VIRTUALIZING CUSTOMER PREMISES WITH SERVICE FUNCTION CHAINING

How OpenDaylight and OPNFV Members Implement NFV's Top Use Cases

Contents

3 Executive Summary

4 Introduction to vCPE and SFC

7 Industry Examples: Operators and Solution Providers

13 Why OpenDaylight?

13 The MANO Factor: Open Orchestrator

14 Conclusion

15 Appendix A: Projects that Intersect ODL and OPNFV

16 Appendix B: Cited Operators, Solution Providers, and Analysts

Executive Summary

Most service provider networks rely heavily on dedicated specialized hardware, which is an expensive, often complex way to manage the network and its resources. Accordingly, NFV continues to gain momentum as a way to migrate towards a more flexible environment using industry standard servers and storage, and to greatly increase agility in rolling out new network services.

Virtual Consumer Premises Equipment (vCPE) is an early and popular proof use case for SDN and NFV. In order for vCPE to be successfully implemented, it is necessary to employ Service Function Chaining (SFC) to access other network functions.

The following public survey results from IHS illustrate the top two use cases for NFV: the vCPE use case and service chaining technology to support it.

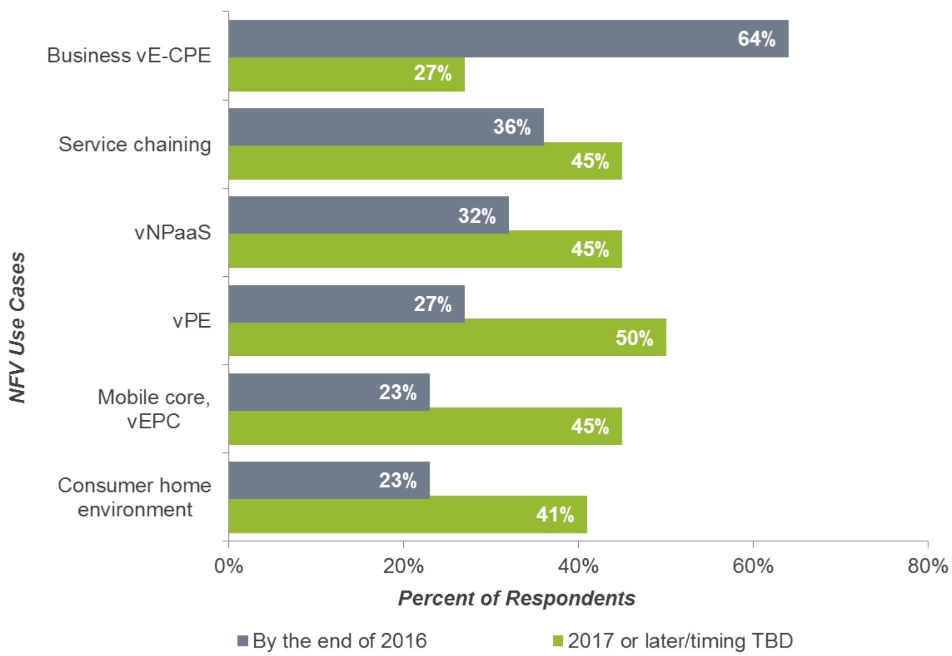

Figure 1: VSPerf's Modular Test Framework

As with all OPNFV projects, and in the spirit of NFV itself, each of the modules is componentized and thus interchangeable. For example, a test setup using any traffic generator can be supported within this framework.

Although this particular chart cites business vCPE, the consumer home environment is also a prominent target for virtualized infrastructure.

[1] See the IHS blog entitled, Global Operator Top NFV and SDN Use Cases.

Many instances of vCPE solutions and service function chaining implementations have been deployed and tested using OPNFV scenarios. And many OPNFV members—including KT Corporation, Orange, CableLabs, AT&T, and China Mobile—are implementing, testing, or otherwise evaluating vCPE using SFC and other technologies implemented by vendor members such as Red Hat and Ericsson. Most recently, the LF's Open Orchestrator project (OPEN-O) is working on vCPE as a top use case.

Introduction to vCPE and SFC

The purpose of virtualizing CPE is to simplify the network and its administration by moving higher layers from the home or business into the network, where they can be handled by a commodity server under control of a network operator. With this flexibility, the operator can reduce costs, dynamically deliver network functions, and provide agile new service rollouts. For example, operators can virtualize IP functions for subscriber and service management, or virtualize Network Address Translation (NAT), Dynamic Host Control Protocol (DHCP), or firewall services.

