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1 ONF Introduction .................................................................................................................................................. 5

2 Carrier/WAN SDN .................................................................................................................................................. 7
   2.1 Commercially Deployed Transport SDN Platform in Action (Korea Telecom) ................................. 7
   2.2 Programmable SDN Algorithm Engine – Flow Engine (Huawei) .................................................. 8
   2.3 Large Data Set Transfer with SDN Metering and QoS (Corsa) ....................................................... 9
   2.4 Brocade Flow Optimizer (Brocade) ................................................................................................. 9
   2.5 L2 VLAN over MPLS Using SDN for Brownfield Networks (NoviFlow) ...................................... 10
   2.6 Multi-vendor IP and Optical Control for Service-provider Core Networks (Sedona Systems) ... 11
   2.7 Live Analysis of Video Feeds Utilizing Edge NFV – Enabling New Business Services for IoT with NFV (ADVA Optical Networking) ........................................................................................................... 12
   2.8 Global SDN Deployment Powered by ONOS ............................................................................... 14

3 Data Center SDN ............................................................................................................................................... 15
   3.1 Multilayer SDN Control of Packet and Optical Networks (ONOS) ............................................... 15
   3.2 Active Path SDN Adaptive Quality of Service (Kemp Technologies) ........................................ 16
   3.3 Multi-site, Multi-domain Data Centre Capacity Management (CENGN) ..................................... 17

4 Campus SDN ................................................................................................................................................. 18
   4.1 Aspen: Real-Time Media Interface Specification (ONF) ............................................................... 18
   4.2 Atrium: An SDN-based Open Source BGP Peering Router (ONF) ............................................. 19
   4.3 Boulder: Intent-Based NBI (ONF) ............................................................................................ 20

5 SDN/NFV .......................................................................................................................................................... 21
   5.1 CORD: Central Office Re-architected as a Datacenter ................................................................. 21
   5.2 Integrating NFV Orchestration with OpenVIM (Luxoft) ............................................................ 22
   5.3 OPNNFV on ARM Reference Platform (Freescale) ................................................................ 24
   5.4 NFV-based LTE Core in the Cloud (CENGN) ............................................................................ 25

6 SDN Testing & Validation .............................................................................................................................. 25
   6.1 Benchmarking the SDN Switch (Spirent) .................................................................................... 25

7 Conclusion ..................................................................................................................................................... 26

8 About EANTC ............................................................................................................................................... 27
List of Figures

Figure 2.1: Integration between multi-vendor IP and optical layers ................................................................. 12
Figure 2.2: Edge NFV running video analysis application for on-site processing Integration .......................... 13
Figure 2.3: SDN-IP as a global SDN deployment .............................................................................................. 14
Figure 3.1: SDN control with ONOS across data plane devices and technologies .................................................. 16
Figure 5.1: The central office re-architected as a data center ........................................................................... 22
Figure 5.2: OpenVIM NFV infrastructure interoperability with MANO .............................................................. 23
Figure 6.1: Testing running an OpenFlow controller ......................................................................................... 26
# 1 ONF Introduction: The Mission of ONF & the SDN Solutions Showcase Program

The Open Networking Foundation (ONF) is a user-driven organization dedicated to the promotion and adoption of Software-Defined Networking (SDN) through open standards development. One of the key drivers of commercial acceptance and deployment of SDN is the creation of an environment designed to demonstrate these technologies in as realistic a manner as possible. Every demo was required to have an operator and a real application, not just vendors. As has been the case with the adoption of other technologies, SDN can benefit when potential customers are able to see real SDN products and services (not necessarily product announcements) demonstrated with real customers who have deployed those products. Confidence develops in the commercial market because potential buyers can see the benefits of SDN realized by third parties with similar business or technical challenges.

The term “SDN” itself is used much more consistently and decisively these days. As SDN-based network designs in wide area networks, data centers and campus networks have been increasingly implemented on a more widespread basis, the participating organizations were able to clearly align their demos with each of these areas. Traditionally, OpenFlow implementations are most advanced in the data center and campus areas. Flow-based solutions are gaining market share in the WAN as well, using a range of protocols. SD-WAN progress has been accelerated by OpenDaylight, which is an open source SDN controller package supporting multiple southbound protocols used by multiple demos.

In order for these demonstrations to take place in as wide a venue as possible, ONF created the SDN Solutions Showcase program in 2014, bringing SDN companies and their customers together to demonstrate “real SDN, with real products and real customers” to the delight of thousands of potential buyers. The program has grown from one Solutions Showcase event in 2014, to two in 2015, with four events now planned around the world in 2016. The Showcase involves tremendous labor and significant expense on the part of participating companies and ONF, but has proven itself to be worth the investment in customer leads, new product visibility, and commercial success.

The combination of Network Functions Virtualization (NFV) with SDN transport networks will clearly be the most beneficial option compared to using legacy MPLS protocols for NFV connectivity. Standardization, open source collaboration and commercial implementations are underway this year, with more work expected to be done in the coming months and year. Two demos already addressed this topic successfully, both covering virtual CPEs and service chaining, one of the most discussed NFV use cases these days.

