UNIVERSITAT POLITÈCNICA DE CATALUNYA
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Facultat d'Informàtica de Barcelona

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UPC

SDN/NFV and Orchestration for Optical Transport Networks: Practical use cases

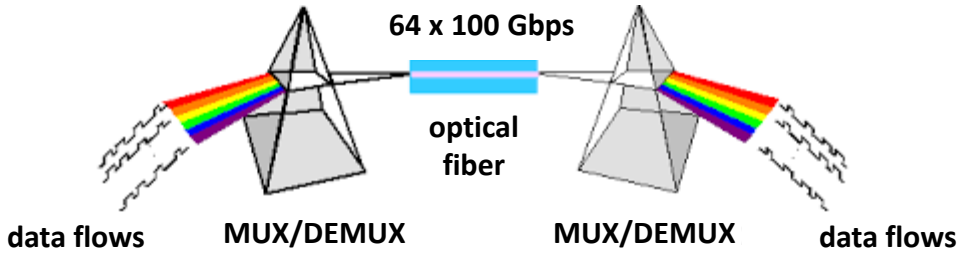
Future Internet Networks (FINE)

Master in Innovation and Research in Informatics (MIRI)

A glance at optical transport networks

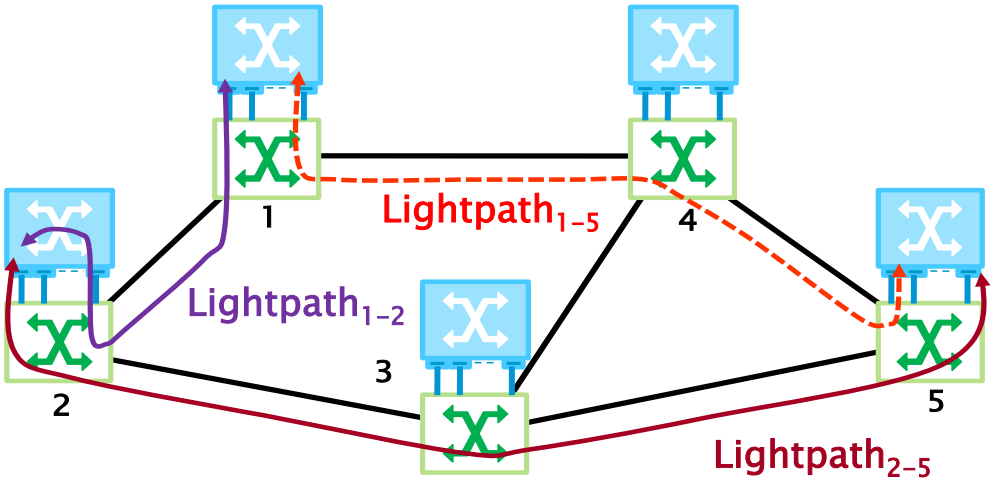
- Motivation
  - Need to cope with the **ever-growing Internet traffic** caused by the emergence of new applications and services
    - From VoIP and VoD to CDN, Cloud services, IaaS, IoT, etc.
  - Stringent **QoS** and **QoE** network requirements
    - (Ultra-)high bandwidth, (Ultra-)low latency
  - Other requirements
    - Energy efficiency (reduced power consumption)
    - Flexibility and low operational cost: Connections that can be established in milliseconds
- Optical transmission technology

Wavelength Division Multiplexing (WDM)



Optical transport technologies

- Optical Circuit Switching (OCS)
  - Establish end-to-end optical connections (**lightpaths**) to carry aggregated data traffic
  - Benefits
    - High bandwidth, guaranteed QoS, scalability
  - Scope
    - Long-lived data flows (bulk data transfer, HDTV, DC storage, …)
  - Scenarios
    - Operator networks (metro/region/core), inter-DC networks, intra-DC (Elephant flows)

