ciena
Experience. Outcomes.

WHITE PAPER

A Smarter Communications Network for the Smart Grid

Driving smart grid transformation with Ethernet-based packet-optical networks

Introduction

As electric utilities evolve to the smart grid, they need a comparable evolution of the underlying communications network. A flexible and future-proof network is critical for meeting a utility's business goals and ensuring that smart grid applications perform securely and reliably. However, most utility networks today are not up to the challenge, and some next-generation network solutions can be very costly and cumbersome when deployed on a large scale.

The smart grid requires an advanced network that:

- Supplies critical voice and data services for grid operations and management
- Meets increased requirements for performance, bandwidth, security, consolidation, and support for legacy applications
- Enhances the flexibility, reliability, security, and efficiency of all smart grid elements
- Enables monitoring, automation, and optimization of grid operations

Today's utility networks, based on SONET/SDH technology, are difficult and expensive to maintain, and cannot support the long-term needs of a smart grid. Additionally, many utilities will need to replace multiple, special-purpose overlay networks that were created to support legacy devices and specific IT and operations requirements.

Continuing to invest in these legacy networks is not viable for the smart grid transition. Instead, utilities should look at options for a next-generation communications network that will help them and their customers fully realize the benefits of the smart grid, as shown in Figure 1.

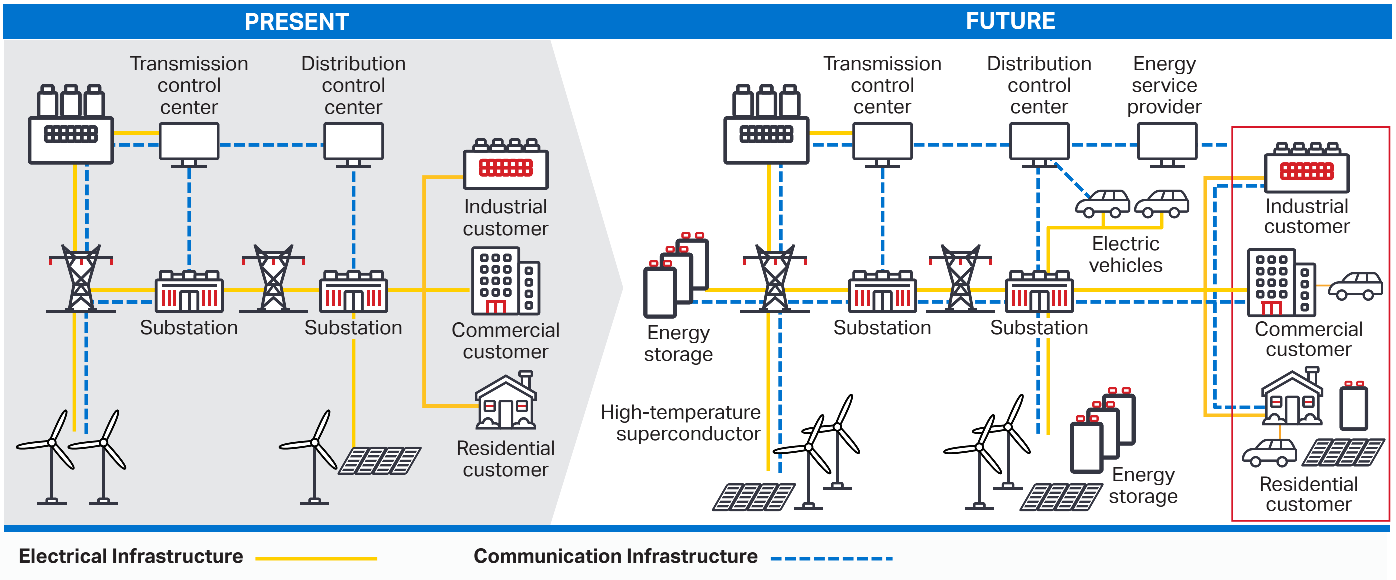

Figure 1. In a smart grid, the network enables communications among systems at every level, both within the utility's grid and IT infrastructure and externally with customers

Supporting key smart grid communications

A communications network that is optimized for a smart grid can support functions such as:

- Aggregating and delivering data from customer meters to the control center, which allows for real-time or near-real-time meter reads and meter data management programs
- Connecting the automation equipment and Intelligent Electronic Devices (IEDs) used in grid control and optimization systems
- Delivering critical, latency-sensitive substation data to monitor and diagnosis programs for improved grid reliability

Alternatives for the communications network architecture

IP/MPLS networks are often the de-facto choice for upgrading a legacy network and many utilities are not aware they have a choice in how to architect a next-generation network. The assumption is often that, because other enterprise networks are IP-based, the only choice is to build a best-effort, router-based IP network that uses Multi-Protocol Label Switching (MPLS) services.