In 2015, ONF partnered on the Solutions Showcase with the European Advanced Networking Test Center, an engineering and technical services firm headquartered in Berlin, with which ONF had enjoyed previous successful collaborations. This new collaboration across the European Union yields an internationally recognized and objective test capability for SDN and other advanced networking technologies. EANTC's insight and experience have proven invaluable to the task of documenting progress in the commercial deployment of SDN.
At the SDN & OpenFlow World Congress 2015\(^3\) held in Dusseldorf, Germany, ONF brought together a range of service providers, vendors, and a few development organizations to demonstrate 19 SDN applications and technical use cases. Many of the demos relied on open source software, and many used the OpenFlow protocol. This white paper documents these demos, providing a comprehensive report on much of the proof-of-concept work that is ongoing across the SDN community.

This white paper demonstrates that SDN is a technology ready for commercial deployment, and we invite your company (and customers) to participate in a future ONF SDN Solutions Showcase. If you are interested in viewing or downloading presentations from various ONF SDN Solution Showcase events, we have archived them at https://www.opennetworking.org/news-and-events/sdn-solutions-showcase-2015. Any comments can be sent to info@opennetworking.org.

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1 For more information about Open Networking Foundation, please visit http://www.opennetworking.org.
2 For more information about EANTC, please visit http://www.eantc.de/
3 Open Networking Foundation has been an active contributor to the SDN & OpenFlow World Congress since the event began in Europe in 2013. The event is produced by the Layer123 event and training organization. For more information about their SDN & OpenFlow World Congress event series, or to view previous event content, please visit http://www.layer123.com/sdn
2 Carrier/WAN SDN

2.1 Commercially Deployed Transport SDN Platform in Action

**Demo Provider:** Korea Telecom; **Demo Partner:** Open Daylight

Korea Telecom showcased its transport SDN project which is set to begin construction in November 2015, with deployment scheduled for January 2016. The project addresses the challenges the operator faces in managing its complex transport network which is composed of multi-vendor, multi-domain, multi-layer devices, the controls of which are closed and distributed over vendor-specific EMSs.

The project allows for centralized device control and PCE over multi-vendor devices and aims to eradicate service deployment delays caused by manual planning and provisioning. Korea Telecom expects to achieve a 95% reduction in the time taken to complete a service order by utilizing simplified and automated provisioning processes with its transport SDN solution. However, this reduction is dependent on live deployment and the participation of many domain operators.

The system as designed has adopted the OpenDaylight Helium release as the SDN controller to reduce time and cost for deployment. This enables integration with legacy transport network management systems such as inventory, topology and fault information. The architecture uses the Yang data model language and in-memory data store to support real-time synchronization for resource changes. Korea Telecom has adopted MSPP, OXC and PTN plug-ins and will have southbound protocol plug-ins for OpenFlow, NetConf and Corba in the future.

Korea Telecom put forward two demonstration scenarios. The first addresses mutually exclusive ethernet path computation with service identification. Utilizing the existing service ID, PCE can compute a new path to ensure the survivability of the customer service. The demo involves a series of user interface pages so the operator can identify the work in a dashboard and then compute the path by simply clicking on it on a live network map.

The second scenario addresses PTN E-LAN path computation over a multi-administration domain. This demonstration automatically computes a tree-like optimal pseudowire path taking into account conditions such as hop count, resource availability and load balancing. Similarly to the first scenario, it enables the user to identify their work, set conditions and optimize the settings at the design stage.

Korea Telecom says additional functions and features will be added after the initial applications go live, nationwide across South Korea in January 2016.
2.2 Programmable SDN Algorithm Engine – Flow Engine

Demo Provider: Huawei; Demo Partner: Beijing University of Posts and Telecommunications (BUPT)

This demonstration showcased the Flow Engine, a Huawei-owned algorithm platform compatible with various SDN controllers including SNC, ONOS and other open source platforms. It enables comprehensive embedding or overlay algorithmic apps, including third party apps.

The Flow Engine is a programmable SDN platform for developing complex algorithms – that can be re-used – to enable the SDN platform to abstract the network and to provide the possibility of a centralized controller. Flow Engine is a toolset to create those re-usable algorithms if an operator needs to implement new services, such as device management services, in an efficient way. Tools that already exist in the Flow Engine can be optimized, and the demonstration included an example of integration with ONOS by Beijing University of Posts and Telecommunications that utilizes the optimization tools in the Flow Engine.

Huawei detailed four key areas in which the technology is applicable. In dynamic services scheduling, the Flow Engine provides the ability for an operator to decide scaling advance and scheduling when to start a service. That’s important for enabling networks to handle the requirement of a large download, for example.

Fast network recovery is another area Flow Engine can address by enabling recovery based on a global network view enabled by online fault analysis.

An additional area of focus for Flow Engine is super bandwidth on demand. This utilizes a bandwidth on demand algorithm in the IP and optical networks to jointly optimize the network across both layers. It also encompasses load-balancing policy.

The fourth key area is a third-party algorithm app. This features a graphical user interface designed using ONOS that enables initial services deployment and re-optimization by the Flow Engine.

