OPEN NETWORKING
FOUNDATION

OpenFlow™-Enabled Mobile and Wireless Networks

ONF Solution Brief
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Executive Summary

The explosion of mobile services has arguably revolutionized communications just as much as mobile's predecessor: the telephone. With the phenomenal growth in mobile devices and recent upgrades from 3G to 4G/LTE, the subsequent surge of mobile traffic (often with unpredictable spikes) requires fresh approaches to networking.

Software Defined Networking (SDN) offers a logically centralized control model, unprecedented programmability, and a flow-based paradigm that is ideally suited for highly scalable mobile and wireless networks, from access to backhaul and core. This solution brief presents the compelling business case for OpenFlow™-based SDN for mobile and wireless networks. Two use cases illustrate the value proposition: wireless network control for inter-cell interference, and mobile traffic management.

The tremendous growth in mobile data, the inherent need to simultaneously operate over multiple wireless technologies, and the rapidly evolving mobile services market impose significant challenges for today's architecture. OpenFlow-based SDN architectures provide an agile and cost-effective communications platform for addressing these challenges, while attaining the high degree of scalability, security, and flexibility needed to support a diverse complement of services.

OpenFlow-based Software Defined Networking delivers substantive advantages for mobile and wireless networks, including:

- Resource optimization for dynamic environments
- Automation to streamline operations
- Granular control and policy management
- Innovation and differentiation
- Openness

SDN Overview

Software Defined Networking is a new architecture that has been designed to enable more agile and cost-effective networks. The Open Networking Foundation (ONF) is taking the lead in SDN standardization, and has defined an SDN architecture model as depicted in Figure 1.

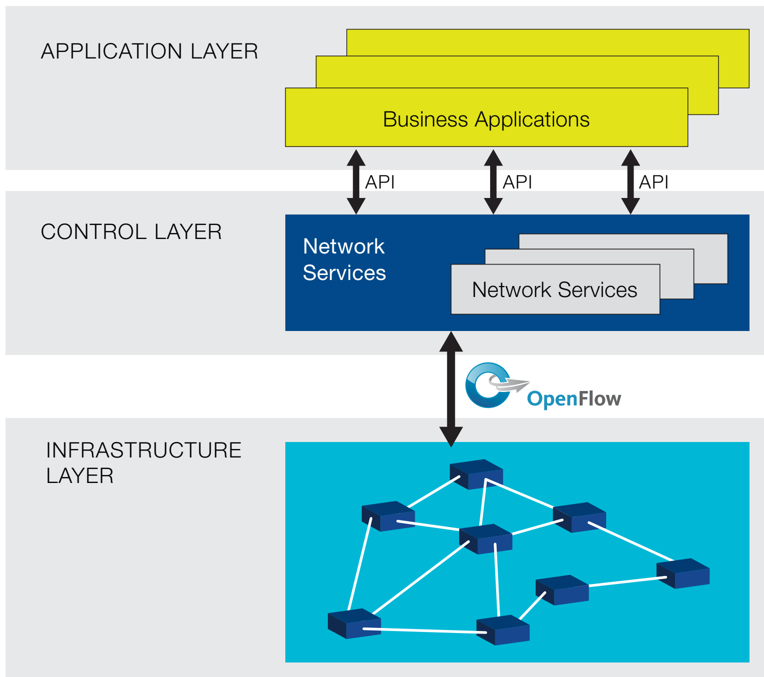


FIGURE 1
ONF/SDN architecture

The ONF/SDN architecture consists of three distinct layers that are accessible through open APIs:

- **The Application Layer** consists of the end-user business applications that consume the SDN communications services. The boundary between the Application Layer and the Control Layer is traversed by the northbound API.
- **The Control Layer** provides the consolidated control functionality that supervises the network forwarding behavior through an open interface.
- **The Infrastructure Layer** consists of the network elements (NE) and devices that provide packet switching and forwarding.

According to this model, an SDN architecture is characterized by three key attributes:

- **Logically centralized intelligence.** In an SDN architecture, network control is distributed from forwarding using a standardized southbound interface: OpenFlow. By centralizing network intelligence, decision-making is facilitated based on a global (or domain) view of the network, as opposed to today's networks, which are built on an autonomous system view where nodes are unaware of the overall state of the network.

