ENRICHING THE CLOUD WITH NFV AND SDN
Operators need to ensure that their networks remain a relevant and vital part of users’ everyday experience, and deliver added value in new and unique ways. Emerging Network Functions Virtualization and software-defined networking technologies will help operators do just this, by enabling a Programmable Network Cloud with common management and orchestration across network resources and cloud applications.
The popularity of cloud computing-based services and applications, enabled by ever-improving broadband connectivity and smartphone capabilities, has skyrocketed in recent years. Whether for enterprise mail, storage and collaboration tools or consumer music services, photo storage, video sharing and social networking, cloud-based services are becoming engrained in our everyday lives, available to us wherever we go.

In addition, the Networked Society brings digital transformation – driven by the three forces of mobility, broadband and cloud – to almost every industry. Networks will have to cope with widely varying demands and a business landscape that will be significantly different from today. Operators therefore need to prepare networks to be programmable and highly automated to be able to respond quickly to various demands.

Cloud services provide an opportunity for operators to add value and improve the timeliness and quality with which they deliver customer services and applications – whether through more efficient telecom and internal IT services, or through value-added cloud services for consumers and enterprises. This will require a high degree of automation for service provisioning, as well as a secure network that can be governed.

Operators can turn cloud-based approaches to their advantage and implement new architectures that provide network efficiency, QoE and shorter time to market for innovative services through network programmability and a common delivery platform.

By including the wide area network (WAN) as an intrinsic component of cloud-based services, operators can unlock the full potential of these services – cutting today’s clouds loose from their physical data center “anchors” and opening them up for innovation.

Through a combination of software-defined networking (SDN) and Network Functions Virtualization (NFV), operators can now simplify their networks, remove the complexities of topology and service creation, and accelerate the process of new service creation and delivery. Cloud capabilities are brought into the network with the flexibility and elasticity required to deploy software applications wherever and whenever they are needed. Services and applications can be deployed, modified and withdrawn in a matter of minutes.

- SDN brings network programmability and payload elasticity to the network (beyond the data center) with policy-based and centralized control.
- NFV enables applications to share network resources intelligently and be orchestrated efficiently. It entails the implementation of network functions in software, meaning they can be instantiated from anywhere in the operator’s network or data center, as well as in consumer or enterprise customer premises.

By adopting a layered, virtualized cloud approach, whether centralized or distributed, operators can orchestrate the network and cloud in sync with common SDN orchestration and operations support systems (OSS) capabilities. This not only optimizes resource utilization, but ensures a truly dynamic service delivery process and improves the user experience – enabling a personalized response to changing connectivity requirements in real time.

Together, these technologies transform the network to make it programmable and highly automated – more fluid, more dynamic and more responsive to emerging service needs.
Rapid innovation in online content and application provision means that an ever-greater share of the consumer wallet is being channeled toward application service providers that use broadband connectivity simply as a delivery mechanism. This presents both a challenge and an opportunity for operators. The challenge is to ensure that the relevance of connectivity is highlighted through solutions that personalize and adapt that connectivity to individual user or application preferences. The opportunity lies in new business models and service offers that operators can now explore.

As new services grow in complexity and sophistication, current centralized data center approaches limit the way certain services can be delivered. New services often need resources and service components that reside in different clouds or network domains, well beyond the boundaries of the traditional data center. WANs and data center networks are becoming increasingly interdependent, driving the need for end-to-end network and integration expertise.

As a result, Service Level Agreements (SLAs) that embrace complexity will be an attractive proposition for users, especially within the enterprise segment.

NETWORK PERFORMANCE IS KEY

The ever-increasing volumes of data traffic in mobile networks, driven by both the rapid uptake of smartphones and the prevalence of streamed audio and video services, create a growing challenge for operators.

Not only do operators need to manage the increase in traffic load, they also need to meet increasing consumer and enterprise expectations of excellent performance throughout their networks. The need for ubiquitous broadband connectivity is becoming critical.

In addition, the fifth generation of mobile communication (5G) will bring diverse new requirements. These may include tangible requirements for increased capacity or higher data rates (such as 1,000 times more capacity than 4G), or intangible requirements such as improved reliability or reduced latency. As a result, 5G networks will need to show higher performance and be more efficient and scalable than 4G [1].

5G is also concerned not only with providing a service for people, but with serving devices that can benefit from being connected. In other words, the next generation of mobile communication should enable anyone or anything to access information and share data anywhere, anytime [2].

Along with the need to handle increasing traffic loads and satisfy growing performance expectations, operators also need to roll out new services rapidly. Getting to market quickly with new services represents a vital competitive edge for any operator or enterprise. New service rollouts that take months or even years to complete will no longer be credible or acceptable.

