Chapter 16: Switched Ethernet in Automation

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Ethernet Basics

- What is Ethernet?

- Why Ethernet? (not FieldBus?)
  - Flexibility, Scalability and Performance
  - Key Strength: many protocols running simultaneously
  - Redundancy and Accurate Synchronization

- Not just a protocol
  - A communication architecture with
  - A set of communication technologies
Ethernet Basics (Cont.)

- Ethernet covers OSI Layer 1 and part of Layer 2

- "Industrial Ethernet": a combination of protocols for industrial automation systems (PROFINET, EtherCAT, IEC61850).
  - Technologies: Switching, routing and networking protocols

- != enhanced Ethernet: most demanding real-time applications. E.g. EtherCAT. Need hardware support.

- 100M, 1G bps, --> 100Gbps

- Full duplex communication in switched Ethernet: no collisions, queuing can still lead to delay
Outline

- Requirements and Challenges
  - Topology | Availability | Performance | Time Synchronization | Security

- Network Architectures

- Switches
  - What is a switch? Switch Architecture

- Networking Protocols
  - Redundancy | QoS | Multicast & VLAN Handling | Time Synchronization | Simple Network Time Protocol | Precision Time Protocol

- Future Outlook
Requirements and Challenges

- Topology
  - Line, Star, Mesh…Hybrid

- Availability
  - 24/7, each hour downtime costs millions

- Performance

- Time Synchronization
  - Relative time vs. Absolute time

- Security
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Network Architectures

- Based on physical layout - topology

- Ring
  - Simplicity and abundance of network redundancy protocol for rings

- Star
  - Controller centric architecture, not very efficient

- Mesh, partial Mesh
  - Difficult for determinism and low recovery time
  - More flexible: Shortest Path Bridge (IEEE 802.1aq)

- Depends on situation, no one cure for all
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Switches

What is a Switch?
- Crucial network device, store/process/forward packet data, to one or multiple other devices through its ports.
- Switch VS. Hub : Layer 1 VS. Layers 2. Signal repeater VS. MAC address sending… Router? (IP address, Layer 3)

Switch Architecture
- Two or more MAC entities
- A MAC relay entity
- A number of higher layer entities (HLEs)
Switch

- MAC Entity
  - Contains Media Access part of the switch. (Ports)
  - Receive and transmit frames
  - Validate checksum
  - Has unique MAC address
  - Check MAC and then VLAN ID, then send to HLE or other MAC entity
  - Recognition, interpretation, addition and removal of VLAN tags
  - Check VLAN ID for port, forward to MAC relay entity
**Switch**

- MAC Relay Entity
  - Distribute packets between switch ports
  - Address Table, unicast or multicast
  - Functions:
    - 1. Store and Forward functionality for Ethernet frames
    - 2. Address learning, unknown destination addresses are normally broadcasted
    - 3. Frame altering (Based on destination MAC addresses)

- Required at least one higher layer entities, e.g., RSTP (rapid spanning tree protocol) for loop freedom
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Network Protocols

- Modern Ethernet: a combination of basic switching functionalities and a set of network management related protocols.

- Protocols handle: Network redundancy, time synchronization, handling of multicast and VLAN traffic

- Without these protocols: transport data in simple manner and not very robust against errors. No features like time synchronization.
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Redundancy

- To create fault tolerant networks, ensure availability

1. Alternate Path Operation
   - Alternate path active when primary path fails
   - Recovery takes 10-200 ms
   - Eg. RSTP (Rapid Spanning Tree) and Media Redundancy Protocol (MRP)

2. Parallel Path Operation
   - Parallel paths operate concurrently, duplicate packets
   - Packet duplication, requires HW/SW support in end nodes
   - Eg. Parallel Redundancy (PRP) and High-Availability Seamless Redundancy (HSR)
Redundancy: Spanning Tree

- Avoid physical loops (Why?)
- Turn any complex physical network into Logical tree.
- Detect failures of an active path, active a backup or redundant path
- Based on timeouts for failures. Long recovery time
- RSTP, Rapid – hand shaking mechanism, much faster than STP
Redundancy: other solutions
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Quality of Service

- Methods to prioritize traffic through the network to reduce latency and jitter

- Traffic prioritization on Layer 2 (7, 6, 5, ..., 1, 0)
  - 7 – highest priority. Network protocol control, eg. RSTP packets
  - 6 – ..... 
  - 1 – lowest priority (background)
  - 0 – default priority
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Multicast and VLAN Handling

- Multicast: simultaneously sending the same packet to multiple receivers,
  - With a group or multicast MAC address as the destination address
- For unknown destination, leads to broadcasting
Multicast

- Two layers can do multicast: MAC and IP
  - MAC multicast: a group or multicast MAC address
  - IP multicast: an IP group of multicast address

- MAC multicast protocols: PROFINET, PTP, IEC 61859-8-1, GOOSE

- IP multicast protocols: FF HSE, Ethernet/IP, and IEEE PTP
Virtual Local Area Network

- 802.1Q, separate logical segments of a network operating on the same physical network.
  - To limit the broadcast domain

- VLAN increases the complexity of RSTP $\rightarrow$ Multiple STP

- Problems with multicast and VLAN in automation
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Time Synchronization

- Why is Time Synchronization Important?
  - Can be solved naturally between a dedicated signal line with a common clock signal between nodes.
  - Additional cabling and hardware make it unfeasible.
  - Synchronized clocks running a protocol that enables the synchronization of these clocks.
Simple Network Time Protocol

- Based on Network Time Protocol (NTP)

- An SNTP client assumes that the delays are symmetrical in both directions

- SNTP synchronization can be done every 16 s or slower

- Typical synchronization accuracy that can be achieved with SNTP is in the milliseconds range for moderately sized networks
Precision Time Protocol

- Different from SNTP, has several modes
  - A hierarchical setup with ordinary clocks and boundary clocks
  - A setup where network switches have transparent clocks and end nodes have ordinary clocks

- Accuracy of PTP
  - 1 microsecond with hardware help, event nanoseconds possible

- PTP Self configuring
Summary

- Key Aspects of modern automation system.
  - Requirements Analysis (Topology, Availability, Performance, Time Synchronization, and Security)
  - Network Architectures
  - Switches, Switch Architecture
  - Network Protocols
    - Redundancy (Spanning Tree)
    - QoS (Priority Layers)
    - Multicast and VLAN
    - Time Synchronization (Simple, Network Time Protocol)
      - Precision Time Protocol (Has multiple modes)
Future Look

- Continues development…
  - Trending away from fieldbus
  - Advanced Ethernet based network with complex functionalities

- Wireless Communication combined …
  - For where it’s hard to put cables

- Number of network management protocols to increase…
  - Telecom and data center techniques will enter industrial domain

- Current protocols evolution
  - E.g : PTP evolution …