Grid Solutions

Packet-switched Communications for UTILITY OPERATIONAL TELECOM NETWORKS

Whitepaper

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INTRODUCTION

Many power utilities are planning to introduce or to extend packet-switching capabilities in their essentially SDH operational telecommunication networks. Generally one or more of the following reasons drive them to undertake these changes:

- Deploy or migrate substation/grid applications requiring Ethernet/IP
- Constitution of a corebackhauling network for their packet-switched services
- Refurbishment or renewal of an end-of-life network with more future-open technology
- Substantial increase in required network capacity due to intensified communications
- Intention to reduce equipment expenditure and operational effort
- Intention to converge enterprise and operational networks (IT and OT)

Before comparing and selecting technologies for this transformation it is essential to define a consistent architectural evolution strategy for the communication network. The evolution strategy should take into account short, medium and longer term requirements, expected time-schedules, as well as existing infrastructures, network operation processes and present organizational realities.

A network design over-dimensioned for present and near future requirements may result in excessive investments for unused capabilities: long term requirements and the market-available technologies can both evolve in time rendering the "future-aware" network unsuitable or non-cost-effective in the future. In the meantime, the over-dimensioned design will have caused enormous operational effort and numerous network outages due to inadequate skills and processes.

A network transformation plan must provide a migration roadmap through a time-phased sequence of network modifications and upgrades with phased investments and gradual build-up of skills, process and tools to deliver required capability at each step according to application requirements and to adapt and adjust according to new requirements and new enabling technologies.

This paper aims to provide some guidelines on alternative architectures and approaches, on different packet technologies, as well as their relevance according to the communication requirements and specificities in each power utility context.

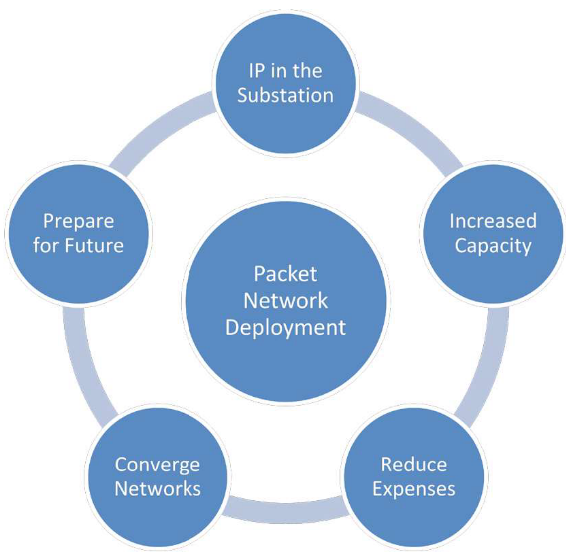


Figure 1 – Utility drivers for packet network deployment

ETHERNET OVER SDH

For a large number of power utilities the immediate requirement is to provide packet capability to their evolving (or new) substation services and to build "preparedness" for facing new network technologies.

Tunneled Ethernet over Time Division Multiplexed channels is widely used in substation networks for SCADA-type applications. Ethernet is mapped over one or multiple sub-E1 slots (64k or Nx64k) or over an SDH Virtual Container (E1 or NxE1). The systems provide E-line (point-to-point) or E-LAN (multipoint) connectivity with operational grade security and availability, similar to non-switched TDM-transported services. Strong service isolation from other concurrent telecom network users, minimal and deterministic delay, short service restoration time after failure and a high Quality of Service due to dedicated resources are some of the characteristics of this solution.

Efficient implementation of Ethernet over SDH however requires a number of standard mechanisms lacking in older generation SDH equipment. These mechanisms of "NG-SDH" are the following:

- Generic Framing Procedure (GFP) provides a generic mechanism to map variable length Ethernet data streams the same manner.
- Virtual Concatenation (VCAT) allows SDH channels to be multiplexed together in arbitrary arrangements and hence to create pipes at any rate.
- Link Capacity Adjustment Scheme (LCAS) is a standard for adjusting dynamically the amount of bandwidth allocated to an Ethernet service.

The simple replacement of an old generation end-of-life SDH system by a new one with enhanced data capabilities responds in many cases to the limited packet switching requirements in electrical substation networks (e.g. migration of existing SCADA and voice applications into IP/Ethernet in a standard vendor-independent manner).

A very simple and low cost solution for adding Ethernet into the substation would therefore be the deployment of newer SDH equipment with a service aggregation Ethernet switch separating VLANs for different substation applications.

SDH is indeed no longer the technology of choice for mainstream "operator" telecom deployment, but the lower-end constituents of the hierarchy (<STM-16) still remain a valid option for time-sensitive private networks available from many suppliers.

