Software Defined Networking (SDN) for Cable Access Networks

A Technical Paper prepared for the Society of Cable Telecommunications Engineers
By

Shridhar Kulkarni
Product Manager, Access Network Solutions
Aurora Networks
5400 Betsy Ross Dr
Santa Clara, CA 95054
408-235-3310
skulkarni@aurora.com

Overview

SDN, or Software Defined Networking, is taking the communications industry by storm and is expected to have a radical impact on how future networks will be architected. Traditional networking systems gear such as switches and routers have a tightly coupled OSI layer architecture with highly integrated management, control and data plane functions. This traditional monolithic approach introduces several inefficiencies in the form of highly rigid and closed network environments causing network operators to be potentially hampered by vendor lock-ins, slow innovation cycles and high equipment costs.

The premise of SDN is to abstract the control plane from the data forwarding plane and largely distribute this control intelligence in the cloud while building a standard protocol messaging layer to interface between the logically centralized control-plane in the cloud and the forwarding-plane in the network gear. The benefits of this new SDN approach are multi-fold, namely, superior network performance, greater network agility, operational flexibility, high network availability and lower equipment costs. While Data center networks are the beach-head applications for SDN, it will not be long before the applicability of SDN is realized for service provider networks as well.

This exploratory paper presents SDN concepts and network virtualization specifically in the context of cable's first-mile fiber access technologies such as PON, DPoE™ (DOCSIS Provisioning of EPON), and Metro Ethernet. The goal of this paper is to identify specific areas within cable's access networks that are highly amenable to SDN and OpenFlow-based architectures. Also, the paper proposes certain SDN-centric applications for building next generation access networks, which cable operators can utilize to reap significant benefits associated with this latest network paradigm.

Content

SDN Introduction

SDN is a new networking paradigm that decouples control-plane and data-plane functions which traditionally have been tightly coupled and highly integrated in the networking hardware. While the focus of data-plane functions is fast and efficient forwarding of network traffic between ingress and egress points on a network device, it is the control plane intelligence that determines the optimal and the most efficient route that the network traffic should take to reach its final destination. This control plane intelligence today is embedded in individual network elements which communicate with their peers to determine the optimal routing paths in an end-to-end network. (Embedded layer 3 routing protocols on network routers are the most common example.)

In the SDN approach, this control plane or routing intelligence is transferred out of the network device and is logically centralized in the software cloud. Figure 1 illustrates the SDN architecture laid out by ONF (Open Networking Foundation), which abstracts the network into three layers: namely the infrastructure layer that is comprised of simple network devices highly optimized for data forwarding, an SDN software controller that forms a network wide operating system and programs the infrastructure devices using a standard API such as OpenFlow, and an application layer comprising a variety of business applications that request and enable services from the underlying network via the software controller.

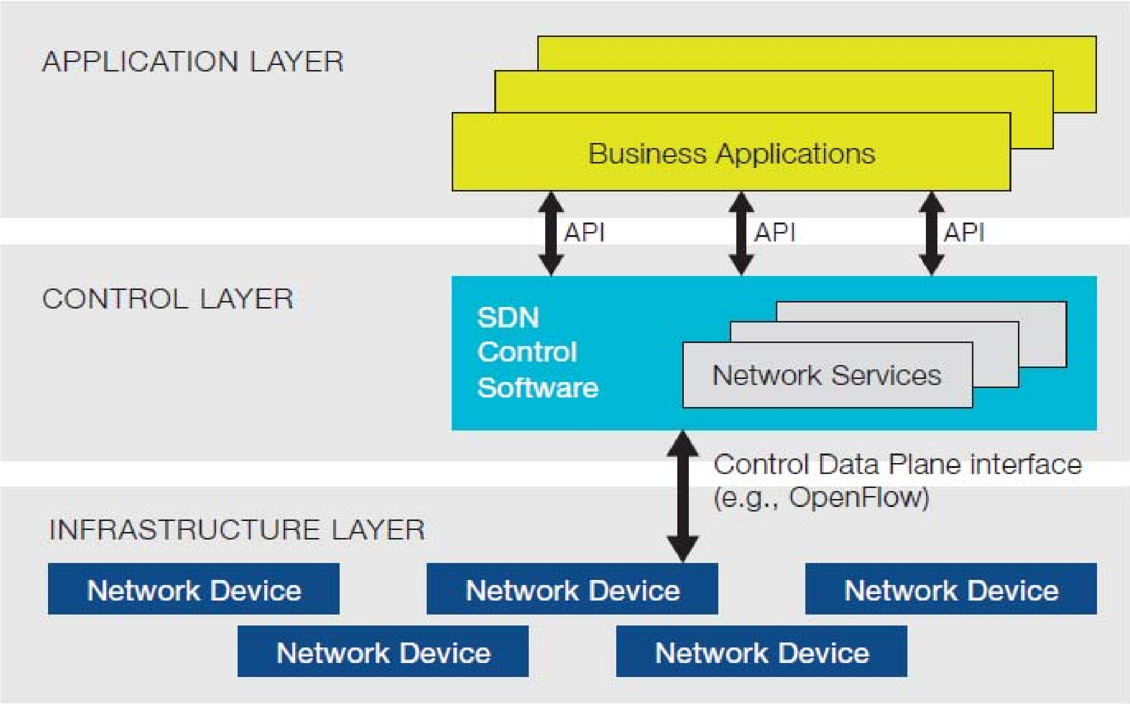

Figure 1 ONF (Open Networking Foundation) SDN Architecture

The control layer software components in this model reside in a remote cloud and utilize COTS (commercial off-the-shelf) servers leveraging the latest performance advancements in the general computing industry rather than being limited by the relatively slow-moving specialized networking counterpart. Moreover, with this split forwarding control plane approach, the network device itself becomes simplified and highly cost effective focusing purely on data switching and forwarding functions. This architecture renders a highly agile, open and programmable network that is benefitted by rapid innovation cycles.

The following sections of this paper discuss SDN in the context of cable's Fiber Access Networks. We will first look at the emerging cable operator fiber access technologies such as EPON (Ethernet Passive Optical Network) and DPoE (DOCSIS provisioning of EPON) and then discuss different areas in which SDN can be applied to the DPoE network architecture.