- **Programmability.** SDN networks are inherently controlled by software functionality, which may be provided by vendors or the network operators themselves. Such programmability enables the management paradigm to be replaced by automation, influenced by rapid adoption of the cloud. By providing open APIs for applications to interact with the network, SDN networks can achieve unprecedented innovation and differentiation.
- **Abstraction.** In an SDN network, the business applications that consume SDN services are abstracted from the underlying network technologies. Network devices are also abstracted from the SDN Control Layer to ensure portability and future-proofing of investments in network services, the network software resident in the Control Layer.

Trends and Challenges

Mobile and wireless networks continue to exhibit a torrid pace of change. As wireless becomes the primary or even sole access method for more and more people, mobile operators must carry higher volumes of traffic and support more sophisticated services. Video-based services in particular account for a larger portion of the traffic, imposing significant demands for new network functions such as media transcoding and content caching. Furthermore, mobile networks must simultaneously support multiple generations of mobile services (i.e., 3G and 4G) along with a range of user services (VoIP, streaming media, and messaging), resulting in widely varying traffic properties. And they must do so in a cost-effective manner at a time where rapidly increasing capacity demands far exceed the growth in revenues—and in the budgets required to address the new demands.

Growing traffic has necessitated more and more cells in the radio access networks (RANs) that provide mobile subscribers with an onramp to wireless networks. Mobile operators are turning to small-cell technology to increase capacity through frequency reuse, especially in densely populated areas. Closer physical cell spacing is one of the factors increasing Inter-cell interference, which is exacerbated for higher and higher bandwidths such as 4G LTE services.

Another trend is the increasing number of wireless technologies in use simultaneously. Typical devices today support 3G and 4G cellular as well as Wi-Fi and Bluetooth connectivity. Such diverse wireless technologies require mobile operators to maintain and operate distinct access and backhaul and core networks, increasing both costs and operational headaches. In addition, carriers need flexible deployment options to migrate from older to newer technologies without impacting the customer experience.

Another significant challenge is the need to seamlessly deliver services across technologies; mobile operators must enforce increasingly complex policies to ensure the right access for the right service and control handoffs between access types.

Quickly-changing business environments require fast rollout of new mobile services and rapid adoption of new technologies. The market for mobile services has traditionally been highly competitive, but today's mobile operators must cope with a new class of competitors such as over-the-top (OTT) players and established Internet giants. Compounding that challenge are falling voice revenues that mobile operators are seeking to replace with revenues from a myriad of new data services, such as location, e-commerce, and analytics. Finally, network capabilities must be highly scalable and agile despite the large capital outlays. This necessitates lowering the cost of hardware where possible, wringing out the maximum utilization from hardware assets while reducing operational costs by embracing new techniques and technologies such as cloud computing and automation.

OPENFLOW-BASED SDN IN THE MOBILE NETWORK

The challenges outlined above compel the need for a new network architecture that overcomes the limitations of today's network architecture. Specifically, current networks are:

- **Difficult to scale.** With mobile video traffic projected to continue to rise, static over-provisioned networks are too inflexible and costly to address the orders of magnitude of additional bandwidth required to keep up with demand.
- **Difficult to manage.** Presently, mobile networks rely on operations support systems (OSS) and management systems that require significant expertise and platform resources to operate the network. Because these systems are manually intensive, networks are prone to misconfiguration errors and lengthy delays in provisioning and troubleshooting.
- **Inflexible**. Today's networks require weeks or even months to introduce new services because of the manually intensive processes for service activation, delivery, and assurance. Multi-tenancy and traffic isolation are limited to such constructs as VLANs and tunnels, with limited policy management mechanisms.
- **Too costly**. With inefficient and inflexible use of network bandwidth and ever-increasing complexity burdening the operations staff, CapEx and especially OpEx is rapidly rising.

OpenFlow-based SDN offers a number of benefits for mobile networks, including wireless access segments, mobile backhaul networks, and core networks.

- The flow paradigm of SDN is particularly well suited to provide end-to-end communications across multiple distinct technologies, such as 3G, 4G, Wi-Fi, etc. Flows can have granular policies for effective traffic isolation, service chaining, and QoS management.
- Logically centralized control allows for efficient base-station coordination, which is particularly useful for addressing inter-cell interference as described in the use cases below.
- SDN enables path management to be optimized based on the individual service needs and not bound by the routing configuration. This is especially important in the mobile environment where end users are constantly changing their location, bandwidth demands vary widely depending on the type of content being sent, and basic wireless coverage is not uniform.
- Network virtualization abstracts network services from the underlying physical resources, for example, from the eNodeB to the enhanced packet core (EPC). Multi-tenancy allows each network slice to have a distinct policy, whether that slice is controlled by an MVNO, OTT provider, single mobile operator, virtual private enterprise network, governmental public services network, or other entity. Such services can readily be offered on a temporary basis, such as video feeds for a sporting or news event.

