EtherNet/IP Topologies
Segmentation
Resiliency
Network Address Translation

John Gajor
Solution Architect
Rockwell Automation
Industrial Networks
Continuing Trends

- Open Networks Are In Demand
  - Broad availability of products, applications and vendor support for Industrial Automation and Control System (IACS)
  - Network standards for coexistence and interoperability

- Convergence of Network Technologies
  - Reduce the number of different networks in an operation and create a seamless information sharing from the plant floor to the enterprise
  - Use common network design and troubleshooting tools across the plant and enterprise, and avoid special tools for each application

- Better Asset Utilization to Support Lean Initiatives
  - Reduce training, support, and inventory for different networking technologies
  - Common network infrastructure assets, while accounting for environmental requirements

- Future Proof – Maximizing Investments
  - Support new technologies and features without a network forklift upgrade
Industrial Network Convergence
Continuing Trend

Traditional – 3 Tier Industrial Network Model

Converged Plantwide Ethernet Industrial Network Model

EtherNet/IP - Enabling/Driving Convergence of Control and Information
Industrial Network Convergence
Continuing Trend

Evolution of industrial Ethernet applications

Information → I/O Control → Safety Applications → Motion Control

Industrial Network Convergence

EtherNet/IP - Enabling/Driving
Convergence of Control and Information
Plantwide Architectures
Industrial Network – Isolated LANs

Enterprise Business Systems

IT Network

Industrial Network

Level 4 – Data Center

Level 3 - Site Operations
- FactoryTalk Application Servers
- FactoryTalk Services Platform
- Data Servers

Level 2 - Control Room

Filling Cell/Area Zone
- Levels 0-2
- Ring Topology
- Device Level Ring

Processing Cell/Area Zone
- Levels 0-2
- Ring Topology
- Resilient Ethernet Protocol (REP)

Material Handling Cell/Area Zone
- Levels 0-2
- Bus/Star Topology

Islands of Automation Systems
Plantwide Architectures
Industrial Network – Plantwide LAN

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Plantwide Architectures
Converged Industrial and IT Network

Enterprise
Business Systems

IT Network

Industrial Network

Level 3 - Site Operations
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Level 4 – Data Center

Business and Plantwide System Convergence
Plant-wide Network Convergence
Trend – Technology Convergence

Convergence

Industrial Plantwide Systems

Suppliers

Enterprise Business System

Customer

IT Domain

Shared Domain

PEOPLE TECHNOLOGY PROCESSES & INNOVATION
Industrial Network Design Methodology

- Understand application and functional requirements
  - What devices are to be connected – industrial and non-industrial
  - Determine data requirements for availability, integrity and confidentiality
  - Communication patterns, **TOPOLOGY** and resiliency requirements
  - Types of traffic – information, control, safety, time synchronization, motion control, voice, video

- Develop a logical framework (roadmap)
  - Define zones and segmentation
  - Place applications and devices in the logical framework based on requirements

- Develop a physical framework to align with and support the logical framework
- Determine security requirements, take into consideration IT requirements and establish early dialogue with IT
- Use technology and industry standards, reference models and reference architectures
Network topology is the manner in which end devices and network devices are all interconnected.

EtherNet/IP is topology neutral – providing the flexibility to meet your application requirements:

- EtherNet/IP is an ODVA technology based on the Common Industrial Protocol (CIP™). As a single, media-independent platform that is shared by a variety of networking technologies, the Common Industrial Protocol (CIP) provides the interoperability that is essential to open networks and systems.
Established & Market accepted!

Market Data:

- #1 share Globally, NA, China
- Major Vendors with EtherNet/IP as core
  - Rockwell, Schneider, Omron
- Major Vendors w/ EtherNet/IP support
  - Emerson, Mitsubishi, Yokogawa
- 300+ vendors supporting
- 1000+ products available

Comes EtherNet/IP competitive advantage

*Figure 2.1 Installed Base of Nodes in Worldwide Industrial Ethernet by Ethernet Variant 2008 and 2013 (Thousands of Nodes Installed at Year End)*

- EtherNet/IP
- PROFINET
- EtherCAT
- SERCOS III
- HSE
- FL-Net
- EPA
- CC-Link IE
- Others

Source: IMS Research

*2013 Forecast for Number of Nodes*

- EtherNet/IP 36%
- Profinet 33%
- EtherCat 7%
- PowerLink 5%
- CC-Link IE 3%
- MODBUS TCP 14%
- FF HSE 2%
Representative Configurations

Production - VLANs
IP Camera - VLAN

Layer 2 Access Link
Layer 2 Interswitch Link/802.1Q Trunk

Stratix 5700/8000/8300
REP
CIP Class 1 & 3

Catalyst 4500s
HSRP
VLAN 103

EtherNet/IP

Industrial Zone
Level 3

Cell/Area Zones
Levels 0–2

VLAN 103

Controller
Controller
Camera
I/O
I/O
I/O

VLAN 43

VLAN 104

VLAN 43

VLAN 103

HMI
I/O

VFD Drive

Servo Drive

Safety Controller
I/O

Controller

Camera

I/O

Levels 0–2
Cell/Area Zones
Industrial Zone

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Topology Selection

- **Physical environment** and **network performance** requirements must be taken into account when determining the **optimal** network topology.

