Market Report

SDxCentral

SDN Controllers Report

2015 Edition

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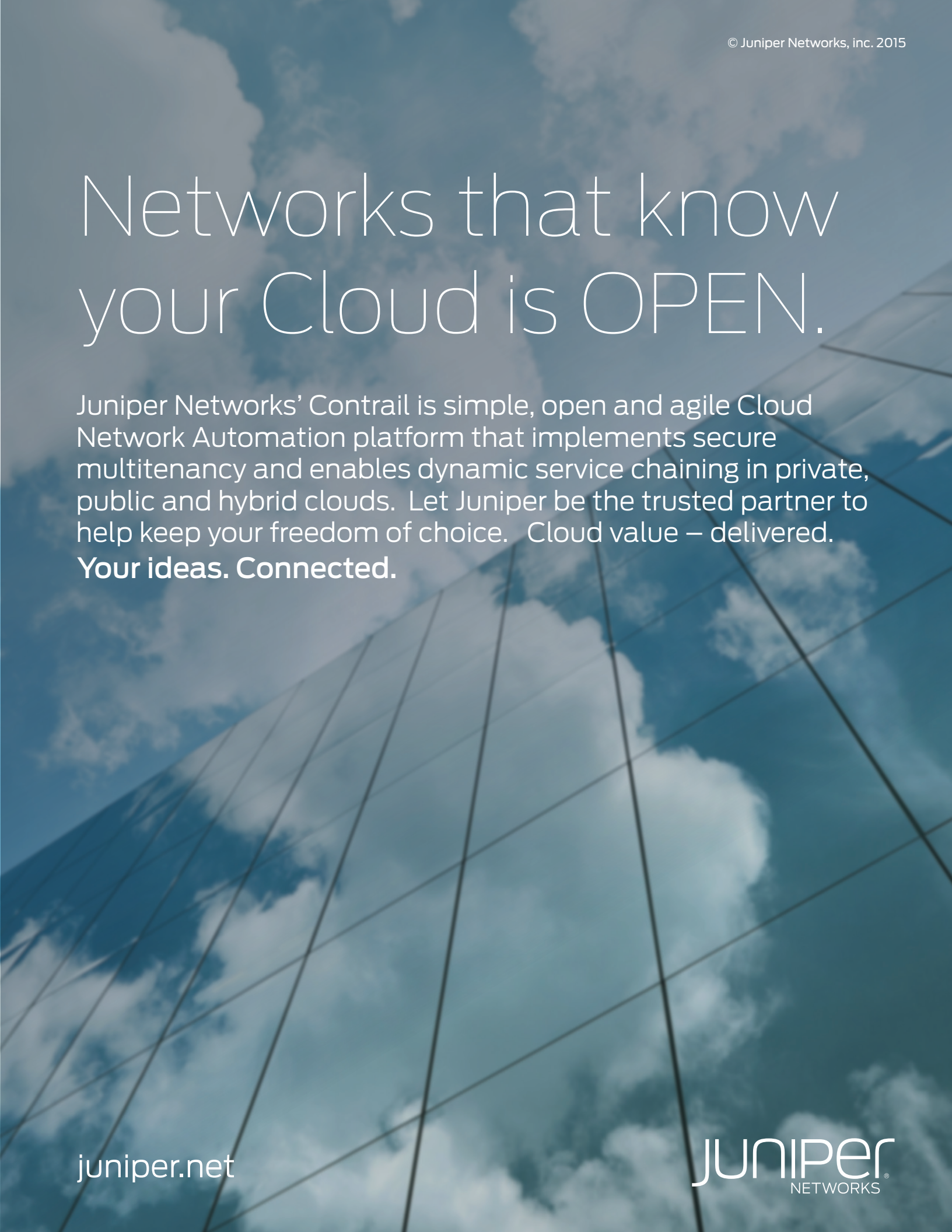

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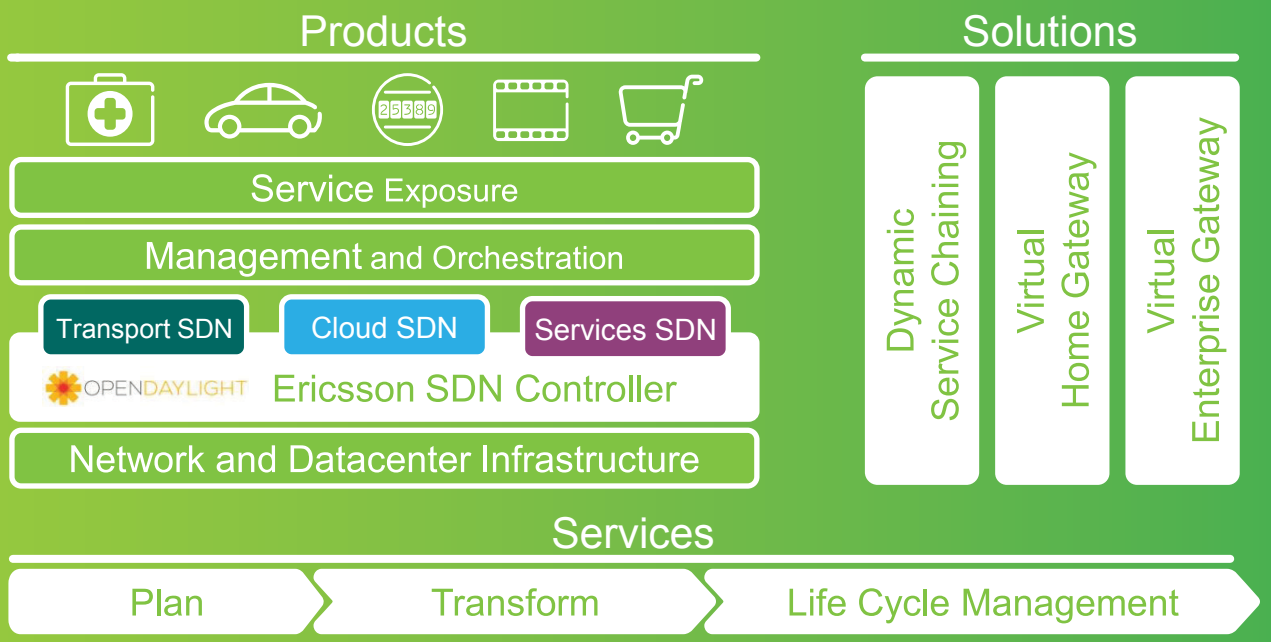

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Report Summary

The 2015 Software-Defined Networking (SDN) Controller Report takes a look at the state of the Controller market, which ultimately provides insights into the maturity of the SDN market at large. Controllers are the "brains" of an SDN environment, acting as the strategic control point in the network responsible for relaying information to the switches, routers and other network devices 'below' (via southbound application programming interfaces (APIs)) and the applications and business logic 'above' (via northbound APIs). Due to the pivotal role they play in a SDN deployment, it is important to understand what Controllers are capable of doing today and where they are going in the coming months/years.

This Report attempts to shed some light on the trends and influences on the Controller market, providing:

- A brief history of Controllers.
- Current core Controller capabilities.
- General use cases that require Controllers today.
- Details on different vendor offerings.
- Guidelines on selecting the right Controller
- Insights into potential evolution paths for Controllers.

We thank you for downloading this Report and hope you find it a useful resource as you educate yourself on the state of the Controller market and make decisions around your SDN environment. If you have feedback on the Report, we would love to hear it – please contact us at **research@sdxcentral.com**.

A Brief History on Controllers

The concept of a Controller was born alongside the introduction of Software-Defined Networking (SDN) itself. SDN separates the control from the data forwarding of the network; all this control is centralized in logic delivered via a software application, a.k.a. a Controller, which is why it is often referred to as the 'brains' of the network.

As the central control point, the Controller can simplify and automate the orchestration of the network, enabling organizations to improve the intelligence, agility, scalability and cost-effectiveness of their overall infrastructure. It does this by using the programmable control APIs that are exposed in an SDN environment; these APIs enable the Controller to communicate to the switches/routers 'below' (via southbound APIs) and applications/services 'above' (via northbound APIs).

The first protocol that popularized the concept behind SDN was OpenFlow. When conceptualized by networking researchers at Stanford back in 2008, it was meant to manipulate the data plane to optimize traffic flows and make adjustments, so the network could quickly adapt to changing requirements. Version 1.0 of the OpenFlow specification was released in December of 2009; it continues to be enhanced under the management of the Open Networking Foundation, which is a user-led organization focused on advancing the development of open standards and the adoption of SDN technologies.