The demo is currently deployed as a real-life use case with a large Chinese service provider and Huawei claims that utilizing the Flow Engine to re-optimize a network can result in a throughput increase of up to 63%.
2.3  Large Data Set Transfer with SDN Metering and QoS

Demo Provider: Corsa; Demo Partner: Spirent

Large data set transfer which service providers need to offer as a bandwidth on demand proposition presents several challenges for service providers. Networks were traditionally architectured to scatter large data sets across the IP network and re-assemble them at the other end. However, large files such as those from academic research projects or data center back-ups can cause huge amounts of congestion which this project aims to avoid.

One element of the solution is a data transfer scheduler that instructs the backbone to set up circuits. At the same time an OpenFlow controller sets up metering and queuing to police and throttle down non-priority traffic while preserving capacity for day-to-day traffic.

OpenFlow is utilized and the demo is run using OpenDaylight, both of which talk to the Corsa box. This negates the need for an operative to read an 800-page CLI manual because the intent is encapsulated in the process.

In the demo, the peer-to-peer traffic is pre-programmed when the customer makes the request, priorities are set, queuing is set and the meter parameter is also decided manually. Corsa says that in live deployments all these steps should be automated to aid efficiency and reduce costs of operation.

The demo is scalable and Corsa points out its box can handle millions of flows. It says that if a service provider were driving 100G with one million different flows there would still be line rate throughput and the service would not be affected. Corsa says its equipment is being utilized by the SDN testbed of ES Net, the wide area network set up to connect all the national labs of the US Department of Energy. Those labs all push massive amounts of data and ES Net has deployed Corsa’s metering and QoS service.

2.4  Brocade Flow Optimizer

Demo Provider: Brocade; Demo Partner: CERN

As virtualization rolls out, operators will be faced with a series of network performance challenges that will require proactive bandwidth management capabilities to address these challenges. A variety of different approaches are being taken and different components are being used to optimize traffic flows. Brocade, with its Flow Optimizer, SDN policy-based app is one example.

The company is demonstrating how the system can detect and manage large Layer 2 to Layer 4 traffic flows with a solution that is based on Brocade proprietary hardware. The company says it is relying on its own hardware in order to enable the demonstration to be dynamic.

The application itself works with an OpenDaylight-compliant controller and supports open networking. It uses policy to detect and manage large flows and offers highly detailed control.
and automation for optimal flow management. The demo consists of two physical devices with 100G links going to a Spirent test set that creates the traffic flows for the demo.

Brocade Flow Optimizer is currently available to address four types of network attack: NTP reflection, DNS reflection, UDP flood and ICMP. It is possible to add further policies as necessary. The application works as the network devices send flow samples by collecting sample flow data. The Brocade SDN application then analyzes and manages flows utilizing a policy-based user interface and REST APIs before escalating to an SDN controller that is programmed either by OpenFlow 1.3 rules, OpenDaylight or Brocade’s proprietary SDN controller.

The application observes traffic flows for a time period and is able to see changes over time and take actions such as drop and redirect or meter and redirect. Brocade is demonstrating three use cases. With Network Attack Mitigation, the system recognizes a flow of attack traffic, takes the sFlow into the Brocade Flow Optimizer, which communicates using OpenDaylight with the Brocade SDN Controller before sending an instruction in OpenFlow 1.3 to redirect or discard the flow.

The system works similarly in an application traffic control use case to restrict the volume of Netflix or YouTube traffic. The process is the same except OpenFlow communicates an instruction to limit, drop or re-mark traffic.

A final use case is flow-based traffic mirroring. The process again is the same with the addition of a policy appliance to enable policy-based flow mirroring.

The application is being trialed by CERN openlab and Brocade foresees content delivery networks as well as standard operators finding applications for the technology.

2.5 L2 VLAN over MPLS Using SDN for Brownfield Networks

**Demo Provider:** NoviFlow; **Demo Partner:** CUBRO

In this demo, NoviFlow presented an SDN to legacy network gateway, to integrate the SDN feature set in existing networks. The basic challenge facing data center operators with global infrastructure and customers that have multiple sites is that with a Layer 2 service you can have small offices sharing the same address space. If you are able to do Layer 2 encapsulation, it looks as if you have one network.

The concept isn’t new but NoviFlow is managing the issue using software on its switch in this demo using OpenFlow to recognize flows. The demo, which is at the proof of concept stage, has been backed by Canadian operator Telus as a project and will be implemented by CENGN in the next few months once CENGN gets MPLS equipment in place.

The proof of concept highlighted SDN to MPLS conversion with LDP integration in the controller, to use cost-effective SDN equipment on the edge of an existing MPLS infrastructure.
network. Among the greatest challenges of attempting to do this in a traditional way is that the process is management intensive. This demo shows a different solution for the southbound side flow network in which everything is provisioned through OpenFlow switches, requiring very light activity on the management side.

The physical set-up for the proof of concept includes NoviFlow switching, a Cubro controller app with MPLS, the MPLS network from CENGN and customer premise equipment from NoviFlow. OpenFlow 1.3 capable switches are used.

NFV, cloud computing and the proliferation of connected devices are exponentially increasing traffic and wild fluctuations in usage patterns, requiring networks to move to agile architectures which support dynamic reconfiguration of both services and the network infrastructures they utilize. For service providers, these capabilities enable new revenues, reduce time to market, increase new service uptake and enhance their ability to meaningfully differentiate their offerings and drive new revenues.