Today, many operators of mission-critical networks around the world are moving to deterministic packet-optical technology. However, some utility IT teams may hesitate to consider packet-optical technology because of two misconceptions about its design and capabilities, compared to a routed network.

The first misconception is that all network services are moving to IP, so it is best to route all traffic. In a utility network, not all traffic is IP, and packet-optical switching is generally more efficient for handling multiple traffic types. While the service layer may include IP addressing, there is no reason to burden the packet transport layer with unnecessary IP routing.

Additionally, IP on its own is a connectionless technology, which makes the important task of traffic engineering inexact and cumbersome. Although the task can be simplified somewhat by using tools for IP traffic engineering, this effort adds unnecessary complexity to network operations.

Finally, while routing is important, it can be unnecessarily costly and complex if deployed everywhere in the network. For example, the need to manually configure individual routers contributes to a linear growth in operating costs as each new device is deployed. Instead, it is simpler and less costly to switch data traffic through a very reliable and deterministic lower transport layer.

The second misconception is that IP routing reduces costs and simplifies overall network architecture by eliminating lower (L0, L1, L2) network layers. In fact, lower layers are advantageous because they can increase network efficiency and availability as well as accommodate the non-routed traffic generated by certain utility applications.

The ultimate goal of packet-optical switching is to provide more network scalability and resiliency, at a lower cost per bit unit than a routed network.

A packet-optical network: How it works

A packet-optical network architecture integrates an agile optical layer, based on Layer 0 Dense Wavelength Division Multiplexing (DWDM), with a Layer 1 Optical Transport Network (OTN) layer and a Layer 2 Carrier Ethernet packet layer. This architecture allows application traffic to be delivered as wavelengths, timeslots, or packets using the most cost-effective network layer.

At its most basic, packet-optical switching converges all transport elements into a single platform that operates in Layers 0 to 2.5. In comparison, an IP router operates only at Layer 3. Not all traffic is IP-routed, and many network services can benefit from lower-layer switching, as shown in Figure 2

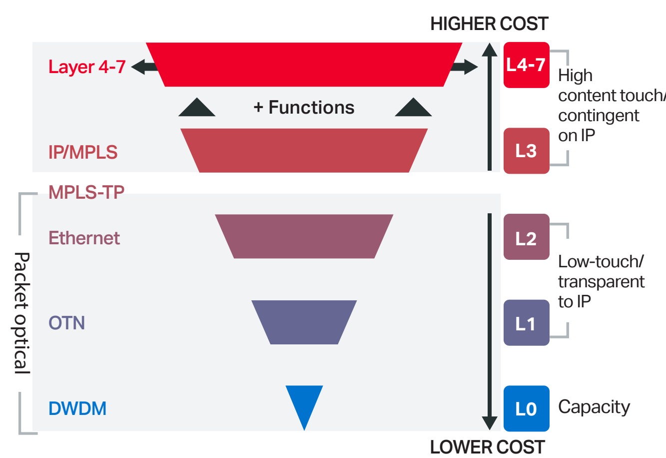

Figure 2. Packet-optical technology operates at layers 0-2.5 to cost-effectively handle multiple types of network traffic.