As the first SDN standard, it is not surprising the first Controllers introduced to the market were dubbed 'OpenFlow' Controllers. NOX is generally considered the original OpenFlow Controller, providing a high-level programmatic interface capable of managing and developing network control applications. It was initially developed by Nicira Networks (now owned by VMware) and was introduced, along with OpenFlow, in 2009. Ultimately, the NOX Controller was donated to the SDN community (it was open sourced), which led to multiple lines of subsequent development –NOX classic (the original), NOX (a faster version, with support for only C++) and POX (a 'sibling' that provides Python support). NOX appears to no longer be under active development today while POX continues to be in limited used by the research community.

The importance of NOX, beyond being the first Controller, is that it established a programming model that heavily influenced the way subsequent Controllers operated. The model was based on OpenFlow messages, with each

incoming OpenFlow message deemed an 'event' that had to be dealt with individually. This model was simple to implement, however, it was hard to scale.

Nicira went on to co-develop ONIX with NTT and Google to create a model that was easier to abstract and distribute for large scale deployments. ONIX became the base for the Nicira / VMware Controller, which is at the core of their Network Virtualization Platform (NVP), and is rumored to be the base for the Google WAN Controller. While ONIX was originally supposed to be opened up, the parties later decided not to make it Open Source, which left the SDN community to focus on developing other platforms.

The Beacon controller became one of the most popular; started in 2010, with contributions from developers at Stanford University, Beacon provided a Java-based OpenFlow Controller that was much easier to deploy and run, with the first built-in web user-interface, which marked a huge step forward for the market. Beacon influenced the design choices of almost all the Controllers that came after it, however, its dependency on Eclipse and OSGi and limited topology (only star topologies) support was constraining.

By 2013, Beacon was starting to wane and one of its forks, Floodlight, started picking up steam. Floodlight was developed by Big Switch Networks, fixing many of the issues associated with Beacon and adding functionality that made it one of the most prolific, feature rich Controllers available. It had a web-based UI, Java-based GUI and could be run as a network backend for OpenStack, using a Quantum plug-in. The OpenStack orchestration system integration meant it could be used to control large pools of compute, storage and networking resources via the OpenStack API, which has been widely adopted by companies everywhere to run their business. This gave Floodlight greater applicability than any other Controller that came before it, which is why most controllers since provide OpenStack support.

Click here for a full list of Open Source Projects

Other open source Controllers of note included Trema (Ruby-based from NEC), Ryu (component-based framework supported by NTT), FlowER, LOOM (both written in Erlang) and the recent OpenMUL. The explosion of Controllers helped advance the overall market, with each contributing new features, thinking, etc. For your convenience, below is a table that shows the current open source Controllers under active development, as well as Controllers no longer actively being maintained.

TABLE OF Open source SDN CONTROLLERS

Active	Not Active
Floodlight	Beacon
LOOM	FlowER
OpenContrail	NOX
OpenDaylight	NodeFlow
OpenMUL	
ONOS	
POX	
Ryu	
Trema	

Current Controller Landscape

In early 2013, a new collaborative open source project was spearheaded, called OpenDaylight. While originally led by IBM and Cisco, it was subsequently hosted under the Linux Foundation and drew industry-wide support and resources. The OpenDaylight platform provides a common foundation and a robust array of services for SDN environments. The platform follows a controller model that enables the use of OpenFlow, as well as alternative southbound protocols; it was the first open source Controller capable of employing non-OpenFlow proprietary control protocols, which can potentially make it much easier to integrate with modern, heterogeneous multi-vendor networks.

The first release by OpenDaylight was Hydrogen in February 2014, followed by Helium in September 2014. The Helium release was significant because it marked a change in direction for the platform that has influenced the way subsequent Controllers have been architected. The change was in the service abstraction layer, the part of the Controller platform that sits just above the southbound interfaces, such as OpenFlow, insulating them from the northbound side, where the applications reside.

Hydrogen used an API-driven service abstraction layer (AD-SAL), which had limitations; specifically, it meant the Controller needed to know about every type of device in the network AND have an inventory of drivers to support them. Helium introduced a model-driven service abstraction layer (MD-SAL), which meant the Controller didn't have to account for all the types of equipment installed in the network, allowing it to manage a wide range of hardware and southbound protocols.

This release is credited with making the overall framework more modular, which meant it was more extensible and scalable. It enabled developer teams to innovate and work independently and then easily piece their advancements together to improve the platform. It also made the framework much more agile and adaptable to changes in the applications; an application could now request changes to the model, which would be received by the abstraction layer and forwarded to the network devices.

The OpenDaylight platform built on this advancement in its third release, Lithium, which was introduced in June of 2015. This release focused on broadening the programmability of the network, enabling organizations to create their own service architectures to deliver dynamic network services in a cloud environment and craft intent-based policies. It was worked on by 466 individuals, with contributions from Big Switch Networks, Cisco, Ericsson, HP, NEC, etc., making it one of the fastest growing open source projects ever. The fourth release, Beryllium, is due to come out in February of 2016.

Many vendors have been developing their own commercial Controller solutions, basing their offerings on the OpenDaylight advancements. The degree to which they leverage OpenDaylight, however, and the business models they deploy vary greatly. Different vendors may use OpenDaylight as:

- A base, but sell a commercial version with additional proprietary functionality – e.g. Brocade, Ericsson, Ciena, etc.
- Part of their infrastructure in their Network as a Service (or XaaS) offerings – e.g. Telstra, IBM, etc.
- A foundation for selling additional integration and development services – e.g. Wipro, TATA Consultancy Services
- Elements for use in their solution – e.g. ConteXtream (now part of HP)

There are commercial Controllers that are proprietary. They tend to be application-specific, such as VMware's NSX, Cisco's APIC and Sonus Naas IQ, or they are designed as platforms to run vendor-proprietary or 3rd party apps, such as Big Switch's Big Cloud Fabric, HP's VAN controller and NEC's ProgrammableFlow Controller.

introduction

Another influence in the market is the Open Networking Operating System (ONOS), which was open sourced in December 2014 and focused on serving the needs of service providers. While not as widely adopted at OpenDaylight, ONOS has been finding success and gaining momentum around WAN use cases. It is backed by numerous organizations including AT&T, Cisco, Fujitsu, Ericsson, Ciena, Huawei, NTT, SK Telecom, NEC, and Intel, many of whom are also participants in and supporters of OpenDaylight.

Time will tell the level of influence and progress these current open source and proprietary projects and controllers will have on shaping the overall SDN market.

The following table lists the commercially available Controllers and their relationship to OpenDaylight. Note, that there are vendors who provide active resources to work on OpenDaylight or invest resources in promoting OpenDaylight, yet ship non-OpenDaylight versions of Controllers.

TABLE OF COMMERCIAL SDN CONTROLLERS

ODL-based	ODL-friendly[1]	Non-ODL Based
Avaya	Cyan (acquired by Ciena)	Big Switch
Brocade	HP	Juniper
Ciena	NEC	Plexxi
Cisco (also ships non-ODL controller)	Nuage Networks	PLUMgrid
ConteXtream (HP)		Pluribus
Coriant		Sonus
Ericsson		VMware NSX
Extreme		
Huawei (also ships non-ODL controller)		
IBM (sold as part of their cloud services)		
Inocybe		

1 Vendors who actively participate and contribute code to the ODL project but only ship their own non-ODL-based controllers.