Network services consist of a set of functions, both physical and virtual, and these functions are more useful if they are not constrained by location. SFC provides the ability to define an ordered list of network services (e.g., firewalls or load balancers). These services are then "stitched" together in the network to create a service chain.

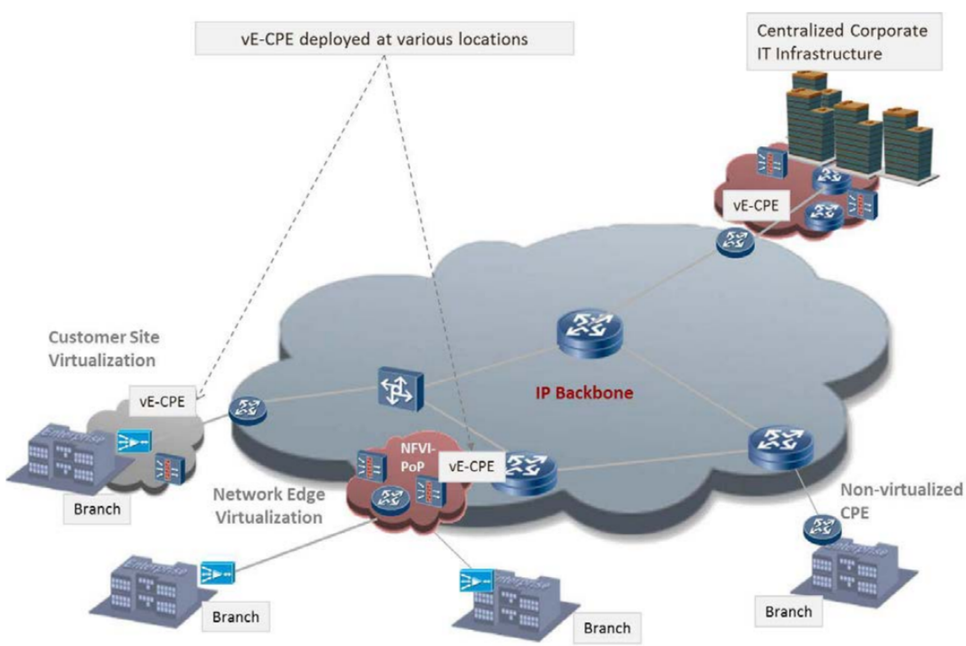

Figure 6: vE-CPE Location Examples

[2] See the section Using Brahmaputra: Testing and Deployment Scenarios on the OPNFV Technical Overview page.
[3] See the source page for Open Orchestrator.
[4] See ETSI GS NFV 001 Network Function Virtualization Use Cases, October 2013.

This includes a corporate headquarters (HQ) with a centralized IT infrastructure, and multiple branches that are connected to this HQ and to each other. The functionality of the vCPE may be in various locations: headquarters, customer sites, branches, in remote data centers as cloud services in regional hubs, or via public cloud service providers.

Of course, for vCPE or for any Virtual Network Function as a Service (VNFaaS) implementation to be viable, it needs to convey the same benefits as physical network functions, and to do so in geographically distributed locations. A service chain is required when a network service consists of a set of physical or virtual NFs, and the traffic needs to traverse in a pre-defined order. Service chains can vary in complexity from simple to very complex.

An example of a simple chain is a firewall and a load balancer sitting in front of a number of DNS servers. A complex service chain might be the service infrastructure sitting behind a mobile gateway device.

In Figure 3, the blue service uses the firewall, WAN optimization, and then encryption, whereas the green server uses the firewall and then has traffic load balanced. These network functions may appear in multiple domains—premises, central office, or Internet Points of Presence (PoP).

