THE LINUX FOUNDATION

Linux Foundation Networking and Orchestration White Paper:

Harmonization 2.0: How Open Source and Standards Bodies Are Driving Collaboration Across IT

A Publication of The Linux Foundation
March 2018

www.linuxfoundation.org

Executive Summary

Standards have played a major role in telecommunications technology adoption for many years, validating the commercial viability of new technologies, facilitating multi-vendor interoperability, improving product portability and essential product quality for customers, and expediting industry adoption and implementation of new technologies instead of wasting resources navigating between competing frameworks.

Cloud-driven operational models have set the stage for a major paradigm shift for software to supersede hardware to offer agility, flexibility, automation, and openness. Software-Defined Networking and Network Functions Virtualization are the catalysts for digital transformation that are disrupting the entire industry, and in 2018, most global network operators have developed transformation strategies based on open source SDN /NFV platforms.

How does open source complement standards efforts to accelerate market adoption? In the last one to two years, both supplier and operator organizations with long experience with Standards Development Organizations (SDOs) have learned to merge the operational knowledge and use cases innate to SDOs, with the collaborative innovation and openness offered by open source.

In this paper, we assess how standards and open source have begun to support each other in delivering rapid and sustainable network innovation. Then we examine The Linux Foundation's efforts to forge an integrated Networking and Orchestration architecture vision in support of cloud automation, IoT adoption, and more.

Introduction

For decades, standardization has been an essential element for commercializing telecommunications/ networking technology innovations, enabling the widespread adoption of mobility and IP Telephony, among many other advances.

Standards have been used to motivate industry cooperation towards achieving multi-vendor interoperability and portability, and establishment of an ecosystem that allows end-users and vendors alike to benefit.

Standards in this context encompass a number of qualities, including:

- Broad agreement over a well-defined scope
- Clearly defined policy and intellectual property guidelines
- Respected by technology contributors and consumers alike, typically accredited by government and or industry associations

Specifications and artifacts are typically available under non-discriminatory terms. However sometimes membership is required, or there is a cost to obtain the specifications.

Software Defined Networking (SDN) and Network Functions Virtualization (NFV), fueled by the ascent of the Cloud, are transforming telecommunications technology, operations, business models, and organizations. Industry standards processes and bodies have not been immune to this sea change. SDN and NFV have necessitated a rethinking of the standards process influenced by the factors below:

- **Impact of a software-centric network.** Traditional network standardization was developed for purpose- built hardware and embedded software that changed infrequently (especially silicon). SDN/NFV has been instrumental in ushering in a software era that requires a more flexible, rapid, and iterative standardization model that can support programmability and configurability. In practice, this puts the focus on software interfaces and data models, and secondarily drives hardware designs to support this highly dynamic, user-driven approach to network operations.

- **New mindset and skills required.** SDN arose alongside a broader set of technology trends coming from the software world. Traditional waterfall-style development began to give way, in some areas, to Agile methodology and DevOps practices. While relatively low impact for server applications, this approach was of course completely contrary

to the traditional approach to network standards, which emphasize stability, certainty and incremental, non-disruptive changes. Yet advocates of SDN saw an opportunity to accelerate network innovation using these new software shifts; a compromise that embraced both agility and operational stability had to be found.

- **End-user expectations shaped by consumer tech.** Easy to use, instant response devices and web-based services have defined the end-user experience in the Internet era. Carriers have found themselves compelled to provide the same level of responsiveness, or risk being bypassed by cloud and OTT providers. SDN/NFV have become a critical set of competitive tools, which allow operators to deliver everything faster, whether new services development, service deployment, troubleshooting, modifications, upgrades, or standards development.

Open source is a critical driver for change and the catalyst for digital transformation underway at many operators. It offers compelling benefits to both operators and vendors--perhaps most importantly, the collaborative innovation that only a diverse community can provide.

