastructure aspects of the Level 3 Site Operations serve an important role, and must be considered in the design and implementation of the network:

- **Industrial Characteristics**—Plant networking assets and cabling used in Level 3 Site Operations are not environmentally hardened but are almost exclusively installed in IP20 or better environments. Environmental risks at Level 3 Site Operations involve thermal management of heat dissipated by equipment and power quality considerations.
- **Physical Network Infrastructure Life Span**—IACS and plant backbone can be in service as long as 20 year or more. Hardware used in Level 3 Site Operations being IT gear has a much shorter life span, generally three to five years. The infrastructure used to connect and house the hardware such as cabinets, cabling, connectivity, and enclosures has a much longer life span, generally 10-15 years. Consideration of higher performance cabling enables current and future data communications needs to be fully met. Choices between copper and fiber-optic cabling assure higher data rate transport requirements.
- **Maintainability**—Note that MACs at Level 3 have dependencies that affect many Cell/Area Zones. Also, changes need to be planned and executed correctly to avoid bringing down the IACS process. Proper cable management such as bundling, identification and access is vital for proper Level 3 Site Operations maintenance.
- **Scalability**—The high growth of EtherNet/IP and IP connections can strain network performance and cause network sprawl that threatens uptime and security. A strong physical building block design accounts for traffic growth and management of additional cabling to support designed network growth. Use a physical zone topology together with structured copper and fiber-optic cabling chosen for high data throughput. Choose building block pre-configured solutions to enable a network infrastructure comprised of modular components that scale to meet increasing industrial Ethernet communications needs in the IACS network.
- **Designing for High Availability**—A robust, reliable physical infrastructure achieves service levels required of present and future IACS networks. The use of standards-based cabling together with measured, validated performance confirms reliable data throughput. Use of redundant logical and physical networks assures highest availability. Properly designed and deployed pathways should be employed to insure redundant cable paths are also resilient.
- **Network Compatibility and Performance**—Cable selection is the key to optimal physical network performance. Network performance is governed by the poorest performing element in any link. Network compatibility and optimal performance is essential from port to port, including port data rate and cabling bandwidth.
- **Grounding and Bonding**—A well architected grounding/bonding system is crucial for of industrial network performance at every level whether internal to control panels, across plants, or between buildings. A single, verifiable grounding network avoids ground loops that can degrade data and have equipment uptime and safety implications.
- **Security**—Network security is a critical element of network uptime and availability. Physical layer security measures, such as logical security measures, should follow a defense-in-depth hierarchy. The Level 3 Site Operations physical defense in-depth strategy could take the form of locked access to industrial data center/control room spaces and cabinet key card access to help limit access, use of LIBO

devices to control port usage and keyed patch cords to avoid inadvertent cross patching. Using a physical strategy in concert with your logical strategy prevents inadvertent or malicious damage to equipment and connectivity achieving service level goals.

- **Wireless**—Unified operation of wireless APs requires a WLC at Level 3 Site Operations and distribution of Lightweight Wireless Access Points (LWAPs) across Industrial Zone and Cell/Area Zones. Autonomous wireless APs, typically WGBs, in Cell/Area Zones involve cabling for APs and WGBs. The Industrial Zone backbone media selection and cabling for APs using PoE are critical for future readiness and bandwidth considerations. PoE is evolving to deliver more power over copper cabling, therefore understanding industrial applications with scalability and environmental considerations is critical.

Industrial Characteristics

Room Environment

A sustainable cooling system design that follows industry best practices is essential to the success of modern Level 3 Site Operations deployments. Optimized cooling management and a more efficient energy system are the results, which means IT equipment is safe from unplanned downtime due to overheating and significant operational expense (OpEx) savings are realized.

The Level 3 Site Operations room is divided into a hot aisle/cold aisle arrangement, to separate the cold inlet air on the front side of the cabinets and the hot exhaust air on the rear side of the cabinets. Cold air in this design is fed through the raised floor via a Computer Room Air Conditioning (CRAC) unit. Cold air can be delivered by several different means, as long as it maintains the hot aisle/cold aisle arrangement. Hot air in this design is exhausted through fans in the ceiling.

Thermal Ducting

Network switches deployed in data centers (for example, Catalyst® 4500-X/6800) often utilize side-to-side airflow cooling. This airflow design requires less vertical space and permits high switch port density. Given proper inlet air conditions, these switches are well designed to cool themselves. However, large bundles of cabling driven by high port density impede airflow. Also, hot exhaust air can recirculate to the intake, raising inlet temperatures and inhibiting the switches' self-cooling ability. For network equipment that utilizes side-to-side airflow patterns, in-cabinet ducting optimizes cooling system efficiency by establishing front-to-back airflow patterns throughout the cabinet. Through the use of Computational Fluid Dynamics (CFD) analysis and testing, ducting solutions have been developed that improve inlet air conditions for cabinet applications.

Physical Network Infrastructure Life Span

IACS and plant backbone technologies can have a lifespan of up to 20 years. IT hardware has a much shorter life span, generally in the 3-5 year range. While a three year refresh cycle is commonplace for IT personnel in enterprise and data center domains, it is not routine in current OT domains. Level 3 physical infrastructure that supports IT hardware should have a much longer lifespan, usually three to four IT hardware refresh cycles. As a result, it is important to consider the structural dependability of cabinets, future proof types of cabling, and pathways optimized for capacity growth projections. It is also important to adhere to structured cabling practices and install upgraded and spare media to protect against physical layer obsolescence. Making informed physical infrastructure decisions from the beginning affect the ability to complete future projects in a timely and cost effective manner.

