ACG RESEARCH

KEY FINDINGS

- Open source collaboration is increasingly necessary to capture new market opportunities for both CSPs and vendors.
- Top CSP motivations for open source adoption are to unify CSP technology investments, avoid vendor lock-in and access a broader talent pool.
- CSPs and OSPC vendors view open source solutions as strategic; DPC vendors view open source more tactically.
- Although CSP and vendor relationships and vendors' revenue profiles change with open source adoption, CSPs indicate a strong preference to continue to collaborate with leading vendors.
- Adopting open source requires investment from vendors to establish themselves as leaders in an open source community. OSPC vendors are already executing on this strategy.
- CSPs expect open source to deliver future financial benefits but acknowledge it is early days for identifying those results.

Succeeding on an Open Field: The Impact of Open Source Technologies on the Communication Service Provider Ecosystem

An ACG Research Report, 2018

Summary

The increasing use of open source technologies in communication service provider (CSP) networks is having a profound impact on the CSP ecosystem. In this report, we explore the attitudes, motivations and impacts of open source adoption on CSPs and their vendors. We analyze changes in revenue, solution content and research and development (R&D) investments over the coming five years.

To bind the scope of the analysis and provide meaningful areas to research, we selected three networking areas to investigate: orchestration, network control with software-defined networking, and packet transport infrastructure, including transport routing and data center switching. Combined these areas represent over $20 billion in annual spend in 2018 and over $40 billion in 2023. We segmented the vendor ecosystem into two categories of suppliers: open source portfolio companies (OSPC) and diversified portfolio companies (DPC). OSPCs perceive open source collaborations as strategic to their business model and have built their companies in the era of open source. Like the CSPs, OSPCs view open source as an opportunity to expand their addressable market.

Diversified portfolio companies view open source collaborations more tactically and are motivated by faster time to market and/or reduced R&D costs for a given development. DPC companies are also driven to participate in open source communities based upon the priority of their CSP customers. DPCs have an opportunity to evolve their products and business models over time, but commitment and adaptation to new business models will be required.

Initial moves are being taken within the ecosystem but succeeding with open source adoption will require commitment and investment from CSPs and vendors to lead communities, drive requirements and execute deliveries. Although CSPs expect future financial benefits, we are still early in the deployment life cycle to ascertain those outcomes.

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Introduction and Key Findings

With the increasing adoption of open source technologies, the nature of solution delivery in communications service provider (CSP) environments is changing. This research identifies and analyzes the impact of open source technology adoption in CSP networking solutions as they pursue networking and business objectives. To obtain a broad ecosystem perspective, we engaged both service providers and product suppliers (sometimes called vendors in this document) in our interviews, discussions and analyses. We focused on open source adoption in three key networking areas: orchestration, software-defined networking (SDN) control and network infrastructure (including transport routing and data center switching). Throughout our analysis we sought to understand motivations, methods and impacts of open source. Impacts include business and financial as well as product and solution evolutions.

Key Findings

- The markets in which the solutions we are focused on in this research are provided to CSPs will grow from an aggregate value of $23 billion in 2018 to over $43 billion in 2023[1]. Of this 2023 total over $11 billion will be in play for being satisfied by solutions based wholly or substantially on open source technologies.

- Incorporating open source technologies into CSP solutions and network infrastructures creates opportunities to access new markets and categories of revenue for both CSPs and product suppliers. One example is adapting open source orchestration tools for use by large enterprise customers. A second example is support of new carrier use cases and deployment environments: virtual central office/CORD, multi-access edge computing (MEC), video, Internet of Things (IoT) and augmented/virtual reality.

- Leading CSPs are responding to global competitive pressures and thinking strategically about how they can utilize open source technologies to enhance competitiveness. Top CSP motivations for adopting open source technologies include unifying technical approaches being used to solve common CSP problems and unifying their investments in addressing them, as well as avoiding vendor lock-in and accessing a broader talent pool than might be realized with any single vendor or by service providers.

- The rate of open source adoption varies by networking segment. On a percentage basis, cloud and virtual system infrastructures currently have the highest rate of open source technology adoption. The next highest percentage of open source adoption is in SDN networking/control, followed by network and services orchestration. Transport network infrastructures are in the early stages of open source adoption with data center switching having advanced more quickly than transport routing.

- OSPC vendors consider their use of open source as strategic; DPC vendors view open source integration as a more tactical choice/selection.

[1] Source: ACG Research, 2017 and 2018 Market Reports on Service Provider Routing, Data Center Switching, SDN, NFV, and NFV Management and Orchestration.

- OSPC companies have business plans and practices highly aligned with open source solution delivery. OSPCs are using professional services, custom tools and migration skills to drive early revenue. As open source software evolves, OSPCs expect the percentage of their revenues based on software subscriptions to grow.

- Our expectation is that software revenues for OSPCs in the orchestration and SDN control segments, for example, will grow from 40% to 60% of their total, while revenues from services will trend downward to 30% from 40% of total, and tools will similarly comprise a smaller percentage as solutions mature, moving from 20% of totals in 2018 to 10% in 2023.

- DPC companies have a much lower concentration of open source content in their offerings and have established business practices that are more aligned around selling proprietary, vertically integrated solutions. However, DPCs have an opportunity to invest in open source collaborations and adapt their solution models to align more closely with CSPs' objectives and maintain a clearly aligned value proposition that resonates with CSP customers more over time.

- In the same categories of orchestration and SDN control as we indicated above for OSPCs, we expect DPC revenues to evolve from 80% based on software licensing and 20% based on services in 2018, to a mixture of 60% based on software licensing, 30% based on services, and 10% based on tools, showing a growing alignment with CSPs' interests in close working relationships and significant leverage of integration services and tools.

- CSP relationships with vendors will evolve with increasing open source adoption; however, in a welcome finding for vendors, CSPs indicate a strong need and desire to collaborate with vendors who can help them achieve their networking and business objectives.

- Leading CSPs and OSPC vendors acknowledge the need to invest in the open source community and are supplying leadership, code and staff to ensure community success, support for their requirements and timely release delivery.

- Vendors and CSPs generally agree that open source solutions are initially more immature than proprietary, single-vendor ones. This immaturity translates into a 30% increase in test/integration resources in the early stages of an open source development.

Industry Context

The ubiquity of the wired and wireless Internet has had profound impacts on networks and their business models. Universal connectivity from any device to any other device and applications means that everyone is empowered to deliver the next killer application. In this context, the first killer application for mobile devices was voice. The mobile phone ran a single application (the phone app if you will) and the CSP central office contained the application server, in this context a mobile telephone switching center. The network existed to connect the app (voice call) to the application server (telephone switch).

Fast-forward to today. Our consumer and business applications still run at the edge of the network and need to be connected to other users and/or information or an application server. What is different today is that our devices have powerful compute and storage capabilities and open software interfaces to enable them to run any application they can download, and our application servers are virtualized and distributed so they do not have to be tied to a specific building or geographic location. The virtual central office or application server can be anywhere. This modern networking reality has enabled Internet content providers like Netflix to become the largest commercial streaming video service in the world with over 100 million subscribers in 190 countries.

To succeed in a networking environment where CSPs own the network but not necessarily the applications and the application revenue, CSPs are looking for innovations that can improve their efficiency and creation of value. They want the ability to expand their services and applications dynamically and continuously. They are searching for orders of magnitude in efficiency improvements in developing and delivering new and enhanced services. Enhancements are needed in residential and industrial, consumer and enterprise and in mobile and fixed services environments. They want progress in both existing applications such as consumer video as well as in rapidly emerging spaces such as industrial, municipal and consumer IoT, augmented/virtual reality and edge computing and analytics to enhanced operations at every layer of the solution delivery environment.

The net effect is a drive for faster and more ubiquitous innovations that increase network flexibility, simplify information and application accessibility, focus greater attention on end user services and enable service providers to reduce artificial barriers and accelerate the creation of new services. The rise of open source communities and solutions is a direct response to CSP needs and pressures. By assembling cooperative collaborators and leveraging the power of the community with not just standards but with shared software implementations and programmatic interfaces, CSPs and their ecosystem vendor partners are developing profound, positive networking and business model impacts to go faster, smarter and further than ever before at a fraction of the time and cost of today's networks.

Analyzing the Impact of Open Source on the CSP Ecosystem

The analysis and project that this report describes developed from a series of discussions between the Linux Foundation and ACG Research over many months. Although the Linux Foundation provided sponsorship, the report was developed and executed independently by ACG Research.

Scope of Study

The introduction of open source technologies into global ICT markets is having a profound impact on multiple segments and solution delivery ecosystems: enterprise information and communication technology, cloud-based application service providers, and CSPs who connect end-users to each other and to applications via a plurality of networking configurations. When exploring the impact of open source adoption on these ecosystems, we first elected to concentrate on the impact of the new models to the CSPs while considering exploration of additional market ecosystems in the future.

CSP solution designs and modes of operation are significantly impacted by the introduction of open source components. In many solution categories, CSPs use tightly integrated, proprietary solutions that interoperate with each other through the implementation of industry specifications and standards.

The rigidity and constraints of the existing solution delivery models have stimulated CSPs to seek improvements in and/or removal of existing limitations from core technology elements that are central to meeting their customers' demands. CSPs require greater flexibility in choosing the components that will best meet their service delivery goals to deliver a global, cloud-based, fully-connected network.

Approach of Study

To acquire a deep understanding of CSP and product supplier attitudes, motivations and intentions, we conducted a series of one-hour to two-hour interviews with more than 20 executives from leading CSPs and product suppliers that have direct responsibility for their companies' technology, product and solution delivery plans. Some interviews were via conference call, other were face-to-face. The executives are from companies in the APAC, EMEA and North American geographies. In some cases, the interviews involved one senior executive from the company; in other cases, two or three executives actively participated simultaneously in the discussion. We spoke with CEOs, CTOs, vice-presidents and directors who were actively involved in the three areas of focus of the study: orchestration, network control or transport infrastructure. Company names and the names of the interviewees remained anonymous, so the participants felt enabled to speak freely.

To provide consistency across the interviews and enable us to quantify the information, we created a questionnaire (one for CSPs and one for product suppliers) that we provided to the interviewees prior to the interview. We also turned the questionnaire into a score sheet that we also shared with the interviewees. During the interviews we populated the score sheet with numerical values (example, rank of 1 to 5) or a bounded set of appropriate responses like higher, lower, yes, and no. We also captured relevant qualitative information and comments. We then combined the score sheets into a common set and analyzed it and compared the results across CSP and product supplier segments and types.

The outputs of the study are reflected in this report. Where we gathered numerical responses to questions about motivations and drivers, we reflect the output as a percentage of the maximum score across all

interviewees in that category. As an example, if an individual motivational item received the maximum score from all respondents for that item, then the bar graph reflects 100%.

We also used a strategic planning tool called Harvey Balls to represent the depth of consistency or inconsistency in a response. As an example, if all respondents answered yes to a yes/no question, then the Harvey Ball was a fully filled circle indicating strong alignment of views. If, however the respondents were split in their responses with half answering yes and half answer no, then the Harvey Ball was half filled. The extent to which the circle is filled (fully filled, filled by ¾, ½ or ¼ or not filled at all) conveys the degree to which the outcome in that cell is being experienced by all representatives of the type of company that is aligned with it. Harvey Balls are a great way to represent relative direction or consistency when the data is not numerical or from a relatively smaller sample size than one might find in a survey. The circles in each cell are colored:

- Green indicates items where a positive response reflects a positive impact on the ecosystem.
- Yellow indicates inconsistency in responses or areas where open source does not definitively produce the kind of outcome being asked for.
- Red indicates items that have a comparatively negative or undesirable effect on the ecosystem.
- Black is used for items that do not have a definitively positive or negative impact on the ecosystem.

The final output tool was a set of comparative pie charts for the product suppliers to identify changes in their revenues, mixture of product contents, and in their R&D budgets, reflecting the impact of open source technology adoption on their plans, over five years. This is where the different business models and solution approaches between OSPC and DPC vendors are most apparent. As the revenue, networks and budgets (and public financial statements) of CSPs are vast and not carved out into the segments we studied in this report, we did not create similar pie charts for the CSPs. There are many forces impacting CSP income statements, and we are early in open source adoption.

Solution Categories in Focus

CSPs broadly employ a network architecture constructed of three dominant types of solution, organized into a functional hierarchy. Each of these categories is the focus of significant development of open source technologies and of openly architected reference designs and specifications for use in elements of operation common across the global CSP community. These categories are orchestration, network control and network infrastructure and form the basis of our analysis.

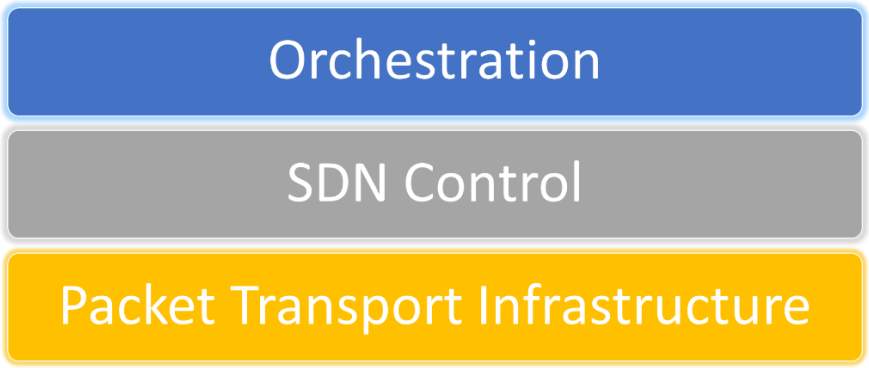


Figure 1. Tiered Analysis Focus of Study

Orchestration refers to the tasks of defining, composing, provisioning, monitoring, managing and evolving the complete service delivery infrastructure CSPs are employing to deliver their services. We broadly divide orchestration solutions into higher level, end-to-end service orchestration and management solutions; and mid-to-lower-level resource orchestration solutions such as those employed in virtual service delivery infrastructures as part of the management and orchestration functionality for network function virtualization (NFV). At each of these layers, there are solutions based on largely proprietary designs, as well as solutions incorporating varying and increasing amounts of open source technology to perform the necessary functions.

Network and SDN Control refers to the logically abstracted and centralized functionality of software-defined networking (SDN) and the controllers and applications closely related to them that unify the operation of diversified network infrastructures. The two broad environments for network control are SDN for CSP multi-layer transport service infrastructures such as L2 and L3 VPNs and multi-service transports; and SDN for cloud and virtual service delivery fabrics that simplify the operation of physical and virtual service delivery infrastructures of various sizes that are generally operated in a data center architectural model.

Packet Transport Infrastructure or just infrastructure refers to the IP, IP/MPLS routing and IP/Ethernet switching infrastructures that provide the widely distributed forwarding planes employed in the transport and data center infrastructures of CSPs. This includes deployments in wide area networking domains such as metropolitan areas and core backbone transports, as well as installations in data center infrastructures in both centralized and, increasingly, in distributed sites such as central offices and edge computing installations.

The Emergence of New Development and Operating Models

CSPs' drive for greater flexibility and speed in the development of solutions has stimulated a broad interest in new types of technology creation and solution development than have dominated their practices in the past.