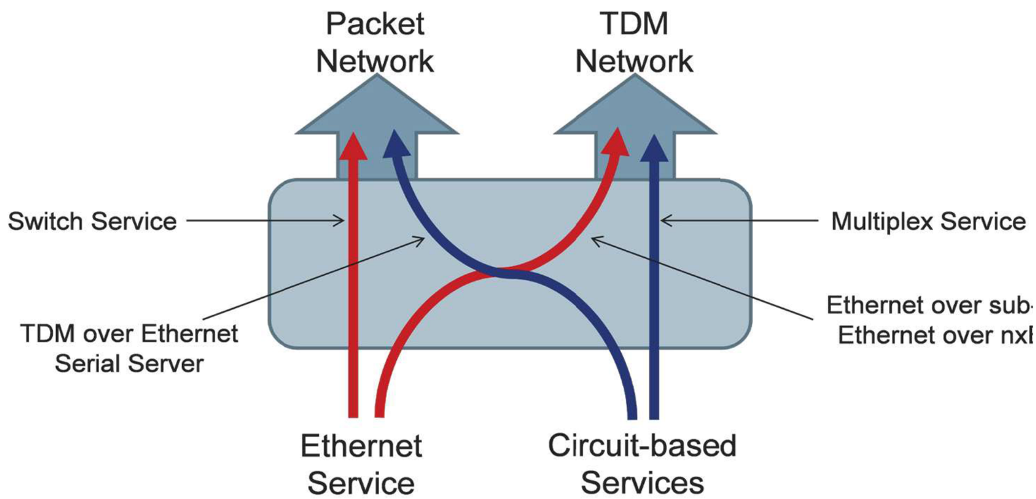


Figure 2 – Ethernet over NxE1/sub-E1 and legacy multiplexing platforms

PACKET-SWITCHING BESIDE SDH

For packet switched capacity beyond that offered by the present day Ethernet over SDH, distinct fibers or wavelengths can be used for building native Ring-protected Ethernet or deploying other packet-switched technologies. In most utilities extra fibers are available in optical cables and the multiplicative potential of wavelength multiplexing is barely used. Adequate optical line interfaces on suitable Ethernet switches allow a line capacity of 1 to 10Gbps without much effort.

In this architecture, legacy services may be maintained over the existing network and gradually migrated when replaced by an IP-based alternative. This is for example the case for SCADA RTUs gradually migrating from serial to TCP/IP. This architecture is presented in figure 3 hereafter.

Connecting the switch on separate fiber or wavelength can be an evolution of Ethernet over SDH transforming the existing arsystem into a Gigabit Ethernet in parallel to the existing SDH. The SDH system can still transport low bandwidth Ethernet in its payload for access into substations without native Ethernet. For substation applications, extensive packet capacity can be added to the existing system through this simple operation.

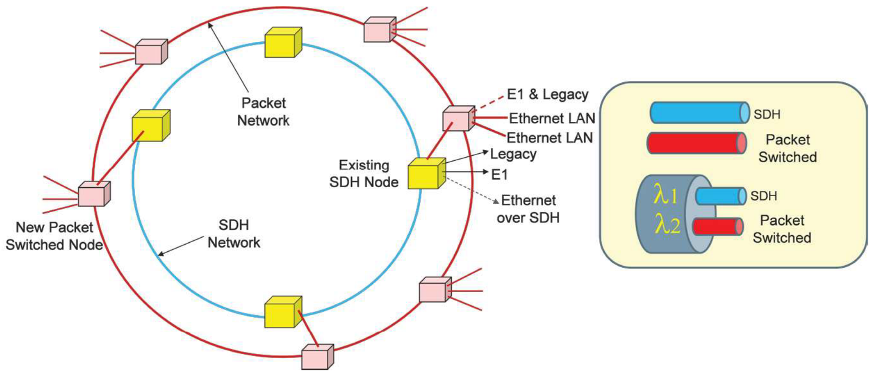


Figure 3- Gigobit Ethernet beside SDH over separate fiber or wavelength

The existing SDH infrastructure can moreover be replaced by a “hybrid” platform providing both native Ethernet and SDH interfaces in the same equipment hence replacing the SDH and the Ethernet switch as presented in figure 4. Such a hybrid platform will provide a conventional TDM replacement for the legacy interfaces while adding new packet capabilities for new services. Distinct line interfaces can be employed for TDM and Packet communications. These line interfaces are connected to separate fibers or multiplexed over distinct wavelengths on the same fiber.

Alternatively, the existing SDH infrastructure can be replaced or supplemented with a higher layer of optical transport network (ITU-T G.709 OTN) capable of time multiplexing the existing SDH stream with additional packet-switched data over the same optical channel. The payload of the OTN is structured in such a way to accommodate SDH and Ethernet data streams over a higher bitrate line interface (e.g. 10 Gbps for OTU2). Considering its high capacity and capabilities, the ITU-T OTN provides a very high level of scalability at the core level of the network.