Maintainability

Patching

The best practice for patching is to land fiber cable into an enclosure or box following a structured cabling approach. When fiber is terminated, several inches of the glass strand are exposed. This part of the fiber is very fragile and needs the enclosure or box to protect the fiber from damage. Terminating directly to a connector without protection or support can lead to failures. For rack/cabinet installations, a 19" style fiber enclosure is a suitable choice. When installing fiber into a control panel, components such as the DIN Patch Panel or Surface Mount Box provide patching. Another advantage for structured cabling is to build in spares ready for use to accommodate growth or for recovery from link failure.

Bundling

The best practice for bundling numerous standard jacket fiber cables is to use a hook and loop cable tie. This cable tie does not over-tighten the bundle, which can lead to damage. However, the environmental impact on the hook and loop tie is an important consideration and for these instances, a more durable cable tie for fiber is the elastomeric tie. It has the ability to stretch to prevent over tension and guard against weather, oil, salts, etc. The use of nylon cable ties can potentially damage the cable and is not recommended for standard jacket fiber cable but it is appropriate for armored or DCF cabling.

Identification

Identification facilitates MACs and aids in troubleshooting. Fiber cabling identification includes labeling and color coding. Labeling can be applied to enclosures, ports, patch cords, horizontal cables, and so on. Since some fiber cable diameter is small, applying a label can be a challenge. A sleeve can be applied to increase the diameter to make the label readable. The text on the labeling should follow TIA-606A standards. A breakdown usually occurs from the enclosure/rack, RU, port, and so on, that is consistent throughout the facility. For example, CP1.PP1.02 could mean control panel 1, patch panel 1 and port 2. Color coding can identify VLANs, zones, functional areas, network traffic type, and so on, and can be achieved with labels, hook and loop cable ties, and color bands. Although fiber cable is color coded by cable type, additional color coding can be performed for clarity using the methods described above.

Scalability

Pathway Decisions - Type and Sizing

Pathways for cables are critical for distributing copper and fiber cabling securely across the plant floor while protecting from physical threats that can degrade or damage the cable. The TIA-1005 standard, ODVA Media Planning and Installation manual, and TIA resources provide recommendations on pathways including cable spacing and installation guidance to minimize risks from environmental threats. Several options exist for routing cables via pathways that simplify deployment using best practices for a variety of environments across the plant. Figure F-1 describes some of the options.

Figure F-1 Pathway Options

Installation Consideration	J-Hook	Wyr-Grid®	FiberRunner®
			
Cable Protection Environment	Mild	Moderate	Moderate to harsh
Cable Density	Light to medium	Medium to heavy	Light to heavy
Applicable in Constrained Spaces	Yes	No	No
Installation Complexity	Simple	Moderate	Moderate to strong
Ease of Moves, Adds, Changes	Simple	Moderate	Moderate

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The simplest and lowest cost pathways are J-Hooks. J-Hooks can be mounted to a wall, beam or other surface. Network cables are held in place by the hook feature and often secured with a cable tie. The J-Hook hook feature maintains proper bend radius control when transitioning down. J-Hook systems should be utilized with cables that have rigidity to have an acceptable bend between spans and is suitable for a small bundle. Standard fiber distribution cable is not suitable for J-Hooks unless supported by corrugated loom tube.

When routing large or many cable bundles, a tray or wire basket can be installed overhead to form a solid and continuous pathway. Since cabling is exposed to the plant environment, cable jackets need to be specified for the environment. Cable tray material should also be rated for the environment. An enclosed tray such as a fiber tray provides a high level of environmental protection for light to heavy cable densities. For highest protection with few network cables, conduit is the preferred choice. Care needs to be taken to maintain proper bend radius and lineal support to prevent cable sag.

Designing for High Availability

Cable Management

Proper cable management is essential for high system performance, availability, and reliability. A resilient cable management system is critical in areas such as MACs (for example, identification and color coding) to verify the proper action is taken and to aid in troubleshooting. Care also must be taken to protect the cabling from excessive bend, flexing, sag, rubbing, crush, etc. A strong cable management system needs to be designed around the following key elements:

- Bend radius control
- Cable routing and protection

Bend Radius Control

It is important to have a bend radius greater than or equal to manufacturer-specified minimum bend radius when handling fiber-optic cabling to prevent it from excessive bending, which can cause physical damage. Two considerations for bend radius control are:

- **Dynamic**—Cable flexing (especially during installation)
- **Static**—Cable held in place

Fiber cable manufacturers specify both radiuses where the dynamic bend radius can be 20 times the Outer Cable Diameter (OD) and the static bend radius is typically 10 times the OD. Although fiber strands are very thin and made of glass, the strand is durable and can withstand some flexing. However, flexing in general can cause deformities in the fiber, leading to signal loss over time (that is, microbend). Therefore, the stricter bend radius is dynamic. Another risk to a properly terminated and validated fiber cable is attenuation due to

excessive cable bend (that is, static). Essentially, the bend allows the light to escape the glass, reducing signal strength (that is, macrobend). The bend radius is based on the OD, therefore the minimum bend radius for the application can vary. For example, a fiber patch cord cable has a static bend radius of 1.1" while a 12 fiber distribution cable has 2.4" bend radius. Bend radius is maintained by spools, clips, fins, and product features and proper coiling. In a 19" data center style server or switch rack/cabinet, bend radius accessories can be installed to route fiber cable vertically and horizontally. Fiber enclosures and boxes used in data center cabinets/racks typically have built-in slack spools. Also, supplied adhesive backed clips secure the cabling and provide strain relief.

