L'architettura di rete: NFV e SDN

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The software evolution of networks

- **Software** will play an unprecedented dominant role in upcoming communication environments

- A new buzzword:

  **Network Softwarization**

  - Computing, storage, connectivity services, present and future application instance
  - will be deployed in the form of virtualized assets
  - within a software-defined infrastructure
  - running on top of general-purpose hardware

  **Everything under the *aaS paradigm**
Software = Programmability = Flexibility

*aaS = General purpose hardware
  - Promise to improve Capex and Opex

Not a new concept in communications
  - Active Networks
  - Software-Defined Radio

Programmability does not answer all questions
  - heterogeneous resource management
  - full service abstraction
  - cross-layer, cross-domain functionalities

Software-Engineered Networking
Enabling technologies

- Devices → Virtualization
  - Embed any application into a Virtual Machine (VM) that can run in the cloud

- Infrastructure → Cloud computing
  - Flexible VM placement and management
  - Tenants isolation

- Control and management → Software Defined Network
  - Design your own network topology on top of the physical network
Enabling Instruments

F Many vendor proprietary solutions but also
F Many opensource projects
  – Virtualization
    ♦ KVM, VirtualBox, libvirt
    ♦ Open vSwitch, linux bridges
  – Cloud Management
    ♦ OpenStack
  – Cloud provisioning
    ♦ Cloudify
  – SDN implementation
    ♦ Pox, Ryu, OpenDayLight
An example that fits all

- Cloud computing
  - OpenStack
- NFV
  - VMs over KVM
- Networking
  - OvS
- SDN
  - Pox, OpenDayLight
Openstack: key physical components

- 4 physical components
  - Same hardware configuration
  - Minimize Capex and Opex

- Controller
  - Management console
- Compute node
  - Host virtual machines and related computing tasks
- Network Node
  - Host shared network components
- Storage node
  - Host shared storage devices
Example of OpenStack platform architecture

Internet

Users

External Net

Controller

Network node

Compute node 1

Compute node 2

Storage node

Data Net

Management Net
The Openstack virtual network

- Every tenant sees its own conventional LAN
  - LAN switch, DHCP and DNS servers, default gateway
- None of these exist as a real device
- It is a virtual network infrastructure VNI
- The VNI is
  - Distributed among compute, network and storage nodes
  - Made of several virtual building blocks

- What are the main components?
- Who manages the VNI?
Virtual Ethernet/SDN Switch

Source: http://openvswitch.org
Location of VNI elements

- DHCP Server
- Gateway/NAT
- VM
- OvS
- Compute Node 1
- Compute Node 2
- Compute Node 3
- Controller Node
- VM Placement
- SDN controller
- Storage manager
- Internet
- Network Node
Software-Defined Networking (SDN)

Applications see the network as a single, logical switch controlled via abstracted API.

Centralized intelligence and network state knowledge to configure the devices.

Simplified network devices do not need to process all routing/switching protocols.

Enterprises and carriers gain **vendor-independent** control over the entire network from a **single logical point**, which greatly **simplifies the network design and operation**.

The OpenFlow Network Innovation

Source: S.Seetharaman, OpenFlow/SDN tutorial, OFC/NFOEC 2012
The OpenFlow Network Innovation

1. Open interface to hardware
2. At least one good operating system Extensible, possibly open-source
3. Well-defined open API

Source: S.Seetharaman, OpenFlow/SDN tutorial, OFC/NFOEC 2012
The OpenFlow Network Innovation

Network Operating System

Feature

OpenFlow

Specialized Packet Forwarding Hardware

OpenFlow

Specialized Packet Forwarding Hardware

OpenFlow

Specialized Packet Forwarding Hardware
Network Function Virtualization (NFV):

- User
- Access Router
- Firewall
- NAT
- DPI
- Switch
- Web Server
- Media Server
- Virtual Bridges/Switches
- Hypervisor
- Kernel
- Standard HW
- VM
- VM
- VM
- VM
- VM
- VM
- Edge Router
Implementing

Network Application (service)

