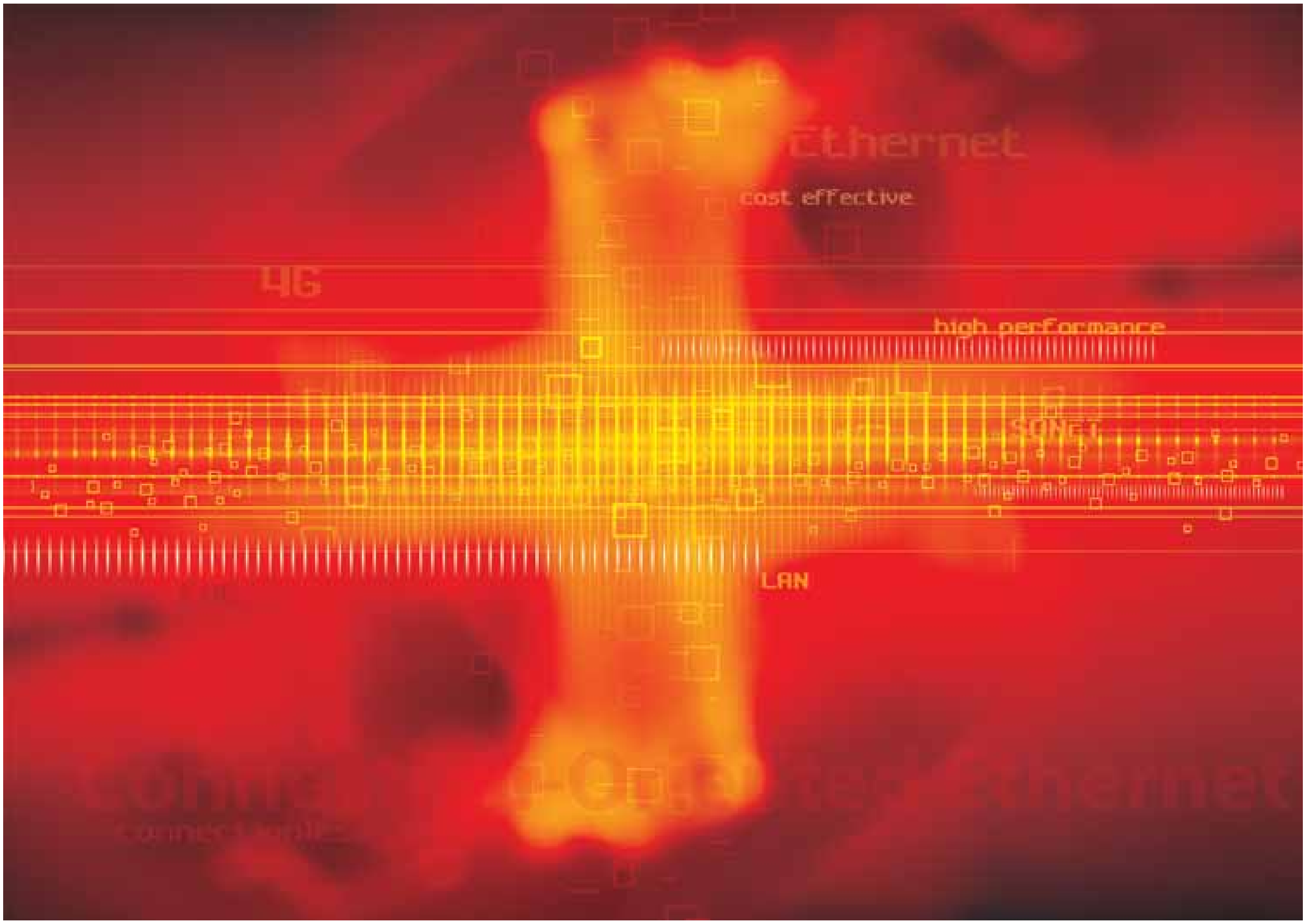
# Connection-Oriented Ethernet: Operational and Deployment Considerations



Connection-oriented Ethernet technology holds great promise. It creates, for the first time, a single metro aggregation and transport infrastructure that service providers can use for:

- Access to IP and other higher layer services
- High-quality private-line site-to-site enterprise services
- Residential wireline broadband backhaul infrastructure
- Mobile broadband backhaul infrastructure