- Topology choice is driven by application requirements:
  - Performance & throughput
  - Latency and jitter tolerance
  - Tolerance to downtime and mean-time-to-repair (MTTR)
  - Future upgrade and expansion requirements

- The topology chosen:
  - Impacts the **availability** and **integrity** of Industrial Network control and information data
  - Has implications on wiring cost and complexity, performance, and installation and maintenance cost
**Managed vs Unmanaged Switches**

<table>
<thead>
<tr>
<th>Managed Switches</th>
<th>Advantages</th>
<th>Disadvantages</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>• Loop prevention</td>
<td>• More expensive</td>
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<tr>
<td></td>
<td>• Security services</td>
<td>• Requires some level of support and configuration to start up</td>
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<tr>
<td></td>
<td>• Diagnostic information</td>
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<td></td>
<td>• Segmentation services (VLANs)</td>
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<td></td>
<td>• Prioritization services (QoS)</td>
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<td></td>
<td>• Network resiliency</td>
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<td></td>
<td>• Multicast management services</td>
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<tr>
<td></td>
<td>• Time Sync Services (IEEE1588 Transparent Clock)</td>
<td></td>
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<tr>
<td></td>
<td>• ODVA Embedded Switch Technology</td>
<td></td>
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<tr>
<td></td>
<td>• Cable simplification with reduced cost</td>
<td></td>
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<tr>
<td></td>
<td>• Ring loop prevention &amp; Network resiliency</td>
<td></td>
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<table>
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<tr>
<th>Unmanaged Switches</th>
<th>Advantages</th>
<th>Disadvantages</th>
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<tbody>
<tr>
<td></td>
<td>• Inexpensive</td>
<td>• No loop prevention</td>
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<tr>
<td></td>
<td>• Simple to set up</td>
<td>• No security services</td>
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<tr>
<td></td>
<td></td>
<td>• No diagnostic information</td>
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<tr>
<td></td>
<td></td>
<td>• No segmentation or prioritization services</td>
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<tr>
<td></td>
<td></td>
<td>• Difficult to troubleshoot</td>
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<tr>
<td></td>
<td></td>
<td>• No network resiliency support</td>
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<tr>
<td></td>
<td>• Limited management capabilities</td>
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<tr>
<td></td>
<td>• May require minimal configuration</td>
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</table>
The Stratix Portfolio
Integrating industrial and enterprise environments

Addressing the needs of automation professionals...

Switches for:
- Applications for small to complex networks
- Monitor and control distributed devices
- Plant floor and enterprise integration

- Productivity
- Energy Savings
- Safe Operations

- Time to Market
- Scale & Modularity
- Protecting IP

Stratix 5100 Wireless AP/WGB
Stratix 8000/8300 Layer 2, Layer 3
Stratix 5700 Layer 2
Stratix 2000 Unmanaged
Stratix 5900 Security Appliance
Stratix 6000 Layer 2
Stratix ETAPs
What is embedded switch technology?

Managed features with minimal / No configuration
Now Shipping Rockwell Automation Products

- EtherNet/IP to Profibus PA Gateway
- EtherNet/IP to Foundation Fieldbus Gateway
- ControlLogix Precision Time GPS Module
- SLC EtherNet/IP Adapter
- RFID (56RF) system
- EtherNet/IP Encoder
- E1 and E3 overload relay
- ArmourStart products

*Ring supervisor products – need at least one to establish device-level ring*
Plant-Floor and Enterprise Requirements
Network Topology - Similarities and Differences

Switch and Device-level Topologies

Redundant Star
Flex Links

Ring Resilient Ethernet Protocol (REP)

Star/Bus Linear

Controllers, Drives, and Distributed I/O
Topology Flexibility with EtherNet/IP

**LINEAR** – Simplify cable management

**STAR** – Connect broad range of devices

**HYBRID** – Obtain maximum flexibility

**RING** – Maximum availability

EtherNet/IP is topology neutral for maximum flexibility
Linear Topology

Simple integration - connect devices directly to the Ethernet port or connects devices to a switch in a linear fashion

- Up to 100 meter's between devices or between switches

- Reduce cabling requirements
- Ease of configuration
- Lower implementation costs
Star Topology

Star topology enables the connection of a broad range of devices – embedded switch and non-embedded switch devices

- Add/remove devices without impacting the operation of other devices
- Mix with linear connected devices to optimize switch port usage and reduce system cost (one port per line of devices)
Ring Topology

Ring topology enables topology resiliency for single fault tolerant (SFT) network operation.

