Overview of PON Technologies and System Architectures

Presenter: Stephen Kraiman
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Author: Michael J. Emmendorfer
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Agenda

- Overview of PON Standards
- Overview of EPON / 10G EPON
- Overview of DOCSIS Provisioning of EPON (DPoE)
- Centralized Access Architecture for PON and Distributed Access Architecture for PON
- Overview of Purpose Built OLT Systems and SDN/NFV Systems for PON

Overview of PON Standards

High-Level

FTTP Technology Overview

Radio Frequency over Glass (RFoG)
SCTE 174 2010

- RFoG is a media conversion PON technology
- DOCSIS is the Data Technology
- Supports existing cable practices and systems
- Coexists with Data/IP PON technologies (e.g. EPON / GPON)

GPON (ITU-T G.984)

- 2.488 Gbit/s down and 1.244 Gbit/s upstream

XG-PON1 (ITU-T G.987)

- Not backward compatible with GPON
- WDM Coexistence (parallel networks)
- 10 Gbit/s down and 2.4 Gbit/s upstream

XGS-PON (ITU G.9807.1)

- XGS-PON (10/10)

NG-PON2 (ITU-T G.989)

- Not backward compatible (GPON, XGS, or XG-PON1)
- 2.4G x 2.4G, 10G x 2.4G, 10G x 10Gbit/s
- Time and wavelength division multiplexed passive optical network (TWDM-PON)
- Defines use of 4 or 8 wavelengths

IEEE PON (Shared Media Standards)

EPON (IEEE 802.3ah)

- 1 Gbit/s Symmetrical

10G-EPON (IEEE 802.3av)

- Define Backward Compatibility with EPON
- 1 Gbit/s Symmetrical
- 10 Gbit/s down and 1 Gbit/s upstream
- 10 Gbit/s Symmetrical

100G-EPON (IEEE 802.3ca)

- 25G, 50G and 100G EPON
- Standard is being defined

IEEE Point-to-Point Standards

- 1 Gbit/s Optical Ethernet (IEEE802.3z)
- 10 Gbit/s Optical Ethernet (IEEE802.3ae)
- 40 Gbit/s Optical Ethernet (IEEE802.3ba)
- Scaling tools CWDM, DWDM, and AWG

Source: *“Comparing IEEE EPON & FSAN/ITU-T GPON Family of Technologies“*, Michael J. Emmendorfer, SCTE-ISBE Workshop, September 2014

PON Standard Wavelengths

	GPON	1G-EPON	XGPON1	10G/1G-EPON	10/10G EPON	NG-PON2	
Spec	ITU-T G.984	IEEE 802.3bk-2013	ITU-T G.987	IEEE 802.3bk-2013	IEEE 802.3bk-2013	ITU-T G.989	Units
PON Rate (Gbps)	2.488/1.244	1.25/1.25	10/2.5	10/1.25	10/10	4X10/10	Gbps
DS WL	1480-1500	1480-1500	1575-1580	1575-1580	1575-1580	1524-1544	nm
US WL	1310±10	1310±50	1260-1280	1310±50	1270±10	1596-1602	nm

EPON: IEEE 802.3ah 1310 nm ±50 is the standard however, MSOs often select the GPON 1310 nm ±10 Narrow wavelength band optics (10G/1G upstream may use narrowband optics as well)

GPON Upstream Wavelength Evolution: G.984.2 1310 nm ±50 Regular wavelength band option, G.984.5 1310 nm ±20 Reduced wavelength band option, G.984.5 1310 nm ±10 Narrow wavelength band option

Overview of EPON / 10G EPON

High-Level

PON Acronyms and Meaning

Term	Meaning
ODN	Optical Distribution Network, referring to the out side plant OSP. Items include fiber and splitters. The ODN is traditional all passive, thus no powered equipment in this network segment.
OLT	Optical Line Terminal; located at the HE/CO. This network element controls the Downstream and Upstream signals. The Downstream are broadcast to each premises sharing a fiber. Upstream signals are combined using a multiple access protocol, invariably time division multiple access (TDMA). The OLTs "range" the ONUs in order to provide time slot assignments for upstream communication. Encryption is used to prevent eavesdropping. The OLT manages traffic to ensure bandwidth amounts and priority for specified services. This is like a CMTS in the cable network but terminates and manages optical connections end to end.
ONU	Optical Network Units; located at the CPE (term associated with EPON or the IEEE version of PON). This is like a Cable Modem or EMTA in the cable network but terminates an optical connections at the home/business/MDU.
ONT	Optical Network Terminals; located at the CPE (term associated with APON, BPON, GPON and is based on the ITU-T version of PON)

Definition of PON

- A passive optical network (PON) is a point-to-multipoint, fiber to the premises network architecture in which unpowered optical splitters are used to enable a single optical fiber to serve multiple premises, typically 32-128.
- A PON consists of an Optical Line Terminal (OLT) at the service provider's central office or headend and Optical Network Units (ONUs) are placed at end users locations.
- A PON configuration reduces the amount of fiber from the CO/HE to the end users compared with point-to-point architectures.
- Downstream signals are broadcast to each premises sharing a fiber.
- Upstream signals are combined using a multiple access protocol, invariably time division multiple access (TDMA).
- The OLTs "range" the ONUs in order to provide time slot assignments for upstream communication.
- Today PON point-to-multi-point fiber technology supports speeds from 1 Gbps to 10Gbps
- Distance from the facility to the end users where often up to 20 km, however today with PON extenders and Remote OLTs distance from the facility to the end users are much further (80 km or even more is possible) this mean active network elements are in the optical distribution network (ODN) making PON not exactly passive.

Source: Wikipedia and the Author of this presentation

Attributes of EPON

- **Shared media** technology (many users share the network)
- **Subscribers** sharing the same PON port could be up to 128 ONUs **but** often fewer (the number of ONU per PON port is typcially optical budget limited)
- EPON **bandwidth** may range for 1, 2, 10 Gbps Symmetrical
- **Time slots** are used dynamically to allocate bandwidth to subscribers
- **Encryption** is used to prevent eavesdropping **(AES)**
- Supports **Voice, Video, and Data** Services

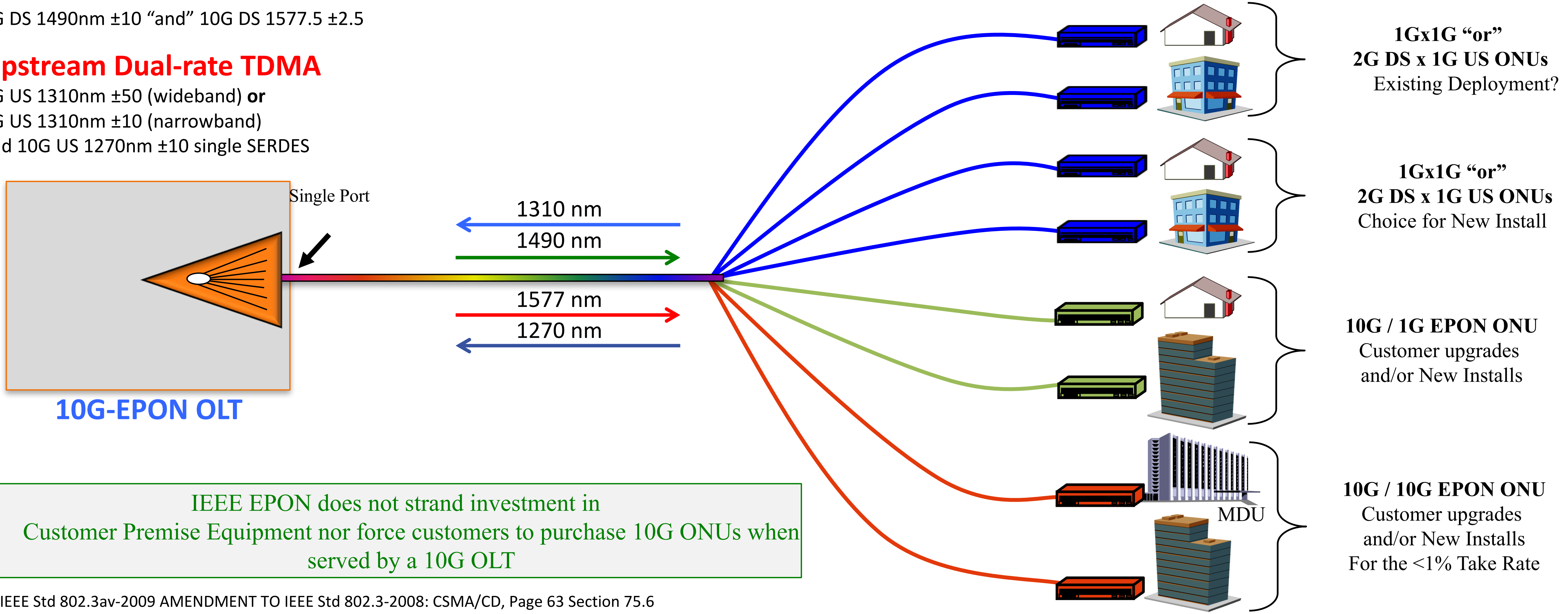
10G EPON OLT System

Downstream Dual-rate WDM

1G DS 1490nm ±10 “and” 10G DS 1577.5 ±2.5

Upstream Dual-rate TDMA

1G US 1310nm ±50 (wideband) **or**
1G US 1310nm ±10 (narrowband)
and 10G US 1270nm ±10 single SERDES



IEEE EPON does not strand investment in Customer Premise Equipment nor force customers to purchase 10G ONUs when served by a 10G OLT

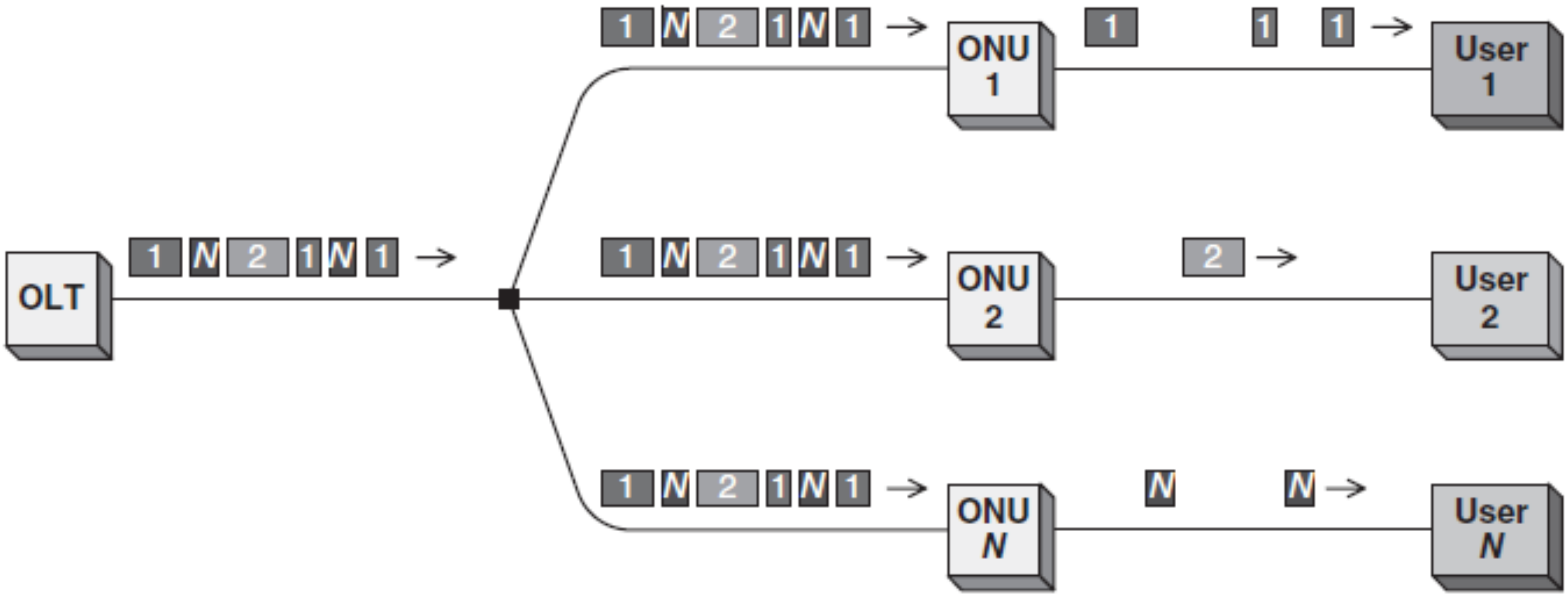
IEEE Std 802.3av-2009 AMENDMENT TO IEEE Std 802.3-2008: CSMA/CD, Page 63 Section 75.6

1 OLT Port Enabling 1G & 10G Downstream & Sharing 1G & 10G Upstream for 3 Types of ONUs

Source: *“Comparing IEEE EPON & FSAN/ITU-T GPON Family of Technologies“*, Michael J. Emmendorfer, SCTE-ISBE Workshop, September 2014