Service providers are considering several existing and emerging technology choices for the deployment of connection-oriented Ethernet. These technology choices include a range of Ethernet-only as well as MPLS approaches including:

- C and S-tag switching (VLAN switching)
- PBB-TE
- PW3/MPLS
- T-MPLS
- MPLS-TP

Each of these approaches theoretically offers the general benefits of connection-oriented Ethernet:

- Deterministic Ethernet connection performance
- Efficient, general-purpose aggregation
- 50 ms guaranteed protection switching speed

In theory, each of these approaches could be implemented at roughly the same network element hardware cost point. However, the operational characteristics of these approaches differ significantly and therefore, service providers must carefully consider these differences when selecting technology for metro aggregation infrastructure. This paper reviews the operational characteristics of the various connection-oriented Ethernet technologies and discusses the deployment implications for the metro infrastructure.

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## Metro Network Characteristics and Key Requirements

When evaluating connection-oriented Ethernet technologies for aggregation network infrastructure, it is helpful to consider several important factors. These are:

- The geographical expanse of the metro network environment
- The large number of elements that may have to be managed
- The hub-and-spoke nature of the traffic pattern.

In the largest metro areas in the U.S., there are often 50–60 central offices and thousands of fiber-fed enterprise locations feeding tens of thousands of circuits, dispersed over hundreds of square miles, as shown in Figure 1.

Accordingly, in these offices and customer locations, there are thousands of low-cost, software-simple aggregation elements that are managed from a single central location. These elements exist to connect customer edge equipment, using point-to-point circuits in a largely hub-and-spoke manner, to a set of more specialized, complex service edge elements that are deployed in a handful of metro core offices.

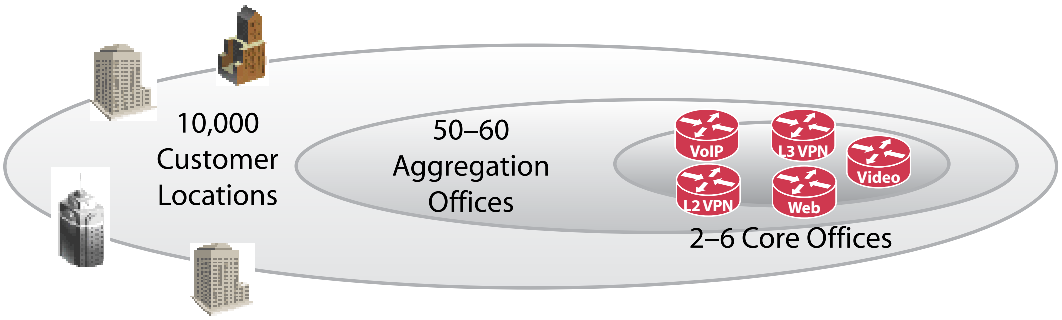


**Figure 1: Example Metro Network Topology**

To support metro geographical and traffic demand requirements, network providers have made significant investments in the areas of OSS systems, operational staff and network equipment.

**OSS systems** – Network providers have invested in OSS systems for such functions as service order processing, inventory management, provisioning, fault and performance management, billing and other functions. These systems are designed to support the management of circuits, defined as entities with:

- Specified origination and termination points
- Specific underlying hardware resources
- Deterministic throughput, delay and delay variation performance
- Long hold times

Accordingly, network elements deployed in the metro environment have extensive management plane functionality to enable their integration with these OSS systems. Network providers who deploy a management-plane-centric connection-oriented Ethernet technology can then derive significant operational efficiency by utilizing the same overall OSS approach to manage all types of circuits—including TDM, SONET, OTN, wavelength and now Ethernet—in the metro environment.

**Operational staff** – Network providers have invested in operational staff trained to manage a circuit-based network. In particular, technicians are trained in fault sectionalization using OAM tools that pinpoint fault locations along a known data path. Metro operations groups are often untrained in the management of address space, access control lists, routing protocols and routing policies associated with the routed network environment of the inter-metro core.

Network providers can benefit by deploying connection-oriented Ethernet that does not require managing the address space, protocol parameters, and access control attributes of an IP data plane.

