ELECTRIC POWER RESEARCH INSTITUTE

Serial/Time Division Multiplexing (TDM) Replacement

Technology Options for Packet-Based Replacement of TDM Circuits

2017 TECHNICAL UPDATE

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Technology Options for Packet-Based Replacement of TDM Circuits

EPRI Project Manager
J. Herman

ELECTRIC POWER RESEARCH INSTITUTE

3420 Hillview Avenue
Palo Alto, CA 94304-1338
USA

PO Box 10412
Palo Alto, CA 94303-0813
USA

800.313.3774
650.855.2121

askepri@epri.com

www.epri.com

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Abstract

Legacy data communications technologies and services based on serial and time division multiplexing (TDM) are rapidly becoming unavailable. Many electric utilities have significant quantities of circuits of these types deployed for operational communications. Planning for the replacement of these circuits is imperative in order to avoid disruptions of service and minimize costs. Packet switched based data communications technologies and services are explored and guidance provided for choosing and specifying appropriate solutions for various utility network requirements.

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PRIMARY AUDIENCE: Utility staff responsible for information technology (IT)/telecom planning and implementation.

SECONDARY AUDIENCE: Telecommunications service providers and equipment vendors interested in the utility communications market segment.

KEY RESEARCH QUESTION

As legacy serial and time division multiplexing (TDM) services and equipment become unavailable, what are appropriate solutions for electric utilities to consider as replacements?

RESEARCH OVERVIEW

Member utilities were surveyed to obtain specifics on the current state of their serial and TDM implementations. Information gathered included the status of notifications from telecommunications service providers' sunsetting of legacy services, existence of ground protection rise (GPR) isolation equipment on copper circuits at substations, use of serial and TDM equipment in members' private networks, overview of the utilities' telecom procurement and implementation procedures, and circuit transition plans at present. Discussions with two large telecommunications service providers (AT&T and CenturyLink) were held during which appropriate replacement services for utility serial/TDM circuits were explored. For the utility private networks, several equipment vendors were contacted, and their product roadmaps and recommendations were obtained. The most common utility telecommunications network needs and organization were cataloged and high-level requirements analyzed and then mapped to the solution set with best fits noted.

KEY FINDINGS

- Transitioning away from serial and TDM leased lines is not an option due to telecommunications service providers (TSPs) sunsetting.
- Video surveillance is a requirement for most member utilities and is typically the largest single bandwidth consumer for the network.
- SONET is still a valid option for private commercial, industrial, and institutional (CII) with at least two original equipment manufacturer (OEM) vendors committing and able to support their product families beyond commodity IC manufacturers discontinuance of commodity components via the use of field programmable gate arrays (FPGA).
- The majority of utility members are in the process of implementing multi-protocol label switching (MPLS) in their private networks, but at least one has decided on Next-Gen Optical instead.
- Successful transition may best be achieved by tailoring a plan of formal requirements and gap analysis.

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EXECUTIVE SUMMARY

WHY THIS MATTERS

Failure to adequately plan for serial/TDM replacement could result in service disruptions of critical operational and business communications. In any case, the costs to support legacy services and equipment are increasing.

HOW TO APPLY RESULTS

Utilities should investigate the sunset dates for all serial and TDM services they obtain from any TSPs. In addition, utilities should obtain from all original equipment manufacturer (OEM) vendors the end-of-life (EOL) dates and roadmaps for all serial and TDM equipment products used in their networks. Next, utilities should perform a requirements analysis and an alternatives analysis before procuring or even issuing requests for proposals (RFPs) for replacement products and services.

LEARNING AND ENGAGEMENT OPPORTUNITIES

- Member utilities have an opportunity to participate in continued collaborative research on this topic in 2018 in the ICT Program under Project Set 161G, Telecommunications.

EPRI CONTACTS: Tim Godfrey, Technical Executive, tgodfrey@epri.com

PROGRAM: Telecommunications Initiative Program 161 Supplemental

Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

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Section 1: Current State

Introduction

Although the telecommunications (telecom) and electric utility industries essentially began at about the same time (the telephone patented in 1876 and the incandescent light bulb in 1879), the former has historically experienced a much more rapid pace of technology evolution than the latter.

> There is a popular comparison that underscores the pace of change—or lack thereof—regarding our nation's grid. The story goes like this: If Alexander Graham Bell were somehow transported to the 21st century, he would not begin to recognize the components of modern telephony—cell phones, texting, cell towers, PDAs, etc.—while Thomas Edison, one of the grid's key early architects, would be totally familiar with the grid. [1]

This mismatch provides some background on the situation that electric utilities find themselves in: the impending retirement of legacy serial and time division multiplex (TDM) technologies. Electric utilities have a history of incorporating new telecommunications technologies into their operations soon after their invention—land mobile radio, point-to-point microwave radio, and fiber optics to name just a few. Communications systems and equipment provide only a supporting role in an electric utility, but they often provide significant benefits, such as increased reliability of the electrical systems and reduced costs of operations and maintenance—hence the incentive for their rapid deployment.

The other side of the dual-edged sword, however, is the relatively quick obsolescence of many telecom and data communications technologies. The continued operation of systems and equipment beyond the point at which they are supported by vendors presents risk in the form of unplanned outages and increased costs. Therefore, a plan to transition from legacy serial and TDM technologies is needed.

This report is organized as follows:

1. Review of fundamental telecom and computer network communications technology evolution and adoption of such for electric utility private network development.
2. Requirements analysis of utility communications use cases.

3. Solutions analysis for both public carrier and private network alternatives, along with a mapping of solutions to use cases.
4. Summary, conclusions, and recommendations for next steps to reduce risk and to transition away from legacy services and technologies.

Telecommunications Technology Evolution

To better understand the challenges, a review of some basic fundamentals of telecommunications technologies is provided. This review is limited to these three steps of technology evolution that are most relevant to this discussion: serial data communications, TDM, and SONET/SDH.

Serial Data Communications

The public switched telephone network (PSTN) was originally developed to carry voice signals, but with the advent of computers and the desire to interconnect them, a method of transmitting data signals across the same voice-grade telephone lines was developed. The device that enabled this was the modem.

Because voice-grade telephone lines are limited in bandwidth (typically 300–3400 Hz), there is a corresponding limit to the maximum data rate that modems are able to operate [2]. Modem technology advanced greatly throughout the 1990s with the use of digital signal processing techniques, which resulted in speeds greater than 30 kilobits per second (kbps).

As a result of the modems being connected to the serial ports of computers, these types of low-speed data connections across telecommunications service provider (TSP) networks are generically referred to as *serial data communications*.

Standardization of the serial interface was achieved, with RS-232 becoming the most popular. This 25-pin port became a standard feature on almost all modems and computers. A 9-pin version was developed soon afterward and was a ubiquitous presence on personal computers (PCs) until serial ports were eliminated as modems disappeared from the home and office environment.

Time Division Multiplexing

Multiplexing refers to methods of combining multiple low-speed communications channels into a single higher speed channel. This was necessary for the commercial telephone network to keep pace with growth in the form of increased demand for circuits. Several analog multiplexing systems were developed and deployed, with the early systems mainly using frequency division multiplexing techniques. In the 1960s, the state of art was advanced with the introduction of digital TDM techniques.

These TDM systems are digital with the voice signals converted into a digital data stream before multiplexing many individual channels into one higher speed signal; this is referred to as a *carrier* signal. The voice signals are digitized by sampling at a rate of 8,000 samples per second and quantized into 8-bit digital words, resulting in a 64-kbps data stream for each voice channel.

In North America, the first-level carrier signal was selected to consist of 24 low-speed channels, and in Europe a 32-channel system was chosen. With the addition of framing bits, the resulting total high-speed line rate for North America is 1.544 megabits per second (Mbps) and 2.048 Mbps for European systems. These systems are also referred to as *T1* and *E1*, respectively.

In addition to being used for efficient transport of voice signals, the TDM carrier systems were adapted for high-speed data communications. Circuits became available from TSPs for transport of digital signals at either the lower speed individual channel rate (64 kbps, referred to as *clear channel*, or 56 kbps if not) or at higher speeds consisting of multiples of 64 kbps, up to the full T1 or E1 carrier line rate.

There is a next-level TDM system in which 28 T1 line rate signals are combined into a T3, which operates at a line rate of almost 45 Mbps.

SONET/SDH

A main disadvantage of TDM systems is that they are asynchronous with regard to timing. The receiving terminal in a TDM system recovers timing from the received signal. Maintaining a certain amount of alignment between the transmitting and receiving equipment clocks is important for error-free sampling of the data. This limitation prevents the ability to add or drop an individual low-speed channel at a terminal without de-multiplexing and then re-multiplexing the entire carrier signal. This inability to build add/drop multiplexors (ADM) was the impetus for the creation of a synchronous system that would have this ability. This next-generation, synchronous digital network technology was SONET in North America and SDH in Europe.

SONET/SDH systems make use of a highly accurate master clock that is distributed to all terminals in the network. The recommended network topology for SONET/SDH systems originally was ring configurations. Various protection schemes and protocols were developed to make use of this topology to create highly reliable networks.

Line rates were also increased over asynchronous TDM systems, with SONET/SDH rates of approximately 50 Mbps, 150 Mbps, 600 Mbps, 2.5 Gigabits per second (Gbps), and 10 Gbps being the most popular. Circuits at these data rates are still generally available from TSPs with SONET/SDH standardized interfaces.