Core Controller Capabilities

As SDN evolves, early adopters have developed opinions around key capabilities that are table-stakes for a Controller in today's SDN environments, regardless of whether the solution based on an open source or proprietary vendor platform. These capabilities include:

- **Rich Southbound Support (OpenFlow, etc.):** enabling the Controller to manipulate and optimize how switches (and routers) manage the flow of traffic. While there are other southbound protocols that can be used, many SDN solutions are OpenFlow-enabled, making it imperative the Controller support it to maximize deployment scenarios.
- **Extensible API Support:** ensuring the Controller can be used within the varied environment in which it is deployed to intelligently orchestrate communications, both at Layer 2- 3 and Layer 4-7. For example, the Controller should be able to support OpenStack orchestration systems, as well as vendor-specific protocols. When it does, it can execute both network functionality and application logic.
- **Programmability:** providing the ability to redirect traffic, apply sophisticated filters to packets (that can be deployed dynamically), leverage templates to streamline the creation of custom applications, ensure northbound APIs make the control information centralized in the Controller available to be changed by applications. This will ensure the Controller can dynamically adjust the underlying network to optimize traffic flows to use the least expensive path, take into consideration varying bandwidth constraints, meet quality of service (QoS) requirements, etc.
- **Centralized Monitoring and Visualization:** offering end-to-end visibility of the network and centralized management to improve overall performance, simplify the identification of issues and accelerate troubleshooting. The Controller needs to be able to discover and present a logical abstraction of all the physical links in the network (topology), with the ability to present how the multiple virtual networks that are running on top of the physical network are operating. The Controller should support standard monitoring protocols, so the information can be integrated with other management and orchestration systems.
- **High Performance:** minimizing the flow setup time and maximizing the number of flows per second the Controller can setup is a critical capability. Controllers need to be both proactive (prepopulates the flow tables, so the switches/routers know how to handle; no setup delay or limit to the number of flows the Controller can support) and reactive (processes flows that don't match a flow table entry; need to ensure the Controller doesn't become a bottleneck).
- **Reliability and scalability:** supporting clustering and high availability, the Controller also needs to effectively scale in the future to control devices and meet the demands of a distributed environment, across multiple geographic locations.
- **Security:** incorporating security-related functionality that ensures the Controller is not the weakest link in the network and cannot be easily compromised. For example, it should encrypt communications, use enterprise class mutual-authentication, provide authorization and other administrative controls, isolate multi-tenants, support denial of service protection, etc.

Core Use Cases for Controllers

As the adoption of SDN, network virtualization and network function virtualization (NFV) grow, so do the deployment scenarios for Controllers. The following are some of the most common use case families (we call them umbrella use cases on our **SDxCentral use case** pages) that leverage a Controller as the strategic control point in the network. We've called out the role of the Controller in reach of these common use cases.

Use Case Umbrella	Description of Use Case	Role of Controller
Network Access Control	Set appropriate privileges for users or devices accessing the networks, including access control limits, incorporation of service chains as well as appropriate quality of service. Generally follows the user/device as they connect from different parts of the network.	Controller integrates with the network equipment to configure appropriate control mechanisms (access control lists) and Quality of Service (QoS) on the switches, as well as set up service function chains to bring appropriate L4-7 services into the network paths.
Network Virtualization	Creates an abstracted virtual network on top of a physical network, allowing a large number of multi-tenant networks to run over a physical network, spanning multiple racks in the datacenter or locations if necessary, including fine-grained controls and isolation as well as insertion of acceleration or security services.	Controller monitors the network topology and configures network ports to create appropriate virtual networks (via direct programming or VXLAN overlays). The Controller also sets up service chains, as appropriate, to insert L4-7 services.
Virtual Customer Edge	Virtualizing the customer edge either through creation of a virtualized platform on customer premises or by pulling in the functions closer to the core on a virtualized multi-tenant platform hosted either in a carrier point-of-presence, regional datacenter, central datacenter (enterprise, telco or over-the-top cloud SP).	Controller aids in configuring data flows on either the cloud or customer-premises network infrastructure, including setting appropriate ACLs or QoS settings for remote branch networks and WAN access, and inserting services for each subscriber, as appropriate.
Dynamic Interconnects	Creation of dynamic links between locations, including between DCs, enterprise and DCs, and other enterprise locations, as well as dynamically applying appropriate QoS and BW allocation to those links.	Controller maintains the topology and sets up WAN connections as needed (driven by BWoD or on-demand network needs). This may include configuring quality of service (QoS) on links as well.
Virtual Core and Aggregation	Virtualized core systems for service providers including support infrastructure such as vIMS, vEPC, as well as dynamic mobile backhaul, flexible MVNO, virtual PE and NFV GiLAN infrastructure.	Controller maintains the network fabric connections across each of the infrastructure services, provides virtualized segmented networks in cases where multiple vEPCs are running (e.g. MVNO use cases), or insert service chains, as necessary, into the S/GiLAN infrastructure.
Data Center Optimization	Using SDN and NFV, optimizing networks to improve application performance by detecting and taking into account affinities, orchestrating workloads with networking configuration (mice/elephant flows)	Controller maintains the network topology and modifies paths or sets appropriate QoS to ensure SLA or optimization goals are met, based on real-time analytics from the network.

Selecting the Right Controller

With the diversity of use cases today and the different controller choices, readers often ask us about the best way to evaluate controllers and pick the right one. And in those conversations, one question that comes up more often than not is whether they should use an OpenDaylight-based controller versus one not based on OpenDaylight. With approximately 50 vendors and over 456 developers (about 360 active) contributing to the code base, OpenDaylight definitely has significant momentum. Beyond momentum though, there are a number key attributes to consider when picking an SDN Controller:

- **Open source versus proprietary**: Our research and conversations with early adopters of SDN indicate that this attribute should only be important if you are considering extending the controller or have proprietary modifications specific to your business. Certainly open source solutions will reduce the probability of vendor lock-in, but with an increasing focus on standards-based Southbound APIs like OpenFlow or ovsdb, and given existing market sensitivities towards preventing lock-in, this is less of an issue right now. More focus should be paid towards functionality and fit, as well as other attributes.
- **Application ecosystem and maturity of Northbound APIs**: SDN Controllers are deployed to solve network problems in conjunction with SDN applications. Paying attention to the business problems and understanding what applications exist for the Controller platform and whether those applications are a good fit for your business problems is one of the top attributes for consideration.
- **Use case fit**: Just as important as understanding whether SDN applications exist to solve your problem, you need to understand if the Controller was designed for the areas of deployment that you care about. Controllers that are designed for WAN deployments might not work as well in the Data Center environment, or a Controller that is designed to work primarily in Enterprise Campus environments could be a poor fit for a WAN deployment. While it is possible that a single Controller could be a fit across all environments, our experience has shown that early Controllers tend to be optimized for a subset of environments.
- **Maturity and realiability of the Controller and compatibility with networking equipment**: Since the Controller will be a key element of the network, it is important to look at the maturity of the solution under consideration and in particular, pay attention to the number of production deployments, areas of deployments and how long these deployments have been running. With SDN still in its early days, it is unlikely you'll find 5-year old deployment; nevertheless, when comparing two Controllers with similar feature-sets, production runtime can be an important attribute. Likewise, ensure that the Controller you are evaluating has been tested (or better yet, certified) with the equipment you intend to use. Even with standard protocols like OpenFlow, there can be small but important incompatibilities in implementation which may impact the efficacy or reliability of your solution.
- **Smoothness of integration into orchestation platforms**: Almost every commercial Controller and many open source Controllers provide OpenStack support in the data center. If you have a data center deployment and have picked a specific cloud management or orchestration platform (OpenStack, VMware vRealize, CloudStack or others), check with the vendor or evaluate the open source distribution to ensure seamless integration into your orchestration environment.
- **Clarity of roadmap and commitment to stable APIs**: Related to the open source versus proprietary attribute, what we've learned is that clarity and stability of the vendor or open source project roadmap is important, as is vendor commitment to stable APIs (which hopefully are also open APIsl). The last thing you want to be faced with is switching from one Controller to a later version of that Controller that no longer supports your current APIs, especially after you've build out a complete cloud solution around it. Open source solutions might provide better transparency, but they do not always provide long-term stable APIs.

Beyond considering these attributes, readers need to understand that the SDN market is early. While OpenDaylight has helped change the landscape dramatically, other open source projects like ONOS and OpenContrail are driving

other use cases, and commercial vendors are still early in their Controller efforts. It still remains to be seen how the competitive market for Controllers will evolve over time. Regardless, if your Controller selection criteria is focused primarily around use case fit and how well it solves your business problems, you can ensure you achieve value from deploying SDN today and be in a position to evaluate future SDN solutions coming down the pike.