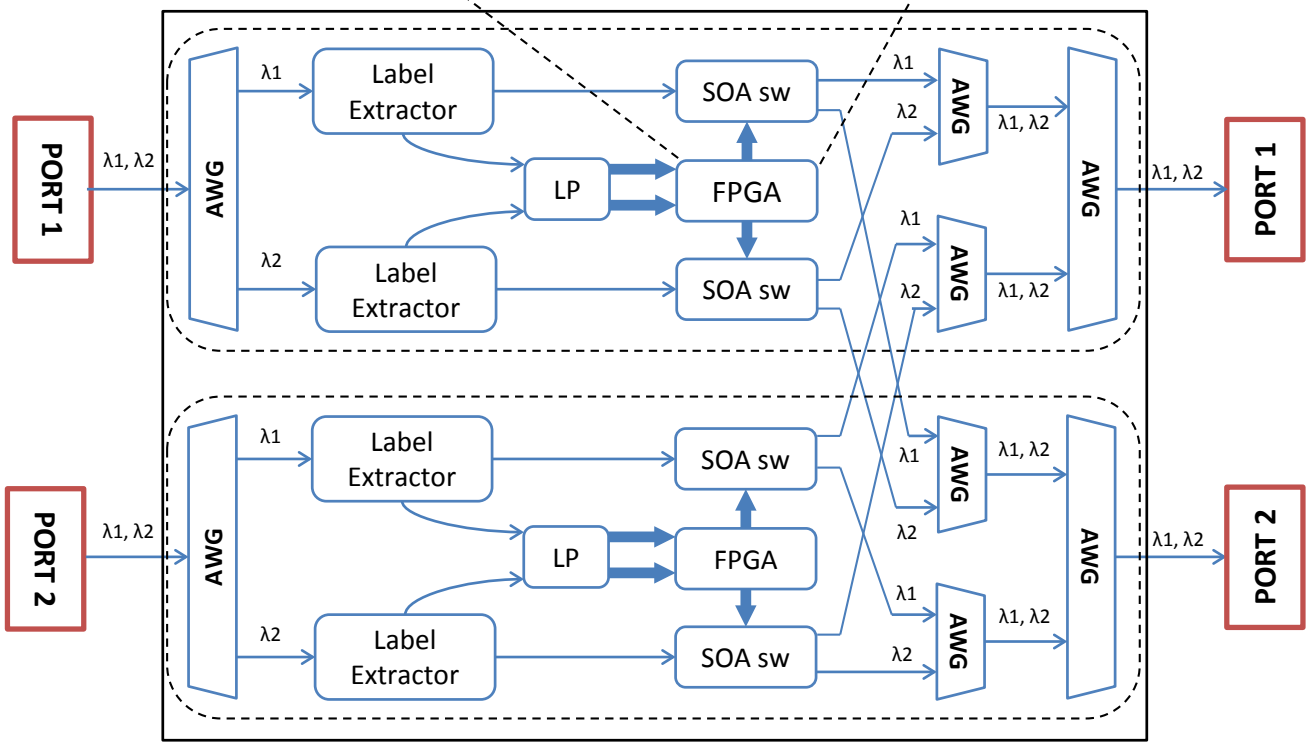


Optical transport technologies

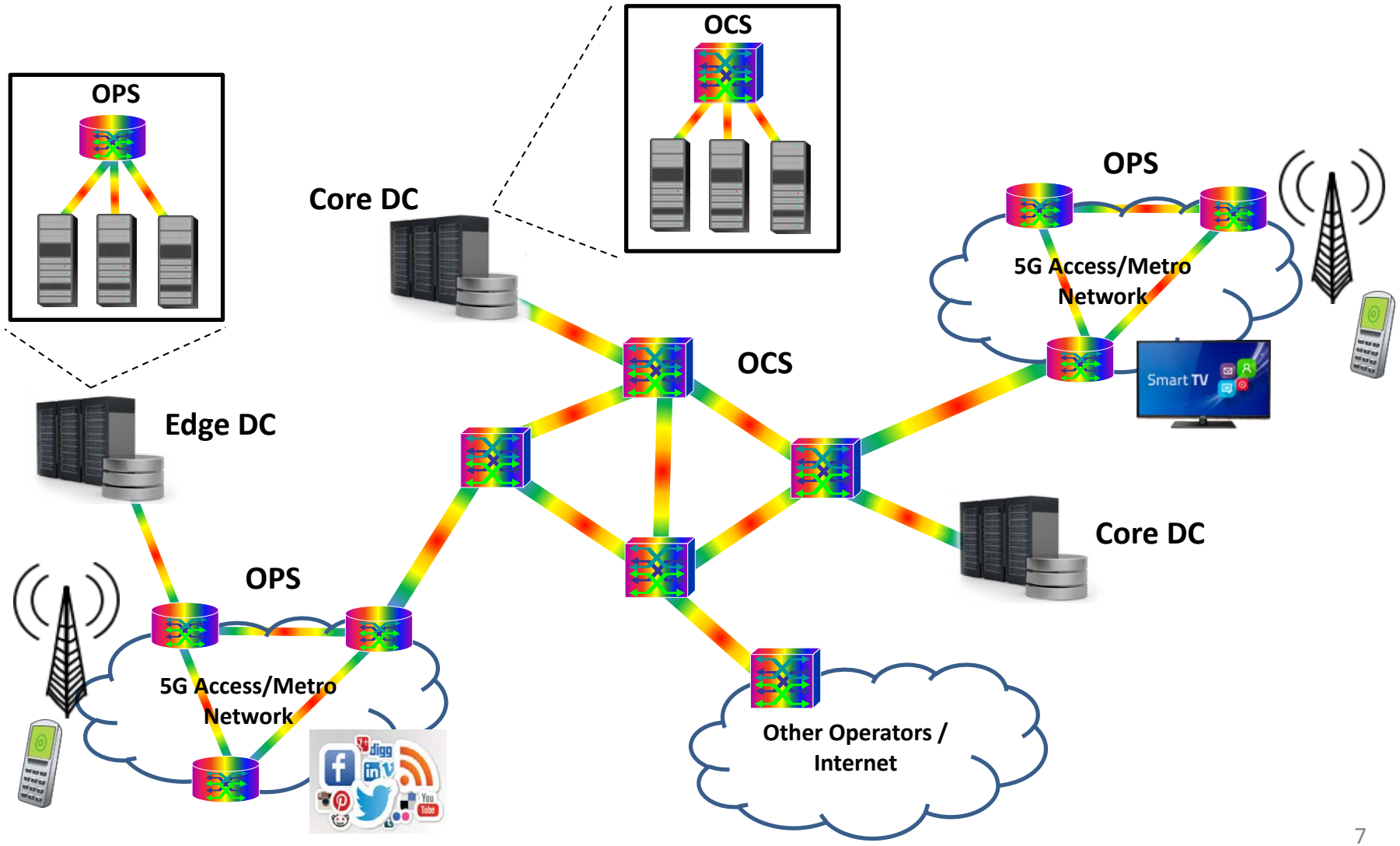
- Optical Packet Switching (OPS)
  - IP packets are aggregated into **optical packets** and sent through WDM channels
  - Benefits
    - High flexibility, statistical multiplexing, optical flow control, priority assignment
  - Scope
    - Short-lived or bursty data flows (VoIP, HPC / Edge Computing, application communication, …)
  - Scenarios
    - Operator networks (access/metro), intra-DC (Mice flows)

OPS switch

Look-up Table		Flow Table		
Label	**Destination**	**Input**	**Label**	**Load**
1	Port 1	1	1	0.5
2	Port 2	1	2	0.5



OPC/OCS-based Transport Scenario

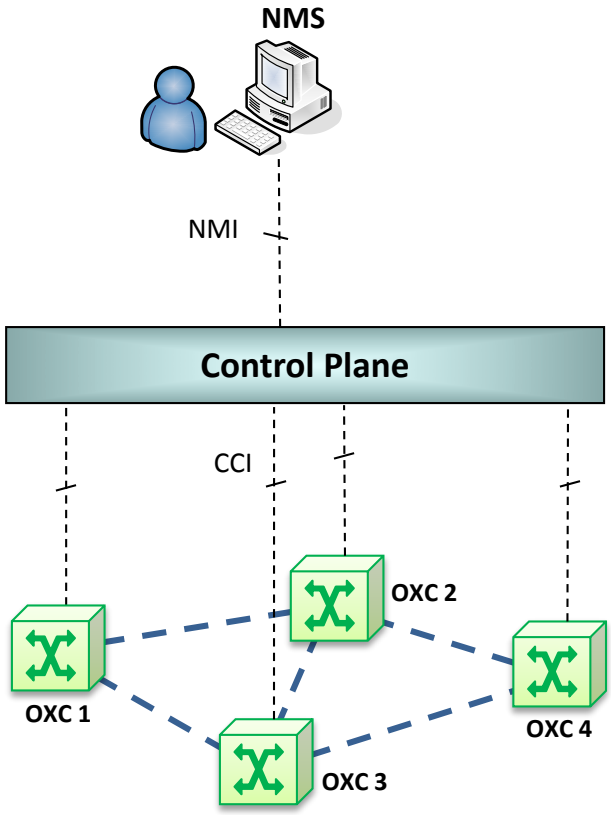


Dynamic optical networks

- Optical Transport Networks require a **Control Plane**
- [Lightpath / Optical Packet flow] **provisioning**
- Routing and [Wavelength / Optical Label] Assignment (**RWA**)
  - Compute the route of the [lightpath / optical packet flow]
  - Assign a [wavelength for the whole route / label for the optical packet]
- **Signaling** → Configuration of the equipment
- Other functionalities → Management
  - Monitoring
  - Accounting
  - Fault management
  - Optimization