Computer Networking Technology Evolution

With regard to computer networking, a review of some basic fundamentals of the technologies is also useful to understand how the industry has arrived at the current state. This field is extremely diverse; therefore, the review is limited to the most popular and relevant technologies and the evolution from one to the next.

The first computers were stand-alone installations that performed batch processing of data that were locally fed into the machines. Interactive terminals were then developed that allowed more dynamic interaction between the programmers/users and the equipment. This quickly led to a desire to move the terminals to remote locations, which created the need for data communications circuits. Analog, voice-grade telephone lines with modems (described previously) were used. A point-to-point topology between the remote terminal and a bank of modems at the data center was the typical arrangement. The telephone circuits used were either normal switched (*dial-up*) or dedicated non-switched (also called *private lines* or *leased lines*).

As the size and cost of computers improved, more machines were installed as many industries found beneficial applications for computers. University and research institutions as well as the financial services industry were the most rapid early adopters.

The interconnection topology started to evolve to the point that in addition to the point-to-point connections between computers and remote terminals, multi-point circuits were implemented. These were still analog, voice-grade circuits, but they were "bridged" so that what was transmitted from one station would be heard at all of the other stations.

Packet Switching

The major paradigm shift that has repercussions that are still being experienced today was the creation of packet switching. This is fundamentally a different approach than the circuit switched technology that the telecommunications industry had begun with and continued to improve upon in an incremental fashion. Packet switching is an enabling technology for widescale computer networking. It accomplishes this by creating an abstraction between the physical and the logical network topologies.

OSI Seven-Layer Model

A good way to understand this abstraction is by examining the OSI seven-layer model created by the International Standards Organization (ISO). OSI stands for *Open System Interconnect* and provided a framework upon which a set of standards could be created for networking of heterogeneous systems and equipment.

> The communications functions are partitioned into a vertical set of layers. Each layer performs a related subset of the functions required to communicate with another system. It relies on the next lower layer to perform more primitive functions and to conceal the details of those functions. It provides services to the next higher layer. Ideally, the layers should be defined so that changes in one layer do not require

changes in the other layers. Thus we have decomposed one problem into a number of more manageable subproblems. [3]

The reference diagram for the model as published by the ISO in the X.200 standard is shown in Figure 1-1.

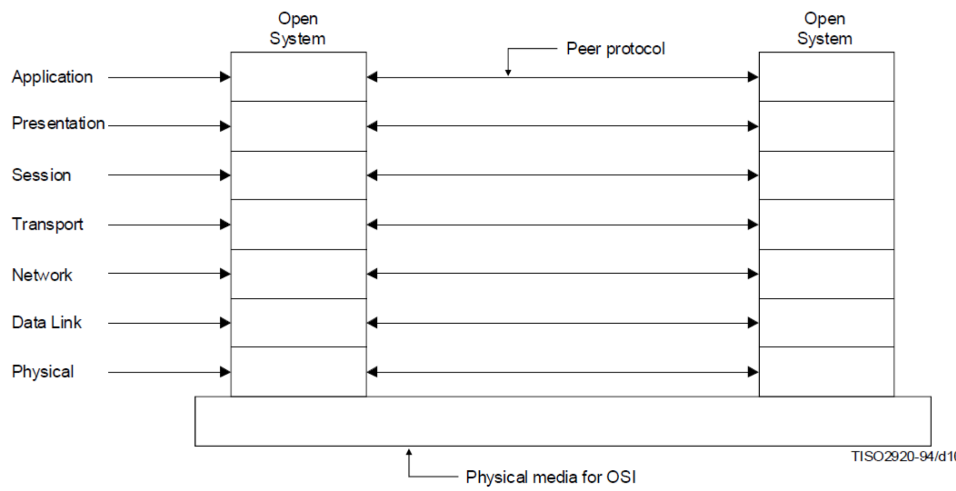

Figure 1-1
ISO Seven-Layer Reference Model for Open Systems Interconnection [4]

Ethernet

The lower two layers of the interconnection model are all that is needed in local area networks (LANs). The structure that obtained the highest rates of adoption for LANs was a bus topology. In this arrangement, all of the stations are connected to the same physical media. To share the access to the media, three techniques are possible: round robin, reservation, or contention.

A round-robin protocol is one in which each station is given a turn to transmit and receive information while all of the other stations wait. The control of which station has access may be centralized, such as a poll-response approach, or decentralized—which was used by the method known as *token-ring*. A reservation approach is very similar to TDM discussed previously, in which rigid time slots are created. However, in a LAN implementation, there may be a dynamic aspect in their assignment to the stations.

Contention-based protocols (also known as *random access*) have their roots in a system called *Aloha* that was developed by the University of Hawaii to interconnect its inter-island campus computer networks via a wireless satellite relay. This fundamental technology was incorporated into the LAN protocol of Ethernet, which became predominant. The standards for Ethernet are maintained by IEEE under the 802.3 working group.

A key improvement of Ethernet over the predecessor Aloha-type protocols is the ability to detect a "collision" when multiple stations attempt to access the channel at the same time.

> The IEEE 802.3 standard defines the carrier sense multiple access with collision detection (CSMA/CD) medium access control (MAC) protocol for bus topology. It also defines a variety of physical layer transmission medium and data rate options…. The MAC protocol is the heart of the 802.3 standard, which is often referred to simply as the CSMA/CD standard. [5]

There have been many updates to the IEEE 802.3 standard as well as changes to the implementation practices. The most notable is the evolution from a bus to a star topology. As the physical media changed from a coaxial cable to twisted-pair wiring, it was found that better flexibility and maintainability could be obtained by aggregating service drops from each terminal at a single location. The practice was to parallel the voice-telephone cabling; therefore, the location for the converged data cabling was the telecommunications closet—at which point a device called a *hub* was in the earlier versions of Ethernet that created an electrical bus from the physically routed star wiring drops. The next evolution was to replace the hub with an Ethernet switch. This allowed for much greater performance by removing collision domains. The Ethernet switch examines the MAC addresses of the data packets and connects individual ports together as needed for the traffic, which isolates them from other ports when they do not need to participate in a particular packet exchange.

Transmission Control Protocol/Internet Protocol

The next few layers up in the idealized ISO reference model have been realized in the Transmission Control Protocol/Internet Protocol (TCP/IP) protocol suite. Originally developed by the U.S. Department of Defense under the ARPANET research program, the TCP/IP protocol suite has become the foundation for the Internet. The standards are maintained by the Internet Engineering Task Force (IETF).

The IP's main function is to attach global addresses to the data packets for both source and destination. The IP packets are then routed through the network via gateways and are sent in a "best-effort" method with no guarantee of delivery or tracking. The next higher layer, TCP, provides all the mechanisms necessary for ensuring reliability. Some of the functions that TCP performs to accomplish this are multiplexing (through the use of port numbers), connection management (including establishment, maintenance, and termination), data transport (ordering, labeling, and flow control), and error reporting [6].

Figure 1-2 shows the four layers of the TCP/IP protocol suite. Note the simplification from the ISO seven-layer model.

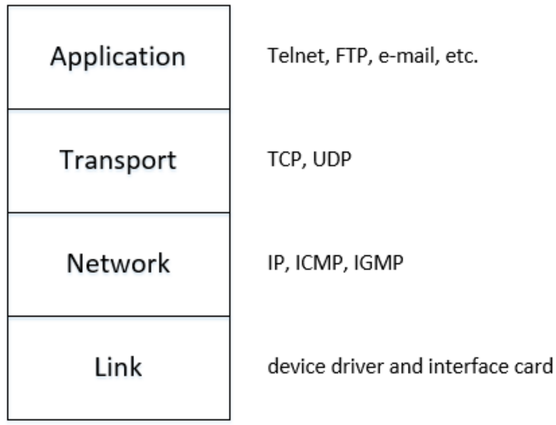

Figure 1-2
The Four Layers of the TCP/IP Protocol Suite [7]

On the right side of Figure 1-2 are listed some additional protocols. UDP is similar to TCP but does not provide the reliability functions; it is therefore used for data streams that are able to suffer some lost packets but are benefited by the lower latency that UDP delivers versus TCP. The ICMP and IGMP are control message protocols used by the nodes in the network and are therefore not seen by the terminal host clients or servers. At the top of the diagram are some of the earliest application protocols that were developed. The practical functionality that they provide was a main reason for the rapid adoption and growth of the Internet.

X.25 Protocol

The earliest commercial implementation of packet switching was through the use of the X.25 protocol. Standardized by the CCITT in 1976, it became widely deployed by TSPs in the 1980s and 1990s [8]. Although the protocol is packet based, it contains procedures for establishing connection-oriented, virtual circuits in addition to connectionless data transfer as is usually associated with packet switching. X.25 service was typically provisioned across TDM distribution system operator (DS0) circuits.

Frame Relay

As a follow-on to X.25, a more streamlined set of protocols was developed under the name *Frame Relay*. Improvements were made to the call control and signaling methods used for setting up logical connections, multiplexing and switching were moved from Layer 3 to Layer 2, and flow control and error control were no longer duplicated at Layer 3 and Layer 2. The result was that Frame Relay performed with lower delay and higher throughput than X.25 [9].