Constraints of Prior Models

Technology developments for CSPs have historically been implemented in closed groups of developers working on a proprietary design for functionalities CSPs and their peer industry colleagues have agreed are necessary for the creation of networks and services. The interoperability and integration requirements of each element are generally described by specifications clarified in industry standards bodies such as the Internet Engineering Task Force (IETF), the Institute of Electrical and Electronics Engineers (IEEE) and the Consultative Committee for International Telegraphy and Telephony (CCITT). Generally, these elements work on a black-box model in which solutions that conform to the standards can be connected to each other and expected to perform an essential baseline of functions that fit the deployment environment the CSP requires (IP network peering, core IP network forwarding, link utilization counters on a network infrastructure node using a standard format, etc.).

This model has done well at generating the foundations of the Internet as we know it today. However, this model has proven itself to be costly in both time for integration of multiple platforms into a common solution for the CSP, as well as slower in delivery of important innovations that the service provider community want. CSPs are not able to move as fast as they would like in realizing new functionality and solutions and they are interested in shifting the technology creation process to increase both flexibility and speed.

This observation is not to say that privately sourced innovations have no place in service provider deployments moving forward. Instead, service providers need the technology creation equilibrium to shift a bit more in their direction and in their favor, so the costly and cumbersome dynamics of working with privately developed solutions can be reduced and the flexibility and cost effectiveness of their operations can increase.

Attributes of New Models

The new solution development models CSPs and many vendors are working on have several, defining attributes.

First, the relatively monolithic nature of proprietary designs is giving way to a model that disaggregates key components and allows them to be integrated on a more flexible mix and match basis that aligns with a specific solution goal. This concept is being applied extensively in software development, where the notion of microservices (versus monolithic subsystem designs) allows for a nimbler aggregation of components into solutions if the execution and interoperability characteristics of the resulting modules are visible and readily understood. The concept is also being applied to hardware designs in both networking and computing. This creates the opportunity for hardware designers to create optimizations for switching and routing, for example, and for software developers focused on switching and routing solutions to adapt their code to a variety of underlying hardware designs, increasing the range of use cases

that can be addressed and the speed with which the solutions can be created. The disaggregation model creates a significantly more open playing field for developers to produce innovations and supports acceleration of innovations across a broad range of opportunities.

A second major dimension of new development practices to which CSPs are gravitating is a preference for leveraging open source technology developments to avoid making redundant investments and reinventing the wheel in areas where multiple CSPs are grappling with the same challenges. In addition to avoiding redundancies and enhancing efficiencies in solution development, open source offers CSPs the advantage of being able to assemble solutions from a set of underlying technologies to which they can contribute and assemble in a manner more of their own choosing as they decide how they want to address application requirements.

There remains a significant amount of independent, proprietary innovation that can be layered on top of open source foundations in creating a new service delivery framework. The main attribute of open source that creates an advantage for CSPs and vendors is the opportunity for all the members in a community to consider which are the most important common elements of functionality that should be provided in a platform and to prioritize on making that foundation useful to the broadest possible percentage of contributors. With this common baseline in place, both CSPs and vendors can concentrate on the unique combinations of the open source baseline and the value add of their own innovation that they can contribute that will accomplish the business goals of the CSPs.

The final dimension of development practices which is shifting is a movement away from what has come to be known as the waterfall development methodology and toward a model commonly referred to as DevOps, or closer synchronization of development and operations disciplines in managing a solution. The waterfall methodology has been strong in its emphasis on strict alignment of work into sequential phases of activity, moving from concept and design work to development and test and ultimately into controlled introduction to operations. After which the cycle is repeated for each new version of functionality the operator decides to deliver.

For all its discipline and rigor, the waterfall model's primary shortcoming became the length of time and overall cost required to yield new capabilities for solutions. Progress simply took too long. The enhancement that has been created over the course of many years of increasing sophistication in both software development and test as well as in operations controls creates a more tightly integrated continuum from developer to testing function to deployment of code into a robust operational platform. The pipeline of functions is substantially more automated, meaning developers can test their new function against a continually running testing environment. And the testing environment can apply more dynamically executed tested regimens, based on the target runtime environment, that allow it to reject the new functionality, or accept it and promote it along into the operational environment in a disciplined live updating cycle that places new functionality into production that meets the operator's requirements more quickly. This shrinkage of distance between developer and operations is the essential agility and productivity enhancement that DevOps has brought into being.

The DevOps methodology can be applied in a new construct of a distributed development community such as those employed in open source developments. In this model the series of contributions that the

project community determines should be brought into the code base can be instantiated by contributors, or committers, from the CSP itself, from a vendor organization focused on the problem space, or from others who are members of the project community such as researchers and other interested organizations.

The breadth of technical insights, and the size of the community committing to the solution's enhancements both have the possibility of expanding by an order of magnitude when employing the three enhanced development practices just highlighted: microservices design, open source development and DevOps methodologies.

These three attributes of the evolved solution development environment on which CSPs are focused moving forward bring with them a significantly expanded opportunity to innovate, along with a new set of practices and relationships to master. The research in this report is focused on those new practices, their relevance in the solution categories we are focused on, and their impact on the operating plans of CSPs and the vendors with whom they are working to develop their solutions.

Industry Communities Driving the Implementation of the New Models

There are numerous communities participating in development of open source technologies today. We describe several them here. One of the organizations working with a wide variety of communities in open source networking currently is the Linux Foundation. The Foundation, which serves as a curator and facilitator of many of the projects cited in this report, was founded in 2000. Its technical origins date back to 1991 when Finnish computer science student, Linus Torvalds[2], created what we now know of as the open source Linux operating system.

Today, the Foundation has more than 1,000 members and is home to some of the largest open source projects in the world. Networking projects range from data plane acceleration developments like the data plane development kit (DPDK) and fast data I/O (FD.io), to the network control and orchestration layers, and to analytics and applications in multiple domains.

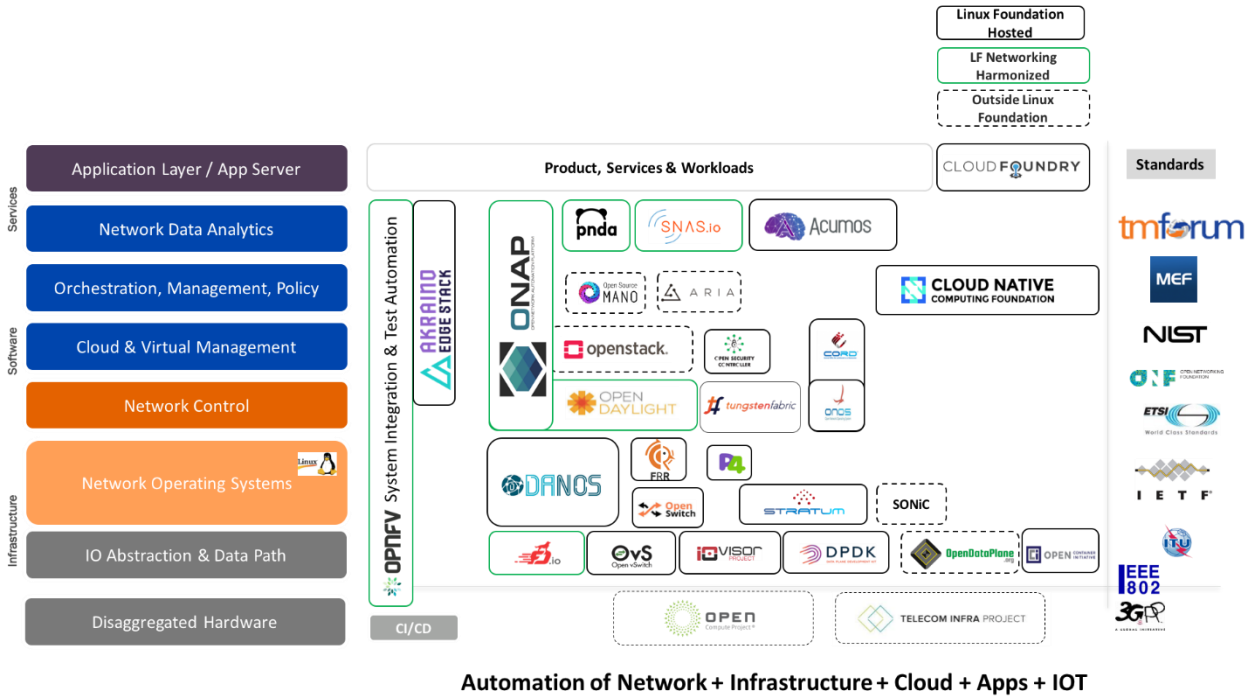


Figure 2. Open Source Networking Communities, Projects and Initiatives

Not all open source communities are hosted by the Linux Foundation. Other open source communities such as the OpenStack Foundation and the Open Source Management and Network Orchestration (MANO) project are outside the Linux Foundation's umbrella. Liaisons exist to aid in coordination and information sharing across the open source organizations. The Foundation also has liaisons with standards development organizations that are involved in network transformation, including the TMForum, MEF and ETSI.

[2]Linus is a Fellow at the foundation and remains active in collaborations related to Linux.

To bring a more coordinated approach to the myriad of disparate but adjacent open source networking projects, the Linux Foundation established the Linux Foundation Networking Fund in January 2018. Nine of the 10 largest open source networking projects are housed in the Linux Foundation. The fund is meant to harmonize between open source and open standards with an eye toward supporting emerging, network-dependent initiatives and innovations. The proactive approach is working to bring communities with shared goals together.

Open Source Orchestration

There are numerous projects focused on developing open source software distributions in network and services orchestration. The Open Network Automation Platform (ONAP) was formed in 2017 by the merger of AT&T's ECOMP orchestration software project and the Open Orchestration project. With broad vendor participation covering over 60% of worldwide mobile customers, ONAP is one of the largest open source projects in the world. Additional orchestration and NFV related projects include Open MANO, the OpenStack Foundation and OPNFV.

Open Source Network Control and SDN

Network control and programmability with SDN also has multiple open source projects. Open Daylight is one of the largest and most comprehensive with participation from service providers, vendors and large enterprise companies. Additional projects include ONOS and Tungsten Fabric (previously Open Contrail).

Open Source Network Infrastructure and Packet Networking Data Planes

There are numerous projects that focus on data plane acceleration and performance. FD.io and DPDK are the most common. Additional data plane and networking infrastructure communities include OVS, Open Data Plane, and Facebook's open compute platform (OCP) and Telecom Infra Project.

Findings of the Study

We present the findings of our analysis in the remaining sections of the report.

We begin by focusing on the size of the markets with CSPs for the categories of products and solutions we have focused on in our analysis for the vendors who are supplying them. This presents a view of the value that is at stake in the evolutions we are analyzing. As part of this illustration we identify emerging opportunities in new applications and services that CSPs are pursuing, in parallel with the evolution of their existing offerings, as a means of envisioning the environments into which their solutions will grow.

We follow this market context with a discussion of the findings of our research on the impact of open source adoption on the members of the CSP ecosystem we have in focus, namely, CSPs and the vendors of orchestration, SDN control, transport routing and data center switching who are working with them. We describe the perspectives of CSPs and vendors on how and why they are bringing open source technologies into their offerings, as well as the impact of this adoption on critical elements of their operating plans, including development and testing methodologies, relationships between CSPs and their vendors, and the impact of open source adoption on vendors' business models, product delivery practices, and financial metrics and expectations.

Sizing and Evolution of CSP Vendor Market Segments

In this section we describe the markets for the product categories on which we focused as they are today in 2018 and as we project they will be in five years (2023). This illustrates the direction of each segment and sets a quantitative context for our analyses in each.

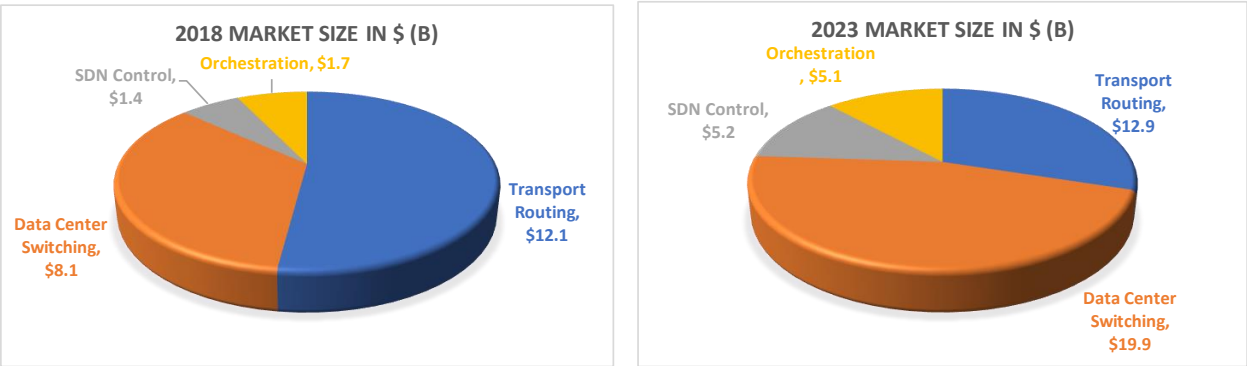


Figure 3. Solution Market Size by Category 2018–2023

The size of the worldwide market for product sales to service providers in the orchestration, SDN and transport infrastructure segments in 2018 and 2023 is shown in Figure 3[3]. We divide transport infrastructure for CSPs into transport routing and data center switching. Transport routing includes the IP/MPLS platforms CSPs use in their edge, backbone/core, and data center edge deployments. It includes both physical and virtual routers. Data center switching includes IP/Ethernet core/spine, top of rack/leaf and overlay virtual networking solutions CSPs use in their data center and other cloud-based service

[3] Source, ACG Research 2017 and 2018 Market Reports in Service Provider Routing, Data Center Switching, SDN Control, NFV and MANO (Management and Network Orchestration).

delivery installations (such as mobile packet cores, enterprise and residential service edges and in the future, vco/CORD and multi-access edge computing sites).

The size of the combined overall market for these product offerings with CSPs is $23.3 billion in 2018, evolving and growing to $43.1 billion in 2023 (with an overall CAGR of 16.7%). Orchestration and SDN software and the data center switching segments (with CAGRs of 32.5%, 38.4% and 25.3%, respectively) are the fastest growing segments. Of the total market available to vendors in 2023, $11+ billion will be in play as the likely opportunity for open source-based solutions across the full set of categories. The order of magnitude of the opportunities by segment shows the greatest amount available in data center switching ($5+ billion), with orchestration, SDN control and transport routing each representing $2+ billion in opportunity for solutions either wholly or substantially based on open source technology components. With these CAGRs and amounts, there is clearly a significant opportunity for solution providers to pursue.