- Maximazed machine uptime
- Reduces cabling complexity
- Less costly wiring

Maximize availability
Hybrid Topology

Combine topologies to meet your application requirements

- Linear, Ring, Star
- Switch, Device with embedded switch
Segmentation
Physical - Multiple NICs

- Isolated networks - two NICs for physical network segmentation

  Information Network

  Control Network

- Converged networks - logical segmentation

  Control and Information Network

- Benefits
  - Clear network ownership demarcation line

- Challenges
  - Limited visibility to control network devices for asset management
  - Limited future-ready capability

- Benefits
  - Plantwide information sharing for data collection and asset management
  - Future-ready

- Challenges
  - Blurred network ownership demarcation line
Segmentation
Physical - Multiple NICs

- Isolated networks - two NICs for physical network segmentation

- Converged networks - logical segmentation - two NICs for scalability, performance, capacity and flexibility

**Benefits**
- Clear network ownership demarcation line

**Challenges**
- Limited visibility to control network devices for asset management
- Limited future-ready capability

**Benefits**
- Plantwide information sharing for data collection and asset management
- Future-ready

**Challenges**
- Blurred network ownership demarcation line
Segmentation
Virtual Local Area Networks - VLANs

• Layer 2 network service, VLANs segment a network logically without being restricted by physical connections
  – VLAN established within or across switches
• Data is only forwarded to ports within the same VLAN
  – Devices within each VLAN can only communicate with other devices on the same VLAN
• Segments traffic to restrict unwanted broadcast and multicast traffic
• Software configurable using managed switches
• Benefits
  – Ease network changes – minimize network cabling
  – Simplifies network security management - domains of trust
  – Increase efficiency
- VLAN Trunking Protocol (VTP)
- Configured by default on Stratix 5700/8000/8300
- Define VLANs at each switch, no centralized management
• Layer 2 VLAN Trunking
  – Independent of physical switch location
  – Logically group assets by type, role, logical area, physical area or a hybrid of these
  – Devices communicate as if they are on the same physical segment – no re-cabling required

• Software configurable using managed switches

• A Layer 3 device (Router or Layer 3 switch) is required to forward traffic between different VLANs
  – Inter-VLAN routing
Segmentation
Virtual Local Area Networks - VLANs

- Inter-VLAN routing
- Layer 3 switch or router
EtherNet/IP - Resiliency
Resiliency Protocols and Redundant Topologies: Layer 2 – Loop Avoidance

Switch and Device-level Topologies

- **Stratix 8300**
  - I/O
  - Controller
  - Servo Drive
  - VFD Drive

**Cell/Area Zone**

- **Cisco Catalyst 3750 StackWise Switch Stack**

**Redundant Star**
- Flex Links
- Controllers, Drives, and Distributed I/O

**Ring**
- Resilient Ethernet Protocol (REP)
- Controllers, Drives, and Distributed I/O

**Star/Bus Linear**
- Controllers, Drives, and Distributed I/O

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Resiliency Protocols and Redundant Topologies: Layer 2 – Loop Avoidance

- Parallel links (paths) create a switching (bridging) loop
  - Layer 2 Ethernet frames do not have a time-to-live (TTL)
  - A Layer 2 frame can loop forever
  - Without proper configuration, a loop will lead to a broadcast storm, flooding the network, which will consume available bandwidth, and take down a Layer 2 switched (bridged) network
- Supervisor blocks traffic on one port
- Sends Beacon frames on both ports to detect break in the ring
- Sends Announce frames on unblocked port
Ring – DLR – Physical Layer Failure
Resiliency Protocols – Device-Level Topology

- All faults that are detectable at physical layer
- Physical layer failure detected by protocol-aware node
- Status message sent by ring node and received by ring supervisor
After failure detection, ring supervisor unblocks blocked port

Network configuration is now a linear topology

Fault location is readily available via diagnostics
Once ring is restored, supervisor hears beacon on both ports, and transitions to normal ring mode, blocking one port.
Ring – DLR - Summary
Resiliency Protocols – Device-Level Topology

- ODVA - open standard enabling suppliers to develop compatible products
- Support for ring and linear topologies, fiber and copper implementations
- Network traffic is managed to ensure timely delivery of critical data (Quality of Service, IEEE-1588 Precision Time Protocol, Multicast Management)
- Ring is a single fault tolerant network
- Designed for 1-3 ms convergence for simple EtherNet/IP device networks
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Stratix 5100
Wireless AP/WGB