Frame Relay was typically provisioned over DS1 circuits or multiple DS0s (known as *fractional T1*). The technology became widely adopted and is only currently becoming retired by TSPs.

Integrated Services Digital Network

The Integrated Services Digital Network (ISDN) was an effort to gradually migrate the entire PSTN from analog to digital technology. There were two interface versions: basic rate (BRI) and primary rate (PRI). The former was developed to work across the twisted-pair copper loops that connected residential and business dial-up telephone lines; the latter was developed to leverage the higher speed DS1 transport equipment.

A BRI line consisted of two *B*, or *bearer* channels, at 64 kbps and one *D* channel used for signaling or low-speed data at 16 kbps. The U.S. version of a PRI line consisted of 23 B channels and 1 D channel, all at 64 kbps, with 30 B channels and 2 D channels for the European version.

Although PRI achieved a reasonable degree of success and was deployed on a wide scale by TSPs, BRI service saw limited rollouts beyond pilots and trials. The transition was anticipated to take “one or more decades” [10]; this was likely the most significant factor in its commercial failure, as cable modems were developed that provided residential subscribers with multi-megabit-per-second data rates. The cable television industry seized the opportunity and deployed cable modem technology, leaving insufficient market share for BRI ISDN.

ATM

The desire to extend the ISDN standards to “broadband” data rates was one of several triggers for the development of the asynchronous transfer mode (ATM) protocol. The higher speeds were needed for the core of the TSP networks and to serve very large enterprise customers.

The ATM standards were jointly developed by American National Standards Institute (ANSI) and International Telecommunications Union (ITU) (formerly the CCITT). The choice was made to use a 48-byte cell (data packets) as a compromise between the optimal needs of voice traffic—which works best with small frequent packets—and data exchange, which operates more efficiently with very large packet sizes.

The main parameters affected by the choice between a fixed or variable cell length are bandwidth efficiency, memory requirements, and delays. Variable-sized cells are more efficient than fixed-size cells. The standards development organizations (SDOs) chose to sacrifice efficiency for smaller memory requirements in the multiplexers and the faster switching times [11].

The ATM specification mapped traffic into one of four classes of service (A, B, C, or D), which consist of various combinations of timing required between source and destination, constant or variable bit rate, and connection oriented or connectionless [12]. The ability to handle digitized video was also a design consideration in the ATM standards, which is best accommodated with medium-sized packets delivered with low latency and without quality-of-service guarantees.

In general, ATM achieved some success over several years in both public carrier and large enterprise private networks. However, ATM was burdened by complexity in configuration and high cost for equipment. The widespread adoption of TCP/IP, which in most cases could be economically transported across SONET equipment, was the likely cause for ATM to all but disappear from the industry.

Multiprotocol Label Switching

Multiprotocol label switching (MPLS) is a set of standards maintained by IETF. The technology addresses many of the same goals that ATM was intended to resolve: support for multiple traffic types, scalability, and low latency.

There are various "flavors" of MPLS, and to describe each would require different sets of acronyms and complicated diagrams. The fundamental concept can be succinctly described this way: for any particular flow of traffic between two endpoints, the MPLS system routes once and then switches the rest [13].

Figure 1-3 is a high-level illustration of the routing and switching mechanism. The first packet of a traffic flow is routed via the network routing protocol (Layer 3) used by the particular MPLS network and the route established by an MPLS technique called *Label Distribution Protocol* (LDP). This is shown in Steps 1a and 1b via the dashed lines with arrowheads.

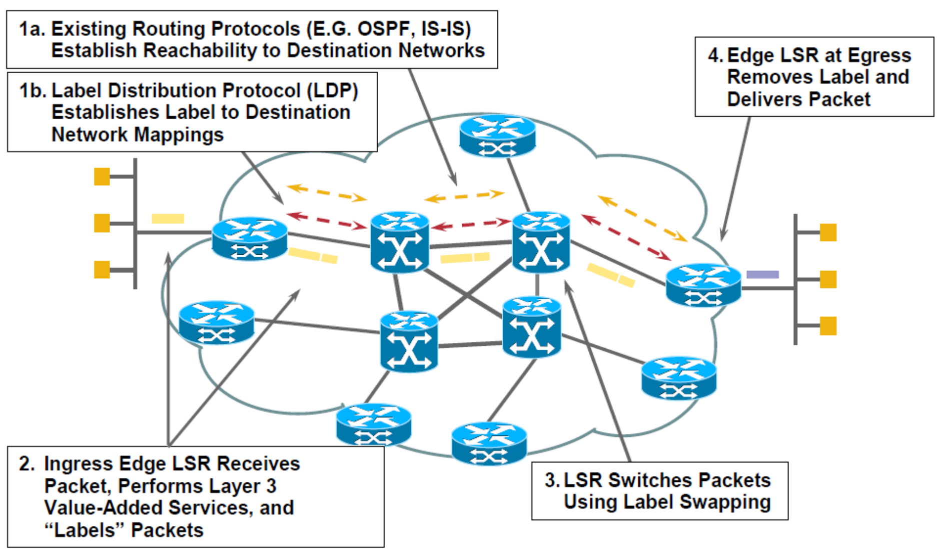

Figure 1-3
MPLS Operation Fundamentals [14]

With the route now established, the rest of the packets in the flow obtain an MPLS label at the ingress MPLS router, shown by Step 2 and the solid yellow lines. In the interior of the network, the packets have labels swapped at each node as they are switched along the path from source to destination (Step 3). At the egress MPLS router, shown in Step 4, the last MPLS label is removed and the packet handed back to Layer 2 for final delivery. For a traffic flow that traverses multiple MPLS networks, labels are stacked as they enter each network and removed as they exit. This technique contributes to the scalability of MPLS.

The MPLS label is added between the transport protocol (Layer 2) header and the Layer 3 header as shown in Figure 1-4. Because of the way that MPLS uses both switching and routing, and the method of placing the label inside the packet (rather than wrapping the packet), it is usually referred to as a *Layer 2.5 protocol*.

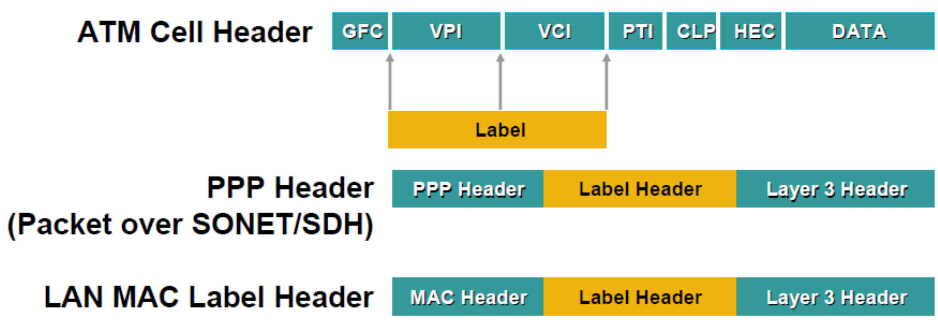

Figure 1-4
MPLS Label Placement [15]

MPLS is seen as a mature technology that was initially deployed in TSP core networks and then moved into access and edge environments [16].

Carrier Ethernet

Carrier Ethernet (CE)—also known as *Metropolitan Ethernet*, or *Metro E*—is the extension of Ethernet beyond LAN and campus environments to the much greater distances needed in metropolitan area networks (MAN) and WAN applications.

An industry alliance known as the *Metro Ethernet Forum* (MEF) was formed, which has created standards and certifies compliance of equipment vendors. The initial standards development, MEF 1.0, defined two architectures and service types. However, MEF 1.0 addressed the capability for TSPs to offer customers CE service only within their individual service areas. There were two initial service types:

- E-Line, for point-to-point service
- E-LAN, for multi-point–to–multi-point service

Under MEF 2.0, additional standards were released that defined the provision of services across interconnected TSP networks. MEF 2.0 also added two additional architectures and service types [18]:

- E-Tree: "rooted" multi-point networks such as broadcast
- E-Access: wholesale access service needed for interconnected TSPs

CE may be procured from a TSP as a "best-effort" service or with guaranteed service-level agreements (SLA). In the case of the latter, the following items are specified when ordering the service [19]:

- CIR (committed information rate)
- CBS (committed burst size)
- EIR (excess information rate)
- EBS (excess burst size)

The sustained effort of the MEFs over several years is likely a key factor behind CE achieving the majority market share with regard to the type of service that TSPs are providing to enterprise customers for a private network solution. Now with the emergence of cloud services and software-defined networking (SDN) and network function virtualization (NFV), the MEF is positioning CE as the best alternative for current and future needs. This is likely in response to the threat to market share that MPLS is posing. Regardless, Figure 1-5 shows the MEF's mapping of MEF standards and recommendations to the SDN/NFV system architecture.

