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WHITE PAPER

An Ultra-low-latency Solution For Utilities

In 2003, the northeastern U.S. suffered the largest power blackout in the nation's history. For two days, 50 million subscribers in eight states and parts of Ontario lost power, resulting in an estimated $6 billion in economic losses. The primary cause of the outage: an inability to recognize, assess, and understand the inadequacies and deterioration of parts of the power grid over wide areas, a story not unfamiliar to critical infrastructure management. From reputation damage and expensive penalties to direct financial losses into the billions of dollars, network reliability at the critical infrastructure level was (and still is) a top concern in the utilities industry.

In addition to causing system and equipment damage that is costly to repair, faults on the power system can result in disturbances to normal system operations. Serious disturbances can even result in the loss of system stability and large-scale blackouts. Fault clearing is therefore an integral component of power transmission and distribution system design, maintenance, and operations. The protection schemes designed to identify and clear faults address a variety of objectives across the network:

- Remove the faulty element from the rest of the system.
- Limit or prevent equipment damage.
- Prevent severe power swings or system instability.
- Minimize adverse effects on customer loads.
- Maintain power system transfer capability.
- Prevent personal injury.

Power to keep the lights on
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Schemes, apps, and convergence

One type of method commonly implemented in power utility substations is a communications-assisted protection scheme across the WAN. This type of scheme facilitates coordination and data sharing between protection devices and makes it possible to employ methods that improve the scheme's dependability, selectivity, security, and speed. Reliable communications enable the implementation of differential comparison schemes, such as line current differential (87L) protection.

WANs are used to carry the relay protection multiplexed channels, in addition to other substation services (voice, teleprotection, telemetry, video, control and automation, email, and corporate LAN) and have become an integral and necessary part of modern power network protection systems.

TDM/SONET has been widely adopted across the power utility industry as the preferred WAN transport technology because it provides low-latency, deterministic, and minimal-asymmetry performance. However, there is a clear trend within the industry to move toward using Ethernet and packet-based networking for all power utility applications and services, including protection. The motivation to move away from TDM-based systems, especially SONET and SDH systems, is driven by a desire to converge IT and OT networks and standardize on a common set of interfaces to reduce capital and operating expenses. The migration to packet-based networking technologies such as Carrier Ethernet has created the challenge of engineering teleprotection services to provide the determinism and guaranteed performance required by protection applications.

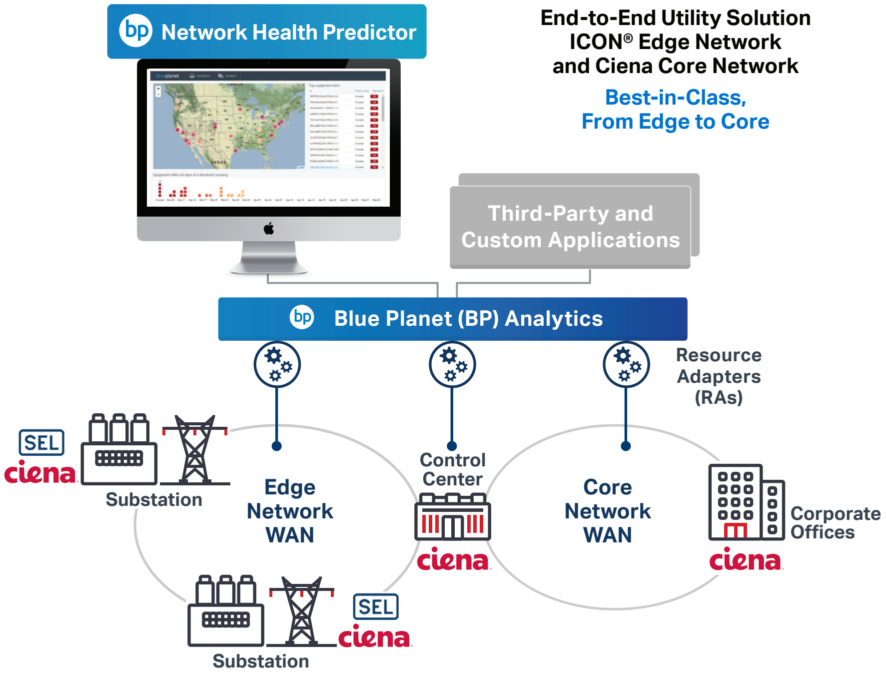

Figure 1. End-to-end utility solution ICON edge network and Ciena core network

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Avoiding another power outage like the one in 2003 requires a solution with ultra-low latency and very fast failover performance. If a power system fault occurs, communications-assisted protection schemes across the WAN operate to isolate the fault and prevent instability around the failure. Fault clearing times for major transmission line infrastructure need to be in the order of milliseconds, and if the power system fault condition is not detected and communicated with the lowest of latencies, equipment damage and larger portions of the power grid could be affected.