Cable Operator Access - FTTX and DPoE

Cable operators face an unprecedented demand for bandwidth capacity due to high-speed data, video and interactive IP applications utilized by both residential and business subscribers. In order to meet this capacity challenge, cable operators are starting to deploy all-fiber (FTTX) access technologies such as EPON (Ethernet Passive Optical Network) that enable gigabit speeds to business subscribers in particular, while greatly optimizing the usage of fiber in cable's first-mile networks. DOCSIS is the prevailing most popular cable technology for transport of high-speed data and IP based services over cable's HFC networks. DOCSIS (Data Over Cable Systems Interface Specification) based OSS (Operational Support Systems) are widely used in cable to provision the existing DOCSIS transport elements such as the CMTS (Cable Modem Termination System) and cable modems. As cable MSOs begin deploying EPON, they have a strong preference to utilize their existing DOCSIS back-office infrastructure, so that they do not have to re-invent the wheel when it comes to back-office service provisioning and subscriber management for the new EPON based transport networks.

DPoE (DOCSIS® Provisioning of EPON) technology is designed to accomplish this exact goal, and enables seamless integration of EPON OLT (Optical Line Terminal) and ONU (Optical Network Unit) network elements into cable operator's existing DOCSIS-based network management, service provisioning and billing infrastructure thus preserving current MSO investments in their back-office OSS software. DPoE enables provisioning and transport of diverse MEF business services applications (E-Line: EPL and EVPL, ELAN, EP-Tree) as well as high-speed internet access (IP-HSD) residential service applications.

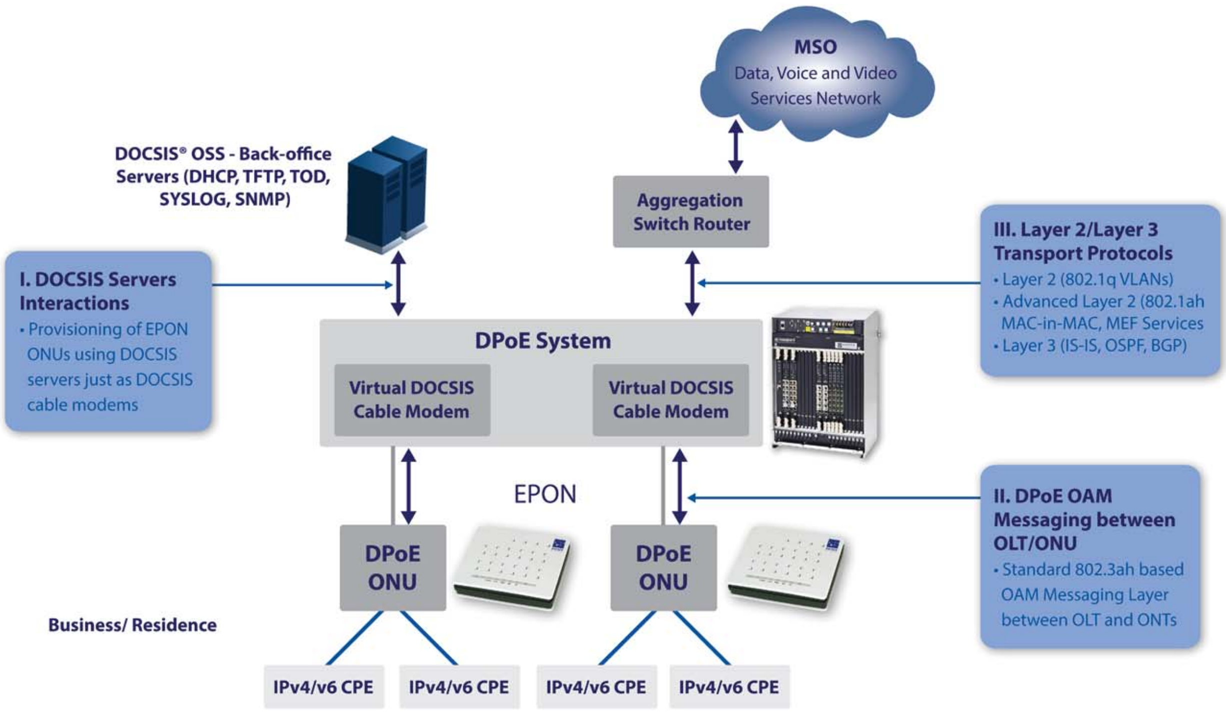

Figure 2 DPoE System Architecture

Figure 2 illustrates a high level architectural view of DPoE with the following main functional areas of operation:

DOCSIS server interactions and provisioning: The primary goal of this functional area is enabling seamless integration with existing back-office DOCSIS infrastructure that currently provisions millions of DOCSIS devices such as cable modems in the cable networks. It involves interaction with DHCP, TFTP, TOD, SYSLOG and SNMP servers for downloading modem specific configuration files, processing the respective DOCSIS TLVs and translating these DOCSIS configuration parameters to EPON specific primitives. (One example is translation of DOCSIS Service Flow Id based QoS parameters to EPON LLID DBA/QoS parameters.) All the DOCSIS related intelligence solely resides in the DPoE system which proxies all the communications on behalf of the EPON ONTs which are completely unaware of the north-bound DOCSIS interactions. Similarly the DOCSIS back-office servers do not know the difference between a CMTS and a DPoE system, and to the DOCSIS OSS the EPON ONU appears just like a DOCSIS cable modem.

DPoE OAM (Operations and Maintenance): The primary goal for this functional area is to implement a standard messaging layer between the EPON OLT and ONU, to facilitate multi-vendor interoperability between multiple EPON OLT and ONU vendors**.** DPoE OAM is essentially an extension to the IEEE 802.3ah EPON OAM and is comprised of all the messages required to accomplish DOCSIS provisioning of EPON ONUs via the OLT.

Advanced L2/L3 Transport Protocols: The primary goal for this functional area is to build a common system architectural foundation for PON in terms of transport protocols in order for operators to implement advanced IP HSD (High Speed Data) Services and MEF (Metro Ethernet Forum) Business services. This area of DPoE involves a whole host of Layer 3 (IGP and EGP) routing protocols such as RIP, OSPF, IS-IS, BGP, MPLS/VPLS/VPN protocols as well as advanced Layer 2 (PB 802.1ad and PBB 802.1ah MAC-in-MAC) tunneling protocols.