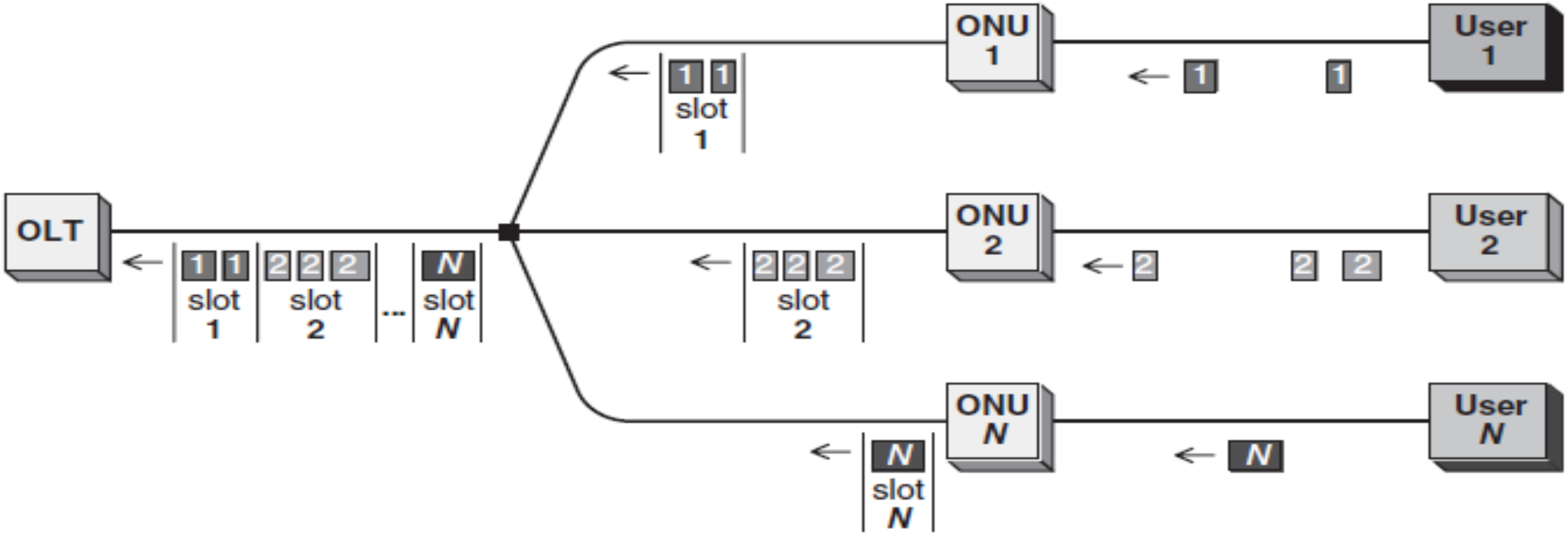
EPON Downstream

- The OLT Broadcasts the data from its transmitter
- Each ONU MAC filters its own traffic based on LLID for processing



EPON Upstream

- The OLT makes sure ONUs do not transmit at the same time to avoid collisions at the OLT optical receiver
- To avoid collisions the OLT allocates Time Slots known as GATES or Grants to the ONU
- When the ONU would like to transmit data a request for bandwidth (time slots) are sent to the OLT this is known as a REPORT



EPON Terms

- **MPCP: Multipoint Control Protocol**
  - MAC Control Protocol that allows the OLT to determine the transmission windows of ONUs in its shared domain. Based in large part on DOCSIS
- **LLID: Logical Link Identifiers**
  - This is a form of marking the ether frames across the shared PON to a specific ONU (CPE)
  - There may be multiple LLID assigned to each ONU
  - The determination of the use of LLIDs may be assign to type of service, e.g. data, voice, video.
- **Packet Classification:**
  - Classification is performed at each ingress point. Specific fields in the frames such as 802.1Q, DiffServ(TOS), Layer 2/3 Address, or Layer 4 ports can be used to map traffic into Link Layer IDs and Service Level Agreements.

Bandwidth Allocation Modes

- **Dynamic Bandwidth Allocation (DBA) Scheduler**
  - DBA may also be referred to as Dynamic Solicited Mode
  - ONUs ask for bandwidth and the OLT issues grants based on the needs of the ONUs needing bandwidth
  - If ONUs are not actively transmitting they are periodically polled
  - If there is no contention for bandwidth ONUs may use the PON link to the maximum SLA
  - If there is no data to transmit the PON time slot are not used

- **Time Division Multiplexing (TDM) Scheduler (supported by some systems)**
  - Grants are issued at a fixed interval, regardless of ONUs need to transmit data.
  - TDM mode is timer based, meaning that bandwidth is allocated when a provisioned timer expires.
  - This may be used in highly congested links to guarantee high priority traffic is carried through the PON

(Most EPON deployments worldwide use a DBA scheduler or dynamic solicited mode)

DBA REPORT and GATE Messages

- **DBA uses REPORT and GATE Messages to request and grant data for the ONU to transmit upstream to avoid collisions and schedules bandwidth across the shared media**

- **DBA: REPORT (Bandwidth Requests)**
  - ONU reports its data transmission needs in its transmit queue
  - ONU is periodically polled in order to be able to send a REPORT or Requests
  - ONUs may add a REPORT at the end of each transmission

- **DBA: GATE (Bandwidth Grants)**
  - OLT Grants transmit opportunities called GATES to ONU
  - Once GATE / grant is sent the OLT expects a burst from this ONU to be received at the OLT at a specific time called a Grant Window

EPON and DOCSIS Comparison

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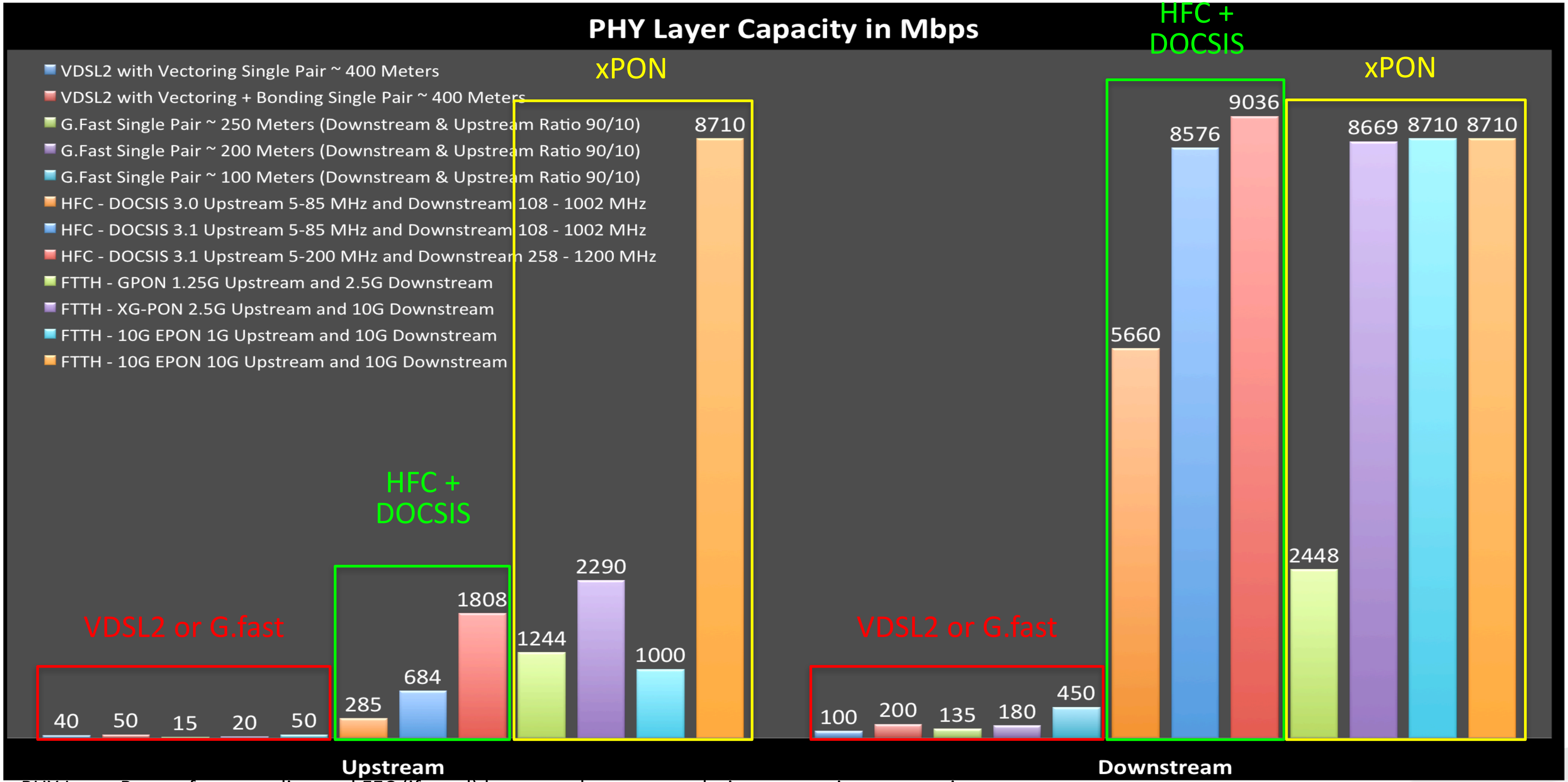
- **EPON LLID are very similar to DOCSIS Service Flows**
  - In fact DPoE adds DOCSIS Service Flow Concepts to EPON OLTs targeting the Cable Market
  - There may be up to 16 bi-directional (downstream and upstream) LLIDs / service flows per ONU
  - Each service flow can have different bandwidth rate limits, priority, and QoS
- **EPON OLT Classifies Downstream and the the ONU Upstream are very similar to DOCSIS (Port based as well as Layer 2 – Layer 4 traffic identifiers)**
- **Bandwidth Allocation Modes (DBA or TDM):**
  - The OLT supports two modes of bandwidth allocation:
    - TDM Mode
    - Dynamic Solicited Mode
  - Each LLID is assigned to one mode.
  - LLIDs assigned to different modes may coexist on the PON
  - EPON does not have an equivalent to UGS like that defined in DOCSIS

Access Network Capacities



PHY Layer Rates after encoding and FEC (if used) however the copper solutions are estimate capacity

What's Next? IEEE 100G-EPON Task Force (802.3ca)

- **Work is underway defining beyond 10G EPON to include 25G, 50G and 100G**

- **802.3ca Task Force Objectives**
  1. Support subscriber access networks using point to multipoint topologies on optical fiber
  2. Provide specifications for physical layers operating over a single SMF strand and supporting the MAC data rate of:
     - 25 Gb/s in downstream and 25 Gb/s in upstream
     - 100 Gb/s in downstream and 100 Gb/s in upstream. This physical layer specification shall accommodate flexible configuration to support operation at reduced MAC data rates.
  3. PHY(s) to have a BER better than or equal to 10-12 at the MAC/PLS service interface (or the frame loss ratio equivalent)
  4. Support coexistence with 10G-EPON
     - Optical power budgets to accommodate channel insertion losses equivalent to those supported by the 10G-EPON standard
     - Wavelength allocation allowing concurrent operation with 10G-EPON PHYs

Overview of DOCSIS Provisioning of EPON (DPoE)

What is DPoE?

- **DOCSIS Provisioning of EPON (DPoE)**
- **Purpose:**
  - Develop specifications for EPON devices to support DOCSIS provisioning and service concepts (Service Flows and Per Services Type QoS)
  - Develop specifications for support with DOCSIS Network Management Systems and IPDR
  - Develop specifications to support delivery of IP and Ethernet Services over EPON
  - Define Standards and Certification program to enable multi-vendor interoperability