**Network equipment** – Network providers have significant investments in SONET and ROADM optical equipment. Network providers can benefit by deploying connection-oriented Ethernet that leverages the actual embedded optical networking equipment.

By contrast, these characteristics of metro networking are different from those of the inter-metro routed core network. In inter-metro networks, there is often a full mesh or partial mesh of demand, and traffic is dynamically routed depending upon the destination of a given IP packet. The elements themselves tend to be centrally located in large offices and PoP locations. They also tend to be heavily IP control-plane driven and consequently have a high degree of software complexity. Figure 2 summarizes the essential attributes of metro networking and contrasts them with those of inter-metro routed networking.

| | **Metro Aggregation Network** | **Inter-Metro Routed Network** |
|---|---|---|
| Traffic demand | • Static<br>• Hub-and-spoke connectivity<br>• Point-to-point<br>• Point-to-multipoint | • Dynamic<br>• Mesh connectivity<br>• Point-to-point<br>• Point-to-multipoint<br>• Multipoint-to-multipoint |
| Existing networking approach | • Circuit management<br>• Centralized intelligence<br>• Management plane centric | • Address, policy, and access control management<br>• Distributed intelligence<br>• Control plane centric |
| Network elements | • Remotely deployed<br>• Lower cost<br>• Software-simple | • Centrally deployed<br>• Higher cost<br>• Software-intensive |

**Figure 2: Attributes of Metro Aggregation and Inter-Metro Routed Networks**

In summary, geographical, traffic demand, and embedded investment characteristics drive important operational requirements for metro deployments of connection-oriented Ethernet and the supporting network elements:

- Point-to-point and point-to-multipoint optimized
- Simple, circuit-dominated management (rather than address-dominated)
- Management-plane driven, centralized intelligence (rather than control-plane driven distributed intelligence)
- Simple, large-scale software upgrade support
- Network element simplicity and low-cost fault tolerance
- Reduction of network layers
- Optical network interworking and interoperability

This set of requirements is a valuable yardstick for evaluating the suitability of the various connection-oriented Ethernet technologies for broad-scale metro deployment. The following paragraphs examine the various connection-oriented Ethernet technology choices and evaluate their ability to meet the listed requirements.

## MPLS-Based Connection-Oriented Ethernet

There are three varieties of MPLS-based connection-oriented Ethernet:

- Classic PWE3/MPLS
- T-MPLS
- MPLS-TP

Each of these technologies encapsulates Ethernet frames into a pseudowire and then into an MPLS tunnel that functions as the connection-oriented entity in the network. These approaches all introduce additional networking layers beyond Ethernet. While each of these protocols leverage the MPLS frame format in the data plane, they differ widely in regards to how they establish MPLS tunnels and the OAM tools they use.

## PWE3/MPLS

PWE3/MPLS is the oldest connection-oriented Ethernet set of standards, created by the IETF so that inter-metro router networks could be used to transport point-to-point Ethernet flows between metros. Traffic arriving on Ethernet attachment circuits is encapsulated into a pseudowire and then into MPLS tunnels. Since this set of standards was created with the inter-metro network in mind, it bears all the characteristics of inter-metro networking. For example, the pseudowire and MPLS tunnels are established with control plane signaling protocols (T-LDP and RSVP-TE) that are carried over the routed IP data plane provided by the router elements.

Applying PWE3/MPLS technology in the metro aggregation infrastructure would therefore introduce routed networking deeply into the metro network. Consequently, this would introduce several levels of complexity and cost in the areas of network design, provisioning, software upgrade administration and implementation, in addition to network element fault tolerance.

## Network Design and Provisioning Implications

Deploying PWE3/MPLS would require operators to design and manage a large, complex IP address space of the order of 100,000 IP addresses per metro area. Multiple IP domains would thereby be required to bound reconvergence times. Operators would further have to provision parameters for the following protocols:

- IGP options per node
- T-LDP/BGP per node for PW signaling
- RSVP-TE per node for MPLS tunnels
- Single-hop BFD per node
- Multihop BFD per node with T-LDP neighbors
- FRR options per MPLS tunnel
- VCCV options per PW

## Network Element Complexity

In addition to the provisioning complexity, PWE3/MPLS technology has important implications for the design of the network elements themselves. For example, since metro aggregation and infrastructure applications require 50 ms protection switching and high availability, aggregation elements would have to employ complex graceful restart and non-stop routing mechanisms that allow for in-service software upgrades. These protocols require precise synchronization of large amounts of state information across plug-in units, much of which is dynamic and rapidly changing. This is in stark contrast to the small amount of static state information that is maintained on the optical elements that have traditionally provided large-scale distributed metro aggregation. As a result optical elements are low-cost and enjoy very simple remotely controlled software upgrade processes.