Finally, in every competitive market there is constant pressure to become more efficient by maintaining or improving performance at a lower operational cost.
A COMMON PLATFORM

Cloud-based approaches enable operators to ensure rapid service creation and rollout by delivering new levels of flexibility, scalability and responsiveness. They also satisfy growing expectations for service performance and QoE, while handling ever-increasing traffic loads.

Operators can make use of cloud technology in three ways (see Figure 1):

- **Telecom cloud** – operators gradually turn their networks into layered and distributed clouds, in which workloads can be located to optimize QoE or data transport, and to offer the best possible elasticity.

- **Private cloud** – operators optimize the use of internal IT resources to deliver an improved customer experience, to reduce time to market for innovative and compelling services, and to improve efficiency and enable cost reductions.

- **Commercial cloud** – operators leverage a platform, or their own cloud, to resell or broker value-added cloud services.

Although these scenarios are all quite different, they share some common requirements, and operators can benefit from the implementation of a common platform across all three.

THE PROGRAMMABLE NETWORK CLOUD

For the telecom cloud, a cloud approach (offering flexible management of applications) to NFV (several virtualized applications on a common hardware platform, which reduces opex and capex) and the network programmability of SDN (as shown in Figure 2) provides a truly software-based network that yields significant advantages. This is called the Programmable Network Cloud.

First, it enables operators to adapt network characteristics and resources easily (and usually automatically) to support the more dynamic and real-time nature of new services.

Second, it extends the virtual infrastructure beyond traditional computing and storage resources to enable applications to encompass WAN resources – making it easier to engage one or more data centers, as well as any other intelligent nodes in the network.

This approach delivers the flexibility and elasticity required to deploy software applications and virtualized network functions (VNFs) wherever they are needed in the network. This improves time to market and enhances innovation, QoE and network efficiency.

Introducing distributed clouds and NFV with the telecom cloud also brings applications closer to the Radio Access Network (RAN). This proximity enables scalable and shared common and commercial off-the-shelf (COTS) execution platforms to be used, and leveraged for cost-effectiveness and flexibility for virtualized RAN functionality as well. If the cloud core functions are pushed out into the network and the RAN is centralized to some degree, there will be a degree of colocation of core and RAN functionality – either with the RAN and core on a server in a distributed fashion, or with the RAN and core executing in a centralized data center environment. This will enable substantially lower latencies for the interconnection between the RAN and core.

The Cloud RAN will support different functional splits in the network architecture, including different levels of functionality implemented as NFVs [3]. A selective centralization of the functionality in a Cloud RAN architecture can provide user experience benefits such as mobility robustness, while spectral efficiency can be ensured through a level of radio resource coordination across radio sites.
To deliver this flexibility for the deployment of software applications, the common platform needs to utilize open source initiatives such as OpenStack and OpenDaylight to enable reuse of common software and to allow application development in an open environment. At the same time, the operator will need a frame architecture that allows VNFs to be deployed in a hybrid environment with native network functions.

Open Platform for NFV (OPNFV) is a carrier-grade, integrated open source platform designed to accelerate the introduction of new NFV products and services. As an open source project, OPNFV is uniquely positioned to bring together the work of standards bodies, open source communities and commercial suppliers to deliver a de facto standard, open-source NFV platform for the industry.

Service provisioning has to be highly automated and governed. All services are being customized and made programmable in order to be able to change instantly. Data integrity also needs to be secured end-to-end. In the platform as a service (PaaS) layer of the cloud, platform policies can be set to govern access to data, such as when legal requirements dictate that data resides in only one country.

SDN adds programmability to the networking such as the service chains in the core network and data center, and to the transport routes in the WAN. It provides capabilities for policy-based and centralized control to offer:

- network programmability, which introduces virtualized, software-based network services onto the Programmable Network Cloud wherever needed
- payload elasticity, which enables resources to be allocated dynamically in real time
- extended reach over the network, without compromising service quality
- new levels of information security.

NFV provides the means to virtualize applications and run them on different hardware platforms, whether telecom-grade or COTS. The virtualization of a network must include the following characteristics:

- seamless user experience of network functionality and management, whether implemented in legacy architecture or as a virtualized application
- support for a variety of SLAs for different workloads
- coexistence with the legacy network, as well as common network management and orchestration.

It is crucial that end-to-end service performance can be guaranteed. Network programmability delivers the flexibility that operators need to offer customer-specific SLAs.