With this growing emphasis on cross-industry software interoperability, Open Source naturally emerged as a leading vehicle for implementing new networking innovations coming out of standards initiatives. In fact, many of the key open source projects have evolved from the standardization effort, as the SDN/ NFV community recognized the need to streamline and enhance the standardization process to accelerate overall adoption (see Figure 1). For instance, the Open Networking Foundation's (ONF) efforts to define a general SDN architecture resulted in several open source and proprietary SDN controllers. Early implementations in turn helped iterate early SDN de facto standards including OpenFlow, , intent-based Northbound Interfaces, and Transport SDN architecture.

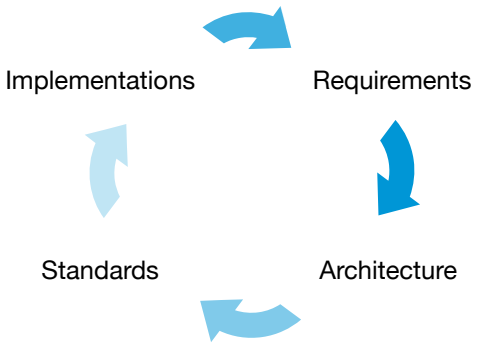


Figure 1a Traditional Methodology
[Output: Standards and Specifications]

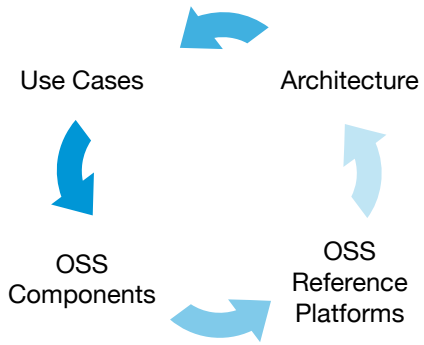


Figure 1b Evolved Methodology
[Output: Software and Architecture]

Similarly, the European Telecommunications Standards Institute (ETSI) NFV Industry Specification Group (ISG), the organization that defined NFV, recognized the need for open source to validate NFV activities. After completing the initial phase of the NFV definition, many of the organizations behind the ETSI NFV ISG spawned the Open Platform for NFV (OPNFV) to refocus on the integration and operational issues in recognition of the growing complexity of large scale software systems. MEF also defined an open source reference platform OpenLSO from the MEF LifeCycle Services Orchestration (LSO) Reference Architecture to address on-demand, inter-provider use cases, building upon MEF Ethernet connectivity services.

As a leader in Open Source best practices, The Linux Foundation has become home to an industry-leading portfolio of Open Source Networking and Orchestration (OS-N&O) projects that span the entire value chain, including from data plane projects such as FD.io, to orchestration, automation and integration initiatives such as OpenDaylight, ONAP and OPNFV, among others.

Widespread support for these open source projects (and many others) has augmented industry convergence and market adoption by helping to:

- Accelerate the entire process by renewing focus on implementation and not just specification
- Validate requirements and use cases using real-world implementations and operational insights
- Refine integration specifications for increasingly complex interactions in large-scale systems
- Assess performance considerations
- Conduct PlugFests to identify and address interoperability issues early in the lifecycle
- Create/automate test plans
- Deliver Proof of Concepts (PoCs) to effectively highlight the benefits of evolving platforms

In addition, open source has also served to refocus standardization on the operationally important use cases and real-world interoperability issues.

While blending implementation into the standardization process is not new—the IETF has long required "rough consensus and running code" prior to ratifying new standards—open source, with its focus on real-world implementations, further democratizes and accelerates the development process.

In an era of digital transformation, standards bodies and open source are converging to drive new architecture and technology initiatives that will reshape the networks and services offerings of the future. Operators and solution providers are choosing from a number of different open source building blocks to deliver interoperable yet customized solutions that address the needs for individual service providers, environments, and deployments.

In their early stages (2013-2016), leading open source networking projects generally progressed as standalone initiatives, albeit influenced by other projects and cross-fertilized by informal interactions. Each project operated with a distinct governance model, development infrastructure, release planning map, and priorities, in spite of the fact that many leading operators and vendors participate in multiple projects.

