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Carrier Ethernet over DOCSIS® (CEoD):

A Proposed Target Architecture for DOCSIS Service Providers

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Introduction

The cable industry and service providers worldwide have embraced Layer 2 Ethernet services as defined by the Metro Ethernet Forum (MEF) [1]. The Metro Ethernet Forum has defined a new class of Ethernet, called "Carrier Ethernet" which includes support for Time Division Multiplexing (TDM) Emulation services and several Ethernet service types, attributes, and parameters to support the adoption of Ethernet beyond the local area network (LAN) to a Carrier-provided service for business and residential end users. Industry drivers for Carrier Ethernet include service providers, equipment manufacturers, the Metro Ethernet Forum (MEF), the Internet Engineering Task Force (IETF), the Institute of Electrical and Electronics Engineers (IEEE), and the Telecommunication Standardization Sector of the International Telecommunications Union (ITU-T). It is critical that worldwide standards are defined so that service providers and equipment suppliers may offer standards-based products to end users. Service providers, including cable Multiple System Operators (MSOs), have offered Metro Ethernet services for years. Recently the Metro Ethernet Forum emerged defining services, technical specifications, and certification standards for carriers and vendors alike; this was pivotal in the worldwide adoption of Carrier Ethernet services. Today, telecommunications providers are positioning Carrier Ethernet services against legacy technologies like Frame Relay, TDM Private Line, Synchronous Optical Network (SONET), and even newer technologies such as Layer 3 MPLS VPNs (also known as IP VPNs) [2].

Opportunity

MSOs and equipment providers have joined the Metro Ethernet Forum (MEF) in promoting Ethernet services, to support the small-medium and large business services market. Most MSOs and other services providers are moving to Ethernet because of its low cost, high bandwidth flexibility and the ease of transition for the end customer. This is due to the broad adoption of Ethernet switches and routers – equipment already in place at many customer locations. Many MSOs providing MEF-based Carrier Ethernet services are doing so over an active Ethernet architecture, utilizing an optical network which is separate from the HFC/DOCSIS network. In the September 2007 issue of CED Magazine [3], Kristine Faulkner, VP of product development and management for Cox Business Services®, stated that only 14 percent of the commercial buildings in the U.S. have fiber connections. Faulkner was quoted in the article as saying, "Where we see a great opportunity for us in hitting the addressable market is with our HFC infrastructure and our HFC network." Faulkner also said, "We can gain a larger footprint with Ethernet by delivering it over our HFC with minimal investment." The ability to offer Carrier Ethernet services over a DOCSIS-based HFC architecture would strengthen the MSO's stance in the marketplace. Meeting this opportunity is a key objective with proposing an alternative architecture.

Challenges

The challenge facing the cable industry is to define a network architecture that enables the full range of MEF-defined Carrier Ethernet services that may be carried over a DOCSIS network infrastructure with the least impact on capital investment and operations, while assuring immediate network-wide readiness, support for end-to-end Quality of Service and service management. Addressing theses fundamental challenges is the core purpose of this technical paper and the basis of a newly proposed target architecture, called Carrier Ethernet over DOCSIS (CEoD). The proposed CEoD target architecture will plan for the full support of MEF Carrier Ethernet services. The challenge of supporting Carrier Ethernet services typically included requirements for network-wide upgrades to the CMTS and the addition of new network equipments north of the CMTS, and yet limitations to support the full range of MEF Carrier Ethernet service types may have remained. The proposed Carrier Ethernet over DOCSIS (CEoD) architecture seeks to eliminate the previous challenges for cable operators to utilize their DOCSIS network for the full support of MEF Carrier Ethernet service types.

Overview

The core purpose of this paper is to explain the CEoD architecture. This proposed target architecture will enable full support of MEF Carrier Ethernet service types, including E-Line, E-Tree and E-LAN, by enabling advanced technology in the DOCSIS customer premises equipment. This architecture also defines an end-to-end framework for Quality of Service (QoS) as well as an Operation, Administration, Maintenance and Provisioning (OAM&P) framework. The architecture will *not require* any upgrades to the CMTS or additional IP Network elements north of the CMTS to facilitate Point-to-Point or Multipoint services. The CEoD architecture will use IP as the Packet Switched Network (PSN) technology and *not require* the implementation of a Multi Protocol Label Switching (MPLS) PSN, though this may be leveraged if so desired. The Carrier Ethernet over DOCSIS architecture will be completely standards-based, deriving from worldwide MEF, IETF, IEEE and ITU standards to allow immediate global adoption and interoperability. The CEoD architecture will also leverage CableLabs® specifications such as DOCSIS, PacketCable™ and Business Services over DOCSIS (BSoD) work. This paper may also serve as a high-level tutorial of Metro Ethernet Forum defined services and current Layer 2 VPN technologies over a DOCSIS infrastructure, including CableLabs' BSOD-L2VPN specifications and a recent architecture that utilizes a L2TPv3-enabled CPE and L2TPv3 Aggregator.

As the intersection of Carrier Ethernet and DOCSIS is likely to emerge in the near future, the contending approaches, Business Services over DOCSIS – Layer 2 VPN (BSoD-L2VPN), L2TPv3-enabled CPE and L2TPv3 Aggregator and the proposed Carrier Ethernet over DOCSIS (CEoD) may facilitate this intersection. This paper will examine the differing approaches, so that interested parties in the Cable industry may have additional information for consideration as initial Carrier Ethernet deployments are planned.

Before considering the proposed architecture in detail, the next two sections will provide an overview of Carrier Ethernet services and current Layer 2 VPN architectures to facilitate comparison.

Carrier Ethernet Services Overview

This section is intended to provide a high-level overview of Carrier Ethernet services as defined by the Metro Ethernet Forum. Additional information is available to the public from the Metro Ethernet Forum web site located at www.metroethernetforum.org.

There are two Carrier Ethernet specifications which provide Ethernet service type definitions and corresponding service attributes and parameters: MEF 6 and MEF 10.1 respectively. The Carrier Ethernet specification defined in MEF 6 called Metro Ethernet Services Definitions Phase I, defines the Ethernet services, such as EPL, EVPL, E-Line and ELAN. The corresponding MEF 10.1 Ethernet Services Attributes Phase 2 defines the service attributes and parameters required to offer the services defined in MEF 6.

Ethernet Service Type Description

There are specific Carrier Ethernet services definitions, service attributes and parameters to replace legacy technologies or to simply extend the enterprise LAN network transparently over a service provider network. As mentioned in earlier sections and in subsequent sections of this document, there are three key Carrier Ethernet service types: E-Line, E-Tree, and E-LAN. Sourced from the Metro Ethernet Forum, below is a list of these service types with associated sub-types and key characteristics found in each.

E-LINE (Point to Point)

- **Ethernet Private Line (EPL)**
    - Dedicated UNIs for Point-to-Point connections
    - Single Ethernet Virtual Connection (EVC) per UNI
    - The most popular Ethernet service due to its simplicity
    - Legacy Equivalent: TDM Private line
- **Ethernet Virtual Private Line (EVPL)**
    - Enables multiple services to be offered over a single physical connection (UNI) to customer premises equipment
    - Multiplexed UNI, for example multiple EVCs per UNI
    - Legacy Equivalent: Replaces Frame Relay or ATM services
- **Ethernet Internet Access**

E-Tree (Point-to-Multipoint)

- **Ethernet Private Tree (EP-Tree)**
- **Ethernet Virtual Private Tree (EVP-Tree) services**

- E-Tree Features:
  - Enables Point-to-Multipoint services
  - Requires less provisioning than typical hub and spoke configuration using E-Lines

E-LAN (Multipoint)

- **Ethernet Private LAN and Ethernet Virtual Private LAN services**
  - Supports dedicated or service multiplexed UNIs
  - Multipoint Layer 2 VPNs
  - Transparent LAN Service
  - Foundation for Multicast networks
  - IPTV

Current Architectures for Ethernet over DOCSIS

The Cable industry has had efforts underway for several years to fill critical gaps that may leverage their DOCSIS-based infrastructure and support MEF-defined Carrier Ethernet Services. In fact, several years ago the Cable industry defined a Layer 2 VPN (L2VPN) architecture through work organized by CableLabs with a specification known as Business Services over DOCSIS (BSoD) L2VPN. Recently, MSOs and equipment manufactures supporting the cable industry have examined an additional architecture for Ethernet over DOCSIS utilizing L2TPv3 in DOCSIS CPE and L2TPv3 Aggregation devices. This paper will refer to this architecture approach as L2TPv3 CPE & Aggregator. These two architectures will be examined in the following sections.

Acknowledging that other Layer 2 architectures have been deployed and may exist, the current architectures under examination must have defined support for Point-to-Point as well as Multipoint services with Standards-based technologies. Regrets if other DOCSIS Layer 2 Ethernet Architectures exist and were not mentioned; this omission was not intentional.

BSoD-L2VPN (Aggregation & Distribution Layer Approach)

The BSoD-L2VPN specification and architecture forced additional enhancements on elements in the MSO network, including the Cable Modem (CM), Cable Modem Termination System (CMTS), and Northbound Multilayer Switch Routers (MLSR) to enable the Layer 2 Ethernet services. Still, additional work is underway to extend this CableLabs specification to support Carrier Ethernet services as defined by the Metro Ethernet Forum. The BSOD-L2VPN specification defines support for Point-to-Point as well as Multipoint Ethernet services. Thus, the Provider Edge (PE) functionality may be classified in two areas when considering the BSoD-L2VPN specification, including the Aggregation Layer (CMTS) and Distribution Layer (MLSR or Tunnel Aggregator). Figure 1 below illustrates these network layers and figure 2 illustrates the BSoD architecture and description of the functions. The illustration in figure 3 is that of a

Multipoint Service providing services to customers in three physical locations, potentially in a single metro market.