Bringing cloud capabilities into the network makes it possible to enhance QoE, while simultaneously improving the efficiency of the network itself. It also enables the flexible distribution of applications to any location in the network, which optimizes the use of available infrastructure and network characteristics such as bandwidth and latency.

This is built on five main criteria:

- Every node is capable of hosting distributed applications in a cloud-execution environment, based on hardware virtualization.
- The execution platforms are located close to the point of data consumption and generation, so that VNFs and innovative software applications can be distributed as needed.
- Customer-specific SLA performance and a strong focus on user experience are essential.
- Perhaps the most attractive benefit of a Programmable Network Cloud is the ability to allocate resources elastically. Operators can scale resources up or down within predefined limits in response to changing demand.
- A highly automated network that provides data integrity and can be governed.

Performance requirements differ between various workloads with respect to latency, throughput and cost. Latency-sensitive workloads (such as gaming, voice and video for personal

![Figure 2: Cloud infrastructure for all workloads.](image-url)
communication, as well as control loops for utilities and automotive applications supporting the Internet of Things (IoT) benefit from the characteristics offered by regional, metropolitan or access clouds. Similarly, best-effort, non-latency-sensitive applications benefit from the cost advantages of national or continent-wide data center solutions. In essence, the cloud should be distributed across a geographical area appropriate to the performance characteristics needed for each service or customer. This means multiple execution platforms such as data centers need to be managed at the same time, with a strong emphasis on efficient networking and distribution of the workload.

A distributed cloud must support the deployment and migration of applications between the infrastructures present in different parts of the network. This is best achieved by using an open cloud execution environment including SDN, orchestrated by a flexible cloud manager. Open standards will support the transfer of services between networks and data centers, and the management of a distributed cloud, and will enable the speedy introduction of new services.

**NFV**

NFV uses standard virtualization technologies to consolidate network functions – which have traditionally been hosted on proprietary hardware appliances – onto industry-standard servers, switches and storage. Virtualizing network functions brings benefits such as rapid scaling of applications, faster innovation, increased high availability and improved utilization of resources.

However, realizing these benefits requires the underlying network infrastructure to be adapted quickly and automatically, and functionality to be deployed in the most efficient way. For example, for a network function either to scale up or migrate onto a new piece of hardware, the security and policy configuration associated with that network function may have to be provisioned on a large number of switches and other network functions. The complexity of configuring networks in such a dynamic environment increases greatly as the number of network elements increase.

**SDN**

One of the benefits of SDN, especially from a network planning perspective, is network virtualization. This enables the exposure of logical abstractions of a network, rather than direct representations of the physical network.

SDN often refers to the separation of the control plane – where the logic of path computation for complex networks has been implemented – from the data plane, where packets are forwarded based on decisions made by the control plane. The control plane in SDN works in conjunction with cloud management systems in order to configure network elements dynamically to adapt to changing resource-use decisions made by cloud orchestration systems. SDN provides the infrastructure required to realize the true potential of NFV.

In cooperation with service providers, the definition and applicability of SDN technology have been expanded beyond data centers, where it has traditionally been used, into the WAN/transport network. However, realizing the full potential of this technology in today’s networks means doing more than just separating the forwarding and control planes. This expanded definition of SDN includes the following (see Figure 3):

- integrated networking control – this unified control layer controls the data center and networking as an integrated entity to provide the desired characteristics.
- orchestrated networking and cloud management – a unified approach that includes legacy network management and new cloud management systems. It is this integrated orchestration of infrastructure capabilities that enables flexible service creation, which in turn makes the network dynamic, adaptive and agile. This cuts introduction and modification cycles for services and removes barriers to innovation.
- service exposure – the SDN architecture provides network awareness to the application layer through service exposure application programming interfaces (APIs). These APIs not only provide raw network data; they are actually composed APIs that deliver actionable information at the application level.

The promise of SDN is to convert the networking layer into a real-time, programmable entity that will enable customization of connectivity and the services offered through that connectivity. This increases the relevance of the operator in the new ecosystem. It contributes to increased customer loyalty, and enables business model innovation between the consumer, the operator, and the content or application provider ecosystem.

The Programmable Network Cloud builds upon the concepts of both NFV (the ability to offer
VNFs) and SDN (the ability to provide abstractions at the transport, IP services and connectivity between the VNFs). The architectural model consists of a common orchestration layer that spans multiple network domains (see Figure 3):

- **Transport SDN**: offers an end-to-end abstracted view of transport network resources and topology optimizing resource allocation and network engineering across the IP and optical layers
- **Cloud SDN**: brings IP routing capabilities to data center networking
- **Services SDN**: binds SDN control capabilities with policy control to offer dynamic flow-steering capabilities in managing connectivity to applications.