DPoE Architectural Foundation

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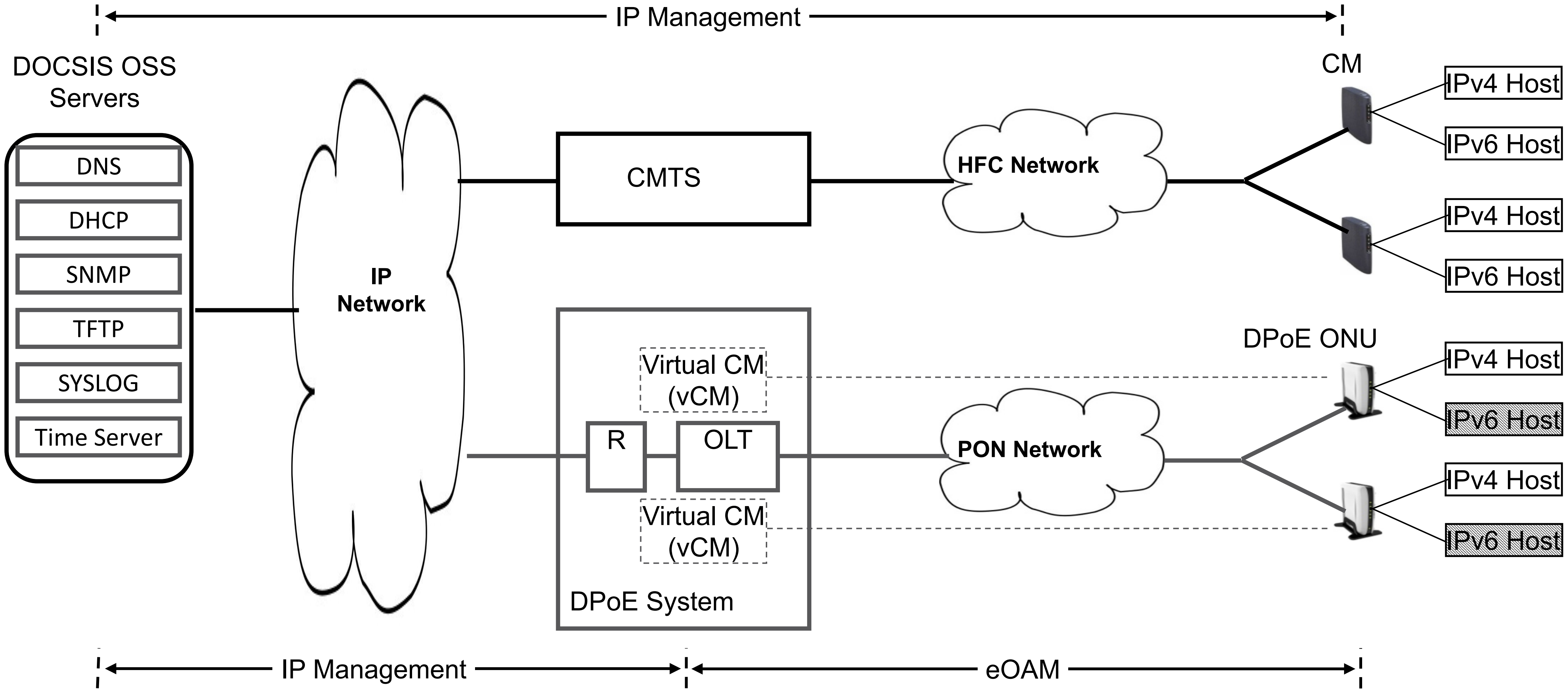
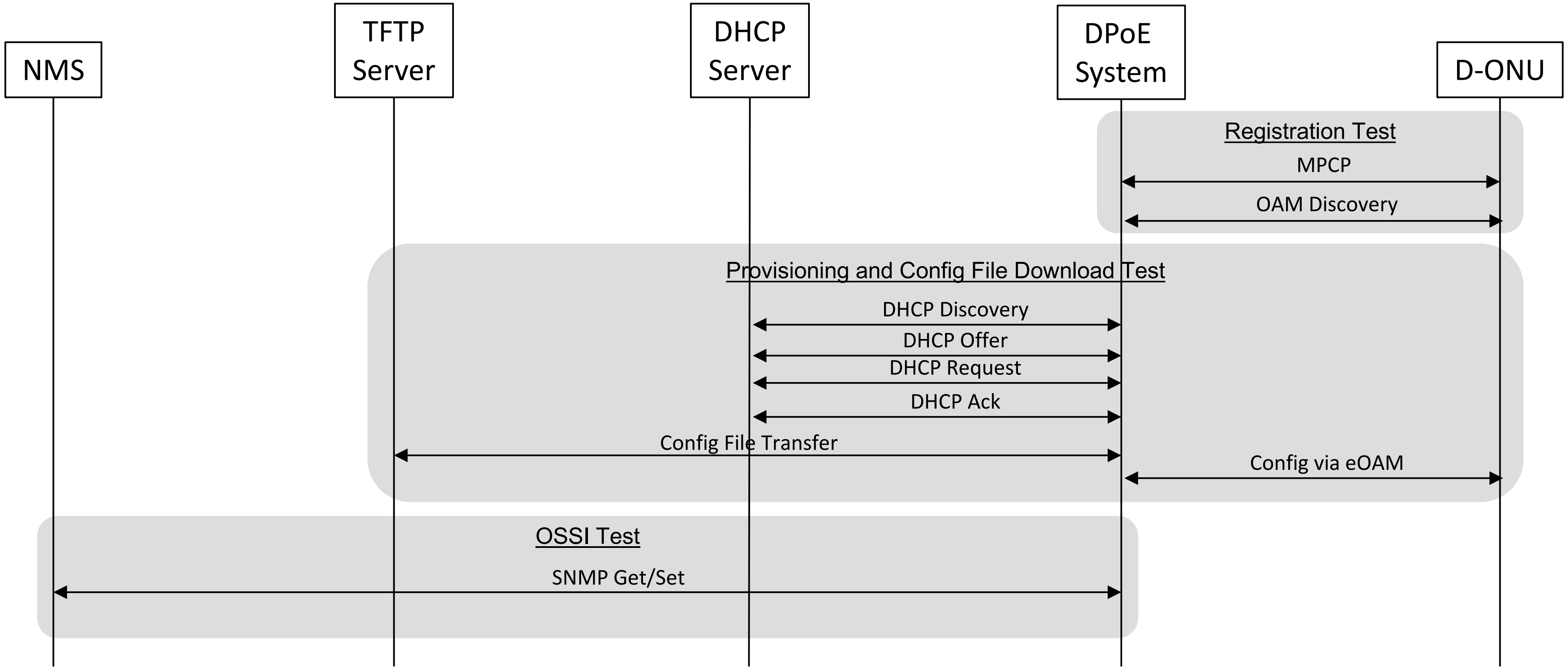


Source: *"DOCSIS® Provisioning of EPON (DPoE™): A Next Generation Business Services Network"*, Curtis Knittle, *CableLabs* SCTE EXPO 2011

Provisioning Interoperability



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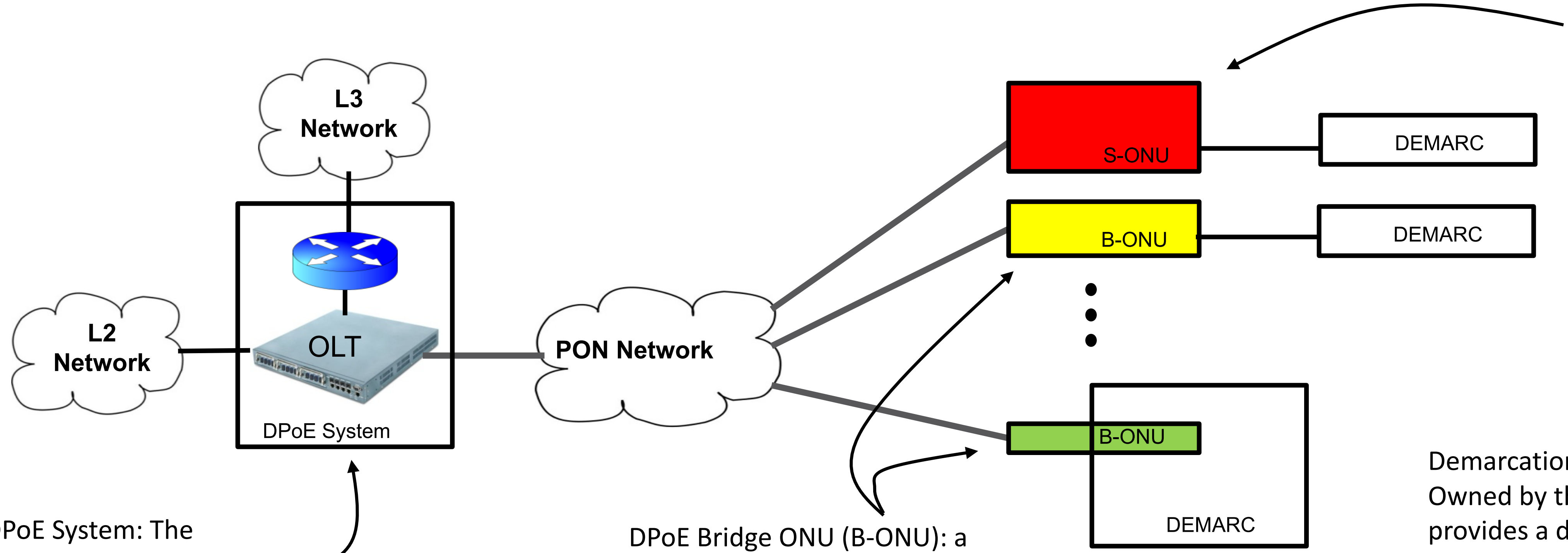
DPoE Network Elements



DPoE Standalone ONU (S-ONU): a type of DPoE ONU with multiple ports that provides both Ethernet services and IP services

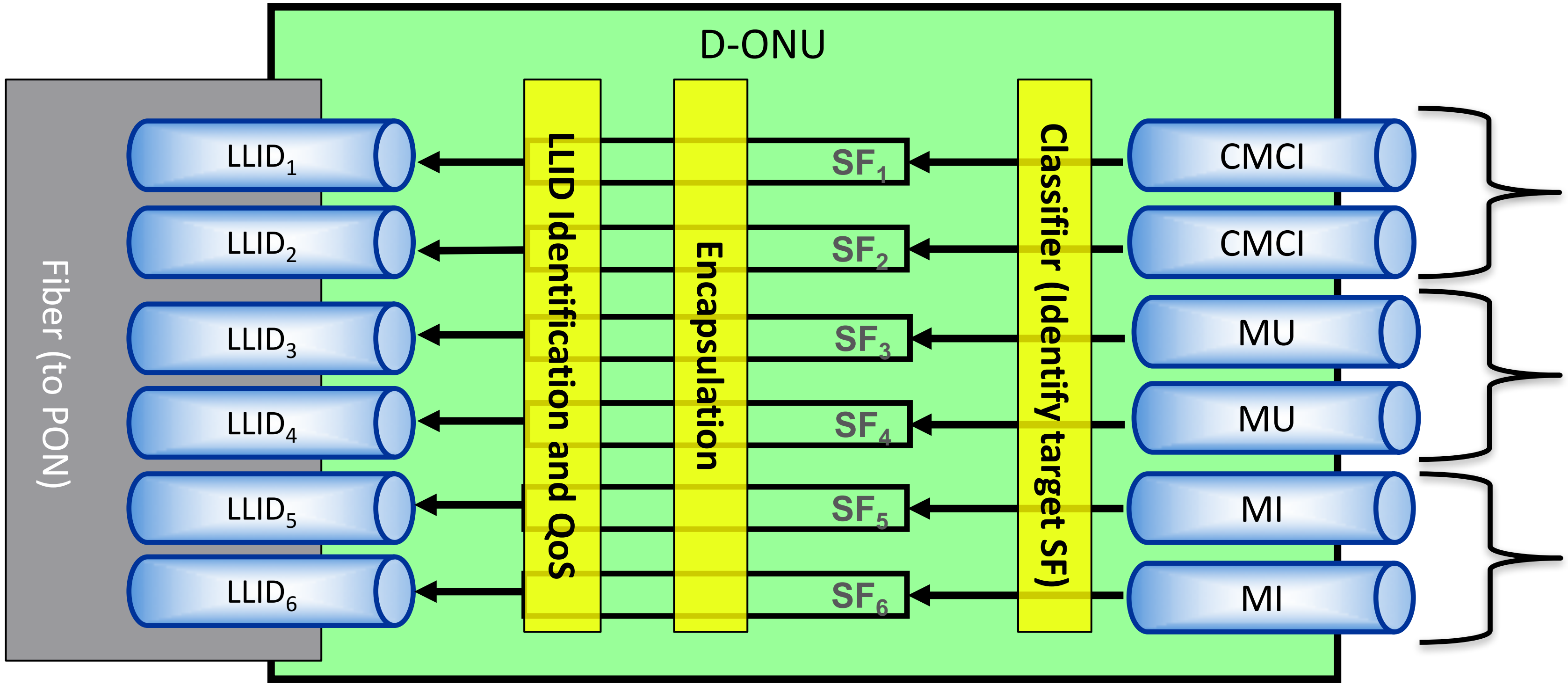
DPoE System: The collection of network elements that provide the DPoE functionality within the operator's network facilities

DPoE Bridge ONU (B-ONU): a type of DPoE ONU that provides only Ethernet services

Demarcation device (DEMARC): Owned by the operator and provides a demarcation point between the customer's network and the operator's access network

Source: *"DOCSIS® Provisioning of EPON (DPoE™): A Next Generation Business Services Network"*, Curtis Knittle, *CableLabs* SCTE EXPO 2011

DPoE ONU Interfaces and Forwarding



Cable Modem CPE Interface (CMCI): Provides IP HSD service

MEF UNI (MU): Provide the demarcation point between a customer's network and the service provider's network

MEF INNI (MI): represents an interface point between two network elements in the same service provider network that provides a UNI to UNI service

Source: *"DOCSIS® Provisioning of EPON (DPoE™): A Next Generation Business Services Network"*, Curtis Knittle, *CableLabs* SCTE EXPO 2011

DPoE Benefits:

- Leverages existing DOCSIS back office systems (provisioning, NMS, IPDR) to support EPON network elements
- Leverages back office systems enables smoother integration into operations and processes
- Enables full vendor/equipment interoperability – similar to CMTS and Cable Modems
- Developed by the MSO community and Cable Labs

Centralized Access Architecture for PON and Distributed Access Architecture for PON

"A Comparison of Centralized vs. Distributed Access Architectures for PON",
Mike Emmendorfer and Sebnem Zorlu Ozer, INTX 2016, Spring Tech Forum