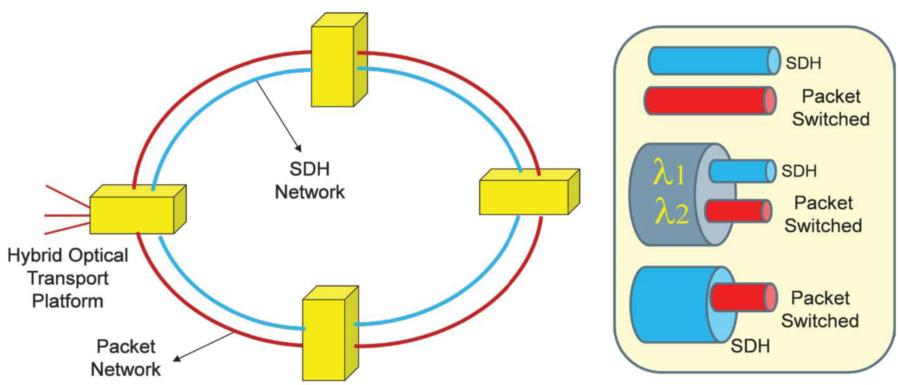


Figure 4 – Ethernet or MPLS-TP and SDH in a Hybrid platform

BUILDING SCALABILITY INTO THE DATA SERVICE

Ethernet over SDH and "Ethernet beside SDH" discussed above have the great advantage of simplicity when applied in a limited size network and for limited packet deployment in the short and medium term. However, neither of them can be made scalable to very large networks.

Scalability in the utility telecom network is the facility to evolve to a much larger network, larger data capacity and larger number of transported data connections without resulting in extremely laborious service configuration or inadequate quality of communication service.

Ethernet path protection is performed through different variants of Spanning Tree Protocol. or Ring Protection none of which is suitable for large networks. The Quality of Service in Ethernet is based on simple Priority Assignment consisting in the allocation of a priority level to each traffic and different queues at each switching node with no guaranteed (committed) bitrate for any data stream.

As already stipulated earlier, however, building scalability needs further knowledge of requirements. It is necessary to examine the required level of scalability, the time-scale associated to it, as well as the traffic exchange requirements across the network. Very often, the intensive traffic growth is not in the substation access but in the transport core, central platforms and in the office networks.

The separation of access network (Network Edge) from the backhaul network (Network Core) and the consequent hierarchical architecture is an appropriate way to introduce a gradual change of scale in the utility network. The core network can be deployed without disrupting existing connections which may gradually migrate to it.

A potential solution in the utility operational context is the usage of Multi-Protocol Label Switching (MPLS) technologies. MPLS in all its different flavors (IP-MPLS, MPLS-TE. MPLS-TP ...) adds "forwarding labels" to different data streams allowing their separation and hence the control of their forwarding across the network. The data traffic across the network can in this manner be shaped and partitioned for optimizing the flow through a process known as MPLS traffic engineering. This traffic engineering can be more or less complex to implement according to the adopted MPLS flavor. SDH and El connections are in this case emulated over the MPLS network through "pseudo-wires".

ITU-T Optical Transport Network (OTN) as already mentioned above, is another alternative for building scalability into the network core. OTN allows the transport of SDH and data traffic over a same payload. It can be assimilated to a very high capacity TDM or a scaled-up alternative for Hybrid TDM/Packet platforms.

SCALABLE CORE AND STABLE EDGE

It should be noted that MPLS data forwarding or any other core technology can also be generalized across the whole network. Such an end-to-end solution allows overall "connection provisioning" and supervision, while a hierarchical core-edge solution allows gradually migrating from a simpler initial solution, the re-use of assets and investments and often less complexity. The existing native Ethernet or Ethernet over SDH would provide in core-edge architectures an attractive solution for sub-networks at the low end of the multi-tier hierarchical network.

Furthermore, there is no need to choose between the two approaches: the network can be MPLS end-to-end for data-rich sites such as control centers. technical offices and major process sites. and have a two-tier architecture using a "network edge" based on Ethernet switches or SDH where smaller throughput is sufficient (e.g. substations). Similarly, the migration plan can be defined with a 2-tier initial architecture. using different core and edge technologies. and gradually push the core technology into the edge and most probably a new core technology in the highest traffic part of the network.