Mobile Network Use Cases

Two use cases will illustrate the benefit of OpenFlow-based SDN:

- Inter-cell interference management
- Mobile traffic management

SDN benefits can also be realized throughout the network from access to mobile backhaul to the EPC. By leveraging SDN's flow-based paradigm, granular policy management, network virtualization, and traffic steering capabilities, operators can address a number of challenges in their current networks. ONF formed the Mobile Wireless Study Group to assess and define use cases based on investigatory work by mobile operators and their vendors.

INTER-CELL INTERFERENCE MANAGEMENT

In recent years, there has been enormous growth in mobile telecommunications traffic in line with the rapid consumer adoption of smartphones and smart devices in general. LTE is the latest wireless communications standard. It enables high-speed data communications at up to 150 Mbps and supports the ever-increasing demand for mobile broadband services.

As LTE networks proliferate and network traffic increases, inter-cell interference can lead to a significant degradation in user throughput mobile service quality, as shown in Figure 2. Adjacent base stations, which result in overlapping cells, need to coordinate their subcarrier allocations to avoid harmful interference among mobile users. The goal, as depicted in Figure 2, is to reduce the signal-to-interference-plus-noise ratio (SINR) using interference management techniques.

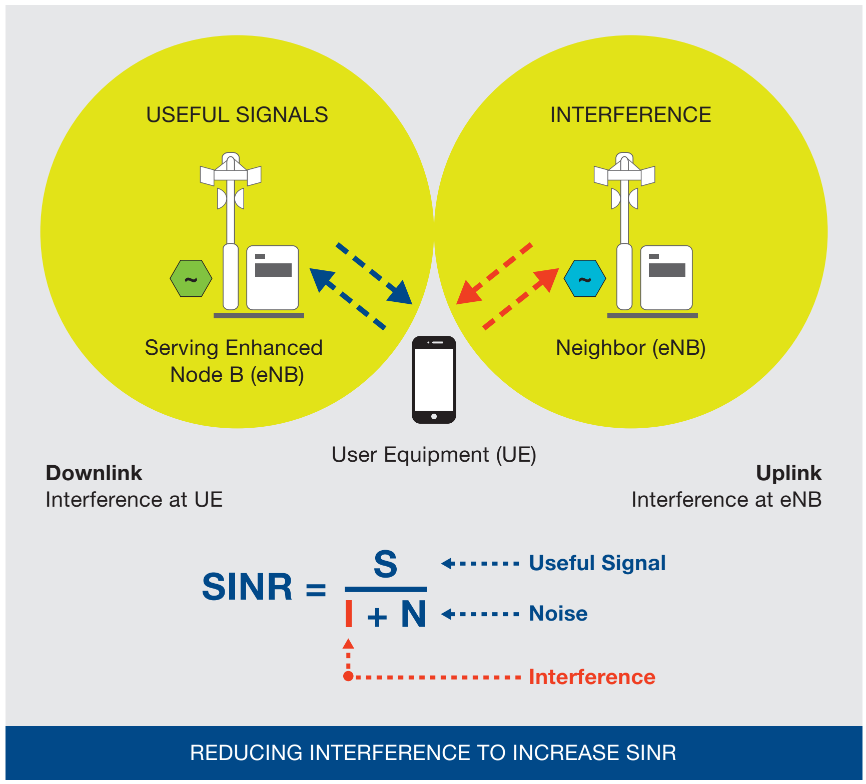


FIGURE 2
Interference within cellular systems

There are a number of techniques in use in LTE networks to address inter-cell interference, including:

- **Inter-cell interference coordination** (ICIC), which selectively reduces the power for subchannels in the frequency domain.
- **Enhanced inter-cell interference coordination** (eICIC), where macrocells are complemented with picocells inside their coverage area (for hotspots in public places such as coffee shops, airports, etc.).
- **Coordinated multi-point transmission/reception** (COMP), where interference is decreased on edge users of cells by jointly scheduling several cells with rather strong edge interference, or by joint transmission so that the reception power and service experience of a cell's edge users can be improved.