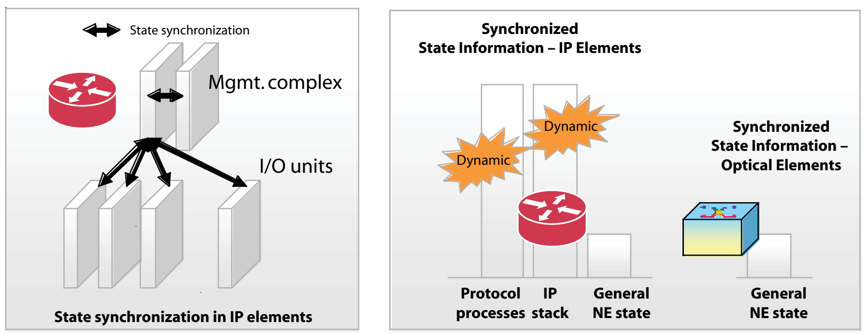


**Figure 3: Comparing State Information Between IP and Optical Elements**

## Software Management Implications

Optical network element software is backward-compatible and therefore, is tolerant of multiple releases being present in the network simultaneously. Conversely, inadvertently running multiple software releases has been a significant cause of large network outages in routed environments. Although running a network on multiple software releases is typically not desirable on a long-term basis, this tolerance affords a degree of flexibility by allowing network software to be upgraded section-by-section.

In addition to network-wide compatibility issues, router elements introduce "compatibility complexity" within a single element. Typically, router elements employ many software processes that can be upgraded independently. These include processes for signaling protocols, interior gateway protocols, exterior gateway protocols, routing information base, and other processes.

Further complicating matters is that these various processes may have dependencies upon one another. Incompatibility and outage can arise if one process is updated and a dependent process is not. Network administrators must maintain compatibility matrices for the various software processes within each element. This can require multiple software download efforts per network element.

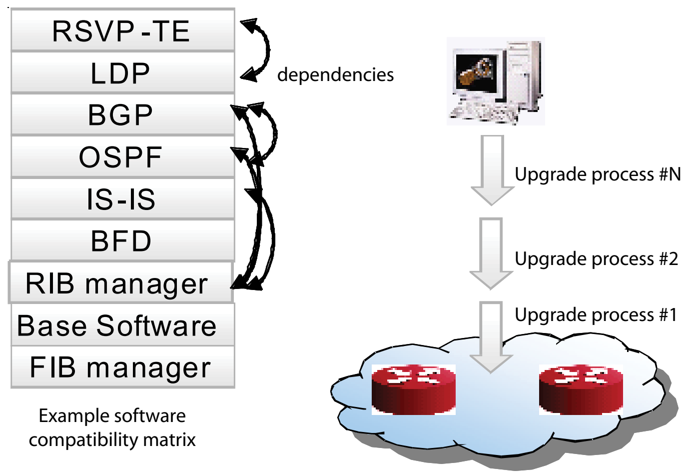


**Figure 4: Inter-Process Software Compatibility in PWE3/MPLS Elements**

For these reasons, software upgrades are often avoided for cost and complexity reasons even on routed network deployments where tens of elements are considered a large quantity. Considering that there may be thousands of aggregation elements, increasing the quantity of routed elements may make such widespread software upgrades both cost- and operationally prohibitive.

## Network Protection

Classic MPLS relies on MPLS FRR protection protocols to achieve 50 ms restoration. These protocols are well suited for inter-metro routed networks where the traffic demand pattern is highly meshed in nature. In metro aggregation and transport environments, where the traffic is largely hub-and-spoke, MPLS FRR requires additional bandwidth and involves significant provisioning complexity. The network administrator provisions link and node protection FRR LSPs; the link protection LSPs must account for the composite amount of bandwidth that is to be protected on that link. By contrast, 1:1 dedicated protection capabilities found with Ethernet-only technologies (such as those provided by G.8031 and 802.1Qay) require the provisioning of fewer protection entities, consume less ring bandwidth, and the bandwidth of the protection entities is much more easily determined.

