White Paper

Software-Defined Metro Networks: Virtualizing the Network & Services Edge

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December 2012

Executive Summary

The communications industry is entering an exciting new era with the emergence of software-defined networking (SDN). Over the past year, we have seen dramatically increased carrier interest in applying SDN architectural concepts and marrying SDN, carrier Ethernet 2.0 and packet-optical technologies to unleash the capabilities of the network in unprecedented ways to support cloud and other next-generation business, residential and mobile services.

A growing number of major service providers worldwide – including AT&T, BT, CenturyLink, China Mobile, Colt, DT, Level 3, KDDI, KT, NTT, Orange, Telecom Italia, Telefónica, Verizon and others – have embraced SDN and are promoting SDN standards, evaluating SDN solutions, beginning early SDN trials and/or deploying SDN technologies. Many of these operators are focused on driving development of carrier-specific, SDN-related initiatives within industry organizations like the Open Networking Foundation (ONF), MEF, IETF, ITU-T Study Group 13 and ETSI's new Network Functions Virtualization (NFV) Forum.

Despite the buzz of activity, we remain in the very early days of what some are describing as an "SDN revolution." *Heavy Reading* survey data and other industry feedback suggests that the vast majority of carrier professionals tracking the SDN trend are still just getting up to speed on definitions, benefits and implementation challenges. While many of these individuals have expressed optimism about the longer-term impact of SDN on carrier business models, they are looking for practical ways that they can be begin now to transition toward an SDN architecture.

This white paper is designed to shed light on how operators can take advantage of emerging SDN solutions to build and operate more efficient and service-friendly metro networks today while putting in place a software-driven infrastructure that will enable them to support a vast array of innovative and differentiating services and applications in the future. We will provide an overview of SDN concepts, examine important near-term and longer-term drivers of carrier interest in SDN, discuss key issues for operators to consider as they begin their SDN journey, and explore opportunities for virtualizing both the photonic transport layer and the carrier Ethernet services edge. We also will share examples of how SDN virtualization can be implemented today and will provide examples of potential SDN-enabled service options available in the future.

This white paper complements a recent webinar on the same topic hosted by *Light Reading* and *Heavy Reading*, An archive of the webinar involving Cyan, CALIENT Technologies, Overture Networks and Sidera Networks can be found here: Metro SDNs – Virtualizing the Network & Services Edge.

SDN Concepts

Perhaps contrary to popular opinion, many of the modern concepts associated with SDN are not new. A number of carriers and other industry players have been working on various aspects of software-driven data networks within their own companies or within the IETF for multiple years. They just did not put an SDN-like framework around their work until recently.
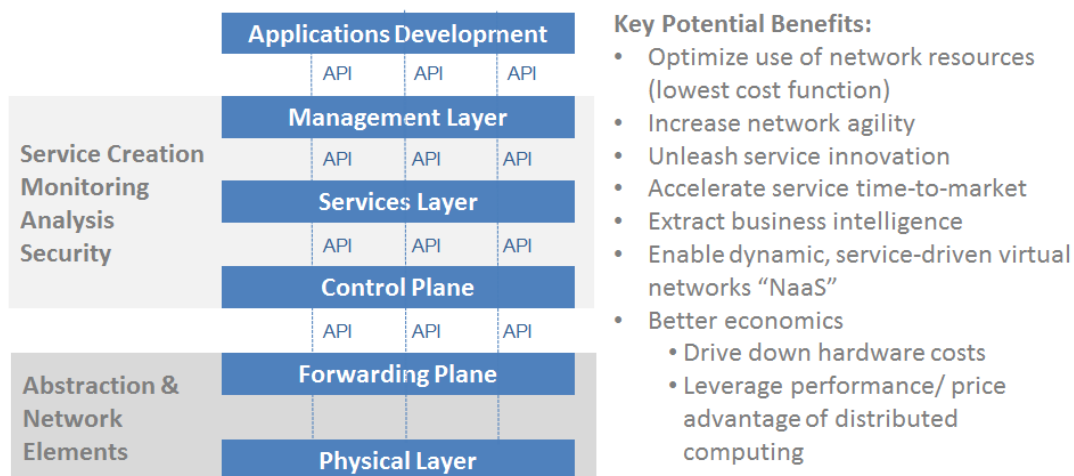
What is new, however, is the excitement generated over the past 18 months about open standards-based solutions, extensive programmability, network virtualization and network-based application-awareness. A growing number of service provider professionals and their suppliers are intrigued by the prospect that SDN could fundamentally transform how carrier networks are built and operated and how services are created, customized, delivered, monitored and monetized.

In our view, SDN is an open, application-aware architectural concept that encompasses programmability of multiple network layers – including management, network services, control, forwarding and transport planes – as well as network virtualization in order to:

- Optimize the use of network resources by seeking to utilize the lowest-cost function possible
- Increase network agility
- Unleash service innovation
- Accelerate service time-to-market
- Extract business intelligence
- Enable dynamic, service-driven virtual networks
- Deliver better economics for the overall network

With SDN, applications can request and manipulate services provided by the network, and the network exposes network state to the applications.