There are some drawbacks to the current inter-cell interference coordination techniques. In existing LTE networks, inter-cell interference management is performed in a distributed fashion. Techniques such as COMP are software-based, driving up complexity and processing overhead and imposing higher power and network resource requirements on the radio access network (RAN). Furthermore, the existing inter-cell interference management algorithms are implemented using distributed graph coloring algorithms[1] that are highly complex and suboptimal.

[1] In computer science, coloring the nodes of a graph with a small number of colors is a special case of graph labeling such that the no two vertices of the graph share the same color; this is called a vertex coloring. Similarly, edge coloring assigns a color to each edge so that no two adjacent edges share the same color, and face coloring of a planar graph assigns a color to each face or region so that no two faces that share a boundary have the same color.

An SDN-enabled LTE network offers the potential to overcome the limitations described for inter-cell interference management. As shown in Figure 3, the logically centralized control layer enables radio resource allocation decisions to be made with global visibility across many base stations, which is far more optimal than the distributed radio resource management (RRM), mobility management, and routing applications/protocols in use today. By centralizing network intelligence, RRM decisions can be adjusted based on the dynamic power and subcarrier allocation profile of each base station. In addition, scalability is improved because as new users are added, the required compute capacity at each base station remains low because RRM processing is centralized in the SDN controller.

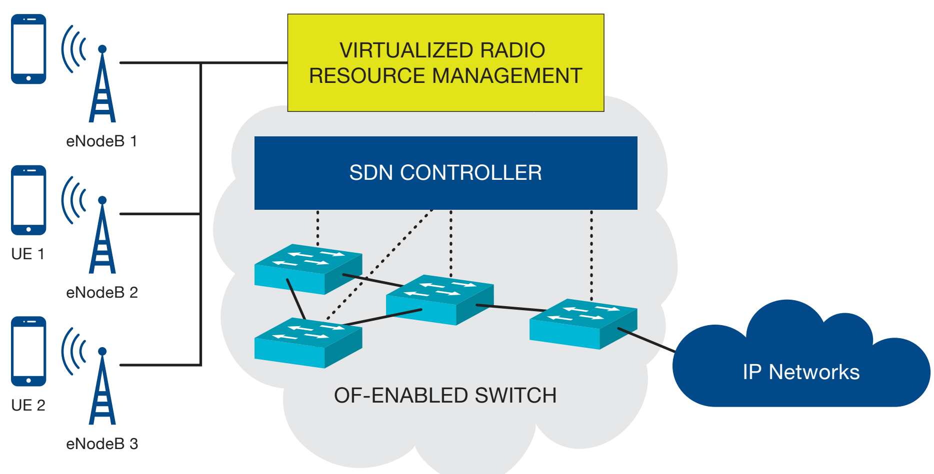


FIGURE 3
OpenFlow-enabled centralized base station control for interference management

Considering that the SDN controller communicates with the base stations through the standard southbound interface (OpenFlow), any RRM upgrades can be achieved independently from the base station hardware.

MOBILE TRAFFIC MANAGEMENT

Traffic steering and path management have received a great deal of attention within the OpenFlow/SDN community. Traffic steering is applicable to a number of areas and potential use cases that include load balancing, content filtering, policy control and enforcement, disaster avoidance and recovery (such as the use of backup paths); essentially, anything pertinent to traffic flow redirection and management.

In the context of mobile and wireless networks there are use cases such as mobile traffic offloading and roaming, content adaptation (such as adaptive streaming), and mobile traffic optimization that could greatly benefit by leveraging OpenFlow as an SDN platform.

When voice predominated, RAN traffic planning was more predictable. The transition to mobile data, and the subsequent exponential growth in audio and video streaming, has resulted in tremendous bandwidth demands that have risen far faster than budgets and average revenue per user (ARPU). A more agile approach is needed to scale capacity, to ensure optimal use of the scarce RAN capacity, and to support service discrimination to maximize revenues.

For the mobile traffic offloading use case, SDN enables traffic to be dynamically positioned or repositioned in a mobile network based on various trigger criteria. Such criteria may include the individual flow rate, aggregate (per application, cell, user equipment, etc.) flow rate or aggregate number of flows on a specific port/link, flow duration, number of mobile users per base station (or in general a Wi-Fi network), available bandwidth, IP address, application type, and NE (switch or port) utilization.

