What Protection Engineers Need to Know About Networking

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GE Grid Automation
Trends in P&C Communications

- In the beginning....RS-232
- Migration to Ethernet in IEDs....circa 1997
  - Only invented in 1972....fast adoption for our industry
- Desire for Interoperability
  - IEC 61850 – defined on Ethernet
- High Availability/Performance Requirement met
- Evolution of the Ethernet architectures
  - Ethernet Hub.....collisions
  - Substation Network / Full Duplex Switch
  - Utility Operations Network / MPLS
  - Coming.....Time Sensitive Networks......TSN
Ethernet Benefits:

- Multiple media (copper, fiber, wireless)
- Easy to deploy
- Low cost
- Mature.....with continuing development
- Well standardized
Ethernet via 900MHz ISM* and Cell

* Industrial, Scientific, & Medical
Point-to-Multipoint via Ethernet GOOSE

Low Latency on 900MHz possible....5ms Point-to-Multipoint 1.25Mbps Throughput Possible
SOF = Start of Frame

Min frame size: Preamble + SOF (8 bytes) + 14 + 46 + 4 = 72 bytes

Max frame size: Preamble + SOF (8 bytes) + 14 + 1500 + 4 = 1526 bytes
Protocol ID = 8100 hex – Identifies that the frame is extended
User Priority – 7 levels – prioritizes processing through an Ethernet Switch
- Required in GOOSE – minimum value of 4
VLAN ID – Virtual LAN address – “Tagged” messages only delivered to the specified VLAN port. 4096 IDs available….a few are reserved
Trunk Port – carries ALL VLAN Traffic between switches
Ethernet and Local Area Network

<table>
<thead>
<tr>
<th>1 to R Ether Dst</th>
<th>Ether Src</th>
<th>Type</th>
<th>IP Dst</th>
<th>IP Src</th>
<th>DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>08:00:20:00:00:03</td>
<td>08:00:20:00:00:02</td>
<td>IP</td>
<td>128.100.1.1</td>
<td>128.100.2.2</td>
<td>DATA</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>R to 2 Ether Dst</th>
<th>Ether Src</th>
<th>Type</th>
<th>IP Dst</th>
<th>IP Src</th>
<th>DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>08:00:20:00:00:01</td>
<td>08:00:20:00:00:04</td>
<td>IP</td>
<td>128.100.1.1</td>
<td>128.100.2.2</td>
<td>DATA</td>
</tr>
</tbody>
</table>
**Routing** – the process of selecting best paths in a network.

**Routers** – devices that forward data packets between networks

**Routing table** – a data table that lists the paths to network destinations

**Routing protocols** – dynamically updating addresses in the routing tables

**Default Gateway** – IP address of the “default” path off of the LAN

**Static routes** – Additional routes off the LAN that are manually configured
IP Address Configuration

- **IP Address**
  - **IPv4** – comprised of 4 bytes / 32 bits
  - **IPv6** – comprised of 16 bytes / 128 bits

- **Two Parts of an IP Address:**
  - Network Address and the Host Address
  - Routers operate on the Network Address

- **10.1.1.0/24** – IP Address and Network Mask
  - 24 Identifies the # of bits in the Network Address
  - In this case: 10.1.1 is the Network Address
  - Known as Classless Inter Domain Routing - CIDR
Protective Relays and Static Routing

Example of Deployment
## Protective Relays and Routing

### The Routing Table for the Presented Deployment

<table>
<thead>
<tr>
<th>Route Name</th>
<th>Route Destination IP Address</th>
<th>IP Mask</th>
<th>Route Gateway (Next hop)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Route 1</td>
<td>10.2.1.0</td>
<td>255.255.255.0 (/24)</td>
<td>10.1.1.1</td>
</tr>
<tr>
<td>Route 2</td>
<td>10.2.2.0</td>
<td>255.255.255.0</td>
<td>10.1.1.1</td>
</tr>
<tr>
<td>Route 3</td>
<td>10.2.3.0</td>
<td>255.255.255.0</td>
<td>10.1.3.1</td>
</tr>
<tr>
<td>Default route</td>
<td></td>
<td></td>
<td>10.1.2.1</td>
</tr>
</tbody>
</table>
Identifies the need for Multicast IP Networking
Multicast Path Establishment

Protocol: Internet Gateway Management Protocol (IGMP) v3
Reliability through Redundancy

Measures for achieving High Availability

- **Redundancy in the network – RSTP (IEEE 802.1D)**
  - Used in general automation systems
  - Response time: less than 500ms

- **Redundancy in the device – IEC 62439**
  - Parallel Redundancy (IEC 62439-3)
  - Parallel Redundancy Protocol (PRP)
  - Response time: 0ms

- **High-availability Seamless Redundancy (HSR)**
  - Response time: sum of delays through each node
Rapid Spanning Tree Protocol (RSTP)

Typical Performance: 500 milliseconds or less… NOT adequate for Protection Applications
**Parallel Redundancy Protocol - PRP**

**send on both LANs:** the stack sends each frame simultaneously on LAN A and LAN B.

Frames over LAN A and B have different transmission delays (or may not arrive at all)

**receive from both LANs:** the stack receives both frames, the entity between the link and the network layer handles the frames and can filter duplicates. Both lines are treated equal.
PRP Frame Identification

Basic Ethernet Frame

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sequence Number</td>
<td>16 bits</td>
<td></td>
</tr>
<tr>
<td>LAN ID</td>
<td>4 bits</td>
<td></td>
</tr>
<tr>
<td>Data+Trailer Size</td>
<td>12 bits</td>
<td></td>
</tr>
<tr>
<td>PRP Suffix</td>
<td>16 bits</td>
<td></td>
</tr>
<tr>
<td>Frame Check</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

PRP Frame Extension

Addition Called Redundancy Control Trailer - RCT
Reliability through Redundancy

Example of HSR Network
Security Principles Applied to P&C:

- Secure Defaults
- Restricted system access - RBAC
  - Separation of duty
  - Principle of least privilege
Message Security

For 61850, defined in IEC 62351

- Client-Server through Transport Layer Security (TLS)
- Device Integrity through Certificate Validation
- Message Authentication through Secure Hash - SHA
- Message Encryption through Advanced Encryption Standard (AES)
- Symmetric Keying
- Symmetric Key Distribution through the IETF Group Domain Of Interpretation - GDOI

Defined in IEC 61850 Routable GOOSE and Synchrophasors
Single Sign On through RADIUS*

* Remote Authentication Dial In User Service

AAA – Authentication, Authorization, and Accounting
Conclusions

- Protective relays are required to participate in complex deployments and rely on Ethernet.

- Baseline networking knowledge becomes very valuable to P&C engineers.

- This paper aimed to give ideas and solutions to some typical problems faced when integrating protective relays in an Ethernet based network.
Thank You

Questions?

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