Figure 1: SDN – Open, Network Virtualization, Programmability at Multiple Layers

Key Potential Benefits:
- Optimize use of network resources (lowest cost function)
- Increase network agility
- Unleash service innovation
- Accelerate service time-to-market
- Extract business intelligence
- Enable dynamic, service-driven virtual networks "NaaS"
- Better economics
  - Drive down hardware costs
  - Leverage performance/ price advantage of distributed computing

Source: Heavy Reading analyst perspective, drawing upon various carrier & vendor views

An important aspect of SDN emphasized by the Open Networking Foundation – and embodied in the OpenFlow standard – is the ability to decouple network control from forwarding and make it directly programmable. As explained by a groundbreaking April 2012 ONF white paper, "This migration of control, formerly tightly bound in individual network devices, into accessible computing devices enables the underlying infrastructure to be abstracted for applications and network services, which can treat the network as a logical or virtual entity… Network intelligence is (logically) centralized in software-based controllers, which maintain a global view of the network. As a result, the network appears to the applications and policy engines as a single, logical switch."

SDN thus gives operators the option to take network intelligence out of the router and put it into a server. What is left in the network element is a simplified packet-forwarding engine with a table lookup mechanism on where to route or switch. The controlling server communicates in a vendor-independent way with SDN-enabled switches or routers via OpenFlow or other standards-based protocols. This vendor-independence is one of the key tenets of SDN, and it helps service providers to avoid being locked-in to a particular vendor's proprietary hardware & software solution bundle.

Another important goal of this approach is to ride the performance/price improvement wave of the server market by leveraging the benefits of Moore's law associated with CPU capacity and storage. This stands in contrast to a traditional approach that would require expensive and extensive router card and software upgrades to take advantage of advances in capacity and storage.

A Longer-Term SDN Goal – NaaS

One of the exciting opportunities envisioned for SDN is to enable operators to offer the network as a service (NaaS) – the ability to support multiple virtual customer networks running over a single shared physical infrastructure. Here, we are talking about transforming carrier networks in a similar way to what is happening in data centers – where dedicated resources are being converted into virtual resources that enable a cloud-based environment with self-service and usage-based billing.

NaaS is a reasonable destination for a communications industry that generally is evolving toward a utility model. Dozens of senior service provider experts surveyed by *Heavy Reading* in late 2011 agreed that a utility model is beginning to emerge in which (a) Ethernet serves as the unifying layer to virtualize access to the network, (b) large data centers sit at the heart of the cloud ecosystem and play the role of power generation plants in the network and (c) high-capacity Ethernet and wavelength services function as transmission lines interconnecting large and small data centers.

SDN has the potential to accelerate the transition to a utility model and make the model smarter by opening up new ways to unlock the value of the physical network. With SDN's open interfaces and software tools now added into the mix, we can envision an almost unlimited array of customized services and applications delivered over a dynamic, programmable, high-performance virtualized infrastructure. This could include applications that are orchestrated end-to-end across data centers and multiple physical networks. With SDN, operators should be able to truly maximize their return on investment in their network assets by evolving the network into a more agile entity that supports "everything-as-a-service" – including the network itself.

What's Driving Carrier Interest in SDN Today?

Many service providers are intrigued by the longer term game-changing potential of SDN, but what is really driving their interest at the moment are practical concerns related to how they run their business. Service providers face particularly daunting strategic challenges when it comes to controlling costs in building, scaling and operating metro networks, introducing new and innovative service types in a timely manner, reducing the time it takes to provision and activate services, and efficiently managing services once they are up and running.

Since the mid 1990s, carriers have been under constant pressure to scale capacity on their networks to keep up with explosive residential, business and mobile traffic demands. At the same time, they have struggled to contain network costs while driving services to more locations and orchestrating the delivery of new content into the metro environment. Operators generally have not been very effective in controlling costs despite advances in fundamentally transforming technologies like DWDM and carrier Ethernet that have delivered dramatic performance/price improvements over the past 15 years.

In the view of many SDN proponents, current networks have grown too complex, static and vendor-dependent to be able to effectively address either the cost challenges or the dynamic service and application requirements of today's metro environment. The architecture of most of the network equipment deployed today is vertically integrated and based on proprietary technology. The routing architecture, for example, uses specialized hardware to support certain network functions and protocols, and the hardware is tightly integrated with a specialized control plane and specialized features. While this approach gives vendors opportunities to differentiate their platforms, it tends to limit the overall pace of industry innovation because the introduction of new capabilities and support for new services is dependent on vendor product cycles.

Network cost in the metro environment essentially is a function of the legacy architecture, which typically consists of multiple closed equipment groups – i.e., service edge routers, carrier Ethernet switch/routers, SONET/SDH MSPPs and DWDM systems – that are difficult to manage in an efficient manner (see **Figure 2**). The groups are often treated as individual network silos, with separate element management (EMS), network management (NMS) and service management systems (SMS) associated with each silo.