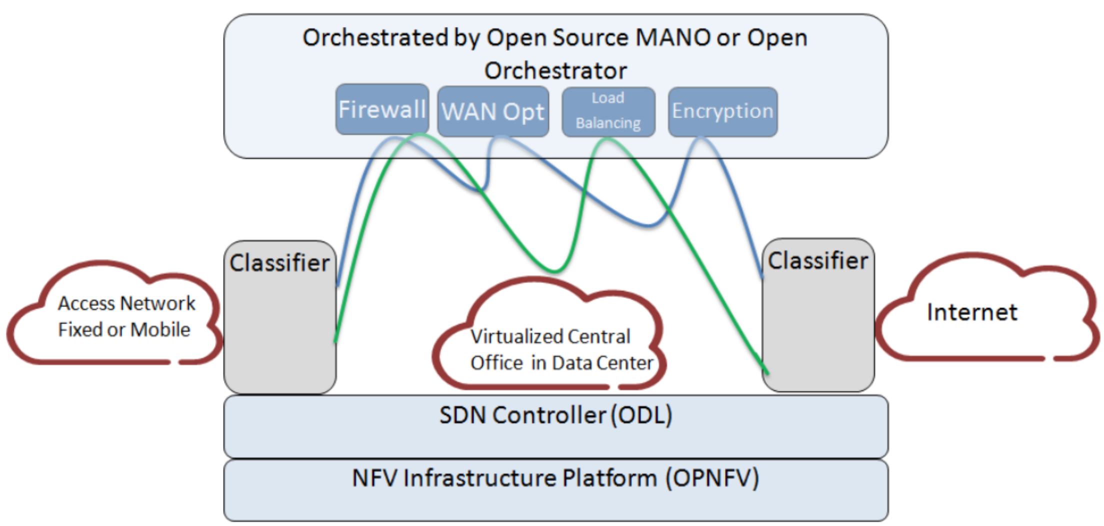

Figure 3: Basic Service Function Chaining Across Multiple Domains

In fact, as more central offices are built out into data centers (see the center cloud in Figure 3), more Fiber to the Premise (FTTP) hardware functions, such as Gigabit Passive Optical Networks (GPON) and Optical Line Termination (OLT), are being virtualized, and OpenDaylight is being investigated by OPNFV members including AT&T and others for this purpose.

"AT&T's vast physical footprint and our rich Edge services for connectivity, security, and now IoT are meant to give customers the best possible experience where they are located. As such, efforts around the Edge Cloud are essential to AT&T's strategy and by extension to OPNFV, OpenStack, OpenDaylight and the community."

– Toby Ford, AVP of Cloud Infrastructure and Platform Architecture & Strategy, AT&T

Operators must cooperate with other operators, and they do this with agreements that are built into the rules of the service chain. In any VNFaaS implementation, one operator may offer services to another, and they each have to automate either the offering or the consumption of the service in their own domain.

This model will also become prominent with more instances of hybrid clouds, either between multiple service providers or enterprises and service providers. In the enterprise case, the key point is that the service provider should handle most of the logic to achieve this.

Figure 4 illustrates how SFC is implemented in terms of the NFV reference architecture, with all the relevant NFVI, controllers, and virtual network functions. As this is an end-to-end service definition, it is implicitly multi-domain, though local element management systems (EMS) will control the VNFs.

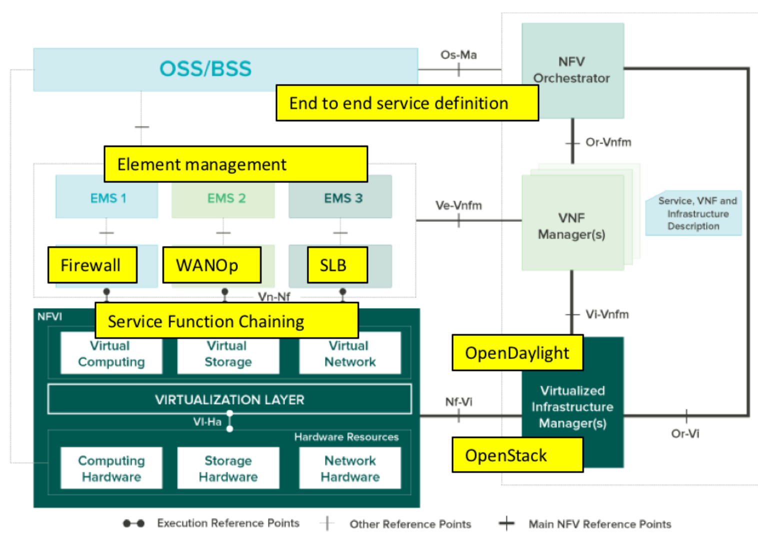

Figure 4: SFC in ETSI NFV: End-to-End Illustration Using ODL and OpenStack

[5] See AT&T's Donovan: We'll Virtualize More Hardware Functions in 2016.
[6] Coexistence between multiple controller instances was a key emphasis in the Beryllium release of OpenDaylight. See the blog entitled, Open Daylight as an NFV Controller.
[7] As a recent example of this, AT&T and Orange in July 2016 agreed to work together to create common specifications for vCPE and other NFV use cases.

The relevant network services are VNFs that are chained together by SFC in the NFVI. This is controlled by ODL and OpenStack, which are part of the Virtualized Infrastructure Manager (VIM) layer of the Management and Orchestration (MANO) stack.