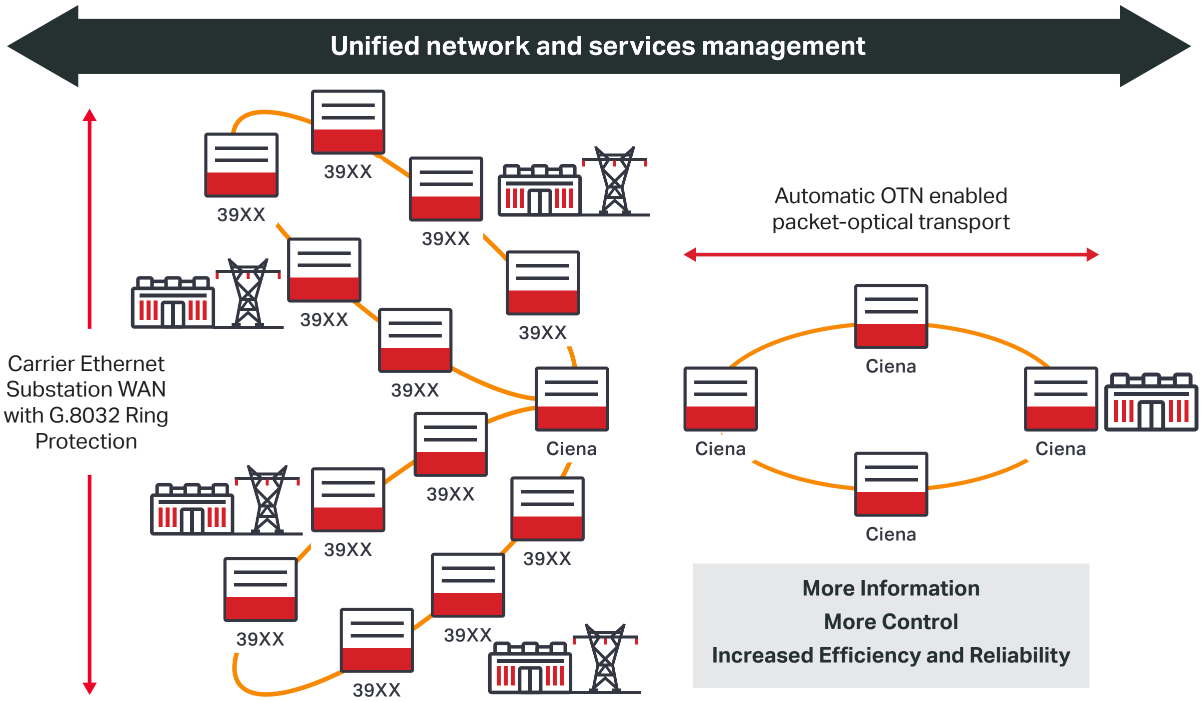

Figure 3. Architecture of a substation aggregation network, based on Carrier Ethernet, that interworks with a core packet transport network enabled by OTN

Another advantage of these lower layers is providing connection- oriented packet transport rather than the connectionless transport of IP. Connection-oriented transport—whether it uses wavelengths, OTN connections, or Ethernet tunnels—has deterministic characteristics for bandwidth allocation, paths through the network, and end-to-end measurements. This design yields much simpler and more predictable packet transport operations, particularly for traffic engineering, maintenance, and troubleshooting.

By using lower layers, the network can tailor solutions for different operations scenarios. For example, one scenario keeps the layers separate and deploys pure Layer 2 Carrier Ethernet substation rings, as shown in Figure 3. This scenario also uses a converged packet-optical core network that carries both Ethernet substation traffic and other protocols, such as Fibre Channel storage data, between a utility's data centers.

Another scenario extends a converged packet-optical network to the substations to carry IP and Ethernet packet traffic along with legacy Time Division Multiplexing (TDM) circuits. In both cases, the mix-and-match approach of packet-optical technology allows for a network design that aggregates and switches traffic at the most efficient and cost-effective layer in the substation and core networks.

Understanding programmable optical bandwidth with OTN

OTN is a very versatile optical transport technology that can replace costly and limited SONET/SDH transport networks. As a Layer 1 technology, OTN handles multiple services over optical transport systems efficiently, cost-effectively, and reliably. It creates a way to insulate the network against changing traffic needs through capabilities for programmable bandwidth.

OTN provides three key functions for programmable bandwidth in the WDM layer: it has containers that can carry any protocol; it allows for efficient wavelength sharing; and it enables traffic switching and grooming across the network. Together, these functions make the bandwidth of a WDM layer more programmable in terms of format, size, and routing of multiple traffic types.

Both SONET/SDH and OTN map protocols into traffic containers. In a SONET/SDH network, those containers are all the same size, but are not always filled up by the data, which makes for an inefficient transport system.

In an OTN, those containers can carry any data protocol in any combination, and the containers can be right-sized to the specific traffic and transport requirements, as shown in Figure 4. This OTN programmability translates into overall network efficiency, meaning OTN can deliver very high bandwidths as utility networks scale to serve data growth.