With the legacy architecture, it can take months to introduce new service types not only because of the need for extensive switch/router upgrades to enable a new service but also because of required changes to provisioning systems (EMS and NMS) and billing systems. Meanwhile, even when fiber is available at a customer site, it can take days to weeks to turn-up services due to the involvement of multiple EMS and NMS systems, inventory discrepancies, internal coordination and other business process factors.

SDN is drawing the attention of major operators worldwide because they see the potential to break free from these and other constraints tied to the legacy architecture. SDN offers a new way of thinking more comprehensively about the components of the network and a new way of orchestrating the behavior of these components that should help control capital and operational costs, speed service innovation, accelerate service delivery, support more customized services and applications, and yield additional business benefits as well.

Figure 2: Legacy Network Architecture
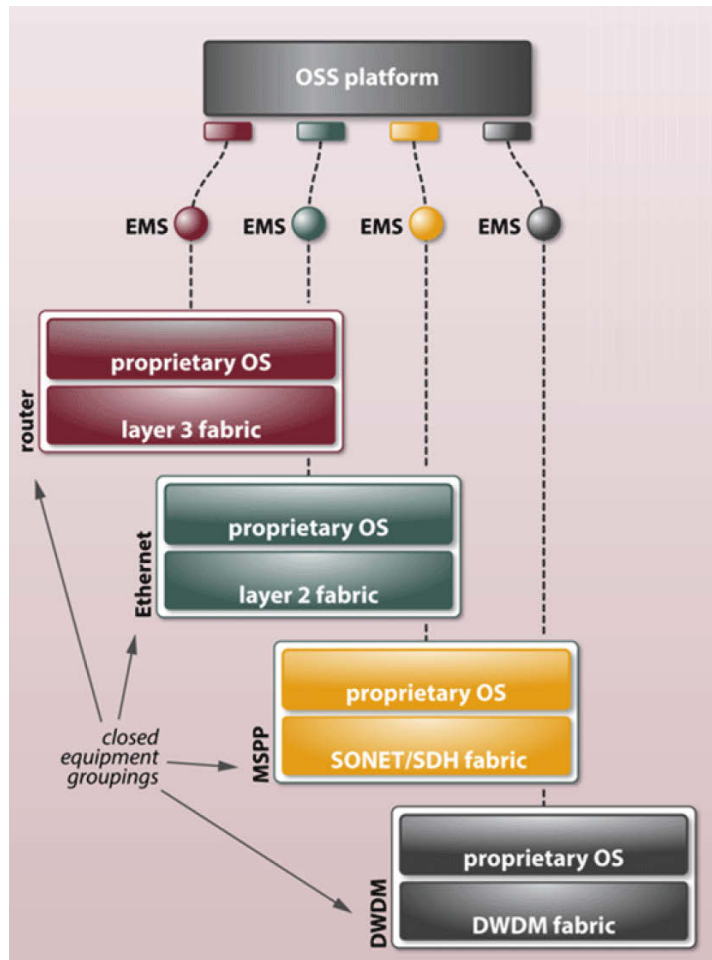
Source: Cyan

Software-Defined Metro Considerations

Below, we highlight some of the practical issues for operators to consider as they begin transitioning their metro networks to an SDN architecture that ultimately should be capable of supporting everything as a service. We believe it is important to think holistically about creating a dynamic network infrastructure that is treated as a single programmable entity and leverages SDN, CE 2.0 and packet-optical technologies.

Network Functions Virtualization

One of the most important industry developments that has the potential to dramatically impact the networking landscape and reshape how networks are built in coming years is the growing interest of major service providers – including AT&T, BT, China Mobile, Colt, Deutsche Telekom, Orange, KDDI, Telefónica, Verizon and others – in virtualizing as many network functions as possible.

As explained in the recently published Network Functions Virtualisation white paper, these operators ultimately want to leverage standardized IT virtualization technology to consolidate different types of network equipment onto standardized high volume servers, switches and storage platforms located in data centers, network nodes or end-user sites. The carriers believe virtualization is necessary to make progress in reducing network costs, speeding service time-to-market, fostering service and application innovation by enabling development ecosystems, and addressing other important business and technology challenges.

While carrier experts have noted that network functions can be virtualized outside the context of an SDN architecture, we believe it is important to include network virtualization in any discussion of the transition to SDN.

Logically Centralized Control Option

Emerging SDN-enabled platforms promise to give operators the flexibility to select the degree to which network functions are centralized in a logical controller or distributed in network elements.

For the last decade, the control plane debate has been dominated by distributed control associated with MPLS and GMPLS. With this approach, control plane agents within each network element talk to each other and coordinate amongst themselves regarding network resources. The problem is this does not scale well because each element has to track information from every other element. This also requires consistency in the protocols used. Innovation is hindered because operators cannot change the protocol in any of the nodes without changing it in all of the nodes.