To address these challenges, Ciena has partnered with a best-in-class solution for the power substation, delivered by Schweitzer Engineering Labs (SEL).

The SEL Integrated Communications Optical Network (ICON) deterministic packet transport solution provides the innovative approach of delivering mission-critical traffic with low and deterministic latency over a Ciena Carrier Ethernet transport network. The concept is to preserve the performance characteristics of TDM, which are presently available in the ICON SONET platform, with no performance degradation when transported over Carrier Ethernet as a WAN transport protocol.

More about the Ciena and SEL solution →

Latency and failover test results of SONET encapsulation through a Ciena Carrier Ethernet core

The following test results demonstrate that it is possible with the SEL ICON Virtual SONET Network (VSN) concept to consistently provide low latency, low channel asymmetry, and extremely fast OT system restoration for failures in the core and edge networks. These performance results meet the requirements for protection applications.

Several standards specify communications channel performance requirements for electric power substation applications. By taking the performance requirements specified in IEEE 1646 and IEC TR 61850-90-12 and including relay manufacturer requirements for asymmetry and restoration, we can establish a summary of the communications channel performance requirements for protection applications (Table I).

Scheme	Latency (ms)	Asymmetry (ms)	Restoration (ms)
87L protection	5	<0.5	5
Pilot protection	8	5	5
Direct transfer trip	10	5	5

Table I. Communications channel performance requirements for protection circuits

Latency performance testing and results

The following test cases provide performance data for service encapsulation using the SEL ICON through a Carrier Ethernet (Ciena 3930/3932 IT WAN Node) core network. This network used the topology shown in Figure 2.

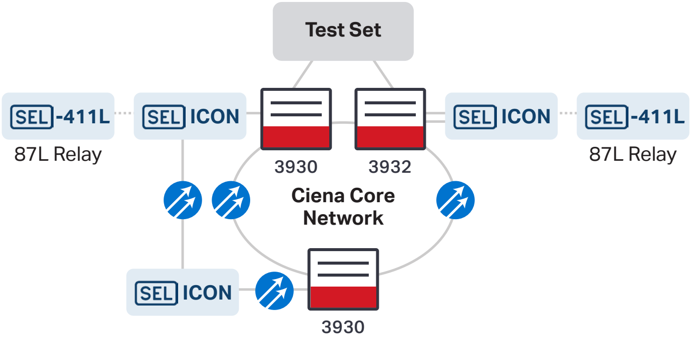


Figure 2. Test network topology

To establish a set of baseline data, two 87L relays were connected back-to-back with a fiber-optic jumper (Figure 3).

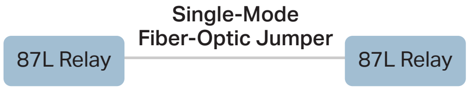


Figure 3. Test network topology

Next, the baseline 87L relays were connected to a three-node VSN. The latency and asymmetry information were recorded for comparison against the baseline relay data. Figure 4 shows the test topology for the VSN test system.

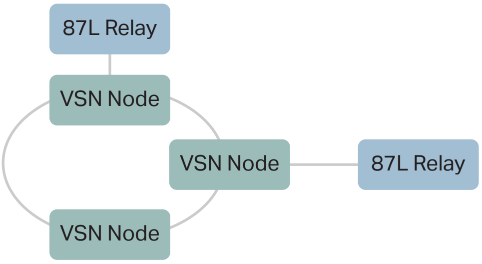


Figure 4. VSN test network

The VSN test network was then expanded to the topology shown in Figure 1. A three-node Ciena Carrier Ethernet WAN was inserted to act as the core network, so the test VSN was tunneled through the WAN and the 87L relays were still connected to the VSN. A test set was used to generate network traffic, simulating typical traffic load conditions. This was done to validate that the core network could use the QoS settings to give the VSN a higher priority over other network traffic to maintain deterministic performance. For the Ciena Carrier Ethernet network core, the VSN was given a Fixed Resolved Class of Service (F-RCoS) of 0 and the traffic from the test set was given an F-RCoS of 7.