Cable Routing and Protection

Often, fiber cable is routed through conduit for protection. Although conduit is an excellent safeguard, it is designed for power cabling and has fittings, junction boxes, and so on, where fiber cable under some tension can potentially bend the fiber cable below the minimum bend radius. Pathways such as wire basket and J-hooks have challenges for sagging and bends that can attenuate the signal, especially for unprotected standard distribution cable. Therefore, the cable must be supported and bends must be controlled. Draping unprotected distribution cable over J-Hooks or laying the cable over an open tray with grids can potentially lead to fiber sagging below the minimum bend radius. To avoid this risk, fiber cabling can be pulled through corrugated loom tube, providing rigidity and support. Typically, fibers in interlocking armor or DCF do not encounter these issues because the armor provides support and restricts the bend radius.

To protect fiber cabling when routed in control panels, it needs to be carefully laid in duct or tubing to avoid snags and kinks, maintaining proper bend radius. Adhesive backed mounting clips can hold fiber cabling in place outside of ducts along the panel wall or top.

Network Compatibility and Performance

Cable Media Selection

Depending on cable construction, many considerations exist for cable media selection such as reach, industrial characteristics, life span, maintainability, compatibility, scalability, performance, and reliability. See Table F-1.

Table F-1 Cable Media Selection Characteristics

Parameter	Copper Cable	Multimode Fiber	Single-mode Fiber
Reach (maximum)	100 m	2,000 m (1 Gbps) 400 m (10 Gbps)	10 km (1 Gbps) 10 km (10 Gbps)
Noise Mitigation Option	Foil shielding	Noise immune*	Noise immune*
Data Rate (Industrial)	100 Mbps (Cat 5e) 1 Gbps (Cat 6) 10 Gbps (Cat 6a)	1 Gbps 10 Gbps	1 Gbps 10 Gbps
Cable Bundles	Large	Small	Small
Power over Ethernet (PoE) capable	Yes	Yes, with media conversion	Yes, with media conversion

*Fiber-optic media is inherently noise immune; however, optical transceivers can be susceptible to electrical noise.

Fiber and Copper Considerations

When cabling media decisions are made, the most significant constraint is reach. If the required cable reach exceeds 100 m (328 feet), then the cable media choice is optical fiber cable. Copper Ethernet cable is limited to maximum link length of 100 m. However, other considerations exists for distances less than 100 m such as EMI where fiber-optic cable is chosen due to its inherent noise immunity. Another consideration is the fact that IES uplinks connected with optical fiber converge faster after an IES power interruption, lessening the duration of the network outage. When it comes to data rates, copper and fiber are similar for typical industrial applications. However, other higher performing optical fiber are available for very high demand networks.

When it comes to media performance, a major consideration is network lifespan. For instance, installing a network with Cat 5e cabling could be obsolete in a couple of years, especially if transporting video. If the expectation is 10 or more years of service, the fastest category cabling should be considered. Note that upgrading networked equipment and switches in the future may only come with higher data rate ports.

Multimode vs Single-mode

Fiber has two types, single-mode and multimode. Multimode has many glass grades from OM1 - OM4. Single-mode has two glass grades, OS1 and OS2. When selecting any optical fiber, the device port must be considered first and must be the same on both ends (that is, port types cannot be mixed). In general, the port determines the type of fiber and glass grade. If the device port is SFP, flexibility exists to select compatible transceivers and the transceiver best for the application. In addition to different media, the number of strands, mechanical protection, and outer jacket protection should be considered.

Grounding and Bonding

It is essential that robust and clean power be supplied to the Level 3 Site Operations to keep the factory network running smoothly without compromises in communications and equipment performance. The incoming power feed typically includes an UPS and one or more Power Outlet Units (POUs) to distribute power for IT assets where needed. POU voltages range from 100 to 125V or 220V to 250V depending upon the region of the world, with currents ranging from 15 to 30 amp. Connectors may be straight blade or twist locks. Popular IEC configurations are C13 to C14 and C19 to C20. Additionally, POUs may include intelligent features such as power and environmental monitoring to aid in troubleshooting and diagnostics.

Grounding of the Level 3 Site Operations is critical to optimizing performance of all equipment located within the Level, reducing downtime due to equipment failures and reducing the risk of data loss. Exemplary grounding and bonding provides demonstrable improvement in bit error rate in data center and enterprise applications. Given the higher potential for EMI in industrial applications, the improvement stands to be remarkable. Also, Cisco and Rockwell Automation logic components require good grounding practices to maintain warranty support. The use of a single ground path at low impedance is commonly achieved through a busbar.

Bridging the grounding connection from Level 3 Site Operations to busbar can occur in several ways: First, a braided grounding strap connects the rack or cabinet to the building ground network. Second, grounding jumpers connect equipment to the housing structure. Finally, paint piercing screws and washers achieve a direct metal-to-metal connection throughout the Level 3 Site Operations. Unless a clear and deliberate effort to confirm proper grounding has been performed, ground loops can be established that result in lost communication data and compromised equipment performance.

Security

Both physical and logical security should be important considerations when designing Level 3 Site Operations. Physical layer security measures, such as locked access to data center/control room spaces and key card access to cabinets help limit access to and help prevent inadvertent or malicious damage to equipment and connectivity to help achieve service level goals. Often overlooked basics such as labeling, color coding, and use of keyed jacks can prevent crossing channels or removing active links inadvertently. Lock-in connectors can secure connections in switches or patching to control who can make changes and help to protect against cables being disconnected unintentionally.

Note For more information, please see the *Securely Traversing IACS Data Across the Industrial Demilitarized Zone Design and Implementation Guide* at the following URL:

- http://literature.rockwellautomation.com/idc/groups/literature/documents/td/enet-td009_-en-p.pdf

Wireless

Secure wireless access in Industrial environments is a growing need. Considerations for jobs to be completed wirelessly and an idea of future growth are needed to begin planning and design. Two main applications are served wirelessly today. These are mobility and WGB communications.