The Future of SDN Controllers

Earlier in this section we discussed the history of Controllers, which explains how they got to where they are today, but even more interesting is the possibilities around where they will go in the future. As we see it, there are several possible evolution paths for Controllers:

1. Controllers could essentially become the **network operating system**. They would become the generic platform on which network applications would be written and provide supporting services, similar to how computer operating systems provides file systems, memory management, APIs for application developers, etc. If the Controller goes down this path, it will definitely grow bigger and more complex as it stretches to provide an increasing number of services that SDN applications can rely on.
2. Controllers end up being **single function solutions** that are tied into a particular application. For example, they would only be used to support Network Virtualization applications or Software-defined WAN applications. On this trajectory, the size and scope of the Controller would become limited; the functionality would likely be embedded within the application itself, versus being delivered as a separate entity.
3. Controllers are subsumed into a **cloud orchestration platform** (e.g. OpenStack) and the network is abstracted into the cloud infrastructure; in this scenario, applications would deal directly with the cloud orchestration platform, putting all the agility and control into the orchestration-level, which limits the ability of the network to proactively make adjustments. Controllers would become completely subsumed into the orchestration platform and no longer standalone.
4. Controllers are reduced to **policy-renderers**; policy and intent-based systems become prevalent and the main role of the Controller is to translate higher-level policies into lower-level device configuration commands. In this scenario, all the control is set within the policy platform and the Controller simply focuses on its translation role in the network.

It is highly likely that all of the above scenarios will occur to some degree; we could even see blended approaches for different parts of the infrastructure, with different instantiations deployed within a single data center. Again, only time will tell.

Controller Profiles

In the next section of the report, we present a list of SDN Controllers for your consideration. The Profiles in this Report consist of both popular open source and commercially available Controllers and the extended profiles can **be viewed online**. The information was gathered via a collaborative effort between SDxCentral's Research Team and the appropriate product experts at the vendors and open source teams.

While every attempt has been made to validate the capabilities listed in the profiles, SDxCentral advises end users to verify the veracity of each claim for themselves in their actual deployment environments. SDxCentral cannot be held liable for unexpected operations, damages or incorrect operation due to any inaccuracies listed here.

SDxCentral welcomes feedback and additional information from end users based on their real-world experiences with the products and technologies listed. The SDxCentral research team can be reached at **research@sdxcentral.com**.

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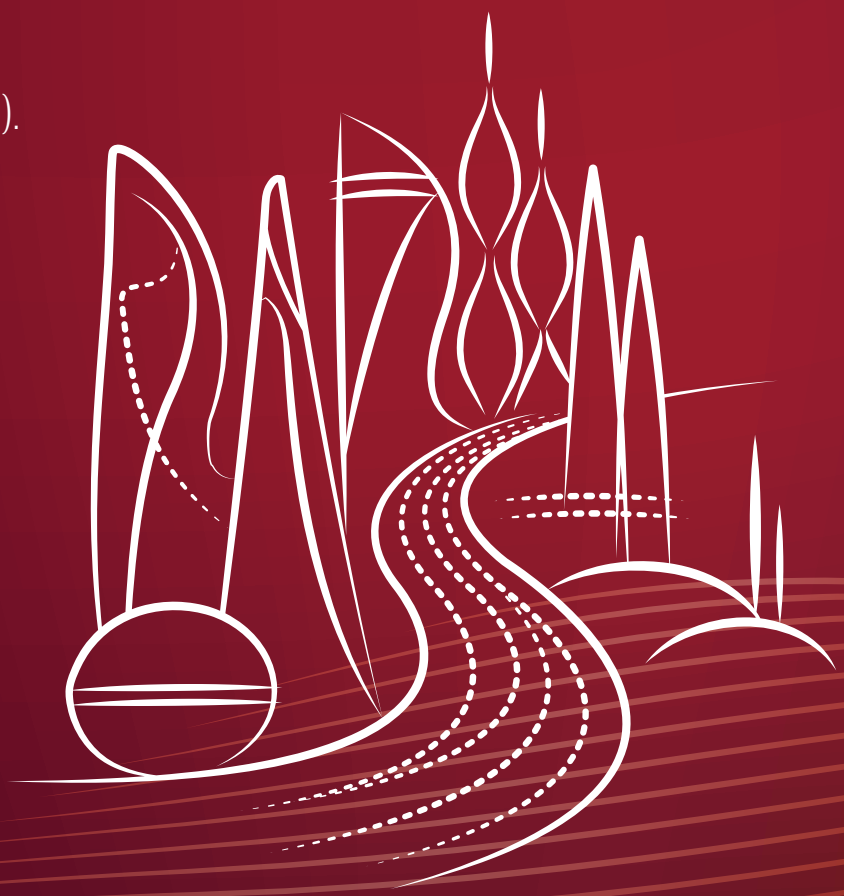

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Brocade SDN Controller (Click for Online Version)

www.brocade.com/en/products-services/software-networking/sdn-controllers-applications/sdn-controller.html

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San Jose, CA 95134
www.brocade.com
888-BROCADE (888-276-2233)

Description of Controller

- Fully tested, extensible commercial distribution of OpenDaylight, the leading open-source SDN controller with a large and vibrant developer community
- Continuously built from OpenDaylight, free of proprietary extensions and with complete portability for your OpenDaylight applications and plug-ins
- Broadest platform for use in multi-vendor environments—able to control physical and virtual networking devices from all major vendors
- Collaborative relationship for innovation—build the SDN environment that meets your needs, with education and support from Brocade's world-class SDN engineers and professional services

Date of Initial Release	**Based on**
December 2014	ODL
Solution Packaging	**Form Factor**
Sold as standalone controller	Virtual machine image
Areas of Deployment	**Production Deployments Today**
Data Center, Campus, Branch, WAN and Transport	Yes
Primary Programming Language	
Java	
Southbound protocols supported	**Northbound APIs Available**
OpenFlow, OVSDB, BGP, NETCONF	Yes
Language Bindings for Northbound APIs	
Python, Ruby, RESTful API	
Specific Applications Bundled with Controller	
Brocade Topology Manager	
Add Ons	
Brocade Flow Optimizer	
Third-Party Applications	
Elbrys SDN School Application for K-12	

Clustered Deployment	**High Availability**
Yes	Yes
Physical/Virtual Network Devices Supported	
• All Brocade products (tested) • Most 3rd-party products supporting the southbound protocols listed above (testing underway)	
Pricing	
Base Edition (for Operations): $100 per network node managed, per year. Includes support contract. (Discounted for multi-year contract). Education and professional services offerings are also available; prices vary by scope.	
Use Case 1: Virtual Customer Edge	
vCE (Telco)	
Use Case 2: Virtual Customer Edge	
On-premise vCPE	
Use Case 3: Datacenter Optimization	
Mice/Elephant Flow Optimization	

CISCO SYSTEMS

170 W. Tasman Dr
San Jose, CA 95134
www.cisco.com
800-553-6387

For more information on each of these controllers click the product name

Cisco Application Policy Infrastructure Controller (APIC)

(Click for Online Version)

http://cs.co/9008BGF18

Description of Controller

Cisco Application Policy Infrastructure Controller (APIC) is the unifying automation and management point for the Application Centric Infrastructure (ACI) data center fabric. It provides centralized access to all fabric information, optimizes the security and application lifecycle for scale and performance supporting flexible infrastructure provisioning across physical containers and virtual resources.

Date of Initial Release	Areas of Deployment
July 2014	Data Center
Language Bindings for Northbound APIs	
Python, Ruby, RESTful API, ACI Toolkit and Open SDK, Group Based Policy (GBP) model & framework	

Southbound protocols supported
OpFlex, L4-7 Device Packages
Use Case 1: Network Virtualization
Data Center Virtual Networks, Data Center Micro Segmentation, Network Functions as a Service, High scale and high performance Network Virtualization, Open service integration with multi-vendor L4-7 ecosystem

Cisco Application Policy Infrastructure Controller Enterprise Module (APIC-EM)

(Click for Online Version)

http://cs.co/9003BGF1f

Description of Controller

The APIC EM delivers policy-based automation to the WAN and LAN. The controller automates and simplifies network configuration, provisioning, and management. From a single x86 or virtualization enabled computer, end to end solutions can be deployed that manage campus network services and user policies.

Date of Initial Release	Areas of Deployment
January 2015	Campus, Branch, WAN
Language Bindings for Northbound APIs	
RESTful API	

Southbound protocols supported
CLI
Use Case 1: Virtual Customer Edge
SD-WAN (ZTD branch router deployment, Automated provisioning of DMVPN, access lists and QoS)

Cisco Virtual Topology System (Click for Online Version)

www.cisco.com/go/vts

Description of Controller

The Cisco® Virtual Topology System (VTS) is a standards-based, open, overlay management and provisioning system for data center networks. It automates fabric provisioning for both physical and virtual workloads. VTS is supported across the entire Cisco Nexus switching portfolio and supports multi-vendor and brownfield environments via software overlays.