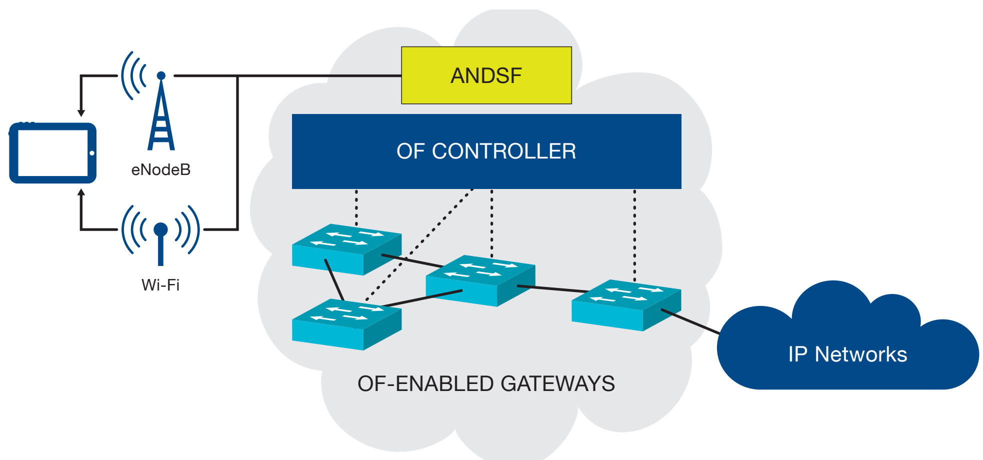
Those criteria can be user- or mobile operator-defined. For instance, the mobile operator may decide, based on the network conditions, to offload mobile traffic. Alternatively, users could opt in based on their preferences; for example, voice calls should not be offloaded while data traffic could be. In an advanced scenario, we would envision that users could connect simultaneously to multiple networks (perhaps even ones of their choice). Network conditions in this context refer to network congestion, quality of service (QoS), or any other type of feedback or network planning mechanisms.

The triggering factors (such as a flow rate threshold) could be set and modified dynamically as mobile traffic is monitored by the mobile operator. For instance, "If the flow rate exceeds 50 Kbps, move the flow from 4G to Wi-Fi." Distinct criteria and thresholds could be applied for different applications running on the same user equipment (UE) or for different users. Again, thresholds could be based on a wide range of criteria: user profile, service plan, location, etc.

Offloading means moving traffic from a mobile network (cellular, small cells, femtocell) to a Wi-Fi network. It is also known as Wi-Fi roaming. The handover process has to be entirely seamless (no loss of data/connectivity, preservation of IP address, etc.) to maintain the user experience (UX). It is the power of software that enables these intelligent choices, offering the potential for a wide range of new services.

Offloading can also be applied in reverse (reverse offload) when congestion on a Wi-Fi network triggers select mobile users to be moved to another Wi-Fi or onto a mobile data connection (3G or 4G/LTE). The OpenFlow controller (OF controller) will have to interact with entities such as the ANDSF (access network discovery and selection function) for discovering wireless networks close to the mobile user and performing the Wi-Fi offload (Figure 4). Selection of the roaming destination can be based on a QoS metric such as performance, signal strength, or distance in order to maintain the UX.

FIGURE 4
OpenFlow-based mobile offload



Mobile traffic offloading leveraging OpenFlow-based SDN requires the mobile network controller (probably residing in the mobility management entity [MME]), to interwork with the access network discovery and selection function (ANDSF), the 3GPP framework that provides information on connectivity of the UE and couples mobile and Wi-Fi networks[2].

Mobile offloading has become extremely important with the surge of mobile traffic and devices because it enables mobile operators to optimize RAN resources, and improve the quality of experience (QoE) for data-intensive mobile applications.[3]

Another interesting application is wireless link aggregation, which consists of bundling available wireless connections (and bandwidth) to expand the aggregate capacity available to the UE. This requires the UE or mobile device to be capable of simultaneously handling different concurrent wireless connections (for instance, a mix of Wi-Fi, or Wi-Fi and 3G/4G).

[2] It is not straightforward whether the SDN controller itself will need to have knowledge of the individual mobile subscriber.

[3] According to Cisco's VNI 2013 Forecast, mobile traffic will grow at 66% CAGR over the next five years, or a 13-fold increase between 2012 and 2017. Mobile data traffic in 2012 was 888 PB/month. Mobile video traffic has already exceeded 50% of total mobile traffic. It is projected that there will be over 10 billion mobile devices in 2017.