Mobility helps knowledge workers and guest workers securely access data to make more timely and accurate decisions, increasing their overall productivity and effectiveness. Therefore, mobility designs must give sufficient coverage to afford access as needed. In addition, knowledge workers such as engineers and technicians employed by the business typically need to access not only the Internet but internal network resources. Guest workers such as contractors and repair personnel deployments are typically used to enable machinery communications. Many times the machinery is dynamic (that is, movement through the facility) and needs to quickly reestablish wireless communications with the network once in place. WGB wireless does an excellent job for this use case.

Note For more information, see the *Deploying 802.11 Wireless LAN Technology within a Converged Plantwide Ethernet Architecture Design and Implementation Guide* at the following URLs:

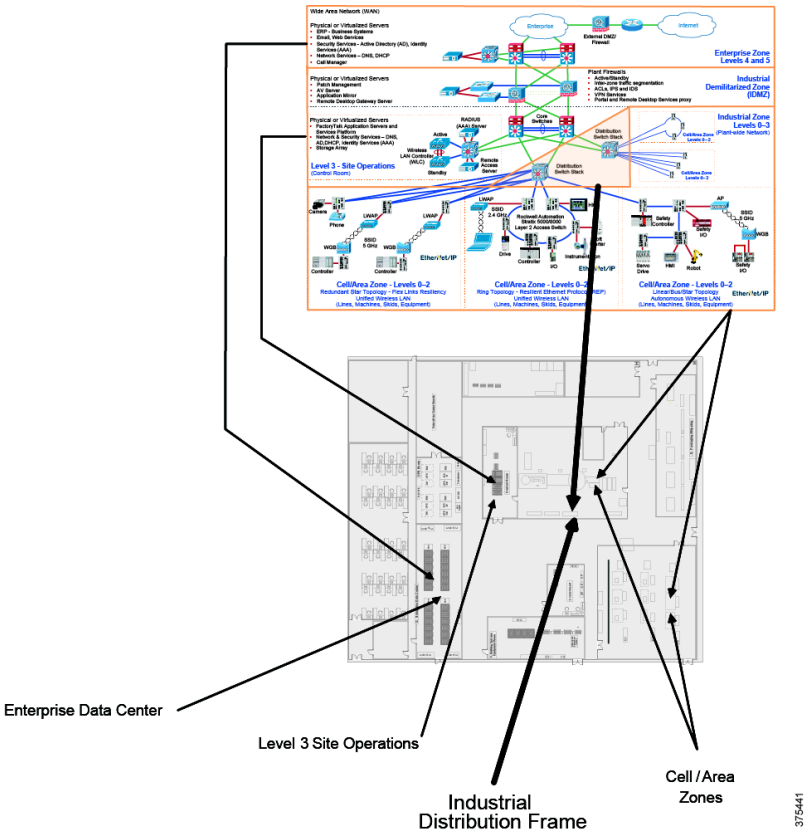
- http://www.cisco.com/c/en/us/td/docs/solutions/Verticals/CPwE/NovCVD/CPwE_WLAN_CVD.html
- http://literature.rockwellautomation.com/idc/groups/literature/documents/td/enet-td006_-en-p.pdf

Physical Network Design Considerations

Logical to Physical Simplified

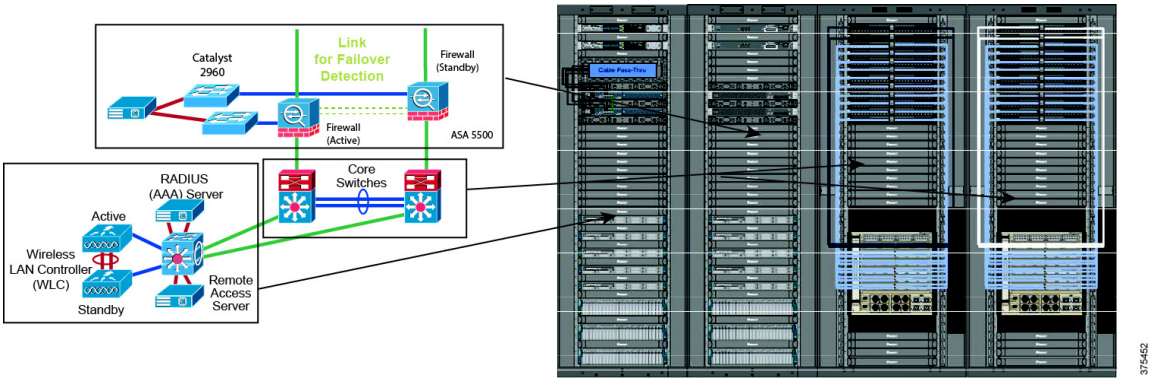
Figure F-2 represents a potential layout of plant floor with enterprise office space. The CPwE logical architecture on the top is mapped to the locations that the different levels of operation could potentially be placed within the plant floor.

Figure F-2 CPwE Logical to Physical Plant Floor



Level 3 Site Operations - Large Scale Deployment

Figure F-3 Level 3 Site Operations Logical to Physical Deployment



Overview

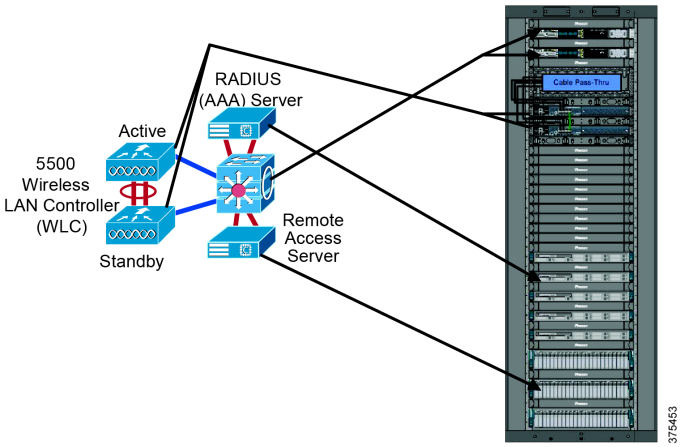
The Level 3 Site Operations can function differently in diverse environments and layouts, but generally it houses the networking to connect the plant floor to the enterprise and applications that allow the plant to operate efficiently. The layout described in Figure F-3 demonstrates a larger industrial deployment. This

