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Revision History

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1.0	10/20/2016	Dean Cheng Huawei	Initial publication

ONF Carrier Grade SDN Working Group Chairs:

Weiqiang Cheng	China Mobile
Shahar Steiff	PCCW Global

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1 Purpose and Scope

1.1 Purpose

As SDN technology keeps evolving, more and more service operators have come to embrace the technology in belief that SDN would greatly ease the complexity of network operation and management, reduce Opex and Capex, quickly introduce and deliver innovative services to their customers with tremendous new business potentials.

Carriers' networks have gone through a long history with several key technological transitions and innovations. A modern carrier's network provides multi-play services to its business and residential customers including voice, video, data and many emergent others. A key requirement in operating a carrier's network is the high availability. In the process of enabling SDN in carriers' networks, many operators would pursue a prudent approach on innovation, field trials, priority and migration in order to maintaining their service continuity however with gradual adoption with new technological elements. Also, via platforms at standards organizations, trade shows and events, carriers and vendors exchange and share experiences in all aspects of SDN, further expedite the maturity and deployment of SDN technology.

This document contains a group of use cases to demonstrate how SDN is used in carrier's networks, how it is integrated into existing network architecture, how it interacts with NFV, what problems it solves along with the benefits. It is expected that these demonstrations would help the industry to identify, clarify, and organize SDN system requirements for next-generation carriers' networks.

1.2 Scope

The scope of this document is to describe use cases of interest for Software Defined Networks in carriers' networks, including but not limited to the following:

- Use SDN technology to manage the entire or a segment of a network.
- Interaction between SDN and NFV.
- Separation of data plane and control plane on existing network equipments.
- Use of hierarchical SDN controllers for scalability.
- High availability considerations of SDN-enabled carriers' networks.
- Interactions between SDN controllers and applications.

2 References

A) ONF, Software-Defined Networking: The New Norm for Networks (2012), available at https://www.opennetworking.org/images/stories/downloads/sdn-resources/white-papers/wp-sdn-newnorm.pdf

B) ONF, OpenFlow Switch Specification Version 1.4.0 (2013), current and previous versions available at https://www.opennetworking.org/sdn-resources/onf-specifications

C) ONF, Migration Use Cases and Methods (2013), current and previous versions available at https://www.opennetworking.org/images/stories/downloads/sdn-resources/use-cases/Migration-WG-Use-Cases.pdf

D) ONF, TR-502, SDN Architecture Issue 1.

3 Template for Use Case

The text structure (in shaded area) below is the template for each single use case in this document.

Title
Simply give a name of this use case.
Contributors
The use case contributors and contact information
Problem statement
A description of the problem that a solution is developed in this use case.

Actors
Key components (with brief explanation or reference) involved in this use case.

Solutions
One or more paragraphs informally describing the solution for solving the problem.

Architectural context
How does the solution fit into overall SDN architecture?

Diagrams
A picture is worth a thousands words.

Business drivers
Why would a carrier operator consider doing this?

Deployment reference
Customer deployment or trial reference.

Related SDO efforts
Any other SDOs known to be working in this technology area?

Related use case(s)
Other similar use cases.

4 Abbreviations and Acronyms

This document uses the following abbreviations and acronyms:

ACCaaS	Access-as-a-Service
ACL	Access List
API	Application Interface
ASON	Automatically Switched Optical Network
BNG	Broadband Network Gateway
BoD	Bandwidth on-demand
BSS	Business Support System
CAPEX	Capital expenditure
CDN	Content Delivery Network
CIR	Committed Information Rate
CO	Central Office
CORD	Central Office Re-architected as Data Center
CPE	Customer Premises Equipment
DB	Database
DC	Data Center
EMS	Element Management System
eNB	Evolved Node B (mobile base station)
FWaaS	Firewall as-a-Service
GPON	Gigabit-capable Passive Optical Networks
GW	Gateway
IDC	Interconnected data center
INTaaS	Internet-as-a-Service
IaaS	Infrastructure as-a-Service
LBaaS	Load balance as-a-Service
LTE	Long Term Evolution

MPLS	Multi-protocol label switching
NaaS	Network as-a-Service
NAT	Network Address Translation
NBI	North Bound Interface
NFV	Network Function Virtualization
NMS	Network Management System
NoSQL	“non SQL”
OF	OpenFlow
ONF	Open Networking Foundation
ONOS	Open Network Operating System
Opex	Operational expenditure
OSS	Operations Support System
OTN	Optical Transport Network
OTL	Optical Line Termination
OTT	Over-the-Top
oVPN	Open VPN
P2MP	Point to multi-point
P2P	Point to point
PTN	Packet Transport Network
QoS	Quality of Service
ROADM	Reconfigurable optical add-drop multiplexer
SBI	South Bound Interface
SDN	Software Defined Networking
SLA	Service Level Agreement
SP	Service Provider
SPTN	Software Defined Packet Transport Networking
SUBaaS	Subscriber-as-a-Service

TOR	Top of Rack
vCPE	Virtual CPE
VDSL	Very high bit rate subscriber line
VM	Virtual machine
VN	Virtual Network
VPC	Virtual Private Cloud
VPN	Virtual Private Network
VPNaaS	VPN as-a-Service
VxLAN	Virtual Extensible LAN
VTEP	VxLAN tunnel endpoint
WAN	Wide-Area Network
XOS	Anything-as-a-service Operating System

5 Introduction

This document contains a collection of use cases that describe how SDN technology is adopted and deployed in carriers' networks. The use cases are contributed by carriers' operators, vendors and research institutes and most of these use cases are associated with live deployment or field trials.

All use cases as documented use the template as illustrated in Section 3 for consistency. Due to the nature of innovation and the evolvement of the new technology, contributions on new use cases and updates from contributors may occur, and so this document will be revised as often as needed.

Note the terminologies used in various use cases may deviate from current published TRs and other industry jargons. The terminology may be revised once other unified projects, such as Common information model, are progressing.

6 Use Case 1: Integration of Data Center Networks and Carrier's Network

6.1 Option 1 - End-to-End Integrated Network/DC Architecture (Deutsch Telecom)

Title:
End-to-End Use Cases for an Integrated Network/DC Architecture

Contributors:
Nicolai Leymann

Problem statement
In current carrier's networks, there is no end-to-end view on Service Chaining, e.g.:

- Typical network designs are using an access/aggregation network and a backbone network which also interconnects to service areas/data centers. Typically, operation and provisioning of DC and network are separated.
- In many cases introducing a new service leads to software updates on networking nodes (service and network are closely coupled).
- Innovation is too slow (no ability to "program" or closely interact with the network).
- Modification of forwarding is mainly through routing protocols (no external interfaces in order to interact directly with forwarding hardware).
- Based on the service the end users have booked the scenarios where it is necessary to redirect individual traffic or sub flows towards the service functions within the data centers.
- Therefore it is necessary to modify forwarding/routing "on the fly" within the network (e.g. through a controller)

Actors
- Aggregation/Access Network: Aggregates business and residential Customers (VDSL, GPON, etc.)
- Service Node: Terminates customer session and provides basic services (e.g. QoS, Multicast Replication, Bandwidth Control, VPN, P2P, P2MP, …)
- Backbone Network: Provides connectivity among customers, towards service areas and the internet
- Data Centers: Providing additional services (e.g. security services, web, network services, etc.)

Solutions

With the new upcoming architectures, DC and SP network are closely coupled. There is the need for information exchange between DC network and service provider network in order to provide and control end to end connectivity.

SDN needs to take into account the different capabilities of the underlying networks (e.g. L2 control in DC, L3 control for SP network). In typical SP network, L3/IP is part of the infrastructure providing connectivity.

Typical service chains spans several different areas of the network (e.g. L2 in data Center, IP or MPLS based in carrier network). Forwarding needs to be controlled based on network capabilities (L2 forwarding entry, injected L3 route, etc.).

Architectural context

- Integrated architecture which takes network and data center into account.
- Service can span from network into data center.
- Flexible placement of service functions.
- Network is programmable (a new service does not lead to a new software release on networking nodes).
- Traffic control and steering needed in network and DC (because service is End-to-End, touching NW and DC as well).

Diagrams

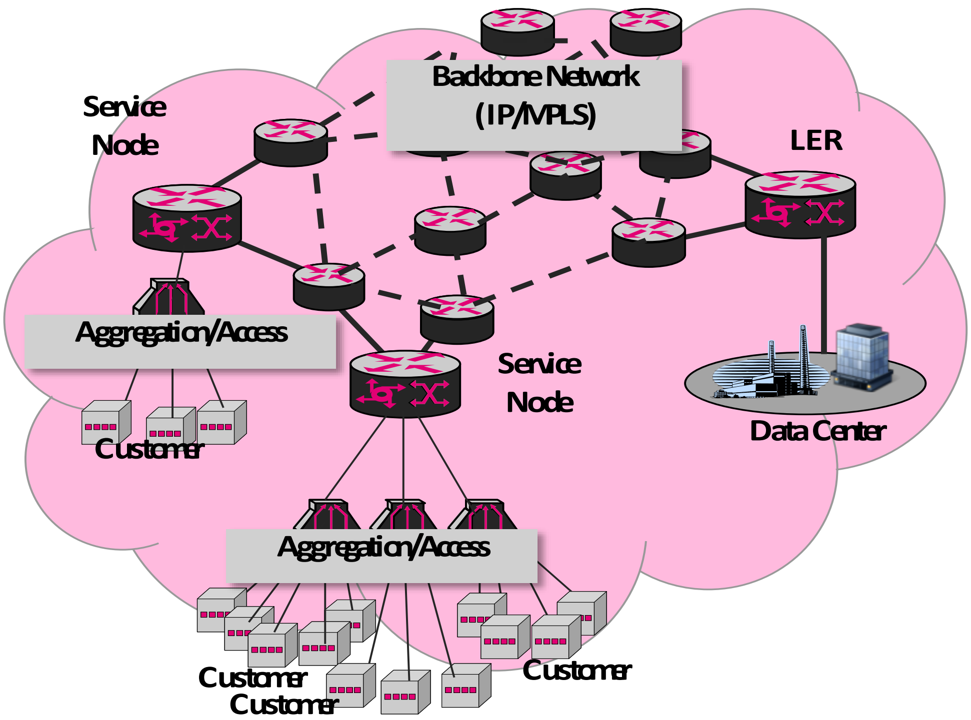


Figure 6-1: A Typical Network Design (Deutsch Telecom)

Business drivers

Why would a carrier operator consider doing this?

Deployment reference

Unknown

Related SDO efforts

Unknown

Related use case(s)

Unknown

6.2 Option 2 – Integration of Carrier's Networks and Data Center Networks (China mobile)

Title:
Integration of Carrier's Networks and Data Center Networks

Contributors:
Chen Li

Problem statement
NaaS is a killer service for SP, which could provide end to end virtualized network for enterprise customer. The visualized network in different scenarios can be summarized as below:

- Data Center: VPC and Service Chain in one or multiple DCs

a. Virtual Private Cloud (VPC): Customs define and manage their cloud network/compute/storage themselves in real time, mostly network provision based SDN. The network provision includes IP address/subnet/ACL/QOS/FWaaS/LBaaS/VPNaaS.

b. Service Chain: Customers define the flow chain for their north-south or east-west traffic themselves. For example, in public and private cloud, the chain nodes include NAT\FW\LB\VPN GW.