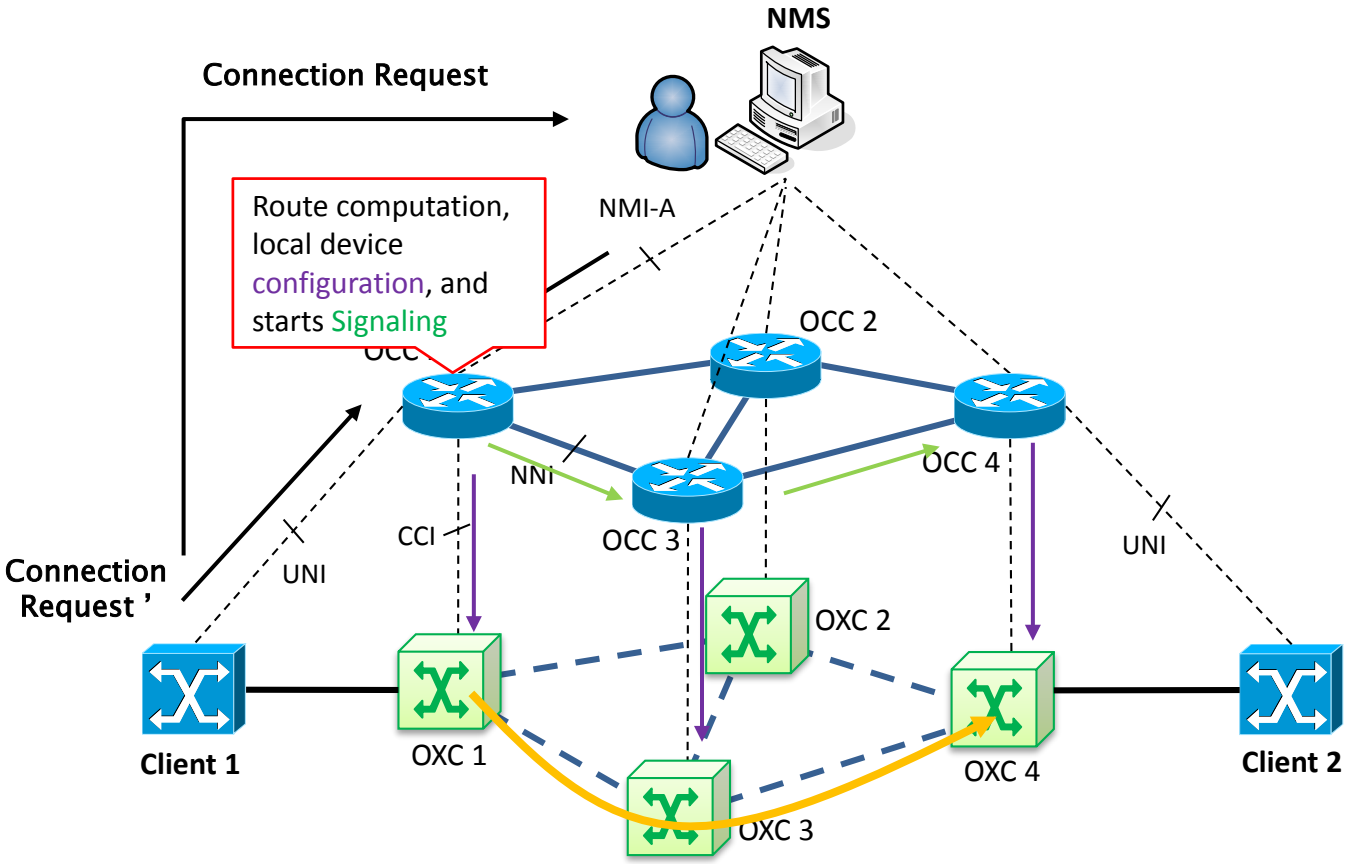
Dynamic optical networks (cont.)

- A **Control Plane** is introduced
  - Automated and dynamic lightpath set up
    - Topology and data plane state dissemination
    - RWA and Signaling
  - Efficient resource management and configuration
  - Fault management and automated restoration
- Other functionalities are kept at the **management** plane
  - Monitoring
  - Accounting
  - Performance (Optimization)



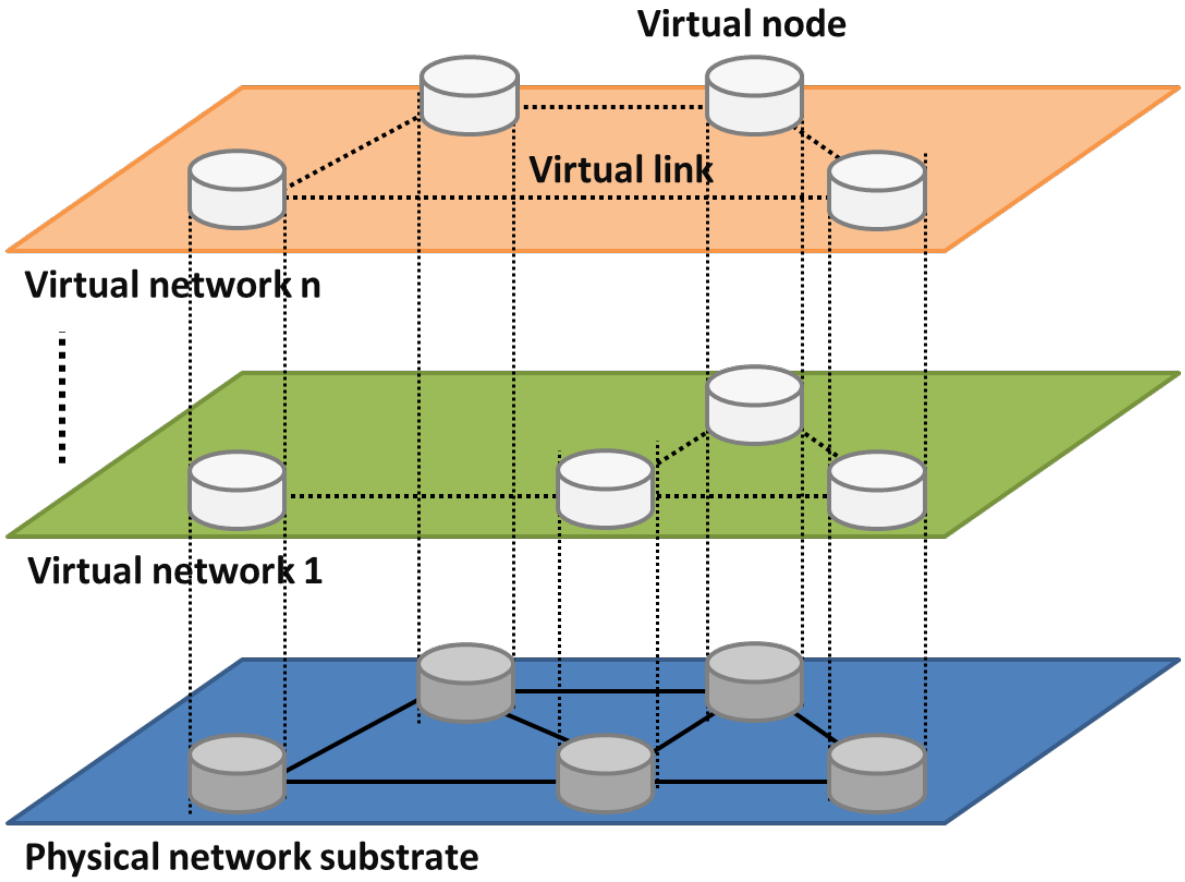
A Control Plane for dynamic OCS networks