Industry Examples: Operators and Solution Providers

There are many examples of service providers, research networks, solution providers and system integrators proving out and deploying virtual CPE solutions. This section cites examples and proofs of concept (PoCs) from CableLabs, Orange, China Mobile, KT Corporation, GEANT and AT&T, as well as implementation case studies from Ericsson and Red Hat.

Although virtual CPE is a use case that can apply both in business and residential environments, the requirements and approaches to the two cases are quite different. CableLabs, a nonprofit research and development consortium for cable operators, has developed both a residential and a business vCPE using OPNFV and OpenDaylight.

With Residential vCPE, some of the functionality residing in the customer's home is moved into the service provider's data center by extending the home domain to a service provider's data center, which may be located
in a central office (CO). Part of the benefit is cost, but the major motivation for the consumer is simplified configuration, enhanced service opportunities, and better visibility (to allow better service) of the home network and its devices.

"CableLabs' position within the service provider community gives us visibility into the long term objectives and the short term goals of organizations engaged in cloud architecture and OPNFV efforts. The opportunities for cost saving and operational flexibility offered by virtualized plug and play network functions gives member operators the flexibility to roll out services and features such as on-the-fly bandwidth boost and custom VPN configurations with an agility that was unimaginable only a few years ago."

– Kevin Kershaw, Director, R&D Software Development, CableLabs

[8] Some of these examples are taken from the 2015 OPNFV Summit Presentation entitled From Virtual to Real: Proofs of Concept in OPNFV by Bin Hu of AT&T.
light. See the blog entitled, Open Daylight as an NFV Controller.
[9] This is discussed here, along with other ways that CableLabs is using ODL.

In the following typical home virtualized CPE example, policies that allow restricted access for certain members of the household are set in a cloud in the data center.

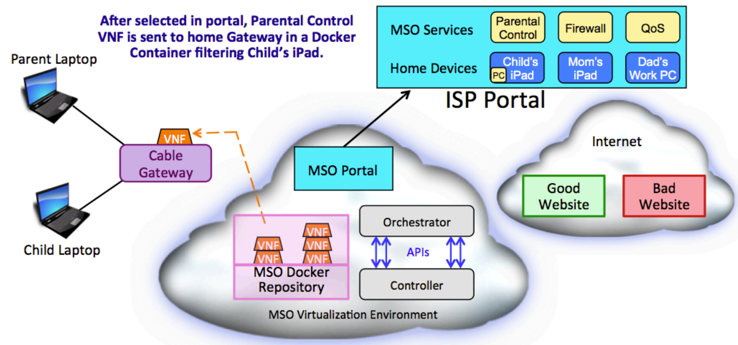

Figure 5: Residential Virtualized CPE (Source: CableLabs)

From a portal, a subscriber visually applies the parental control policy, which self-installs onto the target device. The subscriber can add to the blacklist using the portal to further customize that list.

This simplifies the home configuration and enhances service opportunities, since the home user can easily access services that are made visible by the service provider. The service provider also has visibility into the devices in the home, and can customize the offerings accordingly.

For Business vCPE, the motivation may be that specific functionality needs to execute locally at the branch. Today, this environment often consists of a standalone router surrounded by appliances, each providing a single dedicated function. Thus, the vCPE simplifies the configuration, operations and logistics in providing a highly functional branch environment.

In Figure 6, an Ethernet Private Line (EPL) is provisioned using ODL. A user portal initiates the service, and APIs call ODL to configure the Open vSwitch (OVS) instances as user-to-network interfaces (UNI). The tunnel can later be terminated through the same web portal.

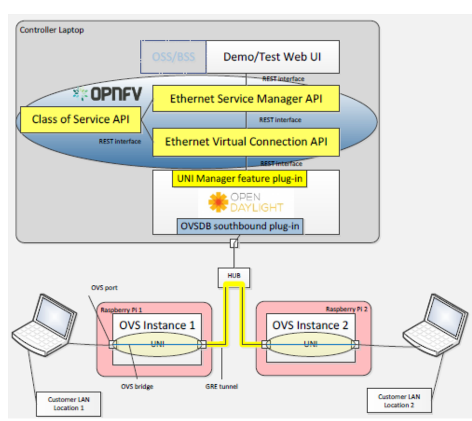

Figure 6: Business Virtual CPE (Source: CableLabs)

"Orange is very interested in vCPE test case. Within OPNFV we managed to show a vCPE PoC during the first OPNFV Summit'. This PoC was realized in less than 2 months including our OPNFV platform in Paris and remote vCPEs hosted in the lab of Orange Silicon Valley in San Francisco."