For each customer, VPC and SC should support to be defined within one or multiple DCs. Sometimes a DC is traditional DC and not controlled by SDN.

- VPN:

Customers define their VPN sites connectivity and bandwidth online which across the carrier's IP/MPLS backbone network. And the VPN service should be provisioned in nearly real time. Compared with the traditional VPN service, Flexible VPN reduces provisioning time greatly.

- WAN Traffic optimization:

With the large traffic increases we anticipate, congestion must happen in some network elements . With current networking technologies, each network device must be configured to handle maximum traffic, though it is unlikely every network element will experience maximum traffic at the same time. SDN's centralized architecture means that excess network capacity is generally unnecessary. We expect to schedule the entire network bandwidth and improve utilization. SDN can even guarantee end-to-end QoS for some services.

Actors
- Enterprise Access CPE: Access enterprise Customers using tunneling protocol (e.g. VxLAN, GRE). CPE could encapsulate/decapsulate the tunnel.
- Metro Network router : load balance the traffic in metro network(relative simple topology)

- IP backbone network router: optimize the traffic, and guarantee end-to-end QoS for high value services (complex topology).
- Data Centers: Providing VPC and Service Chain services

Solutions

TBD

Architectural context

TBD

Diagrams

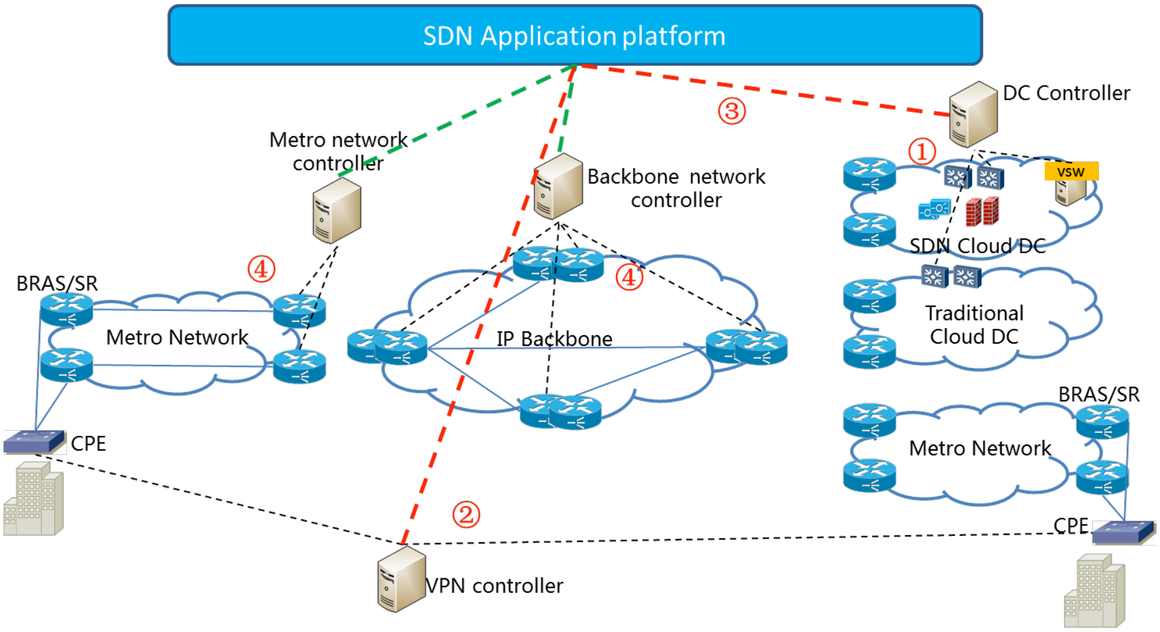


Figure 6-2: A Typical Network Design (China Mobile)

Business drivers

Why would a carrier operator consider doing this?

Deployment reference

Unknown

Related SDO efforts

Unknown

Related use case(s)

Unknown

References

onf2014.183, “Carrier Grade SDN Framework”

7 Use Case 2 – Central Office Re-architected as Datacenter (ON.Lab)

Title:
Central Office Re-architected as Datacenter (CORD)

Contributors:
Larry Peterson, Ali Al-Shabibi, Sheryl Zhang

Problem statement

There are large numbers of Central Offices in carrier's networks today. Each Central Office serves tens to hundreds of thousands of residential, enterprise and mobile customers in the locality. For example, AT&T alone operates 4000-5000 Central Offices. The Central Offices have evolved in piecemeal fashion over the past 40-50 years.

The creation, maintenance and operation of Central Offices have been the source of huge cost in both CAPEX and OPEX; moreover, it is extremely difficult for Service Providers to introduce new services.

It is desirable to restructure Central Office with a commodity infrastructure that is more economic and with much agility to provide scalable and expandable services.

Actors

- Central Office – An office belonging to a Service Provider in a locality to provide telecommunication services to its subscribers.
- CORD hardware - Commodity servers, switches, storage and I/O.
- CORD software architecture that includes:
  - OpenStack – manage virtual infrastructure.
  - ONOS – manage networking fabric and host control apps.
  - XOS – manage services.
- NFV – Network Functions Virtualization. NFV is about moving the data plane from hardware appliances to virtual machines.
- SDN – Software Defined Networks. SDN is about separating the network's control and data planes. This makes the control plane open and programmable, and that can lead to increased innovation.
- Cloud - It defines the state-of-the-art in building scalable services.
- Data Centers – A facility used to house computer systems and associated components, such as telecommunications and storage systems.

Solutions

The solution is called Central Office Re-architected as a Data center, or CORD. The new architecture for the Telco Central Office builds from existing work on SDN, NFV and commodity hardware in order to build cost effective, agile networks with significantly lower CAPEX/OPEX and to enable rapid service creation and monetization.

The CORD approach centers on unifying the following three related but distinct threads:

- The first is SDN. This makes the control plane open and programmable, and that can lead to increased innovation. It also allows for simplification of forwarding devices that can be built using merchant silicon, resulting in less expensive white-box switches.
- The second is NFV. This reduces CAPEX costs (through server consolidation and replacing high margin devices with commodity hardware) and OPEX costs (through software based orchestration). It also has the potential to improve operator agility and increases the opportunity for innovation.

- The third is Cloud. It leverages software based solutions, micro-service architecture, virtualized commodity platforms, elastic scaling, and service composition, to enable network operators to rapidly innovate.

The integration of the three threads above plays a role in reducing costs, and also generates tremendous opportunities for innovative services that can be offered to Telco customers such as:

- Control Plane Services (e.g., content centric networking, virtual networks on demand, cloud-network binding).
- Data Plane Services (e.g., Parental Control, NAT, WAN Acceleration).
- Global Cloud Services (e.g., CDN, NoSQL DB, Analytics, Internet of Things)

CORD is an ON.Lab partnership project, including AT&T, Ciena, Ericsson, and Huawei. It also involves PMC, Akamai, and Sckipio.

Architectural context

The CORD focuses on re-architect today’s Central Office and the access network including Optical Line Termination (OLT), Customer Premises Equipment (CPE), Broadband Network Gateway (BNG), firewall, parental control, caching, etc – all refactored as software running on and controlling commodity servers, white-box switches and merchant silicon I/O blades. The resulting software is then organized as an interconnected set of elastic and scalable services, all managed by open source software— specifically, ONOS, OpenStack, and XOS—to unify SDN, NFV, and the Cloud under a common, intuitive, carrier-grade framework.

Diagrams

As shown in Figure 7-1, CORD provides the following services:

- Access-as-a-Service (ACCaaS) - Implemented by an ONOS control application (vOLT), where each tenant corresponds to a Subscriber VLAN.
- Subscriber-as-a-Service (SUBaaS) - Implemented by a Docker container (vCPE), where each tenant corresponds to a Subscriber Bundle.
- Internet-as-a-Service (INTaaS) – Implemented by an ONOS control application (vBNG), where each tenant corresponds to a Routable Subnet.
- Content Distribution Network (CDN) – Implemented by a global caching hierarchy (including local caches), where each tenant corresponds to a Content Provider.

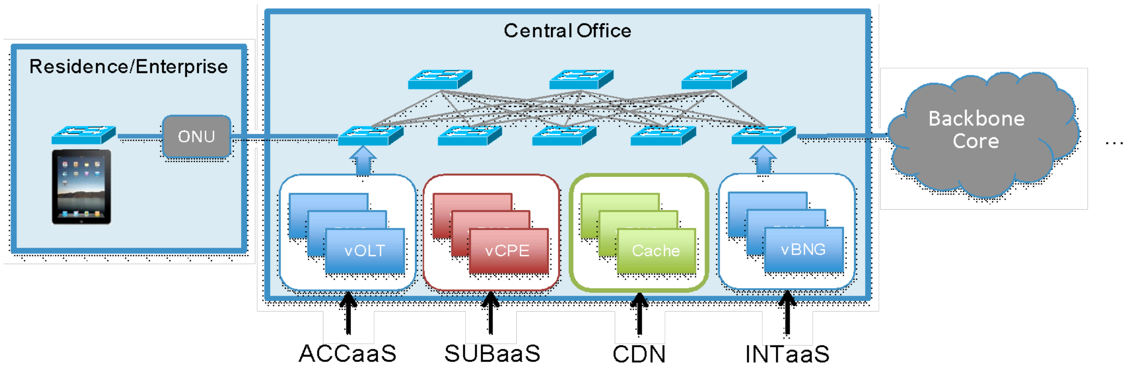


Figure 7-1: CORD as a Central Office

As shown in Figure 7-2, the target hardware for CORD consists of a collection of commodity servers and storage, interconnected by a leaf-spine fabric constructed from white-box switches.