Types of PON Network Architectures

Centralized Access Architecture for PON

- OLT MAC and PHY are located at the Facility
- Complex Systems are not in the ODN / OSP
- ODN is completely transparent O-E-O and/or passive splitters
- Single Data Network
  - P2MP OLT is in the Headend

Distributed Access Architecture for PON

- OLT MAC and PHY are located located in the ODN (node/cabinet)
- Called a “Remote OLT” (R-OLT)
- ODN is an active Layer 2 / 3 architecture
- Requires Two (2) Data Networks:
  - P2P Ethernet Distribution to Remote OLT
  - P2MP from R-OLT to Subscriber

Drivers & Assessment Criteria For CAA vs. DAA for PON

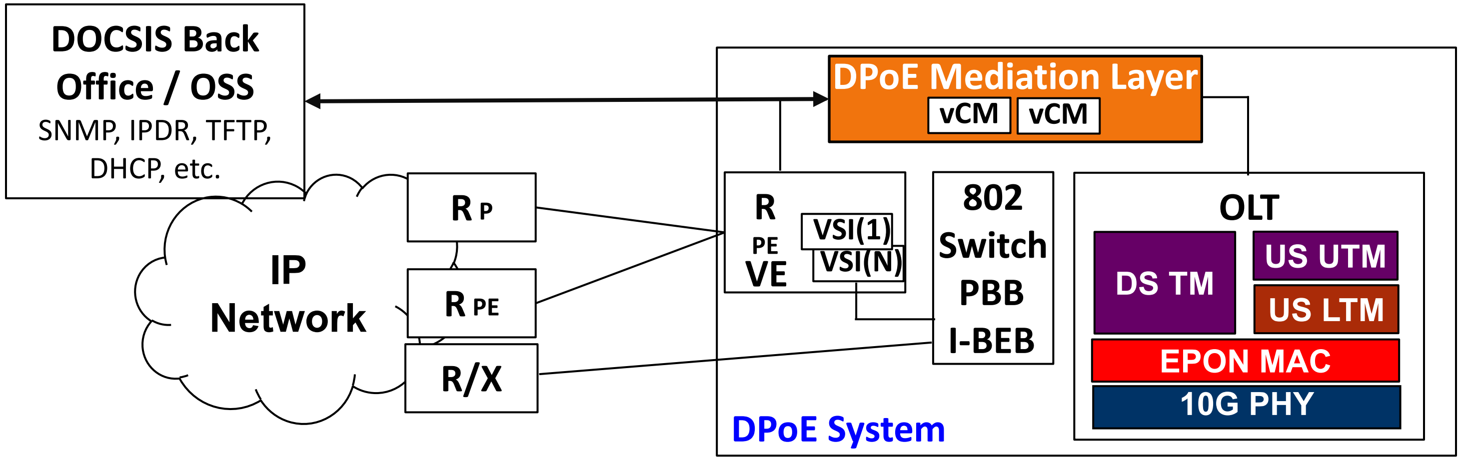
Drivers PON Extender or Remote PON

1. Fiber Utilization
2. Serving Area Distance (Facility to CPE)
3. Space/Power/Scaling Utilization in HE
4. SDN/NFV Support
5. Cost Assessment E2E (OPEX and CAPEX)

Assessment Criteria of Access Architecture

1. Fiber Utilization
2. Serving Area Distance (Facility to CPE)
3. Space/Power/Scaling Utilization in HE
4. Space/Power/Scaling Utilization in ODN
5. SDN/NFV Support
6. Capacity Performance Differences
7. Latency Performance Differences
8. High Availability System / Network
9. System and Operational Complexity
10. Cost Assessment E2E (OPEX and CAPEX)

DPoE Subsystems



vCM:	**Virtual Cable Modem**
R:	**Router**
PE:	**Provider Edge**
VE:	**VPLS Edge (Virtual Private LAN Service Edge)**
VSI:	**Virtual Switching Instance**
802 Switch:	**Switch based on Layer 2**
PBB:	**Provider Backbone Bridging [802.1ah]**
I-BEB:	**I-component Backbone Edge Bridge**
OLT:	**Optical Line Terminal**
DS TM:	**Downstream Traffic Management**
US UTM:	**Upstream Upper Traffic Management**
US LTM:	**Upstream Lower Traffic Management Scheduling / Shaping Algorithms / QoS**

DPoE System Functions

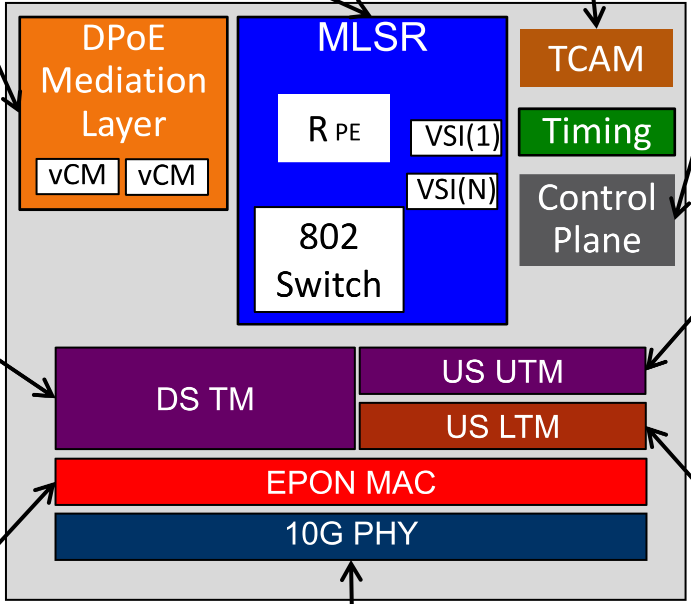
ARRIS

DPoE Mediation Layer Functions
- Mediation between OSS, NMS, and EPON Layers
- Virtual Cable Modem (vCM) for registered D-ONU
- vCM handles all the OAMP functions for DOCSIS
- vCM can proxy requests, signaling, and messages to the D-ONU using EPON OAM messages
- Communicate with D-ONU for provisioning all required services (e.g. IP HSD, MEF etc.)
- vCM Interfaces with System Control Plane for configuration (e.g. service flow, classifier, and downstream QoS etc.)
- Platform Management Interfaces (CLI, SNMP, etc.)

Multilayer Switch Router (Control & Data Plane)
- Routing
- ARP
- NDP
- IS-IS
- OSPF
- MP-BGP
- MPLS
- VPLS
- .1ad / .1ah
- L2 Switching

Ternary content-addressable memory (TCAM)
table lookup and classification of IPv4, IPv6 packets and L2 frames

Control Plane Functions
- Centralized Control for all required configurations (e.g. port, channel and MC domain etc.)
- Centralized Control for sending all the collected stats (e.g. port, channel and mac domain etc.).
- EPON MAC for programming all required functionality (e.g. port, channel, LLID and upstream QoS etc.).
- DS TM for programming all required functionality (e.g. service flow, classifier, and downstream QoS etc.).
- Implement the control plane for multicast forwarding



Downstream Traffic Management (DS TM):
- Subscriber Management Filtering (drop)
- Classification & Policing (to Service Flow (SF))
- Multicast / Packet Replication
- Scheduling / Shaping Algorithms / QoS Priority of SF (LLIDs)(DOCSIS QoS, MEF Metering / Color Marking)
- Packet Counters and Statics (IPDR Raw Data)
- DSCP / ToS / TPID (MEF) Overwrite and Translation
- CoS Mapping
- CALEA / Lawful Intercept (may not be part of TM)

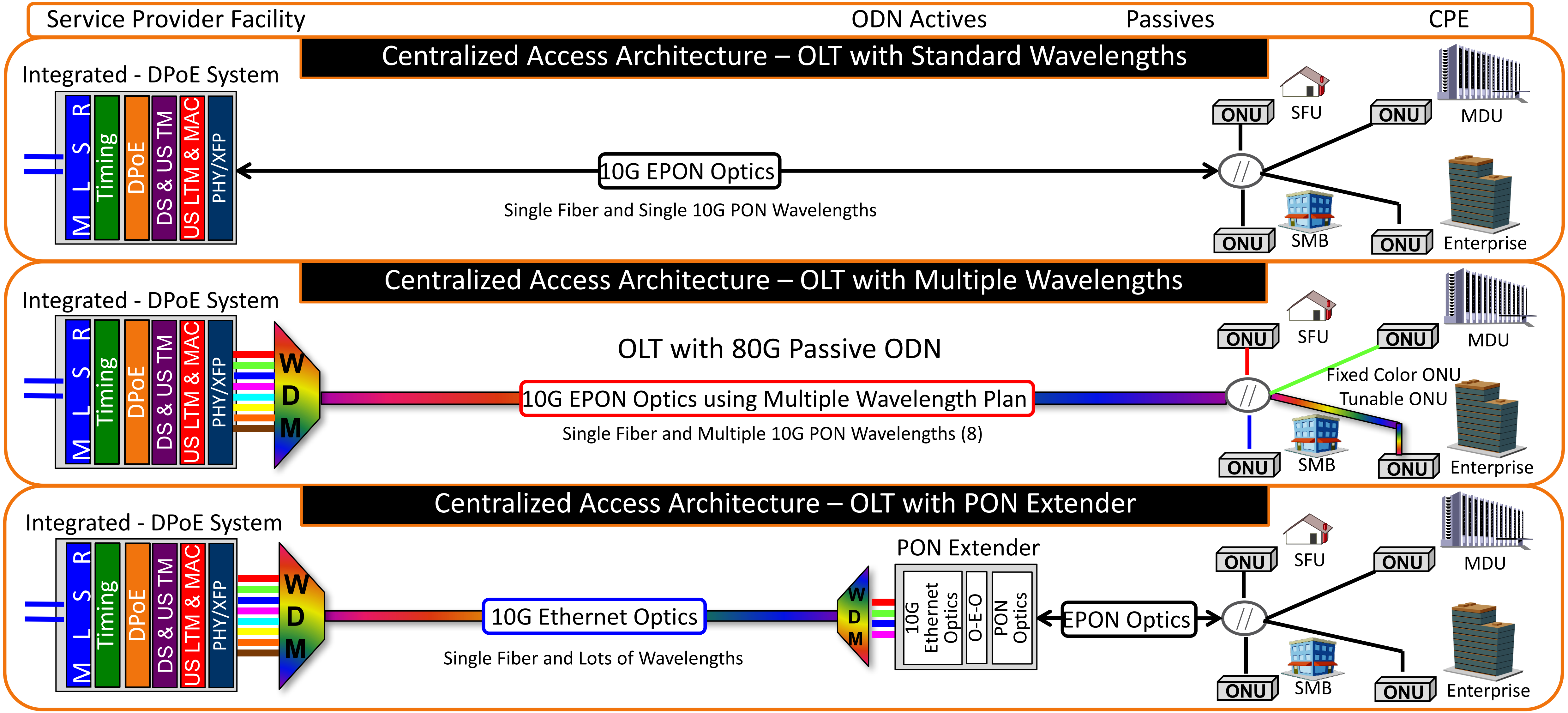
Upstream Upper Traffic Management (US UTM)
- CALEA / LI (may not be part of TM)
- DSCP / ToS / TPID (MEF) Overwrite
- CoS Mapping
- Packet Counters and Statics (IPDR Raw Data)
- Subscriber Management Filtering (drop)
- Cable Source Verify / MAC Learning /Protocol Throttling
- Classification & Policing for forwarding toward the NNI or backplane (aggregate rate limiting)

EPON MAC Layer
- LLID to VLAN (tunnel ID)
- Operation, Administration, and Management (OAM)
- Multipoint Control Protocol (MPCP) (Discovery & Registration, GATE Generation, REPORT Processing, Round Trip Time, LLID / Preamble (Frame Formation)
- Encryption AES 128

EPON PHY Layer (Upstream)
- FEC
- PR-type PMD (PON Optics)