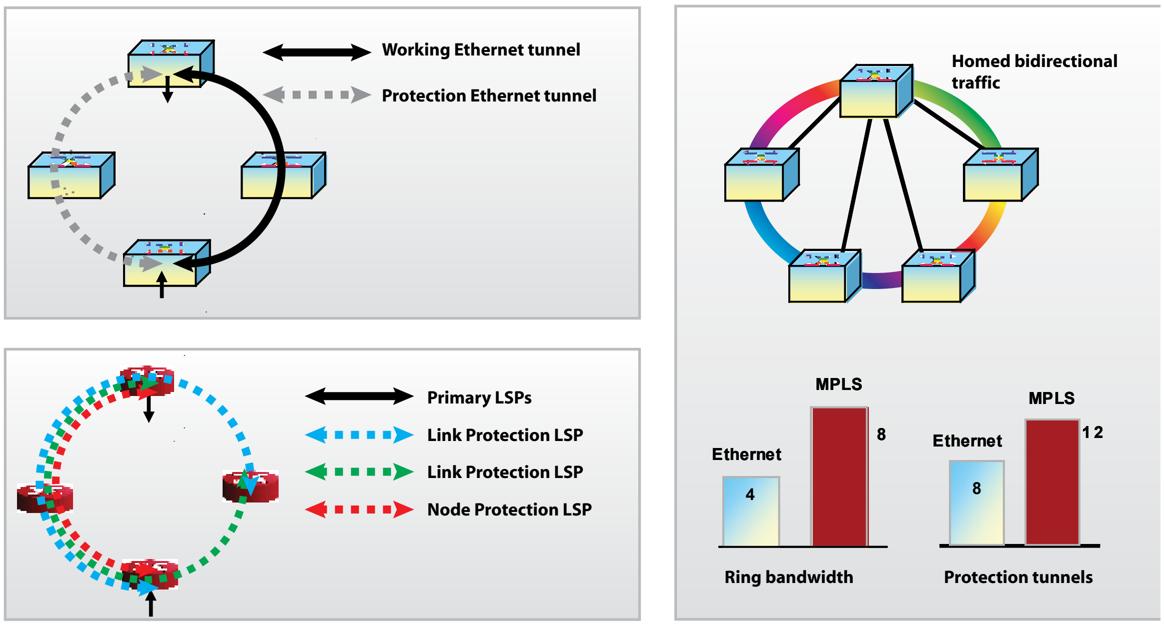


**Figure 5: Comparing MPLS FRR and Ethernet Bandwidth Consumption and Complexity for Metro Applications**

## T-MPLS

This technology was created by the ITU-T in an effort to bring static management-plane-style circuit provisioning for Ethernet. T-MPLS encapsulates Ethernet frames into bidirectional MPLS tunnels and the MPLS tunnels are then cross connected through the network. Because this technology relies on the management plane, it does not require elements to run an IP control plane and its associated IP data plane. Therefore, many of the complex provisioning, management, and software operations concerns with PWE3/MPLS outlined above do not exist in T-MPLS.

However, like the other MPLS variants of connection-oriented Ethernet, T-MPLS requires the addition of the MPLS transport layer and MPLS OAM into the metro network in addition to the required Ethernet layer. As a result of the IETF and ITU-T joint working team, T-MPLS is being abandoned as a standard and replaced by future work on MPLS-TP in the IETF.

## MPLS-TP

This emerging work recognizes the significant deployment and operational issues highlighted above that are associated with deploying a large quantity of devices that require an IP data plane. The goal is to create a "transport profile" of MPLS that is optimized around point-to-point and point-to-multipoint traffic and that does not require the traditional MPLS control plane running over an IP data plane.