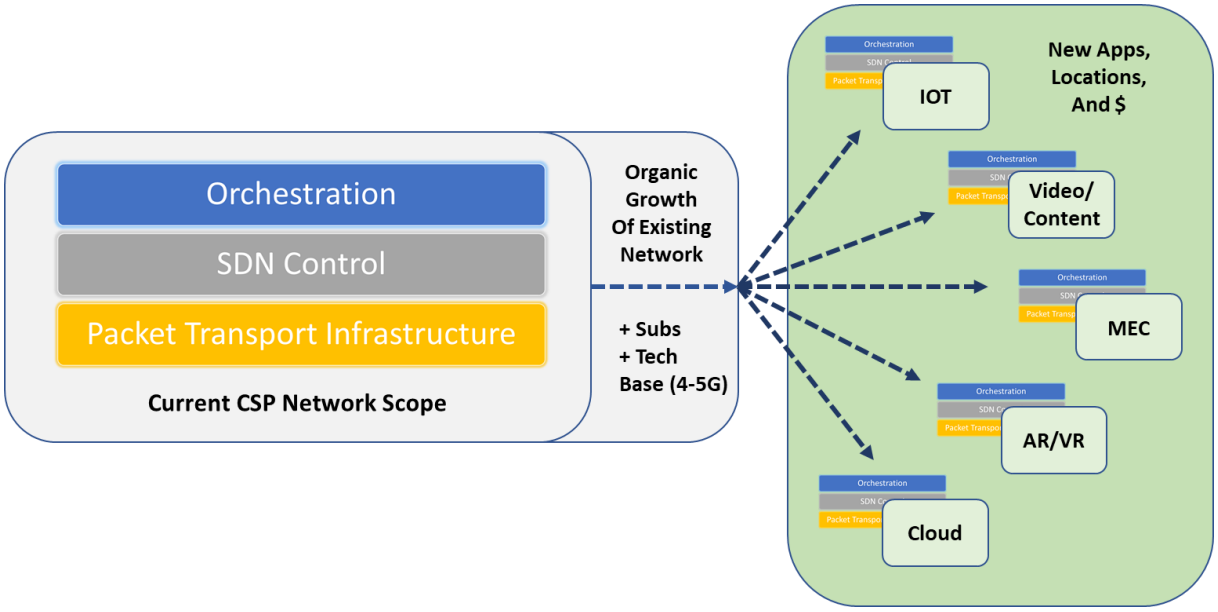


Figure 4. Use Cases and Applications Creating Market Expansions

Figure 4 presents a view of how CSP networks will evolve during this timeframe. One source of evolution in CSP infrastructures is organic growth in services they are currently delivering (such as 4G mobile and wireline broadband Internet). In these categories there is growth in traffic volumes being carried, and there is an architectural transformation under way to incorporate software-driven, disaggregated, and increasingly open source-based solutions.

In parallel there is a set of use cases rapidly emerging that extends the scope of opportunity to distributed sites such as virtual central offices including central offices re-architected as data centers (vco/CORD), multi-access edge computing (MEC) sites, supporting an emerging set of use cases in IoT, video and content distribution; use of augmented and virtual reality in end user applications; and support for cloud-based applications in distributed deployments for reductions in latency and improvements in end user experience. Solutions supporting these use cases are generally based on mini-cloud designs in locations that expand the scale of the CSP networks by an order of magnitude, as illustrated in the diagram. The aggregate of computing power in a global sense that will be deployed for these installations will equal the

computational power of multiple hyper-scale cloud provider data centers, as the installations progress. This transformation is bringing with it an increase in the demand for SDN, orchestration, transport routing and data center switching solutions to support the expanded deployments.

Direction of the Orchestration Total Available Market (TAM)

We now discuss the dynamics affecting each of the segments, starting with orchestration.

CSPs' needs in orchestration are evolving in parallel on several dimensions. These can be considered hierarchically. At the highest level is software that has an end-to-end service role, as is the case in the ONAP project. This software generally supports a service life-cycle perspective, containing functions from design and service creation, to provisioning and activation, to operations management, analysis, upgrade and evolution.

Beneath this tier, in a resource-facing sense, is software that simplifies deployment and operation of virtual system infrastructures in cloud-native applications, NFV, vco/CORD and MEC. This carries the overall tag of MANO and incorporates the domains of NFV (with NFVO, for deployment and operation of virtualized network functions) and virtualized infrastructure management (or VIM, for automating deployment and operation of virtual system infrastructures). Open source developments are significant at each of these layers of orchestration, and each contains a significant portion of the overall orchestration TAM.

In parallel is the functionality for managing hybrid virtual and physical infrastructures, which is the reality in most CSP environments. This can be thought of as a lateral branch to MANO for virtualized infrastructures in the orchestration stack.

Together these categories make up the TAM for orchestration solutions with CSPs. This is a high-priority area of focus for CSPs and is one of the highest growth areas of software innovation and development in support of their service delivery needs. We expect the TAM for orchestration software to triple from 2018 through 2023 at a CAGR of 32.5%. This is partially because of the nascent level of the offerings at the current time, as well as the high priority that CSPs and their vendor suppliers are placing on the domain.

Direction of the Network Control and SDN TAM

We consider SDN to be closely related to both the orchestration and the network infrastructure segments, but also distinct as far as solution deliveries are concerned. This is because of the close relationship SDN controllers and their application modules have with the idiosyncrasies of specific network elements, even while they are abstracting the operation of those elements to make integration with orchestration and automation simpler and more efficient.

SDN software is used by CSPs in both transport, wide area deployments in multiple domains (access, metro, core and edge) and in data center infrastructures supporting NFV, cloud-native applications and emerging use cases at the network edge. Overall, SDN software is used to augment programmability and simplification of network operations in each domain and, like orchestration, is still in the relatively early stages of adoption in the CSP market.

We estimate the SDN software market with CSPs will also grow by more than three times during the next five years, from $1.4 billion in 2018 to $5.2 billion in 2023 (representing a CAGR of 38.4%) based on the requirements to support expanded network scale, growing diversity of use cases and the need for operators to simplify and streamline operational expense.

Direction of the Transport Infrastructure TAMs

Transport Routing

Although the scale and range of deployments of IP routing platforms in CSP networks will expand, the revenues earned from the sale of routing platforms will increase at only a modest 2% rate between 2018 and 2023. This is partially due to the evolving price/performance profile of existing router platforms (which can support vastly greater amounts of throughput per dollar of capital expense spent than prior implementations have been capable of). It is also partially due to the expanded use of virtual routing in an NVF context, where routing functionality is being sold only in a software form, and the underlying hardware is one or another form of general-purpose server or similarly designed appliance. The final influence on the TAM for router sales is the emergence of open source routing functionality through projects, such as Free Range Routing (FRR), and the early stages of experimentation based on disaggregated routing solutions using open source software and open source, merchant silicon-based hardware. All these factors provide a counter-balance in the revenue generating sense compared with the overall growth of the network environments being supported.

Data Center Switching

Based largely on the growth in CSPs' use of virtualized infrastructures and cloud-native designs for several services and in their newer use cases, we expect the market for data center switching in their infrastructures to more than double by 2023, from $8.1 billion in 2018 to $19.9 billion in 2023. The distribution of this growth between use cases is shown in Figure 5. The fastest growing of these cases will be vco/CORD and MEC edge installations, which we project will grow at compound annual rates of 101% and 87%, respectively, through 2023.

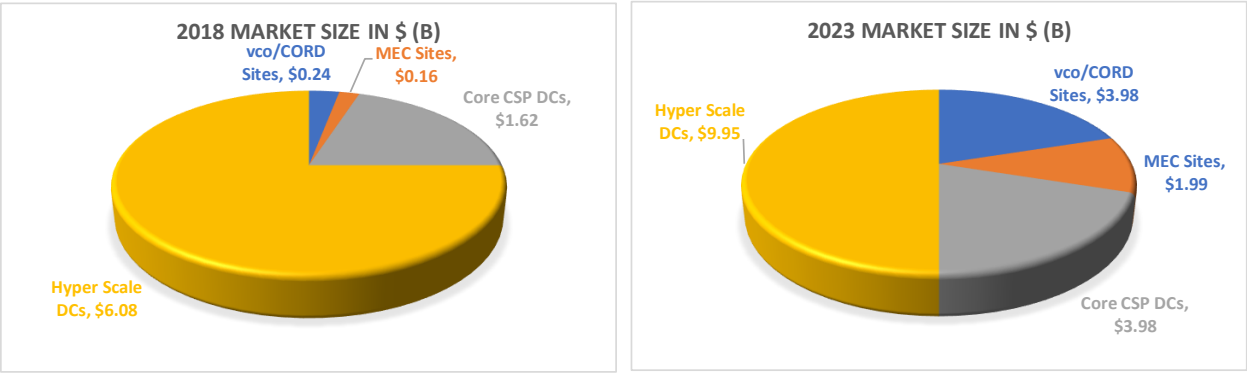
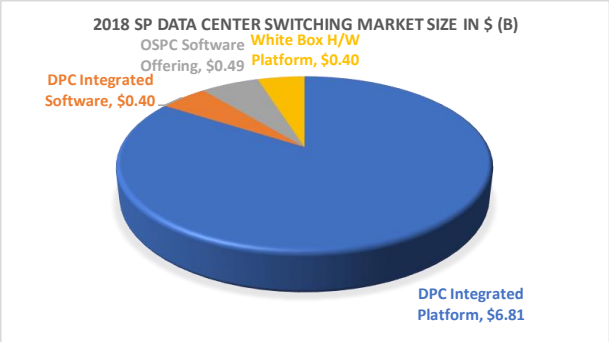


Figure 5. Evolution of Data Center Switching Revenues as New Use Cases Emerge, 2018–2023

This growth will occur in use of both underlay physical switching and overlay virtual networking solutions in all the deployment cases.

The distribution of that growth between DPC and OSPC offerings is shown in Figure 6.



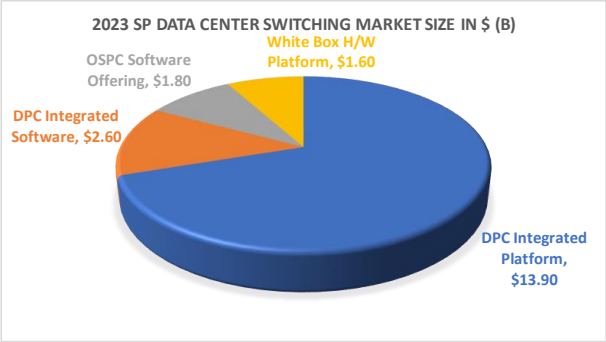


Figure 6. Data Center Switching Market Size 2018–2023

Open source networking software (shown in Figure 6 as OSPC Software Offering) is used in white-box switching platforms. Together these will grow at a compound rate of about 40% through 2023 and are projected to earn an approximately 15% market share by that date.

Privately developed software solutions in both overlay virtual **and** underlay fabric deployments are sold on their own and run on other underlay platforms, either servers in the overlay networking case or white-box, merchant silicon platforms in the underlay case. Most of these offerings are in the overlay category today, but we expect additional cases in which the disaggregation of software and hardware will continue, and the privately developed software running on white-box underlay nodes will become more widely used. In total we expect this form of networking software to command approximately 17% share by 2023.

We expect the final category, integrated physical hardware + software networking platforms sold by DPCs to continue earning most of the market share within service provider data centers, but this share will decline to about 72% from 84% share in 2018, relinquishing approximately 3% per year to the alternatives.

Findings in Communication Service Providers Environments

In our research we interviewed technology and business leaders in CSPs in the Asia Pacific, North American, and Europe-Middle East-Africa (EMEA) geographies about their motivations for pursuing open source adoption, and the impacts of that adoption. We also analyzed CSPs' public reporting records and other materials to inform our analysis.

CSPs are thinking strategically and globally. There is a realization that the competitive landscape for communication and information services is changing rapidly, and it includes global, webscale service providers and over-the-top solutions. Leading CSPs want industry collaboration and cooperation to solve common challenges, overcome their geographic boundaries and avoid fragmented and redundant investments.

The main motivations behind the push for open source solutions in CSP operations are not simply focused on cost reduction as a goal. CSPs are thinking strategically and globally. There is a realization that the competitive landscape for communication and information services is changing rapidly, and it includes global, webscale service providers and over-the-top solutions. Leading CSPs want industry collaboration and cooperation to solve common challenges, overcome their

geographic boundaries and avoid fragmented and redundant investments. They also want access to a broad industry talent pool and to prevent being trapped or having future flexibility limited by vendor lock-in.

Figure 7 is a ranked order of CSPs' drivers for prioritizing on open source developments. Their top three motivations are:

- Unifying multiple service providers around a common approach
- Avoiding vendor lock-in and dependencies on a single vendor
- Accessing a broader talent pool than your own organization or any one vendor could provide

CSPs are not just pushing for open source investments from their vendors. Leading CSPs are also demonstrating their commitment to open source by staffing leadership roles, contributing code and assigning significant development resources (in some cases 100s of employees). To influence the community and ensure a desired outcome and execution timeline, leading CSPs realize that they must simultaneously lead and serve the community.

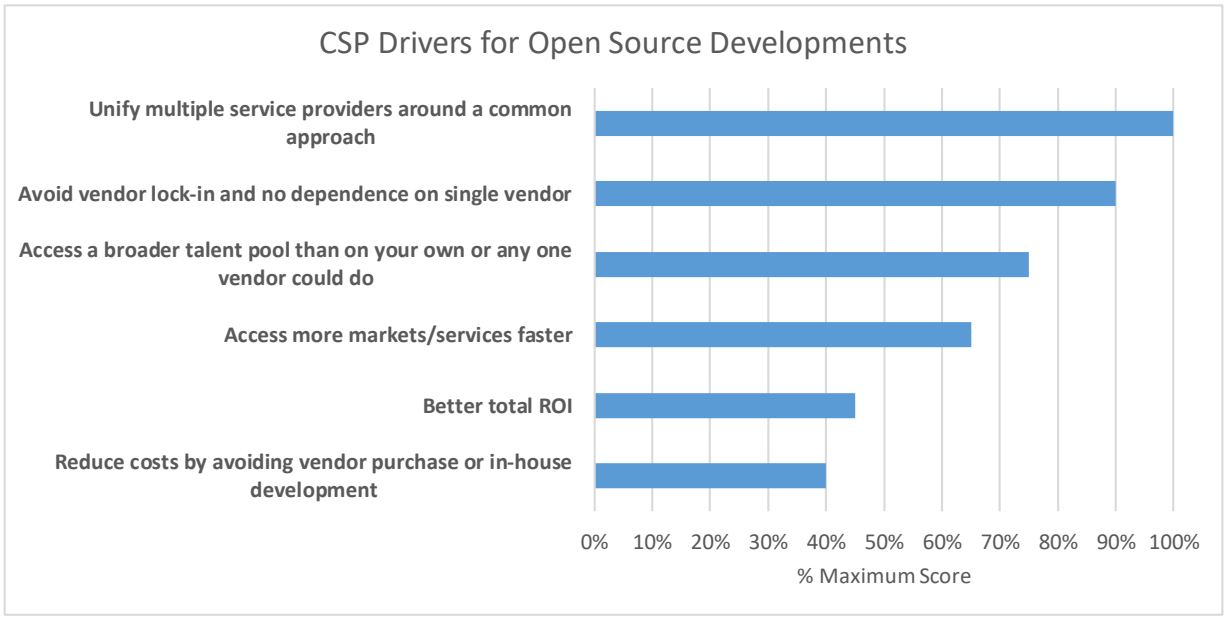


Figure 7. CSP Motivations for Open Source Solutions

Beyond motivations, we explored CSPs' attitudes and beliefs toward open source adoption in four key areas of their operations: solution development, vendor relationships, financial impacts and overall competitiveness.

As we see in Table 1, CSPs believe open source increases their nimbleness and gives them a sandbox for experimentation. Open source also focuses the number of engineers inside the CSP and the industry on a specific problem space. The embrace of the open source development model (which also includes agile/scrum methodologies) and tools also enhances the move by CSPs toward ongoing dev/ops practices.

Although there are multiple perceived benefits, there are also some challenges. Open source developments are currently less mature than proprietary ones and require additional test and integration

resources to ensure appropriate levels of quality. Multiple CSPs and vendors reported a need for an average of 30% more test and integration staffing than proprietary developments in the near term.