In 2017, these projects and their developer communities reached levels of maturity that allowed the groups to contemplate more systematic, cross-project engagement. The beginning of 2018 saw the birth of “LF Networking”, a portfolio of six founding projects sharing resources and collectively prioritizing leading priorities common to all projects. Although the projects retain their technical independence, stronger focus is placed on aligning release schedules between upstream and downstream projects to facilitate integration.

Looking forward, the open source networking community is already documenting the next steps required to support networking requirements in adjacent, emerging areas of information technology.

Legal Implications

Standards can produce valuable contributions to data models, formats, and interfaces that can accelerate open source software development within a community. Conversely, open source development can accelerate standards development with real-time development and testing on usable implementations that can provide immediate feedback into the standards development process.

However, this rapid pace can cause consternation regarding how to align IP models where you have a fast, iterative software development model, and a carefully calibrated and deliberate standard development model. Open source projects tend to have IP policies that promote rapid contribution, iterative evolution through small modifications, and open technical discussions. Standards organizations tend to have more complex processes around IP policies that encourage careful IPR reviews and deliberation on essential patents, often with Reasonable and Non-Discriminatory licensing models.

Both models rely on their community of contributors for licensing rights. The open source IP model often focuses on open contribution and rights for anyone who receives the code; members support the project in various material ways, but have no more control over code changes and direction than any other individual in the community. On the other hand, standards bodies are often focused on protecting everyone implementing the standard.

Sometimes a standards effort will also create a reference implementation or snippets of code demonstrating an implementation. This implementation might quite valuable in furthering an open source project, but the standards licensing model might be incompatible with inclusion in an open source project. This unfortunately must be dealt with case by case based on respecting each others' IPR modes, as each standards body has its specific rules, especially for code-based contributions such as APIs. In the case of ONAP, some standards organizations enabled collaboration with open source through adjustments to their bylaws and/or IPR policies. Examples that facilitate collaboration can include an open source contribution mode that is compatible with the open source project license as well.

Successful collaborations between open source and standards groups allows for the open source project to focus on building the best technical software and pairing that development activity with an architecture input process, with a documentation effort at the end to

document the appropriate interfaces that are expected to be standardized and leveraged for interoperability. Whether the standard and open source code is developed within the same project or in different organizations, there are usually many means to enable close collaboration and alignment. Aligning IP models for open source development and the analogous standards development effort is critical to a strong alignment and feedback loop. An example of this would be **Open Container Initiative** (OCI), which was started by Docker and an ecosystem of contributors looking to evolve a cloud container runtime and image specification standard in parallel. The resulting software is licensed under an Apache License, Version 2.0 while the specifications developed are additionally covered by patent grants from the members under the OWFa 1.0 (Patent Only) Final Specification Agreement.

Open Source Drives Real-World Adoption

The Linux Foundation considers open source software as the currency to enable *the greatest shared technology investment in history*.

Growing an ecosystem around a project takes more than just a license. Building a project that scales requires careful consideration of governance model, leadership, and barriers to collaboration. The benefits to operators and vendors are many, including a means of sharing the investment in non-differentiating functionality, especially when the community will benefit from a common approach. By exposing software issues to a diverse community, open source development achieves solutions faster, with higher quality and security, and greater buy-in than any single contributor can attain. Community supported open source software also provides an escrow function that enables code to be maintained even when individual contributors are no longer able to sustain the work.

Open source projects take many forms:

- **Components-** Projects that address a narrowly defined problem whose output may be consumed as an atomic entity. Examples: **OpenvSwitch** (OVS, virtual switch), a platform plug-in to integrate new hardware or software.
- **Platforms-** Projects whose scope encompasses multiple components to yield a framework that can be adapted to meet a range of different user needs. Examples: OpenDaylight, an SDN Controller Framework; Open Network Automation Platform (ONAP), an open orchestration framework; and OpenStack, a Virtualized Infrastructure Manager.
- **Open Reference Platforms-** Projects that focus on the integration of platforms and components, and are primarily used to test, demonstrate, and validate broader solutions. Examples: OPNFV NFV reference platform and MEF OpenLSO reference platform.