Unified Cable-based Management View of EPON elements: Cable operators utilize standard DOCSIS OSSI interfaces for traditional FCAPS (Fault, Configuration, Accounting, Performance and Security) based management operations. DPoE enables these standard cable OSSI interfaces by supporting an industry standard CLI (Command Line Interface) as well as a whole host of DOCSIS OSSI and SNMP MIBs defined in the DPoE-SP-OSSIv1.0 specifications (RFC4639 DOCS-CABLE-DEVICE-MIB, RFC4036 DOCS-IETF-SUBMGT-MIB, RFC4323 DOCS-IETF-QOS-MIB and RFC4546 DOCS-IF-MIB to name just a few). Also included is support for standard SYSLOG messages and SNMP Traps/Notifications for reporting alarms and critical events to standard NMS systems that helps in effective fault and performance management functions.

Several areas in this DPoE system architecture lend themselves very well to the new SDN and virtualization based network paradigms. The following sections of this paper focus on specific SDN applications for DPoE and how cable access networks can be greatly enhanced by utilizing SDN in conjunction with distributed access architectures.

SDN (DPoE) Application: Virtual Residential Gateway

Increased broadband penetration, proliferation of home networking technologies and growing consumer demand to support advanced networking features in the home such as in-home multimedia sharing, mobility, secured firewall and remote access have fueled the need for operators to deploy residential gateway solutions. A Residential Gateway (RG) is an intelligent CPE device that provides residential, SOHO and business users with a secured means of accessing various WAN services such as Internet, broadband telephony, IPTV and business VPNs. The RG device supports bridging, routing, enhanced firewall, NAT/NAPT, advanced remote management capabilities and interconnects a variety of consumer facing interfaces (High speed GE LAN, VoIP, Wi-Fi, EoC) to high speed WAN interfaces (GE, EPON, GPON, DSL). As cable operators continue to migrate from coax- to fiber-based EPON and DPoE networks, there is a growing requirement to integrate these advanced RG functions in the PON ONTs.

At the most fundamental level the DPoE system acts as a DOCSIS mediation layer which proxies all DOCSIS server interactions on behalf of the EPON ONU, thus virtualizing an EPON ONU into a virtual cable modem or a vCM. Figure 3 illustrates this vCM implementation in a standard DPoE system.

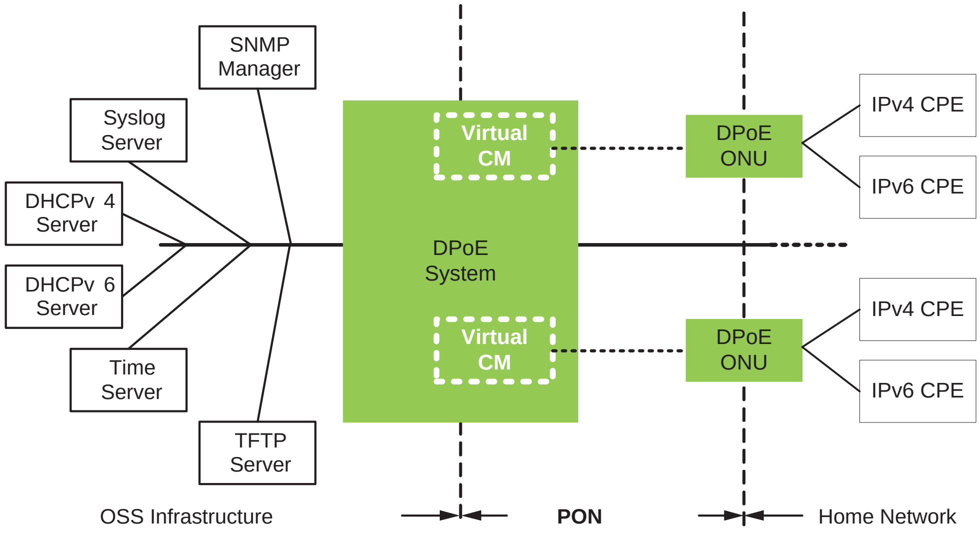

Figure 3 Virtual Cable Modem vCM – CableLabs DPoE 1.0 MULPI Specification

By utilizing SDN this vCM approach can be further expanded to a virtualized residential gateway, whereby several home gateway functions can be offloaded from the CPE into the operator network and efficiently performed in the DPoE system itself or on the SDN software controller that resides in the cloud. Following are some of the most favorable candidate features that can be offloaded from the gateway ONT and implemented in the operator network cloud:

- Network Address Port Translation (NAPT): NAPT allows multiple client users to access outside resources such as the Internet simultaneously with several private IP addresses that map to one or multiple public IP addresses.
- Firewall and Security: The RG supports advanced security and firewall functions with SPI (stateful packet inspection) and packet filtering capabilities for security against various DOS (Denial of Service), IP Spoofing, TCP SYNC flooding, Port scan and various other attacks.
- ALGs, or application layer gateways, facilitate NAPT traversal routines through firewalls for supporting popular applications such as web browser, ICQ, FTP, Telnet, E-mail, News, Net2phone, Ping, NetMeeting, IP phone etc.
- Parental Controls and other rich packet filtering applications for controlling access to internet
- Management protocols such as TR-069 specifically used for provisioning of the home gateway functions

Figure 4 illustrates this concept of RG virtualization in the context of DPoE network.