Development	Enables Experimentation	Increases # CSP Engineers	Moves toward Dev/OPS	Initial SW Maturity	Requires More Test
CSP Open Source Attitudes	●	●	●	●	◕

Table 1. CSP Open Source Attitudes, Development

Open source does have an impact on the relationship between CSPs and vendors; however, every CSP still expects to rely on vendors to supply products and services for their network. A dedication to adopting open source does not bring with it a concurrent desire to break ties with trusted solution suppliers that can support the CSP in realizing its infrastructure goals. They plan to obtain open source solutions through trusted suppliers who can assume responsibility for test/integration, quality, support and migration services. In all cases, CSP leaders indicated a readiness to work with vendors' qualified services staffs as a means of extending their implementation teams to accomplish their goals. CSPs believe that open source enables them to better distribute the investment and share the risk with vendors and other service providers. If a solution contains both open source hardware and software, CSPs also indicated a desire to purchase the hardware and software independently of each other to ensure the best price-performance.

A dedication to adopting open source does not bring with it a concurrent desire to break ties with trusted solution suppliers that can support the CSP in realizing its infrastructure goals.

Vendors	Still Rely on Vendors	OS Spreads Investment	Separate HW & SW Buys	Shared Risk w. Vendors	Use Vendor Pro-Svcs.
CSP Open Source Attitudes	●	●	●	●	●

Table 2. CSP Open Source Attitudes, Vendors

As it is still early in the deployment of open source technologies by CSPs, most were hesitant to discuss detailed financial information and results. Responses from service providers were mixed in terms of open source delivering higher margins or higher returns on investments. Improved margins and profitability are goals, but there is currently not enough evidence to support such a conclusion empirically. Although CSPs believe that open source will eventually deliver capital expense savings (for example, by using white-box hardware) and lower operating budgets through automation, most fully acknowledge that in the near term, open source requires investment (especially if you are going to be a leader) and budgets may have to be higher to support current proprietary vendor developments while simultaneously boot-strapping open source ones.

Financial Impacts	Lowers CAPEX Eventually	Lower Budgets Eventually	Changes CSP Revenue	Higher Margins	Higher ROI for IP
CSP Open Source Attitudes	◕	◕	○	◑	◑

Table 3. CSP Open Source Attitudes, Financial Impacts

As shown in Table 4, all the CSP leaders we met with think the use of open source technologies enhances their competitiveness. CSPs' engineers want to work on open source projects and view such assignments

as a positive and meaningful career opportunity. Many engineers lobby to be assigned to open source projects. In addition, CSPs' large enterprise customers generally view the CSPs' leadership, development and use of open source technologies as a positive reflection on the business. Mobile and residential customers are indifferent about CSP open source technology utilization. Mobile and residential customers want their services to be reliable and cost effective, independent of open source.

Competitiveness	Enhances Competitiveness	CSP Engineers Like	Customers Like
CSP Open Source Attitudes	●	●	◑

Table 4. CSP Open Source Attitudes, Competitiveness

Findings for Product Companies by Type of Company and Category of Solution

We now turn our attention to our findings on the impact of open source adoption on the vendor companies we included in our analysis.

The impact and role of open source technologies in product company offerings varies greatly by type of company and category of solution or product being considered.

Diversified portfolio companies, or DPCs, are companies that rely extensively, and often primarily, on their own innovations as the basis of solutions they offer CSPs and consider using open source technologies in their solutions as one element in a broader concept of differentiation. They exist in every solution category: orchestration, network control, and network infrastructure. Most DPCs have diversified product portfolios, meaning they have businesses in one or more of the focus categories, as well as in lines of business in other market and product segments beyond the categories included in this analysis. As a group they tend to command a majority share of the revenues in the categories we have focused on. We included a select subset of the total number of DPCs that take part in the market segments we analyzed to obtain a representative set of perspectives about their operations in the CSP environment.

There is nuance in how DPCs consider using open source technologies in their plans. In some lines of business in some of the DPCs there is solid interest in incorporating specific open source technologies. This is either because the group involved is a strong or primary contributor to the project or because the group places strong value on the element the project is delivering. However, within the same DPC there are typically also other lines of business that have less interest in adopting open source in the categories on which they are working. This can be for a number of reasons: a belief that the open source solution in their category is not mature enough yet for CSP use; a belief that the company's own developments for the requirements in focus have more value; or a belief that the return on investment of pursuing their own innovation path is better in their category than a path incorporating a larger percentage of open source technologies.

There is nuance in how DPCs consider using open source in their plans … in some groups there is solid interest…in others there is less...thus, we analyze their adoption based on category of solution and type of business model being used.

Because of this nuance we have considered the interests of DPC solution teams based first on the category of solution they are delivering, second on the nature of the business model they are using (example, following an own innovations approach or an OSPC within an DPC in a given case) and finally on the type of company to which the solution's line of business belongs (an DPC or an OSPC). The impact of open source on their operations tends to be related to those considerations and in that order.

OSPCs, by contrast, are companies that have based most of their solution plans on a core of open source technologies within their targeted space. As with DPCs, OSPCs exist in each category of solution: orchestration, network control, and network infrastructure. Although OSPCs often enhance the solutions they offer with components of their own innovation, they tend to focus on supplying an unaltered build of downstream project code along with substantial professional services to ensure the solution they are delivering remains in alignment with the evolving code base of the open source community. There tends to be more reliance on the value of community innovation in OSPCs, along with an emphasis on domain insights and knowledge to support the CSP in succeeding with an open source foundation.

OSPCs tend to supply an unaltered build of downstream project code and to provide substantial services and tools to support deployment and integration.

Because of these distinctions between DPCs and OSPCs, we see the impacts of open source technologies on their business models and operating plans in different ways. Our conclusions about the impact of open source adoption on these businesses are organized first according to the category of solution they are supplying to the CSP (orchestration, network control or network infrastructure) and then in each category according to the type of business model to which they have subscribed (own innovation oriented versus OSPC). The impacts vary along each of those dimensions.

In the following sections we focus first on the higher-level criteria the companies in each of these categories employ when deciding to incorporate open source technologies in their solutions. This data is derived from the answers company leaders provided to our interview questions in each of these categories.

A synthesis of their perspectives at an overall level is provided in Figure 8. In Figure 8 the consideration a company has when considering an adoption of open source technologies is shown in the words at each of the 'points' around the dimensioning axes of the diagram. The closer to the outside of the diagram a type of company's perspective is, the more they agree with the relevance of that criterion. The composite shape that a type of company has – as shown by the colored lines plotting their perspectives in the diagram for each of the open source adoption criteria – describes their orientation to incorporating open source technologies in their offerings. As one might expect, the blue and orange lines representing the open source portfolio companies' perspectives indicate a generally more complete embrace of the open source technology model than the aggregate plot of the DPC companies shows.

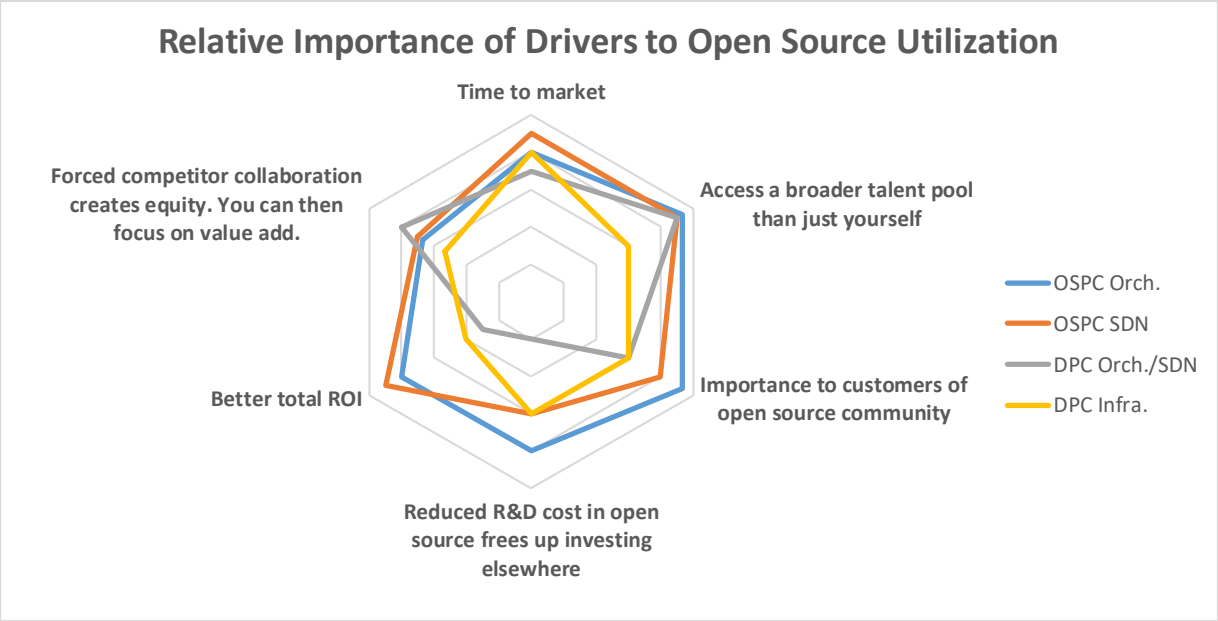


Figure 8. All Vendors Relative Importance of Considerations

Findings for Companies in Orchestration and SDN Network Control

In this section we highlight the findings we obtained when discussing the impact of open source technologies on companies developing orchestration and SDN control solutions.

We started with the question, how do you decide when you will incorporate open source technology in your product as opposed to producing the functionality in-house with your own design and engineering effort? The answers as illustrated in the bar charts indicate which choices the leaders and their team are currently making (as of calendar Q1 2018).

Three charts profile the answers. Figure 9 provides the answers from orchestration vendors operating in the OSPC mode; Figure 10 describers the very similar answers from SDN solution vendors that are also operating in that mode. The perspectives of orchestration and SDN solution vendors that are operating in an DPC based business model are provided in Figure 11.

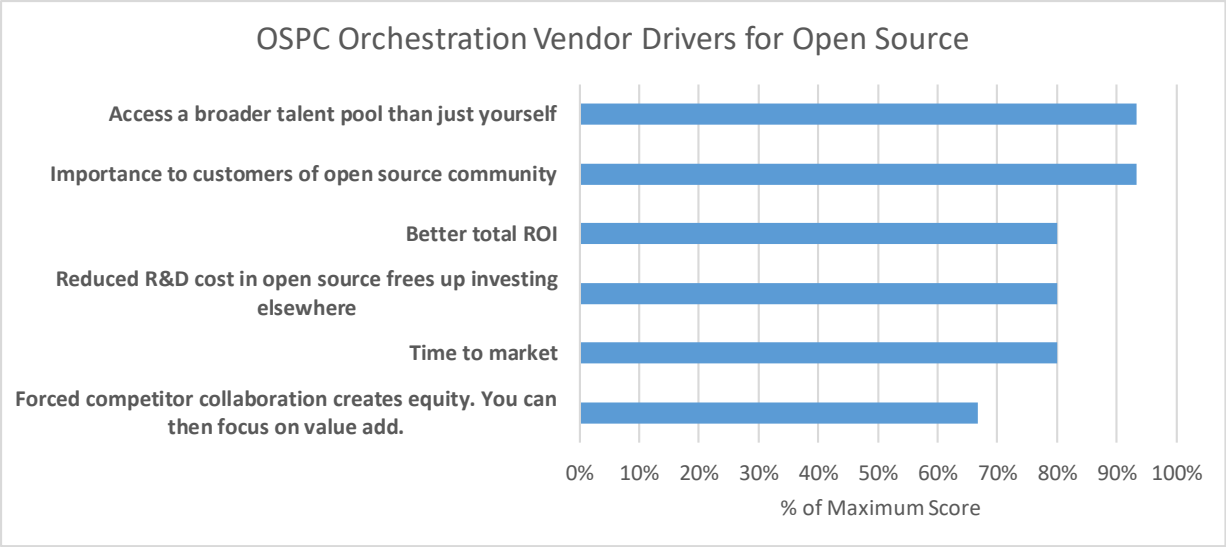


Figure 9. OSPC Orchestration Relative Importance of Considerations

In each figure there is an X axis characterizing the degree to which the leaders emphasize the criterion being measured by that bar in their thinking about whether to incorporate an open source technology in their offering. If the value of the bar reaches 100%, all the respondents to the question in this category give this criterion the highest possible value in their considerations. Conversely, if the bar measures only 0%, then none of the respondents place any value on that criterion in their plans. As a collection of responses, the measures in these charts capture the extent to which the leaders in each type of company value each consideration when developing their plans.

As we can see from this small but influential sample of respondents, the top two considerations for leaders in open source-based orchestration companies for choosing to base their solutions on a primarily open source foundation are grounded in the value that CSPs (their customers) place on open source solution baselines and the value that the broader community of solution developers (and code committers) can bring to the solution delivery process. Not far behind the strength of these beliefs is the perspective that by actively participating in the open source communities focused on orchestration, greater velocity, efficiency, differentiation and return on investment can be achieved versus trying to address the requirements for a differentiated CSP solution from within one's own development staff.

Starting from these perspectives and augmenting with additional observations about the impact of open source on various aspects of operations we can link these beliefs with the impact of open source on the financial and business model profile of the OSPC.

In Figure 10 we see a similar profile of criteria for OSPCs supplying SDN solutions to CSPs. These are firms providing SDN controller and application solutions for multi-layer transport, NFV and data center infrastructures. Clearly, the value of the community and its broader talent pool and the efficiencies in bringing solutions to market are important elements of the OSCPs' business plan.

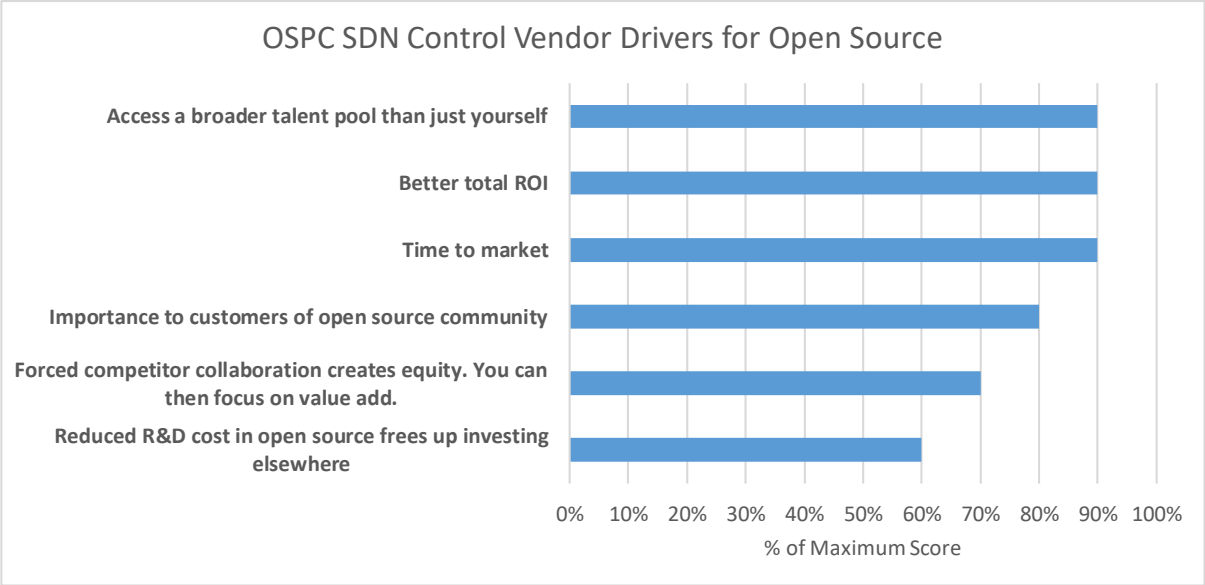


Figure 10. OSPC SDN Control Relative Importance of Considerations

We see a different perspective guiding the criteria that teams working in an DPC use when considering the integration of open source technology components into their orchestration and SDN/network control solutions. These firms tend to have well-established solution offerings already in operation in CSP environments, which have been developed over time with substantial engineering and design contribution from their own development teams. In general, their attitude toward incorporating portions of open source technology into their solution sets is more focused on whether a component of open source code offers a functional advantage for a CSP customer, is mature enough for incorporation into a solution and/or may offer a distinct time-to-market advantage over internal development paths. It is a view that looks at open source as essentially one in a set of tools available for delivering a solution, but which is not inherently more advantageous than proprietary innovation. Although appreciating the theoretical advantages that an open source-based path can supply, the teams overall tend to take a much more measured approach toward deciding when a component would be worth incorporating or not. It is a business model more fully grounded in the value of independently established differentiation in the software while employing open interfaces and APIs for making the solutions interoperable.