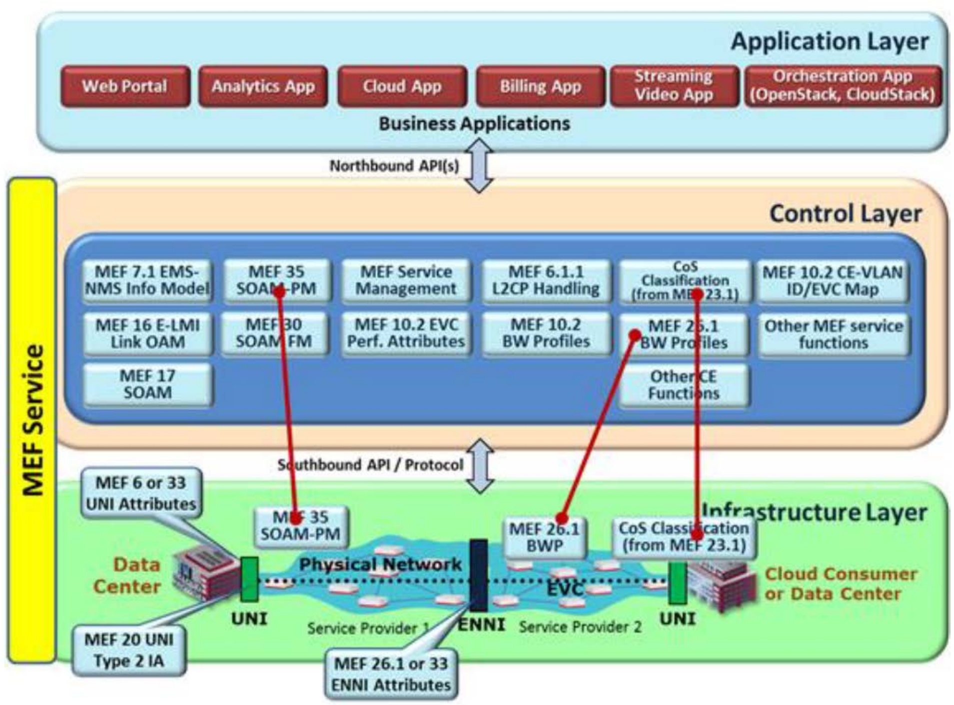

Figure 1-5
Mapping MEF Specifications to SDN/NFV [20]

SDN/NFV

Software-defined networking and network function virtualization are recent developments in the industry and although distinct are closely related. The combined technology has two main goals: 1) enable an increase in the speed with which new network services may be created and 2) reduce the reliance on proprietary technology and the incumbent vendor "lock-in."

The core concept behind SDN/NFV is the creation of an abstraction and a decoupling between the physical network equipment and its control and application programming. Standardized interfaces are being defined for interaction among the three separate planes: a physical infrastructure layer in which the traffic data flows, a control layer for the software that operates the infrastructure, and an application layer used to define the behavior of the network on an as-needed basis. The high-level architecture and interfaces are illustrated in Figure 1-6 as originally published by the Open Network Foundation (ONF), which is the primary SDO working to standardize and promote the technology.

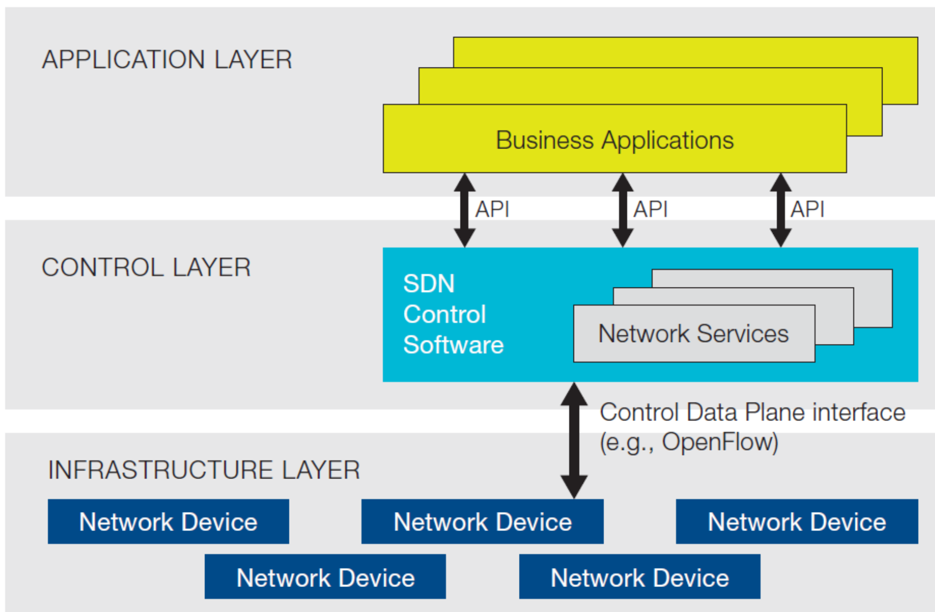

Figure 1-6
High-Level SDN Architecture [20]

It appears that the largest market at present for SDN/NFV is enterprise networks with remote offices that are using cloud services. The technology has enabled these users to reduce their reliance on expensive carrier WAN services with performance guarantees and to use the Internet in a dynamic and secure fashion.

Private enterprise networks are also starting to benefit from SDN/NFV due to the existence of "white box" or vendor-neutral solutions. These have enabled the use of general purpose computer equipment in place of proprietary network switches and routers.

Standards Organizations

There are several SDOs for the telecommunications and the computer networking industries. With regard to the technologies listed previously, the following are the main SDOs:

- American National Standards Institute (ANSI)
- Consumer Technology Association (CTA)
- Electronic Industry Alliance (EIA)
- European Telecommunications Standards Institute (ETSI)
- Metro Ethernet Forum (MEF)
- Open Network Foundation (ONF)
- Telecommunications Industry Association (TIA)
- Telecordia Technologies Inc. (formerly Belcore)
- International Electrotechnical Commission (IEC)
- Institute of Electrical and Electronics Engineers (IEEE)
- Internet Engineering Task Force (IETF)
- International Standards Organization (ISO)
- International Telecommunications Union (ITU)

There is a complex relationship among these entities. Some produce and recommend standards, while others certify them at either a national or international level.

Electric Utility Communications Networks

There are over 3,000 utilities in the business of providing retail electric service in the United States [21]. Consequently, there is an enormous variety of communication network solution sets in use by these companies. Although it would be impossible to list all of them, a high-level categorization of the most common arrangements is a useful tool for our analysis.

The use of telecommunications technology in an electric utility may be divided into two major categories based on the systems that they support: IT applications and operational technology (OT) applications. These two main “silos” have generally evolved through an isolated path to arrive at the current solution sets.

IT Applications/Systems

As with any other customer-focused enterprises with multiple locations and many employees, there is a need for back-office and front-office IT infrastructure. To perform their functions, personnel in headquarters and remote offices need access to many applications, such as the following:

- Accounting

- Billing and customer information system (CIS)
- Customer call center
- Enterprise resource planning (ERP)
- Geographic information system (GIS)
- Human resource applications
- Mobile workforce management system
- Procurement and supply chain management
- Voice telephone (fixed and mobile)

The majority of these applications/systems require minimal WAN and/or field area network (FAN) connectivity; however, two of them do require significant connectivity:

- **Voice telephony.** Provided to almost all workers, with office personnel having fixed line service and remote workers typically being provided with a cellular telephone and/or land mobile radio (LMR) handset.
- **Customer call center.** The number of agent positions is proportional to the size of the utility and often is supplemented with auxiliary positions/locations or outsourced resources during weather events when high call volumes are anticipated.

OT Applications/Systems

Various types of utilities rely on systems that, to perform their function, require data transferred to and from remote facilities and equipment. However, electric utilities are unique with regard to the speed with which their systems must operate versus others such as water/wastewater, natural gas, and pipelines. This difference is based on the nature of the product being supplied. These other utilities are moving a physical commodity that has mass and is moved at rates that are very slow relatively to the near speed of light dynamics of an electrical power system.

Following are some of the most common OT applications and systems used in electric utility operations:

- Advanced metering infrastructure (AMI)
- Distributed energy resources management system (DERMS)
- Distribution management system (DMS)
- Energy management system (EMS)
- Meter data management system (MDMS)
- Outage management system (OMS)
- Protection and control systems (P&C)
- Supervisory control and data acquisition system (SCADA)

Most of these items already exist at the vast majority of electric utilities, but DERMS and DMS are recent/emerging applications and may exist presently at only a small minority of companies in the industry.

Legacy Service Provider Leased Circuits

As with any other large enterprise with personnel at multiple locations, utilities found that services from TSPs were an economical solution to their internal voice and data communication needs. For external communications requirements such as regular business telephone, inbound call center lines, and now Internet access, service from one or more TSPs is a necessity.

For OT telecom needs, there is somewhat of a split in philosophy with regard to reliance on TSPs for connectivity. Many electric utilities over the years developed a reliance on TSP "leased" circuits for a variety of OT systems connectivity. The specific systems that have been implemented with TSP circuits vary by utility, but there are instances in which core applications such as SCADA and various P&C schemes are included.

One category of transmission line relay protection that was deployed in large numbers using TSPs was the first generation of pilot wire relaying. This technology used two-wire leased lines between the substations across which direct current (dc) is passed in order to send blocking or tripping from one relay to the other. This was the original form of teleprotection and enabled faster tripping of faulted lines over previous technologies, limiting equipment damage and reducing hazards to the public.

Subsequent generations of pilot wire have been developed and use carrier tones and even digital data to coordinate protection between two or more ends of a transmission line. However, the practice of obtaining the communications circuit for teleprotection from a TSP was incorporated into many utilities' standard methods and procedures.