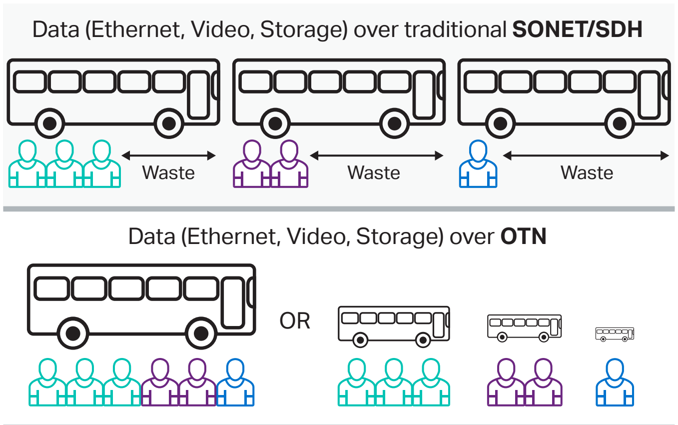

Figure 4. OTN programmability allows for significantly more efficient use of network bandwidth.

OTN also supports simple, secure separation of critical grid operations traffic from corporate and IT traffic when carried over the same fiber network.

Understanding Carrier Ethernet

Carrier Ethernet is the Layer 2 communications technology in a packet-optical network. It brings all the benefits of traditional Local Area Network (LAN) Ethernet (ubiquitous, extremely low-cost, simple, fast, reliable) to demanding Wide Area Networks (WANs). It also offers reliability, manageability, and predictability characteristics comparable to those in a utility's conventional network solutions.

Carrier Ethernet is defined by five significant technical attributes that distinguish it from LAN Ethernet: standardized services, scalability, reliability, Quality of Service (QoS), and service management. These attributes mimic the role of Ethernet within the LAN but transform Carrier Ethernet into a technology suitable for deployment in a WAN. Additionally, just as Ethernet works with IP in the enterprise LAN, Carrier Ethernet works with IP in the WAN.

Carrier Ethernet is a cost-effective evolution from TDM in the distribution and substation networks because it supports IP applications and new, Ethernet-based IEDs. It also avoids Layer 3 security and latency concerns.

For these reasons, utilities are drawn to Carrier Ethernet to control costs and ensure business processes can scale effectively, while maintaining security and control over critical IT and operational functions.

Advantages of a packet-optical network

Bringing packet and optical technologies together delivers two key advantages. First, data based on IP, Ethernet, and legacy TDM can coexist on the same optical WDM network. Second, packet-optical technologies improve network efficiency through attributes such as packet aggregation, QoS, and efficient bandwidth use.

Packet-optical technology retains several benefits of legacy transport services, including familiar operations and management, deterministic performance, resilience, high availability, and low latency. These benefits are enhanced by the key efficiency attributes of packet technology, including low costs, support for multiple services, bandwidth efficiency and flexibility, and QoS assignments.

Packet-optical technology provides the bridge from legacy SONET/SDH networks to next-generation OTN/Carrier Ethernet networks by efficiently supporting any mix of traffic with no stranded investment. The utility can transition the traffic mix over time, simply by stopping the use of legacy circuits and increasing the use of Ethernet-based services.

In addition to these overall benefits of a packet-optical network, Carrier Ethernet technology offers several key advantages for a utility's smart grid communications:

- **Simplicity.** Carrier Ethernet is easy to deploy with automated provisioning and remote turn-up testing and verification. Because faults can be detected and isolated remotely and changes are simpler to make, network management and maintenance reduce demands on a utility's network operations team.
- **Reduced costs.** Carrier Ethernet enables convergence of all communications services over a common network infrastructure, which greatly simplifies operations and controls costs.
- **Improved network security and control.** An inherent layer of security is built in to Carrier Ethernet because it is not a routable protocol, so address snooping is not a concern. By using Ethernet-based data encapsulation, the utility can ensure traffic is delivered to its proper destination.

- **Flexible, scalable bandwidth.** Unlike TDM technologies that are based on fixed increments of bandwidth, Ethernet has very granular scalability that allows for dynamic adjustments to capacity requirements on a per-site basis.
- **Advanced Operations, Administration, and Maintenance (OAM) tools.** Carrier Ethernet supports a very rich set of standards-based OAM tools that provide advanced capabilities for network monitoring and management. These tools give utilities greatly improved visibility into the status and performance of their network connections.
- **Low latency.** Substation and grid automation applications demand extremely low network latency, measured in milliseconds. This high sensitivity to latency presents one of the main challenges for IP-based MPLS networks, which can suffer from jitter, congestion, packet drops, and retransmissions. In contrast, Carrier Ethernet connectivity can be engineered to be very deterministic. Its low latency also makes Carrier Ethernet a viable option for the time-sensitive protocols used in mission-critical applications such as teleprotection.
- **Deterministic traffic flows**. Carrier Ethernet allows for traffic engineering, which ensures the specific route a packet flow will take through a network. These route links, along with the backup routes, can be planned to ensure transmission resiliency with sub-50 millisecond failovers.
- **Protocol transparency.** Unlike IP-based Virtual Private Network (VPN) services, Ethernet VPNs can support all legacy application protocols that may still be used by a utility. This support is achieved through simple traffic mapping into the Layer 2 frames that transparently traverse the network, without additional conversions or processing.