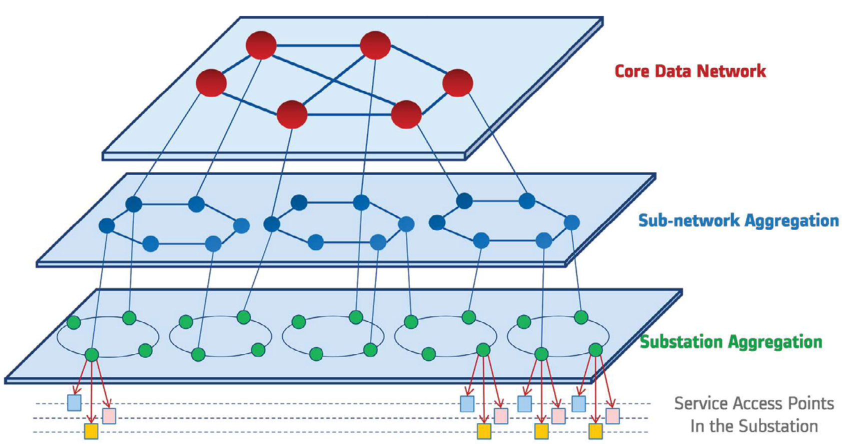


Figure 5 – Hierarchical N-tier network architecture

EMULATING TRAFFIC OVER PACKETS - MPLS

A new packet-switched network such as MPLS can be used to replace the existing SDH network and emulate any residual legacy interfaces using a circuit emulation technique. As discussed previously, this technique can be used in the core network or in the entire network.

When employed in the core, the packet-switched network will need to emulate E1 (2Mbps) or in some cases the entire SDH payload. Circuit emulation implies implementing data buffers to absorb delay variation due to packet-switched store-and-forward mechanism. A large data buffer allows the absorption of a large delay variation but also results in a large absolute delay. It is therefore essential to control delay variation in the packet network if it is to be used to emulate circuits.

When employed in the entire network, then it should be associated to a service aggregation switching or multiplexing device. The MPLS device may itself emulate sub-E1 legacy circuits of different kinds. but it should be noted that large scale usage of sub-E1 circuit emulation over a packet infrastructure is neither technically optimal nor economically advantageous. End-to-end usage of MPLS is to be envisaged only when legacy interfaces in the network are absent or marginal.

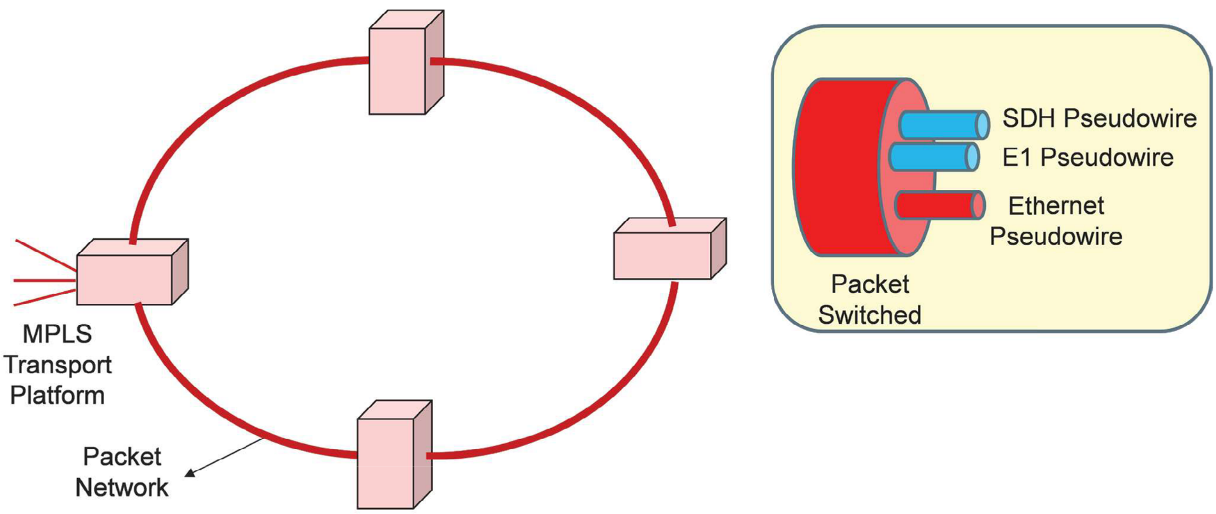


Figure 5 – TDM emulated over new Packet-switched network (MPLS)