Utility Private Network Development

Usually the starting point for a utility private network has been the construction of dedicated, utility-owned telecommunications infrastructure for P&C applications. In a vertically integrated electric utility, the transmission line teleprotection relay requirement for secure and reliable communications was the instigating factor for many to construct some telecommunications infrastructure—specifically, the desire to move beyond pilot wire relaying that was dependent on TSP leased lines. There were two main issues with dc pilot wire relaying—distance limitations and reliability:

> Generally, wire pilots no longer than about 5 to 10 miles are used, but there are a few in service as long as about 27 miles. …the technical limitations on the length of a pilot circuit are its resistance and shunt capacitance. Compensating reactors are sometimes used when the shunt capacitance is too high. A pilot circuit that is rented from the

> telephone company may be much longer than the transmission line for whose protection it is to be used, because such telephone circuits seldom run directly between the line terminals. Therefore, in borderline cases, one should find out the actual resistance and capacitance before deciding to use wire pilot…. In general, wire-pilot relaying is not considered as reliable as carrier-current-pilot relaying, mostly because many of the wire-pilot circuits that are used are not very reliable. The pilot circuit represents so much exposure to the possibility of trouble that great care should be taken in its choice and protection. [22]

The appearance of microwave radio technology in the 1950s and substantial and rapid improvements in later decades provided a compelling solution for utilities' teleprotection needs. Microwave radio terminals were constructed at transmission substations and microwave relay stations as needed at sites in between, in order to provide dedicated, reliable circuits for teleprotection.

Fiber-optic cable and SONET terminals became the next leap in capabilities adopted by electric utilities as a teleprotection solution. The dielectric nature of fiber optics allowed the cable to be safely attached to the power line structures and enables cost-efficient system deployment.

As a result of the continued practice of deploying microwave and fiber optics for teleprotection, many utilities found that they had extensive reach and capacity in their telecommunications networks. It was then economically justified to expand the systems to reach administrative types of facilities such as corporate headquarters, service centers, data centers, business offices, and other locations where personnel are stationed and require voice and data access. The result of proceeding on this path is the current state with many utilities possessing extensive private infrastructure with many generations of technology and equipment.

Section 2: Requirements Analysis

Requirements analysis is the process of eliciting, defining, and refining the complete set of functional capabilities, quantifiable performance specifications, and necessary nonfunctional qualities of a product or service. This process is a subset of the larger discipline of systems engineering that is extensively used in the defense and aerospace industries. Although the replacement of legacy telecommunications services and equipment at a utility is orders of magnitude less complex and costly than procurement of a military weapons system, leveraging some of the techniques of requirements analysis is recommended to help ensure a successful result.

An overview of the inputs and outputs of the requirement analysis element of systems engineering is shown in Figure 2-1.

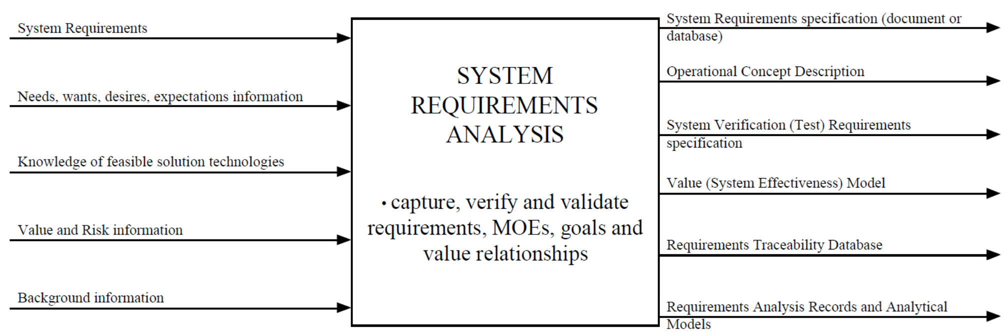

Figure 2-1
System Requirements Analysis Element of Systems Engineering [23]

Guidance is provided next for some of the requirements analysis inputs. The discussion is high-level but specific to the electric utility industry and types of telecommunications needs and organized along these areas:

- Corporate WAN
- Branch office
- Field work force
- SCADA telemetry
- Protective relaying
- Substations

Corporate WAN

Falling into the category of corporate WAN is the connectivity required to enable all of the IT applications that staff use to perform their daily work. It includes the IT resources of both clients and servers as well as the back-end databases, whether hosted at the utilities' own data center or outsourced to a third party or cloud services vendor. Voice telephone capabilities for all personnel are likely to have been converged onto the corporate WAN as a voice over Internet protocol (VoIP) application. If this has not yet occurred, planning for this eventuality is prudent.

Locational Inventory

For either service from a TSP or a utility private network solution, the first step is to inventory the locations where service is needed. For a very large investor-owned utility (IOU), each region or subsidiary operating company will need to be examined separately. Typical facility types are a headquarters or main corporate address, often in the downtown area; one or more data centers typically in an industrial or office park environment; and several service center/warehouse facilities, usually strategically located in all quadrants of the service territory on large parcels of land and close to a major road or freeway.

Bandwidth Assessment

IT management will in almost all cases have access to statistical data on the use of the existing WAN links. They will also likely have a process for staying ahead of growth to avoid situations in which users experience constraints. The planners may use simple rules-of-thumb process and overprovisioning links with excess capacity and, when the headroom begins to disappear, take action to increase capacity. The organization may choose to use a more disciplined approach and perform traffic simulation with network planning software. In either event, the utility telecom team should work closely with IT network staff responsible for the corporate WAN to size each link appropriately.

Reliability and Redundancy

For locations that are on the core of the WAN, the consequences of failure are high—and precautions should be taken to ensure adequate reliability. There are several ways to accomplish this, with the main ones being equipment redundancy, backup power, and multiple and diverse links. One aspect of the link diversity that is often overlooked is the cable entrance into the building. In addition, when intentionally procuring service from more than one TSP, one needs to ensure that the TSP is indeed separate infrastructure and not in actuality consolidated into the same cable and equipment via a carrier-to-carrier sub-ordering arrangement.

Branch Office

Remote branch office locations such as customer bill payment offices, engineering offices, or other smaller locations that have low staff counts (less than a couple dozen) are simply special cases of a core site. The same process should be followed with regard to identifying the locations and bandwidth needs. The reliability and redundancy will typically be relaxed unless there is something unique about the location that requires high levels of reliability.

Field Work Force

The *field work force* category refers to staff that spend the majority of their time in the field, for example, troubleshooters, line workers, and inspectors. For these workers, mobile voice and data solutions are required. Typically, this is accomplished via cellular telephones, laptop computers with cellular cards, and vehicle-mounted and/or handheld mobile radios. For some types of workers and vehicles, an automatic vehicle location (AVL) system is installed. In other instances, a utility may use a narrowband mobile data system when high-speed data rates are not needed, such as for a text-based trouble ticket/work order system.

Because the available mobile technology options have inherent constraints on bandwidth, the requirements analysis typically focuses on identifying the workers that require mobile voice and/or data solutions and the coverage areas over which they need to function. Applications used by the field workers need to take the bandwidth constraints into account when they are being designed.

SCADA Telemetry

Primarily located at substations, SCADA and telemetry have traditionally required low data rates (kbps rather than Mbps) and relaxed latencies (seconds rather than milliseconds). There is a wide variety of protocols, mostly proprietary, from a large number of vendors that have operated in this market over a long period of time. The network architecture for these has typically been point-to-multi-point, or bridged in the case of analog circuits, because many SCADA systems operate primarily in a poll-response type of environment.

The communications port type on legacy SCADA remote terminal units (RTUs) were RS-232 serial. Various vendor-specific proprietary protocols were used; more recently one standardized protocol achieved broad adoption: DNP3. Modern SCADA RTUs have Ethernet ports and therefore operate at 10 Mbps or faster data rates.

Protective Relaying

There are two types of communications used by protective relaying applications. When communications between relay controllers are provided for coordination of tripping (either through blocking or permitting schemes), the practice is referred to as *teleprotection*. Relay controllers often have an additional communications port for remote engineering access, which may be used by relay technicians to examine oscillography data or to modify relay settings. The engineering access communications requirements are similar to those for a workstation, that is, 10/100 Mbps Ethernet; however, because of security concerns, they will be kept separate from the corporate WAN.

Teleprotection Latency, Data Rate, and Reliability

The communications channels for teleprotection have evolved over multiple generations of equipment, and much legacy equipment is still in use by many utilities. The earliest equipment passed dc currents across the twisted-pair copper circuit between relays. The next generation used audio tones to communicate. Newer types of relay controllers pass continuous streams of digital data across a full-duplex channel. The state-of-the-art, however, is the use of Ethernet with TCP/IP and the IEC-61850 protocol. Because of timing and latency concerns, this has as yet been mostly limited to being used within a substation control house or switchyard complex. Deployment between relays at distant substations is an emerging application.

For the bulk power system, guidance for the performance of teleprotection is provided by the regional reliability councils that operate under the North American Electric Reliability Corporation (NERC). From the Western Area Coordinating Council (WECC), the current published guidance document has latency requirements for some relay protection schemes with a maximum end-to-end latency of one 60-Hz cycle, or 16.67 ms, and a functional availability of 99.95% [24].