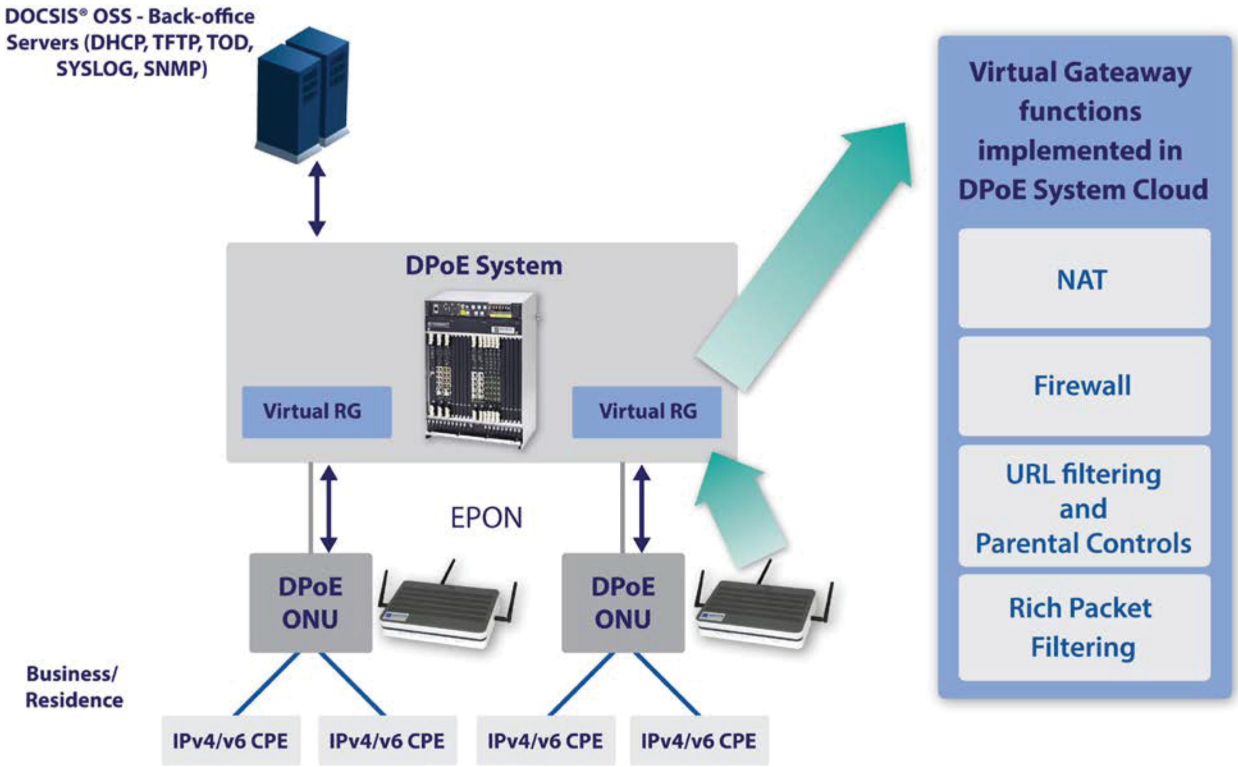

Figure 4 Virtual Residential Gateway

Virtualization of the above gateway functions in the DPoE system or the network cloud has several advantages:

- A virtual residential gateway reaps the inherent benefits that come with network virtualization in the form of enhanced resource sharing (COTS hardware, CPU, memory etc) thus leading to significant CAPEX savings.
- Better network and service agility in managed-operator models whereby operators can rapidly introduce and deploy new value-added services. Since a big functionality piece is offloaded from CPE hardware to cloud, operators are less dependent on vendors for feature and services innovation.
- It is operationally easier to manage millions of CPE devices which are functionally a lot simpler. Also, as more complexity is outsourced to the DPoE system, the number of CPE failures and need for maintenance operations such as firmware upgrades is significantly lower. Coupling this with simplified troubleshooting and management will greatly reduce operational expenditures (OPEX) and volume of expensive truck rolls for resolving complex issues at the customer premises.

SDN (DPoE) Application: Centralized L2/L3 Control plane

Another area within DPoE where SDN concepts can be readily applied is in the realm of advanced (L2/L3) routing and switching protocols. The DPoE standard specifies implementation of advanced Layer2 tunneling (PB and PBB) functions to implement MEF E-Line, E-LAN and E-Tree business services applications. Additionally the EPON OLT functions as a full-fledged Layer3 router, implementing control protocols such as RIP, OSPF, IS-IS, and BGP. The routing requirements for a DPoE system are very similar to a CMTS enabling operators to offer Layer 3 based IP HSD residential services. Moreover, a DPoE system architecture also includes implementation of MPLS LER (Label Edge Router) functions that enable efficient integration of PON OLT with the core cable operator MPLS network facilitating operators to offer network VPN services. MPLS is the most popular protocol in core networks as it offers several advantages over plain vanilla IP/L3 routed networks such as fast (label) switching, ability to support L2/L3 VPNs, superior path diversity provisions, and advanced traffic engineering.

Although features such as advanced L3 routing and VPLS (MPLS) VPN architectures are useful for building large scalable networks with a fast and efficient data-plane, they come with their own baggage of complex control-plane functionality. As an example, implementing MPLS VPN is associated with a whole host of control protocols such as MP-BGP for router auto-discovery, LDP/RSVP-TE for label distribution, VPLS for setting up L2 VPN tunnels, and various IGP and EGP protocols for regular Layer 3 route exchange and distribution. This control protocol baggage results in high complexity and requires heavy computing resources leading to complicated and costly network gear. Moreover, due to the highly distributed nature of these control protocols any change in link state or traffic congestion in one part of the network requires a high level of message exchanges between routers causing high network chatter and slower network re-convergence times.

The SDN based approach removes all the control protocol complexity from network gear and transfers these functions on a logically centralized controller which then talks to the network hardware using standard OpenFlow based APIs. Reference [4] recommends a new open MPLS control plane that implements advanced map-abstraction techniques for building a global view of the entire network. The equivalent routing, discovery and label distribution functions from the traditional MPLS control plane are now implemented on a centralized controller in a much more efficient manner.