Date of Initial Release	Areas of Deployment
April 2015	Data Center
Language Bindings for Northbound APIs	
RESTful APIs	

Southbound protocols supported
NETCONF, RESTCONF, MP-BGP EVPN
Use Case 1: Network Virtualization
Data Center Virtual Network Overlays, Network Functions as a Service, NFV Service Chaining

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Ericsson SDN Controller

(Click for Online Version)

Description of Controller

Ericsson's SDN controller is a commercial (hardened) version of open source OpenDaylight (ODL) SDN controller. Domain specific control applications that use the SDN controller as platform form the basis of the three commercial products in our SDN controller portfolio.

1. Ericsson Services SDN: Services SDN is a product offering that binds SDN control capabilities with Policy Control to offer dynamic flow steering capabilities in managing connectivity for applications
2. Ericsson Cloud SDN: Cloud SDN is a product offering that brings full IP routing capabilities to data center networking. The seamless interworking and management of existing IP/MPLS networks with the networking component of the datacenter makes this product the lynchpin for efficient NFV deployments
3. Ericsson Transport SDN: Transport SDN offers an end to end abstracted view of network resources and topology in a multi-domain, multi-vendor network at multiple layers (Layer 0 – DWDM to Layer 3 IP). Linkage with Radio (RAN) and Packet Core (EPC) ensures application/user awareness in mobile backhaul (MBH) for full programmability.

In addition to these three commercial products, Ericsson also offers pre-integrated solutions for service providers. The goal with pre-integrated solutions is to provide an additional boost of agility to operators in deploying these very common use cases.

Date of Initial Release	**Based on**
November 2013	ODL
Solution Packaging	**Form Factor**
Sold as standalone controller and bundled as a solution package	Virtual machine image, Installable software
Areas of Deployment	
Data Center, Campus, Branch, WAN	
Production Deployments Today	
Yes. Please contact vendor for additional information	
Primary Programming Language	**Northbound APIs Available**
Java	Yes
Southbound protocols supported	
OpenFlow, OVSDB, BGP, NETCONF, PCEP, BGP-LS	
Language Bindings for Northbound APIs	
RESTful API	

Specific Applications Bundled with Controller	
Domain specific control applications are offered as commercial products as indicated in the earlier section. A combination of the controller and specific application forms the commercially offered product. Ericsson Services SDN = Ericsson SDN Controller + Enhanced Service Control Functionality. Ericsson Cloud SDN = Ericsson SDN Controller + Cloud Networking Extensions & applications. Ericsson Transport SDN = Ericsson SDN Controller + Transport Network Control extensions and planning and optimization applications.	
Federation protocols support	
MP-BGP	
Clustered Deployment	**High Availability**
Yes	Yes
Use Case 1: Network Virtualization	
Data Center Virtual Networks, Campus / Branch Virtual Networks, Data Center Micro Segmentation, Network Functions as a Service	
Use Case 2: Dynamic Interconnects	
BWoD, Virtual Private Interconnects / Cloud Bursting, Dynamic Enterprise VPN, Cross Domain Interconnect, Multi-Layer Optimization	
Use Case 3: Virtual Customer Edge	
On-premise vCPE, vCE Telco	

1133 Innovation Way
Sunnyvale, CA 94089
www.juniper.net
Contrail-Info@juniper.net
888-JUNIPER (888-586-4737)

Contrail (Click for Online Version)

www.juniper.net/assets/us/en/local/pdf/datasheets/1000521-en.pdf

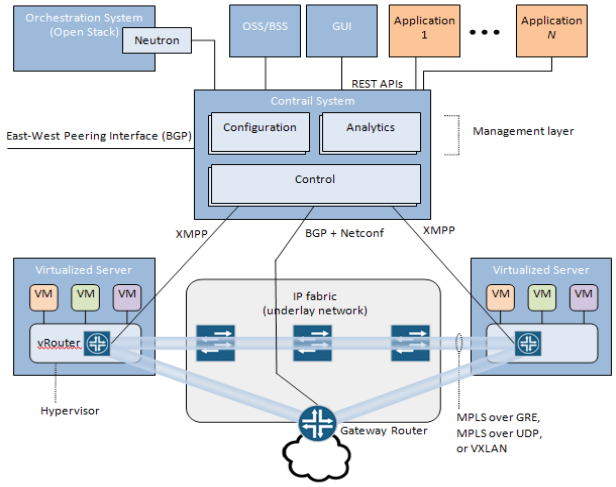
Description of Controller

Juniper Networks' Contrail is a simple, open and agile Cloud Network Automation platform that implements secure multitenancy and enables dynamic service chaining in private, public and hybrid clouds. Contrail Networking and Contrail Cloud Platform.

- Contrail Networking is an open SDN solution that consists of Contrail Controller, Contrail vRouter, an analytics engine, and published northbound APIs for cloud and NFV. Contrail Networking improves business agility by delivering unique security, availability, performance, automation and elasticity capabilities
- Contrail Cloud Platform is a turnkey cloud orchestration and automation platform that consists of Contrail Networking, Juniper's OpenStack Distribution, Server Manager, and Ceph-Based Distributed Storage

Based on the principles of SDN, Contrail leverages BGP signaled end-system IP/VPNs to implement network virtualization overlays. These standards-based overlays, which span cloud boundaries, deliver a vendor-neutral approach for creating multitenant secure virtualized, containerized and bare-metal cloud environments. Infrastructure analytics and visualization features provide insight into virtual and physical networks, simplifying operations and decision making with proactive planning and predictive diagnostic capabilities.

Date of Initial Release	Based on
September 2013	OpenContrail
Solution Packaging	**Form Factor**
Sold as standalone controller and bundled as a solution package	Virtual machine image, Installable software, Source Code (open-source or proprietary)
Performance & Scale	
Please visit: www.opencontrail.org/evaluating-opencontrail-virtual-router-performance	
Areas of Deployment	
Data Center, Campus, Branch, WAN and Transport	
Production Deployments Today	
NTT Innovation Institute Inc. (NTT i3), Orange Business Solutions (OBS), Symantec, CloudWatt, Cloud Dynamics	



www.opencontrail.org/opencontrail-architecture-documentation

Primary Programming Language	Southbound protocols supported
C/C++, Java, Python	BGP, XMPP, NETCONF, OVSDB
Language Bindings for Northbound APIs	
Java, Python, RESTful API, Go	
Specific Applications Bundled with Controller	
vRouter: The vRouter implements the distributed forwarding plane that runs in the hypervisor of a virtualized server, creating virtual overlay networks on top of physical underlays. Although conceptually similar to commercial and open-source vSwitches such as Open vSwitch (OVS), the vRouter also provides routing and other higher-layer services, hence the name.	
Add Ons	
Server Manager: The Server Manager provides a simple, centralized way for users to manage and configure components of a virtual network running across multiple physical and virtual servers in a cloud infrastructure. Ceph-Based Distributed Storage: A storage support solution using OpenStack Cinder configured to work with Ceph, a unified, distributed storage system that provides storage services in cloud data centers, to provide a validated Network File System (NFS) storage service.	
Third-Party Applications	
Contrail is integrated with OpenStack main trunk and various distributions as well as virtual and physical network functions.	
Clustered Deployment	**High Availability**
Yes	Yes

NEC

6535 N. State Hwy 161
Irving, TX 75039
www.nec.com
sales@necam.com
866-632-3226

NEC ProgrammableFlow Networking Suite including ProgrammableFlow PF6800 Controller, UNIVERGE® PF6800 Network Coordinator, and PFTAP Controller (Click for Online Version)