2.6 Multi-vendor IP and Optical Control for Service-provider Core Networks 🍹

**Demo Provider: Sedona; Demo Partners: Telefonica, Alcatel-Lucent, Ciena, Huawei, Cisco, Juniper Networks**

Sedona Systems’ demonstration showcased this integration between Alcatel-Lucent, Ciena, Huawei and Juniper Networks' equipment on a trial network at Telefónica. The participating equipment vendors all wrote an SDN controller layer that abstracts management of the packet switching, optical switching and routing devices so the Sedona multi-layer app platform talks to a populated API.
One of the benefits of using an open and modular technology is that Sedona can hook into each flavor of device interface by writing an adapter. That adapter speaks Alcatel-Lucent’s language southbound, for example, and a common language northbound.

An operator might use the same NOC with optical and IP networks managed in separate cities, and put the two together and map each port in every network element to give the real-time full topology of the network and the traffic through every port.

Applications include: the automatic Layer 0-3 network discovery; the ability to perform multi-layer provisioning; SRLG (Shared Risk Link Group) sharing; and optically-aware IP routing and coordinated maintenance.

The demo utilizes Netconf but could use other protocols including OpenDaylight or OpenFlow. Currently a lab trial, the demo uses real equipment and links 50 live network elements.

2.7 Live Analysis of Video Feeds Utilizing Edge NFV – Enabling New Business Services for IoT with NFV

Demo Provider: ADVA; Demo Partner: BT

ADVA Optical Networking demonstrated the future of managed services built upon network functions virtualization (NFV). The demonstration showcased how specific enterprise applications can harness NFV to share resources and dramatically increase efficiency. As an example deployment use case, the demo focused on CCTV-based video surveillance at UK rail
stations with partner BT. The demo shows how backhaul-intensive applications such as this are currently limited by the need to centrally process enormous amounts of data.

At the heart of the demo is the idea that by utilizing NFV and virtualized CPE, a range of services that use customer appliances can be created, provisioned and operated.

The CCTV-based video surveillance demonstration is an example of how the ADVA FSP 150 ProVM can be used to significantly alter the managed services landscape. Traditionally, this application is hosted centrally. However, the ultrafast network connectivity required to carry high-definition video is not always possible in some scenarios when such surveillance is needed most. Decentralizing key functions and placing them at the network’s edge not only improves the quality and quantity of information available, but also reduces operational and capital costs.

What makes this possible is the ADVA FSP 150 ProVM’s marrying of hardware and application. By combining hardware-supported performance monitoring of the server and the appliances running on it, ADVA Optical Networking has created a carrier-grade NFV platform essential for mission-critical applications.

![Figure 2.2: Edge NFV running video analysis application for on-site processing Integration](image)

ADVA’s new FSP 150 ProVM, with its built-in server, details how these applications can use NFV at the network’s edge to decentralize processes and improve application performance. The video surveillance application is supplied by ADVA’s partner, Alchera Technologies.

Currently purely a demonstration to educate the market about the possibilities of extending virtualization into a new area, BT’s role has been to provide insight into customer requirements, the business case and potential business models for the application. The demo is not live and does not involve service chaining although it has an OpenFlow interface to enable service chaining in future iterations.

A next generation of the demonstration will be available soon, which will feature service chaining and virtualized network functions, starting with router and firewall capability and then WAN analytics and virtual network functions.
2.8 Global SDN Deployment

Demo Provider: ONOS

It’s unusual to hear of live SDN production networks, but this project, led by ONOS, has created three regional networks in the US, Latin America and Europe and enabled them to link to each other. The goal of the project is to create a global SDN network and let entities communicate at Level 3 without legacy routers in the network core. A further aim of the project is to prove that ONOS can work in real networks, providing high performance, high availability and scalability.

To achieve these goals a network of partners has used and installed ONOS, provided feedback and then deployed the latest version of ONOS using an agile deployment model.

Three SDN networks form the joint network in its current state. The Internet2 part is a pure OpenFlow network and connects five universities in North America: the University of Utah; Duke University; the University of Maryland; the Indiana Gigapop; and Florida International University in Miami. This production network utilizes a Flowspace firewall to give abstraction of the network via ONOS and SDN-IP and enables legacy routers of the universities to connect to the Internet2 OpenFlow switches.

The AM Light network in South America links: Florida International University in Miami with REUNA and RedClara in Santiago, Chile; ANSP and RNP in Sao Paulo, Brazil; and CKLN in the Caribbean. The network comprises six OpenFlow switches and utilizes Brocade and Juniper physical hardware. Internet2 and AM Light are connected through a legacy router at Florida International University in Miami.

In Europe, the Géant/GARR part of the project’s network spans Amsterdam, Bratislava, Ljubliana, Prague and Rome, using five OpenFlow switches to connect two institutions – the Università Roma Tor Vergata in Rome and CREATE-NET in Trento, Italy. There are five ONOS clusters in the network locations and one international peering point that enable connection to Internet2, facilitating communication between Rome and Santiago, for example.
The Géant network is not a production network and has been constructed specifically to enable further experimentation.

When put together, the three networks comprise 48 OpenFlow switches, linking 12 institutions on three continents. ONOS acknowledges further work is needed to generate improvements and sees deployment on the provider side as painful because of hardware limitations. ONOS advises providers to rethink OpenFlow support and work to address quality of service more effectively. However, work on commercial deployments is in progress at Kreonet in South Korea and AARNet in Australia. The focus of this work in progress is on stability, performance and scalability.