SDN offers the potential to remove barriers to innovation and to scale in a more cost-effective manner by moving the control plane out of switches and routers and logically centralizing the control function in an elastic compute structure that maintains a global view of the network and can expand independently of the underlying network hardware. A logically centralized controller permits operators to gain vendor-independent control over the network while maintaining a consistent policy and management framework. Operations are simplified by enabling a network administrator to programmatically configure a network abstraction rather than manually configure each individual network device.

The key takeaway here is that various network equipment providers are focused on providing options that will enable either a radical shift to logically centralized control (i.e., using OpenFlow-enabled switches only) or a more evolutionary transition that introduces logically centralized control in certain parts of the network (i.e., using SDN-enabled platforms that support the new OpenFlow protocol as well as current generation networking technologies).

Open Environment With APIs

Operators should expect that their SDN architecture will be able to take advantage of an open environment with both northbound and southbound APIs in place of closed, proprietary systems. The extensive use of standardized APIs at numerous network touch points promises to enable operators to introduce more dynamic solutions that can leverage real-time information on the network topology, understand the capabilities of end devices, adjust application behavior in response to usage, bill with greater granularity and deliver a more personalized customer experience. Meanwhile, the network should be able to leverage application interaction to do such things as fine-tune bandwidth to meet certain application requirements.

Multi-Layer Management, Visualization & Modeling

While much of the initial discussion of SDN has centered on what it means for Layer 2/3 switches and routers, the architectural approach needs to be extended to include Layer 1 technologies like TDM, OTN, DWDM and optical switching as well for comprehensive network and service management, network visualization, network modeling and service orchestration purposes.

Based on discussions with multiple operators and other information, we believe a multi-layer management system with a rich set of OAM capabilities is needed to support a smart utility model with predictable, reliable, on-demand services and applications for a diverse set of residential, business and mobile users. Here, we are talking about a management system that provides traditional FCAPS functionality (fault, configuration, accounting, performance and security management) as well as multi-vendor and multi-technology support to simplify network operations, accelerate service activation and provide end-to-end visibility and control over how services and circuits are routed and groomed.

SDN software tools are available that can help operators visualize all the elements in different network layers and understand how the elements interact. The tools can be used to enhance customer support and to train personnel on the inner workings of the network. Also, virtualized views based on customers, services, markets, regions or other factors can be used to support operational procedures.

New modeling tools also are available to facilitate the design of carrier networks and predict performance on an end-to-end basis. Such a tool can be used, for example, to design a virtual topology of each network layer to supporting grooming and multiplexing. Or perhaps an operator could look throughout all the layers of a network to ensure redundancy at every level in support of a premium service.

Service Orchestration Across Technologies, Layers, & Domains

Once operators have logically centralized control, open APIs, comprehensive service management and visualization/modeling tools, they can then think about
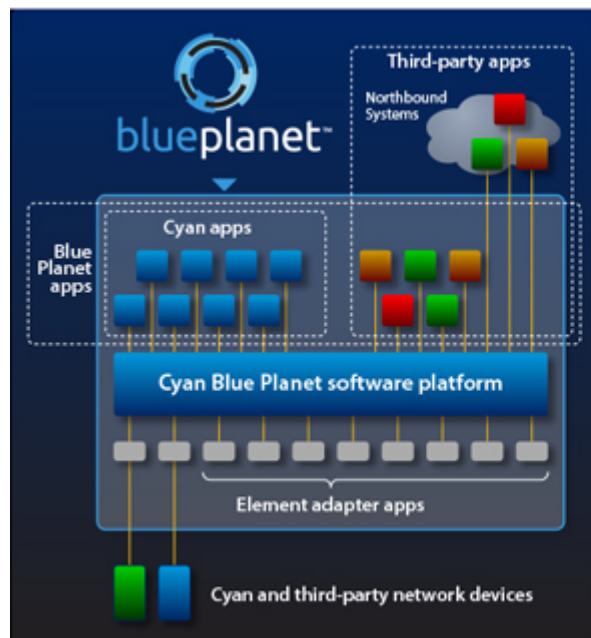
orchestrating services and applications across multiple technologies, network layers and network domains. The idea here is for applications to have access to all of the information about the network and service performance capabilities that they need to know. Armed with this information, applications can coordinate across all of the Layer 1-3 technologies and network domains in order to make the most efficient use of network resources and to ensure the appropriate resources are devoted to meet certain performance requirements.

Orchestration has potentially far-reaching implications because it can enable carriers to get the best economics by grooming higher layer constructs into lower cost, higher capacity tunnels. Stated another way, orchestration may allow operators to no longer be held hostage to Layer 3 router economics and, instead, may finally open up the possibility of fully leveraging the performance/price advantages of Layer 1 photonic and Layer 2 carrier Ethernet technologies.

Cyan's Blue Planet SDN system, illustrated in **Figure 3**, is the type of software orchestration solution that we believe will be warmly received in the market as operators embark on their SDN journey.