- Lightpath set up example:
  - **Connection Request** →NMS-initiated under client request (**Soft-Permanent**)
  - **Connection Request'** → Client-initiated (**Switched**)



SDN and virtualization

- SDN is not only aimed to provide connectivity, but a dynamic network infrastructure capable to offer, establish and manage complex services
- Example of **Virtual Network** (VN) scenario:

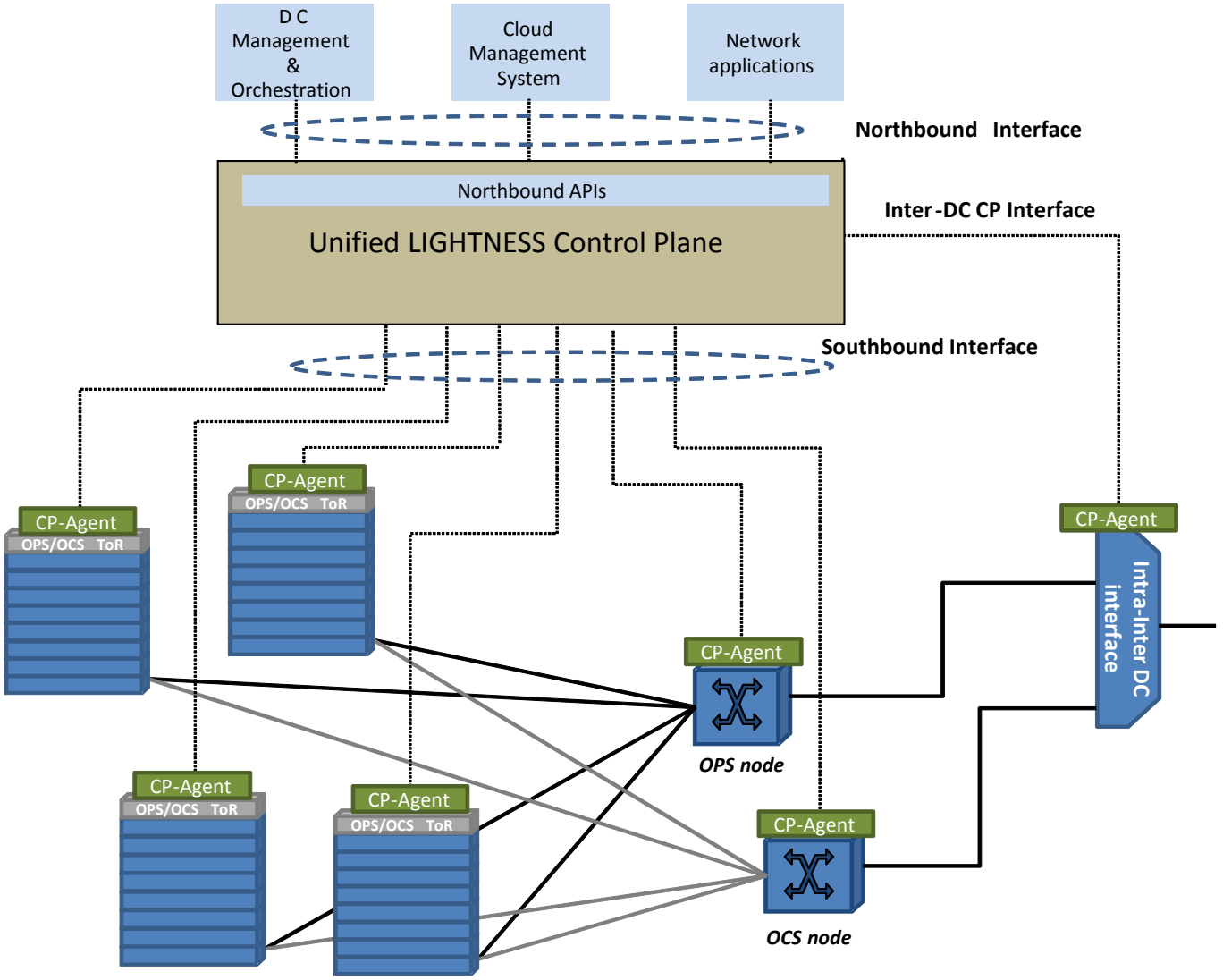


- SDN is a key enabler for network infrastructure virtualization
  - Network **Slicing**
- Physical resource abstraction is needed to compose the VNs
- Independent control and management for the different VNs has to be provided

The LIGHTNESS project

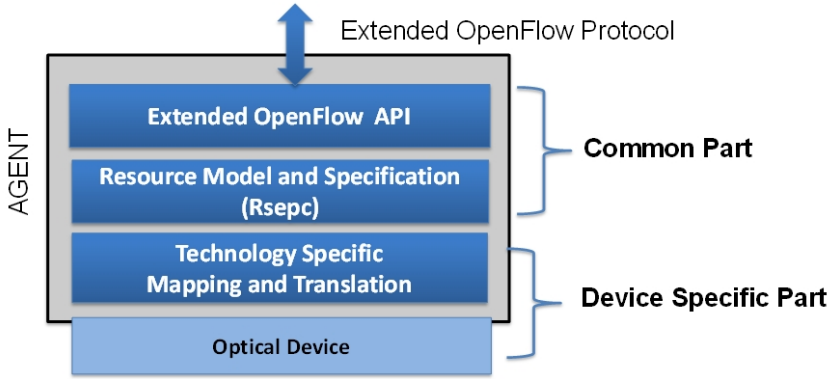
- LIGHTNESS proposed a **novel interconnection network architecture** for intra data center network (**DCN**)
- **Innovation** in three main directions
  - Deploy **optical switching** to overcome limitations of current DCN architectures
    - Static management based on overprovisioning, limited bandwidth due to the used transport technology
    - Bandwidth, latency, energy consumption, etc.
  - Design and develop a **hybrid OPS/OCS flat data center fabric**
    - Nodes: OPS, OCS, Hybrid NIC, optical TOR
  - Design and develop a **unified control plane** for DCNs
    - Leverage on SDN and OpenFlow solution/specs

LIGHTNESS architecture overview



DCN: Optical data plane

- The optical data plane (**DP**) was composed of:
  - Hybrid OPS/OCS Optical NICs equipped in the servers
  - Pure optical TORs
  - OPS
  - OCS
- The OpenFlow protocol was extended to provide SDN-based control to the optical devices
  - OCS: OF v1.0.3 extensions addendum in support of OCS
  - OPS: *Ad-hoc* extensions
- OpenFlow agents were developed for each kind of device