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Layer 2, Layer 3

Stratix 5700
Layer 2

Stratix 5900
Security Appliance

Stratix 2000
Layer 2

Stratix ETAPs

Stratix 6000
Layer 2

Stratix 2000
Unmanaged
EtherNet/IP - Network Address Translation
Stratix 5700 NAT Overview
Network Address Translation

- Provides 1 to 1 IP address translations
  - Maximum 1 subnet and 127 single translations
  - Translations provided on uplink ports
    - One or both ports for ring support
- Translation table is stored as part of switch configuration

---

![Diagram](image)

Machine 1

NAT Translation

192.168.1.2 = 10.10.10.2

Send message to Machine 1 PLC at address 10.10.10.2 when broken connection

Machine 2

NAT Translation

192.168.1.2 = 10.10.11.2

Cable break

Line Controller

Improve system uptime by adding a Ring using REP
Continue to send messages to Machine 1 PLC at address 10.10.10.2 when broken connection

---

Allows duplicate machines to be easily integrated into existing architectures
Stratix 5700 NAT Overview
Network Address Translation

- Provides 1 to 1 IP address translations
  - Maximum 1 subnet and 127 single translations
  - Translations provided on uplink ports
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Machine 1
NAT Translation
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Machine 1
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192.168.1.2 = 10.10.10.2

Machine 2
NAT Translation
192.168.1.2 = 10.10.11.2

Line Controller

Allows duplicate machines to be easily integrated into existing architectures
NAT – Network Address Translation

Identical Machines are Less Expensive to Build, Install and Maintain

Machine A

- 9300-ENA with NAT Application
- PanelView™ 192.168.1.2
- Controller 192.168.1.1
- Network Switch
- Kinetix 192.151.186.1.3

Machine B

- PanelView™ 192.168.1.2
- Controller 192.168.1.1
- Network Switch
- Kinetix 192.151.186.1.3

Machine C

- PanelView™ 192.168.1.2
- Controller 192.168.1.1
- Network Switch
- Kinetix 192.151.186.1.3

Plant Wide Network
**Connectivity to Plant VLAN or NAT**

**NAT**

**Pros:**
- IP Addresses private to machine (not visible outside of machine network)
- Web diagnostics available outside machine

**Cons:**
- Additional cost for NAT device or switch
- Some additional complexity and management

**VLAN**

**Pros:**
- No machine level switch configuration needed if the machine is a single VLAN
- Removes “single point of failure” for NAT device
- Designed to allow network services (SNMP, VPN, DNS, DHCP)

**Cons:**
- IP addressing must be unique at the machine level
- Demarcation less clear
What are the pros & cons for Dual Interfaces vs. NAT for plant connectivity?

**2nd Interface**

**Pros:**
- IP Addresses private to machine
- End user manages external IP address
- Program does not change when Plant network address change

**Cons:**
- Limited Security
- Not available on small or Micro controllers
- Cable resiliency between, machine and plant
- Web diagnostics not available outside machine
- Only CIP will traverse the backplane

**NAT**

**Pros:**
- Same pros as Dual NIC Plus
- Lower network connectivity cost
- Web diagnostics available outside machine
- Will limit access to Machine network (only devices in NAT table will communicate)

**Cons:**
- NAT Table Configuration
- Some network protocols will not traverse through NAT
Networking Design Considerations
EtherNet/IP Considerations

Recommendations and guidance to help reduce **Latency** and **Jitter**, to help increase data **Availability**, **Integrity** and **Confidentiality**, and to help design and deploy a **Robust**, **Secure** and **Future-Ready** EtherNet/IP network infrastructure

- Robust Physical Layer
- Segmentation
- Resiliency Protocols and Redundant Topologies
- Network Address Translation
- Time Synchronization
- Prioritization - Quality of Service (QoS)
- Multicast Management
- Convergence-Ready Solutions
- Security - Defense-in-Depth
- Scalable Secure Remote Access
Additional Material
Rockwell Automation

- Networks Website: http://www.ab.com/networks/
- EtherNet/IP Website: http://www.ab.com/networks/ethernet/
- Media Website: http://www.ab.com/networks/media/ethernet/
- Embedded Switch Technology Website: http://www.ab.com/networks/switches/embedded.html
- Publications:
  - ENET-AP005-EN-P Embedded Switch Technology Manual
  - ENET-UM001G-EN-P EtherNet/IP Modules in Logix5000 Control Systems . . . provides connection and packet rate specs for modules
  - 1783-UM003 Stratix 8000 and Stratix 8300 Ethernet Managed Switches User Manual
- Network and Security Services Website:
  - http://www.rockwellautomation.com/services/networks/