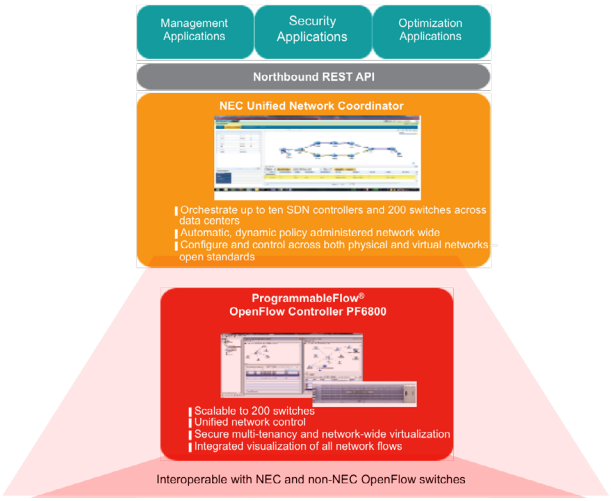
www.necam.com/sdn/doc.cfm?t=PFlowController

Description of Controller

1. ProgrammableFlow PF6800 Controller Version 6: Award-winning application-aware networking and service delivery. Providing a single point of control and management for both virtual and physical networks for over 250 enterprises and solution providers around the world, the ProgramambleFlow Controller delivers better utilization of all IT assets, enabling network-wide virtualization and allowing customers to easily deploy, control, monitor and manage multi-tenant network infrastructure. NEC's PF6800 provides a programmable network fabric that integrates with OpenStack, VMware and Microsoft System Center Virtual Machine Manager for streamlined, flexible network management and orchestration.
2. UNIVERGE® PF6800 Network Coordinator (UNC): Enables construction and orchestration of virtual networks across multiple controllers within a data center as well as across interconnects between data centers.
3. PFTAP Controller: NEC's PF6800 TAP SDN-based controller provides comprehensive flow aggregation and orchestration; scalable filtration; and enhanced network traffic visibility on an OpenFlow-based Network Fabric.

Date of Initial Release	
May 2011	
Solution Packaging	**Form Factor**
Sold as standalone controller and bundled as a solution package	Hardware appliance, Virtual machine image, Installable software
Performance & Scale	
The ProgrammableFlow Controller can connect 20,000 endpoints in under 400 microseconds. The PF6800 SDN Controller can manage 200 switches, 300,000 endpoints and 1000 virtual networks. The UNIVERGE® PF6800 Network Coordinator can manage 10 Controllers for a total of 2000 switches and 3 million endpoints.	

Award-winning* Open NEC Controller & UNIVERGE™ Network Coordinator



* Best of Interop 2014 Management Winner; Tech Target 2013 Networking Innovation Award; Best of Interop 2012 Grand Prize Winner; Microsoft TechEd 2012 Networking Finalist; Best of Interop 2011 Infrastructure Winner

Areas of Deployment	
Data Center, Campus, Branch, WAN and Transport, Data Center Capture and Visibility	
Production Deployments Today	
Over 250 enterprises and service providers in production globally today.	
Primary Programming Language	**Southbound protocols supported**
C/C++	OpenFlow
Language Bindings for Northbound APIs	
RESTful API, XML or JSON	
Specific Applications Bundled with Controller	
NEC's unique Virtual Tenant Network (VTN) technology, integral to the PF6800, provides for isolated, secure, multi-tenant networks. NEC's controller also integrates with VMware VSphere, Microsoft System Center Virtual Machine Manager and OpenStack via networking plugins.	
Third-Party Applications	
NEC established the first OpenFlow-based SDN ecosystem in 2012 with both northbound and southbound partners with interoperable OpenFlow-based switching and L4-L7 services. Apps include increased network optimization, manageability and availability.	
Federation protocols support	
UNIVERGE® PF6800 Network Coordinator federates control domains between the NEC ProgrammableFlow Controller, HP VAN Controller, and OpenDaylight Controller	
Clustered Deployment	**High Availability**
Yes	Yes
Use Case 1: Network Virtualization	
Data Center Virtual Networks	

SONUS

4 Technology Park Drive
Westford, MA 01866
www.sonus.net
Sonus-ISAM@sonusnet.com
855-GO-SONUS (855-467-6687)

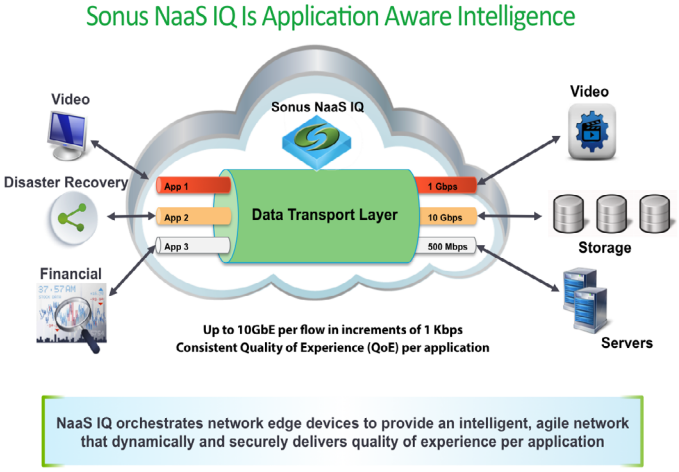
Sonus NaaS IQ (Click for Online Version)

www.sonus.net/sites/default/files/sonus-naas-iq-data-sheet-02262015.pdf

Description of Controller

The Sonus NaaS IQ is a network control platform providing real-time, application-aware, management of application/data traffic between an enterprise and a data center or between data centers across the wide area network (WAN). NaaS IQ orchestrates and dynamically delivers just-in-time WAN connectivity, optimizes WAN bandwidth utilization, securely and reliably delivers application performance, supports prioritized business-critical application, and ensures business continuity if/when a disaster occurs.

Date of Initial Release	Solution Packaging
January 2012	Bundled as a solution package
Form Factor	
Virtual machine image, Installable software	
Performance & Scale	
A single instance of NaaS IQ is specified to handle 1000s of flows on a network of up to 200 switches. Scale and performance may vary based on network topology, types of switches used, bandwidth available and NCP configuration used.	
Areas of Deployment	**Production Deployments Today**
WAN	Telstra International (acquisition of Pacnet), State Street Bank
Primary Programming Language	
C/C++	



Southbound protocols supported	Northbound APIs Available
OpenFlow, NETCONF	Yes
Language Bindings for Northbound APIs	
RESTful API JSON-based, XML	
Add Ons	
• FarSight, Monitoring and Analytics application using Splunk Enterprise (www.sonus.net/sites/default/files/sonus-farsight-datasheet-02262015.pdf) • Customer, multi-tenant Portal. A skinable on-boarding/self service portal to enable Service Provider to sell their WAN as a service by giving an Enterprise the purchasing ability to make service selections and set business priorities. • Integration with Microsoft Skype for Business SDN interface	
Physical/Virtual Network Devices Supported	
Accton Technology (model 5652 and 5610), Centec Networks (model V330), Compass Networks	
Clustered Deployment	**High Availability**
Yes	Yes
Pricing	
NaaS IQ is offered based on tiered pricing as both subscription and perpetual software that resides on standard x86 hardware on VMware and KVM virtualized environments.	
Use Case 1: Network Access Control	
Remote Office / Branch NAC, Pinhole Firewalling/ Access Control	
Use Case 2: Network Virtualization	
Network Functions as a Service	
Use Case 3: Dynamic Interconnects	
BWoD, Virtual Private Interconnects / Cloud Bursting, Dynamic Enterprise VPN, Multi-Layer Optimization	

Avaya SDN Fx Controller

(Click for Online Version)

AVAYA
www.avaya.com

Description of Controller
Controller integrates the necessary components for deploying integrated SDN applications that integrate infrastructure and application effectively. Since most Enterprise SDN applications need to be deployed over a mix of legacy and SDN infrastructures, additional capabilities are provided to support parallel and integrated deployment of legacy, Avaya Fabric Connect and SDN.

Date of Initial Release	Based on
September 2015	ODL
Areas of Deployment	
Data Center, Campus	

Solution Packaging
Bundled as a solution package
Southbound Protocols
OpenFlow, OVSDB, OF-CONFIG, NETCONF, full range of standard ODL southbound interfaces

Big Cloud Fabric (Click for Online Version)

www.bigswitch.com/sdn-products/big-cloud-fabrictm

BIG SWITCH NETWORKS, INC.
www.bigswitch.com

Description of Controller
Big Switch's Big Cloud Fabric™ (BCF) is the industry's first data center fabric built using Open Ethernet switches (whitebox or britebox) and SDN controller technology. Customers benefit from unprecedented application agility due to automation, massive operational simplification due to SDN and, dramatic cost reduction due to HW/SW disaggregation.