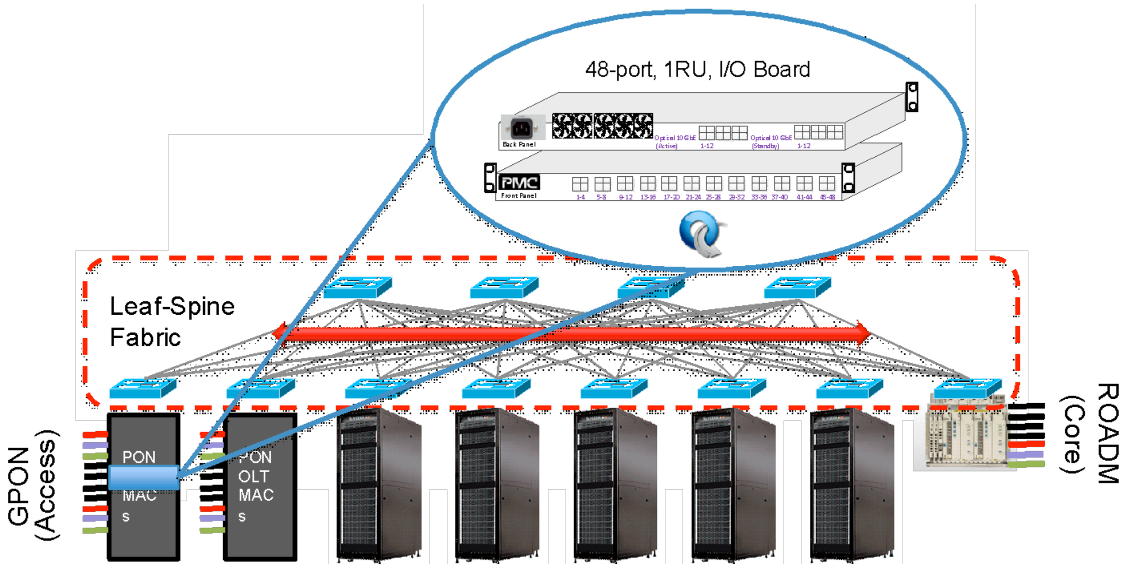


Figure 7-2 CORD Hardware Architecture

As shown in Figure 7-3, CORD has three major building blocks as follows:

- OpenStack is the cluster management suite that provides the core IaaS capability, and is responsible for creating and provisioning virtual machines (VMs) and virtual networks (VNs).
- ONOS is the network operating system that manages the underlying white-box switching fabric. It also hosts a collection of control applications that implement services on behalf of Telco subscribers. An ONOS subsystem is responsible for embedding virtual networks in the underlying fabric, which is in turn accessed via OpenStack's Neutron API.
- XOS is a service orchestration layer that unifies infrastructure services (provided by OpenStack), control plane services (provided by ONOS), and any data plane or cloud services (running in OpenStack provided virtual machines).

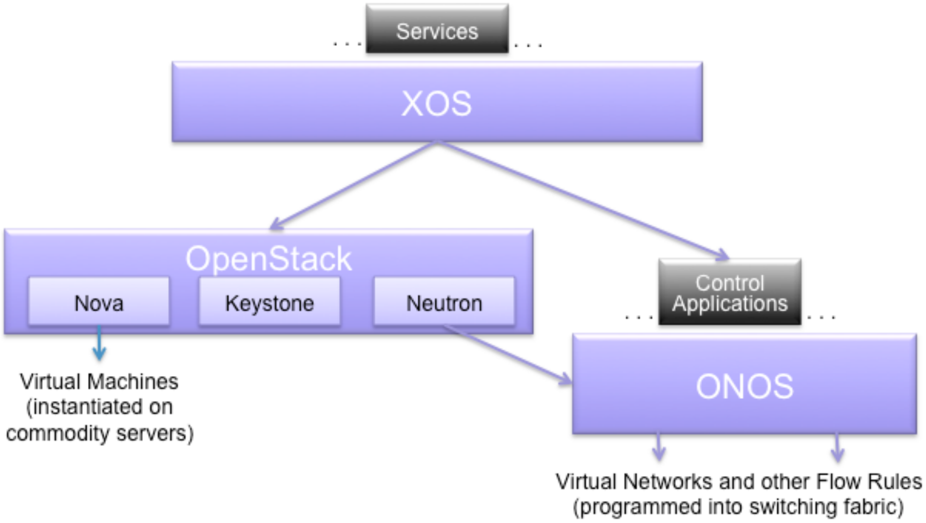


Figure 7-3 CORD Software Architecture

Business drivers

Service Providers are in the throes of unprecedented challenges. The proliferation of video traffic, mobile devices, and OTT services has pushed Service Provider networks into uncharted territory. At AT&T, for example, data traffic has increased 100,000 percent in the last eight years, and looking forward, plans are now underway to roll out ultra-fast fiber and access to 100 cities across the US.

Service Providers want to make their networks efficient, programmable, elastic and agile to meet the challenges of user bandwidth demands, as well as to create new revenue streams with innovative services and new business models. They want to benefit from both the economies of scale (infrastructure constructed from a few commodity building blocks) and the agility (the ability to rapidly deploy and elastically scale services) that cloud providers like Amazon, Google and Facebook enjoy today.

This cloud-inspired cost-effectiveness and agility is especially needed at the edge of Service Provider network—in the Telco Central Office (CO). These facilities contain a diverse collection of purpose-built devices, assembled over fifty years, with little coherent or unifying architecture, making them both a source of significant CAPEX and OPEX and a barrier to rapid innovation. Moreover, large service providers operate thousands of such central offices. For example, AT&T currently operates over 4000 central offices, each of which serves from thousands to millions of residential, mobile, and enterprise customers. By virtue of this scale, cost reduction in each of these Central Offices potentially translates into significant overall CAPEX and OPEX savings for the providers.

CORD addresses this challenge. It uses commodity hardware and best practices from SDN, NFV, and scalable cloud services to build cost-effective, agile networks with significantly lower CAPEX/OPEX and to enable rapid service creation and monetization..

Deployment reference
Unknown

Related SDO efforts
Unknown

Related use case(s)
Unknown

References

[1] onf2015.370.00, Central office Re-architected as a Datacenter(CORD)

8 Use Case 3 – Software Defined Packet Transport Network (China Mobile)

Title:
Software Defined Packet Transport Network (SPTN)

Contributors:
Weiqiang Cheng, Tingting Zhang

Problem statement
China Mobile deployed large scale packet transport networks (PTN) in both metro networks and backbone networks, which are used to carry high quality services such as mobile backhauling and enterprise customer services. The sharp increasing number of services and fast expanding of network scale result in bigger challenges:

- Low efficiency of provisioning and operation
  The enterprise customer services are sensitive to the network quality, have strict time-limit requirement for service establishment (often within several days) and frequent services adjustment. PTN are using static provisioning with centralized Network management system (NMS), and they are hard to meet the requirements of current enterprise services for fast provisioning and efficient operation.
- Multi-domain/Multi-vendor network coordination
  In the large scale networks, multi-vendors equipments are deployed, and the different vendors of networks are managed and controlled by different management system, the interfaces and protocol of which are different. It makes the networks separate, fragmented and vendor-locked. Operator need open interface to coordinate them. SDN architecture can be used solve those issue.
- Low utilization of networks resources
  IP based traffic is dramatically increasing in the carrier's networks. Those traffic is busty and the peak traffic load is 5~20 times than their average bandwidth, such as LTE backhauling, the peak bandwidth for 3 sectors of eNB is up to 320Mbps but the average bandwidth less than 40Mbps in most application scenarios. It is often to set committed information rate (CIR) and peak information rate for each eNB for saving networks resources in PTN networks. However, It is still wasteful. For example, the base stations in workplace need little bandwidth at night but it need full bandwidth support at daytime while residential areas are in the opposite condition. The bandwidth utilization is low. Operators are very interested in leveraging SDN with a dynamic service that would address this conundrum.

- Multi-layer network convergence
  In carrier's networks, Multi-layer technologies are often combined to setup an end-to-end solution. Such as LTE backhauling, the L3 network function is required in core layer, while the L2 E-line services are needed at the aggregation layer and access layer. This application scenario requires the management systems operate in different layers of networks, and leads to separate and fragmented network configuration. Further, the L2 and L3 solutions may be provided by different system. It makes the end-to-end provisioning much more complex.

Actors

- Forward Equipment: For the existing networks, the forward equipment is the traditional PTN nodes with the vendor-based south-bound interface (SBI). And the new deployed network, the OpenFlow based standard SBI will be used.

- Domain controller: The Domain controller deployed in the same position with EMS, and it provides the basic control plan functions such as topology detection, routing and failover solutions and so on. The domain controller reuses the legacy SBI with network management system, while it can provide the standard North bound interface to connect to upper layer super controller.

- Super controller: The Super controller coordinates several different domain controllers with NBI interface. The super controller works as a orchestration for the network services especially for the cross-domain and cross-vendor application scenarios.

Solutions

As illustrated in following Figure 8-1, in order to coordinate multi-vendor/multi-domain resources, the hierarchal controller architecture is used. The hierarchal controllers provide a policy based mechanism to control the service SLA on demand and provide the network slicing functions.

The Domain controller abstracts common model from different physical networks. With those common models such as topology, resources, services, Domain controller can provide the standard open NBI interface to Super controller. The domain controller is independent of EMS. EMS is responsible for basic management and monitoring solution, while the controller handles connection control and services provisioning.

The super controller integrates multiple domains and layers networks based on the common models. The Super controller will provide openness and programmability to different applications, so that the existing networks can also have openness and programmability.

The interface between super controller and domain controller is defined by China Mobile. Configuration and management is model-driven using Yang and Rest-Conf protocol. Vendor-agnostic Yang models is abstract from the field network. The basic Yang models include topology, services, resources, alarms and notifications, which guarantee that different vendors' networks can be managed by the same super controller.

The interface between domain controller and data plane is defined based on Openflow and OF-config. In order to meet the carrier-grade service requirements and sub 50ms protection switching, the Openflow/OF-config is extended to support UNI and NNI conversion, the specific OAM function, H-QoS and protection function. The TTP for SPTN has been submitted to ONF as onf2015.552.02.

Architectural context

The backhaul networks require strict QoS, OAM and protection features. They should provide the clock synchronization function, support 2G/3G/LTE base stations as well as access to future 5G network. The controller must provide service path calculation, the establishment of service, service presentation, traffic optimization, intelligent clock and other network functions.

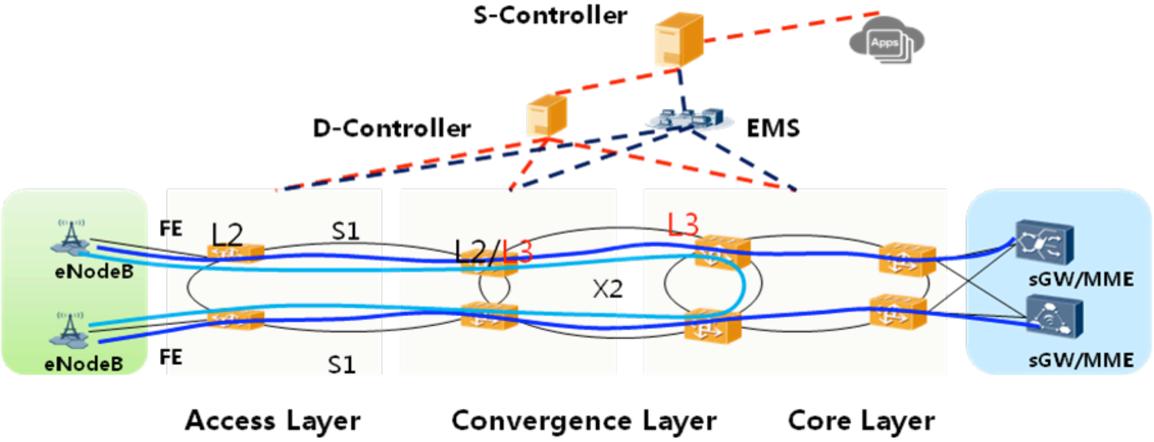


Figure 8-1: The construction of LTE backhaul network

The construction of LTE backhaul network is as Figure 8-1. The access layer and convergence layer should support the L2 function and the core layer should support the L3 function. Controller can provide the connection of different domains, flexible scheduling of traffic and the protection and recovery features.