– Morgan Richomme, Senior NFV Architect, Orange

Another motivation for virtualizing the branch is to reduce the cost and complexity of the branch by supporting some of the branch functionality in the data center. In this case, the approach could involve replacing the branch device with a simple virtualized router or switch.

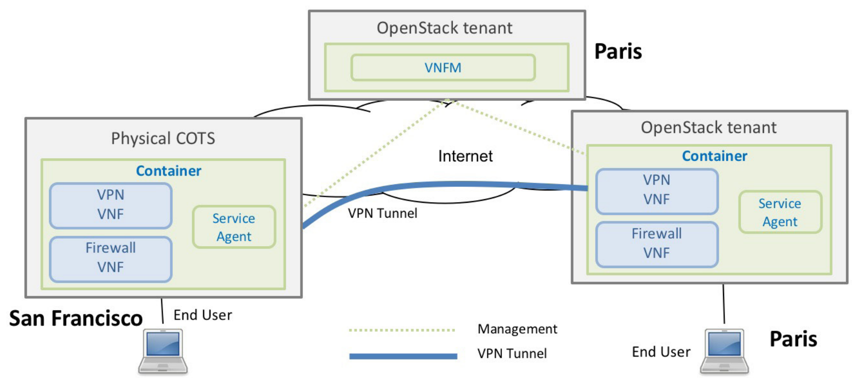

Figure 7: Distributed vCPE Example (Source: Orange)

This can effectively be part of a full software-defined WAN (SD-WAN) solution, delivering dynamic provisioning capabilities in their vCPE solution. The solution incorporates remote MANO functionality to install and configure containers on common off-the-shelf (COTS) hardware in branch offices.

Orange is a founding member of OPNFV and uses ODL in other vCPE PoCs configured using OpenStack Neutron as a northbound interface, and Open vSwitch Database (OVSDB) or OpenFlow to configure the devices. ODL is also used to deploy VXLAN tunnels to manage flow rules.

"vCPE will be the first SDN/NFV use case which could really help the operator by making the profit in addition to reducing the CAPEX. We also see it as a very good example of integrating SDN and NFV for end to end service orchestration."

– Lingli DENG, China Mobile Research Institute

[10] CableLabs also hosted the inaugural OPNFV Plugfest, where a variety of NFVI, SDN controllers, and VNF applications were tested by many operators and vendors. A copy of the report for this event can be found here.

China Mobile included vCPE as part of their carrier-grade Telecom Integrated Cloud (TIC) which was a datacenter design explicitly geared to telecommunication capabilities (Figure 8).

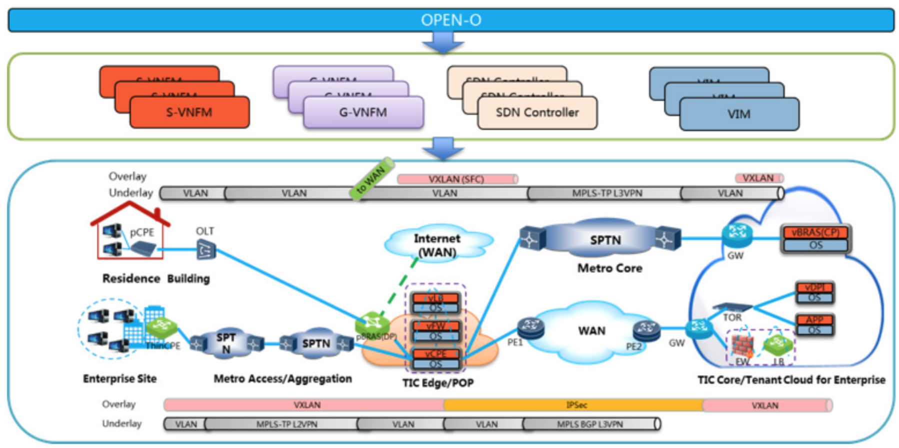

Figure 8: Figure 8: vCPE Use Cases for OPEN-O

Required features include ease of management, automation, high availability and fault management, and high performance for both the infrastructure and the VNFs. The orchestration system for TIC is based on OPEN-), and the SFC support is implemented in ODL.

In other examples, a presentation by GEANT describes the customer and provider sides of the implementation in detail, and a recent vCPE PoC from KT Corporation, along with a discussion of benefits to both its own benefits to both its own operations and those of its customers, was discussed at the 2016 OPNFV Summit.

"KT is working on virtualization over customer premises, central offices, and cloud data centers. The intelligent placement of the virtual resources is beneficial for operators as it enables scalability, reliability, and flexibility of services in a cost effective way by utilizing various virtual resources efficiently. Customers can also have rich QoE (Quality of Experience) options with different subscribing policies."