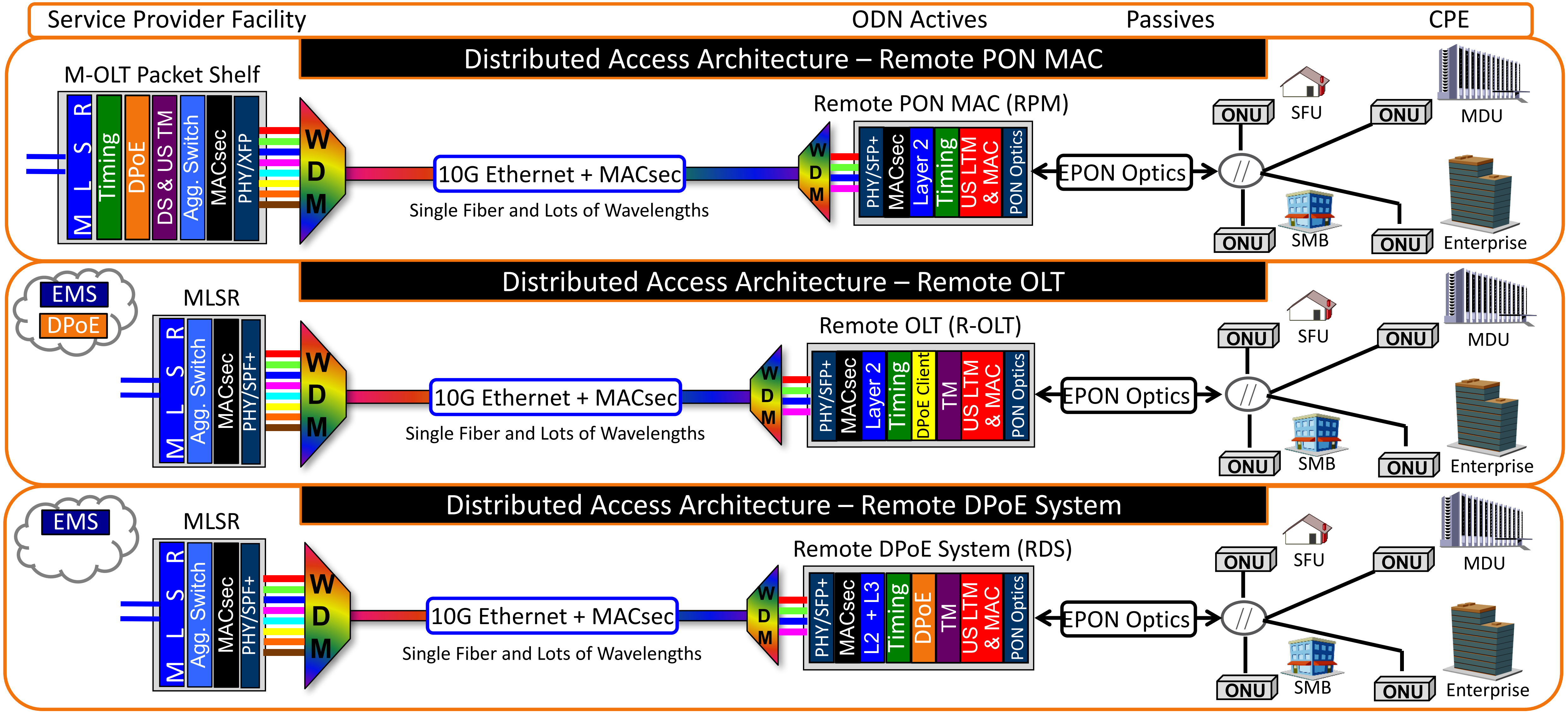
Upstream Lower Traffic Management (US LTM)
- Scheduling / Shaping Algorithms / QoS Priority of LLIDs (Service Flows)
  - Dynamic Bandwidth Allocation (DBA) – solicited scheduling
    - Token Size per LLID
    - Polling Interval per LLID
    - Scheduling / Queuing Algorithm
  - Unsolicited Scheduling
- MPCP Processing

Centralized Access Architecture (CAA) for PON Purpose Built



Note 1: OLT / DPoE System is shown in a single shelf. However, using a SDN architecture design the control and data plane processes may be separated, with the control plane processes placed on servers & control traffic through spine switches. Additionally, using a Network Function Virtualization (NFV) architecture design both control and data plane processes may be placed on servers & traffic through spine switches.

Distributed Access Architecture (DAA) for PON Purpose Built



Note 1: M-OLT Packet Shelf is shown in a single shelf. However, using a SDN architecture design the control and data plane processes may be separated, with the control plane processes placed on servers & control traffic through spine switches. Additionally, using a Network Function Virtualization (NFV) architecture design both control and data plane processes may be placed on servers & traffic through spine switches. **Note 2:** R-OLT is shown using NFV for the DML only and SDN may used as well. **Note 3:** R-OLT and RDS may use SDN.

Leading OLTs System and Network Architectures

1. Centralized Access Architecture (CAA) for PON OLT
   Traditional OLT with PON with All Passive Outside Plant
   (PON MAC in the CO/HE with No Actives in the OSP)

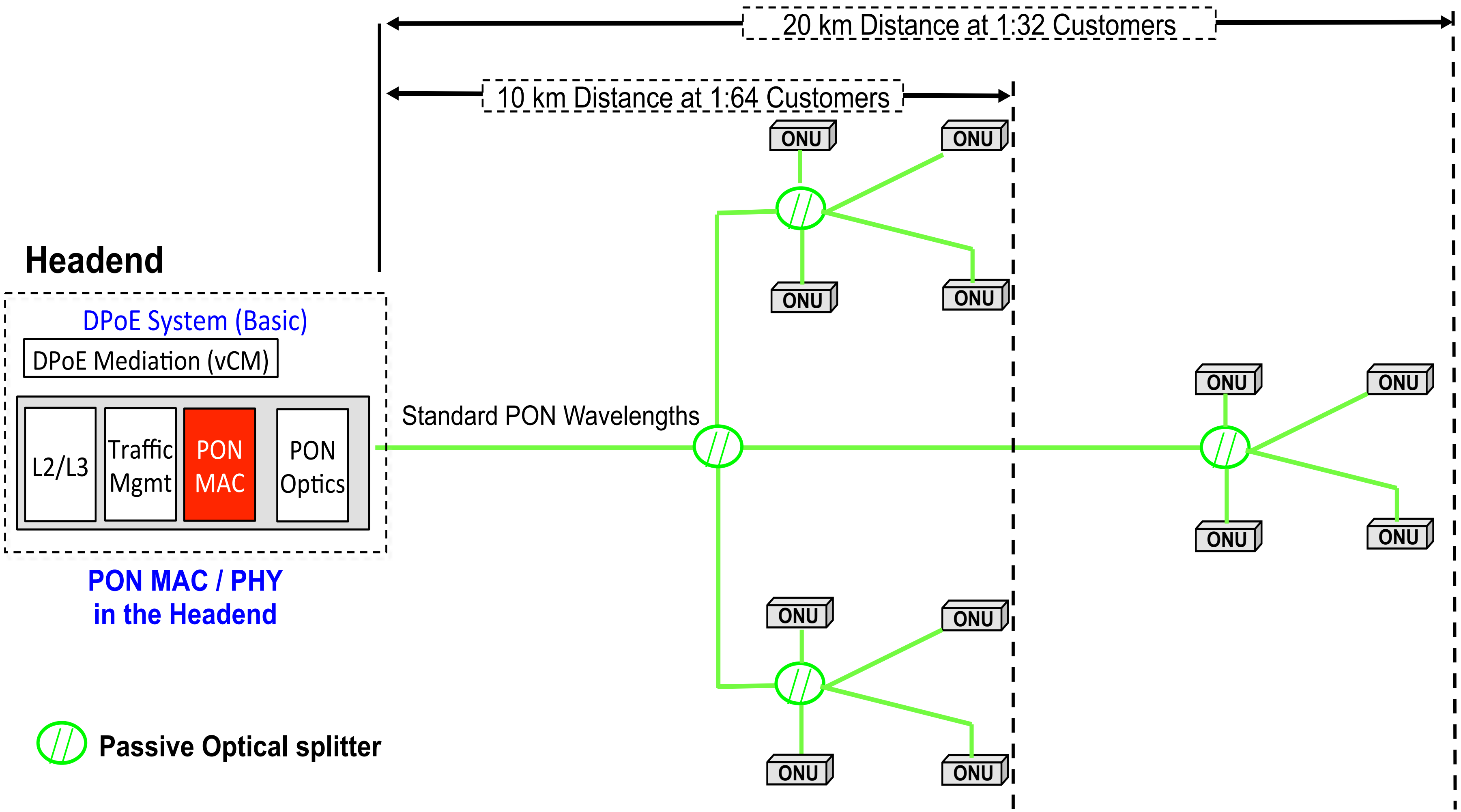
2. Centralized Access Architecture (CAA) for PON OLT
   Traditional OLT with PON Extender and No Software in the OSP
   (Simple Layer 1 Optical-Electrical-Optical (O-E-O) conversion in the node/cabinet)

3. Distributed Access Architecture (DAA) for PON OLT
   Remote OLT in the OSP/Cabinet with Software in the OSP
   (Routing/Switching, Traffic Management, PON MAC/PHY in the node/cabinet)

Centralized Access Architecture (CAA) for PON OLT

Traditional OLT with PON with All Passive Outside Plant

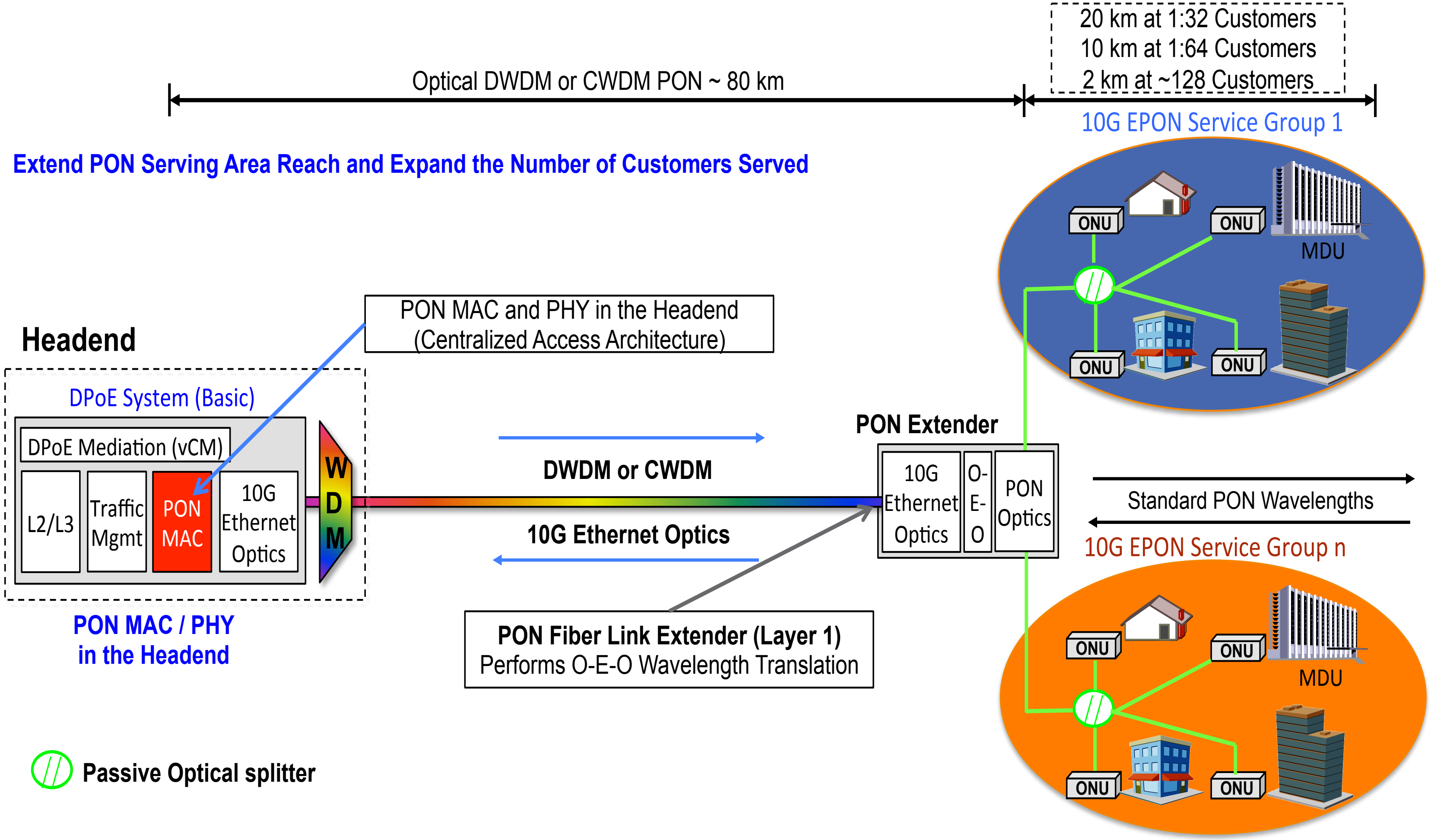
(PON MAC in the CO/HE with No Actives in the OSP)



Centralized Access Architecture (CAA) for PON OLT

Traditional OLT with PON Extender and No Software in the OSP

(Simple Layer 1 Optical-Electrical-Optical (O-E-O) conversion at the node/cabinet)