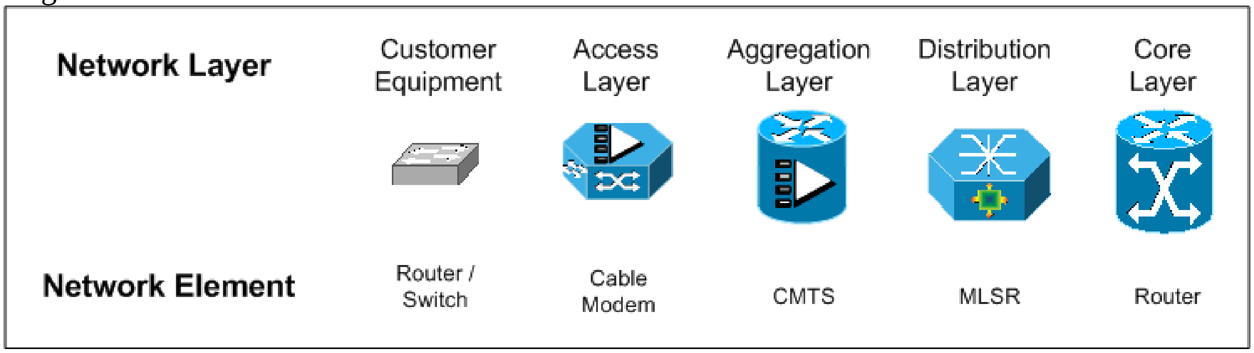

Figure 1 Network Layer Framework

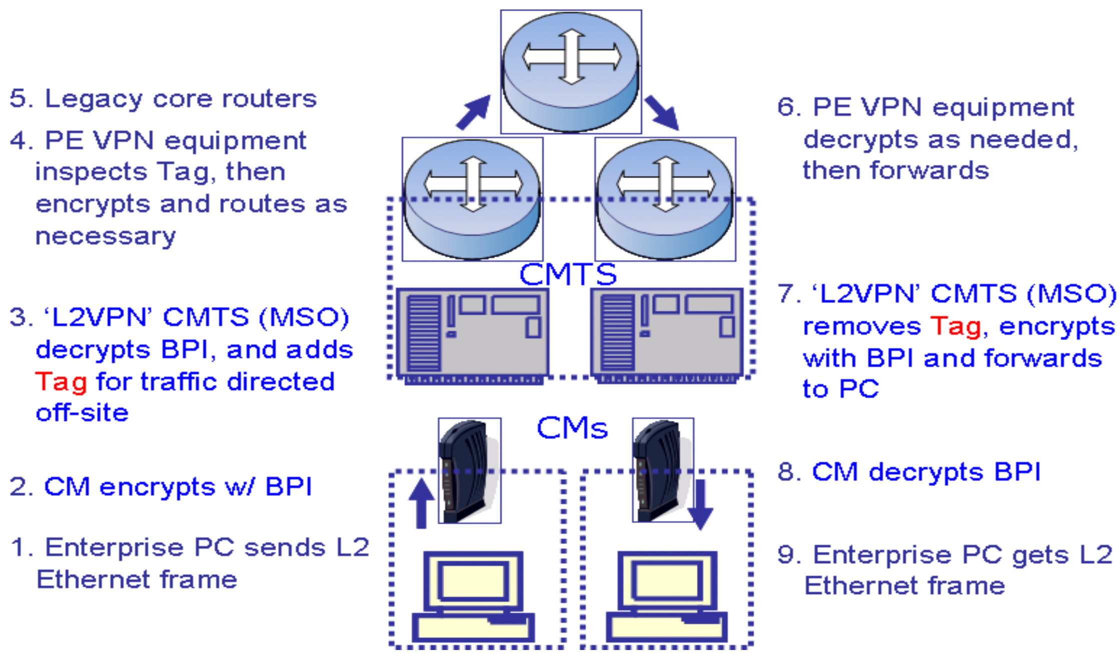

Figure 2 BSoD-L2VPN Reference Architecture
Source: L2VPN Interop Planning Meeting Presentation 5/24/07

The following figure illustrates a BSOD-L2VPN Architecture connecting three locations and supporting Multipoint Ethernet Services.

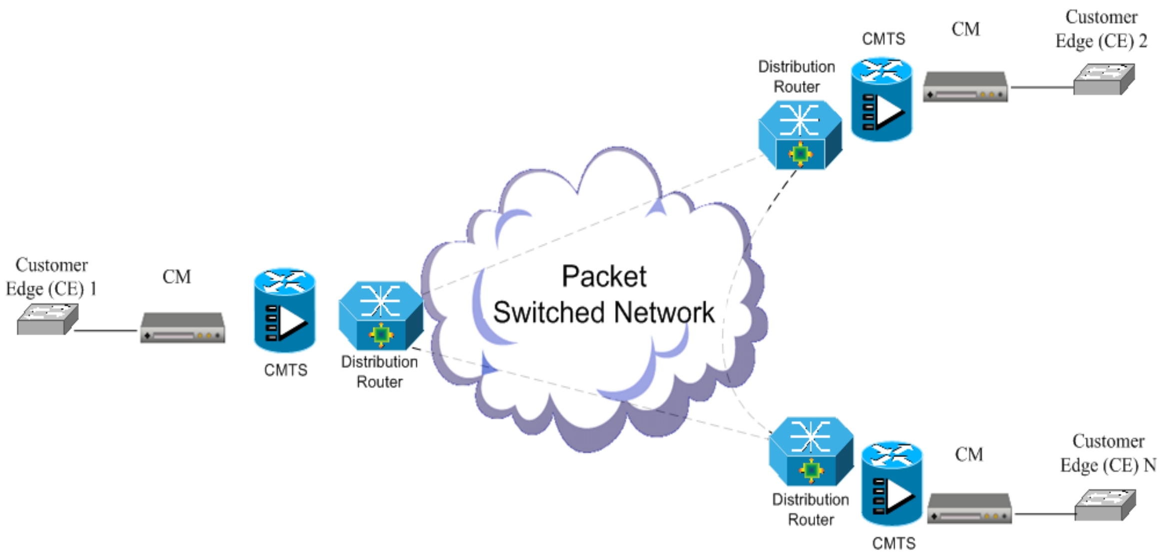

Figure3 BSoD-L2VPN Point to Point or Multipoint Architecture (Multiple Sites)

CableLabs' BSoD - L2VPN Conclusions

- **Pros**
  - Architecture defines support for Point-to-Point and Multipoint Services
  - Utilized a Standards-Based Architecture
  - Architecture has small success-based capital requirement (basic CM)
- **Cons**
  - Provisioning: The BSoD L2VPN architecture requires provisioning of several network devices for the initial VPN service instantiation (in **Figure 2**, six (6) devices are provisioned for single customer VPN and in **Figure 3** there are nine devices provisioned for a single Enterprise customer having three locations).
  - Network Upgrades:
    - CMTS Upgrades required (level depends on services supported)
    - MLSR / Tunnel Aggregator upgrade likely
  - Network wide readiness requires network equipment and back office upgrades prior to service launch and CPE availability day of install.
  - Network Operations and Services Management: The required number of network devices involved in VPN service may impact operations for troubleshooting network events.

- Scalability: If the Enterprise customer is served from several primary hub or headend locations, the number of device involved in the actual Layer 2 Tunnel increases as this is a network-enabled service offering.
- Reliability: The required number of network devices involved in VPN service (tunnel) may impact services reliability. The network elements involved in the VPN Service at the network layer should consider a five 9s availability target.

L2TPv3 CPE & Aggregator (Access & Aggregation Layer Approach)

This architecture defines the use of Layer 2 Tunneling Protocol version 3 (L2TPv3) in a cable modem device and also includes an L2TPv3 Tunnel Aggregator and serves as an alternative to the CableLabs' defined BSoD-L2VPN Network-based VPN approach. The use L2TPv3 as defined in the RFC 4719 specification is a connection between exactly two end points, making L2TP a Point-to-Point service technology. This may limit the Carrier Ethernet service type supported. The L2TPv3 Aggregator can enable additional service support to include complex point-to-point architectures, for example hub and spoke, whereby the hub requires more than one connection. Additionally, the L2TPv3 Aggregator will enable support for multipoint services. Figure 4 illustrates the use of a L2TPv3-enabled CM in a point-to-point Ethernet Private Line Architecture and the following Figure 5 illustrates a multipoint architecture using L2TPv3-enabled CM and L2TPv3 Aggregator.