3 Data Center SDN

3.1 Multilayer SDN Control of Packet and Optical Networks

Demo Provider: ONOS; Demo Partners: Ciena, Huawei, Fujitsu, Corsa

This demo showcased the converged SDN control of packet and optical networks with ONOS to optimize utilization of these networks based on availability, economics and policy. The demo brought together optical hardware from Ciena, Fujitsu and Huawei to enable effective SDN control with ONOS across a range of data plane devices and technologies.

Interoperation between the optical layer and the IP layer is achieved by placing a logical overlay over the ROADM network and coordinating the networks at the optical layer by treating both layers logically and using a single SDN layer to control both.
Currently, the demonstration is an emulation of a live environment but ONOS is working toward the ability to demonstrate it in a production environment. The emulation has two virtual machines running, each representing a switch and a modified mininet, to support demonstration of this use case.

Importantly, ONOS did not want to create three different applications from three different vendors to achieve this multi-layer SDN control. A single control plane supports multi-vendor, multi-protocol networks.

### 3.2 Active Path SDN Adaptive Quality of Service

#### Demo Provider: KEMP; Demo Partners: HP, Open Daylight, Intel

A vital part of ensuring quality of experience for voice, video and high priority traffic, as well as handling the increasing instances of elephant flows across virtual networks, is the ability to control traffic flows. Elephant flows are large spikes in traffic volume caused by huge increases in traffic such as backing up a data center or the streaming of massive media files to large numbers of users. Kemp Technologies places its proprietary load-balancing hardware within the network to achieve this by talking to the northbound interface of the SDN controller.
Kemp’s demo showcases the integration of infrastructure-level intelligence coupled with its application-centric load balancing and quality of service controls to prioritize application traffic of high importance through an SDN network. The demo involves displaying the effect on a video stream from one server that does not have SDN Adaptive QoS turned on when typical east-west traffic or an elephant flow is introduced. The scenario is then repeated with SDN adaptive QoS turned on for side-to-side comparison. The result is continued good video quality where SDN adaptive QoS is turned on but jitter, packet loss and even stream interruption occur when the QoS functionality is turned off.

The Kemp hardware is already aware of the traffic passing through the network and the health and quality of the experiences being provided because the device already has the ability to pull Layer 2 information and can request an alternative path based on what it already knows.

If the device sees congestion it can adjust the weight of the back end service and select a different service that would not be impacted by a congested path. This demo is passive and utilizes the existing data gathered by the Kemp device to define the service affecting parameters. OpenFlow is used to pull statistics from the switches but the rest of the demo relies on proprietary technology from Kemp.

3.3 Multi-site, Multi-domain Data Center Capacity Management (CENGN)

Demo Provider: CENGN; Demo Partners: BTI, Corsa

Among the many challenges facing data center service providers is how to accommodate applications that have a requirement to burst bandwidth when they need to. Known as elephant flows, these large and unexpected network traffic patterns are hard to manage in current, inflexible networks which have connectivity service features tied to network infrastructure and require operators to configure devices individually – and often manually – to handle elephant flows.

This lack of automation makes it difficult and costly to respond to changes in bandwidth requirement at the necessary speed, so CENGN, with Corsa and BTI, created a demonstration of software-defined network for multi-layer control to enable dynamic response to time-sensitive requirements for accommodating elephant flows.

The demonstration involves traffic between two PoPs – in Ottawa and Montreal, Canada – on the Canarie network. The two data centers are connected by a 100G wavelength and Corsa Level 2 and BTI Level 1/0 devices form the data center interconnection (DCI) at both ends. To aid the demo, Ixia traffic generators are used to generate and receive up to 120Gbps of data flows.

An Inocybe OpenDaylight stack and application running in the CENGN data center controls the Corsa hardware using OpenFlow and Netconf/Yang to control the BTI devices. Access for management of the devices is performed through the Internet.
CENGN demonstrated two use cases. The first involves two customers in two different data centers. Customer A is utilizing 40G but Customer B is using 60G and needs to send more than 60G and initiates an elephant flow of 20G. This situation is detected by the Corsa device, but because there is no spare bandwidth available, the controller chooses to use low priority links in conjunction with QoS to provide the elephant flow minimum bandwidth guarantee of 16G. When the elephant flow concludes, the system re-establishes low priority flows.

The second use case detailed in the demo involves Customer A exhausting resources for the workload in data center 1 and requesting 20G bandwidth between the data centers. The set-up is similar to the first use except it takes two 10G client side links from Customer B that are not being used for high-priority traffic.

The controller issues commands to establish the two additional flows across the unused ports and deprovisions Customer B’s ports, pre-empting the low-priority traffic. It then provisions the two new 10G ports for Customer A across. Once the elephant flow is complete, the controller issues SDN commands to re-establish the 20G low priority bandwidth between datacenter 1 and datacenter 2 for Customer B.

Future evolutions could include running a service orchestrator and CENGN is looking to develop an application to pull the data required because OpenFlow 1.3 doesn’t support a status pulling information request. CENGN anticipates further work to commercialize this project.