Substations

Although the previously discussed SCADA telemetry and teleprotection items apply at substations, there is a need to cover the substations as an aggregate item because at present, the largest number of locations and site types for the OT network is a utility's substations. Whether a generation and transmission (G&T) or a distribution utility, substations are the most frequent points at which critical OT communications must be present. Therefore, it is important to perform a thorough assessment of the most common substations telecommunications requirements before analyzing solutions alternatives.

A high-level approach to compiling communications requirements for a typical utility substation is provided in Table 2-1. In addition to the fundamental bandwidth and latency requirements, it is helpful to record the reliability and priority assignments for each application because these can be used for setting packet-switching parameters.

After accurate data transport requirements for all substation applications are gathered, a traffic model for the backhaul facility can be created. In a TDM-based network, all of the data flows would be summed (100% duty cycle). But with a packet-switched network, the practice of *oversubscription* is used, allowing the use of lower speed and more economical links to serve each substation.

Table 2-1
Representative Substation Communications Compilation [25]

Application	Approx. Bandwidth	Max. Latency	Reliability	Priority	Per Device	Per Substation
AMI backhaul	500 kbps	15 s	99	Low	X	
Substation DNP	12 kbps	100 ms	99.99	High	X	
Pole-top device DNP	12 kbps	100 ms	99.9	Medium	X	
VoIP telephones	80 kbps	100 ms	99.9	High	X	
Engineering access	1.5 Mbps	200 ms	99.9	Medium		X
Network management	1.5 Mbps	5 s	99.99	Low		X
Cyber security logging/correlation data	1.5 Mbps	200 ms	99.9	Medium		X
Video surveillance	3.0 Mbps	100 ms	99	Medium	X	
Other future application	10 Mbps	200 ms	99.99	Medium		X

Section 3: Alternatives Analysis

This section is divided into two parts, first an analysis of current public carrier alternatives. It is assumed that even if legacy TDM service types are available from some TSPs, it would not be prudent to consider such services because the trend is toward the complete retirement of any technology not inherently based on packet switching. Any legacy TDM service obtained from a TSP is, or will likely eventually be, based on circuit emulation (pseudowires) and therefore transported across a multiprotocol label switching (MPLS) network.

The second part of this section is an analysis of some currently available packet transport equipment that is appropriate for use in the creation of dedicated, utility private network telecommunications infrastructure.

Public Carrier Alternatives

Discussions with two large public carrier service providers (AT&T and CenturyLink) were held in which appropriate replacement services for utility serial/TDM circuits were explored. The contact information for the provider representatives was provided by telecom initiative members. Most electric utilities of any significant size will have a sales team dedicated by the carrier for the account. It is important when investigating potential solutions to work with this team because other representatives at the carriers typically will not have knowledge of the applications and special requirements of the utility industry. The vast majority of a carrier's data communications business is with large and medium enterprise customers. There will also be products and services focused on the small office/home office (SOHO); however, in most cases these will not be appropriate solutions for utility and other commercial, industrial, and institutional (CII) needs.

A major trend in the TSP business is the consolidation of services toward two solutions: connecting customers to the Internet and to cloud service providers. For many of the electric utility IT applications, these service types may be a fit. Internet and cloud connectivity is not a focus of this report—rather, products and services that may be used in the creation and operation of private network infrastructure for the IT WAN and data transport for OT applications.

Along those lines, there are two current and one emerging category of TSP solutions that are appropriate. The current best fits are MPLS and Metro E, and the emerging solution is SDN/NFV.

Multiprotocol Label Switching

Both AT&T and CenturyLink offer a single "flavor" of MPLS, and that is IP/MPLS. And although SLAs are available from both of the TSPs surveyed for their IP/MPLS service offering, it remains possible that the SLAs would not be met during times of extreme congestion. The MPLS variant of MPLS-TE (TE stands for *traffic engineering*) would be able to ensure performance under all conditions.

The marketing name for IP/MPLS from both TSPs is *MPLS/VPN*. The lowest speed connection onto their network is the T1 rate (1.5 Mbps); the fastest rate is 10 Gbps, which obviously requires a fiber-optic demarcation. The customer/carrier interface may be at either L2 or L3.

Metro E

Standardization has progressed via MEF 2.0, and now service may be obtained that crosses local access and transport areas (LATAs) (that is, handoffs/interconnection between two or more TSPs).

Metro E is available from CenturyLink at speeds between 3 Mbps and 1 Gbps—and up to 10 Gbps in former Quest Communications territories and with fiber-optic demarcation. The service is available with SLAs and three virtual local area network (VLAN) class of service IDs to assist with prioritizing traffic types.

From AT&T, Metro E service is available at data rates from 2 Mbps to 100 Gbps. At data speeds of 10 Mbps and above, a fiber-optic demarcation is required. Otherwise, the AT&T Metro E service offering is similar to what is available from CenturyLink.

Both TSPs advise that Metro E service does not scale well when a large number of locations need to be connected. However, they both also indicate that diverse, redundant paths may be engineered into the design of Metro E solutions—so as a solution for a limited number of key sites, Metro E may be indicated over IP/MPLS.

Software-Defined Networking/Network Function Virtualization

The area of SDN/NFV is rapidly evolving and intensely competitive. The key benefit that both TSPs promote is the "agility and flexibility" of the SDN/NFV solution. The typical configuration has an IP/MPLS network connection in parallel with broadband Internet access at the customer premises. The service is then able to tunnel most of the private network traffic through the Internet; however, during times when performance is degraded, the TSP's private IP/MPLS network is used. In addition, the customer is given network management access and is able to dynamically vary their level of service as often as required.

The SDN/NFV at present is appropriate for the utility enterprise IT and a large variety of applications that require external WAN connectivity. Only a limited set of OT applications such as MDMS and other non-critical hosted/cloud-based systems should use a TSP SDN/NFV solution. As the SDN/NFV standards development progresses and more definitive service level guarantees may be assured, additional OT applications may be moved onto such networks. However, it is difficult to envision SCADA or any level of P&C being appropriate for an SDN/NFV service from a TSP.

Private Network Alternatives

For the utility private networks, several equipment vendors were contacted, and their product roadmaps and recommendations were obtained. The most common utility use cases were cataloged; requirements were analyzed and then mapped to the solution set with best fits noted.

The following private network equipment alternatives were investigated:

- TDM/SONET
- Carrier Ethernet
- IP/MPLS
- MPLS-TP (Transport Protocol)
- Next-gen optical

Ruggedized SONET

Although now considered a legacy technology, there are several original equipment manufacturer (OEM) vendors that remain in the marketplace and that specifically focus on supplying utility and other CII users with TDM and/or SONET equipment designed to operate in harsh environmental conditions. For this reason—as well as the fact that a common practice is for Ethernet to be transported across SONET—it is included in this report.

The following are the main vendors of ruggedized SONET and their product names:

- GE: JungleMUX
- RFL (Hubbell Power Systems): IMUX 2000
- Schweitzer Engineering Laboratories (SEL): ICON

These three manufacturers were contacted regarding their product roadmaps and their ability to continue to provide product into the future. Concern exists in this area because telecom equipment vendors that have discontinued TDM/SONET product lines have done so not only due to diminished demand, but also because of difficulty maintaining supply of component parts. The key items are commodity communications processor integrated circuits (ICs)—in particular, the SONET/SDH (synchronous digital hierarchy) framer and mapper ICs have been discontinued by all of the semiconductor vendors that previously supplied them.

Of the three vendors listed, two have replied that their products are based on field programmable gate arrays (FPGAs), that their companies possess all of the intellectual property used in the programming of these chips, and that they are therefore able to continue producing TDM/SONET equipment for the indefinite future. These two vendors are GE and SEL [26, 27].

With regard to the RFL IMUX 2000, the SONET line card has been discontinued—but the company continues to support the entire TDM portion of the product line [28].

All three of these vendors have on their product roadmaps developments that enable the transition to packet-based transport. For RFL, the chosen path is in the form of Carrier Ethernet, for GE it is MPLS-TP, and for SEL it is 10/100/1000 Ethernet line side interfaces (but not MEF 2.0 compliant).

Carrier Ethernet

The main vendors of Carrier Ethernet–capable equipment with a focus on utility and CII are as follows:

- Cisco
- Juniper
- Nokia
- RAD

These network equipment vendors are some of the largest in the industry, and they each serve both enterprise and carrier markets. Their product lines are extremely broad and diverse—so it would not be possible to cover them in any detail in this report. However, an attempt is made to discuss a few of the products that are most targeted for electrical utilities.

Cisco

The Connected Grid Router (CGR) 2010 and Connected Grid Switch (CGS) 2520 are the main "hardened" products marketed specifically for electric utility use; however, neither is MEF certified—MEF 1.0 or MEF 2.0. The Cisco ASR 902 and ASR 903, which were part of the EPRI April 2017 Serial-to-Packet Protection Workshop (described in report 3002009783), both carry MEF 2.0

certification. A summary of these relevant Cisco products' MEF certification status is listed in Table 3-1.

Table 3-1
Cisco Utility Products' MEF Certifications [29]

Model	MEF 1.0	MEF 2.0
CGR 2010		
CGS 2520		
ASR 902		X
ASR 903		X

Juniper

Juniper Networks over 20 years ago began business as a competitor to Cisco in the area of large core routers for the carrier market. It has expanded its product portfolio and now competes across the entire networking industry with switches, routers, and security appliances—for the edge as well as the core.