deployment is likely much larger than most plants would require, but demonstrates how the Level 3 Site Operations infrastructure would be deployed if this scale were required. The core of the network is utilizing two Cisco Catalyst 6800 with a full fiber distribution network. This deployment is employing virtualized servers to provide efficient and resilient compute power to the plant floor and beyond. Four distinct cabinets house equipment for three different areas of the CPwE architecture: Level 3 Site Operations or IDC, IDMZ, and Core Switching Cabinets. Each of the cabinets is detailed further below.

IDC Cabinets

The IDC cabinet (see Figure F-4) houses the Catalyst 3850 switches that provide access to WLC and the virtualized servers that can provide several services and applications to the plant floor.

Figure F-4 IDC Cabinet Logical to Physical Deployment

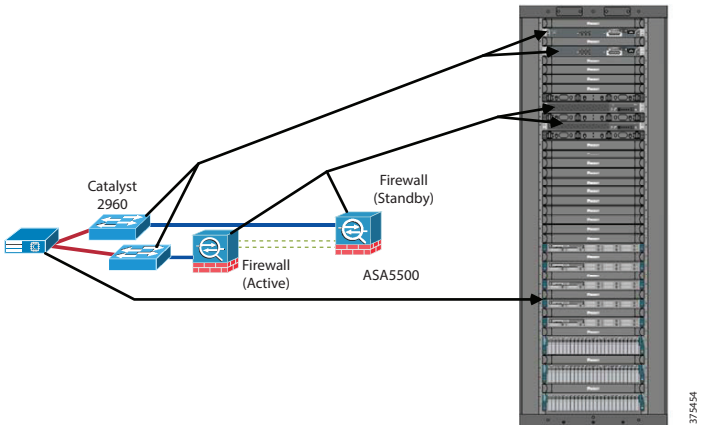


Within the cabinet, the servers are placed at the bottom of the cabinet, and switches are at or near the top. The servers are the heaviest pieces of equipment within the cabinet and are placed at the bottom to create the lowest center of gravity possible. This prevents the cabinet from tipping over and makes it more stable in case it needs to be moved as a unit. The Catalyst 3850 switches are placed at the top of the cabinet to allow for easy connections to the Catalyst 6800 switches. The 3850 switches have a back to front airflow, which means that the port side of the switch is facing the hot aisle. The 5500 WLCs are placed a few RU below the Catalyst 3850 switches. The 5500 WLCs have their ports on the front side and have an airflow from front to back only. This means that to connect to the Catalyst 3850 switches, which have their ports on the back side, a cable pass-through is required to connect. The servers have their network ports on the hot aisle side (or back side), which allows them to connect easily to the Catalyst 3850 switches.

IDMZ Cabinet

The IDMZ cabinet (see Figure F-51) houses the equipment that logically separates the enterprise from the plant floor.

Figure F-5 IDMZ Cabinet Logical to Physical Deployment



The IDMZ Cabinet has two Cisco Catalyst 2960 switches, two (active/standby) ASA 5500 firewalls, and several virtualized servers that house applications and software which needs to reside within the IDMZ. The servers are the heaviest pieces of equipment within the cabinet and are placed at the bottom to create the lowest center of gravity possible. This prevents the cabinet from tipping over and makes it more stable in case it needs to be moved as a unit. The Catalyst 2960 switches are placed at the top of the cabinet to allow for easy connections to the Catalyst 6800 switches. All the equipment has network ports on the hot aisle (back side), which allows for easy connections between equipment.

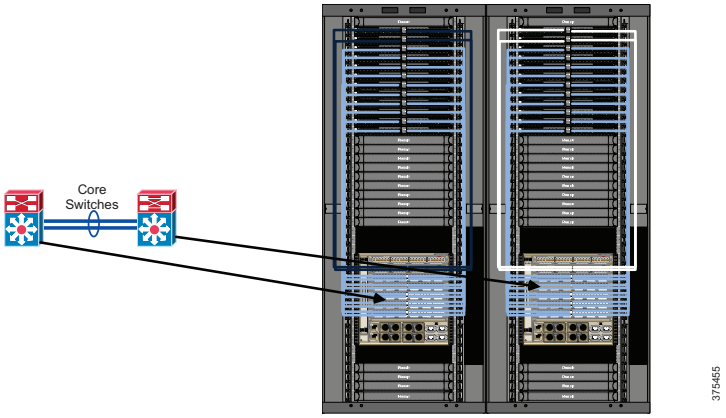
Server Cabinets

Server Cabinets offer several features that enhance cable and thermal management and should be used when deploying servers, such as the Cisco UCS C220. Cabinet air seal features and integration with passive hot and cold air containment components drive efficient utilization of cooling capacity and reduce cooling energy consumption. Modular cable management systems available on server cabinets, enable simplified organization of cables and proper bend radius control. Smart cabinet features allow access to environmental, power, and security information.

Core Switching Cabinets

The core switching cabinets (see Figure F-6) house the redundant Cisco Catalyst 6800 switches that serve as the plant floor core switches and the gateway between the plant floor and the enterprise.