4 Campus SDN

4.1 Aspen: Real-Time Media Interface Specification (ONF)

Demo Provider: ONF; Demo Partners: NEC, Microsoft

Aspen traces its origin to an idea within the unified communications community, which wanted to use SDN to provision services more effectively. Enterprises that deploy unified communications infrastructure typically have some management pieces that should know which flows are important and what quality of service should be provided, and therefore can maintain an awareness of QoS without having to trust the QoS marking on all packets, which would be extremely complex to manage and could be applied fraudulently.

To address this problem, ONF is specifying an API that allows applications to inform an SDN controller regarding the QoS required. The focus was initially on unified communications applications such as Microsoft Lync or Cisco Webex, but has been extended to address media applications in general.

ONF is demonstrating the concept using open source media player VLC to showcase the feasibility of the Aspen concept. The demo use-case scenario involves a mininet set-up in which the network elements are emulated and are managed by the OpenFlow protocol to communicate with an OpenDaylight virtual tenant network (VTN) interface and create a real-time media
network service. That then connects via a real-time media northbound interface, which ONF has developed to the draft stage, with the application, in this case VLC.

The demonstration showed how a VLC wrapper script to feed the RTM network service is sent to initiate a video stream between host 1 and host 4. A UDP stream is then initiated between host 2 and host 5. The system then checks the packet markings and finds that video has priority and UDP doesn’t. This results in good, demonstrated video quality. The demonstration then involved removing session information from the real-time media network service so video no longer has priority. This resulted in bad quality video with interrupted streaming and packet loss and jitter present.

The same effects could be witnessed on a UC session or other network-intensive application using the system. A future extension could involve an interface to the VTN-based real-time media service through security and authentication features but there is a danger that differentiation could be lost if an operator allows every service to request a higher quality of service. As the demonstrator said, this is a proof of concept and yet to be commercialized.

4.2 Atrium: An SDN-based Open Source BGP Peering Router (ONF)

**Demo Provider:** ONF; **Demo Partners:** Atrium, Corsa, Pica8, NoviFlow, Accton

The aim of Atrium is to simplify and accelerate open SDN adoption by making it easy to build applications in a multi-vendor environment. This demo features a community-driven open source SDN distribution – a vertically integrated stack of open-source SDN components, meant to help network operators move quickly towards real world deployments.

The first release, Atrium 2015/A, incorporates the Border Gateway Protocol (BGP), the Open Network Operating System (ONOS), and Open Compute Project (OCP) components. The software elements run in either controllers or switches, communicating via OpenFlow, and include plugin opportunities for other switching solutions to help foster an open ecosystem of interoperable, hardware-based OpenFlow switches.

The Atrium 2015/A package integrates previously standalone open source components. Routing is often the most basic application operators want for SDN, and Atrium 2015/A includes Quagga BGP because it is a popular open source routing stack. Atrium 2015/A is built on ONOS because Quagga runs on ONOS and ON.Lab contributed engineering resources to help with the internal flow objectives interface and other integration efforts.
In the demonstration, the collection of OpenFlow switches behaves like a standalone router and follows traffic based on what it has learned. The vertically-integrated router is composed of switches from vendors including: Accton; Centec Networks; Corsa; Netronome; NoviFlow; Pica8; and Quanta. All of these switches communicate with the ONOS SDN controller using OpenFlow, despite differing technologies within each switch.

Aspen’s aim is to reintroduce interoperability by handling the differences in the switches. To achieve this aim, the controller connects with an abstraction layer called Flow Objectives, the idea being that applications should only be written once to be able to be utilized multiple times so there are drivers for different pipelines and each can be taken as appropriate.

ONF member companies and undisclosed others are already porting Atrium to OpenDaylight for release later this year to enable utilization of widespread industry support and access to a broad variety of use cases including NFV, campus, and data center.

Atrium release 15/B is scheduled for later in 2015 and will feature continued improvements on the current release, including enhancements to hardening and stability, performance and missing features such as runtime configuration and static routes. In addition, the release will contain a hardware-based automated test infrastructure.

### 4.3 Boulder: Intent Based NBI (ONF) 🌟

**Demo Provider:** ONF; **Demo Partners:** HP, Inocybe

Boulder is a project initiated by Inocybe Technologies with support from HP and ONF. The aim of Boulder is to remove fragmentation from the industry so app writers can achieve portability across different interfaces and platforms, using intent-based northbound interfaces to support compatibility.

Boulder exposes intents as a grammar with a subject, predicate and object. The subject could be an endpoint, for example, the predicate is the variable, the what to do, and the object is the target type. The grammar then might run as simply as Bob (the subject) connects (the predicate) Susan (the object). Boulder allows further context to be defined in the grammar such as context and constraints but this is not currently demonstrated.

Although initially reliant on OpenFlow, Boulder can now be utilized as a way of modeling ONOS flows and can use OpenDaylight’s transactional capabilities. As a relatively early stage proof of concept, the intent grammar is limited, with six verbs having been implemented to date including basic intents such as allow, deny, connect or redirect. The project is immature, having been established in March 2015, so apps cannot be written using Boulder yet. However, it is clear that applications developers want the capability to write once and use everywhere across virtualized infrastructures.
There will be an official Boulder release later this autumn and the participants anticipate that this will result in the project picking up speed and add to the current demo.