The International Telecommunications Union Telecommunications Standardization sector (ITU-T) mission statement is representative of the primary goals for many SDOs:

"...to foster the development and use of interoperable, non-discriminatory and demand-driven international standards that are based on openness and take into account the needs of users, in order to create an environment where users can access affordable services worldwide regardless of underlying technology, ..."

Open source development shares many overlapping benefits: multi-vendor interoperability up and down the communications stack, a collaborative decision-making process, and innovation in a vendor-neutral environment. By blending end-user use cases, reference architectures, testing and certification programs, and rigor traditionally provided by SDOs, a new model for standardization and commercialization has been forged—one that easily incorporates user feedback and requirements at every stage of development.

In order to attain a sustainable open source community, operators must invest in the vendors who contribute the majority of developers for large-scale projects. While operators stand to benefit tremendously from open source, all in the community must benefit to fuel a sustainable advantage. That necessitates that greater investment in the innovators come from established vendors and startups alike. Without economic motivation, it becomes increasingly difficult to justify vendor investment in open source projects. All must benefit for the open ecosystem to thrive.

Finally, open source paves the way for operators to elevate their internal transformation efforts to evolve their processes, people, and organization from ops-driven to software-driven. Through experience gained by participating in open source communities, user organizations are becoming more adept at software systems administration with programming of VNF configurations, service and policy configurations, CI/CD test configurations, and virtualization of traditional BSS/OSS (as microservices).

Harmonization 2.0: Across IT Domains

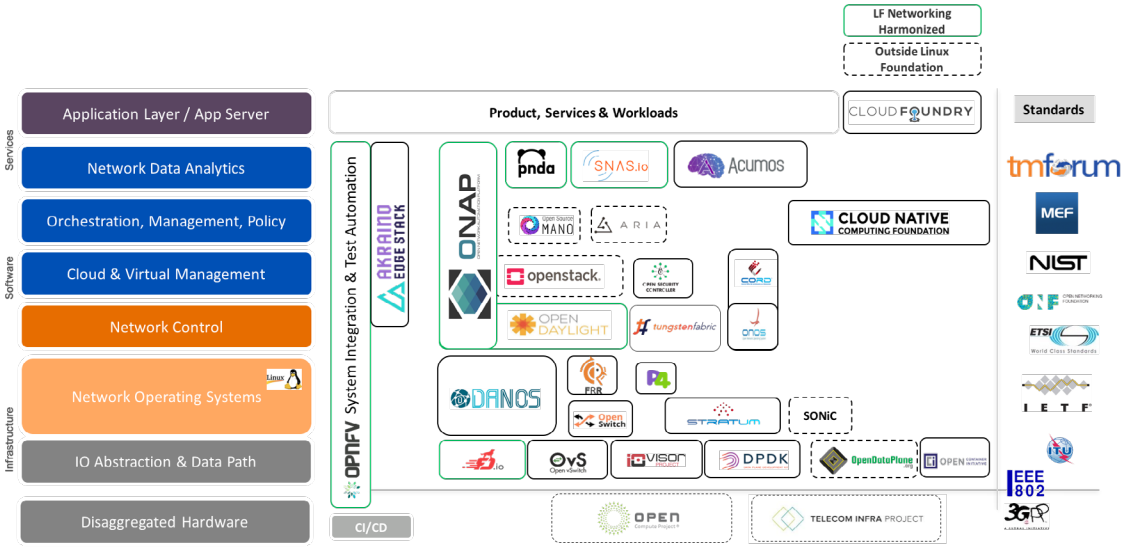
The open movement in telecommunications and networking has led to an umbrella architecture that harmonizes the multitude of networking standards and open source projects. The next frontier will fully integrate software-centric networking within adjacent technology arenas, from cloud automation to IoT.