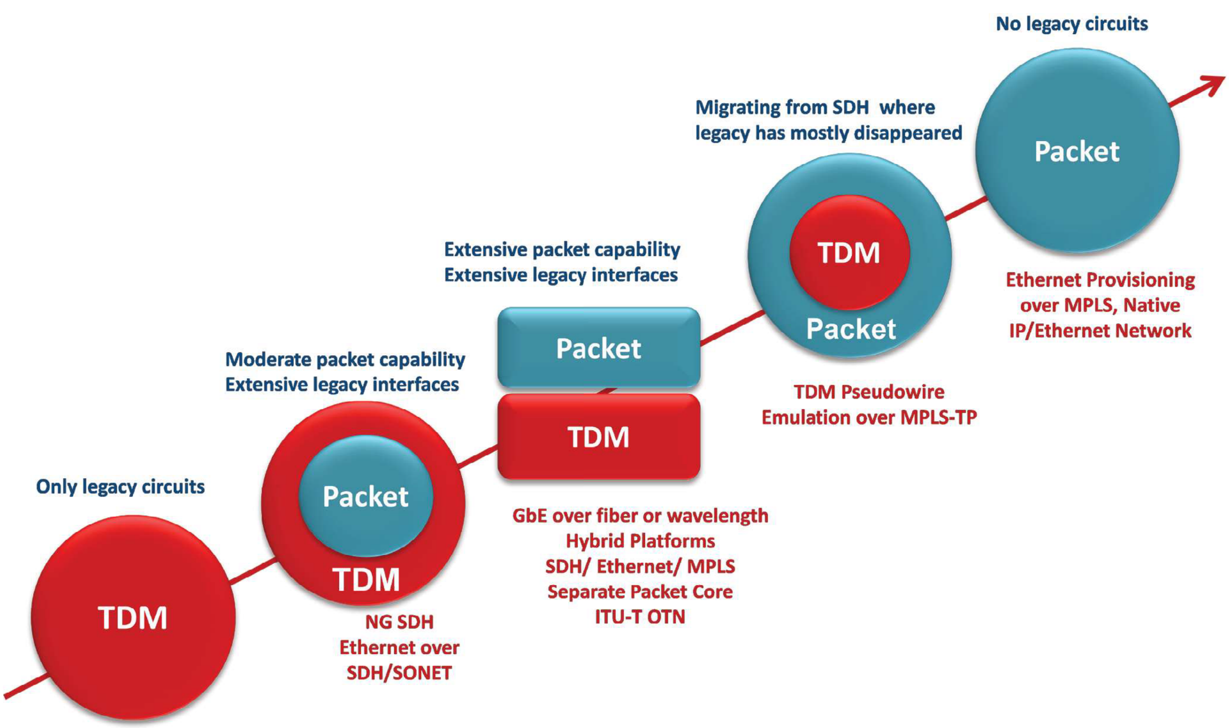


Figure 6 – TDM/Packet integration – A Technology Migration Path

MPLS TECHNOLOGIES

Multiprotocol Label Switching is a packet-switching technology that forwards data packets using traffic labels inserted by the network.

IP-MPLS

The MPLS labels are replaced at each switching node. This provides high flexibility and dynamic routing capability but it requires network-wide intelligence, implying permanent exchange of control information across the network. This is known as a "distributed control plane". Moreover, in order to enable each node to allocate capacity for each traffic stream (Forwarding Equivalence Class or FEC). some traffic rule or policy must be given to the node. A distributed control plane generates critical control traffic across the network and traffic engineering implies some prior knowledge of traffic classes and attributes. The IP-protocol control traffic is transported using a resource reservation protocol RSVP. Such an operation is suitable for extremely large networks with large variations of traffic volumes and source-to-destination paths but well characterized traffic models. This is typically the case for Telecom operator networks. Adjusting Traffic Engineering parameters in such a system is complex but far less laborious than configuring thousands of pre-determined data paths which moreover can change with time-of-day and with seasons according to network users bulk movements. The technique is known as MPLS-TE (TE means Traffic Engineering).

IP-MPLS, in its simplest form, uses no traffic engineering but simple Priority Assignment as in native Ethernet. The most time-sensitive traffic will only have a better delay variation than low priority traffic. Such a system provides traffic isolation advantages of MPLS, dynamic routing through a distributed control plane but no guarantee on resource allocation to each service (except for the control plane exchanges using RSVP). It suits multi-site Enterprise networks such as Utility non-operational networks with no tight time and Quality of Service imperatives.

MPLS-TP

Transport Profile MPLS (or MPLS-TP) is a variant of the MPLS technology simplified for transport-type traffic. A transport network such as SDH provides predefined tunnels between Service Access Points. In MPLS-TP, data traffic is forwarded across the network according to their labels which are added at the network ingress point and removed at the network egress point without being changed at intermediate switching nodes. This provides a pre-determined tunnel with no “distributed control plane”. Packet forwarding tables at each node are provided by a Central Control Platform in the same way as in SDH. The centralized control, moreover allows pre-determined end-to-end alternate routes, and simple resource allocation. The control platform can allocate a maximal capacity (Peak Information Rate, PIR) and if necessary a minimal capacity (Committed Information Rate) to each data stream, hence assuring SDH-like Quality of Service for time-critical services and IP-type flexible bandwidth for non-time-critical services. The operation remains simple for Utility-size telecom networks. It is clear that MPLS-TP cannot suit a large telecom operator network covering final customers due to its fixed "tunnel" approach (transport-profile) and can become laborious for very large numbers of end points and services encountered in the public networks.