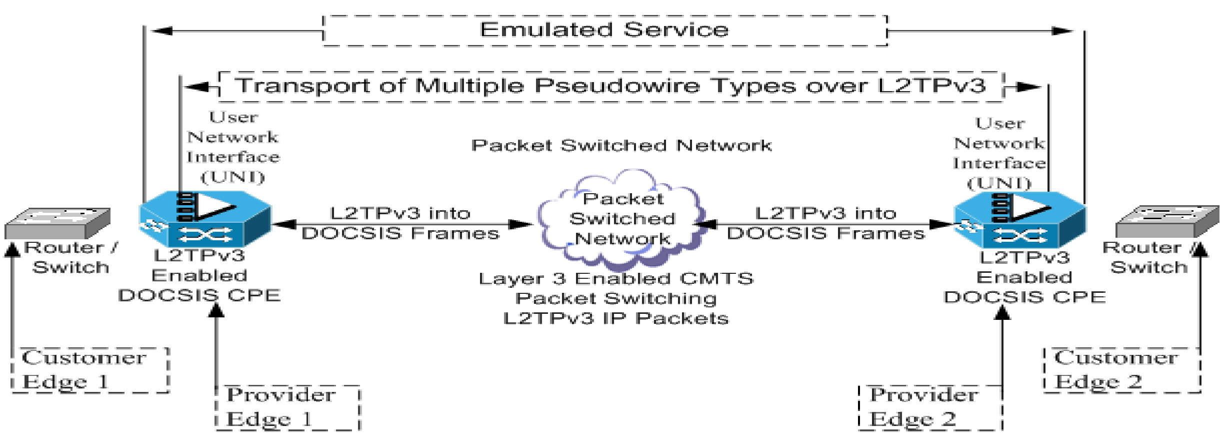

Figure 4 Ethernet Private Line using L2TPv3-Enabled DOCSIS CPE

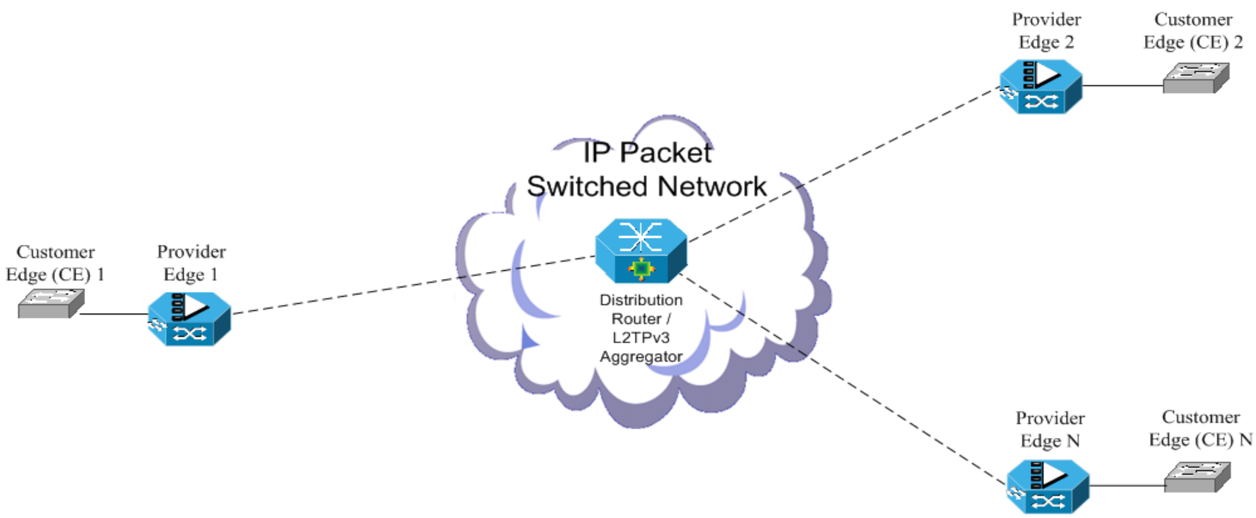

Figure 5 EVLAN using L2TPv3-Enabled DOCSIS CPE

L2TPv3 CPE & Aggregator Conclusions

- **Pros**
  - Architecture defines support for Point-to-Point and Multipoint Services
  - Utilizes a Standards-Based Architecture
  - L2TPv3 eliminates CMTS upgrade requirements across any CMTS
  - Reduces network readiness requirements
  - EPL Service requires "No" Network Layer L2TPv3 Aggregator
  - EPL Service requires provisioning for "only" customer premises devices
  - Reliability: The L2TPv3-enabled DOCSIS CPE, as illustrated in Figure 4, enables the VPN services between only the Access Layer devices. The network north of the CPE is simply performing packet switching, thus not involved in the VPN tunnel. The packet switched network devices as part of the Aggregation, Distribution, and Core Layers will be assumed to be architected with five 9s reliability.
- **Cons**
  - Architecture requires provisioning of multiple network devices for Multipoint and possibly EVPL service instantiations. However, the example in Figure 5 illustrates only the minimum, of one (1) L2TPv3 Aggregator, though real-world deployments may use multiple devices.
  - Network wide readiness requires upgrade to L2TPv3 Aggregator
  - Number of required devices involved in VPN service may impact operations for troubleshooting network events
  - L2TPv3 Aggregator device(s) involved in VPN service may impact services reliability

- Scalability: If the Enterprise customer is served from several primary hub or headend locations, the number of devices involved in the actual Layer 2 Tunnel increases as this is a network-enabled service offering.
- Reliability: The L2TPv3 VPN Aggregator could be a single point of failure depending on the architecture options available and network design. The Aggregator should be engineered with five 9s reliability as this platform is a central point for service creation and for sustained VPN connectivity. A failure of the L2TPv3 VPN Aggregator may result in 1000s of connections being lost and many customers impacted.

Current Architectures for Ethernet over DOCSIS Summaries

The BSoD-L2VPN and L2TPv3 CPE and Aggregator Architectures share some strengths in that both define point-to-point and multipoint service support and each are standards based. Separately, the L2TPv3 CPE and Aggregator Architecture may enable only L2TPv3 CPE elements to create and maintain the Layer 2 VPN, as illustrated in Figure 4. This is a key strength specific to this architecture, enabling the entire network north of the CPE to remain transparent to the VPN service (Tunnel); allowing these network elements to perform packet switching and QoS–typical network functions. However, some weaknesses are also shared, including: provisioning of the services requires touching the network layer and the CPE, and the addition of network layer elements to the architecture may have several capital and performance impacts. Another observation is that fewer devices involved in the actual VPN tunnel would reduce requirements to the provisioning and network layer. Moreover, with fewer devices involved in the actual VPN, this may increase overall service reliability as there are fewer devices supporting the actual VPN services. This next section is an alternative approach that will hopefully address many of the concerns found in the previously examined approaches, while preserving many of the strengths.

Proposed Target Architecture: Carrier Ethernet over DOCSIS

This section of the technical paper defines the goals and technical compositions of the proposed Carrier Ethernet over DOCSIS (CEoD) architecture. The CEoD architecture defines support for E-Line, E-Tree and E-LAN services from an Enhanced DOCSIS CPE. The proposed CEoD Architecture is similar to that described in the section above, called L2TPv3 CPE and Aggregator architecture, in that the Enhanced DOCSIS CPE utilizes L2TPv3. However, the key difference is that the CEoD architecture does ***not*** require the use a L2TPv3 Aggregator / Concentrator, while still supporting all of the Carrier Ethernet services types. In this section of the technical paper, the details of the CEoD proposed architecture will emerge. Through the use of informative text and illustrations, several Carrier Ethernet services types and sub-types are examined.

Carrier Ethernet over DOCSIS Architecture Goals

The initial Business, Architecture and Operational goals of the proposed Carrier Ethernet over DOCSIS (CEoD) solution are outlined in the list below and serve as a foundation for the proposed target architecture.

Business, Architecture and Operational Goals:

1. Support Carrier Ethernet Service Types including: E-Line, E-LAN & E-Tree
2. Utilize a Standards-Based Architecture
3. Minimize network enablement capital
4. Optimally utilize success-based capital
5. Enable rapid network wide readiness
6. Support E-Line, E-LAN & E-Tree Services with an Enhanced DOCSIS CPE while existing network remains transparent to the VPN Tunnel
7. Provide End-to-End QoS
8. Minimize the number of devices requiring Operation, Administration, Maintenance and Provisioning
9. Provide OAM Framework to Reduce Operational Complexity
10. Leverage Existing MSO Provisioning Systems

Carrier Ethernet over DOCSIS Overview

The CEoD Architecture will inherently support Point-to-Point (Pt-to-Pt) connections with L2TP-enabled devices, such as routers, switches, multi-layer switch routers, and other DOCSIS devices. The real distinction in the CEoD Architecture is the expansion to a multitude of features and functionality with Point-to-Multipoint (Pt-to-MP) and Multipoint-to-Multipoint (MP-to-MP) Layer 2 tunnels over a CEoD-Enabled DOCSIS CPE device. This architecture simply pushes the intelligence to the network edge and, therefore, does not require network-wide upgrades. This architecture also enables the network to be transparent to said multitude of services.

<u>Carrier Ethernet over DOCSIS Architecture (The Intelligent Edge Concept):</u>

- **I. A "L2TP-Enabled CPE" – "Just L2TP" supports Point-to-Point Services**
- **II. An "Enhanced CPE" enables L2TP <u>and</u> a Virtual Switch Instance (VSI)**
  - a. Adds a Virtual Switch Instance (VSI) for Switching and Tunnel Selection
  - b. L2TP is used for Tunnel creation and IP Packet Transport
  - c. Supports All Services Point-to-Point, Point-to-Multipoint, Multipoint
  - d. Compliance Targets: MEF E-Line/E-Tree/E-LAN & IETF VPWS/VPLS
- **III. CEoD defines Simplified Provisioning Strategy**
- **IV. CEoD defines an End-to-End QoS Architecture Framework**
- **V. CEoD defines an End-to-End OAM&P Architecture Framework**

The Enhanced CPE may be optionally configured with a Virtual Switch Instance (VSI) and uses L2TPv3 layer 2 encapsulation and IP packet switching for transport. This key feature also provides support for both Point-to-Multipoint (Pt-MP) and true Multipoint-Multipoint (MP-to-MP) services. For example, an Enhanced CPE with VSI may support services defined by the MEF for E-LAN Services and the IEFT Virtual Private LAN Service (VPLS). The VSI in the Enhanced CPE provides emulation of all the IETF- and MEF-defined multipoint services, while using L2TPv3 as session establishment and encapsulation into IP packet for transport across an IP-enabled PSN.

The VSI may provide, among other functions:

- basic switching
- MAC address learning
- flooding unknown frames
- traffic replication
- aging MAC addresses

Figure 6 summarizes the Carrier Ethernet Architectures over DOCSIS. This provides the context for the previous section and against the proposed architecture. Figure 6 illustrates the network layers, devices, functions with Ethernet over DOCSIS impact, or lack thereof, due to transparency.

CARRIER ETHERNET for DOCSIS SERVICE PROVIDER

NETWORK LAYER	CABLE ELEMENT	NETWORK ROLE	BSOD – L2VPN Aggregation & Distribution Architecture Role	L2TPv3 CPE & Aggregator * Architecture Role	CEoD Enhanced DOCSIS CPE Architecture Role
Core Layer	Router	**Purpose:** MSO / Nation Wide Network **Function:** Packet Switching Only (Absolutely No Provider Edge (PE) Functions Take Place) **Typical Location:** RDC and/or Peering Sites **Number of Customer Supported:** Entire Base	Transparent	Transparent	Transparent
Distribution Layer *	MLSR *	**Purpose:** Metro / Regional Network Connectivity **Function:** Generally Just Packet Switching (Generally No PE Functions Take Place) **Typical Location:** Head End/Primary Hub Sites **Number of Customer Supported:** Metro / Regional Market	**Services:** Defines All **Requires:** New Software / Hardware Upgrade **Provide Edge:** Yes **Service Activation:** Yes **QoS Establishment:** Yes **Service Management:** Yes	**Services:** EVPL & E-LAN **Requires:** New Software / Hardware Upgrade **Provide Edge:** Yes **Service Activation:** Yes **QoS Establishment:** Yes **Service Management:** Yes	Transparent
Aggregation Layer	CMTS	**Purpose:** Community / Metro Network Connectivity **Function:** Packet Switching / Service Flow / Enforcement Support All MSO Services **Typical Location:** Head End/Primary Hub Sites **Number of Customer Supported:** Metro 20K Plus, number of customer supported increasing	**Services:** Defines All **Requires:** New Software / Hardware Upgrade **Provide Edge:** Yes **Service Activation:** Yes **QoS Establishment:** Yes **Service Management:** Yes	Transparent	Transparent
Access Layer	Cable Modem	**Purpose:** Customer Premise Equipment / Service Provider Owned / Managed **Function:** Enable Services (EMTA, IPSec, Carrier Ethernet) **Typical Location:** Customer Premise **Number of Customer Supported:** Home / Businesses	**Services:** Transparent **Requires:** Software Upgrade **Provide Edge:** No **Service Activation:** Yes	**Services Supported:** EPL **Requires:** New Software / Hardware Upgrade **Provide Edge:** Yes **Service Activation:** Yes	**Services:** Defines All E-Line, E-LAN- E-Tree **Requires:** New Software / Hardware Upgrade **Provide Edge:** Yes **Service Activation:** Yes **QoS Establishment:** Yes **Service Management:** Yes
Customer Equipment	Router/ Switch	**Purpose:** Customer Equipment **Function:** Premise Networking **Typical Location:** Customer Premise **Number of Customer Supported:** Home / Business			

* L2TPv3 Aggregation functions may take place at the Distribution Layer / MLSR located in the Metro Market HE / PH additional software & hardware may apply

Figure 6 Summarization of Carrier Ethernet Architectures over DOCSIS by Functions

CEoD E-Line Architecture

The CEoD E-Line Architecture, as illustrated in Figure 7, is an end-to-end view of the architecture including the element in between both Provider Edge end points that are not involved in the VPN tunnel, other than packet switching and QoS, to mention a few functions. This end-to-end architecture is providing Point-to-Point (Pt-to-Pt) connectivity. The CE ingress point at the L2TPv3-enabled DOCSIS CPE (Provider Edge PE) receives the Layer 2 traffic and performs encapsulation, for placement into DOCSIS frames and service flows. This illustration shows the access over a shared coaxial network and the emulated service being transported across a Packet Switched Network (PSN) to a corresponding L2TPv3-enabled DOCSIS CPE endpoint labeled PE 2 and CE 2.