Juniper has 21 different products that have MEF certification. The products promoted as most appropriate for electric utility networks are the MX universal edge router, the SRX services gateway, and the EX line of Ethernet switches. Of those three, various MX and EX models are MEF certified.

Nokia

Nokia also participated in the April 2017 EPRI workshop with two models from its SAR 7705 product family. The MEF certification status of the 7705 line is shown in Table 3-2.

Table 3-2
Nokia SAR MEF Certifications [29]

Model	MEF 1.0	MEF 2.0
7705 SAR-A		X
7705 SAR-F	X	
7705 SAR-8		X

RAD

RAD is an international company with a wide range of data communications products for enterprise and carrier markets as well as a particular focus on CII. The MEF equipment vendor certification registry lists 21 individual products from RAD as either MEF 1.0 or 2.0 certified [29].

RAD is a proponent of the view that CE rather than MPLS is best suited for utility private network needs. The conclusions of a white paper comparing the different technologies are provided in Table 3-3 [30]. The table compares CE with the different variants of MPLS across relevant performance categories and attributes of interest to CII. Best-effort MPLS is RAD's name for IP/MPLS. MPLS-TE is discussed above and is MPLS with traffic engineering. MPLS-TP—MPLS Transport Profile—is one of the "flavors" of MPLS but is not described above because it has not had wide adoption in equipment focused on CII networks. At any rate, the entries in Table 3-3 include a (+) for categories in which the particular technology is compliant or meets the needs of a CII network application, a (-) where it does not, and (+/-) for cases in which the needs are partially satisfied.

Table 3-3
RAD Conclusions CE vs. MPLS

Technology	Determinism	Resilience	Monitoring and Diagnostics	Traffic Conditioning	Security	Timing Support
Pure IP	-	-	-	-	+	+/-
Carrier Ethernet	+	+	+	+	+	+
Best-Effort MPLS	-	+/-				
MPLS-TE without TP	+	-	-	+	-	-
MPLS-TP without TE	-	+	+	-	-	-
TE+TP	+	+	+	+	-	-

MEF Certification

With regard to MEF certification, it is important to note the value of standards (along with the certification process), which is to ensure interoperability. And although a utility may decide to deploy a single vendor solution, the ability to interoperate provides leverage in the procurement process and may alleviate concerns with obsolescence.

MPLS

The main vendors of MPLS equipment with a focus on electric utilities and CII are the same as those for CE. The main standards development organization for MPLS is the IETF. Because there is no alliance that certifies compliance, significant research would be required to compile a list of the different flavors and functionality as well as the different vendors' various products. This may be a desired area for future research under Program 161G.

Next-Gen Optical

Next-generation optical networking is a technology that builds on the earlier success of optical transport networking (OTN). OTN was standardized by the ITU-T under recommendations G.872 and G.709 and enables the interoperability of ROADMs, or reconfigurable optical add-drop multiplexers. ROADMs, like OTN and next-gen optical, are based on dense wavelength division multiplexing (DWDM).

The very large aggregate data speeds combined with the flexibility make this set of technologies very attractive to service providers and enterprise network operators. Several OEMs participate in this field, including the following:

- Adva
- Cisco
- Ciena
- Coriant
- ECI
- Ekinops
- Fujitsu
- Infinera
- MRV
- Nokia

The optical equipment marketplace is dynamic and, through mergers and consolidations, constantly changing. In addition, the largest deployments are by carriers and data centers, and much of the equipment for those spaces may not be appropriate for utility needs where equipment must be deployed in harsh environments.

Comparison Matrices and Analysis

The following sections map the recommended applicability of the various alternatives to utility needs by network area.

TSP Alternatives Analysis

As a summary of the previous discussion and analysis, Table 3-4 provides conclusions regarding valid deployment areas for the main TSP service types. These conclusions are empirical and subjective and not necessarily applicable to a particular utility's unique set of circumstances with regard to the TSP vendors in its operating territories or its use cases.

Table 3-4
TSP Alternatives Mapped to Network Areas

TSP Service Type	WAN Core	Branch Office	SCADA	P&C
MPLS/VPN	Yes	Yes	No	TBD
Metro E	Yes	Yes	Yes	TBD
SDN/NFV	TBD	Yes	No	No

Private Network Alternatives Analysis

As a summary of the previous discussion and analysis, Table 3-5 provides conclusions regarding valid private network technology options mapped to network areas. These conclusions are empirical and subjective and not necessarily applicable to a particular utility's unique set of circumstances with regard to its internal policies and technical standards or its use cases.

Table 3-5
Private Network Technology Mapped to Network Areas

Equipment Type	WAN Core	Branch Office	SCADA	P&C
IP/MPLS	Yes	Yes	Yes	TBD
MPLS-TE	Yes	Yes	Yes	TBD
CE	Yes	Yes	Yes	Yes
TDM/SONET	TBD	Yes	Yes	Yes
Next-Gen Optical	Yes	Yes	TBD	TBD

Section 4: Member Survey Results

This section of the report covers a member survey that was conducted on the topic of the individual member companies' current status with regard to serial-to-packet replacement.

Survey Intent and Design

The main intent of the survey was to obtain input to better focus this report toward addressing the most important aspects of the issue as being experienced by a range of member companies. Information solicited included specifics on the current state of their serial and TDM implementations, status of notifications from their TSPs on sunsetting of legacy services, existence of ground protection rise (GPR) isolation equipment on copper circuits at substations, use of serial and TDM equipment in member's private networks, overview of the utility's telecom procurement and implementation procedures, and circuit transition plans at present. For this last item, a matrix of technology choices was created for survey participants to complete, with the X/Y axis of "from/to" in order to see at a glance the transition path different members may have chosen.

Survey Results and Analysis

The individual survey questions are listed next, followed by a discussion of the range of responses and some brief analysis, mostly in the area of commonalities.

Question 1

Does your existing serial solution use Telco or other carrier services? If so, please list the carrier(s), their name for the service, generic name for the service/circuits, and rough costs.

Question 1 Range of Responses

Ameren reports using six different carriers in various regions, and Duke has service relationships with eight providers. Seattle reports that it is not aware of any leased carrier services for utility operations. Remaining members report some use of carrier services.

With regard to costs, Ameren provided a total annual cost of $5.4M but no circuit count. Duke provided a detailed list with 69 circuits but without cost (total or individual). For individual circuit costs, CenterPoint stated that it is becoming "prohibitive." KCP&L provided the monthly range of $100 to $3200 per circuit, with most costing between $200 and $300.

Question 1 Commonalities/Analysis

All recognize the issue and have begun to transition away from serial/TDM circuits, but the majority have some carrier circuits remaining.

Question 2

How many of your service providers have given you a legacy circuit sunset notification? Which types of technology and circuits are affected?

Question 2 Range of Responses

Ameren received unofficial sunset notification from AT&T. CenterPoint has been told that existing circuits are grandfathered but if they fail must be replaced with Ethernet. Duke provided a detailed list; in summary, AT&T, Level 3, and Sprint have provided sunset dates for certain service types. KCP&L is tracking AT&T's Federal Communications Commission (FCC) filing regarding copper abandonment by 2020. Others requested but have not received answers on sunset dates.

Question 2 Commonalities/Analysis

AT&T notified more than one member of sunsetting particular services.

Question 3

Can you give examples of typical circuit cost increases or impending increases?

Question 3 Range of Responses

Ameren is experiencing 40%/year increases. Duke notes that AT&T provided dates when contractual discounts will end for certain service types but has no specifics on increases. KCP&L has concerns that MPLS service costs are a multiple of the serial/TDM circuits that they are replacing.

Question 3 Commonalities/Analysis

Several members are actively cutting over to private networks such as point-to-point microwave to avoid cost increases.

Question 4

If your existing serial solution is a utility private network, please indicate if it is wireline, wireless, or both.

Question 4 Range of Responses

Multiple address radio (MAS), microwave, and fiber were all mentioned.

Question 4 Commonalities/Analysis

Most indicate both wireless and wireline private network infrastructure.

Question 5

Do you have GPR isolation equipment installed on existing copper circuits?

Question 5 Range of Responses

All that have copper telecom circuits indicate having GPR isolation equipment, provided by either the carrier or the utility. CenterPoint has a meet-me point with carriers and then has fiber into the substations. SRP also mentions fiber only into substations.

Question 5 Commonalities/Analysis

None has copper without isolation equipment in substations.

Question 6

For both cases (telecom or utility provided), please list the type of terminal equipment in use, including manufacturer, model numbers, basic configuration, data rates (for both network and equipment sides if multiplexers are used), and any other pertinent details.

Question 6 Range of Responses

Two did not answer; others provided different amounts of detail; some included relay and RTU make/models. Table 4-1 is a compilation of the terminal equipment in use by the survey respondents that provided a detailed answer.

Question 6 Commonalities/Analysis

There was a wide variety of equipment among utilities and even within a utility, especially Duke with variation between regions. GE JMUX is used at Duke, KCP&L, and SRP.

Question 7

List the end devices and applications using serial communications in the typical substation.

Question 7 Range of Responses

Table 4-2 is a compilation of the serial devices, and Table 4-3 lists the serial applications in use by survey respondents.