As with the first, intra-networking phase of harmonization, this movement will address a number of aspects that affect both standards bodies and open source:

- Ease of integration through well-defined information models, APIs, and interfaces
- Common development environment to make it easier to integrate and test the components in a highly automated manner
- Close coordination among the activities, to align based on use cases, functional requirements, schedules, etc.
- Facilitate participation in the activities
- Coordination to streamline exchange of information including IPR, governance, licensing, etc.

In 2017, the Linux Foundation proposed a unified open architecture for a Networking and Orchestration project, as indicated below. The architecture is intended to clarify how the many OS-N&O projects and standards relate to one another, and offer a starting point for much broader harmonization.

Figure 2 below introduces a high-level OS-N&O architecture, which maps standards, open source projects, and open reference architectures.



This end-to-end architecture set the stage for an industry-wide dialogue on cross-domain harmonization, building on the fruits of collaboration between networking open source projects and SDOs, to support emerging areas of technology.

Table 1 describes the architecture elements in additional detail, including the mapping of standards and open source into the communications layers.

Layer	Description	Standard(s)	Open Source Projects
Orchestration & Service	Enable end-to-end composite services	MEF LSO TMForum ZOOM ITU-T	ONAP (Open Orchestrator) PNDA (Network Analytics Platform) ARIA (TOSCA enablement)
Control and Management	Provide network control and management (NFV, SDN, and legacy networks)	NFV MANO IETF Routing IETF (many) ONF (OpenFlow)	OpenDaylight (SDN Controller); OpenSwitch (Whitebox NOS) JuJu (NFV G-VNFM) OpenStack (NFV VIM)
Infrastructure	Provide Network Data Plane and NFV Infrastructure	ETSI NFV-I IEEE 802 3GPP OIF	OpenvSwitch (virtual switch) FD.io (data plane acceleration); DPDK (fast packet processing) KVM (Hypervisor)

Table I- Unified Open Networking & Orchestration Architecture Description

This next stage of harmonization is predicated upon a new degree of collaboration and introspection to thoroughly integrate open source and standards process across IT domains. Such an ambitious goal will not be attained overnight, but there are steps that have already been taken to encourage progress:

- **Ongoing, open communication** to resolve the cultural differences between standards bodies and open source in different domains. In addition to implementing good tracking methods and governance on both sides, this means open source collaboration must be seen as part of the strategic program within the standards organization to ensure the feedback loop is there, as this requires both human and governance resources.
- **Continuous learning and harmonization:** It is necessary to synchronize changes made by each group involved to ensure changes made in an open source implementation are fed back to the next release of the standards development, and vice versa. One open source project, ONAP, has taken the step of including a SDO Coordination committee under the TSC (Technical Steering Committee). It consists of volunteers who are active in both the affiliated standards organization and ONAP projects. The committee provides frequent updates on the latest standards developments applicable to the ONAP community as well as the coordination between various standards groups and how they can be joined up to add value to ONAP.Close coordination among the activities, to align based on use cases, functional requirements, schedules, etc.

- **Multi-SDO/open source activities**, such as the Information Modeling initiative, containerization of networking applications and services and more
- **Cooperation on a revised technology adoption methodology** that blends standards, open source, operator-contributed use cases, and vendor contributions. Some standards organizations are now using proof-of-concept projects as a way to introduce new features into open source. This allows SDOs to focus on their specific interests. For example, some groups are looking closely at how to connect OSS/BSS to ONAP; others are interested in scenarios such as 5G and IoT integration, for which features may not the focus in of upcoming open source project releases. Decoupling the open source project schedule from SDO schedule is key to accelerating innovation and rapidly expanding the ecosystem.

While there is growing collaboration in the SDN/NFV standards/open source community, the path to cross-domain harmonization must address a particularly important set of business factors, including resolving the legal, IPR, licensing, and governance.

We envision a model where end-users engaged in projects across multiple areas of IT articulate their needs synchronously across the relevant projects and facilitate engagement between developer communities, through use case definition and high-level priorities. These in turn enable creation of open reference architectures to scope the functionality required to address the requirements. Reference architectures will help refine a series of open source projects and platforms, and channel critical mass to avoid unnecessary proliferation of solutions. And of course iteration based on real-world data and experience is essential towards realizing this vision.