Figure F-6 Core Switching Cabinets Logical to Physical Deployment



The Catalyst 6800 cabinets use switch cabinets or network cabinets, which provide additional space for cable and thermal management. The switch cabinet has an air dam installed that separates the cold air in the front of the cabinet, from the hot exhaust air that is located on the back side of the cabinet. Because the Cisco Catalyst 6800 switch has a side-to-side airflow, the use of a 6800 thermal ducting system is required to operate within a hot/cold aisle arrangement in the data center. The Cisco Catalyst 6800 switches are located at the bottom of the cabinet because they are the heaviest equipment within the cabinet and create the lowest center of gravity. The patch panels at the top of the cabinet provide connectivity to the plant floor and to the IDMZ cabinet.

Network Cabinets

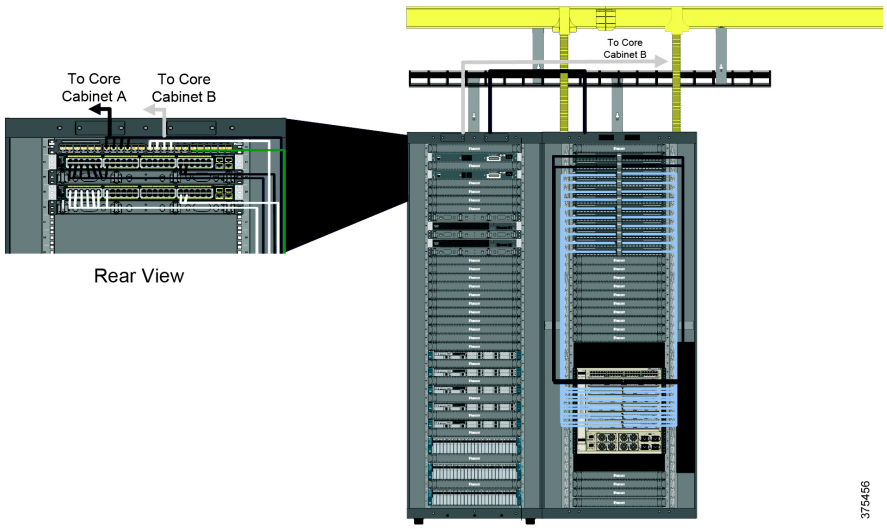
Network cabinets offer several features that enhance cable and thermal management and should be used when deploying large chassis-based switches, such as the Cisco Catalyst 6800 switch. An inset frame design efficiently manages large quantities of cables and provides space for access maintenance. Cabinet air seal features and integration with passive hot and cold air containment components drive efficient utilization of cooling capacity and reduce cooling energy consumption. Dual-hinged doors reduce time needed to perform MACs. Modular cable management systems available on network cabinets, enable simplified organization of cables and proper bend radius control.

Physical to Physical Simplified

IDMZ Cabinet to Core Switching Cabinets

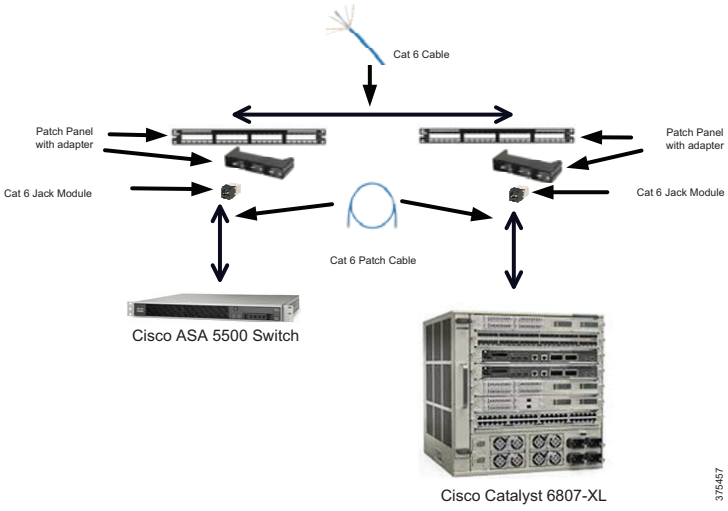
The IDMZ to Core Switch connections shown in Figure F-7 and Figure F-8 can be copper or fiber depending on the model of firewall and the line card used in the Catalyst switch.

Figure F-7 IDMZ Cabinet to Core Switches Cabinets Physical to Physical Deployment



n Figure F-7 and Figure F-8, copper connects the Cisco ASA firewall and the Cisco Catalyst 6800 switch. Starting at the ASA firewall, the one side of the Cat 6 patch cable plugs into the ASA firewall port and the other side plugs into the jack module that is housed in the adapter, which is connected into the patch panel. On the back side of the jack module the Cat 6 horizontal cable is connected and runs to the core switch cabinet. When the Cat 6 horizontal cable reaches the Catalyst cabinet it is attached to the back side of the jack module. On the front of the jack module, the Cat 6 patch cable is plugged in and on the opposite side the Cat 6 patch cable is plugged into the RJ45 port on the Cisco Catalyst 6800 line card.

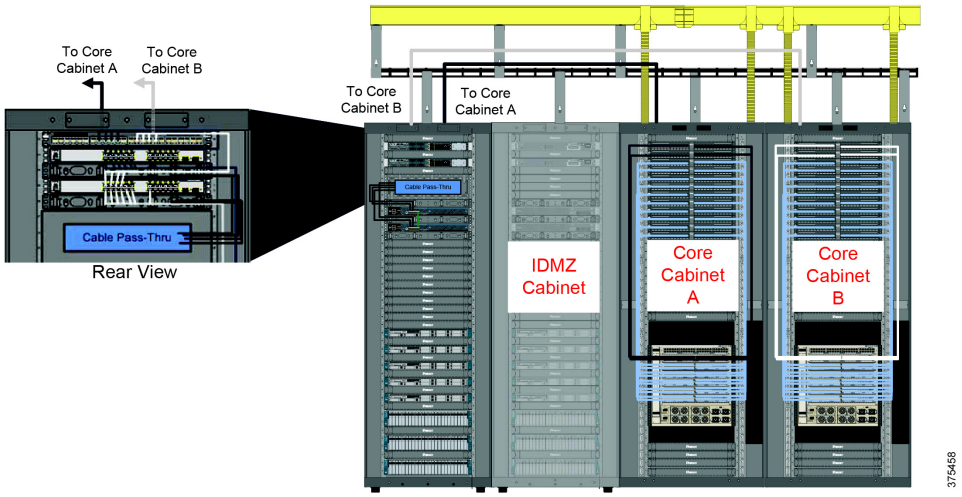
Figure F-8 ASA 5500 Switch to Catalyst 6800 Switch Single Line