Formally announced in November 2012, Blue Planet is an open architecture platform that allows Cyan and third-party applications to interrogate and control the underlying network architecture. It is designed to work with a wide range of OpenFlow-enabled devices as well as devices that are not SDN-enabled. Blue Planet already is being used by NTT Communications to increase network efficiency and to facilitate more rapid Ethernet service delivery, according to the carrier's Vice President of Engineering.

Figure 3: Snapshot of Cyan's Blue Planet SDN System

Source: Cyan

Figure 3: Snapshot of Cyan's Blue Planet SDN System (Continued)

SYSTEM ELEMENTS	DESCRIPTION
SDN Orchestration Platform	This service orchestration platform includes an operating system, a hypervisor, a messaging system, middleware, and a Web portal – all of which run in a distributed computing environment. It also includes APIs for application development as well as network services such as databases, inventory and asset management, topology management, and security.
SDN Applications	The SDN platform supports a variety of Cyan applications and incorporates an application development environment to facilitate the creation of third-party applications. Cyan's applications fall into three groups that are aligned with the service life cycle: 1) planning applications that enable the designing and planning of multi-layer and multi-vendor networks; 2) service performance and SLA monitoring applications that provide real-time and historic information on the performance of individual services; and 3) operations applications that include FCAPS functions and other innovations designed to simplify operations and management. Many of the Cyan applications employ the company's 3-D visualization capability.
Element Adapters	Cyan provides element adapters that enable the SDN platform to control the company's packet optical platforms as well as Layer 1-3 devices from 20+ other network equipment suppliers.

Source: Cyan

Virtualizing the Photonic Layer

The convergence of SDN and next-generation photonic platforms makes it possible for carriers to dynamically reconfigure the optical network to support high-capacity data flows with guaranteed low-latency for on-demand applications and NaaS requirements. In this section, we discuss what it takes to virtualize the photonic layer and share examples of how this can be implemented today.

Why Virtualize the Photonic Layer?

The continued rapid growth in traffic demands on networks, combined with dynamically changing traffic patterns associated with mobile data, video and cloud services, can lead to situations in which metro networks become overloaded, latency increases and application performance suffers. Up to now, operators have had little choice but to spend scarce capital on over-designing the network for a worst-case scenario in order to ensure that the proper amount of bandwidth is available and that service quality is maintained. This leads to poor utilization of network resources with a certain amount of stranded capacity that yields no direct revenue benefit. This is not profitably sustainable especially at a time like today when traffic demands continue to increase while revenue growth remains fairly anemic for a number of services.

Operators obviously would prefer a more efficient approach to get the most out of their network investment. They are not only looking for a bandwidth-on-demand capability that allows them to direct network capacity where it is needed, when it is needed. They also are looking for guaranteed performance-on-demand to support the various latency, jitter, packet loss and availability requirements of a diverse set of real-time and non-real-time applications. The photonic layer is the foundation for all other virtual services that ride above it, and the ability to partition and dynamically reassign resources should start here.

Virtualizing With Optical Circuit Switching + SDN

Traditional solutions fall short when it comes to readily reconfiguring optical networks. While suitable for short, bursty traffic, they generally are not designed to handle the switching of large data flows in an economic manner, nor are they designed to deliver the low latency performance required by many applications. However, optical circuit switches (OCS) like those offered by CALIENT Technologies can support massive data flow switching with low latency. Built with 3D MEMs technology, these platforms require no optical-electronic-optical conversion and can switch in 25 milliseconds. They are designed to support switching up to 100 Gbit/s and beyond without an equipment upgrade.

We discussed earlier that one of the goals of the SDN architecture is to utilize the lowest-cost function possible. Optical circuit switching takes us a step in that direction by leveraging the performance/price advantage of photonic technology, but we still need a way to have coordinated control over both the optical circuit switches and the packet switches/routers deployed in a converged network. This is where SDN steps in.

Both the SDN management plane and the SDN control plane have roles to play in dynamically reconfiguring the optical network. The management plane analyzes flows within the network in coordination with the photonic and routing control planes, creates new topologies and related configurations based on operational

needs, and propagates the configuration to the respective control planes for execution. The SDN control planes then orchestrate topology-related changes. A photonic engine handles changes across the optical switches, and a routing/ switching engine deals with changes across routers/switches. Both the photonic and routing/switching engines maintain the status of execution of each step in the configuration flow and communicate this status to the management plane.

Are combined OCS + SDN solutions available today? In November 2012, CALIENT introduced a new OpenFlow API that – when combined with an OpenFlow controller – allows the company's S320 optical circuit switches to reconfigure networks to optimize high-capacity data flows. Connections can be changed at the instruction of the OpenFlow controller based on time of day, real-time application requirements or predictive algorithms. The OpenFlow API on the S320 is available for interoperability testing, as of December 2012.