Summary

SDN and NFV represents one of the most significant shifts in networking in decades, accompanied by an unprecedented shift from hardware-centric to software-driven architectures. Such a change not only results in new technologies, but automated operations, dynamic business models, and software-driven organizations.

Harmonizing networking open source and standards has paved the way towards the long-anticipated adoption of software-accelerated networking innovation. Next, the Linux Foundation is actively engaged in aligning its rapidly growing portfolio of Networking and Orchestration projects, which span the entire stack, with open source projects and SDOs in adjacent technology realms.

Our goal is to engage more closely with key operators to ensure our projects are directed towards the greater good. Along the way, we intend to resolve the major differences to realize our vision of collaborative innovation to enable the entire industry to benefit from the greatest shared technology investment that is transforming one of society's most important industries.

Acknowledgements

The Linux Foundation gratefully acknowledges review comments from: Steven Wright, former Chair, ETSI NFV ISG and Chair; OPNFV Advisor's Group (AT&T) Thomas Li, Director, Standardization and Industry Development (Huawei); Pascal Menezes, MEF CTO; David Marr, Vice President, Legal (Qualcomm); Jenny S Huang, Lead of OSS/BSS Strategy Group, AT&T Standards and Industry Alliances

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Appendix I

Acroynms

BSS- Business Support Systems

CI/CD- Continuous Integration / Continuous Deployment

DPDK- Data Plane Developer Kit

ETSI- European Telecommunications Standards Institute

G-VNFM- (NFV) Generic VNF Manager

IETF- Internet Engineering Task Force

ITU-T- International Telecommunications Union Standardization Section

LF- Linux Foundation

LSO- (MEF) LifeCycle Services Orchestration

MANO- (NFV) Management and Orchestration

NFV- (NFV) Network Functions Virtualization

ONAP- Open Networking Automation Platform

ONF- Open Networking Foundation

ONOS- (ON.LAB) Open Network Operating System

OPEN-O- (LF) Open Orchestrator Project

OPNFV- (LF) Open Platform for NFV Project

OS N&O- (LF) Open Source Network and Orchestration

OSS- Operational Support System

SDN- Software Defined Networking

SDO- Standards Development Organization

VIM- (NFV) Virtualization Infrastructure Manager

VNF- (NFV) Virtualized Network Function

Appendix II

SDN/NFV SDOs & Open Source Projects

SDOs

3GPP- SDO devoted to telecommunications mobile services/platforms

ETSI NFV ISG- European Telecommunications Standards Institute Network Functions Virtualization Industry Specification Group (ISG)

IETF- Internet Engineering Task Force

ITU-T- International Telecommunications Union Standardization Section

MEF- Telecommunications SDO focused on Carrier Ethernet and Orchestration

TOSCA- (OASIS) Topology and Orchestration Specification for Cloud Applications

ONF- SDN SDO & Industry Group

TMForum- Telecommunications SDO focused on services

Open Source Projects

ARIA- TOSCA enablement

DPDK- Packet Processing acceleration

ECOMP- Enhanced Control, Orchestration, Management, and Policy

FD.IO- (LF) Fast Data I/O

JuJu- Open VNFM

ONAP- (LF) Open Networking Automation Platform

ONOS- (ON.LAB) Open Network Operating System SDN Controller

OpenDaylight- (LF) SDN Controller Framework

OPEN-O- (LF) Open Orchestrator

OpenLSO- (MEF) SDN open source reference platform aligned with LSO

OpenStack- Cloud Management

OpenSwitch- (LF) Open Network Operating System for Whitebox Switches

OPNFV (LF) Open Reference Platform for NFV

OSM- (ETSI) Open Source MANO

PNDA- (LF) Platform for Data Network Analytics

The Linux Foundation promotes, protects and standardizes Linux by providing unified resources and services needed for open source to successfully compete with closed platforms.

To learn more about The Linux Foundation or our other initiatives please visit us at www.linuxfoundation.org