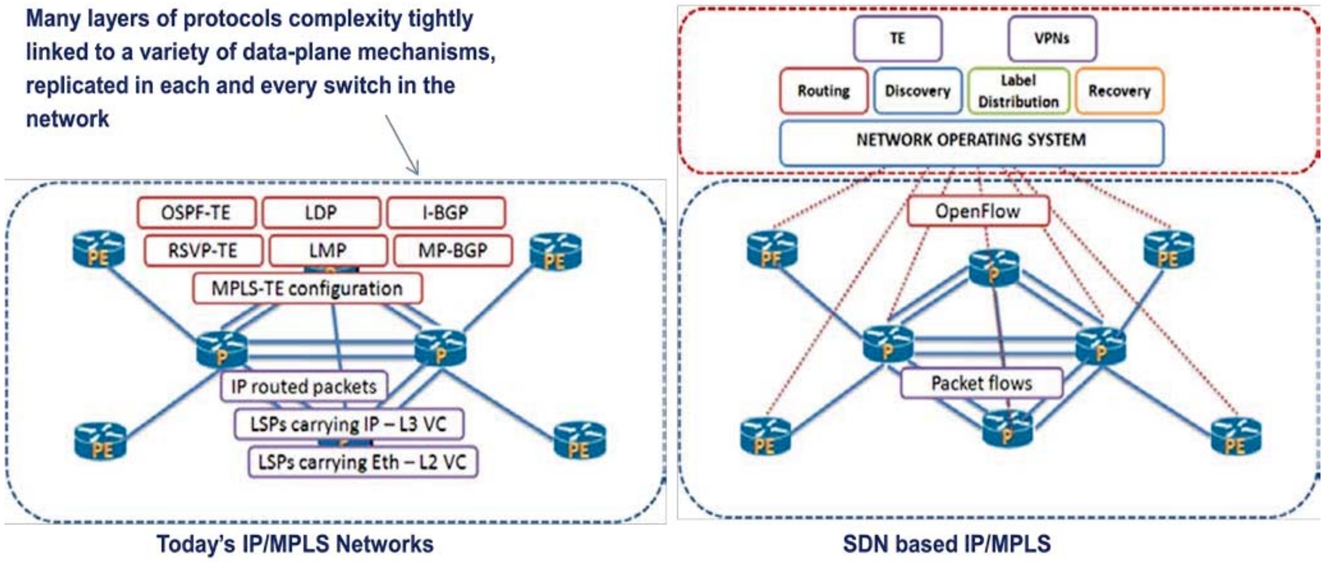

Figure 5 MPLS with an open control plane [4]

Figure 5 illustrates this SDN based IP/MPLS concept [4]. The centralized controller with a network-wide operating system has a global view of the entire network with access to forwarding information on all network elements, and hence can rapidly reconfigure network paths in response to any path failures, link state changes or critical bandwidth congestion events in certain parts of network. Moreover, as opposed to traditional SPF (Shortest Path First) routing that only takes into account link state and cost for route determination, a centralized SDN controller can make more intelligent routing decisions as it has access to detailed forwarding tables on all the network elements that are under its purview.

In the context of DPoE (and PON) the centralized controller with a global network view can program MPLS flows in the forwarding tables of the PON OLT so that network traffic can be switched efficiently between the access and the network side interfaces on the PON OLT. This renders a highly simplified and cost-effective EPON OLT that is designed to efficiently perform the MPLS data forwarding functions. The centralized controller (either an external server or embedded on the DPoE System on the controller blade of the chassis) utilizes standard OpenFlow API to program MPLS or regular switching flows in the forwarding tables of the EPON and the switch fabric of the big chassis.

SDN (DPoE) Application: SDN and Node PON

The centralized control-plane approach as explained in the previous section can be creatively married with certain emerging Distributed Broadband Access Architectures [6] in cable such as Node PON for building highly effective first-mile networks. This cable node-based PON design illustrated in figure 6 differs from the traditional headend or hub-based PON architectures in that it leverages existing HFC infrastructure utilizing the cable node as a POP location for providing gigabit-speed PON services. The EPON MAC functionality is separated from the high-order aggregation and routing functions of a typical chassis PON OLT and integrated into a regular fiber-optic HFC node. Each individual node OLT module supports one or multiple PON ports thus supporting 1 Gbps or more in the case of EPON) and 10 Gbps rates in the case of 10G-EPON. Also, the Node PON OLT module has multiple 1GE or 10GE links for uplink connections to the head-end.

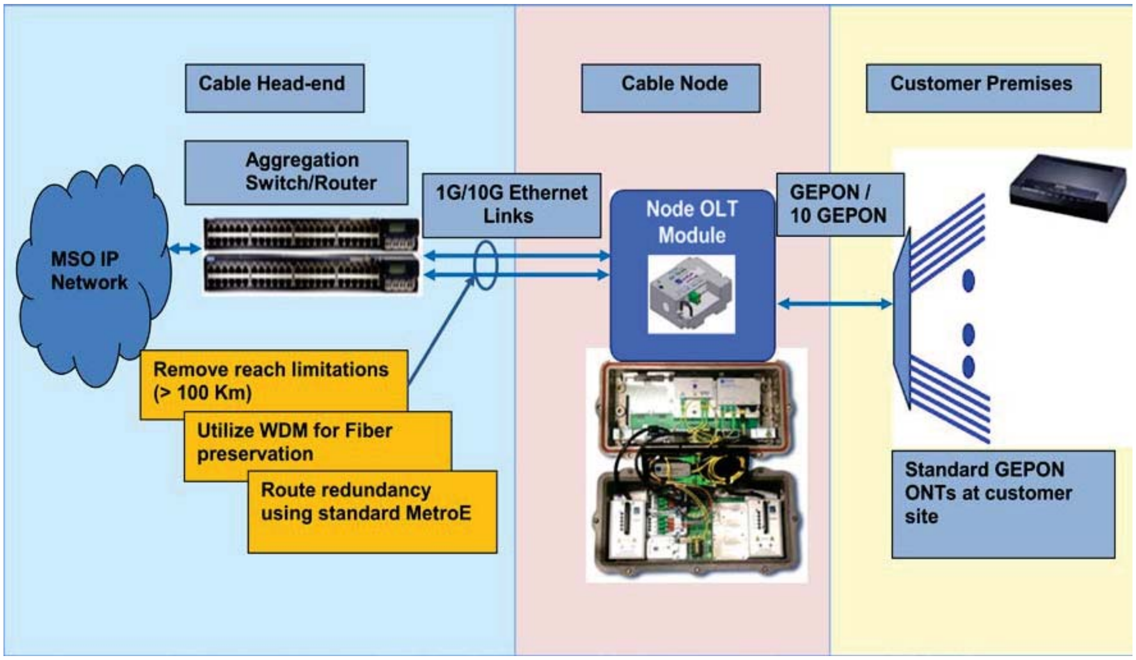

Figure 6 Node PON Architecture

Node PON architecture offers several advantages over traditional PON such as greater fiber reach (beyond 20 km) enabling wider serving areas, fiber preservation utilizing WDM (from Node OLT back to head-end), significant savings in precious head-end real estate and powering, improved resiliency as well as minimal start-up costs for lower density commercial services deployments.

The Node PON architecture fits very well with the SDN approach of architecting a network. A Node OLT to begin with has a highly optimized hardware design for optical aggregation and layer 2 forwarding between the access-side PON interfaces and the network-side GE/10GE interfaces. The Node OLT can be further enhanced by building SDN/OpenFlow compatible forwarding and switching elements.