Example 1 – Maximizing Cloud Performance

Let's look at an example of where it makes sense in the metro setting to virtualize the photonic layer. Here, we have an operator that is looking to maximize the performance of cloud services by improving the way capacity is managed among data centers. A couple of SDN-enabled capabilities that are applicable include rapid service provisioning & reconfiguration and dynamic network optimization, which permits the carrier to deal effectively with fluctuating traffic.

Figure 4 illustrates multiple data centers interconnected over a metro fiber network. The connections most likely would be implemented as wavelengths on a fiber ring. Based on the time of day or a particular event, we see a need for additional capacity between datacenters 3 and 4. An SDN controller responds to this need by ordering the OCS to reallocate capacity from other nodes to support the short term demand. This type of reallocation of capacity – which would have been largely impossible prior to SDN – could take place multiple times in a single day in an application-driven network environment.

Figure 4: Maximizing Cloud Performance by Virtualizing the Photonic Layer
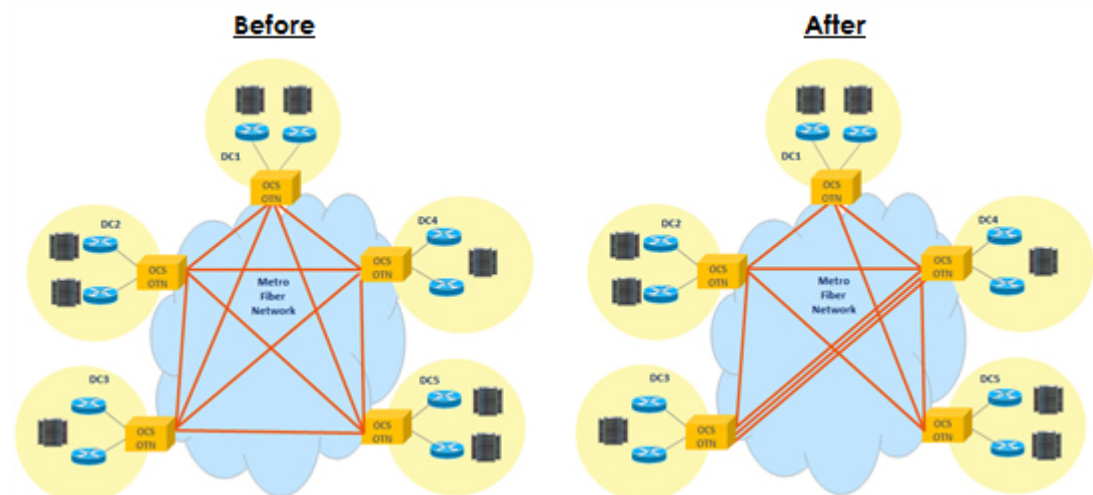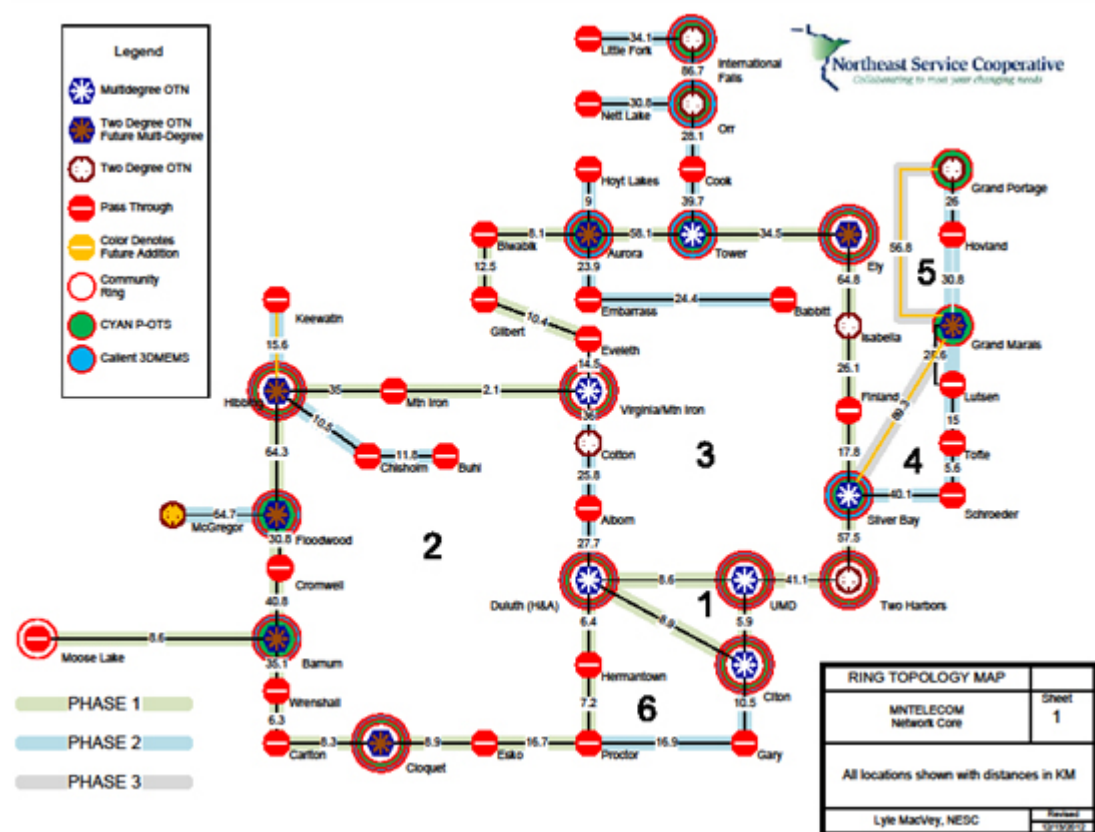
Source: CALIENT Technologies