The enterprise customer services have strict requirements of security, bandwidth, latency and other network SLA indicators, (optional) provide a clock synchronization function.

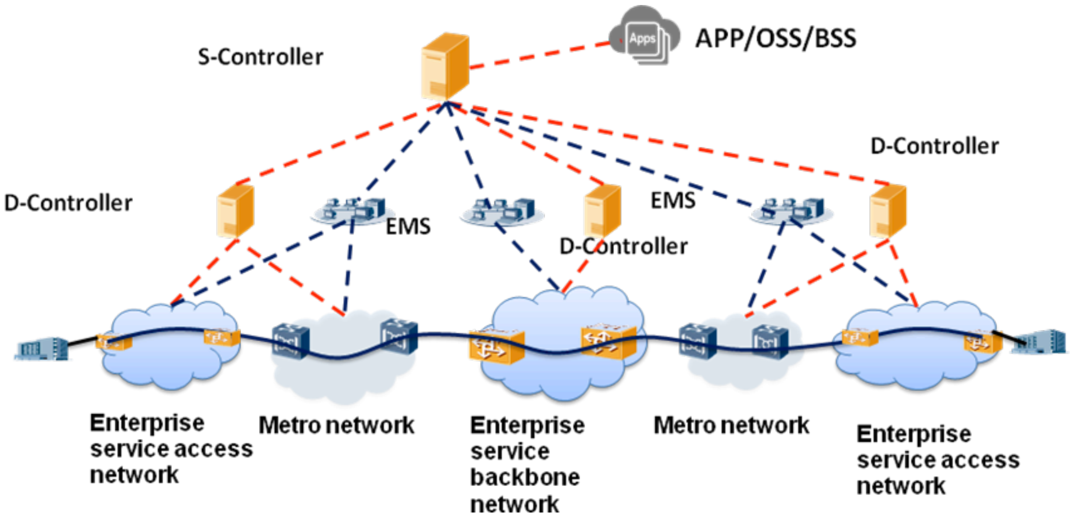


Figure 8-2: The construction of the enterprise customer services

The construction of the enterprise customer services is as **Figure 8-2**. The path computation between different domains is accomplished by Super Controller and the domain path computation is by Domain Controller. When the PTN devices can't support the SPTN function, the path configuration can be achieved by Super Controller using EMS/SNMS with added Domain Controller module.

Diagrams

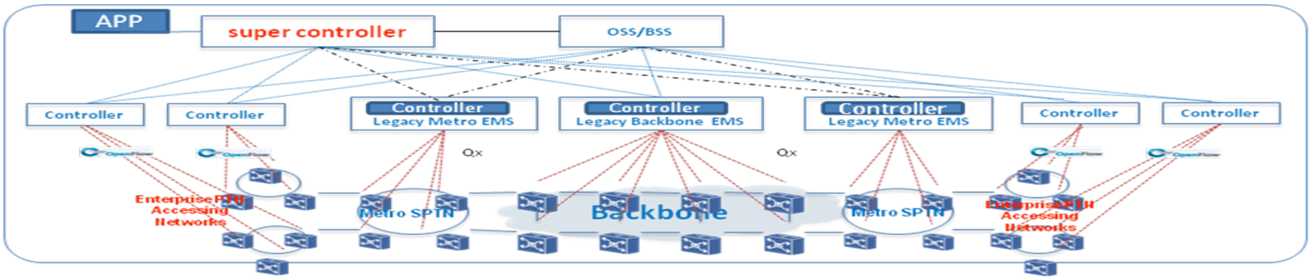


Figure 8-3: End to End SPTN network

Business drivers

PTN is based on MPLS-TP which can provide end to end transport tunnels, and currently it is using the centralized network management system for static provisioning. The forwarding layer and control layer of PTN are separated naturally, which is similar to the architecture of SDN. In order to improve the provisioning, operation and cost, PTN need to evolve to support SDN architecture.

Deployment reference

China Mobile have developed prototype and the field trial have been completed with success in more than 4 provinces in China.

Related SDO efforts

The MPLS-TP is defined by ITU-T and IETF.

Related use case(s)

Unknown

References

[1] onf2015.101.00, NBI requirements in Carriers networks
[2] onf2015.120.00, SPTN Extensions for Carrier Grade SDN
[3] onf2015.107.00,SDN Startup in PTN
[4] onf2015.552.02, MPLS-TP OpenFlow Protocol Extensions for SPTN
[5] onf2016.136.00, SPTN OpenFlow Protocol Extensions

9 Use Case 4: – Software Defined Optical Network (China Telecom)

Title:
Software Defined Optical Network

Contributors:
Feng Wang, Ruiquan Jing, Yunpeng Xie

Problem statement

Optical transport network is the basis of carrier network. Currently, there are several management problems listed as below:

- Transport network constructed with multi vender equipments and always has multi domain and multi layer architecture. It is too hard to do a unified management although some standards have been proposed, such as ASON E-NNI, NMS-EMS.
- Network capability of optical network was always closed in past time and it hindered business innovation in transport network. Especially, the isolation between IP network and optical network is a big barrier to improve network utilization.

Actors

- Carrier SDN controller: The network element in the network to manage and control multi-vender/multi-domain/multi-layer transport network. It is logically centralized deployed and always has a hierarchical architecture.
- Vender SDN controller: The network element in the network to manage and control network equipment from specific vender. It should provide NBI interface for carrier SDN controller.

Solutions

- Hierarchical SDN controller implements unified management for multi-vender/multi-domain. A SDN controller (single-domain controller) is deployed in each vendor equipment control domain, which is usually developed by specific vender. A multi domain controller (coordination controller or carrier controller) is set above equipment vender controller, developed by operators or third parties. In this SDN network architecture, SNI between single-domain SDN controller and transport network elements obey the rules from venders. However, interface between single-domain controller and multi-domain controller must be open. The end-to-end link control and management in multi-vendor/multi-domain network can be realized through hierarchical SDN controller.
- Unified management and control of multi-layer transport network. Currently, OTN（P-OTN）equipment has integrated multi-layer network technologies, such as ROADM, OTN, MPLS-TP/Ethernet, and it is urgent to get a effective method for unified

controlling and management of multi-layer network. SDN based transport network achieve multi layer network control and management by centralized deployment, which will reduce the complexity of NE control plane, as wells as solving the resource conflict and network optimization caused by distributed control, therefore the control and management of multi layer network can be much more efficiency

- Delivering transport network service capability by controller NBI interface opening to push transport network business innovation. SDN based transport network can provide a number of new business types via openness of standard NBI interface, such as customizable path selection, OVPN, BoD. Transport network perceive the dynamic business requirements through open API, including bandwidth, relay, geographical location and time slot, and then deliver better service response time and higher network resource utilization. Virtual transport network service is a typical example of introducing innovative service based on open API of SDON.
- SDN based "IP + Optical" cooperation enhances transport network capability. Introducing a network controller in IP network and transport network respectively referring to the SDN centralized control, above which a comprehensive SDN controller at the same time. "IP + Optical" cooperative networking can handle burst traffic rapidly, coordinate the protection mechanism of IP and optical-layer and promote network resource utilization. Obviously, introducing of unified control fully exploit advantages both of IP and transport network, and robust global optimization and high utilization of the network.

Architectural context

- Data Plane: Transport network element functions implementation according to management and control from centralized controller.
- Control Plane: Centralized SDN controller manages multi-vender and multi-domain network, and implement "IP + Optical" network integration.