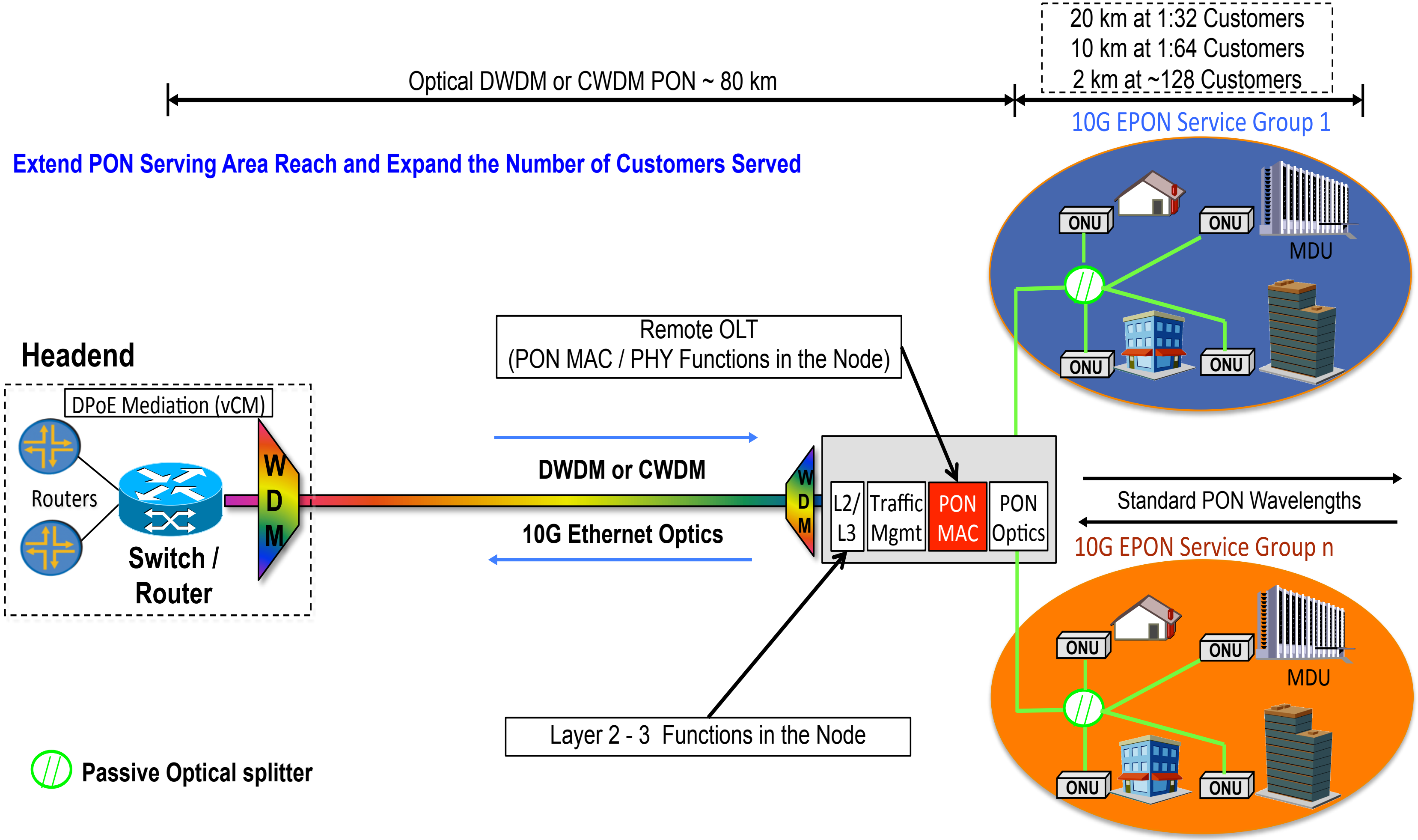


Distances of 5 km from the PON Extender to the ONUs have been observed to support 128 customers / ONUs

Distributed Access Architecture (DAA) for PON OLT

Remote OLT in the OSP/Cabinet with Software in the OSP

(Routing/Switching, Traffic Management, PON MAC/PHY in the node/cabinet)



Distances of 5 km from the Remote OLT to the ONUs have been observed to support 128 customers / ONUs

Overview of Purpose Built OLT Systems and SDN/NFV Systems for PON

"A Comparison of Purpose Built OLT Systems vs. SDN-NFV Systems for PON",
Mike Emmendorfer and Sebnem Ozer, SCTE-ISBE Workshop, Sept. 2016

What is SDN and NFV?

- **SDN separates data and control and management plane to enable:**
  - A software programmable network
  - A centralized controller with dynamic management and provisioning
  - Reuse of parity control features over multiple access technologies
  - Dynamic creation, modification and deletion of services

- **NFV decouples SW from HW to enable:**
  - Using COTS hardware and open software
  - Dynamic resource and service management
  - Reuse of parity forwarding features over multiple access technologies
  - Defining efficient network and service chains

What are the Drivers behind SDN/NFV? (1 of 2)

- **Elasticity and Scalability Enable by System Modularity (Disaggregation of CCAP & OLT)**
  - Disaggregation: Separation of Hardware and Software Functional Blocks
    - (PHY, MAC/PHY, Traffic Management/Service Gateway, Switch Fabric/Backplane, Control, WAN/NSI Link)
  - Separation of Control and Data Planes
  - Separating the network functions allows placement of capacity where and when needed
    - (IO capacity for access layer like PON, P2P Ethernet, DOCSIS, etc. where and when needed)

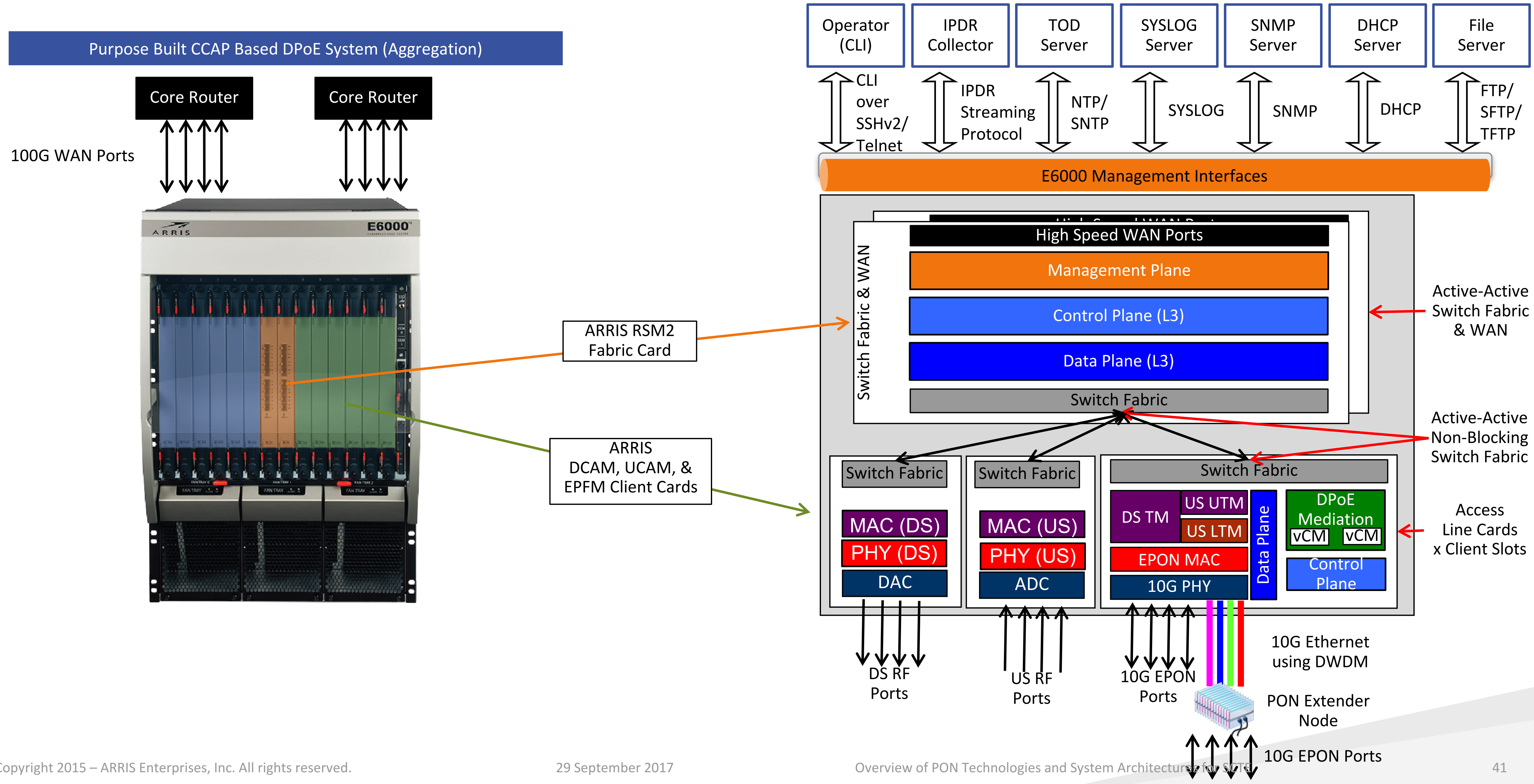
- **Agility Enabling Time To Market**
  - Service Creation and Provisioning Automation
  - End-to-end Analytics assists in determining resource service capacity
  - Consistent services and features across vendors and access technologies (DOCSIS, PON, Ethernet, Wireless)

- **Open Platform Ecosystem**
  - No Proprietary System Vendor software or protocols
  - System Vendor, Network Operators, and Community develop features / applications
  - Automate OAM&P
  - Interoperability
  - Innovation

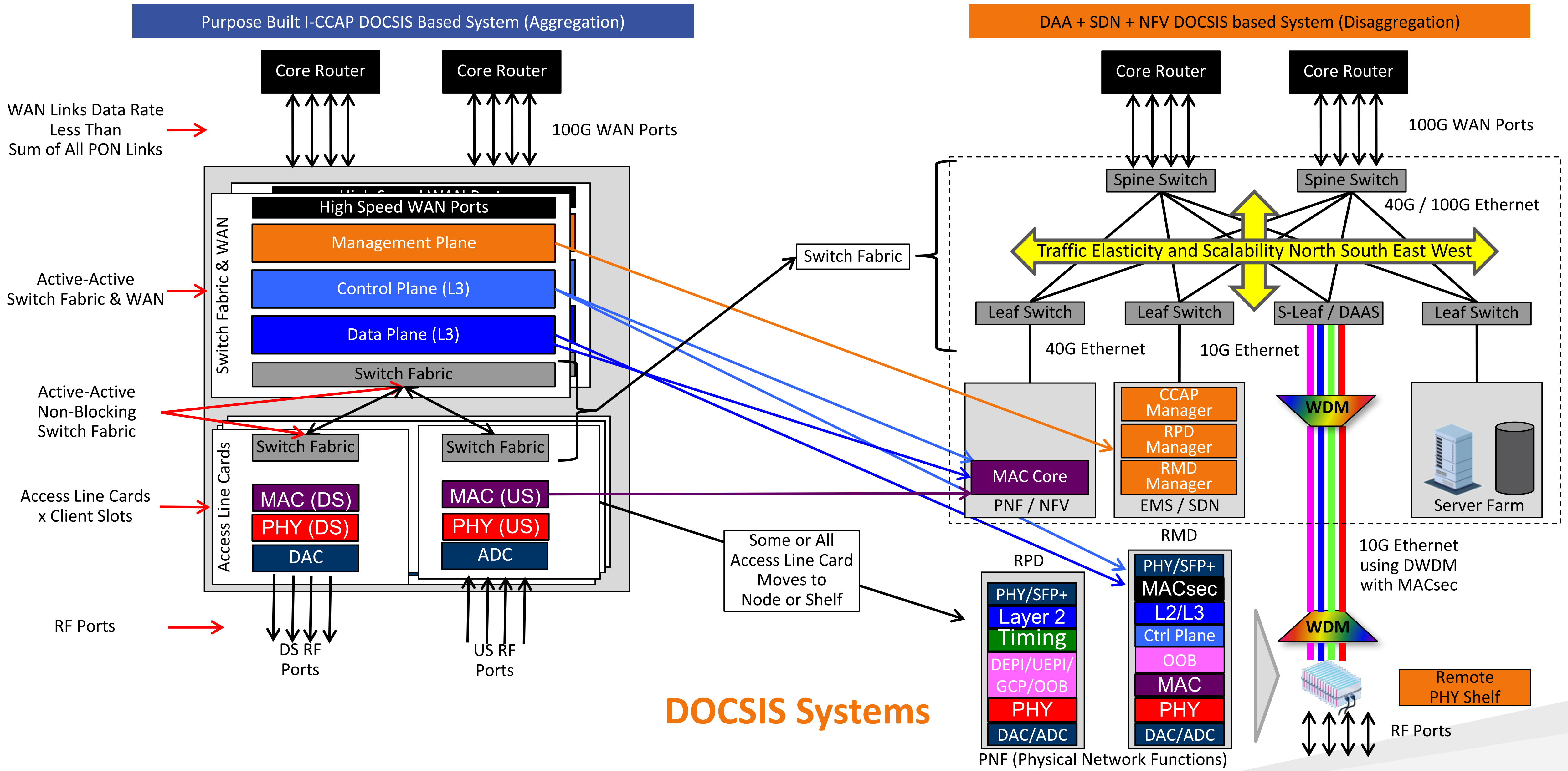
What are the Drivers behind SDN/NFV? (2 of 2)

- **Reduce CAPEX**
  - COTS switches, servers, storage, compute elements
  - Reduced headend estate, power and cooling
  - Ability to scale per demand and integrate only needed functions
  - New pricing options using licenses per subscriber, throughput, features enable (pay-as-you-grow)
  - Open Software platforms from multiple vendors
- **Reduce OPEX**
  - Reduced headend power and cooling
  - Zero touch provisioning and programmable networks and services with reduced complexity
  - End-to-end visibility, analytics and service assurance orchestration
  - Dynamic and efficient resource management (self healing/optimizing networks)
  - Standard APIs, control and management interfaces
- **Agile Services and New Business Models**
  - Abstracted service models and automated networks for shortened service integration
  - Enhanced QoE and customer and business portals
  - Cloud based applications and abstracted service models for business to business services
  - Centralized control of distributed functions directed and composed by service specific requirements