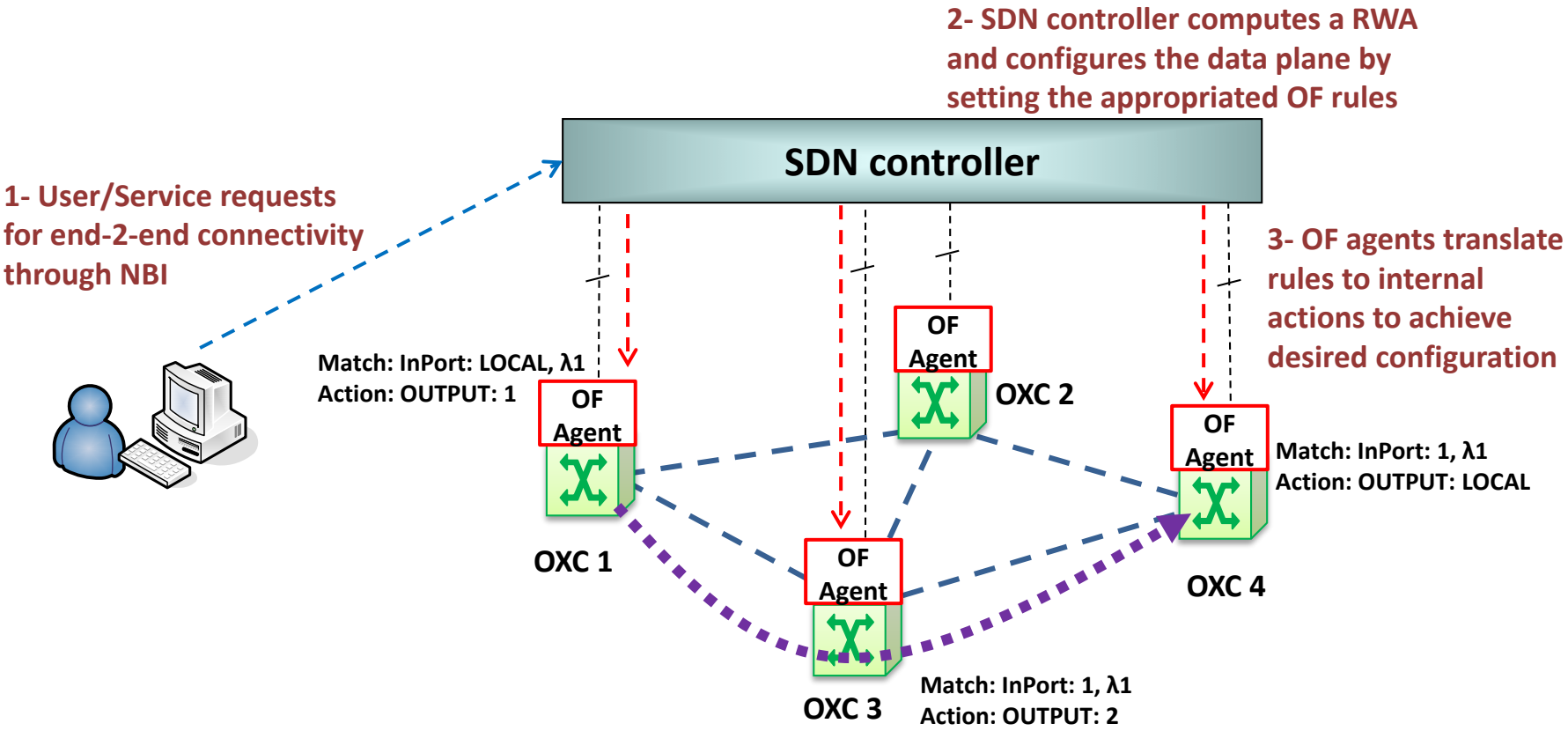


OF extensions in support of the optical DP

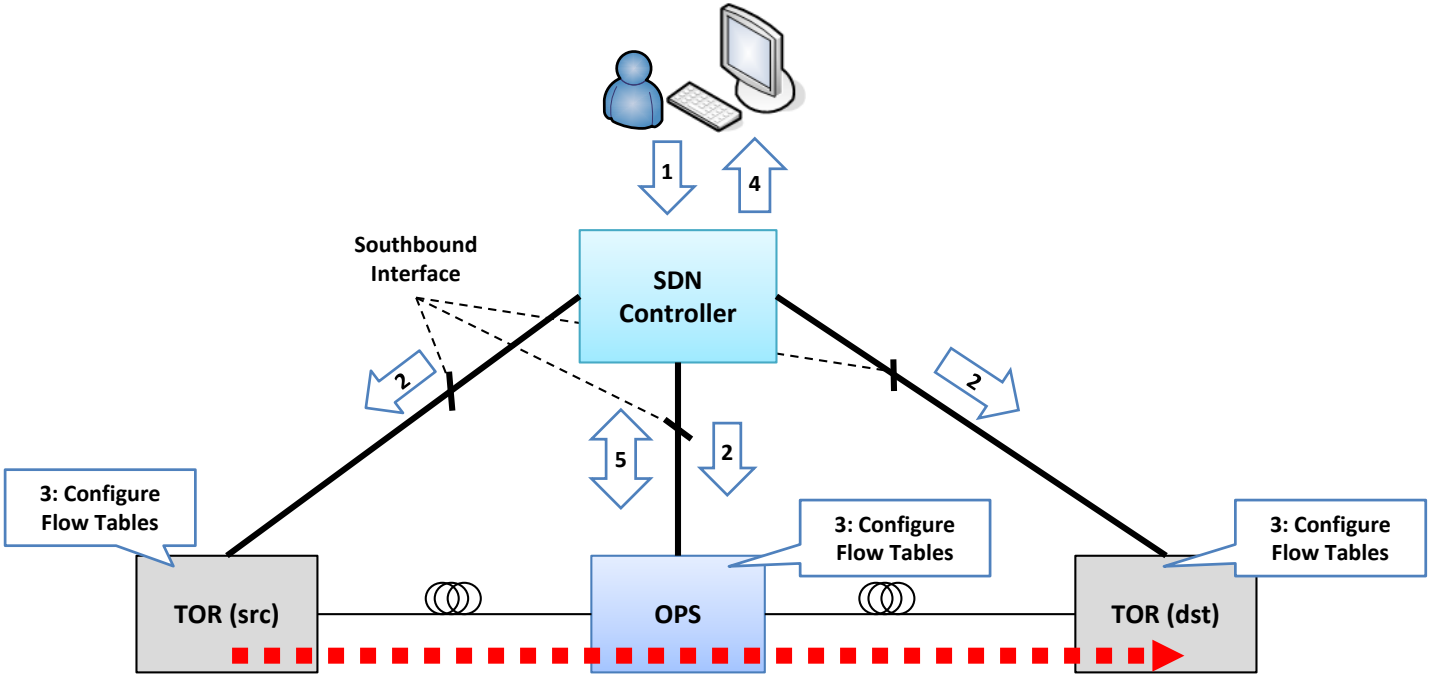
- OCS extensions:
  - Support for optical ports (CPort) → supported wavelengths info, OCS switching capability, …
  - Match is replaced by of_connect structure → in/out ports, wavelength
  - Circuit Flow (CFlow) → New actions (CKT_INPUT, CKT_OUTPUT)
- OPS extensions:
  - Uses CPort
  - New match types: Input Wavelength, optical label
  - New actions: SET_LABEL, SET_LOAD
    - Uses OUTPUT