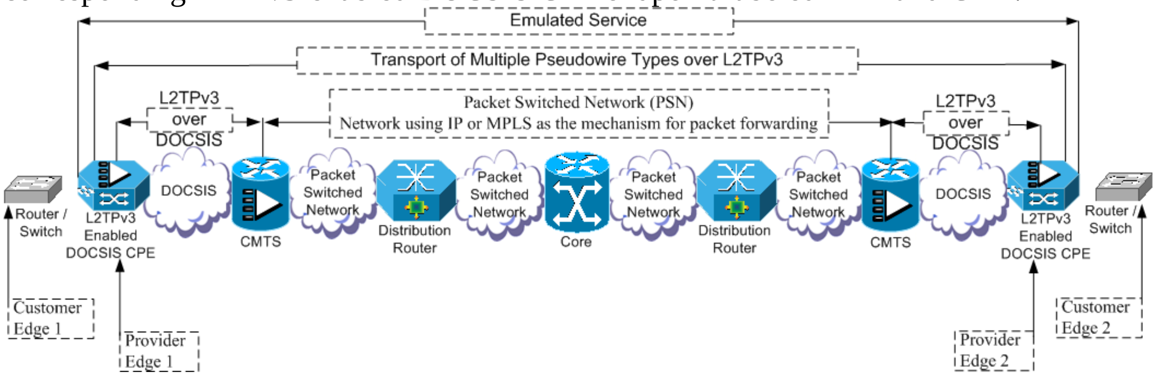

Figure 7

Figure 8 shows a case similar to Figure 7. However, the corresponding endpoint Provider Edge (PE) 2 is a Router with L2TPv3 enabled. This illustrates that the L2TPv3-Enabled DOCSIS CPE may terminate on other non-L2TPv3-Enabled DOCSIS CPE devices in conformance with the IETF informational and standard track protocols. In this example, the router may have L2TPv3 implemented in the Operating System to serve as the Provider Edge 2. This architecture will solve problems in that the headquarter location can provide greater bandwidth than that of DOCSIS systems, thus Optical Ethernet may be deployed in this case.

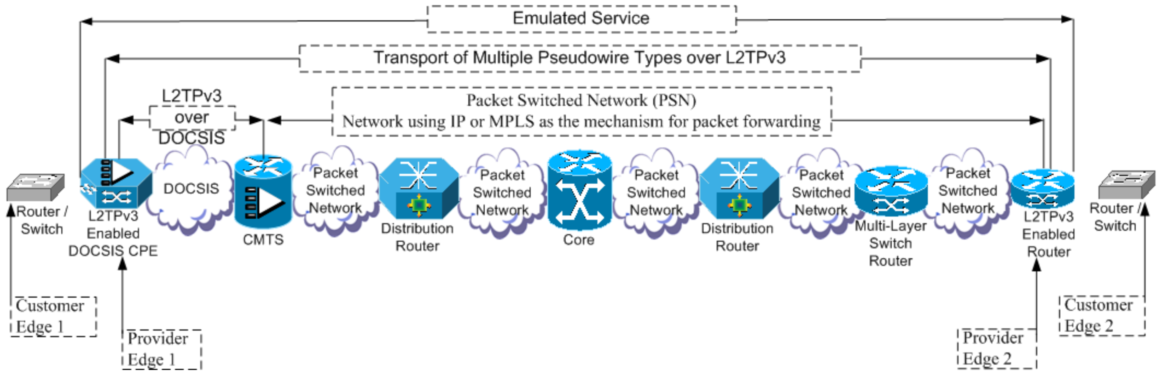

Figure 8

Figure 9 illustrates a simplified architecture using a Point-to-Point (Pt-to-Pt) connection with L2TPv3 over DOCSIS Encapsulation in the Access and the CMTS, which is part of the Packet Switched Network (PSN) transporting L2TPv3 traffic from Provider Edge (PE) 1 to Provider Edge (PE) 2.

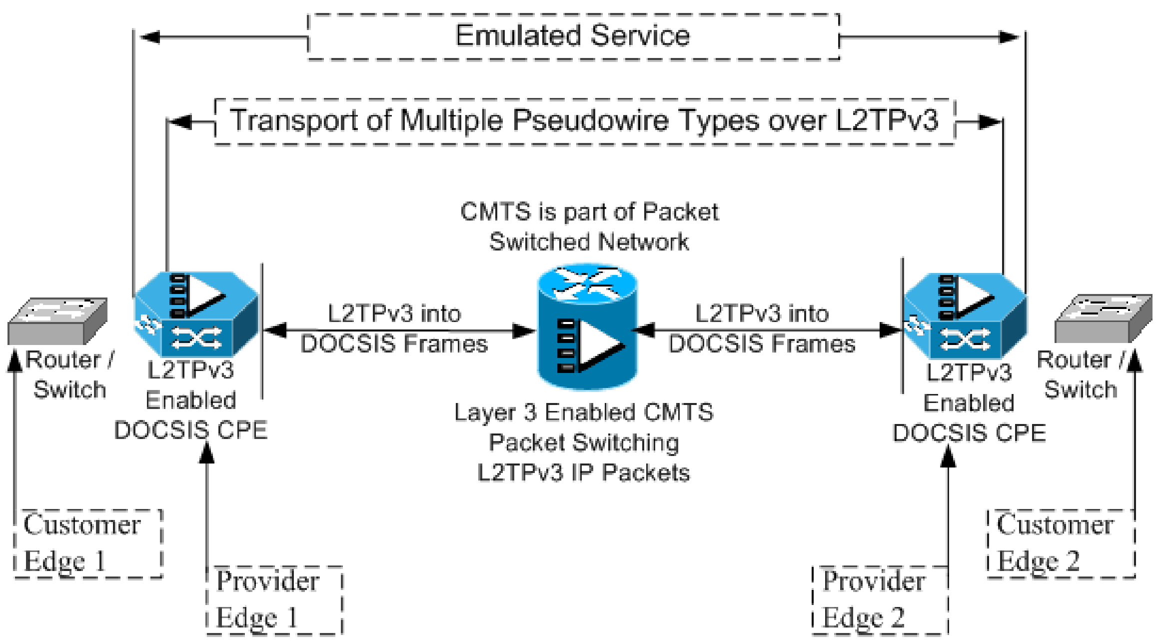

Figure 9

Figure 10 illustrates a simplified architecture using a Point-to-Point (Pt-to-Pt) connection with L2TPv3 over DOCSIS Encapsulation in the Access and the CMTS, which is part of the Packet Switched Network (PSN) transporting L2TPv3 traffic from Provider Edge (PE) 1 to Provider Edge (PE) 2. This CMTS would have DOCSIS interfaces for Layer 2 connections to DOCSIS Cable modems as part of the packet switched network providing the Layer 3 switching to connect the emulated service endpoints. The term User Network Interface is the demarcation point between the customer and provider network.

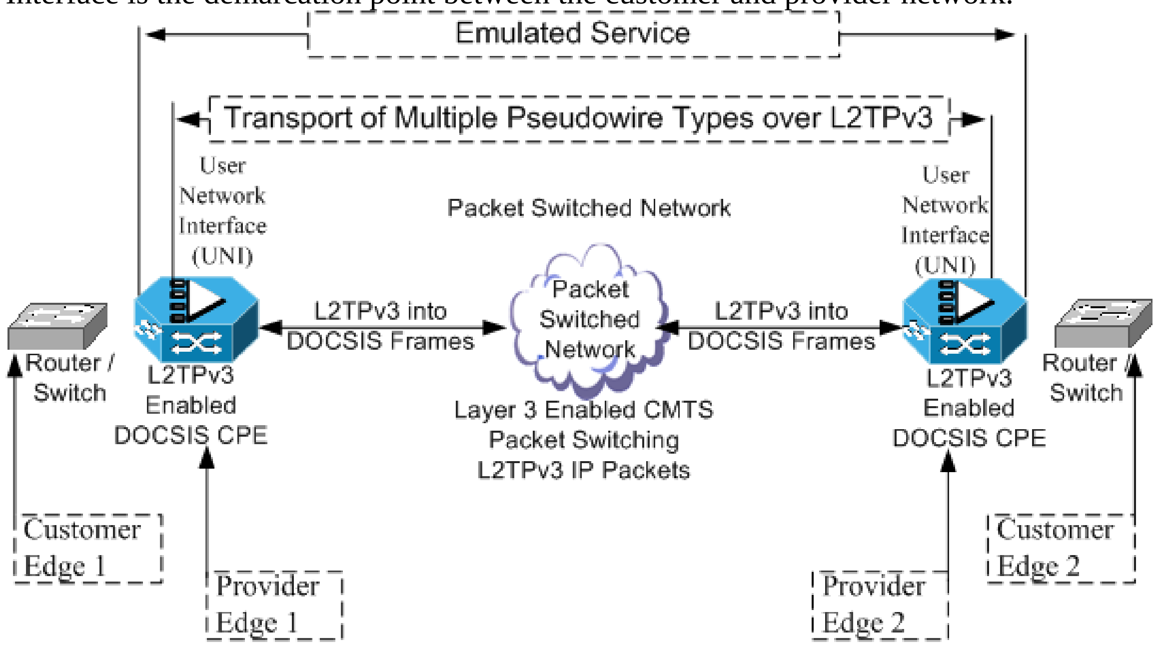

Figure 10

Figure 11 illustrates a simplified architecture using a Point-to-Point (Pt-to-Pt) connection with L2TPv3 over DOCSIS Encapsulation in the Access across the Packet Switched Network (PSN) transporting L2TPv3 traffic from Provider Edge (PE) 1 to Provider Edge (PE) 2. In this illustration, the L2TPv3 Ethernet Pseudowire Type defines (Pt-to-Pt) Ethernet port-to-port mapping. This should be compliant with the IETF's Virtual Private Wire Service in that an ingress frame at one UNI can only be an egress frame at the other UNI.