IDC Cabinet to Core Switching Cabinets

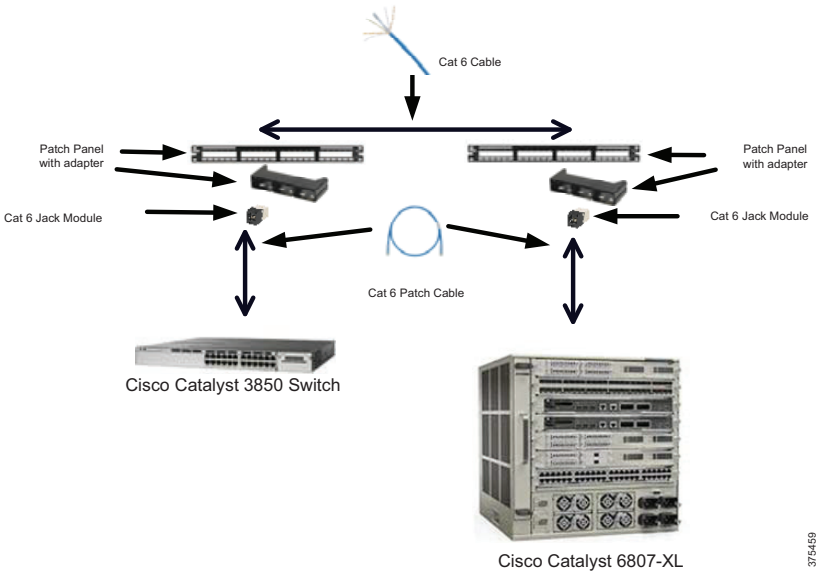
The IDC Cabinet-to-Core Cabinets connections shown in Figure F-9 and Figure F-10 can also be copper or fiber depending on the model of switch in the IDC cabinet and the line card used in the Catalyst switch.

Figure F-9 IDC Cabinet to Core Switching Cabinets Physical to Physical Deployment



In this scenario, copper connects the Cisco Catalyst 3850 switch and the Cisco Catalyst 6800 switch. Starting at the Cisco Catalyst 3850 switch, the one side of the Cat 6 patch cable plugs into the RJ45 port on the Cisco Catalyst 6800 switch and the other side plugs into the jack module that is housed in the adapter, which is connected into the patch panel. On the back side of the jack module, the Cat 6 horizontal cable is connected and runs to the Catalyst cabinet. When the Cat 6 horizontal cable reaches the Catalyst cabinet, it is attached to the back side of the jack module. On the front of the jack module, the Cat 6 patch cable is plugged in. On the opposite side, the Cat 6 patch cable is plugged into the RJ45 port on the Cisco Catalyst 6800 line card.

Figure F-10 Catalyst 3850 Switch to Catalyst 6800 Switch Single Line

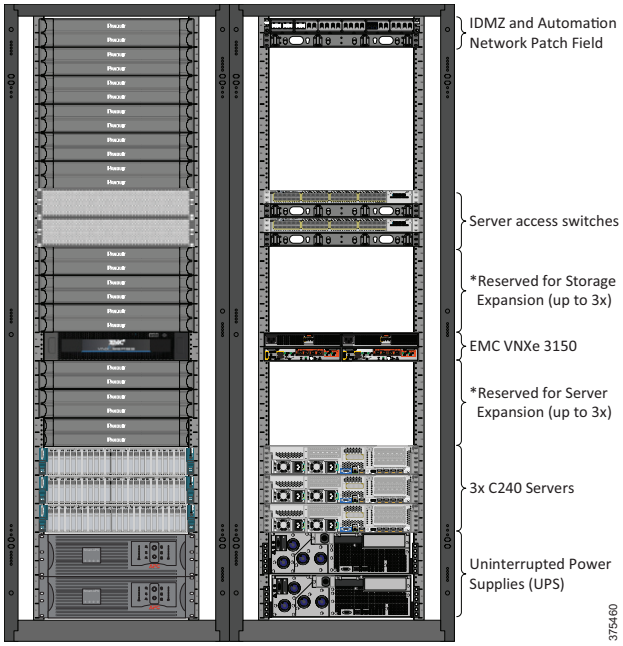


Level 3 Site Operations - The Industrial Data Center from Rockwell Automation

The IDC from Rockwell Automation (see Figure F-11) can help your business realize the cost savings of virtualization in a production environment through a pre-engineered, scalable infrastructure offering. All of the hardware you need to run multiple operating systems and multiple applications off of virtualized servers are included in the cost. Industry-leading collaborators including Cisco, Panduit, EMC, and VMware collaborating with Rockwell Automation to help your business realize the benefits of virtualization through this integrated offering.

As a pre-engineered solution, the IDC from Rockwell Automation is designed to ease the transition to a virtualized environment for your business, saving you time and money. Instead of ordering five different pieces of equipment with five purchase orders, in addition to hiring the correct certified installation professionals to get you up and running, the IDC combines equipment from industry leaders that are pre-configured specifically for the manufacturing and production industries. All equipment is shipped pre-assembled and a Rockwell Automation professional will come to your site and commission the system.