The testing was performed over Ciena Carrier Ethernet core WAN nodes shown in Figure 1. In each test, an 87L relay was used to establish an 87L protection circuit, and the internal measurement capabilities of the relays were used to measure the latency and asymmetry of the channel. The latency and asymmetry performance parameters were recorded for the Carrier Ethernet network implementation. A series of five separate measurements were made in each test, and the average latencies and asymmetries were calculated.

Table II shows the results compared with the baseline and VSN-only data. Each VSN OT edge device used a variable-size jitter buffer based on the PDV of the core network to optimize latency through the IT core network. A PDV setting was used to adjust the size of the jitter buffer. For the Carrier Ethernet network, a PDV of 50 µs was used.

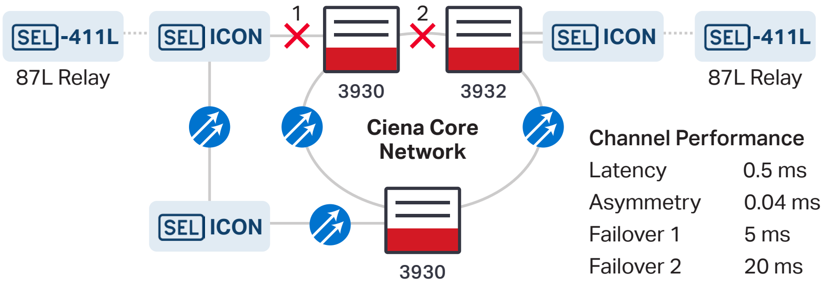
The test results in Table II show that the Ciena Carrier Ethernet network only introduced an additional 1 ms of round trip latency compared with the baseline and VSN-only configurations. The core network introduced minimal asymmetry and results are well within the communications channel performance requirements for 87L protection circuits summarized in Table I.

Parameter	Baseline (ms)	VSN (ms)	VSN and Carrier Ethernet (ms)
Latency (RTD)	0.1	0.1	1.1
Asymmetry	0.0	0.0	0.04

Table II. Communications channel performance test results

More importantly, the testing validated that appropriate QoS settings can be defined to provide VSN circuits with sufficient priority over other services to ensure the deterministic delivery of VSN frames, and thereby preserve the integrity and timing of the encapsulated SONET data.

Deterministic Packet Transport Delivers Industry-Leading Performance



Channel Performance	
Latency	0.5 ms
Asymmetry	0.04 ms
Failover 1	5 ms
Failover 2	20 ms

Figure 5. Core and edge network failover test results

Network healing test results

Network healing performance for the VSN paths can be optimized by provisioning unprotected point-to-point tunnels through the core network. Network healing is then performed by the VSN OT edge device rather than by the core network.

The following healing tests were performed to measure the comparative performance of edge versus core network failovers. The core network failover test involved breaking the fiber on the link, as shown in Figure 5 (Failover 1), and having the core network perform a failover to the redundant path on the opposite side of the ring. In the edge network failover test shown in Figure 4 (Failover 2), a link from the OT edge device to the Ciena Carrier Ethernet WAN node was broken and the OT edge network performed the healing.

The failover test results in Figure 5 show that a significant performance advantage can be achieved by using the OT edge network to perform network healing.

Summary

Utilities are implementing highly intelligent energy grids to improve operating efficiency, address consumer demands, and meet government mandates. These smart grids are powered by a two-way communications network that must be highly reliable and low latency, yet affordable to install and operate.

This paper has demonstrated that a VSN approach provides a method to deliver mission-critical protection and control system traffic over a Carrier Ethernet WAN while ensuring that the communications channel performance attributes meet the requirements specified in IEEE 1646 and IEC TR 61850-90-12. It elegantly addresses the challenge of migrating TDM-based protection circuits to Ethernet without impacting the performance of the network. OT network design, planning, and implementation are greatly simplified for complex networks with substation edge and core network elements that involve a combination of manufacturer equipment and transport technology.

This solution uses a simplified provisioning model that easily scales as the network topology changes and grows. Using point-to-point tunnels through the Carrier Ethernet core network with the highest QoS setting below the NMS ensures that the performance of critical circuits are maintained as changes are made on the network, avoiding the need to individually manage each protection circuit. Additionally, even though the traffic has higher priority, the delaying of all the other traffic is negligible (a maximum of 0.1 μs per network link for a 10GbE core network).

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