Diagrams

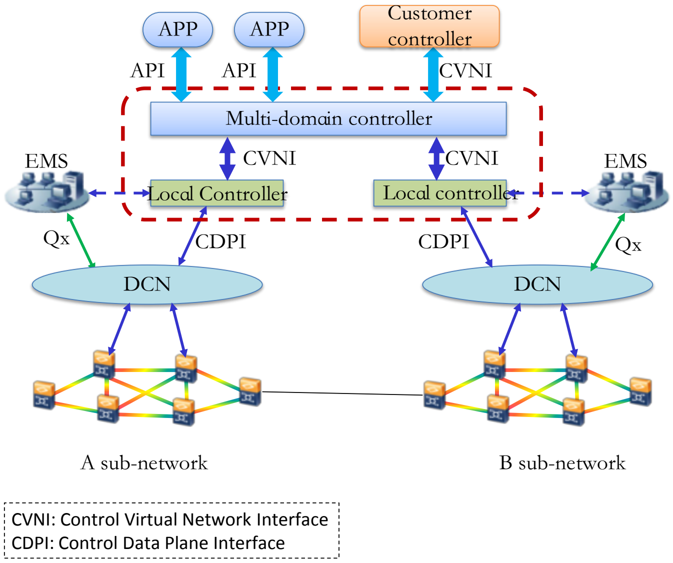


Figure 9-1: Hierarchical SDN controller architecture

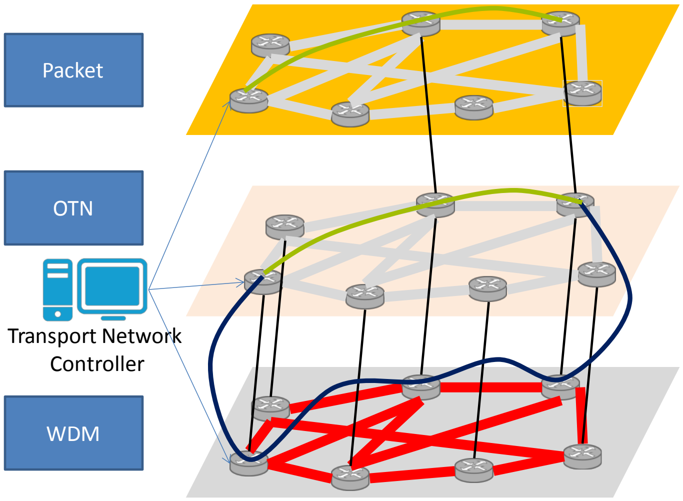


Figure 9-2: Unified management and control of multi-layer network

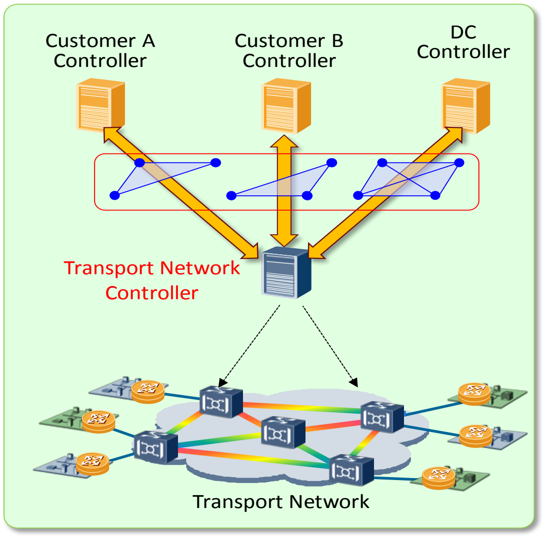


Figure 9-3: OVPN business innovation based on open SDN controller NBI

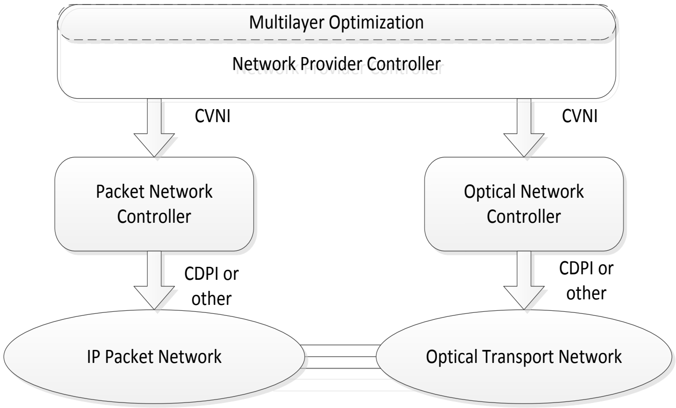


Figure 9-4: "IP + Optical" integration network

Business drivers

SDN- based intelligent management make carrier gain more profits from transport network. The main advantages include promoting resource utilization and operation efficiency, pushing business deploy more rapidly and enhancing service efficiency.

- Introducing SDN into transport network is helpful to make an evolution from "static artificial configuration" to "real-time dynamic intelligent control", and improve service speed and simplify network operation and maintenance.
- Unified control and management of multi-layer/multi-domain network and multi-vendor equipments can be supported by adopting hierarchical controller framework. Through the coordination of multi-layer network SDN controller to realize the unified intelligent networking.

- New network capacity and open northbound interface support innovation of transport network business, for example: smart direct line, OVPN, virtual transport networks and so on. The innovative businesses improve customer experience via providing customized control and management ability of network.

Deployment reference
Unknown

Related SDO efforts
Unknown

Related use case(s)
Unknown

10 Use Case 5 - SDN-Enabled IP + Optical Synergy (Huawei)

Title:
SDN-Enabled IP + Optical Synergy: A Cloud-Driven Backbone Network Architecture

Contributors:
Aihua Guo

Problem statement
Today's backbone networks contain both optical and IP network segments, which are usually managed by different administrators and therefore they are planned, designed and operated separately. This reality can not catch up with the evolvement of Internet based ecosystem, and the challenges that carriers are facing including the following:

- It is very difficult to predict the traffic pattern and traffic volume hence the allocation and utilization of network resource become inefficient and sub-optimized.
- Much of the network operation including provisioning and monitoring is manual based; this does not scale, driving up the Opex, and increasing TTM with customers' dissatisfaction.
- Today's Cloud based ecosystem requires agility and elasticity in the backbone network, i.e., reacting rapidly in traffic pattern changes, resource (re-) allocation based on customer-based applications. The current backbone network is far behind this requirement.

Actors
- NetMatrix – a service orchestrator for E2E service orchestration and management.
- Unified SDN controller for IP and Optical network segments – PCE based multi-layer operation and policy management.
- GMPLS UNI – standards based protocol to glue IP and optical data path end-to-end.
- MS-OTN Network – L0/L1/L2 converged switches with GMPLS control plane.

Solutions
To upgrade the existing backbone network so that its behavior and performance will satisfy the requirements and demands from customers and increasingly innovated applications, SDN technology is introduced to integrate IP network and optical network, with logical centralized controller and orchestrator, virtualized network functions, PCE based control plane for multi-layer operation. The ultimate goal is to have an integrated backbone network with much agility, elastics and scalability, along with much lower OPEX and high customers' satisfaction.

The overhaul of the existing backbone network will not complete overnight and a smooth migration path is as follows:

1) Deploy separate SDN controllers for IP network and optical network respectively. Deploy unified orchestrator to coordinate both IP and optical SDN controllers for service needs. Implement GMPLS UNI and PCEP protocols to interconnect IP and optical at the control plane to support automatic end-to-end data path provisioning and resiliency.
2) Integrate IP and optical SDN controller into one IP + Optical super SDN controller; introduce centralized path computation with multi-layer PCE, for integrated and end-to-end service over IP and optical networks in a single domain environment with Huawei equipment.
3) Enhance IP + Optical super SDN controller to support multi-domain topology and service coordination in network domains built with Huawei equipment, as well as network domains built with 3rd party vendors' network equipment and their SDN controller, by means of implementing standard north-bound interfaces between the super SDN controller and domains' SDN controller.

Architectural context

1) Deployment of SDN technology
    a. Logically centralized SDN controller
    b. Standards based PCE for multi-layer data path control
    c. Orchestration for multi-layer resource management

2) Enabler - powered by Cloud based Data Center
    a. High performance for path calculation
    b. Large scale network deployment
    c. Global visibility and scalability

3) Enabler – powered by big data
    a. Full information on topology, traffic and service
    b. Leverage big data analysis technologies
    c. Smart and intelligent capability

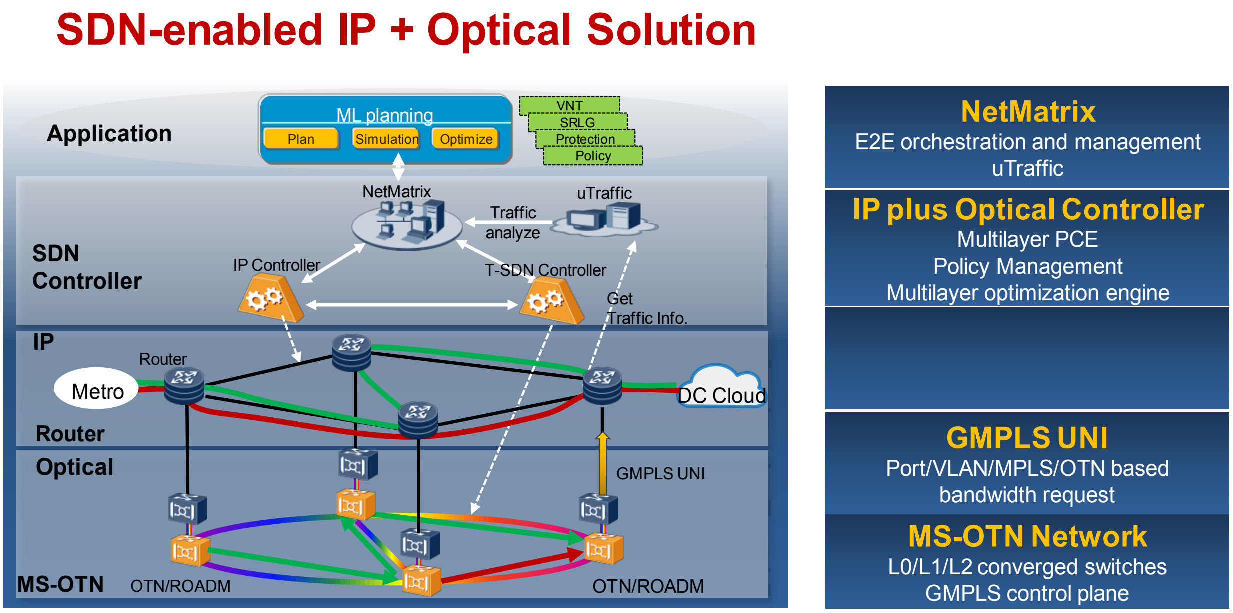
4) Enabler – powered by NBI
    a. Network function abstraction and virtualization
    b. Easy integration via north bound API (NBI)
    c. Openness and programmability

5) Enabler – re-using existing protocols and interfaces
    a. Based on existing equipments and their functions
    b. Full respect to the demarcation between networks and departments

c. Network compatibility.

Diagrams

Figure 10-1 illustrates the solution of SDN-enabled and integrated IP + Optical networks.


SDN-enabled IP + Optical Solution

NetMatrix
E2E orchestration and management
uTraffic

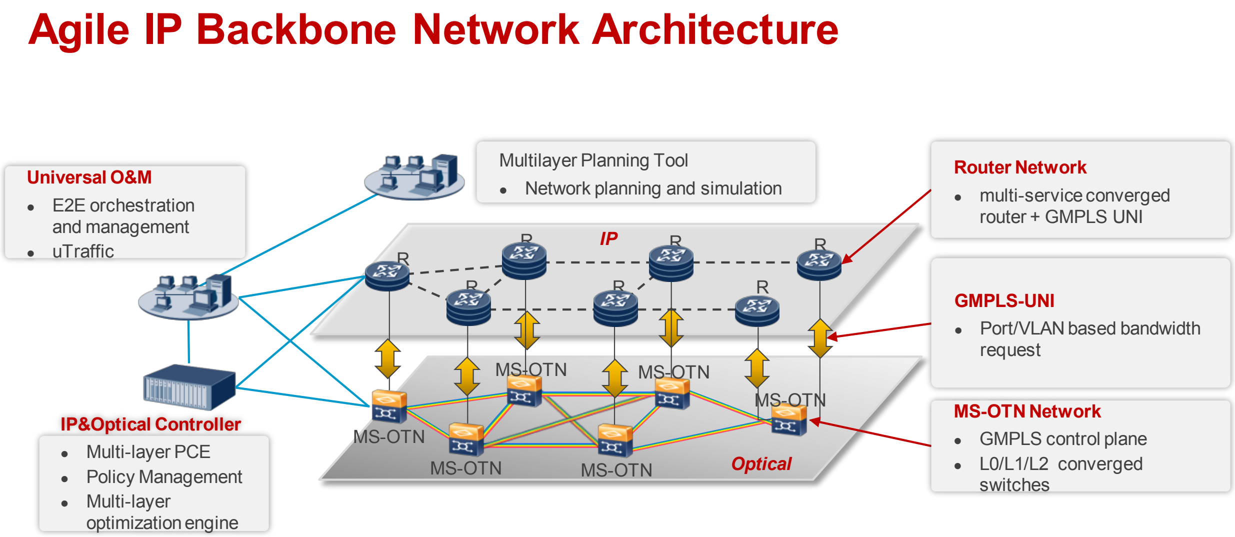
IP plus Optical Controller
Multilayer PCE
Policy Management
Multilayer optimization engine

GMPLS UNI
Port/VLAN/MPLS/OTN based bandwidth request

MS-OTN Network
L0/L1/L2 converged switches
GMPLS control plane

Figure 10-1**: SDN-Enabled and Integrated of Integrated IP + Optical Networks**

Figure 10-2 illustrates the architecture of SDN-enabled backbone networks with multi-layer operation.


