Deterministic Communications for Protection Applications Over Packet-Based Wide-Area Networks

Kenneth Fodero, Christopher Huntley, and Paul Robertson
Schweitzer Engineering Laboratories, Inc.
Many utilities are moving toward converged IT / OT networks.

IT solutions are being pushed into OT systems.

Network visibility and management are moving toward centralized model.
Segregated vs. Integrated OT / IT Model

- Wind Generation
- Hydroelectric Generation
- Control Center
- Corporate Offices
- Solar Generation
- Fossil Fuel Generation
- OT Network
- IT Network
- Segregated Network
- Transmission Substation
- Distribution Substation
Segregated vs. Integrated OT / IT Model

- Distribution Substation
- Transmission Substation
- Control Center
- Wind Generation
- Hydroelectric Generation
- Solar Generation
- Fossil Fuel Generation

OT / IT Network

IT Network

Corporate Offices

Integrated Network
Communications-Assisted Protection Minimizes Fault-Clearing Times

- Enables high-speed tripping
- Provides coordination
- Enables differential comparison
Communications Channel Failure Negatively Affects Protection Dependability

- Increased tripping times
- Longer fault current duration
- Reduced equipment life
- Greater risk to safety
## Protection Performance Requirements for Critical Circuits

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Latency (ms)</th>
<th>Asymmetry (ms)</th>
<th>Restoration (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line current differential (87L)</td>
<td>5</td>
<td>&lt;0.5</td>
<td>5</td>
</tr>
<tr>
<td>Pilot protection</td>
<td>8</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Direct transfer trip (DTT)</td>
<td>10</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>
Preserving Deterministic Time-Division Multiplexing (TDM) Performance Over Packet Transport Virtual Synchronous Network (VSN)
Achieving Deterministic Packet Transport

Left Protected Line Module (PLM)

- Ethertype Handler
- Packetizer
- TDM Engine

Right PLM

- Ethertype Handler
- Packetizer
- TDM Engine

Deterministic Packet Transport

TDM Transport

TDM Circuits or Critical Ethernet
VSN Tunnel Across Core Transport

OT Edge Node

OT Edge Node

OT Edge Node

Core Network

Single provisioned path through core for all protection circuits
Bridging the Technology Gap

Core Network

OT Edge Node
OT Edge Node
OT Edge Node

SONET

OT Edge Node
OT Edge Node
OT Edge Node
OT Edge Node
Third-Party Validation of VSN
VSN Over Carrier Ethernet and Multiprotocol Label Switching (MPLS) Core Network

Three-Node Core Network Ring

- Core Node A
- Core Node B
- Core Node C
- Relay
- OT Edge Node
- Traffic Generator
# Third-Party Testing Results

VSN Over Carrier Ethernet and MPLS Core Network

<table>
<thead>
<tr>
<th>87L Channel Measurements</th>
<th>Carrier Ethernet (ms)</th>
<th>MPLS (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Round-trip delay</td>
<td>1.0</td>
<td>1.1</td>
</tr>
<tr>
<td>Transmit delay</td>
<td>0.5</td>
<td>0.6</td>
</tr>
<tr>
<td>Receive delay</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Asymmetry</td>
<td>0.04</td>
<td>0.16</td>
</tr>
</tbody>
</table>
Core Network Failover
Carrier Ethernet and MPLS Core Network

Relay → OT Edge Node → Core Node A → Core Node C → OT Edge Node → Relay

Line-current differential

Core Network

OT Edge Node → Core Node B → OT Edge Node
Edge Network Failover
Carrier Ethernet and MPLS Core Network
<table>
<thead>
<tr>
<th>Network Type</th>
<th>Failover Type</th>
<th>Technology</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core Network</td>
<td>Failover</td>
<td>Carrier Ethernet</td>
<td>~20 ms</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MPLS</td>
<td>~50 ms</td>
</tr>
<tr>
<td>Edge Network</td>
<td>Failover</td>
<td>VSN</td>
<td>5 ms</td>
</tr>
</tbody>
</table>
## Required Committed Information Rates (CIRs)

<table>
<thead>
<tr>
<th>STS-n (user-selectable)</th>
<th>Core Network CIR (Mbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>STS-1&lt;sub&gt;FE&lt;/sub&gt;</td>
<td>75</td>
</tr>
<tr>
<td>STS-1</td>
<td>94</td>
</tr>
<tr>
<td>STS-2</td>
<td>150</td>
</tr>
<tr>
<td>STS-3</td>
<td>204</td>
</tr>
<tr>
<td>STS-4</td>
<td>257</td>
</tr>
<tr>
<td>STS-5</td>
<td>309</td>
</tr>
<tr>
<td>STS-6</td>
<td>361</td>
</tr>
<tr>
<td>STS-7</td>
<td>413</td>
</tr>
<tr>
<td>STS-8</td>
<td>465</td>
</tr>
<tr>
<td>STS-9</td>
<td>517</td>
</tr>
<tr>
<td>STS-10</td>
<td>569</td>
</tr>
<tr>
<td>STS-11</td>
<td>621</td>
</tr>
<tr>
<td>STS-12</td>
<td>673</td>
</tr>
</tbody>
</table>
## VSN Is More Bandwidth-Efficient

<table>
<thead>
<tr>
<th>Network Technology</th>
<th>Bandwidth Efficiency (network-wide)</th>
<th>Quality of Service (QoS) Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPLS</td>
<td>60 IEEE C37.94 circuits = 120 Mbps</td>
<td>Per circuit</td>
</tr>
<tr>
<td>VSN</td>
<td>672 IEEE C37.94 circuits = 94 Mbps</td>
<td>1 setting</td>
</tr>
</tbody>
</table>
# Core Network Quality of Service (QoS) Settings

<table>
<thead>
<tr>
<th>Priority Queue</th>
<th>Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Network management</td>
</tr>
<tr>
<td>2</td>
<td>VSN</td>
</tr>
<tr>
<td>3+</td>
<td>All others</td>
</tr>
</tbody>
</table>
Deliver TDM Performance Over Ethernet Packet Core Network

- Set VSN as next highest priority after network management system (NMS) software
- Use strict priority scheduling for VSN
- Provide fixed path through packet core network
- Perform healing using network edge devices
Many Utilities Use Leased Ethernet Services for Substation Communications

- Analog leased services – end by 2020
- Migration from analog to Ethernet service
- Cost and latency performance challenges

Diagram:
- Substation
- Utility Analog Circuit
- Channel Bank
- Leased Ethernet Services
- 4-Wire VF Circuit
- T1 Circuit
- Channel Bank
- Substation / Control Center
Solution for Leased Analog Replacement

- Has equivalent performance to analog circuit (<5 ms latency for contact transfer)
- Minimizes migration cost
VSN Preserves Protection Channel Performance Over Ethernet Packet Core Network

Performance

- Jitter: submillisecond
- Latency: submillisecond
- Asymmetry: submillisecond
- Recovery: <5 milliseconds
- IT / OT integration: simplified
Questions?