As with other MPLS variants, this standard will require service providers to deploy, inventory, and manage an MPLS layer in addition to the Ethernet layer. The current direction of the standard also does not reuse existing classic MPLS OAM. The OAM tools that are being developed for MPLS-TP are conceptually similar to Ethernet OAM tools, although they reside on an additional layer. There is also no plan to extend classic MPLS tunnels in the inter-metro network seamlessly down through the metro network. Instead, the vision for MPLS-TP is that those tunnels are configured via a management plane (or a control plane that runs on non-routed data plane such as G-MPLS), then terminated at the border between the metro and inter-metro, then classic MPLS tunnels are established. This loses the important potential benefit of a uniform MPLS layer across both metro and inter-metro environments.

## Ethernet-Only Connection-Oriented Ethernet

Two Ethernet-only approaches to connection-oriented Ethernet avoid the large operational complexity of IP-routed PWE3/MPLS without introducing the additional transport and OAM layers proposed by T-MPLS and MPLS-TP.

## S + C Tag Switching (VLAN Switching)

VLAN switching is where network elements forward Ethernet frames strictly based upon the VLAN identifiers—either in the C-tag or the S-tag or both. Implementations often allow for sophisticated tag translation and stacking, providing a high degree of flexibility in managing Ethernet connections through the network. The FLASHWAVE® 9500, FLASHWAVE CDS, and FLASHWAVE 4100 Packet ONPs implement this Ethernet-centric approach to COE.

This function does not follow standard IEEE 802.1 bridging standards that forward based on the destination MAC address and use the VLAN tags to filter any flooding of frames whose destination address location is unknown.

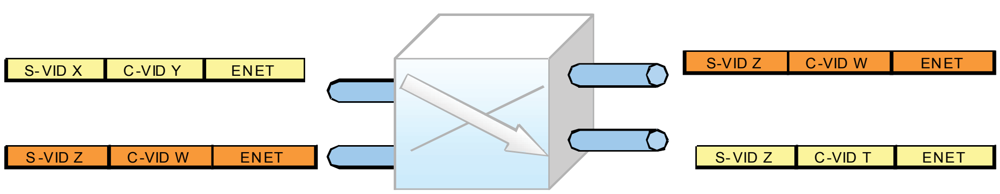


**Figure 6: Example VLAN Tag Translation and Stacking**

VLAN switching functions provide all the functional requirements of connection-oriented Ethernet. They achieve this without forcing either an extra MPLS layer into the network or imposing a complex IP data plane and associated routing protocols and software complexity. VLAN switching allows for a large number of services, because each VLAN tag identifier is only locally significant and VLAN switching machines are typically capable of translating tag values as the frames flow through the network. Connection-oriented Ethernet flows are established using existing management plane OSS systems. This technology is somewhat widely deployed even though it is, strictly speaking, non-standard.

PBB-TE

## PBB-TE

PBB-TE (IEEE standard 802.1Qay) is a method for point-to-point and point-to-multi-point connection-oriented Ethernet. PBB-TE leverages the IEEE 802.1ah provider backbone bridging (MAC-in-MAC) standard and enhances it, by disabling classic MAC flooding behavior and introducing a dedicated automatic protection switching protocol. The standard provides for an additional tag space—the backbone tag (B-tag) and an ISID field that can be used to specify a service instance. See the Fujitsu white paper titled "Understanding PBB-TE for Connection-Oriented Ethernet" for more information about PBB-TE.

Both the VLAN switching and PBB-TE methods for connection-oriented Ethernet provide significant operational advantages over the various MPLS approaches:

- Ethernet-only approaches require no design or provisioning of an IP data plane found in PWE3/MPLS networking.
- Ethernet-only connection-oriented Ethernet approaches leverage the existing management-plane-centric OSS system and operational staff environment.
- Ethernet-only approaches enabled the full benefits of connection-oriented Ethernet without the deployment of an additional transport layer and OAM, saving significant network integration costs and fault and performance management complexity.
- Because neither PBB-TE nor VLAN switching approaches to connection-oriented Ethernet require deployment of an IP data plane, as does PWE3/MPLS, the aggregation network elements themselves can be greatly simplified, which drives cost from the network. Similarly, traditional optical elements implement Ethernet-based connection-oriented Ethernet but require only a small amount of static-state synchronization to achieve in-service software upgrades.
- Ethernet-only connection-oriented Ethernet approaches allow for backward compatibility of software. They thus eliminate concerns about complex network element software compatibility matrices for the multiple software processes that may run within a single PWE3/MPLS element.
- Ethernet-only approaches to connection-oriented Ethernet employ simple, dedicated network protection schemes that deliver 50 ms protection switching with less bandwidth consumption and provisioning complexity.