Traditional I-CCAP (e.g. I-CCAP DOCSIS or PON OLT System)

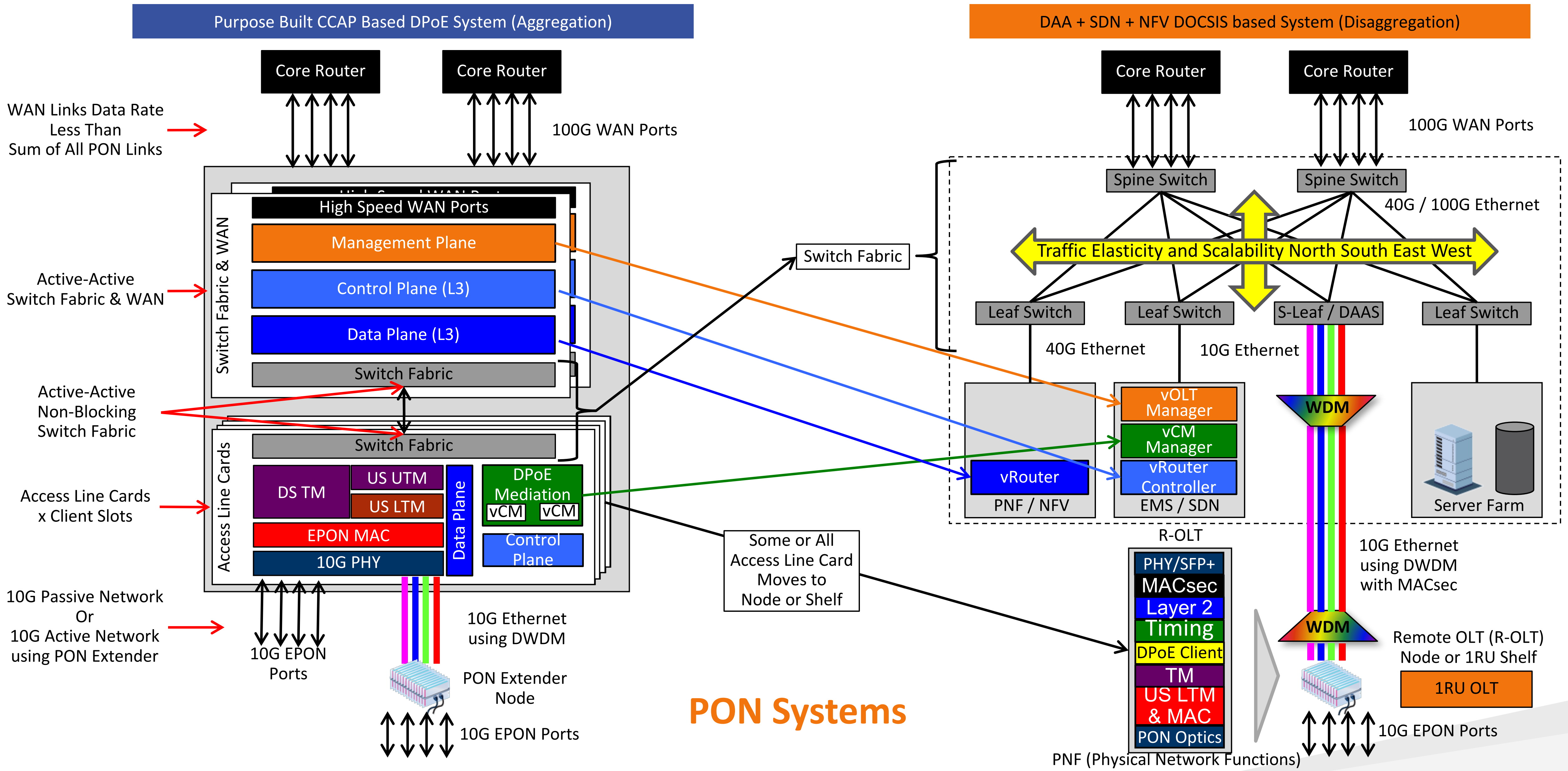


Aggregation to Disaggregation (CAA to DAA + SDN + NFV)



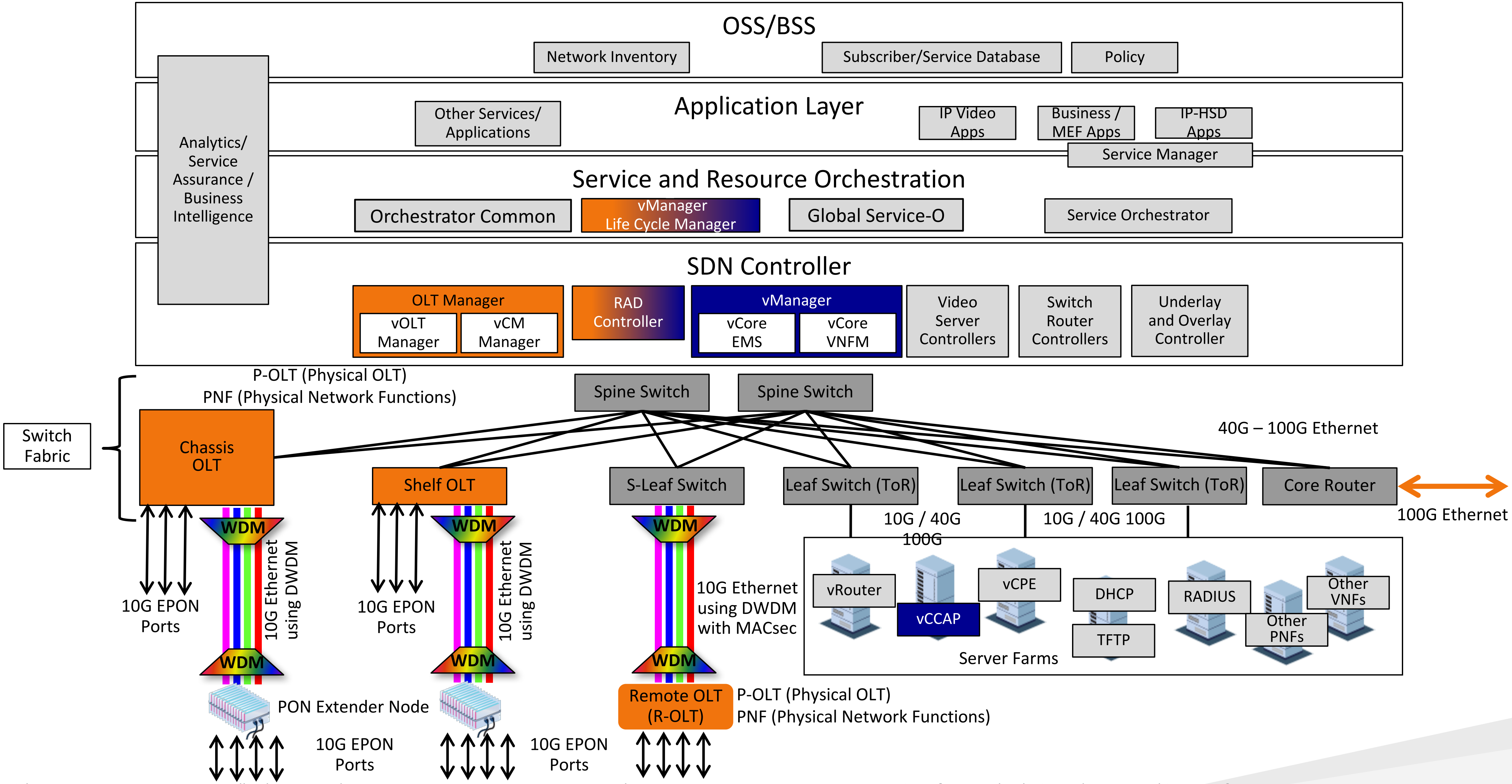
DOCSIS Systems

Aggregation to Disaggregation (CAA to DAA + SDN + NFV)