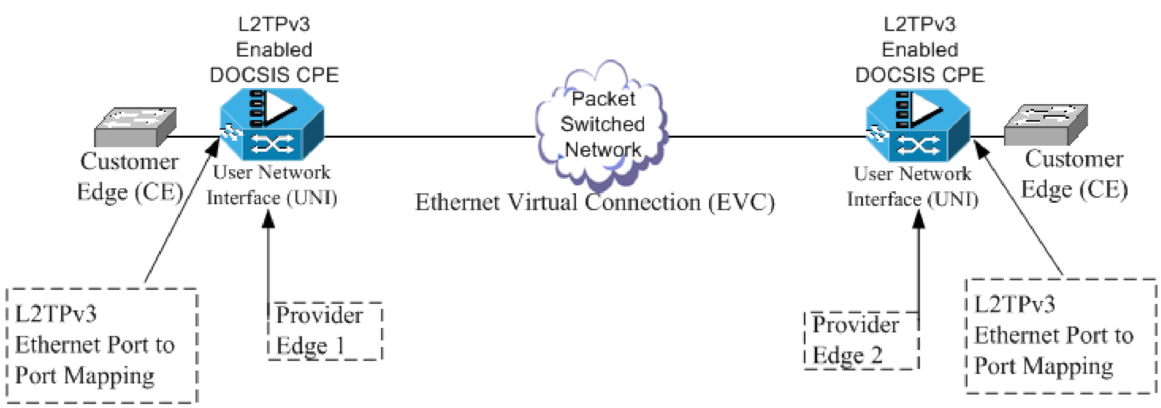

Figure 11

Figure 12 illustrates an architecture using Point-to-Point (Pt-to-Pt) connections with L2TPv3 over DOCSIS Encapsulation in the Access. The Cable Modem Termination System (CMTS) is part of the Packet Switched Network (PSN) transporting L2TPv3 traffic from Provider Edge (PE) 1 to Provider Edge (PE) 2 as well as Provider Edge (PE) 3. The UNI is the demarcation point between the customer and provider network. In this illustration the L2TPv3 Ethernet Pseudowire Type defines (Pt-to-Pt) Ethernet port-to-port mapping and is a non-multiplexed UNI with two (2) Point-to-Point (Pt-to-Pt) connections between two endpoints, either separate physical endpoint locations or simply two egress ports at the same location. As an ingress frame, the UNI can only be an egress frame at exactly one other UNI endpoint and, although this illustrates a Point-to-Multipoint topology, this would not be applicable to a Point-to-Multipoint service. Figures 13 and Figure 14 represents connections defined by Virtual Local Area Network (VLAN) instead of those mapped by port in figure 12.

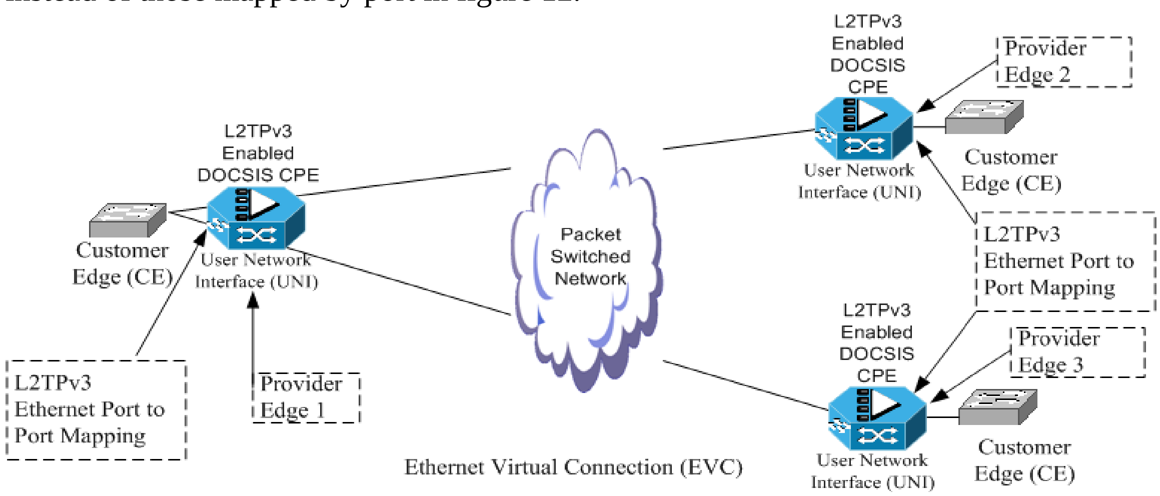

Figure 12

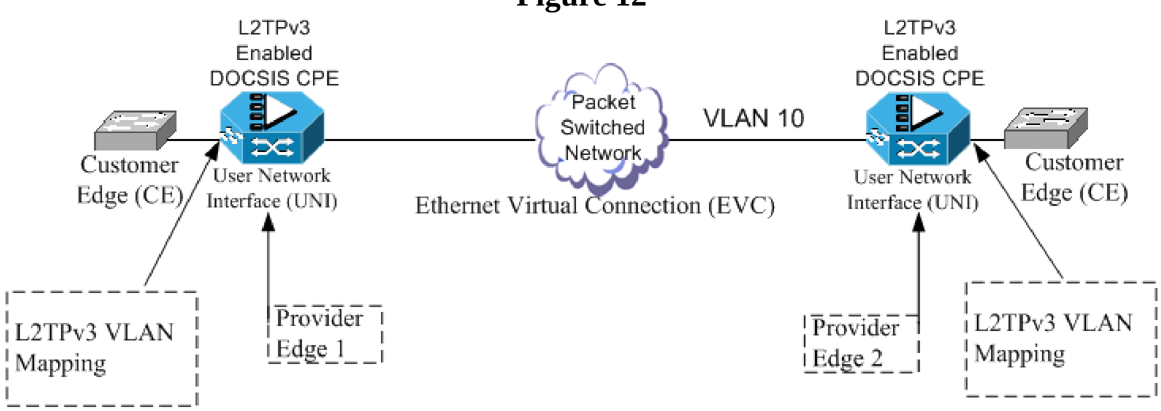

Figure 13

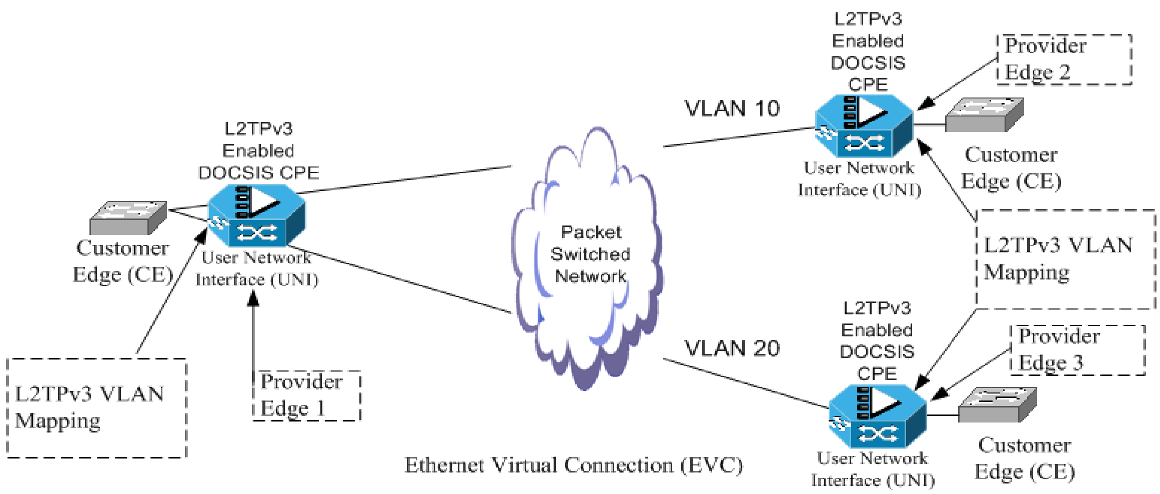

Figure 14

CEoD E-Tree Architecture

Figure 15 illustrates an architecture using a Point-to-Multipoint (Pt-to-MP) connection with L2TPv3 over DOCSIS Encapsulation in the Access. In this illustration, the L2TPv3 Ethernet Pseudowire Type defined as Point-to-Multipoint (Pt-to-MP) enables an Ethernet connection to be multiplexed at the User Network Interface (UNI) with two (2) connections or more at the Provider Edge 1 and establishing two or more provider edge connection points. Figure 15 illustrates traffic separation between PE 2 through N.

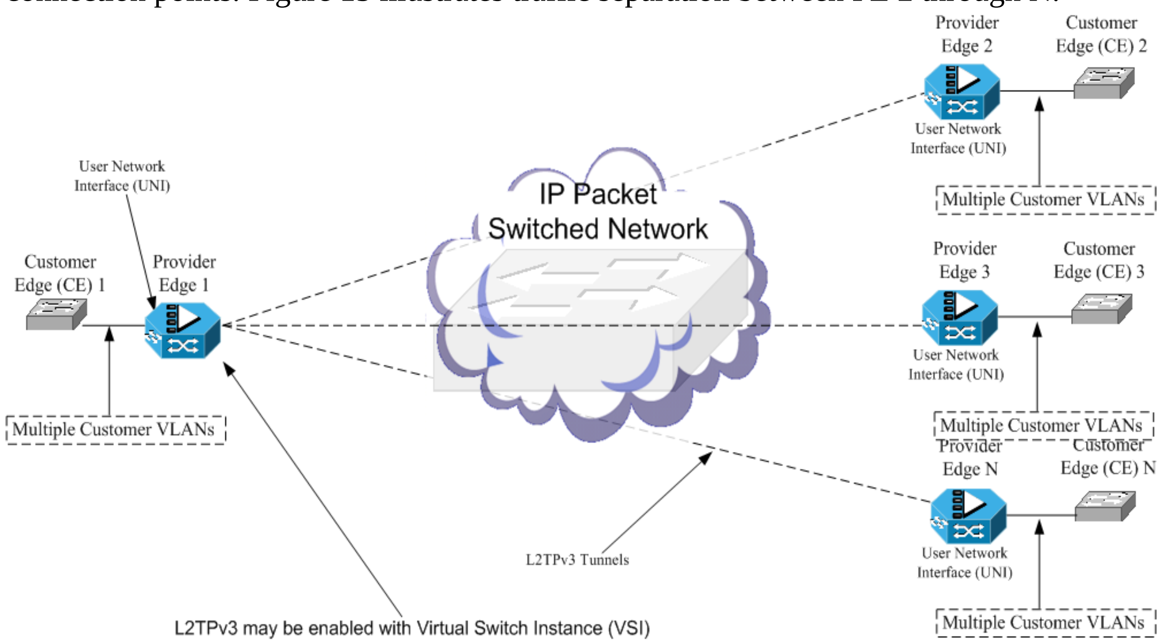

Figure 15

CEoD E-LAN Architecture

The CEoD enabled DOCSIS CPE will have optional support for true Multipoint-to-Multipoint services, which will support services defined by the Metropolitan Ethernet Forum (MEF) for E-LAN services and the IEFT's Virtual Private LAN Service (VPLS). The CEoD-enabled DOCSIS CPE configured with a Virtual Switch Instance (VSI) (may be referred to as Virtual Switch Interface) will support true MP-to-MP services. The use of a VSI is not required for the CEoD-enabled DOCSIS CPE to perform Point-to-Point services as defined in E-Line. CEoD-enabled DOCSIS CPE would emulate IETF- and MEF-defined Multipoint services at the CPE, without the requirement of additional Network-based systems.