Figure 7 illustrates the relative simplicity of Ethernet-based connection-oriented Ethernet compared with a PW/MPLS approach. T-MPLS and MPLS-TP remove the IP layer provisioning associated with PWE3/MPLS, but many of the remaining additional protocols and OAM functions still exist.

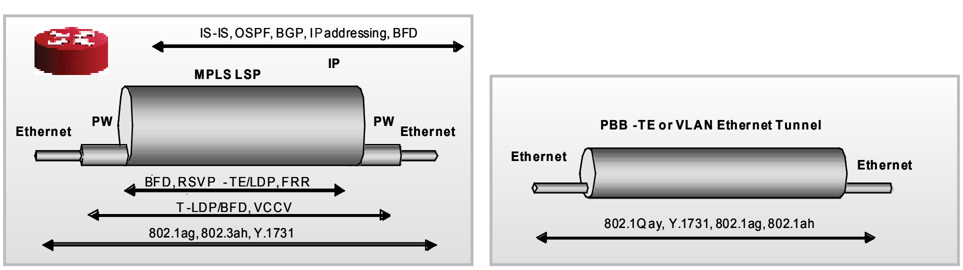


**Figure 7: Ethernet-Only Approaches Reduce Network Layers and Protocol Complexity**

Figure 8 summarizes the operational attributes of the various approaches for connection-oriented Ethernet.

| | PWE3/MPLS | T-MPLS | MPLS-TP | VLAN Switching | PBB-TE |
|---|---|---|---|---|---|
| Simple, circuit-based provisioning | | ✓ | ✓ | ✓ | ✓ |
| Management plane driven, centralized intelligence | | ✓ | ✓ | ✓ | ✓ |
| Simple software upgrades | | ✓ | ✓ | ✓ | ✓ |
| Low-cost fault tolerance | | ✓ | ✓ | ✓ | ✓ |
| Simple, dedicated protection | | ✓ | ✓ | ✓ | ✓ |
| Reduced network layers | | | | ✓ | ✓ |

**Figure 8: Comparison of Connection-Oriented Ethernet Operational Attributes**

## Packet Optical Networking and Connection-Oriented Ethernet

Because of the above operational capabilities, Ethernet-based connection-oriented Ethernet technologies offer network providers the ability to integrate connection-oriented Ethernet directly into the existing optical aggregation infrastructure environment by leveraging the OSS, operational staff and network equipment investments they have already made.

In particular, service providers can derive significant capital and operational cost savings by tightly integrating Ethernet-based connection-oriented Ethernet functionality directly into Packet ONPs. Packet ONPs with centralized connection-oriented Ethernet fabrics and optional ROADM units enable service providers to aggregate connection-oriented Ethernet flows into transport wavelengths in the same network element without intervening transponders or inter-element cabling and management.

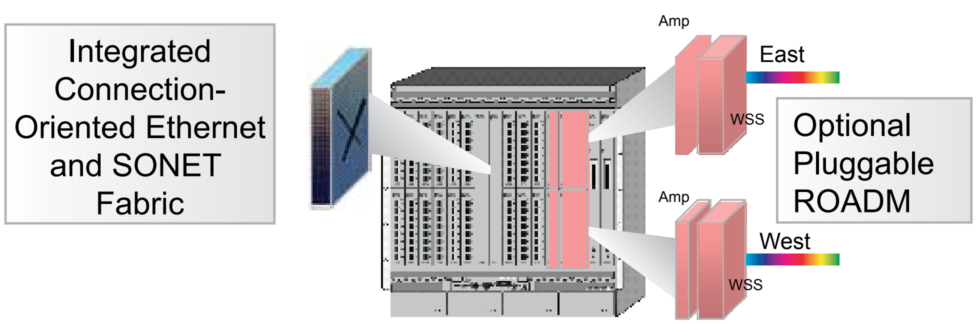


**Figure 9: FLASHWAVE 9500 Packet Optical Networking Platform Implementation**

In particular, considerable cost savings are realized at hub site locations where combinations of SONET and connection-oriented Ethernet traffic are both accessing IP service edge router elements. An example of such savings is shown in Figure 10.