- Kisang Ok, Leader of NFV Platform Project, Korea Telecom

[11] A video discussion of this demo in conjunction with ClearPath Networks can be found here.
[12] More detail on how Orange is using OpenDaylight can be found here in this article by Jamil Chawki.
[13] Here is a video discussion of China Mobile's Telecom Integrated Cloud PoC.
[14] More detail on what China Mobile is doing with OpenDaylight can be found here.
[15] See NFV Experiences Using GEANT and Other Infrastructure.

All of these vCPE implementations require robust SFC mechanisms. Figure 9 illustrates the SFC support for a parental control system (not unlike the one shown above for residential vCPE in Figure 5).

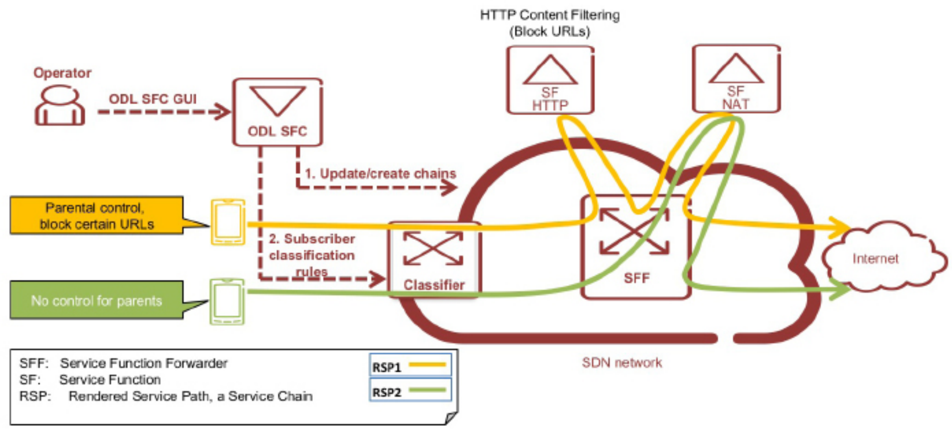

Figure 9: SFC for Parental Control (Source: Ericsson)

This may be achieved by using a network service header (NSH), or BGPVPN. The NSH adds metadata to a packet's Ethernet header, defining a service plane for creating dynamic service chains via a service function path. This is a simple and flexible forwarding technique, but it requires special support in both the service functions and the hardware underlay.

The alternative, BGPVPN-based SFC, supports vCPE as well as many other services such as Data Center Interconnect (DCI). This can be a more complex approach, requiring multiple control plane protocols and data plane encapsulations, but has the advantage of supporting both physical and virtual infrastructure. Like NSH, BGPVPN-based SFC utilizes separate service, control, and data planes. BGPVPN-based SFC, as implemented by AT&T, is illustrated in Figure 10.

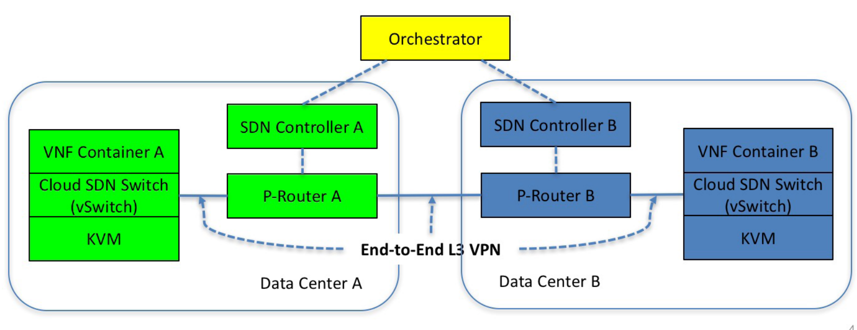

Figure 10: SFC with BGPVPN (Source: AT&T)

[16] See Experience with Enterprise on Premise vCPE Service, OPNFV Summit 2016.
[17] For a detailed analysis of these two techniques and technologies underpinning SFC, see a video of the presentation by Tim Rozet of Red Hat and Bin Hu of AT&T entitled, Service Function Chaining Technology Analysis and Perspective at OpenStack Austin 2016.
[18] The IETF specification for NSH can be found here.
[19] See the video describing this implementation from an OPNFV Summit PoC.

This demonstrates end-to-end Layer 3 VPN connectivity between two data centers, set up by ODL. KVM and NFVI are running in each data center, hosted and managed using OpenStack. An OpenStack-compliant orchestrator is used to manage and configure SDN Controller components and VNFM. This enables service chaining between virtual machines or containers using multiple virtual network functions (VNFs).