Figure F-11 The Industrial Data Center from Rockwell Automation - Physical Layout



Features and Benefits:

- **Reduced Cost of Ownership**—Decrease the server footprint in your facility and realize savings over the lifetime of your assets
- **Uptime Reliability**—Deliver high availability and fault tolerance
- **Designed for Your Industry**—Engineered specifically for use in production and manufacturing environments
- **Ease of Ordering and Commissioning**—Pre-assembled solution that includes configuration service. No need to place multiple equipment orders
- **One Number for Technical Support**—Includes TechConnect^{SM} support so you have one phone number to call. Additional support levels include 24x7 support and remote monitoring

Panduit List of Materials

Table F-2 is a sample list of materials for best in class physical layer solutions for the Level 3 Site Operations from Panduit.

Table F-2 Sample List of Materials

Part Number	Description
Cabinets	
N8222B	Net-Access™ N-Type Cabinets -Network Cabinet, 800mm, 42RU, 1200M Depth, Black
S7222B	Net-Access S-Type Cabinets - Server Cabinet, 700mm, 42RU, 1200M Depth, Black
Patch Panels	
QPP24BL	QuickNet™ Patch Panel
TLBP1S-V	1RU Tool-less Cage Nut Blanking Panel
QPPABL	MiniCom® Patch Panel Adapter
CJSK688TGBL	Cat 6 MiniCom® Connector
Cable	
UTP28SP5BU	Cat 6 Patch Cable - 5 ft, Blue
UTP28SP4IG	Cat 6 Patch Cable - 5 ft, White
FZE10-10M2	OM4 LC-LC Duplex Fiber Patch Cable - 2M
Cable Management	
CMPHHF1	RU D-ring Cable Manager
Pathways	
Various	WyrGrid® - Overhead Cable Tray Routing System
Various	FiberRunner® - Fiber Cable Routing System

APPENDIX G

Acronyms and Initialisms

Acronym	Definition
AP	Access Point
ASIC	Cisco Application-Specific Integrated Circuit
AVB	Audio Video Bridging
AVC	Cisco Application Visibility and Control
AWG	American Wire Gauge
CAPWAP	Control and Provisioning of Wireless Access Points
CFD	Computational Fluid Dynamics
CIP	Common Industrial Protocol
CPwE	Converged Plantwide Ethernet
CRAC	Computer Room Air Conditioning
DCF	Dielectric Conduited Fiber
DLR	Device Level Ring
EMB	Effective Modal Bandwidth
EMI	ElectroMagnetic Interference
EO	Equipment Outlet
EPC	Equalizing Potential Conductor
ERSPAN	Cisco Encapsulated Remote Switch Port Analyzer
FAP	Fiber Adapter Panel
FHRP	First Hop Redundancy Protocols
FIB	Forwarding Information Base
FNF	Cisco Flexible NetFlow
HDPE	High-Density Polyethylene
HMI	Human Machine Interface
HSRP	Hot Standby Routing Protocol
IACS	Industrial Automation and Control Systems
IDC	Industrial Data Center
IDF	Industrial Distribution Frame
IEC	International Electrotechnical Commission
IDMZ	Industrial Demilitarized Zone
IES	Industrial Ethernet Switches
ISE	Cisco Identity Services Engine

Acronym	Definition
LACP	Link Aggregation Control Protocol
LIBO	Lock-in/Block-out
LOS	Loss of Signal
LWAP	Lightweight Wireless Access Points
MAC	Moves, Adds, and Changes
MACsec	Media Access Control Security
MDF	Master Distribution Frame
MEC	Multi-Chassis EtherChannel
M.I.C.E.	Mechanical Ingress Chemical/Climatic Electromagnetic
MPLS	Multiprotocol Label Switching
MQC	Cisco Modular Quality of Service
MTTR	Mean-Time-To-Repair
NaaS/NaaE	Network as a Sensor/Network as an Enforcer
NAT	Network Address Translation
NFPA	National Fire Protection Association
NSF	Nonstop Forwarding
OD	Outer Cable Diameter
OEE	Overall Equipment Effectiveness
OIR	Online Insertion and Removal
OM	Optical Multimode
OpEx	Operational Expense
OT	Operational Technology
PAC	Programmable Automation Controller
PAgP	Port Aggregation Protocol
PCF	Polymer Coated Fiber
PNZS	Physical Network Zone System
PoE	Power over Ethernet
POU	Power Outlet Unit
REP	Resilient Ethernet Protocol
RIB	Routing Information Base
RPI	Requested Packet Interval
RSSI	Received Signal Strength Indication
RU	Rack Unit
SFP	Small Form-Factor Pluggable
SNR	Signal to Noise Ratio
SSO	Stateful Switch Over
STP	Shielded Twisted Pair
STP	Spanning Tree Protocol (STP)
SVI	Switched Virtual Interface
TIA	Telecommunications Industry Association
TSB	TIA Technical Services Bulletin
UADP	Cisco Unique Access Data Plane
UPS	Uninterruptable Power Supply
UTP	Unshielded Twisted Pair
VFD	Variable Frequency Drives
VLAN	Virtual LAN

Acronym	Definition
VRRP	Virtual Router Redundancy Protocol
VSL	Virtual Switching Link
VSS	Virtual Switching System
WGB	Work Group Bridge
WLAN	Wireless Local Area Network
WLC	Wireless LAN Controller
XPS	Cisco Expandable Power System

APPENDIX H

About Cisco Validated Design (CVD) Program

Converged Plantwide Ethernet (CPwE) is a collection of tested and validated architectures developed by subject matter authorities at Cisco and Rockwell Automation 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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