Agile IP Backbone Network Architecture

Universal O&M
- E2E orchestration and management
- uTraffic

Multilayer Planning Tool
- Network planning and simulation

Router Network
- multi-service converged router + GMPLS UNI

GMPLS-UNI
- Port/VLAN based bandwidth request

MS-OTN Network
- GMPLS control plane
- L0/L1/L2 converged switches

IP&Optical Controller
- Multi-layer PCE
- Policy Management
- Multi-layer optimization engine

Figure 10-2 Architecture of SDN-Enabled Backbone Network

Business drivers

A unified IP+Optical network control and orchestration solution with SDN control delivers efficient and better customer experience for carrier networks that are usually complex and large in scale. It utilizes centralized intelligence and brings network automations and resource coordination for both IP and transport networks, lowering OPEX and shortening TTM. The unified SDN solution also protects the investment for current carrier networks, by providing a smooth migration path and a mean to inter-work with existing protocols and management systems deployment.

Deployment reference

Huawei has developed integrated IP+optical SDN controller under joint innovation with its key carrier partners, and has made many successful field trials and commercial deployments worldwide.

Related SDO efforts

Unknown

Related use case(s)

Unknown

References

onf2014.183, “Carrier Grade SDN Framework”

11 Use Case 6 – Virtual Data Center Network (China Telecom)

Title:
Virtual Data Center Networking

Contributors:
Feng Wang, Ruiquan Jing, Yunpeng Xie

Problem statement

Virtualized networking is a key requirement for carrier data centers inter connection:

- Cloud service customers have some special requirements, such as build a large scale application system based on crossing region resource, so cloud computing resource should be provided by multiple IDCs at different locations.
- Single IDC resource capacity cannot meet customer's racks requirement, and other IDCs in the same location or some other locations have to be joined to deliver resources. Meanwhile, the interconnection network among IDCs is necessary.
- Data backup and disaster recovery crossing IDCs is an important application which needs an interconnection network among IDCs.

Actors

- VDC (Virtual Data Center): A product of the IaaS (Infrastructure as a Service) delivery model of cloud computing. It is a pool or collection of cloud infrastructure resources which reside in virtual space being hosted by one or more actual data centers
- IDC: Providing data center resources and a range of solutions for systems deployment and operation for Internet application. It usually has a large scale of resources with the introduction of cloud computing technology
- SDN controller: A logically centralized entity in charge of translating the requirements from the SDN Application layer down to the SDN data paths and providing the SDN Applications with an abstract view of the network (which may include statistics and events). Different SDN controller are used for control corresponding network resources, so there are many types of SDN controller in industry, for example data center controller, WAN controller.
- Orchestrator: An element in a network to coordinate the required networking hardware and software elements to support applications and services. It always involves coordinating software actions with an SDN Controller and provides the important "glue" between a wide range of technologies that enable cloud-based network and communications services.

Solutions

- Introduce SDN controller in IDCs at different locations to control data center internal network, for example partitioning sub-network, assigning IP address, and building overlay network.
- Introduce SDN controller in WAN to control interconnection network among data centers， for example building overlay/underlay connection, guaranteeing QoS. Different network solution maybe need different controller.
- Introduce orchestrator to receive customer requirements, and drive cooperation between data center controllers and WAN controller to build an end to end network connection.

Architectural context

- Data Plane: Overlay network or underlay network, enable layer 2/layer 3 interconnection network among multiple IDCs.
- Control Plane: Centralized SDN controller manages overlay network (e.g. VxLAN network) or underlay network by collecting network status and pushing network control l information to keep synchronization and consistency of control plane information.
- Application Plane: Orchestrator which receives customer requirements, and drives coordination and scheduling of data center controller and WAN controller to build an end to end network interconnect on demand.

Diagrams

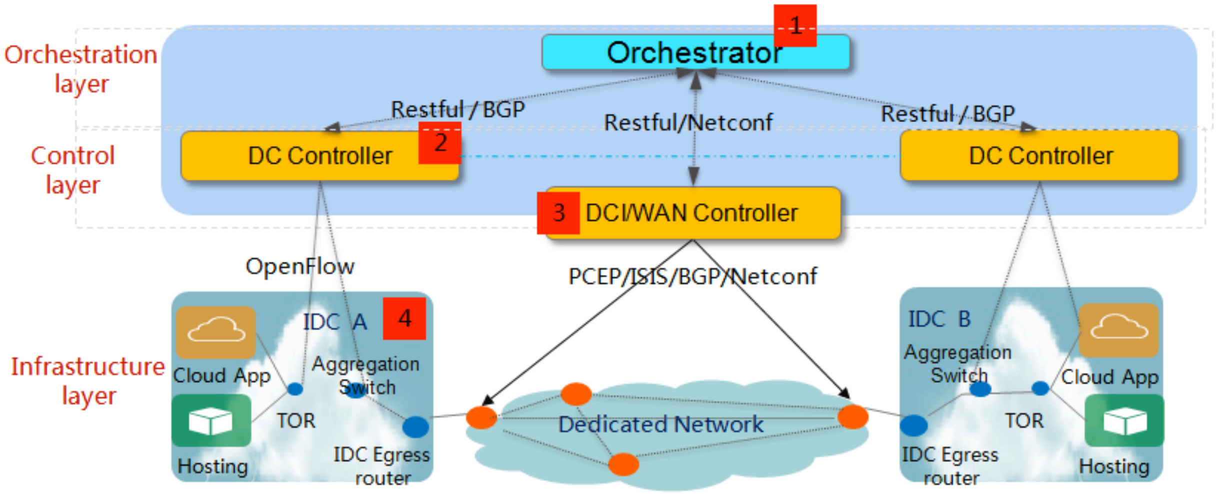


Figure 11-1: A Typical VDC Network Design

Business drivers

- Interconnection network based on SDN make crossing IDC network integration in MAN more flexible. It meets requirements of cloud service customers and reduces complexity of IDC network operation.
- SDN-based dedicated network provide high-speed DCI connection. Cloud-network convergence enables the global optimization for inter-DC traffics scheduling.

Deployment reference

China Telecom has deployed SDN-based VDC solution in Cloud Computing Key Laboratory consisting of three nodes including Beijing, Shanghai and Guangzhou.

Related SDO efforts

Unknown

Related use case(s)

Unknown

12 Use Case 7 – Multi-Carrier and Multi-Domain Orchestration (PCCW Global)

Title
Multi-Carrier and Multi-Domain Orchestration

Contributors
Shahar Steiff – PCCW Global

Problem statement
When orchestrating a service spanning multiple domains (either within one carrier network boundaries or across carrier network boundaries) an assumption of a single top-level orchestrator that has end to end visibility of all network components may not necessarily be valid. This use-case discusses this scenario and proposes a federated-orchestration approach.

Actors
The key components in this use case are the Customer (that consumes the service), the Service-Provider (that provides the Service to the Customer) and the Partner (that provides elements of the Service to the Service Provider to complement the elements of Service that the Service Provider can not fulfill themselves).

The Service Provider and the Partner are further divided, each, internally, into different functional components: The Business component (traditionally referred to as BSS), the Orchestration component (traditionally referred to as the OSS), the Infrastructure Control and Management component (traditionally referred to as NMS) and the Element Control and Management component (traditionally referred to as EMS). Those internal components, and the interfaces connecting them, as well as the external interfaces connecting components across carrier boundaries, can be realized and implemented using both legacy and new methods, including SDN.

The MEF LSO Architecture diagram shown below (**Figure 12-1**) depicts the actors, components and interfaces mentioned above.

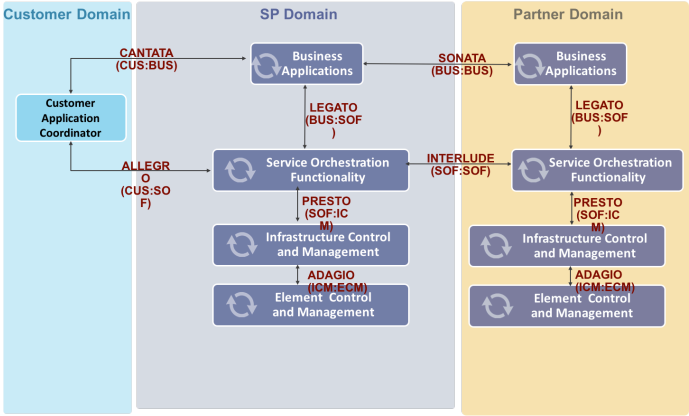


Figure 12-1 MEF LSO Architecture

Solutions

A service provider typically puts together multiple Network, Data-Centre and other elements that are bound together to provide a complete solution to the customers' requirements. In many cases some of the elements of such solutions are sourced by the Service Provide from third-party providers, namely Partners. Those elements may be connectivity into locations where the Service Provider does not have coverage (referred to as "off-net" locations - such connectivity is typically provisioned through a Network-to-Network-Interface) or Computational/Storage/Packet-Manipulation related activities such as Firewalls, Routers, DPI (such activities are typically referred to as Network Functions, or, in their virtualized form - VNFs).

The integration of such multi-domain, or multi-carrier (in the event the domains are operated by different carriers) Services – requires tight integration between the respective players from three angles:

1. The Operational perspective (process alignment);
2. The Service perspective (Service Specifications alignment, Information Model alignment, interface alignment);
3. The Orchestration perspective (Analysis of a requirement; Dividing it into deliverable components; Selecting the Partners for delivery of "off-net" component; activating, or requesting partners to activate, the components; Integration of the components into an end to end service)

In the absence of a top-level orchestrator (which is the typical case in a service provisioned across Carrier borders) the interactions between domains must then follow standardized Service definitions, Standardized Information Models, Standardized Processes and Standardized Orchestration Architecture. Otherwise – domain orchestrators will not be able to effectively request services from neighbor orchestrators and integrate them into an end-to-end service automatically.

One may correctly assume that orchestration of multiple domains within a single administrative domain is relatively simpler to solve than orchestration across administrative domains.

Architectural context

SDN is an optional (and preferred) internal architecture for the Service Provider and its partners. In order to allow automated orchestration across multiple domains - It is mandatory that the Service Provider, and each of the partners, is capable of delivering their respective components of the end to end service – independently and in an automated fashion. It is also mandatory that the components and players are able to interface and communicate with each other to perform the functions required at different phases of the lifecycle of a service (e.g. inquire capability, request activation, report performance, bill, change management, terminate). SDN is a key enabler to the above as it provides the ability to configure elements using software. If any of the domains involved in delivery of the end to end solution can not be automated – then the ability of end to end automation can not be achieved.

Diagrams

Below (**Figure 12-2**) is a (fictitious) example of an end to end multi-carrier service. The end to end service delivered is a 3-point ELAN between the HR department of a (fictitious) bank, based in Houston, TX, and two of the bank's branches – located in Timbuktu and in Athens.