SDN & OF in OCS networks

- SDN-enabled optical transport network:



SDN-based control for OPS

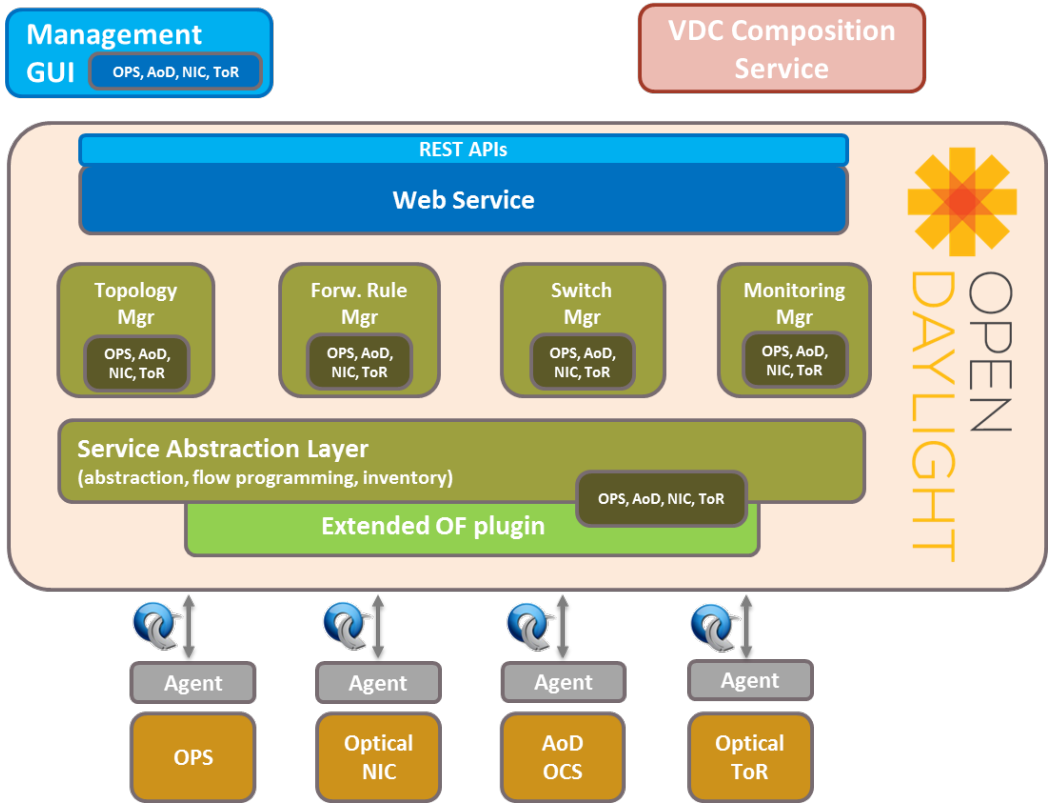


Configuration work flow (Top-down):

1. The user sets up the OPS flow through the GUI of the SDN Controller
2. The Controller computes the route, wavelength an label and sends an OF FLOW_MOD message to the OF-Agents of the TOR and the OPS
3. Each OF-Agent configures the hardware flow tables according to the flow requirements
4. The SDN Controller shows the flow information in the GUI
5. Periodical statistics are requested by the Controller to the OPS node

SDN-based control plane architecture

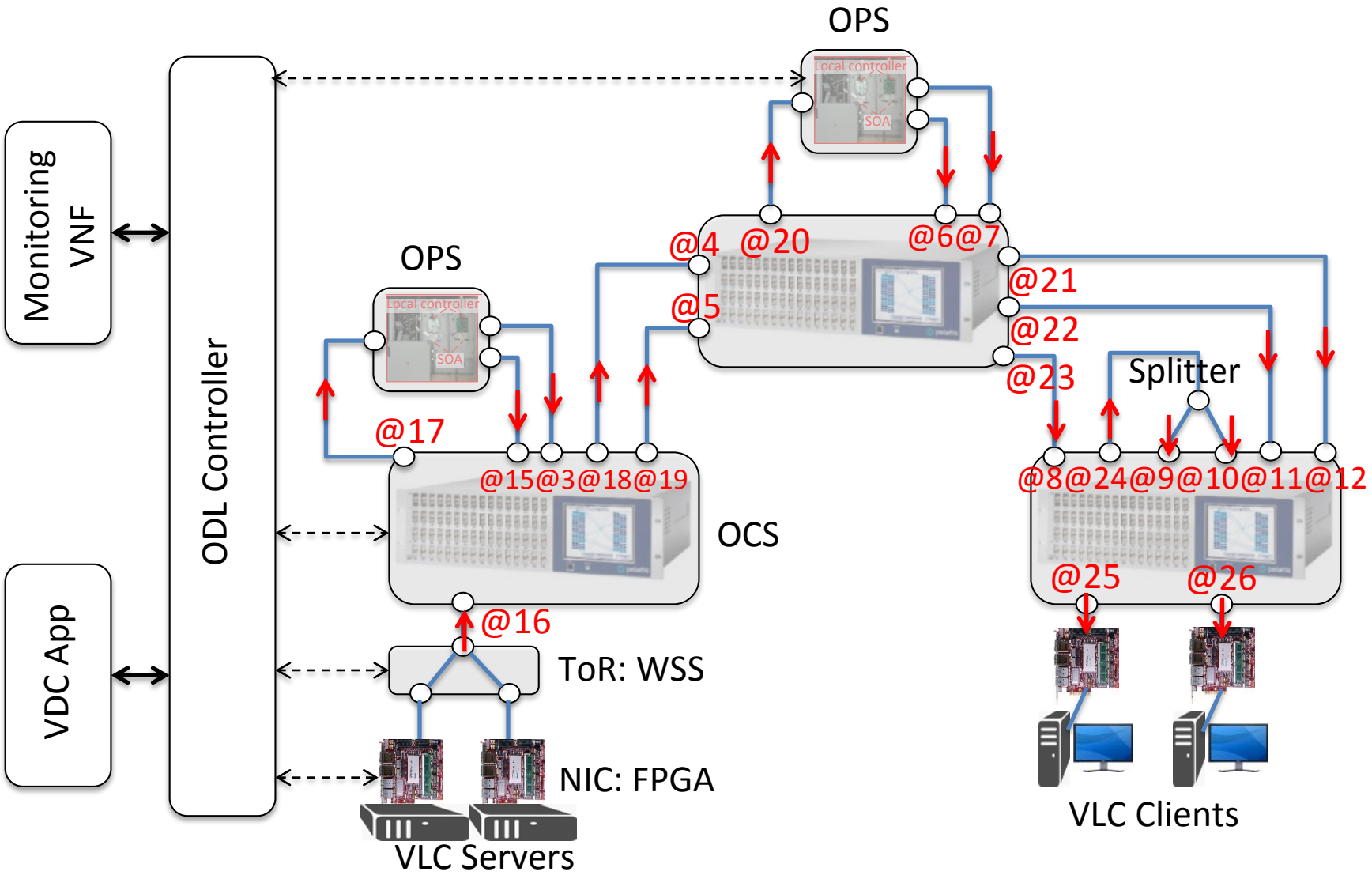
- Based on the **SDN architecture** proposed by the **ONF**
- Specialized, modular and open **Northbound** APIs
- **Extended OpenFlow** at the **Southbound** with dedicated agents
- **OpenDaylight** controller deeply extended in support of optical technologies
- **VDC composition** for virtual slices and topologies provisioning and **monitoring VNF** to guarantee proper **QoS**