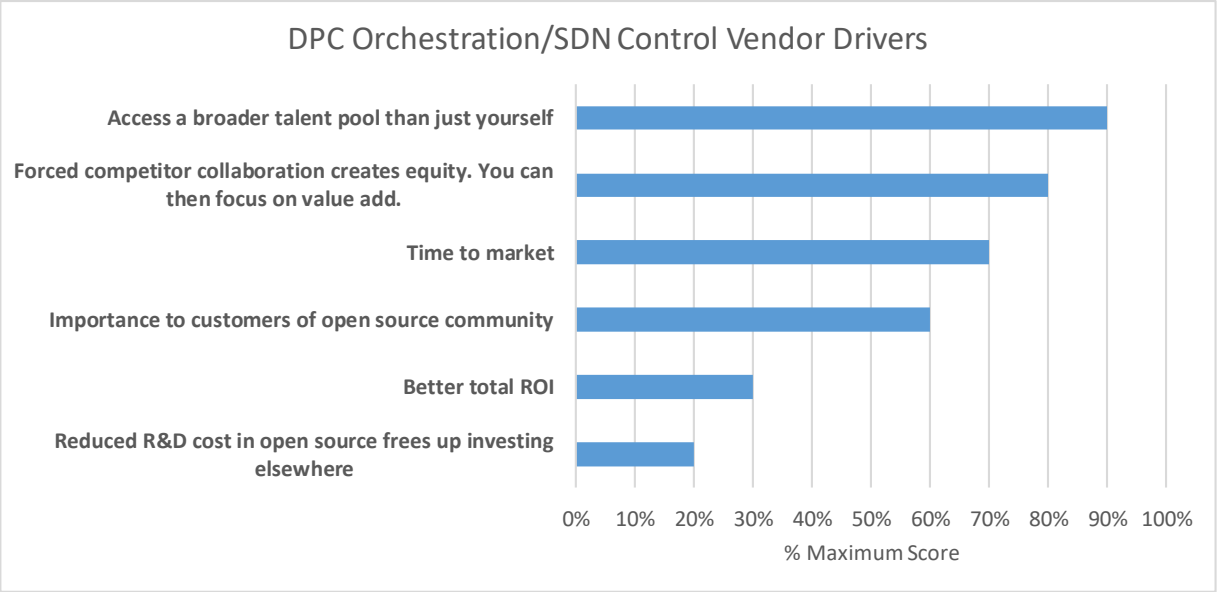


Figure 11. DPC Orchestration/SDN Control Relative Importance of Considerations

In addition to the insights into vendors' high-level criteria for incorporating open source or not, we also explored their perspectives on the impact of adopting open source on other aspects of their operations. These include the impact of adopting open source technologies on their development and testing practices, how incorporating open source impacts the way they manage their relationships with CSP customers, and the impact of adopting open source on their companies' financial practices, metrics and outcomes. These outcomes are provided in Tables 6–9.

Impact on Solution Development Practices

Development Impacts	Enable Experimentation	Increases # Engineers in Area	Accelerate Dev. Cycles	Initial SW Maturity	Require More Test
OSPC Orchestration Vendor	●	●	●	◕	◑
OSPC SDN Control Vendor	●	●	◑	●	●
DPC Orch./SDN Control Vendors	●	●	◑	●	○

Table 5. Orchestration/SDN Control Open Source Attitudes, Development

In Table 5 each type of solution vendor is listed in a row header on the left. The headers for each *column* indicate the area of development operations that incorporating open source impacts. For example, when answering whether incorporating open source allows them to experiment more and take relatively smaller, less risky bets on developing new functionality, all the solution vendors indicated that it does.

Table 6 shows the perspectives of orchestration and SDN product company leaders on the impact of adopting open source technologies for their solutions on their development operations. In all the companies there is a belief that using open source is helpful in enabling experimentation in developing new capabilities, in placing bets of smaller sizes than in conventional development practices and gaining evidence more quickly on whether the functionality has promise. This is a very strong positive in the context of accelerating innovations and the differentiation that goes with them.

Each of the companies also values strongly the access that participating in open source communities gives them to a broader, more diverse pool of engineering talent to help advance the capabilities of their solutions. Although these two attributes are clearly seen as strengths, only the open source-based orchestration companies believe participating in open source communities helps accelerate their overall pace of development. For both open source SDN and diversified portfolio vendors in this category, participating in open source communities does not have a material impact on development schedules. For DPCs, the open source components are just one in a substantially larger mix of functionality that needs to be completed for every release. For open source SDN suppliers, it is because the additional support services and tools that accompany their open source solution must be made customer-ready as well, and this has as much of an effect on their delivery cycles as ensuring the code itself is ready to deploy.

> *In all the companies there is a belief that using open source is helpful in enabling experimentation and placing bets of smaller sizes on developing new functions.*

Balancing the positives of open source in their solutions is the fact that, especially in the earlier stages of work in an open source project, the software a community produces is less mature, stable and complete than solutions developed over longer periods. Both OSPCs and DPCs underscored this point in our discussions. This characteristic of the code in each solution space causes OSPCs to invest substantially more in their test and validation processes for the open source components of their solutions than they invest in the elements that are purely of their own development (value-adding applications and tools, as examples). For DPCs, however, because they have developed their testing processes so extensively over time, it is more the case that the effects of incorporating the open source elements that they use can be flattened out and inserted into their system test operations with a less dramatic impact than it is for the OSPCs (even though it is necessary in their cases as well to overcome the downsides of the relative immaturity of open source code).

Impact of Open Source on Orchestration and SDN Vendors' Relationships with CSPs

CSP Relationship Impacts	Use OS for Comp. Advantgae	Add Extra on Top of OS	Use Enhanced Services	Requirements Harder?	Change Patent/Innovation
OSPC Orchestration Vendor	●	●	◕	◕	●
OSPC SDN Control Vendor	●	●	●	●	●
DPC Orch./SDN Control Vendors	●	●	◑	○	●

Table 6. Orchestration/SDN Control Open Source Attitudes, CSP Relationships

Incorporating open source technologies to one degree or another in one's solutions introduces a range of new dynamics into the relationships that solution vendors can maintain with their CSP customers. In cases where the CSP is an active participant in the open source community that is supplying the software that is being integrated, having that integration causes the solution vendor to engage with the CSP as a co-creator and developer of the solution and the code. This tends to bring with it a shift in the balance of considerations to some degree toward the CSP, even while the overall development is a community

responsibility. The exact balance that is struck depends on the solution category, the CSP and the vendor that is engaged, but introducing this consideration into the dynamics of a vendor's relationship with the CSP is one unmistakable impact of the decision to include one or more elements of open source code into a vendor's offering.

Additional impacts of the decision to adopt open source in orchestration and SDN solutions re shown in Table 7. In the first column, in all cases vendors consider incorporating open source code into their solutions as a competitive advantage. One reason is the value CSPs place on an open technical foundation, which increases the consideration they are likely to give to a vendor's offering. When CSPs know that a vendor is meaningfully engaged in an open source initiative and is an active committer with the resources to follow up on developing capabilities on which the community has decided to prioritize, the vendor's participation in the open source community is, indeed, valuable to the CSP. When leveraging an open source base, the vendor can deliver solution content on a cadence that will be aligned with the broader solution community overall, which simplifies the task of aligning solution sets with each other in a multi-layer, multi-domain deployment environment composed of multiple code bases and solution offerings.

Although solution vendors all consider open source a competitive advantage, they also, uniformly, add extra functionality on top of the open source they use to round out and add value to their offerings. Additional software can be developed in integration and deployment tools or in applications that extend capabilities in the use cases being supported.

Although solution vendors all consider open source a competitive advantage, they also, uniformly, add extra functionality on top of the open source to add value to their offerings.

Similarly, vendors in each category use professional and integration services to enhance the value of their solutions. Every vendor, but especially those operating in the OSPC model, places value on easing the integration and deployments of their offerings with CSPs; the quality and extent of engagement and support offerings is in fact a signature attribute of the vendor business models that are gaining a positive reception in the CSP community.

Although incorporating open source creates the advantages for vendors, it also introduces an extra level of effort in clarifying requirements and making trade-offs in how development resources should be applied. The additional steps factor in the dynamics occurring in the upstream open source development project and add them into the decision-making process for whether and when to bring them into a deliverable or to consider adding proprietary functionality on top of the open source base. This is by no means a blocker by itself in the set of considerations about adopting open source in the vendor solutions. It is simply an attribute of the process that all involved believe needs to be accounted for in the set of impacts that using open source components entails.

Impact on Financial Practices and Metrics

Finanical Impacts	Change Business Model	Change What you Charge	Change How you Charge	Change Financial Metrics	Change R&D Investments
OSPC Orchestration Vendor	●	◕	◕	◑	◑
OSPC SDN Control Vendor	●	●	●	●	●
DPC Orch./SDN Control Vendors	○	◑	●	◑	○

Table 7. Orchestration/SDN Control Open Source Attitudes, Financial Impacts

Using open source in vendors' orchestration and SDN solutions also impacts the financial practices and metrics the companies employ to varying degrees. In general, firms in the orchestration and SDN market segments are moving toward a path based on subscriptions for the right to use and access support services for their solutions versus perpetual and term licensing practices that have been used more in the past. This shift in practices applies to both open source and proprietary software offerings moving forward. The more distinct changes in business models that vendors emphasized, especially OSPCs, is in the proportion of services, tools and software that comprise their revenue streams, compared to the mix employed by DPC solution suppliers, whose offerings have been in market for a longer period.

In the business models that are being used, the payment for the solution is more in line with a usage-based (or level of use) philosophy. A significant portion of the revenue stream in the open platform environment that CSPs are pursuing is from slightly more ephemeral components: professional services and tools. When the purposes of those components have been satisfied, the customer's commitment to paying for them can terminate. All of this illustrates a shift taking place toward a set of revenue elements whose value must be justified and calibrated on an ongoing basis of close mutual understanding between the CSP and the vendor. It places a much higher premium on how well the vendor is understanding and addressing the CSP's needs. The pace at which each type of company in this solution category is making these adjustments has a great deal to do with the baseline offering with which their operations are starting. The longer-term impacts of the shift are likely to pull the companies in each category toward the practices that make these terms of operation viable: a nimbler, continuously validated and continuously updated solution framework.

New methods of solution delivery place a much higher premium on how well the vendor understands and is addressing the CSPs' real needs.

Impact on Company Competitiveness

Competitiveness	Enhances Competitiveness	Vendor Engineers Like	CSP Customers Like	OS is Strategic
OSPC Orchestration Vendor	●	●	●	●
OSPC SDN Control Vendor	●	●	●	●
DPC Orch/SDN Control Vendor	◑	◑	●	◔

Table 8. Orchestration/SDN Control Open Source Attitudes, Competitiveness

As we report in Table 8, OSPC leaders firmly believe that their open source foundations are a source of competitive advantage with CSPs. Although DPC leaders are open minded about when and how to incorporate open source technologies into their solutions, they see it as only one aspect of their overall competitive positioning and not necessarily the most important one. Even though their perspectives on how much open source contributes to their competitiveness differ to some extent, leaders in both OSPC and DPC companies clearly understand that CSPs value the readiness of their suppliers to incorporate important open source technology components in their solutions and to contribute to the open source communities that the CSPs believe are most important.

On a different level of company positioning and competitiveness in the market, OSPCs clearly see their commitment to open source communities as an important element in attracting and retaining top engineering talent for their developments. There is a close relationship between engineers' desires to advance the state of the art in key open source technologies and their enthusiasm in contributing to the success of an OSPC company. Although DPC suppliers of orchestration and SDN solutions for CSPs acknowledge the relevance of participating in select open source communities, they do not see those engagements as the most compelling overall reasons for developers being inspired about contributing to their solutions. Their overall differentiation and value propositions tend to be grounded on the distinct differentiation they believe their own innovations contain, and those tend to factor more heavily into their thinking about how engineers take their inspiration for contributing to the enhancement of solutions.

Blending these perspectives into a final view on whether open source technologies are strategic and central to their plans for success, OSPC leaders firmly believe that developing their business plans on an open source foundation is a central pillar of their strategies. By contrast, leaders in the corresponding DPC lines of business view the use of open source as less strategic to their success and more as one element of the toolkit they have at their disposal for addressing the needs of CSPs.

Impact on Evolving Orchestration/SDN Software Revenues, Solution Content and R&D

In addition to its impact on the companies' operating methods and plans, we explored the impact of open source on the **revenues** vendors expect to earn in the orchestration and SDN solution spaces and discussed its impact on the **software content** of their offerings and the focus of their **R&D investments**.

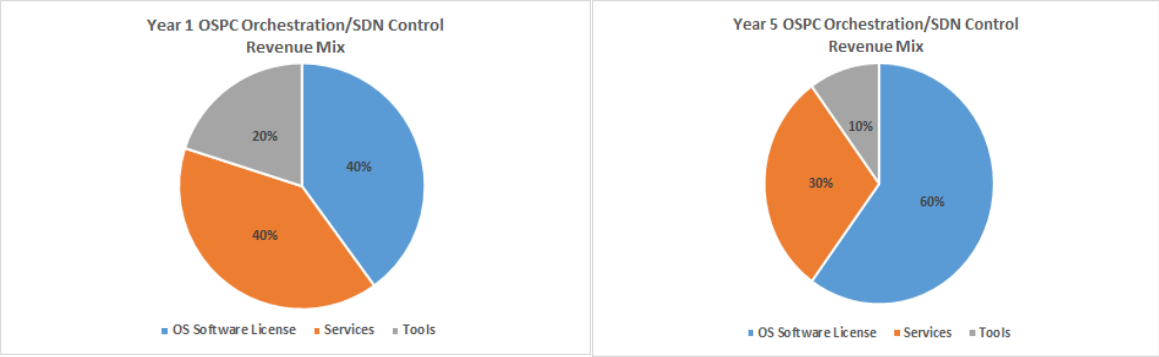


Figure 12. OSPC Orchestration and SDN Solution Revenue Mix Evolution

As we report in Figure 12, the year 1 revenue profile for OSPC solution vendors includes both their software offerings as well as significant amounts of professional and integration services, and tailored deployment and integration tools that ease the integration of offerings into CSPs' environments. OSPC leaders believe that as their offerings mature and the content of their open source software expands, the portion of revenues coming from the software platforms will expand; and the percentage coming from services and tools will contract, as shown in the Year 5 Revenue Mix chart on the right in Figure 12.