Example 2 – Minnesota Telecom Evolving Toward SDN Architecture

Cyan and CALIENT are currently involved in an SDN-related network evolution project launched in mid 2012 by Minnesota Telecom's Northeast Services Cooperative (NESC). The operator has deployed an integrated solution consisting of Cyan's Blue Planet SDN platform, Planet Operate network management applications and Z77 packet-optical transport platform, as well as CALIENT's S320 photonic switch. This solution is being used to deliver a variety of broadband services for enterprise, government and residential customers over a 915-fiber-mile network.

The initial phase of the project has focused on centralized management, provisioning and testing for all nodes in the network. Having a single multi-layer management system for both the packet-optical and photonic switching platforms enables the operator to avoid contention – that is, having two different flows of traffic trying to use the same wavelength at a given node.

In a later phase, Minnesota Telecom plans to utilize software-defined customer control that, among other things, will permit bandwidth levels to be changed on the fly.

Figure 5: Minnesota Telecom – Multi-Layer Management

Sources: CALIENT Technologies & Cyan

Virtualizing the Carrier Ethernet Services Edge

Virtualization of the carrier Ethernet services edge has the potential to help operators become operationally more efficient, speed service deployment, ensure a consistent end-user experience and create dynamic service offerings for the cloud era. In this section, we explore some of the key steps operators can take to virtualize the edge and share an example of how virtualization is being used to accelerate service turn-up.

Why Virtualize the Carrier Ethernet Services Edge?

Operators face a multitude of challenges that negatively impact their ability to generate a profit from the traditional edge service delivery architecture. These include:

- **Lack of consistency & scalability.** Carriers typically deploy a variety of point solutions from multiple vendors, which can make it difficult to integrate these products into back-office systems, maintain consistent service offerings or roll out new features across platforms and across the edge network.

- **Slow service velocity.** The current complexity of the network edge, combined with the typical process of manually provisioning circuits on access devices, also makes it difficult to quickly deploy new services and efficiently manage moves, adds and changes.

- **Revenue de-coupled from bandwidth demand.** Customer demand for more bandwidth does not necessarily translate into additional revenue. In fact, it is not uncommon to see customers shift to an Ethernet service with the expectation that they will get much more bandwidth for the same price that they were paying for a lower speed legacy TDM circuit. The operator can be left facing potentially higher operating costs at the edge without an increase in the average revenue per user (ARPU).

In addition to the profitability challenges, many carriers also are on the hook to ensure highly reliable access in an increasingly on-demand cloud services environment.

How Virtualization Addresses Service Edge Challenges

SDN-enabled virtualization promises to help address cost and service-related challenges in numerous ways. Among other things, virtualization provides operators the ability to:

- Abstract service creation and management and thereby create a more dynamic service deployment environment.

- Simplify IT and back office integration by masking or hiding some of the complexity of specific network elements and access technologies.

- Leverage the flexibility of OAM-rich multiple access options to deliver a consistent service offering with performance guarantees to all customer locations.

- Better integrate multi-vendor or third-party demarcation platforms, which can help control operational costs.

- Accelerate time-to-service by opening the northbound control plane interface.

- Accelerate service turn-up via increased automation.