Figure 16 illustrates an architecture using an Ethernet Pseudowire Type enabling Multipoint-to-Multipoint (MP-to-MP) connections from Provider Edge (PE) 1 to Provider Edge (PE) 2 as well as Provider Edge 3. In this illustration, routing protocols are used by the CE to direct traffic to specified endpoints and traffic is carried transparently through the service provider's DOCSIS and Packet Switch Network and even the public Internet. Cable Operators, using specially architected L2TPv3-enabled DOCSIS CPE devices, may transport Layer 3 routed network traffic similar to that of Frame Relay network service providers. The L2TPv3-Enabled DOCSIS CPE requires separate physical interfaces for multiple routed destinations. The emulation service will appear as if the routers are physically (port-to-port) connected, the control and data plane will be transported across the L2TPv3-Enabled DOCSIS CPE transparently. The Customer Edge facing interfaces are mapped into L2TPv3 sessions that will be mapped into DOCSIS service flows.

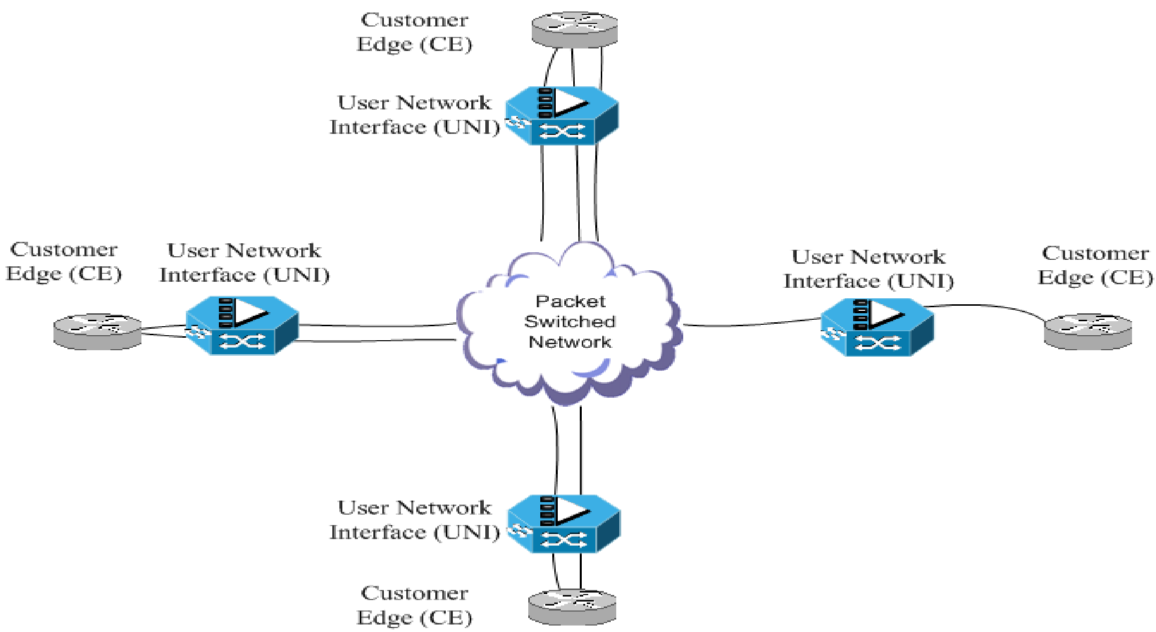

Figure 16

Figure 17 illustrates an approach to increase L2TPv3 to perform Multipoint-to-Multipoint Layer 2 services. The Customer Edge (CE) connects to the Provider Edge (PE) using 802.1q. The L2TPv3-Enabled DOCSIS CPE with Virtual Switch Instance (VSI) is the PE and emulates an IEEE Ethernet bridge. This approach will allow the L2TPv3 -Enabled DOCSIS CPE with VSI to perform flooding, forwarding, and learning with multiple LCCE VSI endpoints (example contains three PEs). Figure 18 provides another depiction in a logical format.

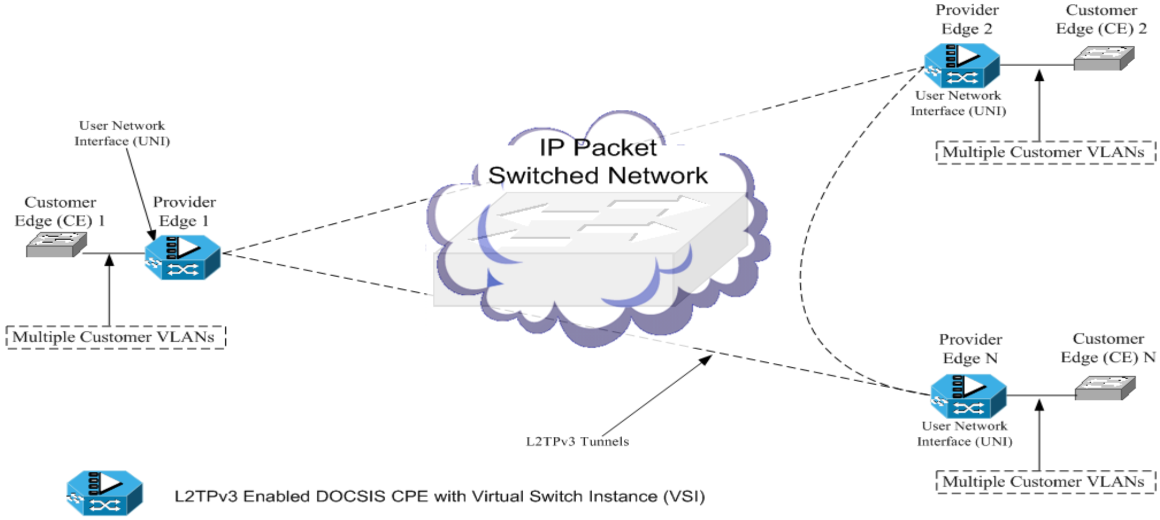

Figure 17

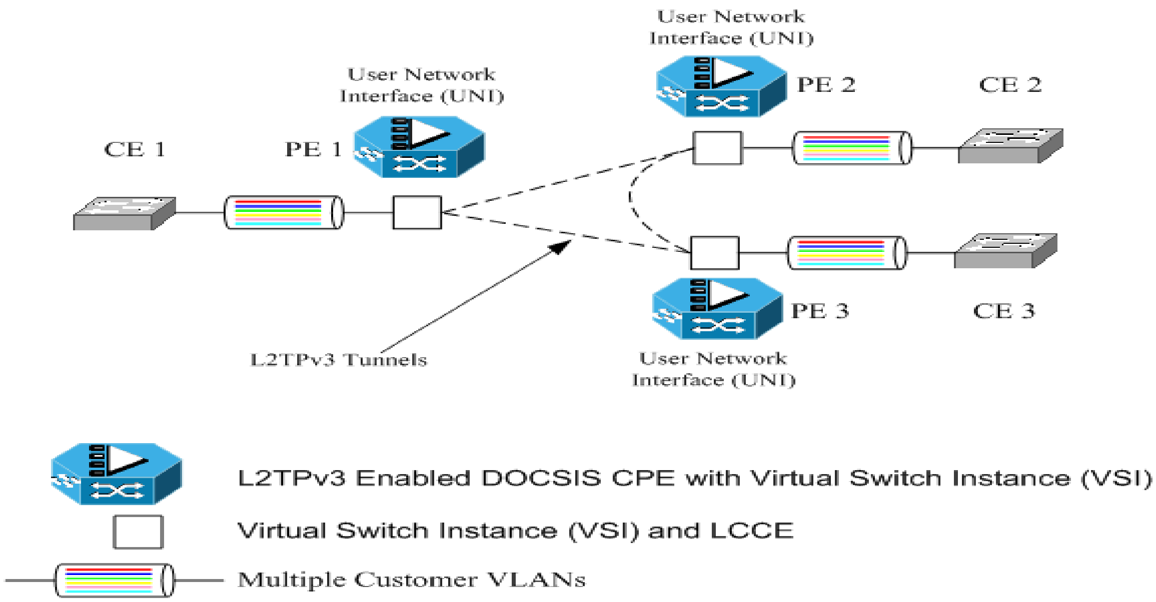

Figure 18

Figure 19 illustrates a simplified architecture using a Multipoint-to-Multipoint (MP-to-MP) connection with L2TPv3 over DOCSIS-enabled CPE with VSI. In this illustration, the L2TPv3 Ethernet Pseudowire Type, defined as Multipoint-to-Multipoint (MP-to-MP), enables an Ethernet connection to be multiplexed and/or non-multiplexed at the User Network Interface (UNI) with two (2) or more connections at the Provider Edge locations. The L2TPv3 DOCSIS device may have MAC address learning and aging as well as forwarding and actually perform switching for the customer private network into the proper VPN tunnel. The Customer Edge device may be a switch; however a router may have best desired result.