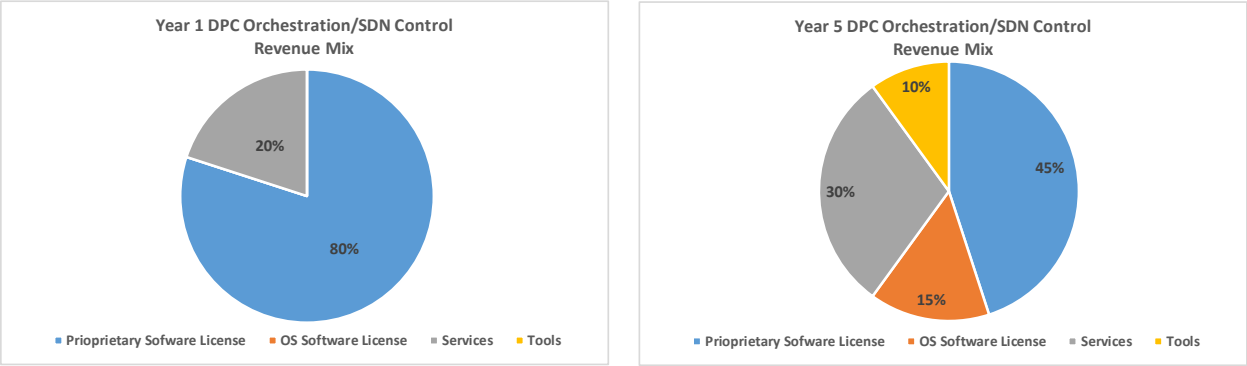


Figure 13. DPC Orchestration and SDN Solution Revenue Mix Evolution

The evolution of the revenue mix for DPC orchestration and SDN solution vendors has a markedly different profile, as shown in Figure 13, primarily born from their hybrid model of solution delivery in these categories. The preponderance of their current offerings is based in software of their own design, augmented with professional services for custom integration and deployment support. Looking forward, however, DPC leaders clearly envision incorporating a greater percentage of open source software in each solution category (orchestration and network control) and also anticipate operating in a closer loop orientation with their CSP customers, such that their revenue streams will include a greater percentage of services dedicated to specialized needs of CSP customers deploying their solutions, as well as the development of targeted deployment and integration tools and value-adding software to help in on-boarding and running their solutions efficiently. Over time this mix begins to look a bit more like an OSPC's revenue mix even though a measurably greater percentage of the DPC vendor's revenue stream will continue to come from licensing its own proprietary implementations.

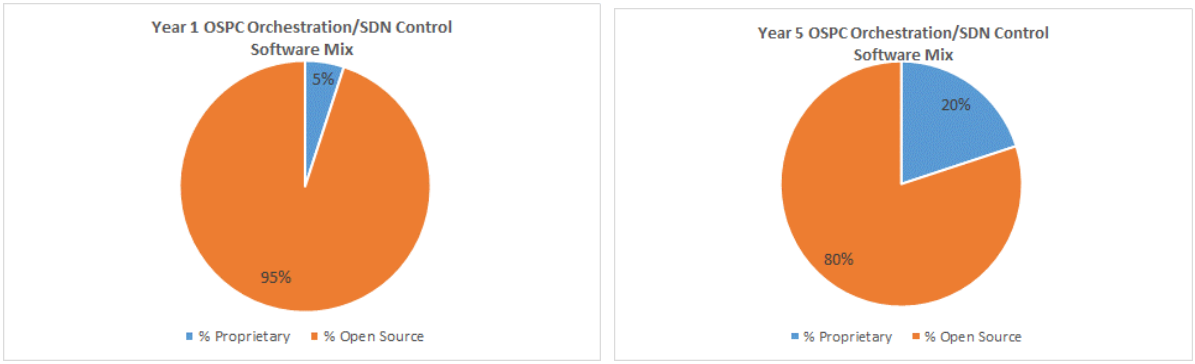


Figure 14. OSPC Orchestration and SDN Software Content Evolution

Regarding the mix of software included in their solutions, leaders in the OSPCs and DPCs expect an essentially inverse evolution of their content in the coming five years. Although OSPCs, understandably,

are launching into market with a predominantly open source software baseline, as shown in the 95% open source mix in Figure 14 on the upper left, they expect their solutions to contain incrementally greater amounts of software of their own design (as a percentage of their total) as their solutions evolve because as the open source code base matures and expands, they expect the amount of customization based on CSP environment and use case being supported to expand and the value of incremental software and tools to increase as the operators evolve their plans.

By contrast, as seen in Figure 15, DPCs expect their software to contain incrementally greater percentages of open source software as the open source code becomes increasingly viable and as their solutions evolve. If the code meets the CSP's requirements and is strong enough to include in the DPC's offering as a component, then the DPC can evolve to address more nuanced or expanded requirements in a proprietary component, while the main aspect of the CSP's requirement in that area is addressed by the open source components.

Figure 15. DPC Orchestration and SDN Solution Software Content Evolution

Expectations about how their R&D investments will be made in readying their offerings for market show a slightly less divergent pattern as far as the activities in which R&D resources will be concentrated.

Figure 16. OSPC Orchestration and SDN Solution R&D Evolution

In both cases we see a healthy percentage of R&D resources being applied to system integration and testing work. For OSPCs (Figure 16) there is an expectation, as their software matures and their expertise in integrating their various code streams into their solutions strengthens, the percentage of total they

need to apply to test and integration will decline, and they can focus the wood behind their arrows on expanding their contributions to open source and their own value-adding software developments.

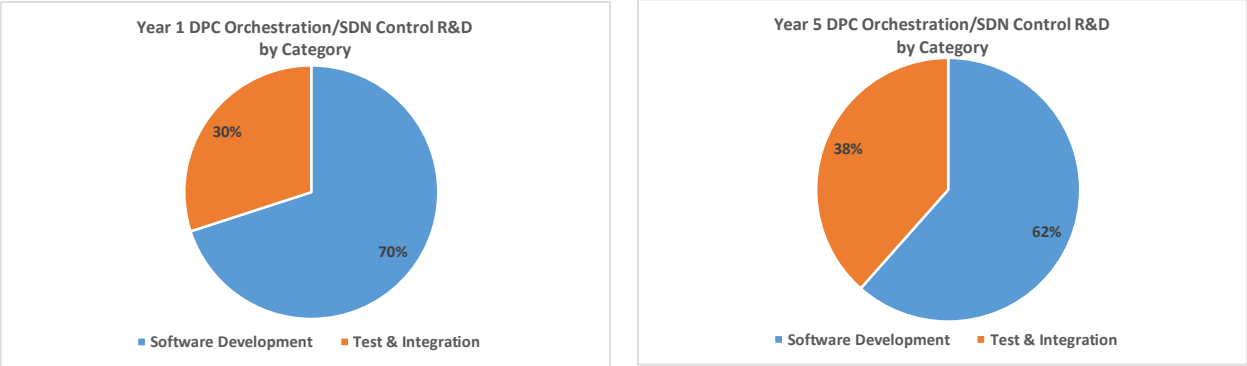


Figure 17. DPC Orchestration and SDN Solution R&D Evolution

For DPCs the trend is modestly different (Figure 17) largely because of the expanding integration of open source code streams into their solutions and their need to address the evolving interactions of their own software elements with the newer solution models coming in from the open source community process.

All in all, we see an increasing relevance of open source community software in the orchestration and SDN solution categories and a significant evolution of the vendors' business plans and operating procedures to align with CSPs' solution priorities and evolving consumption models for the areas of deployment on which they are focused.

Findings for Companies Supplying Transport Infrastructure Solutions: Transport Routing

DPC Infrastructure transport routing vendors provide a contrasting view from the one shared by OSPC orchestration and control vendors. The difference in perspective is at least partially driven by the maturity and highly concentrated nature of the market with the top four vendors supplying over 85% of the revenue.[4] Transport routing solutions are traditionally proprietary and vertically integrated with custom hardware. Software is developed independently by each leading supplier with conformance to a common set of specifications and protocols like RFCs from the IETF. Protocol conformance testing is done either by the vendor or in collaboration with organizations like the InterOperability Lab at the University of New Hampshire. Multi-vendor interoperability is achieved via testing in CSP labs or in collaboration with organizations like the European Advanced Network Test Center.

Drivers and Attitudes

Open source software may be included in transport routing solutions to address targeted issues or challenges. DPC transport routing vendors are generally less enthusiastic about open source than the OSPC vendors in every single category (Figure 8). In Figure 18, the top driver for DPC Infrastructure vendors is reduced time to market.

[4] 2017 ACG Research CRS WW Market Report.

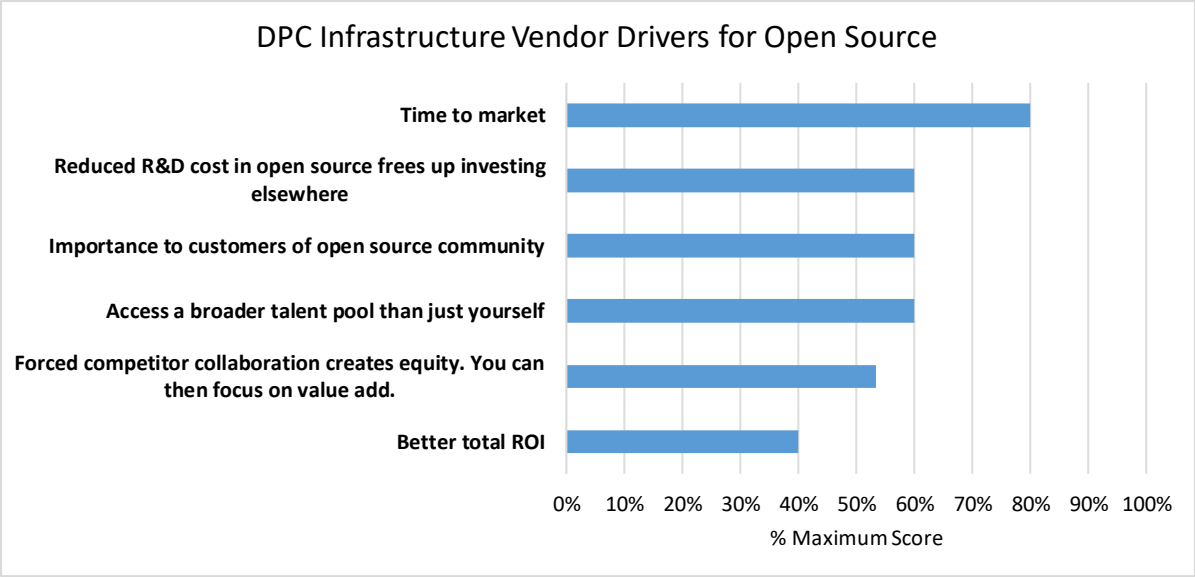


Figure 18. DPC Infrastructure Motivations for Open Source Solutions

If DPC infrastructure vendors can deliver a software component faster with open source, they will do it. The subsequent three responses all have equivalent weight and include:

- Reduced R&D costs
- Importance to customers of the open source community (CSPs promoting open source)
- Access to a broader talent pool than the vendor's engineers only

In Figure 19 we combined similar drivers between the CSP and DPC lists. As an example, we combined reduced costs from the CSP list with reduced R&D cost from the vendor list. There are two questions that remained distinct and separate between the two groups: avoid vendor lock-in and importance to customers of the open source community (which means CSPs from vendor perspective). These two items are included on the graphic, but a score is only provided for the relevant constituency.

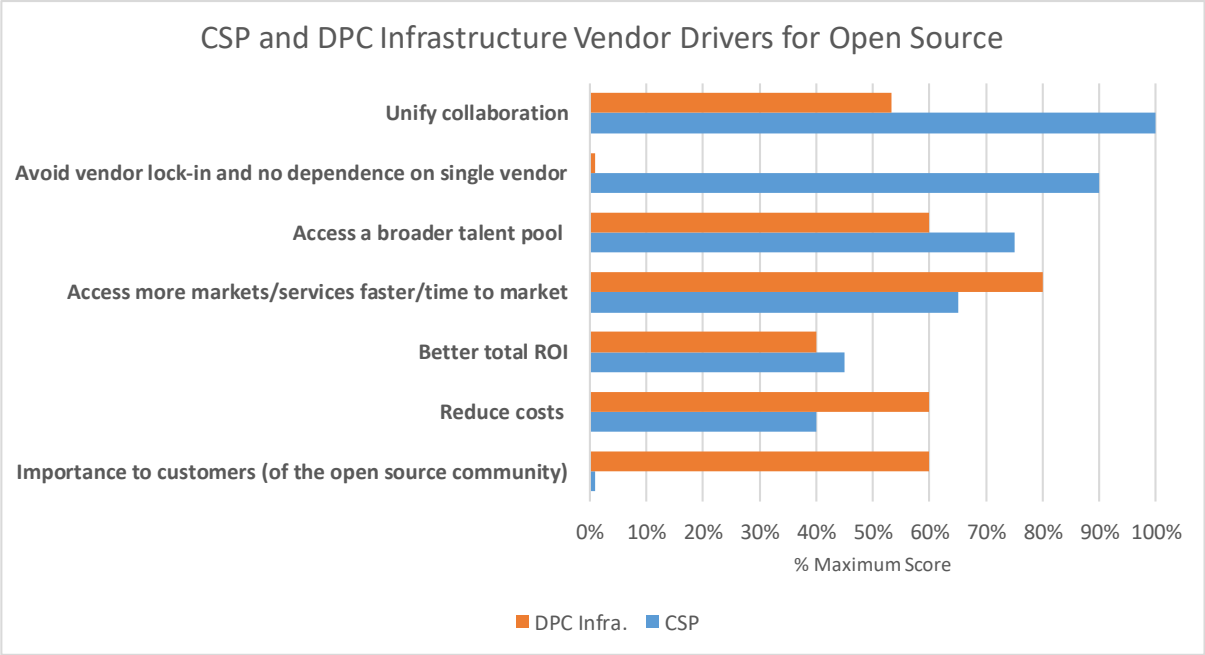


Figure 19. CSP and DPC Infrastructure Motivations for Open Source Solutions

DPC transport routing vendors agree that open source improves nimbleness and enables experimentation. However, attitudes are mixed as to whether open source increases the number of engineers concentrating in a given area (as existing engineers may be repurposed) or if open source accelerates development cycles. With a holistic view toward development, test and integration, reducing software development time for any individual function may or may not accelerate overall development cycles. Although it is agreed that open source is initially less mature than proprietary solutions, DPC vendors do not cite open source as requiring more test resources. The rationale for this apparent dichotomy is that DPC transport vendors believe that their existing development, test and integration environment assumes responsibility for all aspects of product quality. Any new software that is integrated into the DPC vendor solution requires vendor knowledge, ownership and support regardless of the origins of the codes. Thus, DPC vendors do not list extra testing as a hallmark of their tactical use of open source.

Development Impacts	Enable Experimentation	Increases # Engineers in Area	Accelerate Dev. Cycles	Initial OS Maturity	Require More Test
Infrastructure Vendor	●	◑	◑	●	○

Table 9. DPC Infrastructure Open Source Attitudes, Development

Utilization of open source by DPC transport routing vendors does impact the relationship with CSPs. Vendors are mixed as to whether open source produced a competitive advantage. All vendors agree that they added extra functionality on top of any open source utilization. Vendors also have mixed views as to their use of enhanced services to support their competitive position. As vendors already collect feature requirements directly from CSP customers, DPC transport routing vendors do not believe that open source made requirements gathering any easier or more difficult. Increased use of open source does result in half the vendors altering their approach to patents and innovation. Those that expressed this change talked about working in adjacent areas or in extra areas on top of open source for patent and innovation purposes.