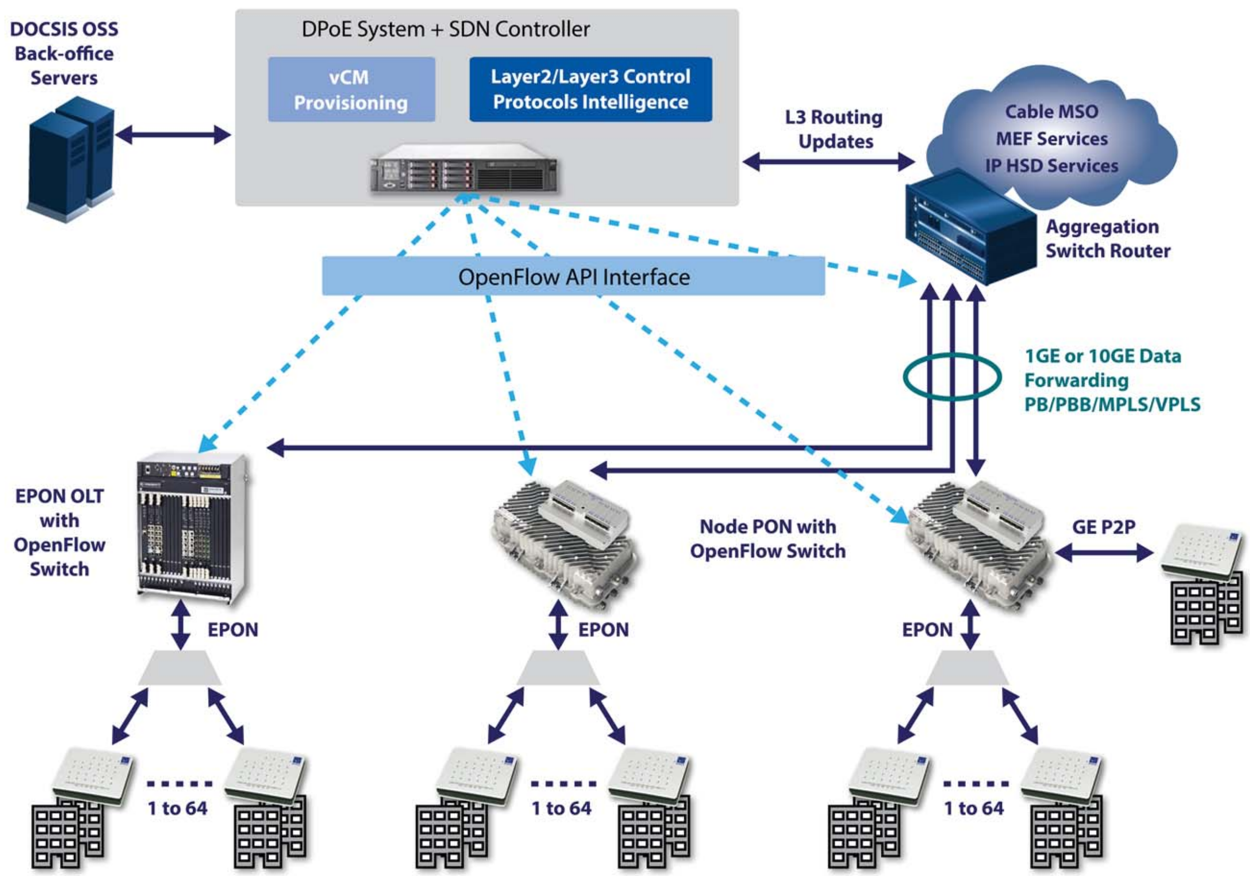

Figure 7 SDN coupled with Node PON

Figure 7 illustrates this concept of SDN applied to Node PON architecture. The Node PON module is managed via a DPoE system hosted on a remote appliance in the cloud. The DPoE system is further enhanced by integrating SDN controller functionality and L3 routing protocol intelligence. This enhanced SDN-based DPoE system performs both routing and DOCSIS provisioning functions on behalf of the Node PON OLT that remains a highly optimized low-power data forwarding device. The combined DPoE/SDN controller in the cloud utilizes OpenFlow API to dynamically program the data flows in the Node OLT forwarding tables along with their associated flow attributes related to VLAN tagging, bandwidth, priority and quality of service levels.

Thus SDN-enhanced Node PON architecture renders highly resilient, programmable and service-agile network architecture, while maximally leveraging upon the existing HFC infrastructure and at the same time providing all the advantages of distributed access architectures such as head-end space, power and cooling conservation, deeper-reach, fiber preservation and superior resiliency.

SDN (DPoE) Application: Policy Control and Big-Data Analytics

One other area where SDN techniques can be applied to Cable Access networks is in the realm of Policy Control, Usage accounting and Big-data Analytics. Policy Control enables operators to dynamically allocate network resources (such as bandwidth and QoS) in response to a subscriber's changes in device, application and network usage. Large scale proliferation of tablet PCs, IPADs and web-enabled devices coupled with ubiquity of video, gaming and social interactive applications is leading to an unprecedented level of diversity and dynamism in the way in which consumers are accessing network resources. The goal of instituting policy control is to efficiently manage network resources, at the most granular level possible, with the goal of improving overall QoE (quality of experience) for all subscribers. Usage-based accounting enables operators to accurately track network usage data for accounting and billing operations. Also, operators are employing big-data analytics tools in order to mine network intelligence for better understanding their subscriber usage patterns. Harnessing this data in the right manner can help operators perform intelligent network-capacity planning and help drive operational efficiencies that are more subscriber-centric in nature. Moreover, by gathering operational network data and intelligently correlating it with other subscriber interactions from other billing, CSR and OSS databases, operators can greatly reduce subscriber churn and improve customer satisfaction leading to higher ARPU.

PCMM (PacketCable Multimedia) is one of the traditional protocols used for implementing policy control and dynamic resources reservation in traditional cable access networks. Figure 8 illustrates the PCMM architectural framework utilized in the context of DOCSIS networks.