Packet-optical reference architecture for a smart grid communications network

Figure 5 shows Ciena's packet-optical network reference architecture for end-to-end smart grid communications, divided into four district network domains.

The home-area network domain uses a wired or wireless network within a customer's home to transfer information between the grid and customer devices such as displays, computers, energy management devices, and smart meters.

The field-area network domain supports two-way delivery of information between smart meters and data collectors or access points. This network can be wired or wireless and may be owned by the utility or a third-party service provider.

The next two domains—the backhaul and core backbone networks—cover most of the grid's critical transmission, distribution, and control systems. These domains have

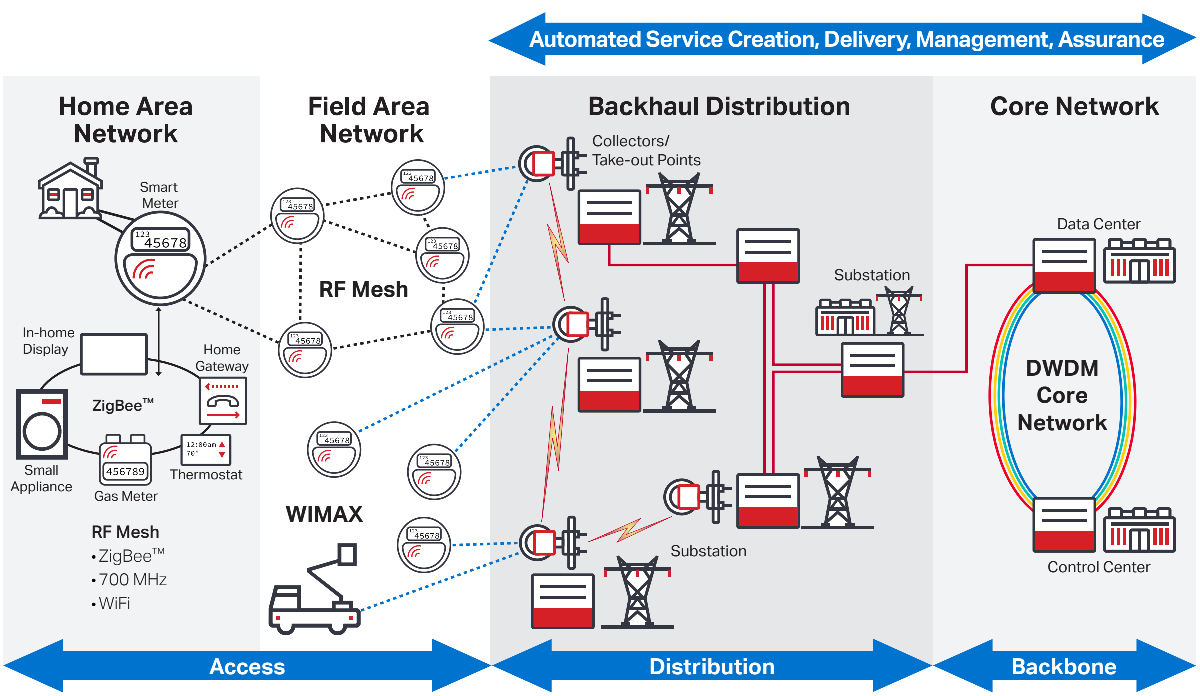

Figure 5. Reference architecture for a packet-optical network to support smart grid communications

the most stringent network requirements, including high availability, scalability, low latency, interoperability, and security.

The backhaul network connects all of a utility's data collection points—such as the smart meter data collectors and transmission and distribution substations—to central operations control centers. This network typically uses a combination of high-capacity fiber, wireless microwave communications, and leased telecom circuits.

The core backbone network contains the high-capacity nodes that interconnect a utility's control centers, data centers, and substation distribution networks. This network typically has a ring or mesh topology that allows any-to-any connections among devices.