MPLS-TP OR IP-MPLS IN OPERATIONAL CONTEXT

In power utility operational network, deploying MPLS is not a “build from scratch” but part of an evolutionary transformation plan as discussed in the previous sections. Migration is a key word in deciding upon technologies. The present network is often SDH or SONET, time-sensitive legacy services are designed for circuit mode operation, and synchronous data streams such as E1 and SDH often need to be emulated across the packet core. Moreover, the utility controls its telecom network from a central network management platform with processes and skills which are adapted to such operation.

MPLS-TP in this context is a more appropriate technology than IP-MPLS with or without Traffic Engineering. The main reasons are summarized below:

- **Maintaining full Control of the Network** – In MPLS-TP forwarding labels are produced by a central NMS allowing end to-end main and alternate route definitions as presently done through SDH/SONET. In IP-MPLS on the other hand, the proper operation of the network depends upon control plane communications. Moreover, if a deterministic behavior is necessary for some data streams, then adequate Traffic Engineering must be introduced to govern nodes decision. Adjusting Traffic Engineering parameters in an IP-MPLS network (MPLS-TE) is complex and requires tuning and adjust ments rendering the network subject to non-optimal settings.

- **Quality of Service and deterministic behavior** - Some utilities using dedicated resources such as separate fibers for Protection may imagine that these constraints are definitively out of their network. In reality, other protection-like applications with network-wide coverage will be deployed in the coming years and dedicated fiber used between adjacent substations can no longer be the solution (e.g. System Integrity Protection Schemes SIPS). Being able to implement time-sensitive applications remains a "must" in an operational network.
- **Size of network and type of traffic** – By its SDH-like behavior, MPLS-TP responds to all existing service requirements, as well as new packet-based services in Utility-sized networks. Deploying MPLS-TE on the other hand, is suitable for public networks with highly dynamic data traffic characteristics and too many nodes for centralized control: traffic rules are hence given to nodes so that they can build the forwarding labels at any moment (TE).
- **Capability versus complexity** – IP-MPLS provides numerous technical capabilities but with increasing complexity. Implementing QoS through Dynamic Resource Reservation (RSVP) can be done in IP-MPLS but making it for hundreds of connections is far from being trivial. So much complexity for a "by nature" static service is totally unreasonable. Similarly, performing any meaningful Traffic Engineering in IP-MPLS (MPLS-TE) requires fairly good knowledge of the traffic shapes and characteristics which is far from being the case for a lot of new coming and future services over the operational network. The important question is not how many utilities have adopted IP-MPLS but how many utilities have deployed large IP-MPLS networks and deployed Traffic Engineering used for time-sensitive applications.
- **Migration from SDH** – Transition to packet for a network operator having extensive SDH infrastructure, management tools and skills is almost smooth for MPLS-TP because of its SDH-like behavior and network management. IP-MPLS is a jump into another type of network operation. With a large telecom network they will become entirely dependent on their supplier. IP-MPLS suppliers provide specific tools and features to overcome some of the basic problems but in a non-standard manner causing further dependence on a single supplier that can disappear or abandon the product line at any time.

	IP-MPLS	MPLS-TP
QoS and Time Control	• Is not implicit. Must implement Traffic Engineering (TE) and RSVP (Resource Reservation Protocol) which is complex and requires prior knowledge of traffic characteristics and tuning	• Is implicit and simple to implement • Each traffic flow is given a PIR (Peak Information Rate) and can be given a CIR (Committed Information Rate). The network guarantees throughput for critical data streams
Path Control	• Forwarding tables are established dynamically through the IP-based distributed control plane (each node swaps forwarding labels)	• Forwarding table is static with end-to-end alternative path (like SDH) under control of a central NMS – System engineering is similar to SDH
Migration from SDH	• Fundamental differences with SDH makes IP-MPLS a radical change necessitating the complete redesign of the system. IP-MPLS is a natural migration path from a multi-service IP network	• SDH-like behavior allows smooth and easy migration from existing SDH with almost no change at the NMS level
Network Management	• IP-MPLS management is completely separate from existing SDH management. It could be integrated into a multi-service IP network's management (integrates service and transport)	• Management of MPLS-TP and SDH can be integrated to a great extent. MPLS-TP tunnels / pseudo-wires can be treated together with SDH/PDH channels and integrated in a same system (e.g. e-terraSentinel)
Deployment References	• Most deployments in utility concern Corporate Enterprise (administrative) communications with no Traffic Engineering. • Numerous studies/attempts during many years to use it for operational service have failed, postponed or abandoned often in favor of existing SDH.	• MPLS-TP being a much newer technology, deployments are less frequent but based on critical service capability and selected against long existing IP-MPLS alternative.