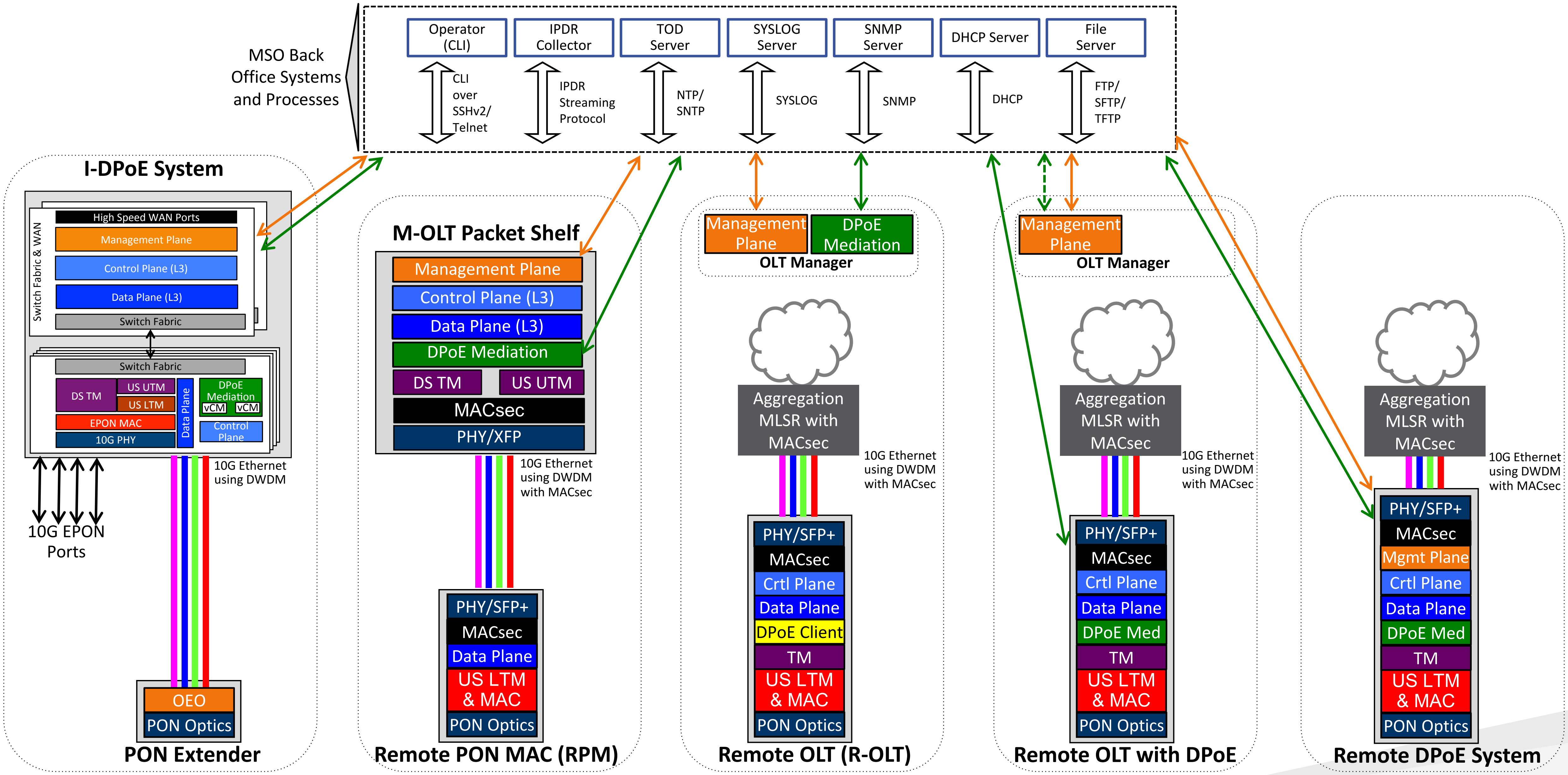


PON Systems

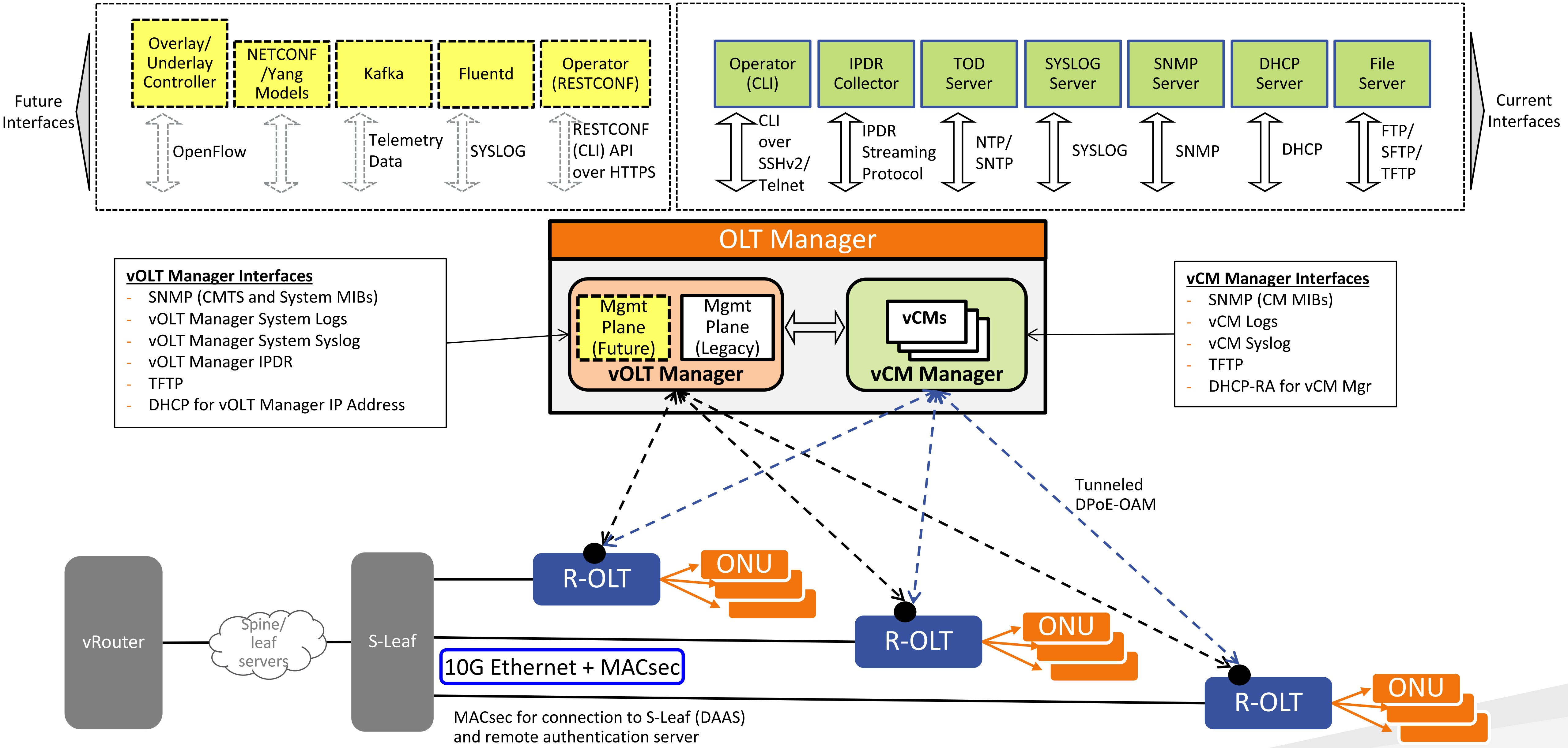
High-Level MSO SDN/NFV Architecture for 10G EPON



CAA OLT/DPoE System & DAA OLT/DPoE System Options



Example of a Remote OLT with OLT Manager Interfaces



Initial Pros & Cons of Purpose Built DPoE Systems

- **Pros**
  - Hardware and software integration create a highly reliable system
    - Maturity of System enables low MTTD and MTTR
  - Hardware and software are optimized for each function
    - (example high packet processing in less space, power, and cost that commodity server NFV)
  - Suppliers can rigorously test and troubleshoot known hardware and software
  - Enable customers to go to a single supplier to resolve hardware and/or software issues

- **Cons**
  - Accused of slow innovation of hardware and software features
  - Closed purpose built systems have rigid scalability which binds access ports, fabric, WAN ports, type and number of slots all together, if any one is exhausted another system is required to address capacity.
  - Purpose built system vendor hardware and software may not be repurposed to run different software
  - New access technologies (DOCSIS, PON, and Ethernet) on the CCAP require rewriting of similar functions
  - Lack of programmability from a single controller (EMS) to all system components

Initial Pros & Cons of SDN/NFV DPoE Systems

ARRIS

- **Pros**
  - Disaggregation = Elasticity and Targeted Scalability where/when needed
  - Ability to Pay-as-you-grow where capacity is needed (client cards, WAN, control, chassis independence)
  - New pricing options using licenses per subscriber, throughput, features enable (pay-as-you-grow)
  - Agility consistent services and features across vendors and access technologies (DOCSIS, PON, Ethernet, Wireless)
  - Promises of open platform ecosystem (No Proprietary System Vendor hardware, software, interfaces)
  - Readiness for control plane using commodity x86 exist
  - New business relationships for SDN/NFV hosted web services for disaster recovery and capacity augmentation
  - SDN / NFV enables the service provider to select hardware and software platforms and require system vendors to develop on those systems. This enables consistent platforms, vendor hardware independence, and migration to different system vendors.

- **Cons**
  - Disaggregation = Complexity and Integration
  - Many white-box switches use merchant silicon for accelerated and specialized packet processing (not open/off shelf)
  - x86 for high packet processing data plane require more space, power, and cost
  - Scalability of some server based network functions (vRouter) are not at all at the level of purpose built systems
  - Lack of standards and certification
  - Interoperability issues may be troublesome among various hardware, software, and interfaces
  - Maturity of system may impact end-to-end MTTD and MTTR
  - Open source does not mean the same implementation


Questions?

Thank you!

References

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- *“Next Generation Networks for Multiple Dwelling Units (MDUs)”,* Michael J. Emmendorfer, SCTE-ISBE Workshop, September 2014
- *“Comparing IEEE EPON & FSAN/ITU-T GPON Family of Technologies“*, Michael J. Emmendorfer, SCTE-ISBE Workshop, September 2014
- “*A Comparison of Centralized vs. Distributed Access Architectures for PON*“, Mike Emmendorfer and Sebnem Zorlu Ozer, INTX 2016, Spring Tech Forum
- “A Comparison of Purpose Built OLT Systems vs. SDN-NFV Systems for PON”**,** Mike Emmendorfer and Sebnem Ozer, SCTE-ISBE Workshop, Sept. 2016
- “*End-to-end IP Video Services over 10G EPON Access Network Architectures*“, Sebnem Zorlu Ozer and Mike Emmendorfer, SCTE-ISBE Journal of Digital Video, Volume 1, Number 2, Sept. 2016

PON Acronyms and Meaning

Term	Meaning
APON	ATM Passive Optical Network
BPON	Broadband-Passive Optical Network
GPON	Gigabit-Passive Optical Network
GEPON	Gigabit Ethernet - Passive Optical Network (aka EPON)
EPON	Ethernet Passive Optical Network (aka GE-PON)
10 EPON	10 Gigabit Ethernet PON
DPON	Data Over Cable Service Interface Specification - PON uses EPON for MAC/PHY and DOCSIS defined transactions and standards for OAM&P. (aka: DOCSIS over EPON or DPON)
RFoG	Radio Frequency over Glass (aka: Radio Frequency PON (RF-PON) or Radio Frequency over Glass (RFOG) or Hybrid-Fiber-Coax PON (HFC-PON) or Cable PON
WDM-PON	Wavelength Division Multiplexing PON
FTTx	Fiber To The x (FTTH Home, FTTB Business, FTTP Premise, FTTC Curb)

High-Level MSO SDN/NFV Architecture for 10G EPON

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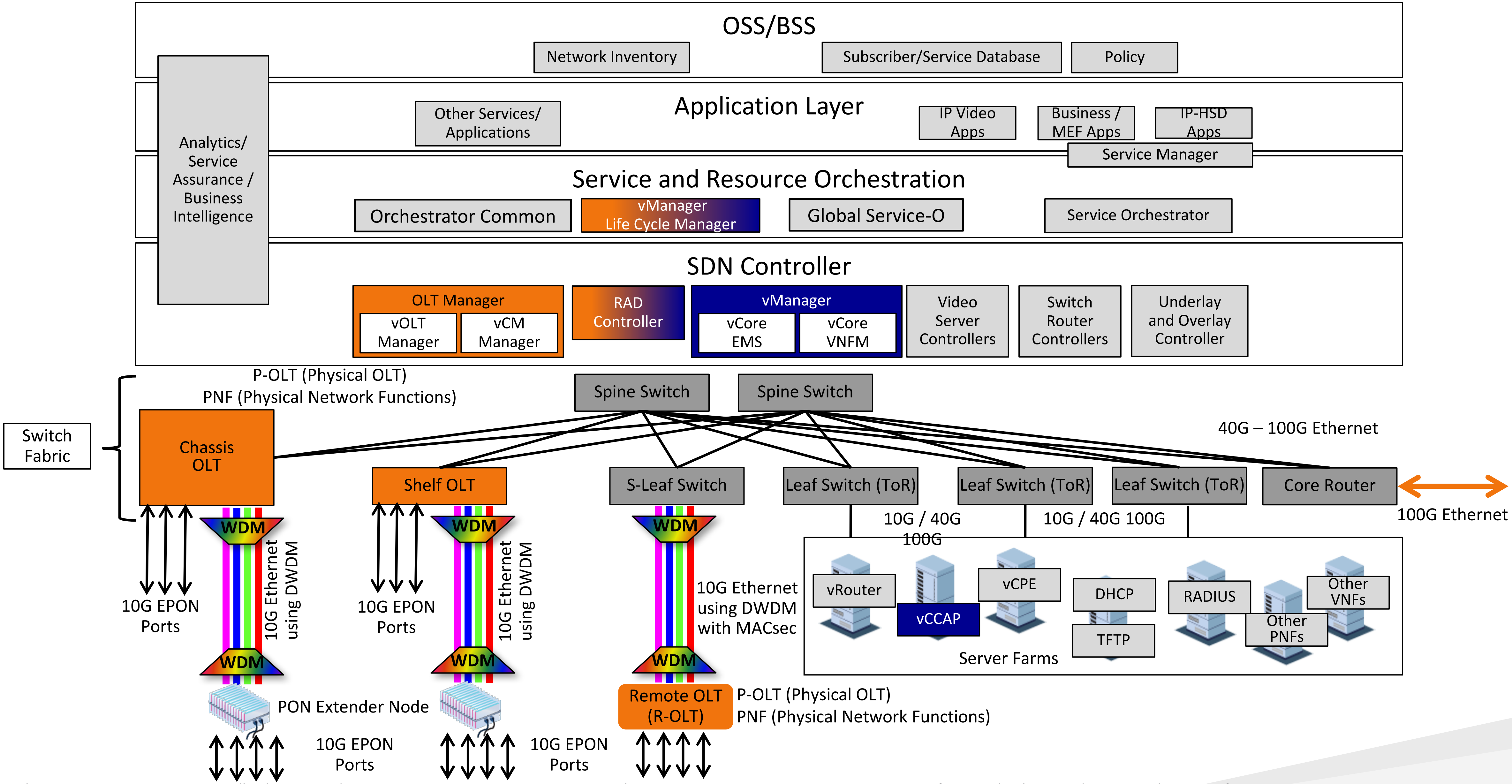

System Architecture

- **OSS/BSS and Application Layer**
  - Maintain service and business policies, subscriber and other business customer databases and network inventory and topology database
  - Customer care, operator and partner portals
  - Provide cable operator's directives on services, subscribers and networks for both initial design (configuration of elements, static services) and runtime operations(dynamic services and scaled services) operations.
  - IP-HSD, IP Video, Business and other (e.g. tenant) services
  - Business Intelligence, analytics and topology information
  - Cloud Foundry (industry standard platform for Open Source cloud applications)

- **Orchestration Layer**
  - Service and resource (networking, compute and storage) orchestration
    - Service Orchestration (XOS) VM Orchestration on server and cloud (OpenStack, CloudStack, Hypervisor…)
  - Service and network chaining, management of NFVIs
  - Elastic resource management based on capacity, performance and power requirements and resource optimization and load balancing
  - Support for legacy EMS/NMS
  - End-to-end service assurance and monitoring
  - Underlay fabric and overlay network management

System Architecture

- **SDN Controllers**
  - NETCONF/YANG for configuration and management (FCAPS); OpenFlow for programming forwarding; legacy SNMP/CLI ; Proprietary APIs
  - Access network and service controllers
    - vDPoE System and vCM controller
      - Mediation between OSS, NMS and EPON layers
      - Configuration and management of DPoE based OLT and ONU (DOCSIS OAMP functions)
    - R-OLT controller
      - Remote access device specific configuration and management
    - vRouter/MLSR controller
      - Configuration and management of OLT routing functionality
    - Switch/router controller
      - Configuration, management and control of fabric switches/routers
    - Video controllers
      - Configuration and management of video functions such as Multicast (M-ABR) , S-ABR, nDVR, vCDN etc…
  - Network Controller (OpenDayLight, ONOS)

System Architecture

- **Network Functions**
  - Virtual (SW on COTS elements) and physical (embedded in HW) and purpose built network functions
    - Data volume, control transaction rate, performance and security requirements
  - Access network and service functions
    - vRouter/MLSR: OLT Routing functionality
    - vCPE: CPE/SG related functions such as parental control, firewall
    - vVideo: Video service specific functions such as M-ABR, S-ABR servers, nDVR recorder, CDN/edge cache…
  - Disaggregation of functions into common and specific features
  - Support for control/management by controllers and orchestrators
  - Support for analytics
  - Implemented as VMs, containers

- **Fabric Network**
  - Spine and leaf switches
    - Controlled and managed by SDN controller/orchestrator
  - Access specific S-leaf switch