CSP Relationship Impacts	Use OS for Comp. Advantage	Add Extra on Top of OS	Use Enhanced Services	Requirements Harder?	Change Patent/Innovation
Infrastructure Vendor	◑	●	◑	○	◑

Table 10. DPC Infrastructure Open Source Attitudes, CSP Relationship Impacts

DPC transport vendors do not see their tactical use of open source as having a meaningful impact on their business model. The majority do not identify changes to financial metrics or R&D investments. All vendors thought open source changes how they charge (example, perpetual license vs. subscription) for functionality, but views are mixed as to whether open source changes how much to charge (example, reduced price per use).

Finanical Impacts	Change Business Model	Change What you Charge	Change How you Charge	Change Financial Metrics	Change R&D Investments
Infrastructure Vendor	○	◑	●	◔	◔

Table 11. DPC Infrastructure Open Source Attitudes, Financial Impacts

DPC transport routing vendors generally view open source technologies as a tactical tool to solve time-to-market issues. Only a small number think open source enhances company competitiveness or is strategic to the business. All vendors acknowledged that their customers, the CSPs, like vendors to use open source. The vendor's engineers view working on open source projects positively for themselves and their company.

Competitiveness	Enhances Competitiveness	Vendor Engineers Like	CSP Customers Like	OS is Strategic
Infrastructure	◔	◕	●	◔

Table 12. DPC Infrastructure Open Source Attitudes, Competitiveness

Revenue, Solution Content and R&D Evolutions

In addition to the qualitative analysis, we also developed a five-year analysis of and evolution of DPC transport routing revenue, solution content and R&D mix.

DPC revenue today is dominated by the sale of custom hardware with embedded software. Associated services also derive a sizable portion of vendor revenue. We anticipate that vendor revenue will continue to disaggregate, resulting in expanded services and software revenue with declining hardware. Over the five years, open source hardware platforms and increasingly capable merchant silicon will cannibalize proprietary, custom ASIC based chassis solutions, especially at the edge and access/aggregation locations.

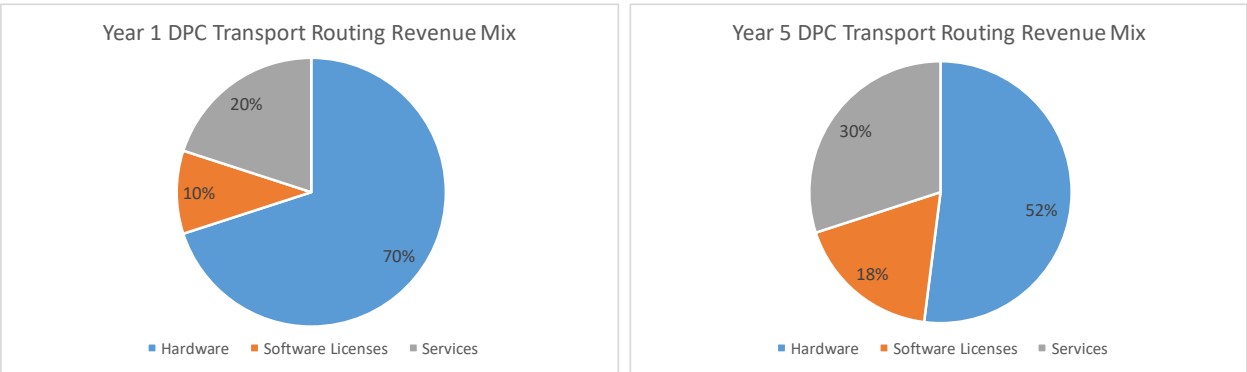


Figure 20. DPC Transport Routing Revenue

DPC transport routing vendors will utilize increasing amounts of open source software, but we anticipate the adoption rate to be relatively modest. With the creation of the FRR open source community, AT&T's announcement of a disaggregated network operating system and open source collaborations like Open Network Linux from the OCP for bare metal switches, we believe that pressure from CSPs and the competitive market will result in increased open source software adoption. Although we show open source growth movement from 2% to 20% over five years, we fully acknowledge that if a communication service provider or protocol software stack vendor were to commit its routing software stack to open source, the amount of open source in DPC transport routing solutions would likely increase and timing would be accelerated. Given the stable, multi-billion-dollar transport routing market, such a scenario is both a risk and an opportunity for DPC transport routing vendors.

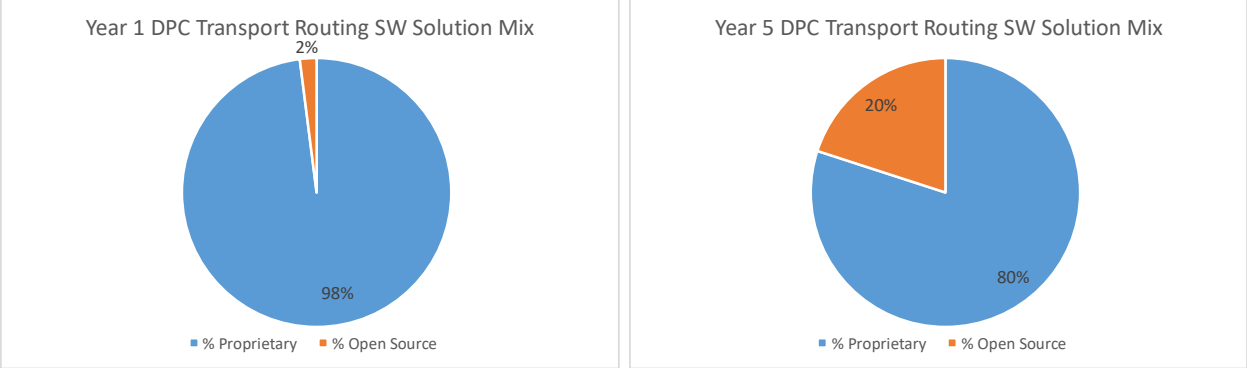


Figure 21. DPC Transport Routing Software Solution Mix

Open source also includes hardware. Highly programmable merchant network processing units continue to be enhanced with every new release and generation of hardware. We expect migration toward merchant silicon-based hardware solutions especially at the network edge and access aggregation locations of the network. With increasing disaggregation, the underlying hardware can be purchased directly from a contract manufacturer. Although CSPs express a willingness to negotiate and purchase software and hardware separately, if DPC transport routing vendors supply open source or merchant silicon-based hardware at competitive prices packaged with their global service and support, there is an opportunity to continue to supply the hardware in addition to the disaggregated routing software.

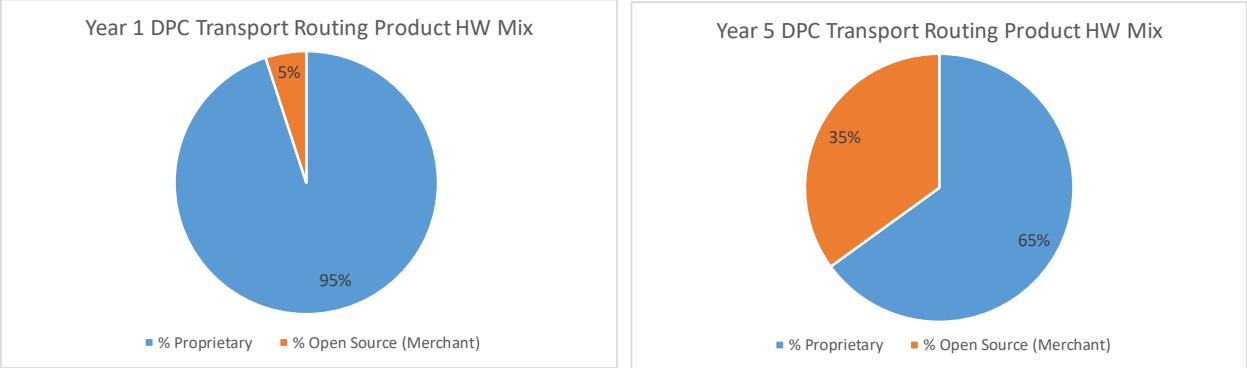


Figure 22. DPC Transport Routing Product Hardware Mix

The amount of R&D resources dedicated to hardware development is expected to decline over five years. Increased use of merchant silicon and open hardware platforms especially at the edge and access aggregation locations will result in reduced engineering and prototyping expenses by DPC transport routing vendors. Despite the current DPC infrastructure vendor perspective that open source does not require additional testing, broader adoption of open source software and hardware by DPC infrastructure vendors will result in additional resource requirements for test and integration. Although utilizing open source should translate into reduced software development resources over time, this must be balanced against the need for leading suppliers to assign resources and actively participate in open source collaborations. Leading open source suppliers dedicate software development resources and lead portions of development to ensure crisp execution and to establish themselves as experts in areas of the community. The modest software development decline reflected in our five-year R&D mix analysis is a direct result of the need for DPC vendors to invest in the open source community if they want to retain a leading position in transport routing with CSPs.

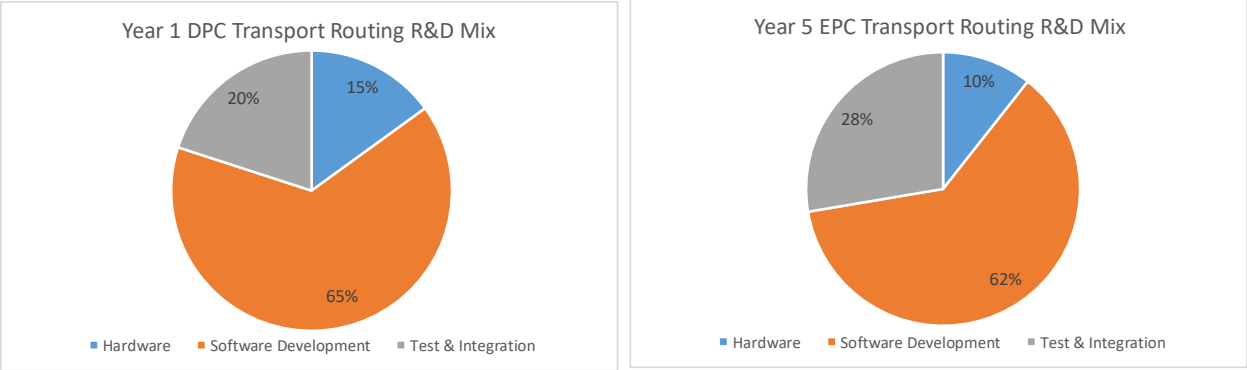


Figure 23. DPC Transport Routing R&D Mix

Findings for Companies Supplying Transport Infrastructure Solutions: Data Center Switching

As CSP infrastructures evolve to include more virtualized implementations, several types of sites will be designed using cloud data center-oriented frameworks. Sites such as mobile packet cores, central offices re-architected as data centers, and MEC installations will all gravitate toward these designs. This has significant implications for the overall switching market, but most of the shifts are occurring at the edge rather than in the data center core.

Vendors supplying products in data center switching are both DPCs and OSPCs. They deliver solutions in both physical and virtual form factors. DPCs have historically concentrated on integrated hardware and software platforms based largely on their own designs. OSPCs have come into the market more recently and have frequently chosen designs that use a disaggregated hardware and software implementation leveraging white-box, merchant silicon hardware and a significant amount of open source network software. Much of the evolution in these market segments is closely tied to the evolution of SDN, open computing and networking hardware designs, and open source software initiatives in several important aspects of network operation (data plane, control plane, machine learning and analytics, and others).

In many ways the perspectives of DPCs in the data center switching market mirror those of DPCs in transport routing. Indeed, some of the same vendors participate in each of those segments, albeit in

different business units and teams. Despite these similarities in the circumstances between the segments, CSPs and customers in other segments are supplying an accelerated level of pressure on the companies to wrestle with their interests in disaggregation, open hardware and software designs, virtualization of overlay networks in support of cloud-based applications and networking, and smooth integration into SDN and orchestration platforms to control them. The willingness of DPCs to consider integration of open hardware components into their offerings is a bit further along in the data center switching segment than it is in the transport routing segment.

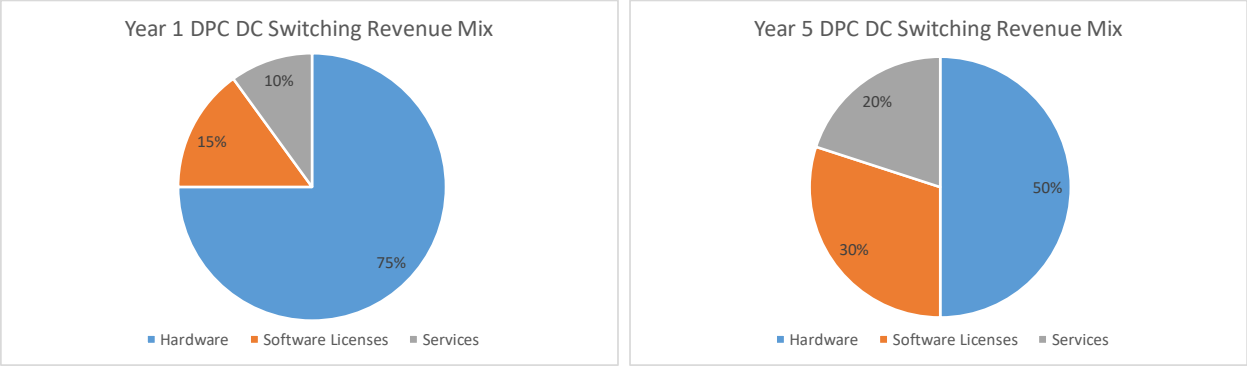


Figure 24. DPC DC Switching Revenue Mix

One way this willingness appears is in the percentage of software revenue as a part of their mix in this segment that DPCs are earning now and will be earning moving forward. This amount includes the software employed in overlay virtual networking, as well as software running in or enhancing the operation of the physical network elements. This amount is expected to double as a percentage of total over five years.

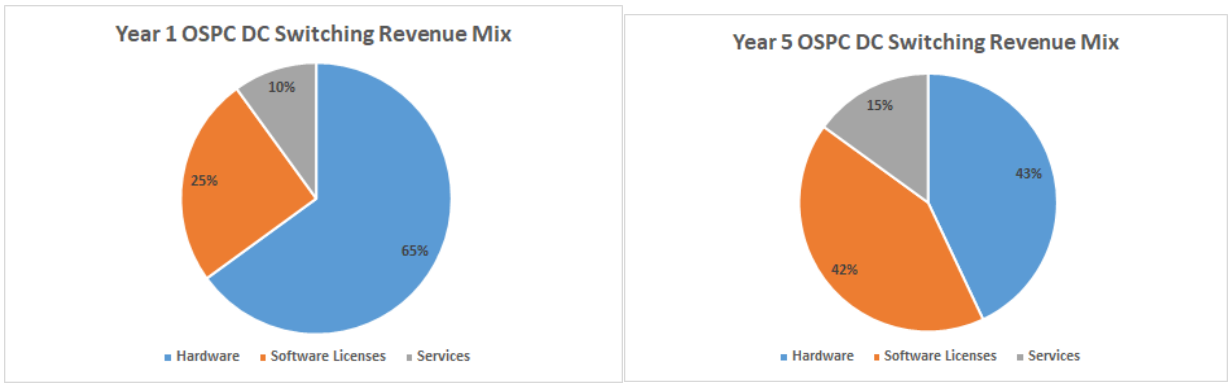


Figure 25. OSPC DC Switching Revenue Mix

In the OSPC data center switching case, this percentage is larger today and will be larger in five years.