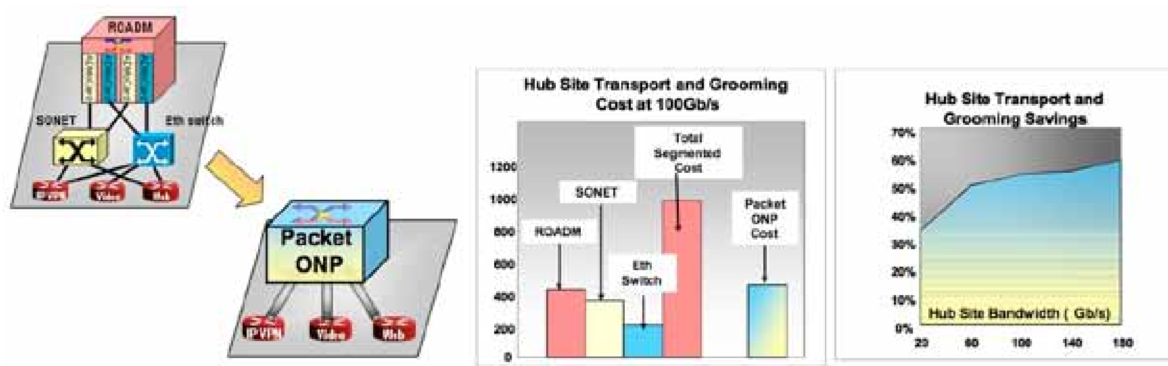


**Figure 10: Example Cost Savings for Connection-Oriented Ethernet and Packet Optical Integration at Hub Site**

## Conclusions

Connection-oriented Ethernet holds great promise for creating, for the first time, a single aggregation and transport metro infrastructure that service providers can use for:

- Access to IP and other higher layer services
- High-quality private-line site-to-site enterprise services
- Residential wireline broadband backhaul infrastructure
- Mobile broadband backhaul infrastructure

The Ethernet-based connection-oriented Ethernet technologies—VLAN switching and PBB-TE—uniquely allow service providers to enjoy the deterministic performance, efficient aggregation and 50 ms protection switching capabilities of connection-oriented Ethernet in a manner that is most easy to operationalize:

- Simple, circuit-based provisioning with no IP provisioning
- Management-plane-driven to fit into the existing OSS and operational structure of the metro aggregation network
- Simple software structure that facilitates simple software upgrades in the highly distributed metro environment
- Low-cost fault tolerance that allows for low-cost, highly robust, upgradable elements
- Minimizes the number of network layers to streamline the OSS integration and ongoing management of connection-oriented Ethernet.
- Integrates directly into next-generation Packet ONPs to eliminate additional network elements, cabling, and management complexity.

| Acronym | Definition |
|---|---|
| BFD | Bidirectional Forwarding Detection |
| BGP | Border Gateway Protocol |
| FRR | Fast ReRoute (MPLS) |
| GMPLS | Generalized MPLS |
| IETF | Internet Engineering Task Force |
| IP | Internet Protocol |
| IGP | Interior Gateway Protocol |
| IS-IS | Intermediate System to Intermediate System |
| ITU | International Telecommunications Union |
| LDP | Label Distribution Protocol |
| LSP | Layered Service Provider |
| MAC | Media Access Control |
| MPLS | Multiprotocol Label Switching |
| MPLS-TP | MPLS-Transport Profile |
| OAM | Operations, Administration and Maintenance |
| OSPF | Open Shortest Path First |
| OSS | Operations Support System |
| OTN | Optical Transport Network |
| Packet ONP | Packet Optical Networking Platform |
| PBB-TE | Provider Backbone Bridging with Traffic Engineering |
| PoP | Point of Presence |
| PW | Pseudowire |
| RIB | Routing Information Base |
| ROADM | Reconfigurable Add/Drop Multiplexer |
| RSVP-TE | Resource Reservation Protocol with Traffic Engineering |
| SONET | Synchronous Optical Networking |
| TDM | Time-Division Multiplexing |
| T-LDP | Targeted Label Distribution Protocol |
| VCCV | Virtual Circuit Connectivity Verification |
| VLAN | Virtual Local Area Network |
| WSS | Wavelength-Selective Switch |