Orchestrator

SDN Controller
Openstack

Physical Routers and Switches

OVS
Router
dhcp

VM1
VM2
OVS
NFV Chaining & dynamic traffic steering

Data flow $f_1(t_0)$

Edge Network Data Center

Core Network

Edge Network Data Center

VNF  VNF  VNF

VNF  VNF

VNF  VNF  VNF  VNF
NFV Chaining & dynamic traffic steering

Data flow $f_1(t_0)$

Data flow $f_2(t_0)$

Edge Network Data Center

Core Network

Edge Network Data Center

Space chaining diversity
NFV Chaining & dynamic traffic steering

Data flow $f_1(t_0)$
Data flow $f_2(t_0)$
Data flow $f_2(t_1)$

Edge Network Data Center

Core Network

Time chaining diversity

Edge Network Data Center

VNF  VNF  VNF

VNF  VNF  VNF

VNF  VNF  VNF  VNF
A simple use case

- QoS control and SLA enforcement

- 3 Virtual Network Functions
  - Deep Packet Inspection and traffic classification
  - Wireless acceleration (traffic squeezing)
  - Traffic control (traffic policing and packet dropping)

- Goal:
  - Safeguard the SLA with premium users
  - Exploit bandwidth acceleration
  - Allow best effort users in residual bandwidth
Proof of concept: SDN controller design

**Hybrid SDN approach:**
- ARP processed according to *NORMAL* action
- TCP and UDP flows processed dynamically according to SLA and network traffic conditions

Rules installed at *startup phase*:
- Broadcast storm avoidance
  - Prevents loops
- Any other rule not requiring flow by flow processing (e.g.: apply action *NORMAL* to ARP packets)
  - Decrease load on controller
Proof of concept: SDN controller design

Phase 1: classification

Rules installed in SW1:
- Traffic from BU to DEST is forwarded both to VR1 and DPI
- Similarly for inbound packets

- BU/RU: Business/Residential User
- DEST: Destination Server
- DPI: Deep Packet Inspection
- WANA: WAN Accelerator
- TC: Traffic Conditioner
- VR: Virtual Router
Proof of concept: SDN controller design

Rules installed in SW1:
- Traffic from BU to DEST is forwarded to VR1 via WANA1
- Similarly for inbound packets

Phase 2: SLA compliance

Rules installed in SW1:
- BU/RU: Business/Residential User
- DEST: Destination Server
- DPI: Deep Packet Inspection
- WANA: WAN Accelerator
- TC: Traffic Conditioner
- VR: Virtual Router
Proof of concept: SDN controller design

Phase 3: no congestion  →  SLA not enforced

Rules installed in SW1:
- Traffic from BU to DEST is forwarded directly to VR1
- Similarly for inbound packets
Proof of concept: SDN controller design

Phase 4: classification

Rules installed in SW1:
- Traffic from **BU** to **DEST** is forwarded directly to **VR1**
- Traffic from **RU** to **DEST** is forwarded both to **VR1** and **DPI**
- Similarly for inbound packets
Proof of concept: SDN controller design

Phase 5: SLA compliance & congestion → SLA enforced

Rules installed in SW1:
- Traffic from **BU** to **DEST** is forwarded to **VR1** via **WANA1**
- Traffic from **RU** to **DEST** is forwarded to **VR1** via **TC** Similarly for inbound packets

Layer-2 SDN Edge Networks

- **BU/RU**: Business/Residential User
- **DEST**: Destination Server
- **DPI**: Deep Packet Inspection
- **WANA**: WAN Accelerator
- **TC**: Traffic Conditioner
- **VR**: Virtual Router
Multi-tenant test scenario: NFV case study

OpenStack dashboard view when N = 4
A 5G transport network can be divided in two segments:

- **Small cells transport**
  - Aggregates the traffic to/from the wireless small cells
  - Technology and topology are test case dependent

- **Metro/aggregation**
  - Connects different site types (i.e., macro, small cells access and fixed access) among themselves and to the core network
  - Common DWDM-centric network
Small cells transport (1/2)

- The main technology options can be categorized as:
  - **Copper-based**
    - Rates in the order of a few Gbps over relatively short distances. Preferred in the areas where there is a large installed base of copper that can be reused
  - **Fiber-based**
    - Provide high data rates over long distances in an energy-efficient way. Good and long term candidate for 5G small cells transport networks
  - **Wireless-based**
    - High capacity using advanced radio technologies. Attractive where cost of deploying wired transport infrastructure is prohibitively high
Small cells transport (2/2)

Overview of fiber-based technologies for small cells transport:

<table>
<thead>
<tr>
<th>Technology</th>
<th>Compatible services</th>
<th>Capacity</th>
<th>Costs (CAPEX)</th>
<th>Costs (OPEX)</th>
<th>Technology maturity</th>
<th>Open challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active Ethernet (CAT 5/6 and/or grey optics + packet switching)</td>
<td>Ethernet</td>
<td>1-10G (drop) 10G-100G (feeder)</td>
<td>Equipment (low)</td>
<td>General (high)</td>
<td>Mature</td>
<td>Control and management of active resources (switches/links)</td>
</tr>
<tr>
<td>PtP grey optical links</td>
<td>• Ethernet • CPRI • RoF</td>
<td>1-100G</td>
<td>Equipment (low)</td>
<td>General (high)</td>
<td>Mature</td>
<td>Fiber deployment/handling</td>
</tr>
<tr>
<td>TWDM-PON</td>
<td>• Ethernet • WDM overlay with CPRI/RoF over same fiber infrastructure</td>
<td>≤40G (drop)</td>
<td>Equipment (med)</td>
<td>General (low)</td>
<td>Standardized</td>
<td>• Handling of clients with stringent service requirements</td>
</tr>
<tr>
<td>DWDM-PON</td>
<td>• Ethernet • CPRI • RoF</td>
<td>1-10G (drop) ≤380 WL per fiber (feeder)</td>
<td>Equipment (med)</td>
<td>General (low)</td>
<td>Products available for less cost sensitive segments Low cost technologies (3-5 years)</td>
<td></td>
</tr>
<tr>
<td>UD-WDM-PON</td>
<td>• Ethernet • CPRI • RoF</td>
<td>1-10G (drop) ≤1000 WL per fiber (feeder)</td>
<td>Equipment (very high)</td>
<td>General (low)</td>
<td>Concept/demo stage Low cost technologies (5+ years)</td>
<td></td>
</tr>
</tbody>
</table>

Equipment costs refer to the cost of equipment required for the technology. Deployment costs refer to the cost of deploying the technology. Energy costs refer to the energy consumption of the technology.
Metro/aggregation network

- The (D)WDM transport technology provides extremely high capacity for the metro/aggregation network:
  - Hierarchy of interconnected optical rings
  - Different options for metro node design
  - Different options for the placement of the BBU functions

AE: Access Edge
MN: Metro Node
ME: Metro Edge

Optical DWDM transport network
Data plane design strategies

- Two main design strategies for 5G transport networks:
  - **Overprovisioning**
    
    The challenge of providing high capacity on-demand with (possibly) fast resource reconfiguration is satisfied thanks to the ubiquitous availability of ultra-high capacity transport
    
    - **Pros:** relatively low complexity at the control plane
    - **Cons:** potentially high cost because of inefficient use of network resources
  
  - **Smart transport networks**
    
    1. **Dynamic resource sharing**
      
      - Re-configurable systems for dynamically sharing limited transport resources
    
    2. **Network functions virtualization**
      
      - Dynamically push network functions to different locations, such as closer to the users so that a portion of the traffic requests can be served locally
Dynamic resource sharing

- The type of resources and how they can be shared depends on:
  - Radio deployment solution/architecture
  - Transport technology
  - User traffic dynamicity
- Resources that can be shared:
  - Packet switching: traffic engineering to allocate switching capacity
  - Fiber: wavelength division multiplexing (WDM)
  - Wavelength: time division multiplexing (TDM) or dynamic wavelength allocation
  - Spectrum: time, frequency or code multiple access
- Example of dynamic resource sharing by exploiting temporal traffic patterns:
Network Functions Virtualization

- The type of resources that can be dynamically virtualized depends on:
  - User traffic type
  - Business model (agreement between wireless and transport providers)

- Example of resources that can be virtualized:
  - Wireless network functions
    - BB processing
    - Evolved packet core (EPC)
  - Transport network functions
    - Packet aggregation
  - Cloud resources
    - Cache/storage

- Servers needs to be available in different network locations:
The use of dynamic resource sharing and NFV puts requirements on the control plane.

A software-defined networking (SDN) based control plane with programmable control of network resources and end-to-end orchestration could provide a framework for such a scenario.

Possible control plane architecture:
Control plane design (2/2)

› Demonstration video …
› https://www.youtube.com/watch?v=1BA0qW14MAU
Open issues

- Performance may be an issue
  - Smart network and traffic engineering

- Orchestration
  - Description tools and languages
  - Application building tools

- Multi-domain
  - Coordinate different orchestration logics
  - VNF standardization