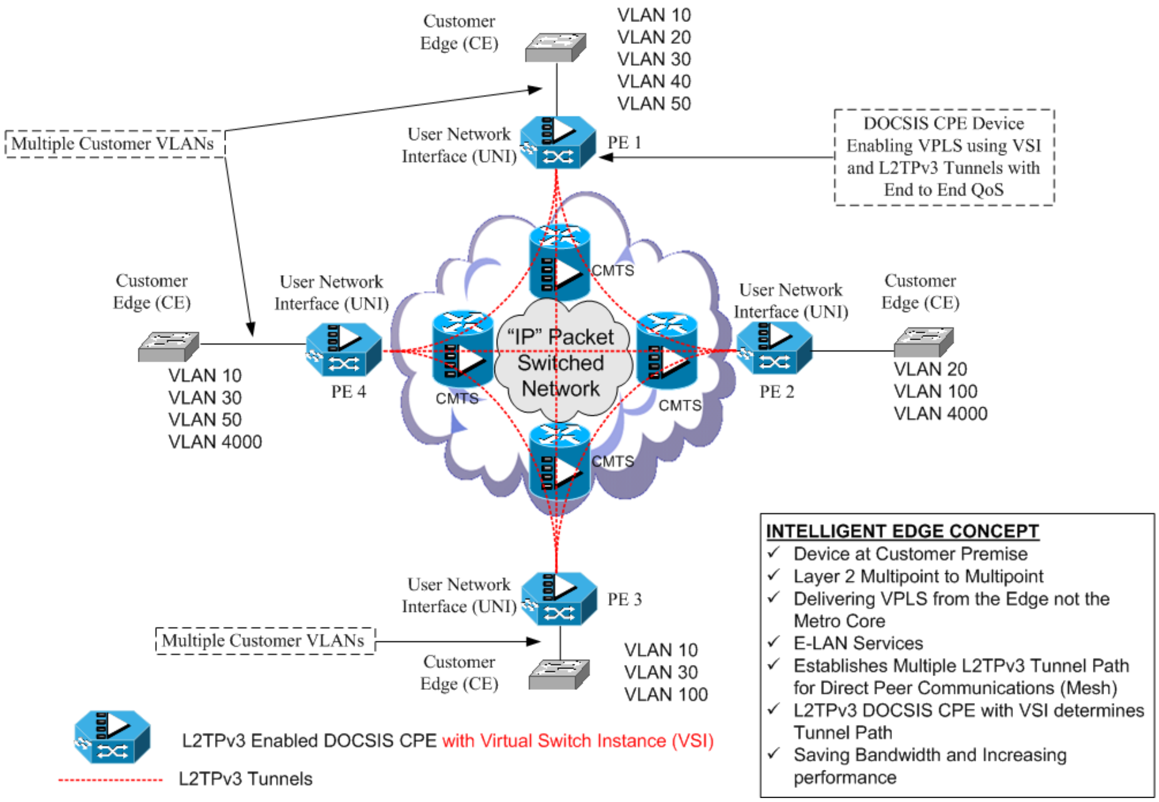

Figure 19 – VPLS Architecture Using L2TPv3 for MP-to-MP Connectivity

Hierarchical CEoD (H-CEoD) Architecture for Scalability

The use of L2TPv3-enabled DOCSIS CPE with VSI capabilities supports a network architecture we are calling Hierarchical L2TPv3. The use VSIs and L2TPv3 offers advantages over the hub and spoke designs or full flat mesh architectures that have the common scaling problem of N*(N-1). In a hub and spoke, all of the traffic terminates at the hub and then is retransmitted to the desired spoke locations. This has higher costs in terms of bandwidth (paying for traffic twice) as well as lowers performance. The L2TPv3-enabled DOCSIS CPE configured with VSI, will establish L2TP Tunnels to all of the participants.

CEoD High Availability Architecture

There are several factors when considering high availability. These may include the number of network elements, architecture and functional requirement of each. The CEoD architecture defines the end-points as part of the Layer 2 VPN service, thus all other network elements are performing just packet switching (transport and traffic management services). For example, the CEoD architecture enables the CPE device to manage the

VPN sessions, thus only one Enterprise customer would likely be part of the VPN. In the event of a VPN outage, only a single site or single customer may be affected in a CEoD architecture. If we consider alternative architectures whereby the VPN service establishment and tunnel traffic occurs at the Aggregation Layer, a failure of this device may affect a significant number of customers. Figure 20 illustrates end-points that are responsible for the VPN services.

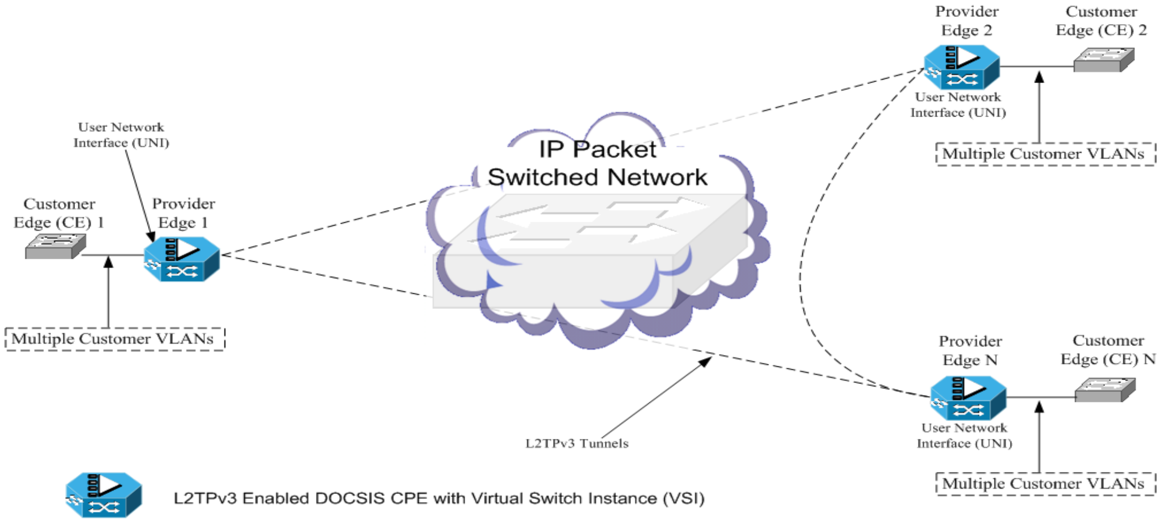

Figure 20

CEoD End-to-End QoS

The CEoD architecture considers traffic classification and Quality of Service (QoS) treatments essential requirements for many business customers and service providers. The CEoD defines the mapping of Customer Edge (CE) traffic into QoS mappings for the IP packet switch network as well as into DOCSIS packet classifiers and service flows for ingress and egress traffic across a two-way DOCSIS system and across an IP- or MPLS-enabled packet switch network. The section will describe the techniques of mapping CE and L2TP traffic types into DOCSIS classifiers and service flows for Quality of Service across DOCSIS systems. Examples may include voice traffic with greater priority over best effort data flows. Another example may include support for Committed Information Rate (CIR) and Excess Information Rate (EIR) for defined traffic types.

This approach will add critical functionality not defined in the L2TPv3 standards for Quality of Service, including mapping L2TPv3 QoS into DOCSIS service flows. This key feature will allow traffic marked by the customer premises equipment (CPE) device and/or marked at the ingress connection point of the L2TPv3 session to be mapped into DOCSIS service flows for Quality of Service and special traffic treatment and priority through the DOCSIS two-way system.

This approach may map 802.1p or VLAN ID for the CE into Differentiated Services (DS) field [RFC2474] for the L2TPv3 traffic (Packets) independent of sessions. The approach will allow the DS values to be carried internally to the DOCSIS layer for classification and service flow creation. The approach will also create a new technique that will allow the CE 802.1P/Q packet fields to be placed into L2TP tunnels and the device may then add another 802.1P/Q packet field(s) to the outside of specified L2TP packets. The Cable modem device may identify the user priority based on the service provider 802.1P and/or VLAN ID 802.1Q tag for classification and service flow. The value is that the cable operators can expand the QoS treatment beyond those defined in ToS/DS values. The approach will ensure that the traffic priority, CIR, and EIR information expected from the CE will be mapped into proper classifiers and service flows in the shared DOCSIS access network.

Figure 21 illustrates an approach to add critical functionality not defined in the L2TPv3 standards for Quality of Service including mapping L2TPv3 QoS into DOCSIS service flows. This key feature will allow traffic marked by the customer premises equipment (CPE) device and/or marked at the ingress connection point of the L2TPv3 DOCSIS device to be classified and mapped into DOCSIS service flows for Quality of Services and special traffic treatment and priority through the DOCSIS two-way system. This will enable L2TPv3 traffic carried across the DOCSIS system's traffic classification and Quality of Service (QoS) treatments as well as include support for CIR and EIR for defined traffic types. The L2TPv3-Enabled DOCSIS CPE may perform stacking of L2TPv3 packets into service provider VLAN tags along with 802.1p. This will then be marked into DOCSIS classifiers and into service flows. This addition will allow Operators to select from a great number of QoS treatments when compared to DS mappings.

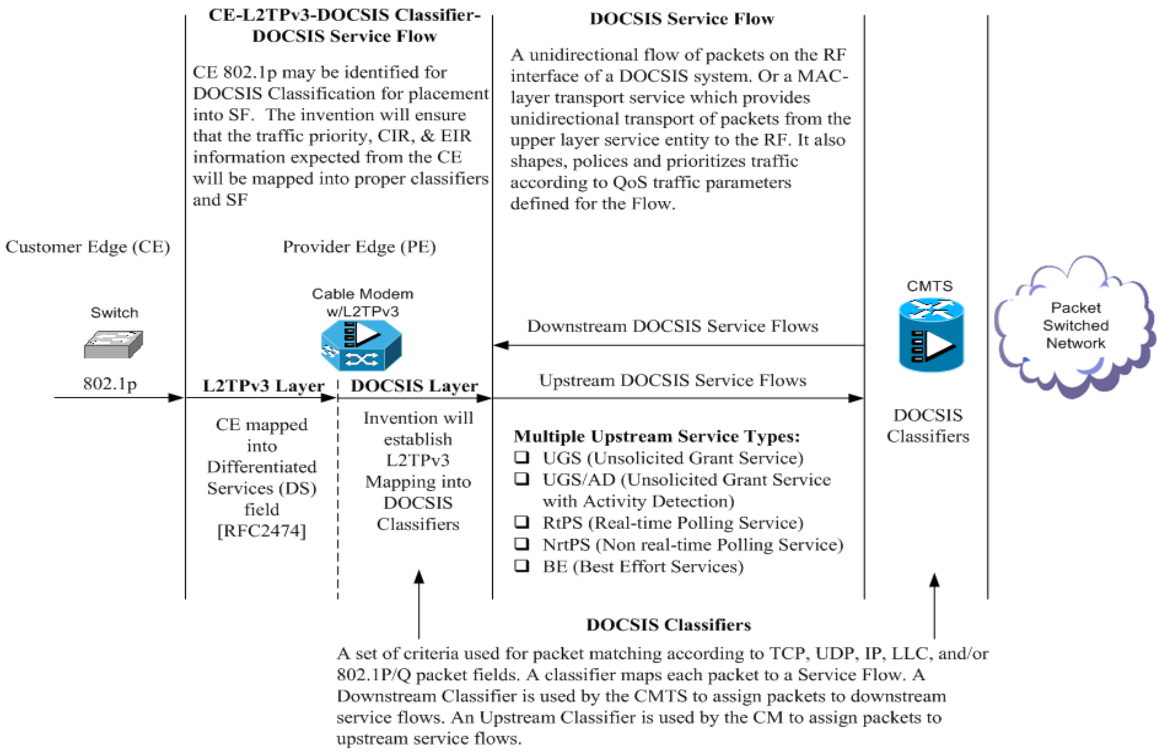

Figure 21

CEoD OAM Framework

Services Providers require support for critical OAM functions from the Ethernet port layer, service layer (the tunnel) and through the Packet Switch Network. An OAM architecture framework should also consider the placement of test points for real-time diagnostic measurements. The framework captured in Figure 22 is a graphical illustration of segments of the network under measurement, monitoring, and test.