Table 4-1
Terminal Equipment Used by Survey Respondents

Make/Model	Ameren	Duke	KCP&L	Salt River Project
4RF Aprisa IP radios			x	
Alcatel-Lucent DMXplore		x		
Alcatel-Lucent MDR-8000		x	x	
ALU/Nokia 9500 MPR		x		
Cisco 2010 CGR		x		
Cisco 2520 (CGS)		x		
Cisco 15310-MA		x		
Cisco 15310-CL		x		
Cisco 15454		x		
Fujitsu 4100ES		x		
GarrettCom DynaStar		x		
GarrettCom RuggedCom		x		
Garrettcom 10XTS				X
Garrettcom DX940				X
GE Orbit MCR dual-band radios			x	
GE iNet				X
GE MDS 9790/9710			x	
GE MDS SD9			x	
GE JMUX		x	x	X
GE T1MX				X
Harris-Farinon DVM 645			x	
Newbridge TDM			x	
Nokia 7705			x	
RFL IMUX 2000	x			X
RFL 9740	x			
SEL ICON		x		
Wescom				X

Table 4-2
Devices Using Serial Communications by Survey Respondents

Serial Devices	Ameren	CenterPoint	Duke	KCP&L	Salt River Project	Seattle
RTUs (not specified)	x	X				
RTU with legacy protocols: Vancomm, Modbus, Conitel			x			
RTU with legacy protocols: CDC Type 1, L&G 8979				X		
RTU with DNPv3				X		
SEL 311				X		
SEL 421				X		
SEL DTAC				X		
SEL RTAC					x	

Table 4-3
Applications Using Serial Communications by Survey Respondents

Serial Applications	Ameren	CenterPoint	Duke	KCP&L	Salt River Project	Seattle
RTU/SCADA	x	X	x	X		
Backup RTU/SCADA (aggregated at hub substations)					x	
Transfer/trip relaying	x	x				
Limited ARD (auto ringdowns)	x					
OPX (Off-Premise Extension from PBX)	x					
Pole-top switches		x				
Metering		x				

Question 7 Commonalities/Analysis

RTUs for SCADA applications using legacy protocol are common to almost all.

Question 8

Are you using modem sharing, serial port splitters, or other hardware that enables one circuit to serve multiple DTE devices?

Question 8 Range of Responses

Answers ranged from "no," to "limited use of bridging," to "extensive use with complicated arrangements." For Duke, only Florida is noted as using Tellabs 4445 bridge with DACs to consolidate a single line into the energy control center (ECC). KCP&L has three schemes: one for RTUs to appear in main and backup control centers and two methods of aggregating remote modems—one an analog audio bridge and another that uses a purpose-built digital bridge. SRP has some Tellabs bridges but is working on removing them.

Question 8 Commonalities/Analysis

Most indicated limited use of bridging to minimize the quantity of control center circuits.

Question 9

Has security video surveillance been installed or planned in any of your substations? If so, is telecommunications a requirement, and what method has been implemented or planned?

Question 9 Range of Responses

All have some security video, and the interface is Ethernet/IP. Some are transporting via T-1 and have therefore constrained the video bandwidth, with the lowest given at 512 kbps. Others have video being transported on MPLS from a wireline carrier, and one utility is using wireless long-term evolution (LTE) as an interim solution.

Question 9 Commonalities/Analysis

Video surveillance is a requirement and acknowledged as the largest single bandwidth consumer.

Question 10

Can you provide insights into your organizational structure and how it relates to the group that has responsibilities related to engineering, construction, and maintenance of equipment in substation control houses?

Question 10 Range of Responses

All respondents provided detailed answers, with process and participants identified. As few as 3 (Duke) and as many as 12 (SRP) different organizations listed as having some responsibility related to telecom in substations.

Question 10 Commonalities/Analysis

Effective interaction between multiple entities is required to make additions or changes to substation communications.

Question 11

Is there a single group responsible for procurement and maintenance of any and all telecommunications at substations?

Question 11 Range of Responses

Ameren and KCP&L have a single group responsible for substation telecommunications. For others, procurement/engineering and operations/maintenance are performed by different groups. Still others noted that different equipment or communications types (internal versus external connectivity) have multiple organizations involved.

Question 11 Commonalities/Analysis

Consolidating telecom responsibilities for substations is possible.

Question 12

Please describe any current or evolving plans for serial-to-packet transition.

Question 12 Range of Responses

All except Duke have plans or programs started for implementation of an MPLS solution. Duke has chosen not to deploy MPLS in the internal network (but will interconnect with TSPs via MPLS) but rather is moving the private network to next-gen optical.

Question 12 Commonalities/Analysis

The majority have selected MPLS for internal networks, and several have also begun significant expansion of fiber infrastructure—particularly to connect substations.

Serial-to-Packet Transition Plans Matrices

A few of the survey participants completed a matrix of technology choices (see Table 4-4 through Table 4-6). In the responses, the X/Y axes are for “from/to” of the transition path that has been selected.

Table 4-4
Ameren Serial-to-Packet Transition Matrix

Serial to Packet	Telecom	Telecom	Telecom	Commercial Cellular	Utility	Utility	Utility
From/To	**DSL**	**Metro E**	**MPLS**		**Fiber MPLS**	**PTP Wireless**	**PTMP Wireless**
Telco dry pair	NA	NA	NA	NA	NA	NA	NA
Telco analog PTP data circuit		X, secondary if private fiber not available	X, secondary if private fiber not available		X, primary		
Telco analog bridged data circuit					X		
Telco digital data circuit					X		
Telco PTP T-1					X		
Telco frame relay (T-1 or subrate)	NA	NA	NA	NA	NA	NA	NA
Utility wireline: analog copper					X		
Utility wireline: TDM copper					X		
Utility wireline: fiber – TDM					X		

Table 4-5
KCP&L Serial-to-Packet Transition Matrix

Serial to Packet	Telecom	Telecom	Telecom	Commercial Cellular	Utility	Utility	Utility
From/To	**DSL**	**Metro E**	**MPLS**		**Fiber: MPLS**	**PTP Wireless**	**PTMP Wireless**
Telco dry pair							
Telco analog PTP data circuit							
Telco analog bridged data circuit				X (only 69 kV and below/ distribution substations; pilot)	X	X	X
Telco digital data circuit							
Telco PTP T-1			X		X		X
Telco frame relay (T-1 or subrate)							
Utility wireline: analog copper					X	X	
Utility wireline: TDM copper					X	X	
Utility wireline: fiber – TDM					X		

Table 4-6
SRP Serial-to-Packet Transition Matrix

Serial to Packet	Telecom	Telecom	Telecom	Commercial Cellular	Utility	Utility	Utility
From/To	**DSL**	**Metro E**	**MPLS**		**Fiber: MPLS**	**PTP Wireless**	**PTMP Wireless**
Telco dry pair							
Telco analog PTP data circuit							
Telco analog bridged data circuit							
Telco digital data circuit							
Telco PTP T-1							
Telco frame relay (T-1 or subrate)							
Utility wireline: analog copper					X	X	X
Utility wireline: TDM copper					X	X	X
Utility wireline: fiber – TDM					X		

Duke Response to Question 12

Although Duke did not complete a serial-to-packet transition matrix, a separate written description was provided with a discussion of its plans. It did not break down the decisions in the categories of the rows/columns of the matrix; however, it did provide detail on Duke's decision not to deploy MPLS on the internal network. In addition, it provided model numbers for three different Ciena products that will be deployed at core, aggregation, and edge sites. Furthermore, the document stated that the Carrier Ethernet capabilities of the Ciena products would be used.

Section 5: Summary

Conclusions

Based on the survey of members, a best practice is evident for planning a network transition. A process is outlined below to create a plan tailored to specific circumstances in resolving serial-to-packet replacement issues. Using this systematic process reduces risk and improves the odds of successfully meeting the objectives. Many members have already accomplished several of these steps, but for completeness and as a best practice example, the steps are outlined next.

Recommendations

- Obtain and catalog every type of leased circuit in use throughout all regions or operating entities of the utility and the TSP's sunset dates for the circuits.
- Obtain and catalog all private network equipment used in both OT and IT private networks; then work with the OEM vendors to obtain their product roadmaps for the equipment lines in use with specific attention paid to anticipated end-of-life dates.
- Complete a detailed requirements analysis for current and future IT and OT networking needs.
- Perform a gap analysis that identifies current capabilities and future needs for all areas of the IT and OT networks.
- Analyze the ability of the applicable solution technologies outlined in this report against the requirements and gaps, and reduce the list to three or fewer options.
- Engage the vendor community (TSP and equipment vendors as appropriate) to validate the solutions analysis and to obtain budgetary cost projections.
- Document the best fit plan, and obtain executive support for moving into procurement and execution phases.

Next Steps

There appears to be value from sharing lessons learned among the member utilities as plans are finalized and transition projects are implemented. Several technical issues still need to be resolved in the serial-to-packet transition, especially in the area of protective relaying. The project set 161G is poised to continue research in these areas as needed.

The 161G project set is organized around three areas: WAN, FAN, and Telecom Network Management Systems and Planning.

Tasks may be added to the 161G efforts to assist members with implementing these recommended steps. One possible tool is a set of templates with utility cases studies. Members could use these templates to obtain TSP pricing in various regions for multiple solution technologies. Comparing and contrasting the TSP proposed solutions (including pricing) would likely be informative and could empower members in obtaining optimum results.

Other collaborative efforts could be performed as needed to assist in the serial-to-packet transition process as issues arise.

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3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com