With integrated network control and an orchestrated network, operators can use their network features – including QoE, edge functions and real-time activity indicators – to deliver a superior user experience. This transformation requires the integration and unification of legacy network management systems with new control systems, in addition to OSS and business support systems (BSS).

The next logical step is to be able to expose key elements of the orchestration platform and control plane to network and subscriber applications and services. Using northbound APIs, the orchestration platform can be exposed to key network and subscriber applications and services. Together, the APIs and platforms enable application developers to maximize network capabilities without requiring intimate knowledge of their topology or functions.

### COMMON MANAGEMENT AND ORCHESTRATION

Managing resources in the cloud requires a structured, disciplined approach that automates and orchestrates the provisioning processes and makes resources available on demand. However, the approach must also be capable of managing these resources in the context of complex, dynamic systems that require resource access control, as well as service quality management and optimization. It should be flexible enough to enable operators to create services from scratch, or to reuse internal resources and broker an ecosystem involving third parties, where the brokering adds value primarily through management.

Cloud management encompasses:

- self-service portals and API exposure, which enable the rapid uptake of new services
- automatic orchestration of the provisioning of software applications onto virtualized resources, either owned or accessed from third parties
- cloud business models that provide billing based on measured usage and allocated capacity
- the definition, implementation, enforcement and validation of end-to-end SLAs.

Security is also a key requirement. Operators need to meet customer expectations, while optimizing the use of resources in compliance with all legal and regulatory restrictions. Self-provisioning capabilities must also come with appropriate levels of security.

The service control layer of the SDN architecture brings elastic, real-time allocation of resources for networking services. It enables these services to be defined and provisioned through self-service portals in a matter of minutes, rather than the days, weeks or even months that are traditionally required.

This demands a platform with integrated control across networking domains that exposes composed APIs for new revenue generation. End-to-end hybrid network management manages radio, IP and transport, core, and virtual network functions. It also performs the VNF and network

---

**figure:** SDN architecture (with use case examples on the right).

---
slice orchestration, and leverages network analytics capabilities to provide proactive and predictive service assurance. Hybrid network management creates further efficiencies, develops greater responsiveness, and enables more reliable planning, provisioning, activation, adaptation and control of new service connections.

The goal is to couple cloud management to a programmable network via SDN controllers to achieve full integration of the cloud and network, where cloud resources are no longer confined to a single data center, but are spread throughout the network.

Using common orchestration for end-to-end service management as well as for operations, administration and maintenance reduces operating costs in areas such as provisioning, monitoring and fault-finding.

More importantly, end-to-end orchestration enables flexible service creation, which makes the network dynamic, adaptive and agile.

NETWORK SLICES
The concept of network slices is central in the context of 5G and business expansion. A network slice is a logical network serving a defined business purpose or customer. To make such a new approach to building networks feasible, an underlying Programmable Network Cloud is a necessary enabler. It allows flexibility in deployment in order to meet diverse customer requirements. The programmability also reduces time to market and time to consumer, while providing the ability to multiplex payloads contributing to the lowest possible TCO.

USE CASES
A cloud system that integrates seamlessly with a real-time, programmable network – enabled by SDN – can provide significant value to operators and their subscribers, both consumers and enterprises. Today, most subscribers do not rely on connectivity alone. Instead, they demand a wide range of cloud-hosted services, and they require the network to play a role in offering the right connectivity for the desired application. This is where the real value of an SDN-based, real-time Programmable Network Cloud becomes apparent.

One use case is in Virtual Enterprise IT Infrastructure, where an SDN-based gateway or Virtual Enterprise CPE (vE-CPE) can be put into the cloud to eliminate the need for hardware and software on the enterprise’s premises. The solution features tight coordination between a feature-rich cloud controller and an SDN controller. This enables the instantiation, replication and migration of network and cloud-based services to the best available location, based on the tenant’s requirements, overall network congestion and cloud availability. True to the ideal of not tying cloud services to the constraints of a physical data center, this solution implements flow tracking and policy enforcement at a “logical” cloud level. This encompasses multiple operator data centers, irrespective of their geographic locations and the network infrastructure connecting them.

Another similar case is the virtual home gateway or Virtual Customer Premise Equipment (vCPE). This is an example of virtualizing some of the functions of a traditional home gateway and hosting them in a network-enabled cloud. Virtualization reduces the complexity of the home gateway by moving most of the sophisticated functions into the network. As a result, operators can prolong the home gateway refreshment cycle, cut maintenance costs and reduce time to market for new services. The most important aspect of this solution, however, is that it gives the network visibility to all the devices that were traditionally hidden behind the home gateway. This opens up significant revenue opportunities through the ability to offer services that are personalized in a much more granular way. This also opens up for dedicated connections to IoT services such as smart meters and HD video cameras for security, which can be given appropriate SLA-driven connectivity.