The following table describes the differences in the two SFC techniques:

Table 1: SFC via BGPVPN or NSH

NSH	**MPLS/BGP VPN**
Classifier required	Classifier not required
Encapsulation based on NSH; tunnel based VXLAN, GRE or Ethernet	Overlay encapsulation via Layer 3 VPN
Virtual deployment only	Either physical or virtual deployment
VM attached to Layer 2 (Open vSwitch)	VM attached to Layer 3

[20] From ONS 2016, Technology Analysis of Service Chaining Approaches.
[21] See the ODL blog entitled, Intelligent Application Sharing with OpenDaylight.

Why OpenDaylight?

ODL continues to focus heavily on developing SFC support, with load balancing and failover capabilities, as well as application coexistence and the automatic scaling of service functions based on load. Other areas of interest are the ability to insert and remove service functions dynamically, and to support service chains with multiple southbound protocols, such as OpenFlow, Vector Packet Processing (VPP), and NETCONF.

More generally, operators want a platform that evolves within an open ecosystem. In view of the heterogeneous environments most operators must manage, controllers should not be tied to individual vendors' equipment or proprietary protocols--they should solve the challenges of interoperability and management complexity. In addition, there should be no need to change applications.

The ODL MD-SAL allows for this flexibility in a systematic way. This is important because there is inevitably much legacy equipment in any large carrier infrastructure. Some of ODL's flexibility stems from the fact that it is a modular framework, wherein features are selected and utilized to suit the individual implementation. Implementers and consumers draw from a common architecture and code base, and operators can limit their "technical debt" as they explore a variety of customized implementations. ODL encourages and rewards innovation, with a collaborative, non proprietary approach. Finally, SFC-related projects in ODL and OPNFV are closely aligned (see Appendix A).

The MANO Factor: Open Orchestrator

In the 2016 Heavy Reading Survey, Management and Orchestration (MANO) ranked second in technologies that OPNFV should investigate. Given the growing interest in and work on the topic of orchestration, the OPNFV board in December of 2015 decided to lift any initial scope restraints that would have restricted work in this area. In line with how operators believe OPNFV should engage MANO (Figure 11), OPNFV is now supporting the integration of MANO projects into the OPNFV platform, and providing upstream feedback to MANO components.

[22] For more information, see OpenDaylight Open Ecosystem.
[23] ODL's architecture is discussed in detail in the document entitled, OpenDaylight Performance: A Practical, Empirical Guide.
[24] The full set of slides showing the raw data for the report is available here from OPNFV's Resources Page, and there is also a video of the survey results presented by veteran telecommunications industry analyst Roz Roseboro.

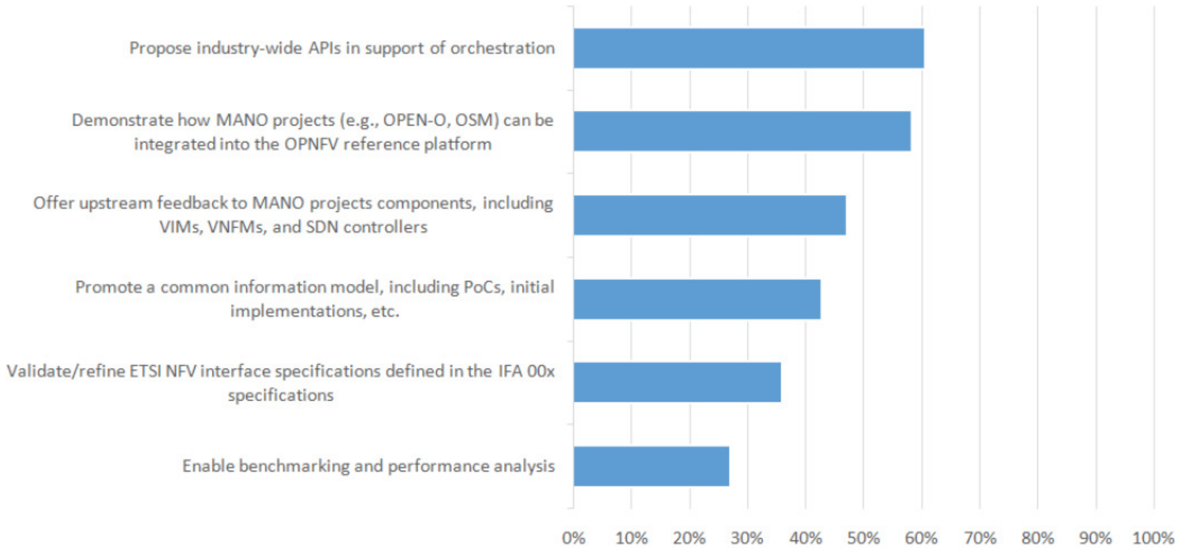

Figure 11: How OPNFV Can Help Address MANO

These are critical for leading NFV use cases, and are dealt within the OPEN-O open source project and in orchestration projects within OPNFV.