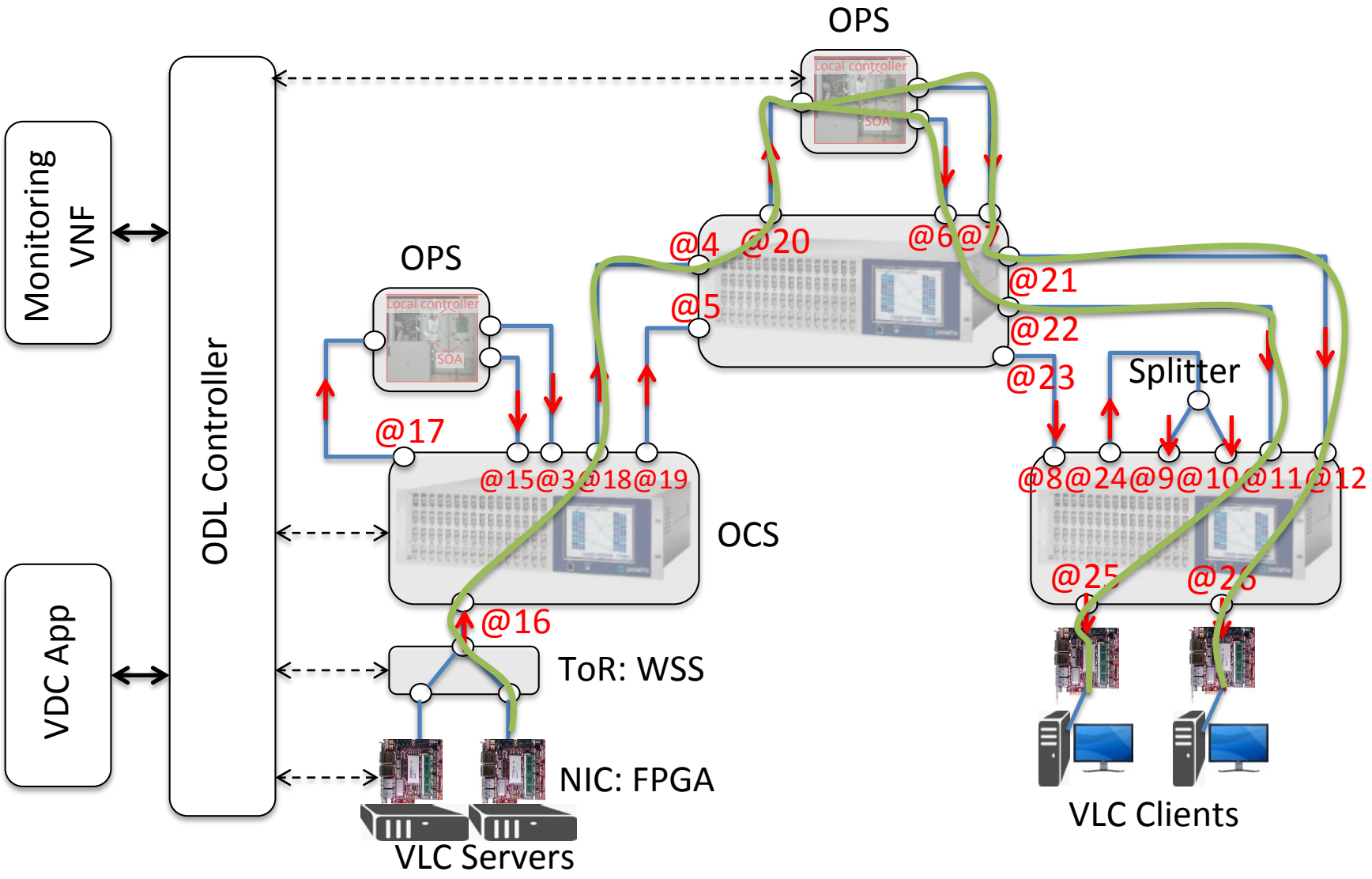
LIGHTNESS final demo

- Scope
  - **Programmable transport and switching** of data flows over the hybrid optical flat DCN
    - Full integration of SDN control plane and optical data plane
    - Optical switches configuration and monitoring through OpenFlow
  - **On demand VDC network provisioning** and **reconfiguration**
    - Creation of **multicast VDC network** using OPS resources
    - Deployment of **monitoring VNF** to retrieve and process status statistics
    - Automated **OCS/OPS and multicast/unicast switch-over**
- Scenario and components
  - End-to-end all-optical network testbed
    - OF-enabled POLATIS OCS switch, OPS switch, FPGA-based hybrid NIC
    - **OpenDaylight** SDN controller
    - **VDC composition** application and **monitoring VNF**