The backhaul and core networks support critical grid operations such as Supervisory Control and Data Acquisition (SCADA) control and monitoring systems. These networks also connect field equipment for automating power distribution, including Remote Terminal Units (RTUs) and IEDs such as circuit breakers, reclosers, switches, capacitors, and transformers that allow remote monitoring or control.

Migrating legacy infrastructure for substation automation

Substation automation is a key element in transforming a utility's infrastructure for the smart grid. The International Electrotechnical Commission (IEC) standard 61850 specifies network requirements to support information and applications for substation automation. In principle, this standard will lead to a simpler, more unified infrastructure for the substation network, based on Ethernet, with reduced costs and better reliability.

However, the task of migrating from a legacy substation to a next-generation substation promised by IEC 61850 is challenging. Many utilities have not fully committed to the standard due to their need to continue support for legacy network TDM interfaces on non-IEC 61850 equipment.

It is important to understand that migration to the IEC 61850 standard does not force replacement of protocols already in place. Solutions can be implemented that allow parts of the IEC 61850 standard to be added to the network while continuing to use legacy protocols. With the right plan, utilities may modernize at their own pace, using packet-optical communications as a bridging technology between the legacy and packet protocols.

Figure 6 shows one approach to that legacy migration challenge. For the substation, the network must support a potentially long list of installed legacy protocols, in addition to newer IP/Ethernet devices. The utility may plan to replace legacy SCADA devices with modern Ethernet IEDs.

In this example, a purpose-built substation multiplexer is used to aggregate the low-speed serial and TDM interfaces, then hand-off an Ethernet LAN interface to the packet backhaul network. At that point, the packet-optical features enable very manageable, resilient, and converged data transport between the substations and control centers.

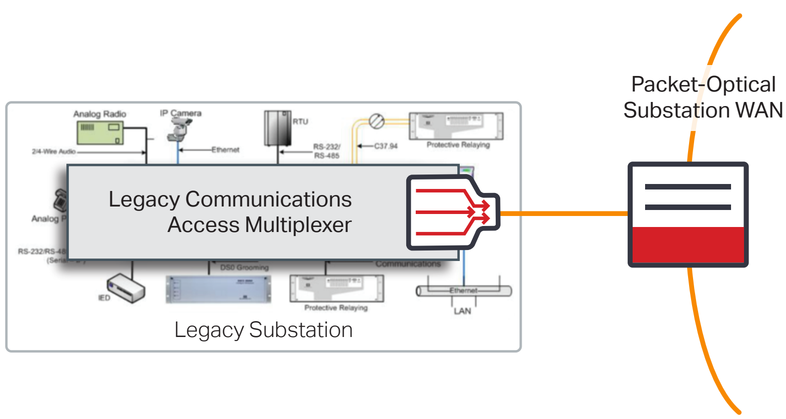

Figure 6. Packet-optical networks enable converged data transport between and within substations and control centers.

Northeast utility deploys a statewide packet-optical network

Ciena worked with a statewide utility that manages a 650-mile electricity transmission system connecting 20 electric distribution utilities throughout Vermont. The utility's existing network environment was based on a legacy OC-48 SONET fiber infrastructure and leased T1s connecting to the substations. Within the substations, a variety of devices were used to multiplex legacy services such as TDM phone systems, analog voice, and legacy RTU and SCADA devices.

For its next-generation network, the utility is using a statewide packet-optical network solution from IBM and Ciena. This network provides lower operating costs with greater performance, scalability, and interoperability with all of their connecting distribution utilities. The new network also allows the utility to support current operational requirements such as relay traffic, SCADA, enterprise voice and data, and an advanced metering infrastructure. As it implements new smart grid programs, the utility can manage the new network with a relatively small staff.

A smarter model for smart grid communications networks

Ciena offers a smarter approach to modernizing utility networks, with a robust, manageable, and cost-effective alternative to SONET/SDH and routed IP/MPLS networks. Although packet-optical architectures may be new to the utility industry, these technologies are field-proven in demanding wireline and wireless networks around the world. Packet-optical networks offer utilities the benefits of lower capital and operating costs, more deterministic behavior, and predictable benefits for multiple network services.

Looking to the future, Ciena solutions support straightforward upgrades from 1G to 10G to 100G bandwidth. This easy scalability will become increasingly important as information grows to become the cornerstone of a utility's business and operational transformation.

With the Ciena building blocks of DWDM, OTN, and Carrier Ethernet technology, as well as unified management, utilities can tailor their evolving networks for any smart grid operational paradigm.

Visit the Ciena Community
Get answers to your questions