Conclusion

vCPE is likely the leading use case for NFV, with numerous PoCs in many major service providers (in every geographical region) and deployments underway. The chief underlying technology for vCPE and for many other VNFaaS applications is SFC, which is a major development focus for ODL and in much of the infrastructure deployed in OPNFV scenarios.

[25] Examples include Multisite and EdgeNFV.
[26] For a video describing OPNFV projects, see OPNFV Projects and Project Lifecycle.

Appendix A: Projects that Intersect ODL and OPNFV

The following diagram provides a high level categorization of the projects in OPNFV.

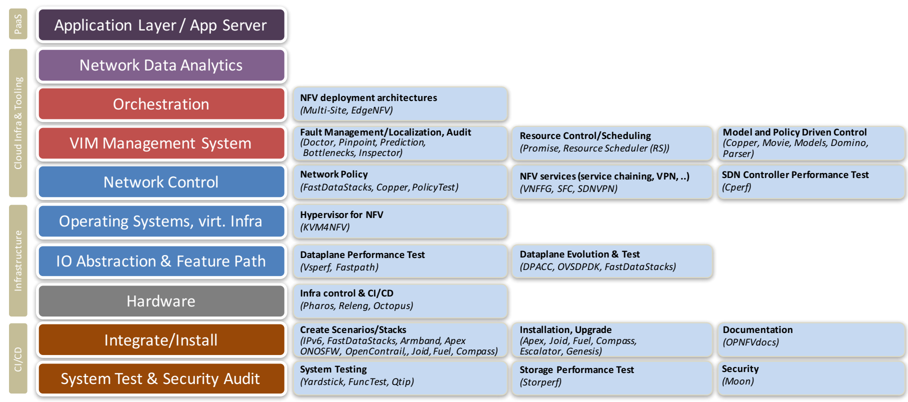

Figure 12: Categorization of OPNFV Projects

The following OPNFV projects intersect with ODL:

• FastDataStacks: creates and composes a set of scenarios which include the virtual forwarder supplied by the FD.IO project.

• Copper: deals with virtualized infrastructure deployment policies, aiming to help ensure that policy deployments comply with goals of the VNF designer/user. Relates to Group Based Policy (GBP) in ODL.

• VNFFG: The VNF Forwarding Graph (VNFFG) project provides an end-to-end VNF services. Relates to OpenStack-based VNF Forwarding Graph in ODL.

• SFC: The OPNFV SFC project creates a link to the ODL Genius project. The ODL Genius project provides the infrastructure (for instance, chaining logic and APIs) needed for ODL to provision a service chain in the network and an end-user application for defining such chains. These two projects share many community members who are working to streamline how ODL releases are integrated within OPNFV.

• SDNVPN: addresses integration and deployment of VIM and virtual networking components to provide Layer 2/3 VPN services in OPNFV. Works in collaboration with the related BGPVPN project in OpenStack and with ODL's Neutron interface to BGPVPN. Relates to SDN Distributed Routing and VPN in ODL.

• CPerf: The Controller performance (CPerf) project provides application-based controller performance testing for ODL and other controllers.

[27] For more information on all of these projects, see the ODL Project Wiki and the OPNFV Project Wiki.
[28] More information on FD.IO can be found at the project's home page.

Appendix B: Cited Operators, Solution Providers, and Analysts

The following table describes the companies listed in this paper.

Table 2: External Entities References in this Report

Name	Description	URL
AT&T	American multinational telecommunications corporation	www.att.com
CableLabs	Nonprofit R&D consortium for cable providers.	http://www.cablelabs.com/
China Mobile	Telecommunication company; service provider	http://www.chinamobileltd.com/en/global/home.php
Ericsson	Network equipment vendor providing communication technology and services	https://www.ericsson.com/
GEANT	Pan-European research and education network	http://www.geant.org/
Heavy Reading	Market research arm of Light Reading	http://www.heavyreading.com/
IHS	IHS is an international market research firm who acquired Infonetics, a telecommunications industry analyst	https://www.infonetics.com/
KT Corporation	South Korea's largest telecommunications company	http://www.kt.com/eng/main.jsp
Orange	Telecommunication company; service provider	http://www.orange.com/en/home