The demo itself is built on JavaScript and describes how applications can, using intent grammar, be mapped across both OpenDaylight and ONOS domains. In ONOS domains, the application makes an initial request through Boulder, which makes a capability request using one of the six established Boulder verbs to an ONOS runtime engine. The ONOS runtime engine then makes a capability response to Boulder, which pushes an intent to the runtime engine and then pushes the intent from the engine as an ONOS intent to be acted upon.

Similarly, in the OpenDaylight-based demonstration, Boulder, having received the initial request, pushes a capability request to a network intent composition layer on top of OpenDaylight, which provides a capability response back to Boulder. This is then escalated by Boulder to the OpenDaylight NIC in native grammar to create an OpenDaylight intent, such as an instruction to allow or to apply policy.

In its current state, Boulder addresses two controller domains – ONOS and OpenDaylight, but as the project develops the plan is to support other controllers, potentially OpenStack. Extending the project in this way is beyond its current scope, and the main aim at this stage is to prove the concept of enabling application writers to write apps once for utilization in multiple domains.

5 SDN/NFV

5.1 CORD: Central Office Re-architected as a Datacenter

Demo Provider: ONOS; Demo Partners: PMC, AT&T, Akamai, Sckipio, ON.LAB

Operators across the world have a large number of central offices. In Spain alone, for example, there are more than 2,000. Such offices are expensive to operate and were designed for the circuit-switched era. They host a wide variety – as many as 300 unique devices – of equipment, each of which is managed in its own way by its own EMS and is highly specialized. The promise of virtualization is to reduce the number of function-specific machines, thereby bringing down the capex and opex associated with management and operation and also reducing the number of central offices required.
The concept of this demo is to re-architect the central office as a data center utilizing a fabric controlled by ONOS and a range of virtual machines controlled by OpenFlow and Netconf.

A deployment scenario involves a simple CPE running nothing but an OpenFlow switch and an ONT. If authentication is successful, the system receives back basic information such as whether the customer has IPTV and VoIP and what the bandwidth is like.

In a future architecture, currently under development, the services are commissioned accordingly and changed in a cloud architecture with additional services, such as parental controls, brought into the service chain within the CORD environment. Other examples of services brought into the service chain could include CDN caching, deep packet inspection or others. The service chain is realized using ONOS and the XOS orchestration tool.

The concept has been previously demonstrated using CORD ONOS on Vimeo to showcase deployment of parental controls using vCPE.

The CORD architecture is set to be trialed by AT&T next year and ONOS expects to see operators engaging in live deployments of the CORD architecture in 2017.

### 5.2 Integrating NFV Orchestration with OpenVIM 🌟

**Demo Provider: Luxoft; Demo Partners: Qosmos, Telefonica**

This showcase focuses on addressing the real pain points of service providers who need to orchestrate and automate the full lifecycle of VNFs and service chains of a variety of VNFs, such
as DPI, firewall and VPN, that are often requested by tenants for a given network path. The solution demonstrates that an existing MANO system can take advantage of the high-speed, high-performance NFV infrastructure that OpenVIM provides.

Service providers need to enable NFV and offer DevOps agility and programmability to their customers, so the demo addressed how open source (OpenVIM) NFV infrastructure interoperability with MANO and commercially available VNFs can work. The demo also addressed orchestration and complete lifecycle management of multi-vendor VNFs and on-demand service chaining instantiations and dissolution as per tenant requests. In addition, the challenges of SLA guarantees via smart allocation of bandwidth, and network intelligence for operators regarding analytics and diagnostics were also tackled in this demo.

Participants in the demo were: Luxoft, with its SuperCloud NFV Orchestrator; Telefónica with Open VIM; Certes Networks with its open VIM engine; Qosmos with SAM DPI engine; and open source technologies OVS and Ryu.

![Diagram of OpenVIM NFV infrastructure interoperability with MANO](image.jpg)

Figure 5.2: OpenVIM NFV infrastructure interoperability with MANO

The Telefónica OpenVIM in OpenMANO provides for high and predictable performance in NFV infrastructure. The Qosmos SAM DPI on-switch service delivers network intelligence that
recognizes existing Internet video traffic, such as YouTube, consuming high bandwidth in the network.

In the demo, the tenant request comes to the Luxoft SuperCloud Orchestrator for SLA guaranteed VPN traffic between two remote sites. Luxoft’s bandwidth on demand feature sets up network connectivity automatically between sites. It also throttles bandwidth for recreational traffic to honor the tenant’s SLA.

Certes Network’s VPN VNF service encrypts traffic only for the tenant’s subscribed network path as directed by SuperCloud. Another firewall VNF service chained after VPN allows remote site access only through the VPN.

Benefits showcased by the demo include: network forwarding path capabilities with QoS and SLA capabilities; Layer 4 to 7 traffic steering based on service chaining; bandwidth and QoS control in network infrastructure; extension of VNF Ecosystem; and an enhanced open source NFV infrastructure which provides high and predictable performance for VNFs.

5.3 OPNFV on ARM Reference Platform

**Demo Provider: Freescale; Demo Partners: ARM, ENEA**

As operators seek an end to being locked-in to network equipment vendors, there is a danger that they could instead become locked-in to vendors of proprietary IT hardware as they virtualize. This demonstration, created by Freescale, ARM and ENEA utilizes OPNFV on an ARM reference platform to provide a level playing field for systems from multiple vendors. The aim is to avoid the construction of different islands of proprietary technology, and to ensure interoperability between different platforms.