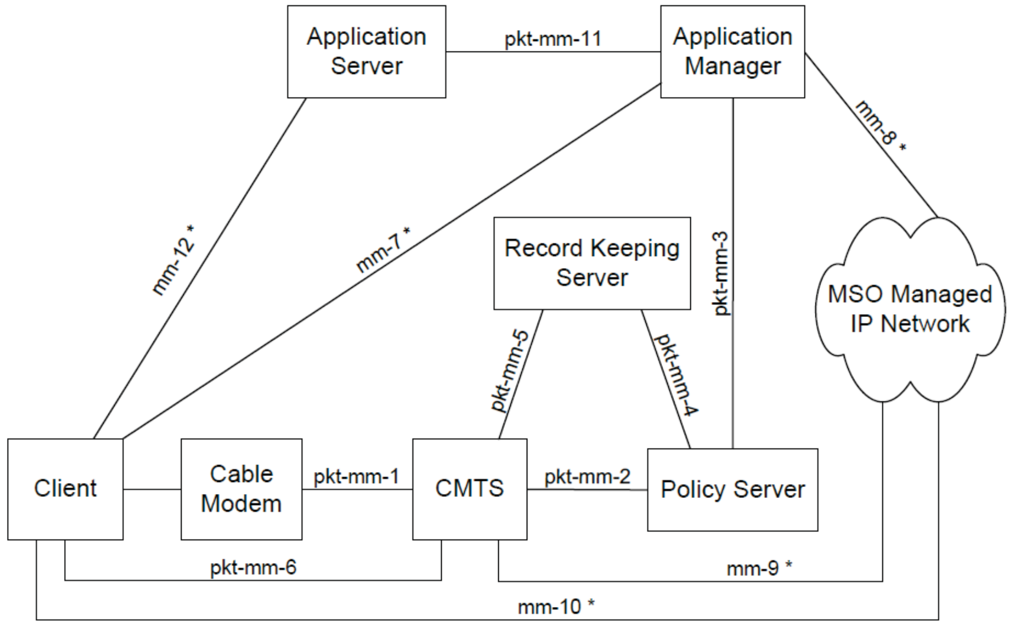

Figure 8: PCMM Architectural Framework [5]

While a detailed discussion of PCMM is outside the scope of this paper, simply, the policy server serves as a policy decision point (PDP) and implements policies or rules aligned with MSO defined authorization and resource management procedures. The policy server is MSO managed and installs policy decisions on the CMTS which acts as a PEP (policy enforcement point). These policies are in response to QoS and resource reservation requests from the clients or end-user devices in the access network (such resource reservation requests are also made by application server and application manager acting on behalf of clients). The Record Keeping Server (RKS) maintains a database log of all the events generated within the PCMM system.

IPDR/SP (IP Detail Record/Streaming Protocol): IPDR is an additional tool in cable's network toolbox that enables bulk data collection from network elements. The IPDR protocol was invented to address some of the scalability related issues with traditional network management protocols such as SNMP in regards to transferring bulk information such as statistics and counters from network elements to external servers. One of the top applications for IPDR is accounting and billing management and SAMIS (Subscriber Accounting Management Interface Specification) defines an accounting specific IPDR SD (service definition). Information transferred using IPDR can also be used for usage based metering and long-term network trending and profiling applications.

DPoE implementations can be further enhanced by incorporating both PCMM and IPDR hooks in the combined DPoE/SDN controller. Figure 9 illustrates this enhanced SDN - based DPoE implementation that incorporates PCMM and IPDR protocol interactions. Specifically the DPoE System interacts with the Policy Server north-bound utilizing

Gate-Control (COPS) API and acts as PEP or enforcer of QoS policies in the underlying PON OLT/ONU network elements. The PEP interactions southbound are implemented using the OpenFlow protocol. Similarly the SDN-DPoE system controller can proxy all the network resource change-requests on behalf of the clients behind the ONUs. Thus, in this enhanced DPoE framework the network flows and associated QoS/bandwidth within the DPoE system are dynamically controlled utilizing SDN OpenFlow techniques leading to a more efficient usage of bandwidth and network capacity. Moreover IPDR/SP protocol intelligence (and SAMIS interface) built within the SDN controller enables offloading of bulk flow-based counters, statistics and additional network-related information to external billing systems and network-usage applications.