Date of Initial Release	Based on
September 2014	Open Network Linux
Areas of Deployment	
Data Center	

Solution Packaging
Bundled as a solution package
Southbound Protocols
OpenFlow

Agility (Click for Online Version)

www.ciena.com/resources/data-sheets/Multilayer-WAN-Controller---product-datasheet-ENG.html

CIENA
www.ciena.com

Description of Controller
Ciena's Agility Multilayer WAN Controller is built atop the open-source baseline of the OpenDaylight Project—an open, modular framework created by a vendor-neutral ecosystem (rather than a vendor-centric 'ego-system') that will enable network operators to source network services and applications from both Ciena Agility and others.

Date of Initial Release	Based on
July 2014	ODL
Areas of Deployment	
WAN and Transport	

Solution Packaging
Sold as standalone controller and bundled as a solution package
Southbound protocols
OpenFlow, OVSDB, BGP, NETCONF

ContexNet 4.0 (Click for Online Version)

CONTEXTREAM (ACQUIRED BY HP)
www.hp.com

http://www8.hp.com/h20195/v2/GetDocument.aspx?docname=c04726792

Description of Controller

ContexNet is an OpenDaylight-based carrier-grade distributed SDN fabric that leverages virtualization and grid computing technologies. It runs on standard off-the-shelf computing platforms and enables network operators to create a service abstraction layer on top of traditional networks that can quickly add new network applications and services, deliver services customized per-subscriber flow, and more.

Date of Initial Release	Based on
December 2014	ODL
Areas of Deployment	
Data Center	

Solution Packaging
Bundled as a solution package
Southbound protocols
OpenFlow

Transcend SDN Transport Controller (Click for Online Version)

CORIANT
www.coriant.com

www.coriant.com/solutions/transport_sdn.asp

Description of Controller

High scalability and availability targeted for new centralized control plane functions e.g. restoration, immediate service provisioning, responding to the dynamics of the traffic loads and network resource availability with elastic transport capacity provisioning. Integrates management of the Optical Layer for optimal use of reconfigurable optics. Provides REST Application interfaces based on OIF and IETF specifications.

Date of Initial Release	Areas of Deployment
October 2014	WAN and Transport
Solution Packaging	
Bundled as a solution package	

Southbound protocols	
NETCONF, SNMP, TL1	
Clustered Deployment	**High Availability**
Yes	Yes

Cyan Planet Operate (Click for Online Version)

CYAN, INC
www.cyaninc.com

www.cyaninc.com/assets/docs/literature/Planet_Operate_Data_Sheet_v3G.pdf

Description of Controller

Planet Operate is the industry's first multi-vendor, multi-layer SDN controller and management application for wide area networks. Providing centralized SDN control and automation, in addition to end-to-end fault, configuration, accounting, provisioning, and security (FCAPS) capabilities that leverage advanced 3D visualization, Planet Operate dramatically simplifies network operations.

Date of Initial Release	Areas of Deployment
November 2012	WAN and Transport
Solution Packaging	
Sold as standalone controller and bundled as a solution package	

Southbound protocols	
OpenFlow, OVSDB, BGP, NETCONF	
Clustered Deployment	**High Availability**
Yes	Yes

OneController (Click for Online Version)

EXTREME NETWORKS
www.extremenetworks.com

http://learn.extremenetworks.com/rs/extreme/images/OneController-DS.pdf

Description of Controller
OneController leverages the OpenDaylight framework to provide an open-standards-based SDN Controller providing simple, fast, and smart automation and orchestration. It forms the basis of Extreme Networks' SDN Platform for innovation allowing you to choose best-of breed products. OneController tightly integrates with existing and multi-vendor hardware and software network infrastructure.

Date of Initial Release	Based on
April 2015	ODL
Areas of Deployment	
Data Center, WAN and Transport	

Solution Packaging
Sold as standalone controller
Southbound Protocols
OpenFlow, OVSDB, NETCONF, OpenFlow 1.0, OpenFlow 1.3, SNMP, SOAP/XML, etc.

HP Virtual Application Networks (VAN) SDN Controller

HEWLETT PACKARD
www.hp.com

(Click for Online Version)

http://h20195.www2.hp.com/v2/GetDocument.aspx?docname=4AA4-9827ENW&doctype=data%20sheet&doclang=EN_US&searchquery=&cc=us&lc=en

Description of Controller
Provides a unified control point in an SDN-enabled network, simplifying management, provisioning, and orchestration and enables delivery of a new generation of application-based network services for campus, data center or service provider environments. The building block of the HP Open SDN Ecosystem, the controller allows 3rd party developers to deliver innovative SDN solutions.

Date of Initial Release	Areas of Deployment
September 2013	Data Center, Campus Branch
Solution Packaging	
Sold as standalone controller and bundled as a solution package	

Southbound Protocols	
OpenFlow, NETCONF, SNMP	
Clustered Deployment	**High Availability**
Yes	Yes

Agile Controller (Click for Online Version)

HUAWEI TECHNOLOGY
www.huawei.com

http://e.huawei.com/en/products/software/network-software/agile-controller

Description of Controller
The Agile Controller is the core component of HUAWEI Software-Defined Networking (SDN) Agile Network Solution. Based on OpenDayLight architecture, the Agile Controller provides an end-to-end networking solution, helping customers build more intelligent, flexible, open and stability cloud networks and enabling networks to be more agile for cloud services.

Huawei Agile Controller-Smart Network Controller (Huawei AC-SNC) (Click for Online Version)

Description of Controller
A core SDN component which works with the NetMatrix, uTraffic, NE series routers, and DC series switches to provide Huawei E2E SDN solution. Features include: Full Network Scenario Coverage, Support for Multiple SDN Solutions, Elastic Distributed Architecture, Minimum Network Convergence Time, Open and Programmable Northbound, Multiprotocol-compatible Southbound, Carrier-Class Reliability, Robust Security Protection Solutions.

Inocybe's OpenDaylight Distribution (Click for Online Version)

INOCYBE
www.inocybe.com

www.inocybe.com/opendaylight

Description of Controller
A non-opinionated distribution of OpenDaylight. We act as a curator to the OpenDaylight content providing enhanced stability and ease of use to users of our distribution helping them choose the features they need. We are committed at making OpenDaylight easy to use, from documentation to guidance, based on our continuous deployment and curated-distribution strategies.

Date of Initial Release	Based on
February 2014	ODL
Areas of Deployment	
Data Center, WAN and Transport	

Solution Packaging
OpenDaylight Distribution bundled with Support and Services
Southbound Protocols
OpenFlow, OVSDB, BGP, NETCONF, PCEP Southbound Plugin

Nuage Networks Virtualized Services Platform (VSP)

(Click for Online Version)

NUAGE NETWORKS
www.nuagenetworks.net

www.nuagenetworks.net/products/virtualized-services-platform

Description of Controller
Nuage Networks VSP provides SDN capabilities for clouds of all sizes. It is implemented as a non-disruptive overlay for all existing virtualized and non-virtualized server and network resources. No proprietary or purpose-built hardware is required since all components install in Docker containers, hypervisors or virtual machines. The platform eliminates the constraints of legacy networking approaches.

Date of Initial Release	Areas of Deployment
April 2013	Data Center, Campus, Branch, WAN and Transport
Solution Packaging	
Sold as standalone controller and bundled as a solution package	

Southbound Protocols	
OpenFlow, OVSDB, BGP	
Clustered Deployment	**High Availability**
Yes	Yes

Plexxi Control (Click for Online Version)

PLEXXI INC.
www.plexxi.com

www.plexxi.com/wp-content/uploads/2015/07/PlexxiControlDataSheet-Final1.pdf

Description of Controller
An advanced network platform that builds an understanding of the relationships between compute, storage and network resources. It combines workload-driven network fabric orchestration with network management and visualization, defining policies that optimally fit the network to each workload and automatically orchestrating the network fabric mapping network performance to application needs.

Date of Initial Release	Areas of Deployment
December 2013	Data Center, Campus, Branch, WAN and Transport
Solution Packaging	
Sold as standalone controller and bundled as a solution package	

Southbound Protocols	
Active MQ and Java Messaging Service (JMS)	
Clustered Deployment	**High Availability**
No	Yes

PLUMgrid Open Networking Suite for OpenStack (Click for Online Version)

www.plumgrid.com/wp-content/uploads/documents/PLUMgrid_ONS_For_OpenStack.pdf

PLUMGRID
www.plumgrid.com

Description of Controller

PLUMgrid Open Networking Suite for OpenStack is a comprehensive virtual networking software suite that enables secure and scalable cloud infrastructure. PLUMgrid ONS provides: Terabits of scale out performance, Production grade resiliency, Secure multi-tenancy, Scalable architecture, Rapid service insertion, Broadest distribution support, OpenStack compatibility for hybrid data centers.