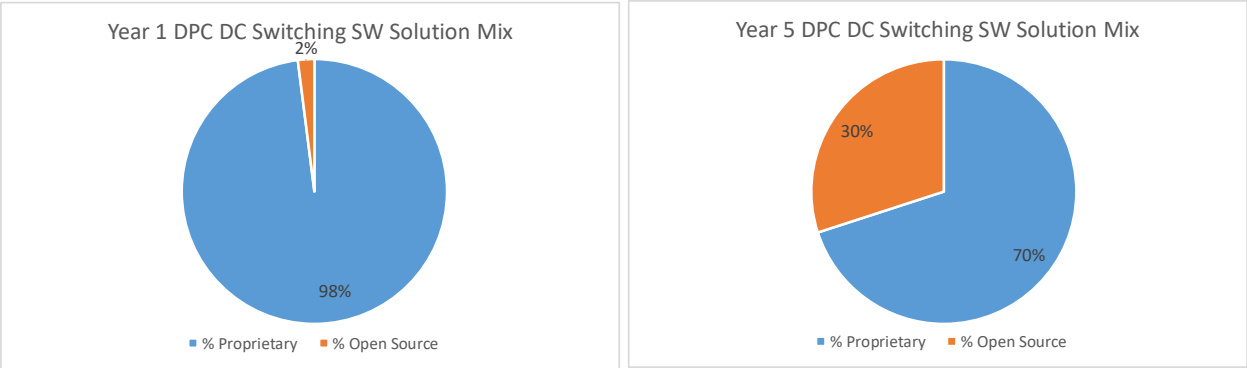


Figure 26. DPC DC Switching Software Solution Mix

Another interesting parallel with the transport routing segment is in the degree to which DPCs will be incorporating open source software into their offerings. As we see in Figure 26, although the proportion of open source software content in the DPC DC switching portfolio is relatively small today, DPCs are expected to increase that proportion over five years. These integrations are likely to occur on a more surgical and tactical basis by function as opposed to a more wholesale adoption of full open source distributions for entire system implementations. Including functionality on a targeted basis for data plane, telemetry, configuration management and other functions allows for a more incremental integration of open source technologies into the solutions, enhancing their value to the CSP, while not undermining the ability of the vendor to deliver a solution that is stable and suited overall to the CSP's requirements.

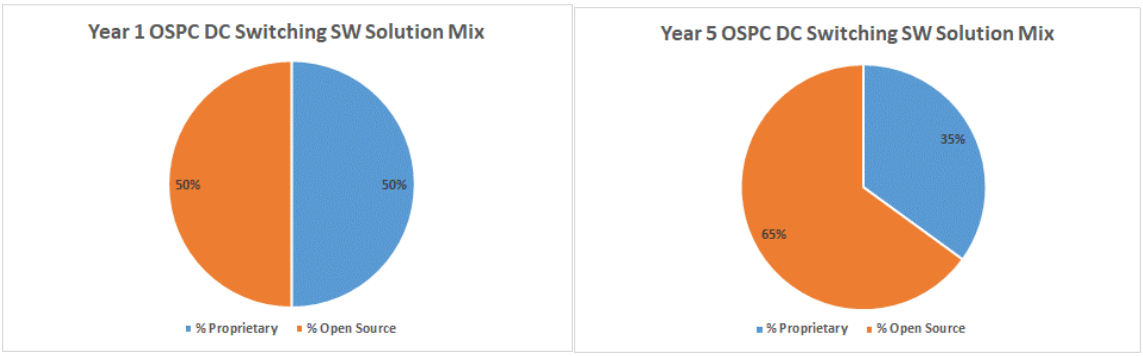


Figure 27. OSPC DC Switching Software Solution Mix

The evolution of software in the OSPC DC switching case is shown in Figure 27. Although OSPCs expect the percentage of open source software in both virtual and physical deployments to increase, they still expect to add value by simplifying the user experience and operations processes.

Figure 28. DPC DC Switching Product Hardware Mix

In a manner like their adoption of open source technologies in their software offerings, DPCs will bring a larger percentage of merchant silicon designs into their platforms in the next five years. Again, this will not be a wholesale makeover of platforms. Rather, it will be by selective integration in areas such as programmable data planes and visibility/telemetry support. Although there will be strong customer and market pressures to move in a more fully disaggregated direction, DPCs will continue to add value in customized areas of functionality while maintaining significant percentages of hardware design from their own implementations.

By contrast OSPCs have firm expectations of following a path largely oriented to leveraging hardware designs created by the open source hardware engineering community. Reference designs being developed by those communities are drawing high interest in many SP environments today, and that percentage will only increase, ultimately being the preference in the majority of OSPC offerings over five years.

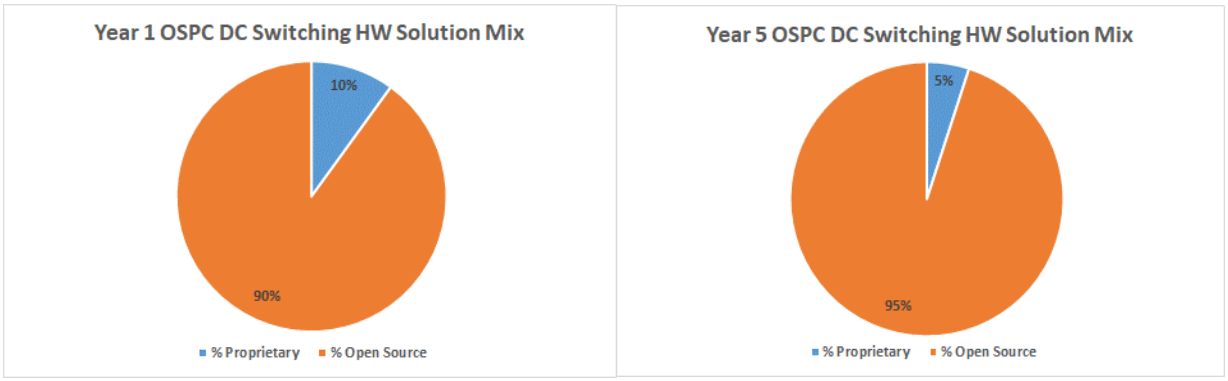


Figure 29. OSPC DC Switching Hardware Solution Mix

R&D investments in each company category mirror this emphasis on leveraging increasing proportions of merchant silicon and open source hardware components and focusing R&D efforts on enhancing the value and appeal of the software in their offerings. As the mix of technologies in the DPC case evolves, the percentage of effort applied to testing and integration will modestly increase.

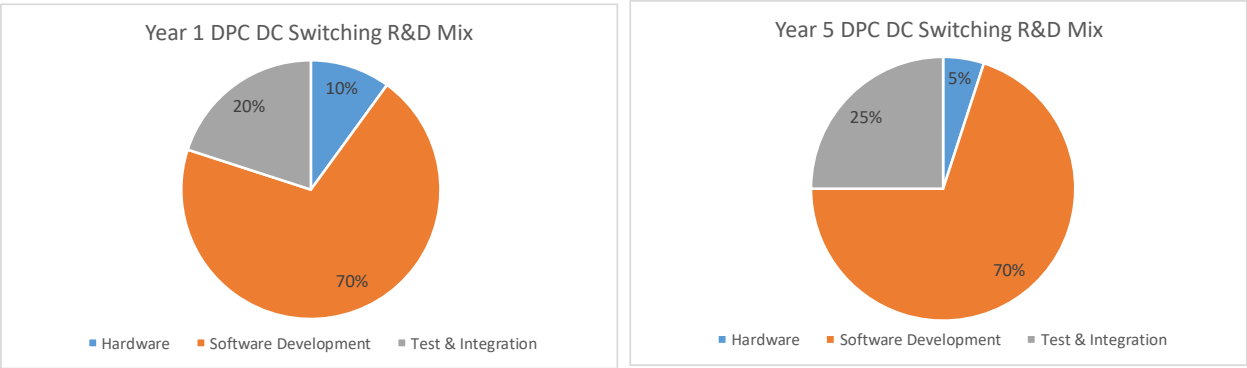


Figure 30. DPC DC Switching R&D Mix

As the capabilities of merchant silicon and open hardware reference designs expand, OSPCs expect to concentrate most of their R&D resources on software innovations, testing and integration to support the increasing variety of use cases their solutions will support.

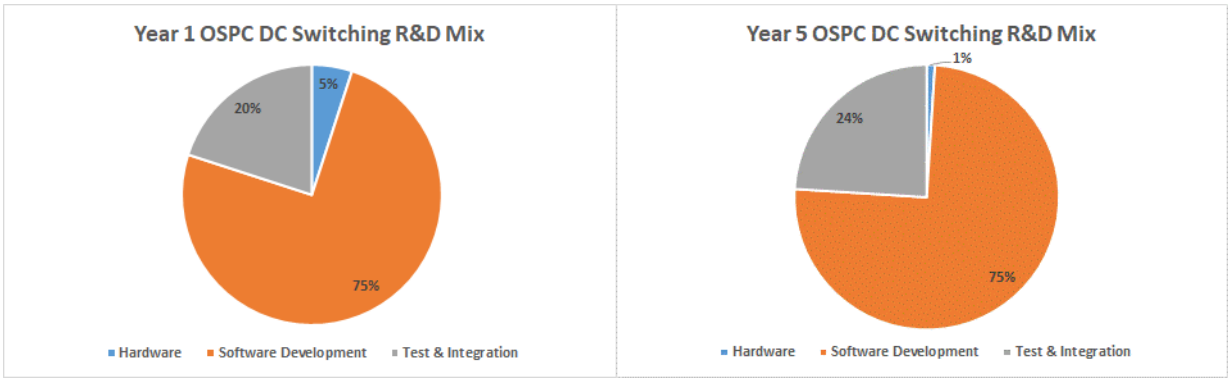


Figure 31. OSPC DC Switching R&D Mix

Conclusions and Implications

The needs of communication service providers for greater agility and flexibility in their operations is stimulating them to adopt new solution development methodologies that impact many aspects of their network infrastructure and operations. Along with embracing a more modular and microservices-based design philosophy and developing more tightly integrated model of continuous innovation leveraging DevOps, a key pillar of their strategy is to incorporate a greater percentage of open source technologies at the core of their platforms. They can benefit from solving common functional problems with other CSPs, obtain greater flexibility in how they construct their solutions and focus their investments more on their own differentiation over time.

The size of the evolution stimulated by these interests is significant. In the categories we analyzed in our research, out of $43 billion in overall value in 2023, greater than $11 billion in orchestration, network control, transport routing and data center switching will be available for vendors to earn with CSPs with solutions based either wholly or substantially on open source technologies. Happily, for vendors in all these categories, CSPs uniformly expressed a desire to continue working closely with vendors that can help them achieve their goals.

For vendors to earn and retain this business an evolution in practices and the basis of their differentiation will be required. Success will demand adjustments over time in the focus of development and differentiation of their offerings. Vendors will need to cultivate demonstrable and sustainable skills in contributing to and integrating the deliverables from the CSP ecosystem's most valuable open source communities. In parallel vendors will need to shift the focus of differentiation toward adding value onto open source foundation and collaborating with CSPs to mold the combination of technology components into a compelling solution that meets or exceeds expectations. We expect the percentage of open source technology components in diversified portfolio companies' solutions to increase between 5 and 10 X between 2018 and 2023 from the predominantly proprietary mix they currently employ. The mix of technology sources in the open source portfolio companies' offerings, by contrast, can be expected to remain dominant ensuring unaltered distributions of open source community solutions, augmented by customized services, applications and tools to facilitate integration and deployment.

In parallel with the evolving mix of technologies, the revenue mix DPC vendors will be able to realize in these categories is likely to transition and incorporate a greater percentage of services and tools. We expect a typical evolution to involve a doubling of services revenues and a reduction of proprietary product content by approximately one-third over five years (proportions to vary based on product category). Although these adjustments are significant, especially in a portfolio generating several billions of dollars each year in revenues for a firm, they will be made simultaneously with maintaining a healthy and effective relationship with important CSP customers, based on alignment of vendor and customer priorities and practices. If anything, the prospects of innovation in the relationships and of shared benefits from that innovation will increase.

Although the contours of this innovation will be shifting to align with these priorities, the opportunity to continue participating in significant and growing segments and in emerging use cases will be the prize and will underpin the vitality of the ecosystem. The companies that make these adjustments most deftly and demonstrate an ability to support CSPs' priorities on agility in new services creation and unification of core technology investments are likely to be the companies that earn a larger share of the CSPs' networking infrastructure markets moving forward.

Appendix A: About the Authors

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Paul Parker-Johnson (PJ) leads ACG's cloud computing and data center virtualization market research and consulting practice. His work examines market sizes, innovations and trends in cloud computing, service delivery platforms, and the virtualization technologies that enable them.

PJ brings his trademark analytic skills to bear on developments in virtual computing, cloud services software, service orchestration, network simplification and related enablers of cloud computing services. In-depth market segmentation and sizing is complemented by point topics research on innovations, early adopter use cases, and factors critical to success in developing platforms and services for the cloud.

PJ's passion for the cloud springs from a rich history of engagement in network and application innovations for over 30 years. Prior to joining ACG he was director of cloud computing solutions development and marketing at Juniper Networks, delivering advanced network, software, and partner platform solutions to service provider and enterprise customers globally. Direct experience designing and delivering solutions in the XaaS and virtual data center landscapes informs his work. Prior to his work in data centers and the cloud PJ served in Juniper's service provider and emerging markets strategy teams, bringing numerous platforms and innovations in routing, switching, security and advanced network services to market over a ten-year span.

Prior to joining Juniper, he held senior product management and marketing positions in switching and routing with Lucent Technologies and Cisco Systems, participating in early delivery of ASIC-based and gigabit scale forwarding technologies for Ethernet and IP networks. Prior to Cisco PJ was a member of BBN Communications' professional services and network engineering teams, developing and deploying X.25 and early stage IP networking platforms into experimental and production networks. His initial experience in large scale computing and networking platforms came with IBM deploying online trading and transaction processing systems for financial services customers in New York from 1978 to 1983.

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Tim Doiron is Principal Analyst, Intelligent Networking practice, at ACG Research. Doiron's work is focused on network innovations and transformations in the areas of packet optical networking, data center interconnect, transport/multi-layer software-defined networking, mobile anyhaul and enterprise services virtualization with network function virtualization and vCPE/SD-WAN. Tim has ongoing collaborations in areas of network programmability, visibility, telemetry and automation. Tim has more than 25 years of networking and telecommunications experience across business and technical organizations. He has served in multiple executive and managerial roles: Vice-President/General Manager, Vice-President of product management, director of marketing, product manager, business development manager and software engineering manager at vendor and service provider companies including Coriant, Tellabs, ARRIS, Cadant, Ericsson and AT&T Mobility. Tim has extensive experience bringing new products to market.

Tim is a frequent speaker at industry conferences and has authored numerous articles. He holds a Master of Business Administration, Webster University; a Master of Science in electrical engineering, Virginia Polytechnic Institute and State University; and a Bachelor of Science degree in electrical engineering, Southern Illinois University. Doiron also holds eight U.S. patents and is a member of IEEE and the Optical Society (OSA). He is an active member of the Electrical and Computer Engineering Industrial Advisory Board at Southern Illinois University where he serves as an advisor to the department chair.

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