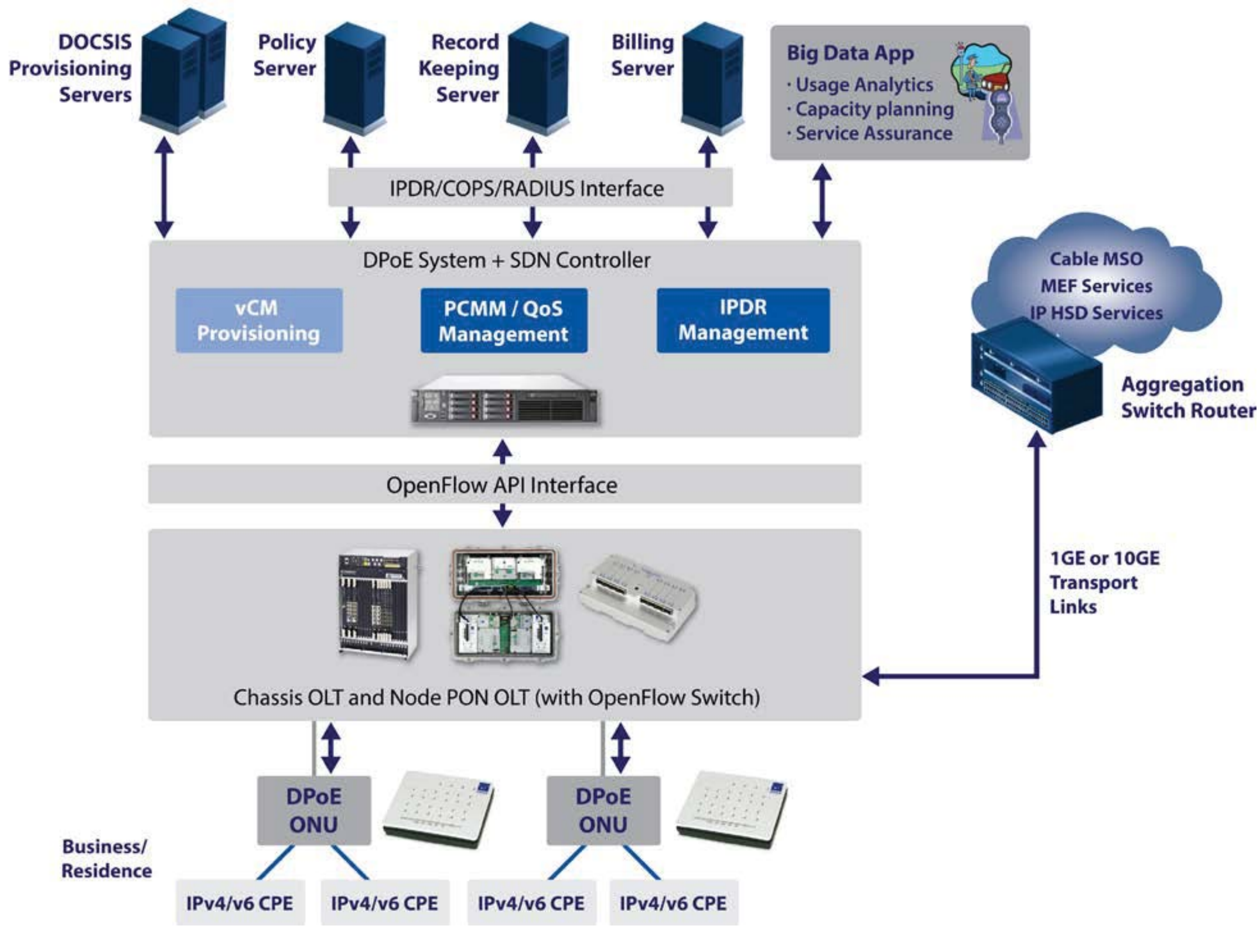

Figure 9: SDN-DPoE System with Policy Control and Big Data Analytics

The benefits of implementing this SDN-enhanced DPoE system is two-fold: first, seamless integration with cable's existing deployed policy control and accounting frameworks such as PCMM and SAMIS which goes beyond the traditional DOCSIS back-office systems. Second, utilizing a SDN-based framework opens the doors for building a robust software ecosystem that will make it easier to build software-applications in the areas of network planning, service assurance and big data analytics.

With a more software-centric design that supports intelligent apps framework (akin to the consumer devices apps), operators can potentially embark onto newer business and revenue models centered around intelligent data analytics, targeted advertising and social networking.

Conclusion

SDN (Software Defined Networking) is a new network paradigm that intelligently abstracts and de-couples the control and forwarding planes leading to more open and agile network architectures. As concepts of SDN and virtualization continue to foray in data-center networks, they are fast beginning to catch the attention of service providers. Architecting programmable networks that enable rapid delivery of innovative service-offerings to consumers in a cost-effective manner, has been a long-standing goal of network operators and SDN promises to help achieve that goal. This paper explored and presented applicability of SDN in cable operator first-mile access networks specifically in the realm of the emerging DPoE (DOCSIS Provisioning of EPON) and FTTX networks.

DPoE enables seamless integration of EPON network elements into cable's DOCSIS based back-office provisioning infrastructure and builds a unified system architecture for implementing end-to-end residential and MEF business services applications. Virtualization of ONU to mimic a cable modem is one of the central tenets of DPoE, and by utilizing the SDN approach this concept can be further expanded to include virtualization of Residential Gateway functions in the network cloud. RG virtualization offers benefits of better utilization of computing resources and high operational efficiency. Additionally, DPoE systems implement a whole host of advanced Layer2 and Layer3 protocols in the EPON OLT. An SDN-enabled DPoE system enables offloading of control protocol intelligence from the OLT hardware to the cloud, leading to simpler and more deterministic network elements that are controlled via a logically centralized software controller.

SDN's control and forwarding split-plane approach is also highly synergistic with certain innovative distributed access architectures in cable such as Node PON. An SDN enhanced DPoE system when utilized to manage Node PON combines the advantages of SDN such as high network agility with the benefits of Node PON implementations such as fiber preservation, superior resiliency and conservation of head-end space, power and cooling. Finally, an SDN-enabled DPoE System has high applicability in the areas of Policy control and Big Data analytics, creating new software platform that facilitates seamless integration in cable operator current back-office OSS along with the ability to deliver innovative business models in the future.

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Abbreviations and Acronyms

ALG	Application Layer Gateway
ARPU	Average Revenue per User
BGP	Border Gateway Protocol
CAPEX	Capitol Expenditures
CMTS	Cable Modem Termination System
COPS	Common Open Policy Service
COTS	Commercial off-the-shelf
CPE	Customer Premise Equipment
CSR	Customer Service Representative
DPoE	DOCSIS® Provisioning of EPON
DHCP	Dynamic Host Control Protocol
DOCSIS	Data over Cable Service Interface Specification
DSL	Digital Subscriber Line
EGP	Exterior Gateway Protocol
ELAN	Ethernet Local Area Network
EPON	Ethernet Passive Optical Network
EPL	Ethernet Private Line
EP-Tree	Ethernet Private Tree
EVPL	Ethernet Virtual Private Line
FCAPS	Fault Configuration Accounting Performance and Security
FTP	File Transfer Protocol
FTTX	Fiber to the x
GPON	Gigabit Passive Optical Network
HFC	Hybrid Fiber-coaxial
HSD	High Speed Data
ICQ	Internet Chat Query
IGP	Interior Gateway Protocol
IP	Internet protocol
IPDR/SP	IP Detail Record/Streaming Protocol
IS-IS	Intermediate System to Intermediate System
L2	Layer 2
L3	Layer 3
LDP	Label Distribution Protocol
LER	Label Edge Router
LLID	Logical Link Identifier
MEF	Metro Ethernet Forum
MIB	Management Information Base
MP-BGP	Multiprotocol BGP
MPLS	Multiprotocol Label Switching
MSO	Multi System Operator

NAT	Network Address Translation
NAPT	Network Address and Port Translation
OLT	Optical Line Terminal
ONF	Open Networking Foundation
ONT	Optical Network Terminal
ONU	Optical Network Unit
OPEX	Operational Expense
OSPF	Open Shortest Path First
OSS	Operational Support Systems
OSSI	Operational Support System Interface
PB	Provider Bridging
PBB	Provider Backbone Bridging
PCMM	PacketCable Multimedia
PDP	Policy Decision Point
PEP	Policy Enforcement Point
QoS	Quality of Service
RG	Residential Gateway
RIP	Routing Information Protocol
RKS	Record Keeping Server
SAMIS	Subscriber Accounting and Management Interface Specification
SDN	Software Defined Networking
SNMP	Simple Network Management Protocol
SYSLOG	System Logging
TCP	Transmission Control Protocol
TFTP	Trivial File Transfer Protocol
TLV	Type Length Value
TOD	Time of Day
UDP	User Datagram Protocol
vCM	Virtual Cable Modem
VLAN	Virtual Local Area Network
VPLS	Virtual Private LAN Service
VPN	Virtual Private Network
WAN	Wide Area Network
WDM	Wavelength Division Multiplexing