There are three basic types of platforms that work as a "system" to virtualize the services edge. These include a service orchestration/management platform, a service aggregation switch (what Overture calls a service exchange switch) and service nodes (i.e., NIDs or demarcation devices).
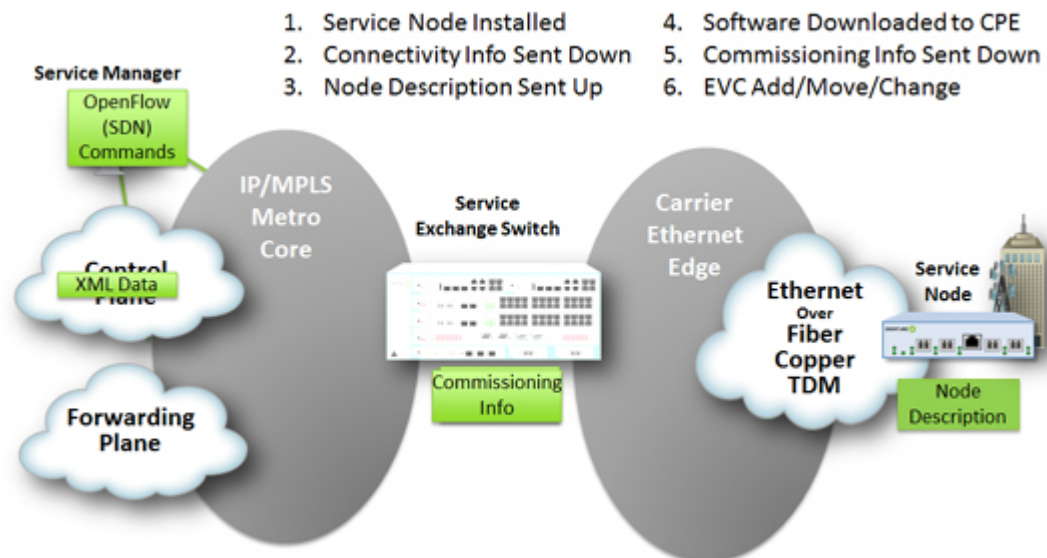
Example – Rapid Service Turn-Up With Virtualization

Let's take a moment here to explore how virtualization can help accelerate service velocity.

Today, zero touch provisioning solutions are available from Overture and a small number of other suppliers that reportedly can help operators save as much as 15% to 20% on operational costs by eliminating unnecessary truck rolls and streamlining the service provisioning and activation process. With zero touch provisioning, the service orchestration platform can discover a service node, store the node's configuration, pre-provision the node for service turn-up and periodically download software updates in order to upgrade the edge network.

Going forward with SDN-enabled virtualization, operators should be able to do network-wide flow-through provisioning from the metro core to the enterprise customer site (see **Figure 6**). In this scenario, following the installation of a service node, the service aggregation platform engages in a short series of communications back and with the node to ensure that it is properly configured and the service is commissioned. An operator could then use SDN/OpenFlow commands to orchestrate dynamic service creation and EVC moves, adds and changes.

Figure 6: SDN-Enabled Virtualization & Network Wide Flow-Through Provisioning

1. Service Node Installed
2. Connectivity Info Sent Down
3. Node Description Sent Up
4. Software Downloaded to CPE
5. Commissioning Info Sent Down
6. EVC Add/Move/Change

Source: Overture Networks

Looking Ahead: SDN-Enabled Service Options

The convergence of carrier Ethernet, SDN and the cloud promises to make networks operationally more efficient, flexible and scalable and to unleash faster service innovation. We are just at the beginning of what is shaping up to be an extraordinary paradigm shift in the way networks are built, operated and utilized.

We have highlighted some practical applications enabled by emerging SDN solutions and also discussed a longer term vision in which operators can utilize an SDN architecture to provide the network itself as a service. But we have only begun to explore what the future could bring.

The following are several additional examples of emerging service options enabled by the transition toward an SDN metro architecture and extensive use of service OAM, service orchestration, centralized control, network programmability and virtualization of network resources.

- **Increasingly sophisticated real-time capacity management**. During an Ethernet Expo Americas keynote in November 2012, tw telecom's SVP for Business Development & Strategy Mike Rouleau shared an outlook for real-time capacity management that involves an evolution from: 1) manual control today to 2) threshold management and eventually to 3) API-driven management. Earlier this year, tw telecom introduced the capability for customers to manually double or triple their capacity in real time via a Web service portal. In the future, the operator expects to have the ability to adjust bandwidth based on utilization triggers, events or scheduled capacity changes. Eventually, tw telecom envisions being able to use APIs to automatically drive bandwidth-on-demand, with applications signaling to the network to turn bandwidth up or down on the fly, thereby eliminating the need for dedicated overlay networks with stranded capacity.

- **API-driven performance-on-demand**. We could also envision API-driven performance-on-demand, in which the network dynamically ensures not only that the appropriate capacity is available for a given application, but also that a guaranteed level of performance is delivered. Here we are talking about using service orchestration and logically centralized control to choose the best paths in the network to meet SLA targets for latency, jitter, packet loss and availability, then dynamically allocating the necessary resources along those paths to make sure those targets are met.

- **Private cloud services**. In mid 2012, NTT Communications became the first operator in the world to introduce an enterprise cloud service that utilizes an SDN/OpenFlow infrastructure. Doug Junkins, the CTO of NTT Americas, recently shared that the operator already has deployed OpenFlow-enabled switches in its data centers in Hong Kong and Tokyo and is on track to have switches deployed in the U.S. and Europe as well by the end of 2012. NTT Communications is tying the orchestration of its customer portal and cloud controllers into an OpenFlow controller to completely automate the SDN network and enable customers to quickly spin up and spin down virtual machines. The service will enable customers to have precise control of server resources as well as network resources – such as a virtual firewall, virtual load balancer and virtualized networks. An online portal also permits customers to monitor usage of server and network resources and change settings on a real-time basis.