Figure 7 – IP-MPLS and MPLS-TP assessment in the operational network

BRIDGING THE IT AND THE OT

Unifying the operational communications with the enterprise IT communications into a same network is subject of substantial debate is many utilities. One expected benefit is indeed an economy of infrastructure and of operation and maintenance effort.

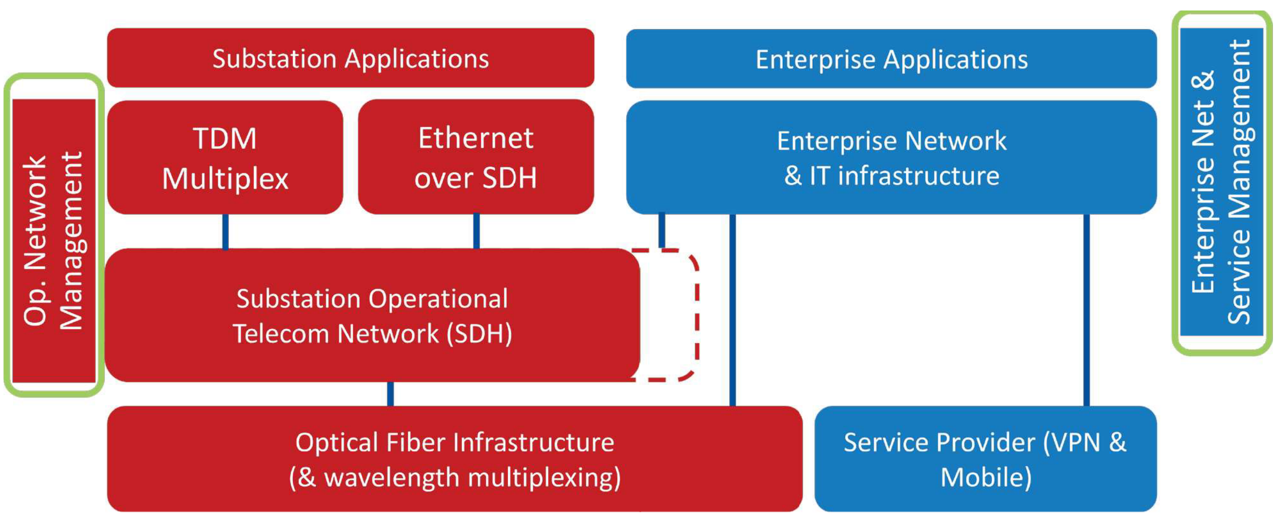
Moreover. there is a growing need for information exchange beyond the traditional separation of field area and office networks. The access of Asset Management staff in technical offices to data and devices in the operational process sites. remote diagnostics through monitoring systems and field worker support are typical examples of substation access requirements from the office network.

However, such a converged network has a number of major drawbacks:

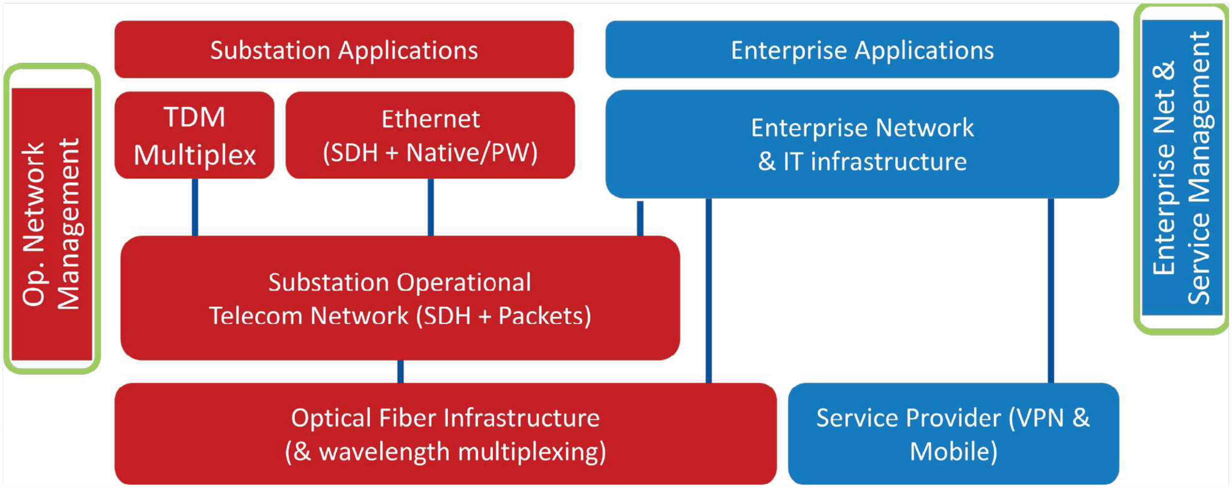
- Operational service quality requirements are very different from those of the corporate enterprise network. Operational services need very high dependability, time control and very high stability. On the enterprise side, a feature-rich network continuously upgraded to meet latest advances and ever increasing bandwidth is required. Unifying the two implies major complications in the enterprise network to meet operational requirements. Moreover, network updates and enhancements for enterprise applications result in unnecessary re-testing and re-commissioning for “invariable but critical” devices such as protection relays, which is totally unacceptable for the grid operation.
- Enterprise networks maintenance can be performed by out-sourced staff or contracted externally while the operational network maintenance is generally performed by utility staff only due to severely controlled site and required security and safety qualifications.
- Governance processes for Enterprise IT and for Operational infrastructure (OT) are fundamentally different. The operational world often requires a simple process for fast intervention in order to assure power continuity while the enterprise IT governance is complex and generally optimized for pre-planned interventions.
- Enterprise IT network is by nature open to the external world. Its cyber-security is assured by frequently renewed security patches. peer authentications and security filtering. A major security barrier of an operational network (not the one indeed) is “isolation”.