Date of Initial Release	Areas of Deployment
June 2014	Data Center
Solution Packaging	
Entire Virtual Network Infrastructure. PLUMgrid ONS	

Southbound Protocols	
Supports IO Visor	
Clustered Deployment	**High Availability**
Yes	Yes

Netvisor Premium, Open Netvisor Linux (Click for Online Version)

http://www2.pluribusnetworks.com/l/36732/2014-11-14/2q4wk/36732/54132/datasheet_netvisorOS.pdf

PLURIBUS NETWORKS
www.pluribusnetworks.com

Description of Controller

Netvisor Premium and Open Netvisor Linux are Distributed Network Operating Systems. Open Netvisor integrates a traditional, interoperable networking stack (L2/L3/VXLAN) with an SDN distributed controller that runs in every switch of the fabric. Open Netvisor offers a set of SDN applications to dramatically simply network automation, provide integrated (tap-free) analytics, and network segmentation with multi-tenancy.

Date of Initial Release	Based on
March 2014	Linux, Illumos
Areas of Deployment	
Data Center	

Solution Packaging
Offered as a bundled solution of switch hardware plus software or offered as software-only on ONIE compatible devices
Southbound Protocols
Direct PCIe control. Server-style control-data plane separation

NSX Virtual Network Platform (Click for Online Version)

www.vmware.com/files/pdf/products/nsx/VMware-NSX-Datasheet.pdf

VMWARE
www.vmware.com

Description of Controller

VMware NSX™ is a network virtualization platform that delivers the operational model of a virtual machine for the network. NSX reproduces the entire network model in software, enabling any network topology to be created and provisioned in seconds. It enables a library of logical networking element and services.

Date of Initial Release	Areas of Deployment
August 2013	Data Center
Solution Packaging	
Bundled as a solution package	

Southbound Protocols	
OpenFlow, OVSDB, BGP, NETCONF	
Clustered Deployment	**High Availability**
Yes	Yes

category: ■ open source

BEEM Controller (based on OpenMUL) (Click for Online Version)

www.kulcloud.com/product/beem2

KULCLOUD
www.kulcloud.com

Description of Controller

BEEM combines network orchestration, control and full network management in a simple, easy-to-use and easily extensible software platform. It ties together compute (virtual and physical) and network resources tightly under a single management umbrella. KulCloud's BEEM Controller shares the same core engine and open APIs with Open MUL, an open source SDN Controller.

Date of Initial Release	Areas of Deployment
February 2014	Data Center
Active Committers	
Under 10 Developers	

Primary Programming Language	Southbound Protocols
C/C++	OpenFlow, OVSDB, NETCONF, MUL API
Clustered Deployment	**High Availability**
Yes	Yes

Loom (Click for Online Version)

http://flowforwarding.github.io/loom

LOOM

Description of Controller

The purpose of the LOOM project is to design and prototype an experimental network switch controller that implements the OpenFlow 1.3.x and 1.4 protocols. The project explores the scalability and robustness of such controllers on a scale much larger than typically considered: 100,000s of end points, 10,000s of switches.

Date of Initial Release	Areas of Deployment:
October 2013	Campus
Active Committers	
10 to 50 Developers	

Primary Programming Language	Southbound Protocols
	OpenFlow, OF-CONFIG, NETCONF
Clustered Deployment	**High Availability**
Yes	Yes

NOX (Click for Online Version)

www.noxrepo.org/nox/about-nox

NOX
www.noxrepo.org

Description of Controller

NOX is a platform for building network control applications. In fact, while what we now call SDN grew from a number of academic projects (perhaps chiefly SANE and Ethane), the first SDN technology to get real name recognition was OpenFlow, and NOX was initially developed at Nicira Networks side-by-side with OpenFlow.
NOTE: NOX does not appear to be actively maintained and is included because of its legacy.

Date of Initial Release	Areas of Deployment:
June 2008	Campus
Active Committers	
0	

Primary Programming Language	Southbound Protocols
C/C++	OpenFlow
Clustered Deployment	**High Availability**
Yes	No

category: ■ open source

Ryu (Click for Online Version)

https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr201408fa4.html

NTT LABS
www.ntt-labs.jp/saiyo/e

Description of Controller

Ryu is a component-based SDN framework. Ryu provides software components with well defined API that make it easy for developers to create new network management and control applications. Ryu is primarily supported by NTT and used in its cloud data center offerings. Ryu supports various protocols for managing network devices. Ryu supports fully OpenFlow 1.0, 1.2, 1.3, 1.4 and Nicira Extensions.

Date of Initial Release	Areas of Deployment:
2012	Campus
Active Committers	
Approximately 40	

Primary Programming Language	Southbound Protocols
Python	OpenFlow, OVSDB, BGP, OF-CONFIG, NETCONF
Clustered Deployment	**High Availability**
Yes	Yes

OpenContrail (Click for Online Version)

www.opencontrail.org

OPENCONTRAIL PROJECT
www.opencontrail.org

Description of Controller

OpenContrail is an open-source version of Juniper Networks Inc.'s commercial Contrail controller.

For more information on OpenContrail, please refer to Juniper Networks, Inc.'s Contrail controller

LIKE OUR COVERAGE OF OPEN SOURCE CONTROLLERS? CLICK TO SHARE

ODL Lithium (Click for Online Version)

www.opendaylight.org/lithium

OPENDAYLIGHT PROJECT
www.opendaylight.org

Description of Controller

OpenDaylight is a highly available, modular, extensible, scalable and multi-protocol controller infrastructure built for SDN deployments on modern heterogeneous multi-vendor networks. OpenDaylight provides a model-driven service abstraction platform that allows users to write apps that easily work across a wide variety of hardware and south-bound protocols.

Date of Initial Release	Areas of Deployment:
December 2013	Data Center
Active Committers	
Approximately 360	

Primary Programming Language	Southbound Protocols
Java	OpenFlow, OVSDB, BGP, NETCONF
Clustered Deployment	**High Availability**
Yes	Yes

category: ■ open source

ONOS (Open Network Operating System)

(Click for Online Version)

OPEN NETWORKING LABORATORY
http://onosproject.org

Description of Controller

A new SDN network operating system that offers high availability through clustering and distributed state management, scalability through clustering and partitioning of network device control, northbound abstractions for a global network view, network graph, and application intents, pluggable southbound for support of OpenFlow and new or legacy protocols, REST API, CLI & modern web GUI.

Date of Initial Release	Areas of Deployment:
December 2014	Data Center, WAN and Transport
Active Committers	
Approximately 80	

Primary Programming Language	Southbound Protocols
Java	OpenFlow, BGP, TL1
Clustered Deployment	**High Availability**
Yes	Yes

POX (Click for Online Version)

www.noxrepo.org/pox/about-pox

POX
www.noxrepo.org/pox/about-pox

Description of Controller

POX is NOX's younger sibling. At its core, it's a platform for the rapid development and prototyping of network control software using Python. Meaning, at a very basic level, it's one of a growing number of frameworks (including NOX, Floodlight, Trema,, etc.) for helping write an OpenFlow controller..

Date of Initial Release	Areas of Deployment:
2012	Campus
Active Committers	
1	

Primary Programming Language	Southbound Protocols
Python	OpenFlow, OVSDB
Clustered Deployment	**High Availability**
No	No

Trema (Click for Online Version)

http://trema.github.io/trema

TREMA
http://trema.github.io/trema

Description of Controller

Trema is an OpenFlow controller programming framework that provides everything needed to create OpenFlow controllers in Ruby. Many of its committers work for NEC Japan. It provides a high-level OpenFlow library and also a network emulator that can create OpenFlow-based networks for testing on your PC. This self-contained environment helps streamline the entire process of development and testing.

Date of Initial Release	Areas of Deployment:
2011	Campus
Active Committers	
2	

Primary Programming Language	Southbound Protocols
C/C++, Ruby	OpenFlow
Clustered Deployment	**High Availability**
Yes	Yes

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