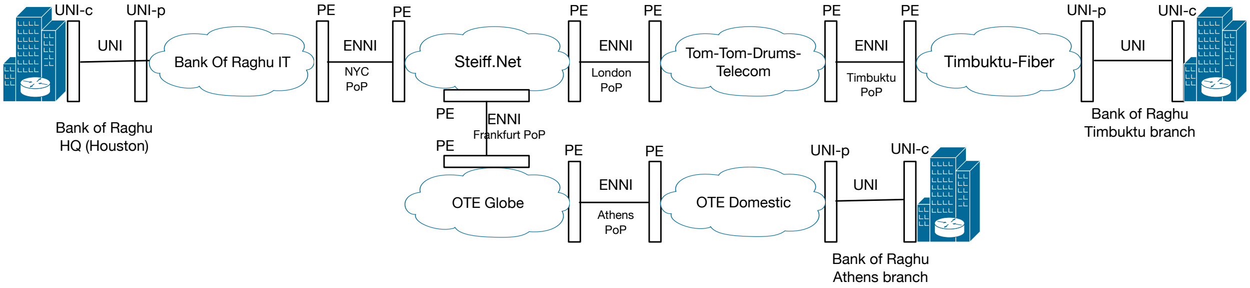


Figure 12-2 Example of end-to-end Multi-carrier Service

The Carriers involved in the delivery of said service are:

1. Bank of Raghu's IT department, that operates a domestic network within the USA and will provide the connectivity between the Houston, TX, office up to their NNI with Steiff.Net in New-York.
2. Steiff.Net is a (fictitious) Carrier that has an international network with PoPs in New-York, Frankfurt and London.
3. Tom-Tom-Drums-Telecom is a (fictitious) carrier that has an international network with PoPs in London and Timbuktu.
4. Timbuktu-Fiber is a (fictitious) carrier that has a domestic access network within Timbuktu.

5. OTE Globe is a carrier that has an international network with PoPs in Frankfurt and Athens (there actually IS such a carrier!).
6. OTE Domestic is a carrier that has a domestic access network within Athens.

For the purpose of this use case we could have added additional components (e.g. Routers and firewalls– real or virtual) to be installed at the customer locations.

Though the above diagram describes service offered by fictitious carriers to a fictitious customer, it resembles many real services offered by real carriers to real customers today. It is important to note, though, that due to absence of standardized processes/information models/orchestration framework – the delivery of such services today is manual.

Business drivers

While many carriers have come up with automation or semi-automation of their internal network operations - the delivery of inter-carrier services today is manual (as stated above). This results in lengthy lead times, cumbersome operations and limited capability to offer effective change management.

Being able to automate service lifecycle operations and orchestration across carrier boundaries could shorten lead times, simplify change management and thus allow more flexible service offering that better address customer demand and thus generate new revenue streams.

Deployment reference

Several carriers have already deployed on-net automation, and examples include the following:

- PCCW Global
- Colt
- Telstra and Cisco

Inter-carrier automation has, to date, been deployed in PoCs only. There is no commercial offer yet, primarily due to lack of respective standards. One such example is the TMF ZOOM Catalyst presented by Oracle/InfoVista/Juniper in the TMF-Live! Event in Nice in May 2016 (refer to TMF-Live Event). The diagram below shows the components of said Catalyst.

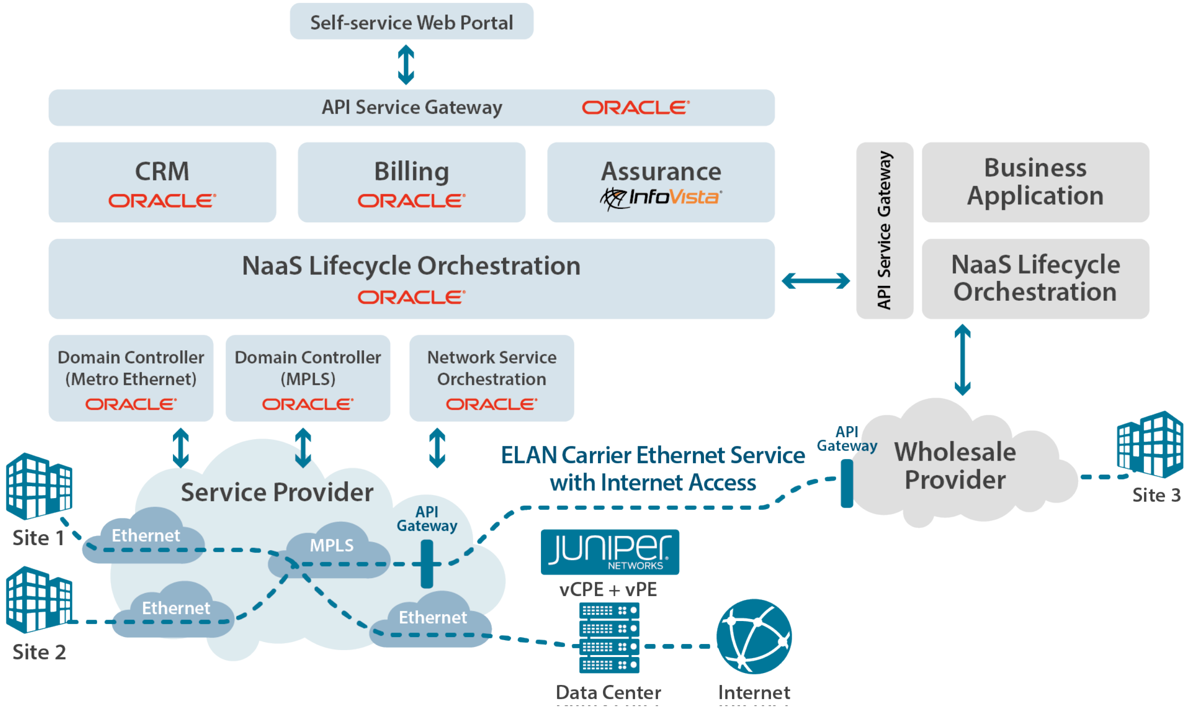


Figure 12-3 TMF ZOOM Catalyst

Related SDO efforts

The most prominent projects related to multi-carrier orchestration are the MEF LSO (MEF-55) and the TMF API framework. Both tackle an environment where multiple carriers participate in the delivery of a service to a customer and both allow an assumption of absence of a top-level orchestrator – leading to a federated orchestration approach.

Related use case(s)

Unknown

References

[1] ONF, SDN Architecture (Issue 1), TR-502
[2] MEF-55, https://www.mef.net/Assets/Technical_Specifications/PDF/MEF_55.pdf
[3] TMF API Framework, https://www.tmforum.org/strategic-program/apis

13 Use Case 8 – Salable and Flexible Optical Architecture for Reconfigurable Infrastructure (SAFARI)

Title

Scalable And Flexible optical Architecture for Reconfigurable Infrastructure

Contributors

- Tetsuro Inui, Takafumi Tanaka, Akira Hirano, Yutaka Miyamoto – NTT
- Ulrich Häbel, Klaus Pulverer – Coriant
- The EU-Japan coordinated R&D project on "Scalable And Flexible optical Architecture for Reconfigurable Infrastructure (SAFARI)" by the Ministry of Internal Affairs and Communications (MIC) of Japan and EC Horizon 2020 [1])

Problem statement

The required growth in network capacity over the years has been relentless. As an example, Figure 13-1shows the commercial system capacity in NTT's core network in the last 30 years. The growth rate is very stable at 40-50 % per year. The situation is almost the same as that of the global trend.

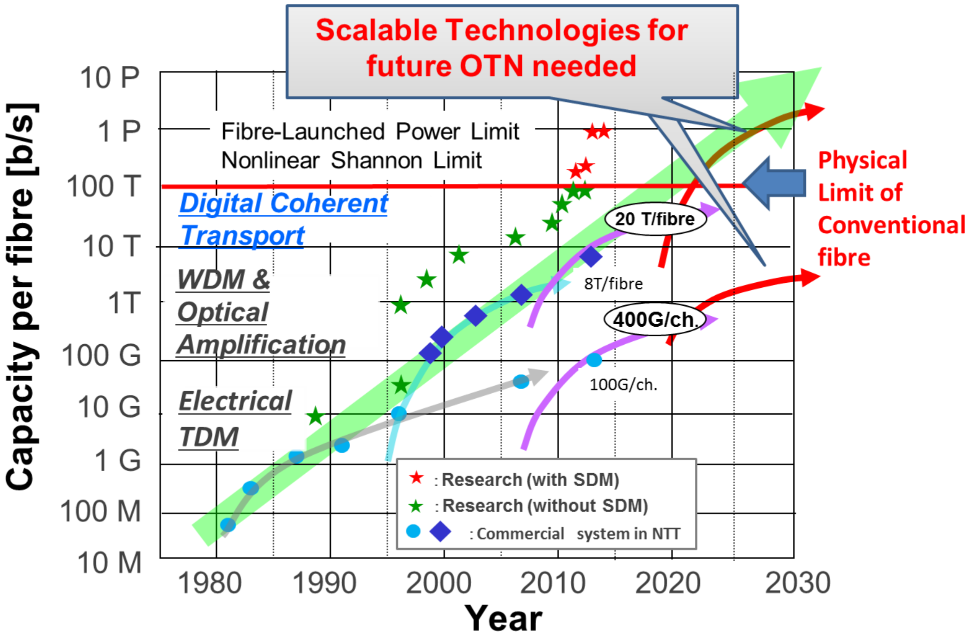


Figure 13-1 Commercial system capacity growth

In order to sustain such growth rates also in the future, the optical transport network needs to become more flexible in terms of optical carrier allocation, choice of modulation formats and so on. In addition to that, to overcome the capacity limit of standard single-mode fibers (SMFs), multi-core fibers (MCFs) have been attracting much attention for their potential to enhance the transmission capacity by orders of magnitude. To catch and fully utilise these cutting edge transport technologies in a carrier or service provider's network, they can no longer be viewed as an independent set of pipes hidden invisibly below the higher transport layers. Transport capabilities and restrictions interact with traffic patterns and require dynamic control, and we need to invent novel architecture or designs to support these optical features in a fully programmable manner with a carrier grade quality of service. One of the important issues is to ensure the scalability needed for the carrier network which may cover one country and/or be of international scale, with a potentially a huge number of nodes. Another is to take account of optical transport impairments such as cross-talk (XT) when making routing choices.

Considering the value of programmability for future OTN, great care has to be taken when exploiting programmable optical hardware: too much programmability leads to too much complexity and non-scalable networks, whereas too little programmability will not achieve the desired flexibility.

Actors

- Ultra-high capacity optical transport network: Optical transport network using at least 400 Gbps/channel digital coherent technologies and multi-core fibers as the transmission lines to accommodate huge traffic in a carrier network
- Hierarchical controller: Layered controller which consists of a line and a service control layer
- Line control: Control layer which directly manages optical hardware and plays the role of intermediate layer between physical and logical layers
- Service control: Control layer which manages resource abstraction within the transport networks and provides the interface for service management

Solutions

The optical transport layer is becoming increasingly powerful and complex. Due to the continued increase of data rates, it is inefficient to move all decision taking to higher layer routers or switches, with optical-electrical-optical conversions at every step. Several research projects have already taken this situation as the basis for studies of all-optical network architectures. However, the control of such networks is not yet well covered.