Key Benefits

OpenFlow-based SDN provides a number of benefits for mobile wireless networks, as exemplified by the inter-cell interference management and mobile traffic management use cases just described.

- **Centralized control of multi-vendor environments.** SDN control software can control any OpenFlow-enabled mobile network component from any vendor. Rather than having to manage groups of devices from individual vendors, mobile operators can use SDN-based orchestration and management tools to quickly deploy, configure, and manage multi-vendor networks.

  For the inter-cell interference management and mobile traffic management use cases, logically centralizing control, and in turn intelligence, enables more efficient and optimal resource management decisions, improving the utilization of scarce RF spectrum. In addition, computational-intensive processing may be offloaded from the base stations, reducing RAN costs and increasing scalability.

  Centralization and decoupling of the control plane from the NEs allows the various network congestion management algorithms to be updated from a central point, without the burden and cost of touching each individual NE. Mobile operators can adaptively apply offloading policies based on actual traffic patterns, as opposed to today's static policies that cannot adapt to changing network conditions.

- **Higher rate of innovation.** SDN adoption accelerates business innovation by allowing mobile operators to literally program—and reprogram—the network in real time to dynamically address specific business needs and user requirements. By virtualizing the network infrastructure and abstracting NEs from individual network services, SDN and OpenFlow offer mobile operators the ability to tailor the behavior of the network and introduce new services and network capabilities in a matter of hours instead of days. In addition, mobile operators can quickly innovate and test various approaches to manage network congestion and new ways to classify and offload flows at a much faster rate than was previously possible, without impact to operational traffic.

- **More granular network control.** The OpenFlow flow-based control model allows mobile operators to efficiently apply policies at a very granular level—including the session, user, device, and application levels—in a highly abstracted, automated fashion. This control enables mobile operators to support multi-tenancy while maintaining traffic isolation, security, and elastic resource management when customers share the same infrastructure.

For the inter-cell interference management and mobile traffic management use cases, the ability to assign policies based on a service or user level provides significant flexibility that is infeasible with traditional methods. For instance, higher-revenue-producing corporate clients can be offered preference over lower-yielding consumers; there is no notion of customers in today's policy management mechanisms. Policies can also be established to make offload and resource management decisions based on applications; for example, SalesForce could take precedence over YouTube or Spotify.

In the mobile traffic management use case, SDN enables more intelligent decision-making to offload flows for select applications to the Wi-Fi network while maintaining critical flows on the mobile network. Being able to manage traffic at more granular levels allows for a much more efficient and optimal usage of the mobile network.

Conclusion

Mobile service providers are challenged to optimize their CapEx, OpEx, and ARPU, while facing aggressive competition not only from other carriers but also from over-the-top Internet services such as Skype, Facebook, and Google. The application of OpenFlow-based SDN architectures enables service providers to effectively address these business challenges while at the same time positioning their networks (comprising RAN, access/aggregation, and EPC elements) as differentiated, value-added assets rather than low-margin "dumb pipes."

The use case presented in this solution brief exemplifies how SDN brings tremendous OpEx improvements through the scalability of network control functions, the flexibility to adjust network resource allocation and steer traffic dynamically in response to changing traffic patterns and mobile or wireless network conditions, and the ability to transparently provision additional network resources to address new "killer apps."

SDN simplifies the network, offering mobile operators unprecedented programmability. It also enables traffic to be intelligently controlled for quick reaction to dynamic network conditions. In turn, this agility accelerates time to new service, while reducing OpEx through highly automated orchestration and management.

SDN also helps maximize ARPU by enabling service providers to attract and retain the subscribers who generate the highest margins. Typically, these subscribers are heavy users of streaming media and online gaming. Through the use of SDN and advanced analytics, service providers can market differentiated services (such as location-based services and e-commerce) and an improved customer experience (such as low latency and high bandwidth) to those subscribers who are most willing to pay for those benefits.

In order for “mobile SDN” capabilities to be delivered via a cost-effective infrastructure, critical enabling technologies such as network virtualization, high-performance software-based networking, and sophisticated orchestration must be available. Fortunately, those are exactly the kinds of solutions provided by ONF member companies as part of the overall SDN ecosystem.

In short, SDN has the potential to redefine mobile network architectures, enabling the development of next-generation network controllers that enhance application performance and efficiency, ultimately improving the end user’s experience.

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