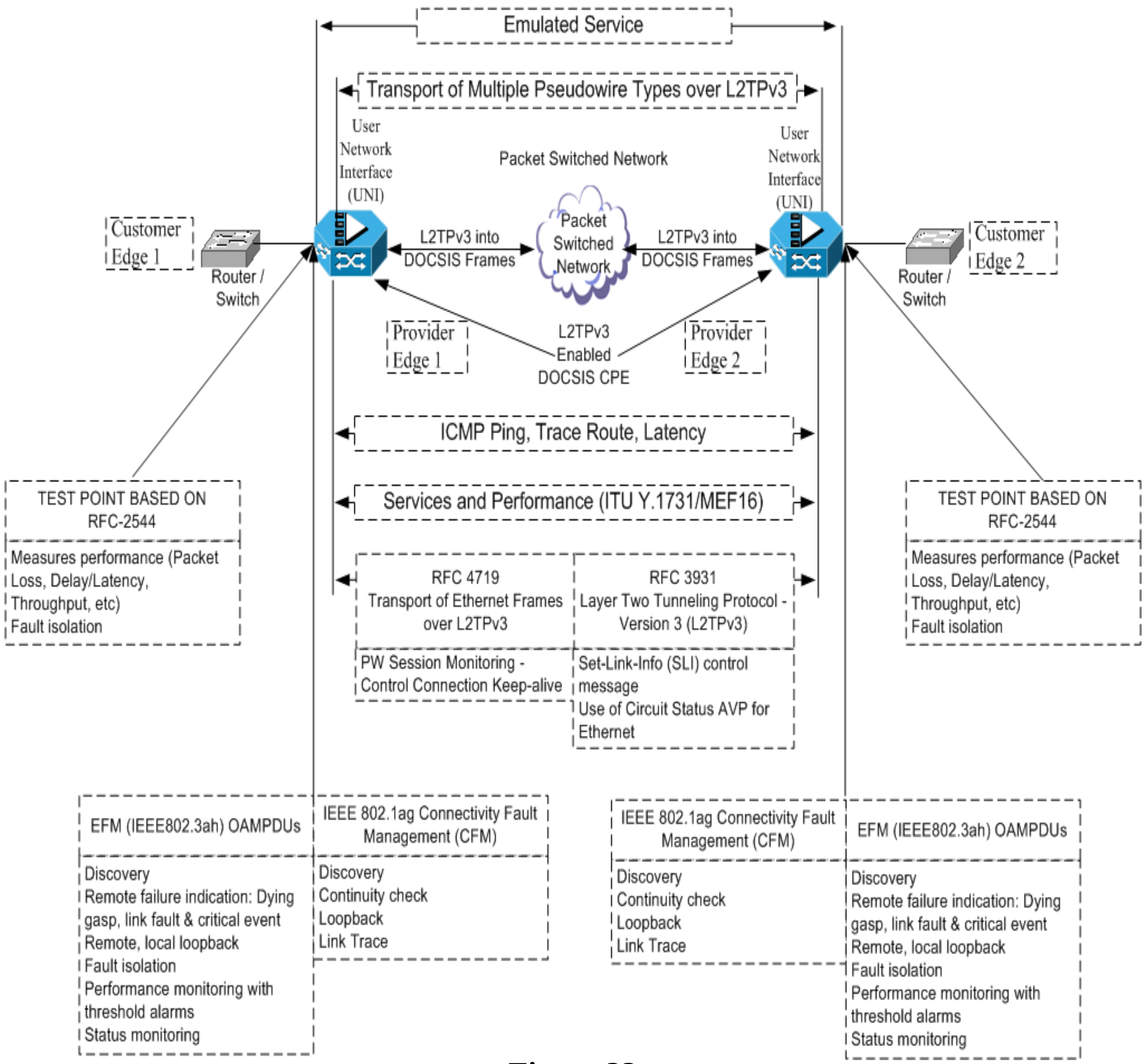

Figure 22

CEoD Provisioning

The device may use IP address or fully qualified domain name (FQDN) for establishing connectivity between other end points. The use of IP address assignments may create an inventory management challenge, but, if static IP address assignments are effectively managed by the services provider, this would remain an option. The use of FQDNs may provide the MSO a solution for automation by leveraging the PacketCable™ infrastructure and the use of a configuration file with connection endpoint information. The transaction would be similar to the PacketCable provisioning process as well as the connection establishment.

CEoD Standards-Based Architecture

The CEoD architecture relates to the use of many Internet Engineering Task Force (IETF) informational and standard track protocols in the area of Layer 2 Tunneling Protocol - Version 3 (L2TPv3) and Pseudo Wire Emulation Edge-to-Edge (PWE3) Architecture, as defined in RFC 3193, RFC 3931, RFC 3985, RFC 4591, and RFC 4719. Though the architecture defines an optional VSI on the platform for Multipoint services, this will allow connections with L2TP network devices without VSIs.

CEoD Extending Services Beyond Your Network Borders

The CEoD architecture enables MSOs to extend the reach of their Layer 2 Services where their existing network facilities may not exist. The MSO may leverage an IP connection to enable the endpoint location (and this transport may be across a public and/or private IP network). A MPLS network would require additional encapsulation. The support for "off-net" subscribers may alter the service level agreements for those customers or off network site locations.

Carrier Ethernet over DOCSIS Conclusions

- **Pros**
  - Supports Carrier Ethernet Service Types including: E-Line, E-LAN & E-Tree
  - Utilized a Standards-Based Architecture
  - Reduces network enablement capital
  - Network wide readiness
  - Supports E-Line, E-LAN & E-Tree Service with an Enhanced DOCSIS CPE allowing the existing network to remain transparent to the VPN Tunnel
  - Defines an End-to-End QoS Target Architecture
  - Reduces the number of devices to as "few as possible" requiring Operation, Administration, Maintenance and Provisioning service support
  - OAM Framework Reduces Operational Complexity
  - Leverages Existing MSO Provisioning Systems
  - **Scalability:** The distributed approach of the architecture enables high scalability.
  - **Reliability:** Placing the VPN service instantiation within the Access Layer enables high reliability. The failure of an Access Layer (CPE-enabled VPN) may only cause one customer or site to be affected when compared to placement of VPN service instantiation within the aggregation layer or network layer where many VPNs customers may be affected.
- **Cons**
  - Success Capital (CPE) costs will likely be higher than a typical cable modem

Conclusions

Ethernet represents the most important evolutionary step in service provider networking over the next decade. Ethernet technology is extensively being deployed for the delivery of high-speed business connectivity. The MEF mission is to accelerate worldwide adoption of Carrier-class Ethernet filling a void not currently addressed by existing standards bodies for defining and marketing Carrier-class Ethernet technologies and services over fiber and coaxial networks.

The work of the MEF is driven by a wide range of actively participating membership–now 138 members–made up of service provider telcos and cable MSOs spanning the globe and representing all Carrier Ethernet industry stakeholders.

The Cable industry has several Ethernet over DOCSIS architectures to choose from, including the BSoD L2VPN network-based approach, L2TPv3 CPE and Aggregator hybrid approach. The CEoD approach is a CPE-based approach to support Ethernet over DOCSIS. All of the Ethernet over DOCSIS architectures examined in this paper defined support for point-to-point and multipoint MEF-based services, though each may vary in the defined support for a particular Carrier Ethernet service type. The Carrier Ethernet over DOCSIS network architecture proposed herein defines support for the full range of MEF-defined Carrier Ethernet services. The CEoD architecture avoids network-wide upgrades or, in fact, any upgrades to the CMTS and does not require additional network equipment north of the CMTS, such as MLSR or VPN Aggregators, to initiate or terminate VPN tunnels. The CEoD architecture defines the least number of devices to provision for the Layer 2 VPN service, this allows operators to avoid touching the network layer for VPN service establishment and for ongoing operations support of the VPN service. The CEoD architecture defines only the Access Layer of the Network as the Provider Edge, allowing the Aggregation and Distribution Layers of the network to perform packet switching and priority handling. The CEoD architecture is an Intelligent Access Layer concept for the enablement of the full range of Carrier Ethernet services on a CPE. This architecture will remain flexible such that the VPN Concentrator concept will be supported. The MSO, while evaluating the alternative approaches, may consider the multitude of challenges for providing Ethernet services, such as capital and operational requirements, scalability, reliability and complexity, of each of the solution architectures. Perhaps, as this architecture is examined more closely, it may be considered as an option for Ethernet over DOCSIS services.

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Abbreviations and Acronyms

ATM – Asynchronous Transfer Mode
BPI – Baseline Privacy Interface
BSoD – Business Services over DOCSIS
CableLabs® – Cable Television Laboratories, Inc.
CE – Customer Edge
CEoD – Carrier Ethernet over DOCSIS
CIR – Committed Information Rate
CM – Cable Modem
CMTS - Cable Modem Termination System
CPE – Customer Premises Equipment
DOCSIS® – Data over Cable Service Interface Specification
DS – Differentiated Services
E-Line – Ethernet Line
E-LAN – Ethernet Local Area Network
EIR – Excess Information Rate
EP-Tree – Ethernet Private Tree
EPL – Ethernet Private Line
EVC – Ethernet Virtual Circuit
EVPL – Ethernet Virtual Private Line
EVP-Tree – Ethernet Virtual Private – Tree
FQDN – Fully Qualified Domain Name
HFC – Hybrid Fiber/Coax
IEEE – Institute of Electrical and Electronics Engineers, Inc.
IETF – Internet Engineering Task Force
IP – Internet Protocol
IPTV – Internet Protocol Television
ITU-T – Telecommunication Standardization Sector of the International Telecommunications Union
L2TP – Layer 2 Tunneling Protocol
L2TPv2/L2TPv3 – Layer 2 Tunneling Protocol (L2TP) version 2 and version 3
L2VPN – Layer 2 Virtual Private Network
LAN – Local Area Network
MEF – Metro Ethernet Forum
MLSR – Multilayer Switching Routers
MP-to-MP – Multipoint-to-Multipoint
MPLS – Multi Protocol Label Switching
MSOs – Multiple System Operators
OAM&P – Operation, Administration, Maintenance and Provisioning

PacketCable™ – CableLabs-led initiative to develop interoperable interface specifications for delivering advanced, real-time multimedia services over two-way cable plant
PE – Provider Edge
PSN – Packet Switched Network
Pt-to-MP – Point-to-Multipoint
Pt-to-Pt – Point-to-Point
PWE – Pseudowire Emulation
PWE3 – Pseudowire Emulation Edge to Edge
QoS – Quality of Service
RFC – Request for Comment
SONET – Synchronous Optical Network
TDM – Time Division Multiplexing
ToS – Type of Service
UNI – User Network Interface
VLAN – Virtual Local Area Network
VPLS – Virtual Private LAN Service
VPN – Virtual Private Network
VPWS – Virtual Private Wire Service
VSI – Virtual Switching Instance