Scale in and scale out, and load balancing of VNFs, are further examples demonstrating the value of a combined real-time Programmable Network Cloud solution with the ability to dynamically extend network functions into the cloud – with SDN, NFV and the cloud all working together. As the load on a network appliance increases, the SDN controller can request a peer cloud manager to instantiate a virtual network function in the cloud and to start load balancing between the physical appliance and the virtual appliance, treating it as a common entity.

With SDN comes the ability to steer the IP flow through the core network based on policies or real-time events. The benefits include effective composition of new services, cost savings due
to better utilization of appliances, shorter time to market for new services and better operational efficiency. For inline services, such as content filtering, header enrichment, firewalls and Network Address Translation (NAT), operators use different appliances or value-added services to manage subscriber traffic. These inline services can be hosted on dedicated physical hardware or realized as VNFs. Service chaining is required to route certain subscriber traffic through more than one such service. AVNF Manager (VNFM) platform manages the lifecycle of the VNFs. Current solutions are either static or their flexibility is significantly limited by scalability inefficiencies.

Dynamic service chaining can optimize the use of extensive high-touch services by either selectively steering traffic through specific services or bypassing them completely. This can provide capex savings through efficient use of capacity. Greater control over traffic and the use of subscriber-based selection of inline services can lead to the creation of new offerings and new ways to monetize networks.

The network-enabled cloud provides the necessary virtual resources for software appliances, whether on dedicated physical hardware or on virtual machines, and supports the efficient distribution of these resources wherever needed in the network; for example, to meet latency requirements in the most effective way.

Scaling of a software appliance can be achieved either by requesting more cloud capacity in the network-enabled cloud or by requesting virtual resources in a centralized cloud data center. The flexibility of the distributed cloud is greatly enhanced using the SDN real-time control mechanism, in which software appliances can be moved within or between clouds while preserving the networking attributes and requirements.
Operators are in a unique position to offer services that transcend the boundaries of the traditional data center without compromising on quality. New levels of innovation are possible when leveraging resources residing in different clouds or network domains. The Programmable Network Cloud provides new capabilities, made possible by implementing a combination of:

- distributed cloud, which extends virtual infrastructure beyond traditional computing and storage resources to encompass network resources across an operator network
- NFV, allowing portability of VNFs to different hardware platforms as well as the flexible lifecycle management of VNFs, including elasticity of the network function
- network programmability from SDN, which enables operators to adapt their networks more easily to the real-time requirements of new services
- a highly automated network that can cater for frequent and almost instant changes of differentiated services in a way that is properly governed and secure.

The result will be an improved experience for both consumers and enterprises, while at the same time delivering greater efficiency, lower costs and higher margins to operators.
### GLOSSARY

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>API</td>
<td>application programming interface</td>
</tr>
<tr>
<td>BSS</td>
<td>business support systems</td>
</tr>
<tr>
<td>COTS</td>
<td>commercial off-the-shelf</td>
</tr>
<tr>
<td>IaaS</td>
<td>infrastructure as a service</td>
</tr>
<tr>
<td>NAT</td>
<td>Network Address Translation</td>
</tr>
<tr>
<td>NFV</td>
<td>Network Functions Virtualization</td>
</tr>
<tr>
<td>OPNFV</td>
<td>Open Platform for NFV</td>
</tr>
<tr>
<td>OSS</td>
<td>operations support systems</td>
</tr>
<tr>
<td>PaaS</td>
<td>platform as a service</td>
</tr>
<tr>
<td>RAN</td>
<td>Radio Access Network</td>
</tr>
<tr>
<td>SaaS</td>
<td>software as a service</td>
</tr>
<tr>
<td>SDN</td>
<td>software-defined networking</td>
</tr>
<tr>
<td>SLA</td>
<td>Service Level Agreement</td>
</tr>
<tr>
<td>VCPE</td>
<td>Virtual Customer Premise Equipment</td>
</tr>
<tr>
<td>vE-CPE</td>
<td>Virtual Enterprise CPE</td>
</tr>
<tr>
<td>VNF</td>
<td>Virtualized Network Function</td>
</tr>
<tr>
<td>VNFM</td>
<td>VNF Manager</td>
</tr>
<tr>
<td>WAN</td>
<td>wide area network</td>
</tr>
</tbody>
</table>
REFERENCES