Software defined networking (SDN) is quickly becoming the method of choice for controlling networks at a higher layer (IP and above), through the OpenFlow protocol. This approach offers a lot of flexibility which would make it ideal to control transport networks. To do this, we intend to introduce an intermediate entity to mask the complexity of the physical layer. This approach encompasses:

- Provide an interface to SDN based on the OpenFlow protocol, which permits the creation and removal of optical paths across the network according to quality parameters as required by the different services.
- Represent the transport network to the SDN layer as a simplified structure which essentially looks like a large switch, offering connections between a number of inputs
- Make use of different modulation formats and link capabilities offered in different parts of the network.
- Take account of physical effects such as cross-talk between different MCF cores when assigning optical paths.

Architectural Context

In future ultra-high capacity optical transport network using at least 400 Gbps/channel digital coherent technologies and MCFs as the transmission lines, crosstalk (XT) between adjacent cores is a dominant factor limiting the attainable distance. XT accumulates as the signal propagates along MCFs, and the allowable XT depends on the modulation format [2]. XT between neighboring cores was already identified as the main additional impairment that may reduce transmission reach for multi-core optical transport. Wavelength/core routing and assignment complexity will significantly increase when considering this new type of inter-core XT. In addition, a high number of cores per fiber significantly increases hardware and software resource demand when deploying MCFs. Besides physical aspects such as network element size, the manageability of such large transport systems creates additional capacity issues for management applications and control traffic bandwidth. It is therefore necessary to reduce management complexity by mechanisms such as network abstraction (e.g. multi-core link aggregation) and delegation. This strategy embraces transport network architecture as well as management function distribution aspects.

Figure 13-2shows a hierarchical controller model indicating a line and a service control layer. The line control layer directly manages programmable optical hardware and plays the role of intermediate layer between physical and logical layers. The service layer manages resource abstraction within the transport network context and provides the interface for service management.

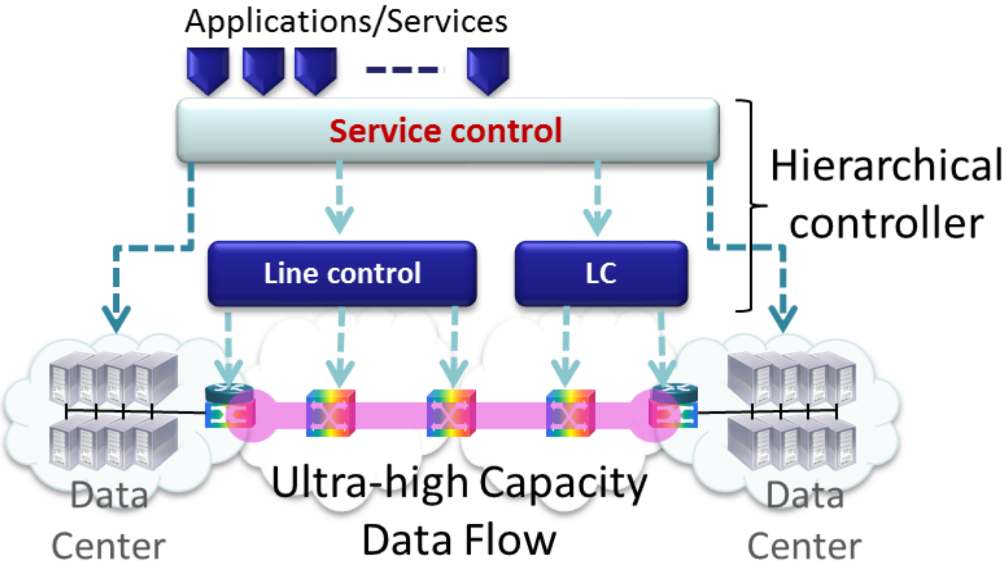


Figure 13-2 Hierarchical controller model

Diagrams

Figure 13-3illustrates the effect of cross-talk in an MCF deployment scenario by looking at the example of an ultra-high capacity network connecting data centers in major cities to accommodate massive traffic. Here, we consider the use case that MCF is incrementally deployed in several steps to increase the capacity of an existing network. Figure 13-4 shows why the effect of XT suddenly becomes an issue when MCF deployment becomes dense. To start with, the network is composed of conventional single-mode fibres (SMFs). In the second step when one or more isolated SMF links (A-B) are replaced by MCF, it is not necessary to consider the XT value in network design (XT-Free) as long as the distance of the MCF link is limited and the XT meets the guaranteed maximum value. At this stage, the deployment of MCFs is only sparse. In the third phase when the SMF link (B-C) is also replaced by an MCF, long connection paths (e.g. from A to C) become possible which are no longer XT free, and we need to select the applicable core in the MCF depending on the XT and the modulation format in order to limit the impairment. The non-sparse MCF deployment represents a network that requires careful XT consideration for network planning and operation.

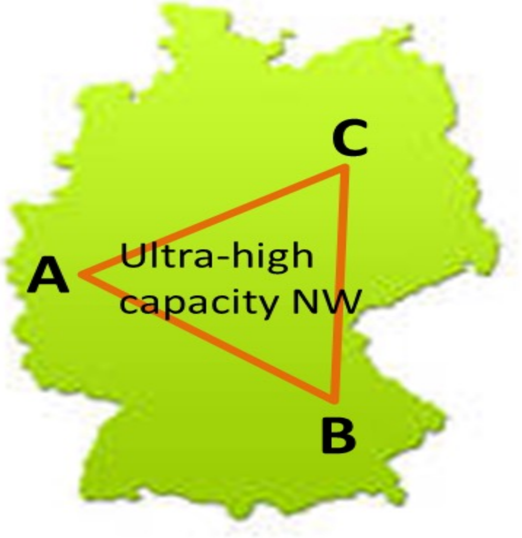


Figure 13-3 An example of future ultra-high capacity network in Germany

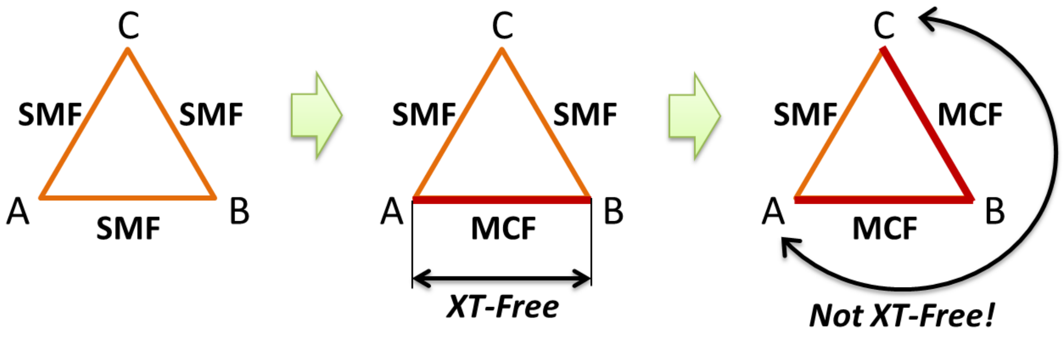


Figure 13-4 MCF deployment scenario

Business Drivers

Figure 13-5 shows the XT related network planning & provisioning for programmable ultra-high capacity optical transport networks. The graph shows the Q-penalty (quality-penalty) induced by XT in case of various modulation formats as a function of the transmission distance. From carrier's point of view, there are two operational modes: conventional operation and emergency operation.

If the distance is short and the XT is negligible (XT-Free), the cores can be bundled indiscriminately. We can treat the link as a multi-core aggregated link and realize the information abstraction, even if a high number of cores per fibre significantly increases hardware and software resource demand when deploying MCFs. In the intermediate distance where the XT is not negligible, there will be a restriction on modulation format. Here, we can select applicable modulation formats depending on their XT tolerance.

In emergency operation, network operators may need to provision a long distance detour route for critically important services, whose length is beyond the allowable XT penalty for normal modulation formats. To serve this scenario, restrictive measures have to be supported in order to reduce XT to a manageable level for those critically important services. Transmission may be restricted to a sparse distribution of cores in order to reduce adjacency effects. In addition, non-overlapping wavelengths distributions in adjacent cores may be used, and XT monitoring information (see for example [3]) may be taken into account. Furthermore, there could be other methods such as using an enhanced forward error correction (FEC) and reducing the number of sub-carriers. A centralized and automated control layer is required to support these functions in order to give network operators continuous controllability for the ultra-high capacity optical transport even in such a disaster recovery use case, and to ensure quick reaction times.

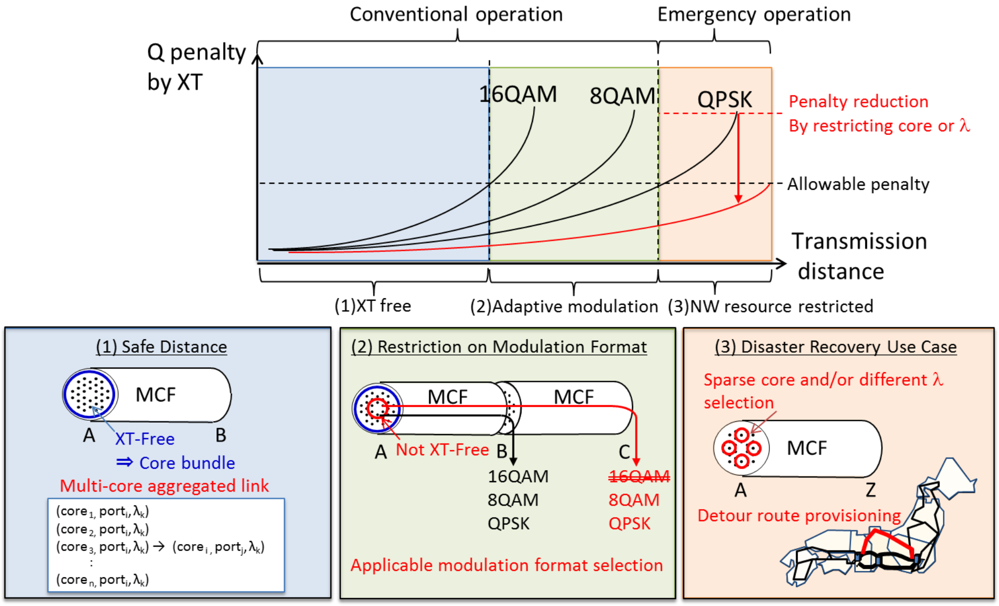


Figure 13-5 XT related network planning and provisioning for ultra-high capacity optical transport networks

Deployment reference

Unknown

Related SDO efforts

Unknown

Related use case(s)

Unknown

References

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