The demonstration assembled by Freescale, ARM and ENEA highlights OPNFV on ARM and includes Freescale’s LS2085A-based software on a chip (SoC) as one of the compute nodes. Other compute nodes demonstrated include Cavium ThunderX and AMD Hierofalcon. These are managed by an OpenStack controller from Applied micro and the entire stack runs on ARM v8 architecture. A third party virtual network function from Cosmos provides deep packet inspection and Layer 7 firewall and QoS VNF in the service chain. The VIM (virtual infrastructure manager) runs on Applied Micro’s service with eight ARM v8 cores. NEA’s Linux operating system is the common thread between the different technologies.

The platform has an orchestration tool to instantiate the services that configure the OPNFV infrastructure to implement the services as virtual machines. The common software architecture means the demo could also run using x.86 servers but the cloud can be extended by putting smaller and more cost-efficient compute nodes in place instead of x.86 hardware.

The demo currently focuses on OPNFV and awaits the next release due in February 2016. Enea is also working on the Pharos-compliant community lab based on ARM v8 servers. The Pharos
project specifies a standard hardware configuration on which to develop, test and deploy an OPNFV release. In addition, Enea is developing expertise in hardening open source NFV platform software that developers can rely on for next generation network solution designs.

5.4 NFV-based LTE Core in the Cloud 🍃

Demo Provider: CENGN; Demo Partner: Expeto

This proof-of-concept demonstrated a method for rapidly deploying and managing an end-to-end, cloud-based LTE core network. This showcase included the dynamic deployment and enablement of hardware, software and associated SDN/NFV elements to address the layers of complexity within the traditional operator.

For the purpose of the demo, the virtual evolved packet core (vEPC), virtual IP Multimedia Subsystem (vIMS) and additional open source software -not OpenFlow- were run in the CENGN lab, while the small cell (eNodeB) was located at the SDN & OpenFlow World Congress.

By utilizing Expeto’s evolved packet core integration cloud (EPIC) solution and coupling it with analytics, CENGN was able to demonstrate capability of launching a complete LTE Core to a small cell in approximately four seconds by spinning up a containerized vEPC at the conference on bare metal at CENGN’s location in Canada. Suggested applications include connecting sensors to communicate data in the oil industry but the demo remains a proof of concept.

The current status of the demo has seen CENGN execute on the SDN components and the use case of OPNFV and the company claims to have paying clients for these elements.

6 SDN Testing & Validation ✅

6.1 Benchmarking the SDN Switch (Spirent)

Demo Provider: Spirent; Demo Partner: Corsa

Understanding, deploying and managing SDN in today’s networks gives more control to operators, and opens up new ways to understand and manage network performance. This showcase from Spirent demonstrated that SDN can run at a 100G line rate, with circuits enforced, queuing working at congestion points while millions of flows, covering multimillion address spaces, are added to the flow table.
The showcase was run at the Spirent test center utilizing an OpenFlow controller on a single port and four ports of data into a Corsa SDN 100G Switch. Traffic was connected at this switch at 10G although Spirent claims similar results at 100G.

Figure 6.1: Testing running an OpenFlow controller

Spirent demonstrated two tests. The first was a flow table depth test that assessed the impact of a flow table downloaded to an OpenFlow switch with multiple entries. The demo then created one million flows through port 1 and added a miss string that had to go through the entire flow table.

The second demonstration was a meter test to assess the impact on performance of high scale and 100G SDN. The aim of this test was to demonstrate that meters work on OpenFlow and that scalability could be achieved. The outcome was that 250 million IP addresses could be handled.

In summary, the tests found that OpenFlow 1.3 is a real technology that, if implemented correctly, is ready to scale and provide high performance at 10G and 100G. It is ready for production today subject to benchmark testing.

7 Conclusion

While it is clear from the status of the demos that substantial work remains to be done to bring SDN deployments using open source technologies into reality, these demos showcase that network and data center operators are keen to learn how the technologies will transform their businesses. At this stage much of the work is proof-of-concept based and only isolated demonstrations utilize production networks. Nevertheless, many of the demos have development plans that involve deployment in live production environments.

It’s also clear that OpenFlow has many benefits as a protocol to control and help manage virtualized applications and services. However, OpenFlow is not alone in providing significant
value to this emerging market. Other protocols exist and have valuable functionality to aid the market, as well.

In an immature and rapidly developing market, several standards can co-exist and continued interoperation and co-operation are required in order to benefit the market as a whole.

8 About EANTC

EANTC was commissioned by ONF to review and document all showcase demonstrations presented by ONF members. Since the first edition of the ONF showcase at the SDN & OpenFlow World Congress in Düsseldorf 2014—one year ago—EANTC has been a participant in several significant deployment scenarios. Most showcase demos focused on manageability, network migration and multi-layer or multi-vendor integration. These are important aspects for future production grade network deployments of SDN.

By interviewing showcase participants, the EANTC team got very valuable, new insights into a wide range of SDN solutions. We hope that our insights are conveyed in this white paper and make it a useful read. Enjoy!