Information exchange between the two worlds can be assured without integrating the networks. Specific "access points" may be deployed between the office and operational networks transferring exchanged data between substation-based data servers and pre-identified office workers.

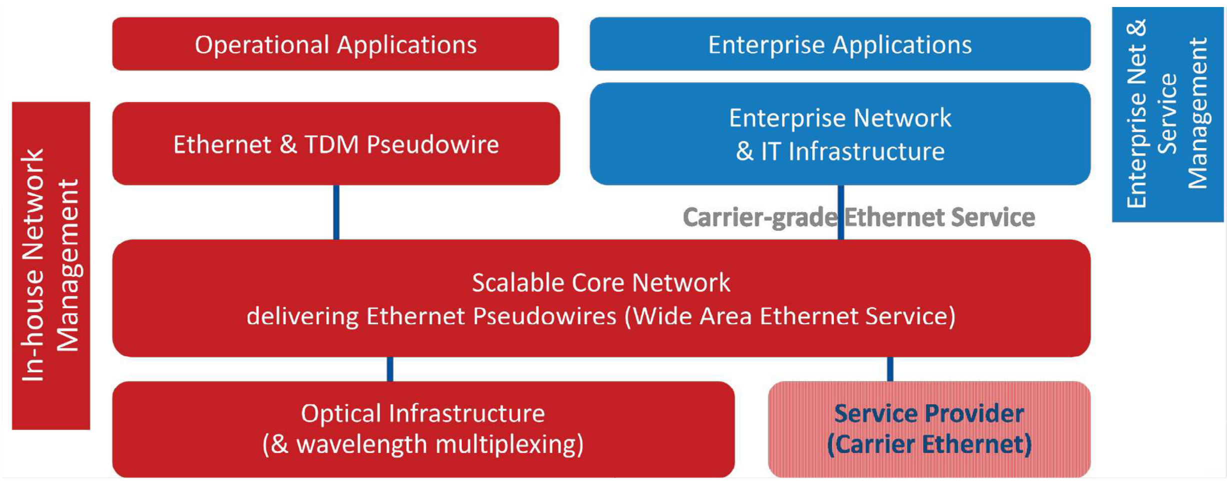
The Enterprise network may use “transport tunnels” provisioned across the substation operational network or a scalable core (e.g. Carrier-grade E-Lines) to interconnect Enterprises data switching nodes without interfering with the operational communications network as presented in figure 8. In this arrangement. each network can evolve at its required pace and shall provide the required quality. The scalable core only provides transparent connection trunks at a high level of service availability and fast service restoration.



A – Substation and Enterprise networks with disjoint network resources.



B – Substation network feeding connectivity to the Enterprise network



C – A Scalable Core Network feeding TDM/Packet connectivity to Substation and Enterprise networks

Figure 8 - Potential evolution of Operotional IOTI and Enterprise UT) networks

CONCLUSIONS

Technological migration cannot be driven by supplier pressure and despite operational shortcomings; it must be planned and performed by the utility for enhanced operational benefits (i.e. maintaining present capability and enabling new applications).

In this context, a broad analysis of targets, constraints and a time-line for the migration of services and infrastructures is essential if some clear benefit is to be sought from the network transformation. Technologies cannot be compared or assessed without knowing what we want to do with them.

Building a network is not just assembling technology blocks and somehow getting it work. It is also about building the capability to operate it, to maintain it, and to carry out modifications and extensions without degrading its initial performance. This requires building up skills, processes and adequate tools.

Adopting technologies which are more compatible to existing resources of the company allow faster and less erroneous take-over and consequently full control of the utility over its critical communication infrastructure.

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