LIGTHNESS final demo set up



LIGTHNESS final demo set up



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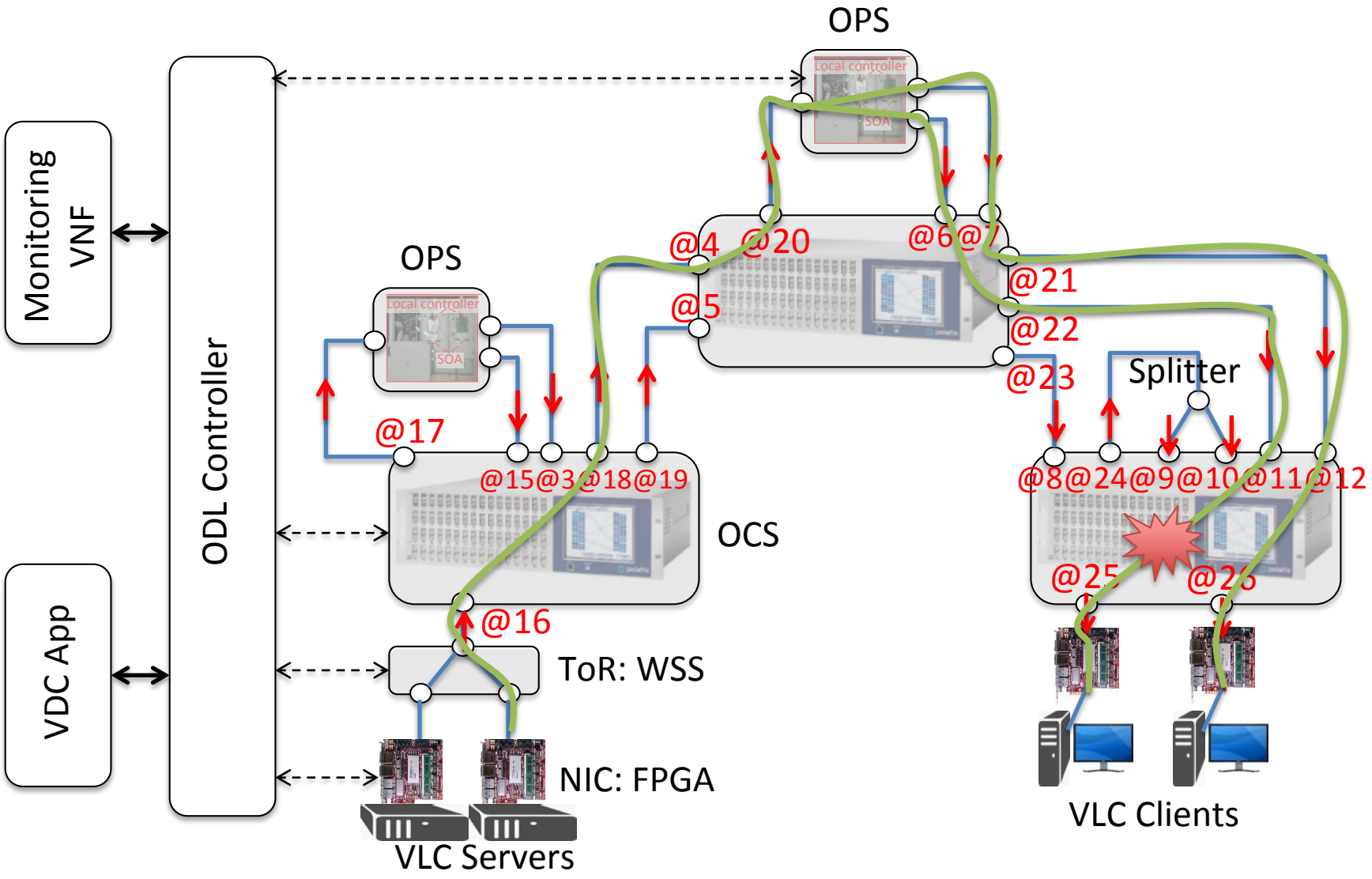

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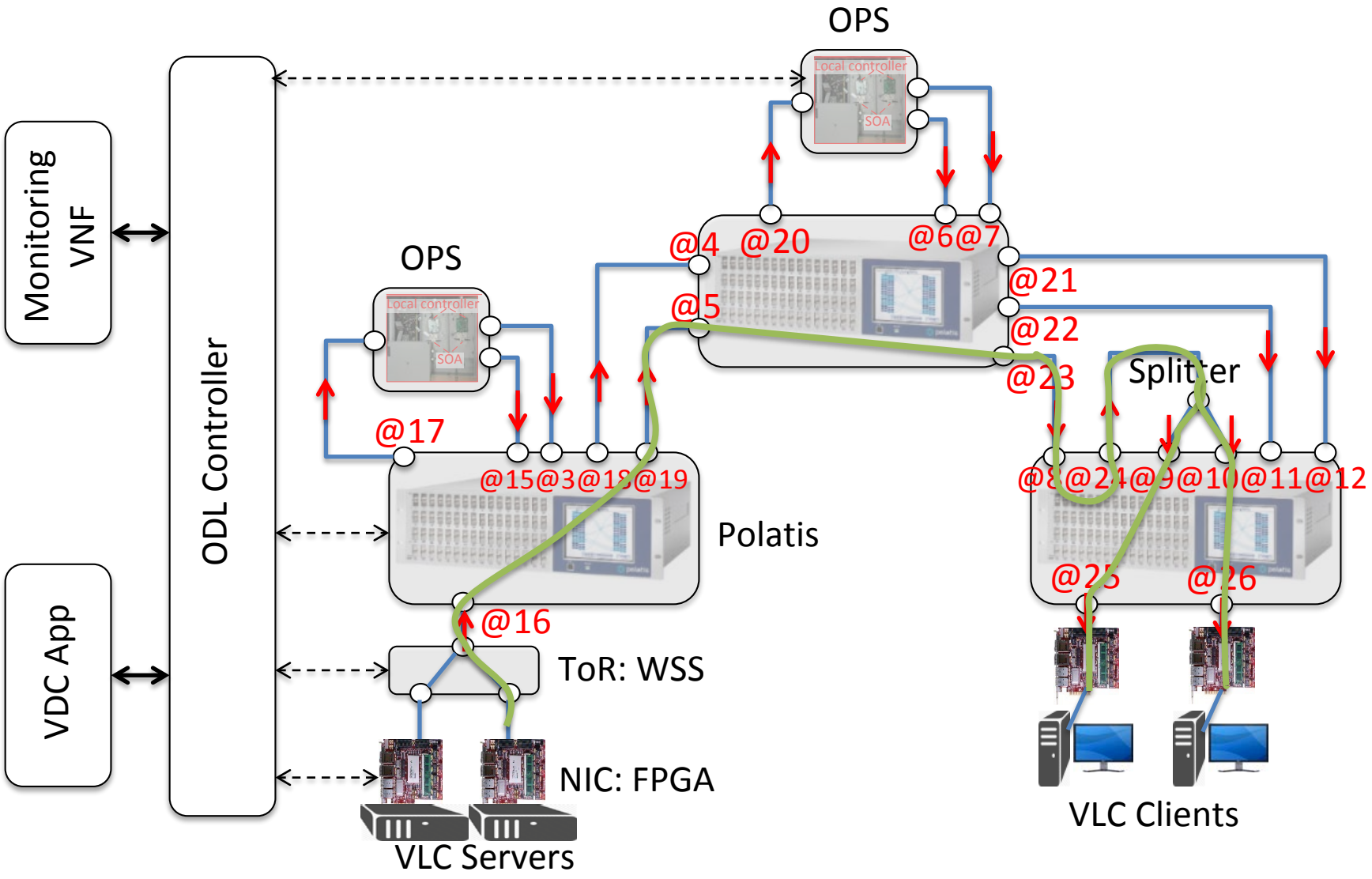


The COSIGN project

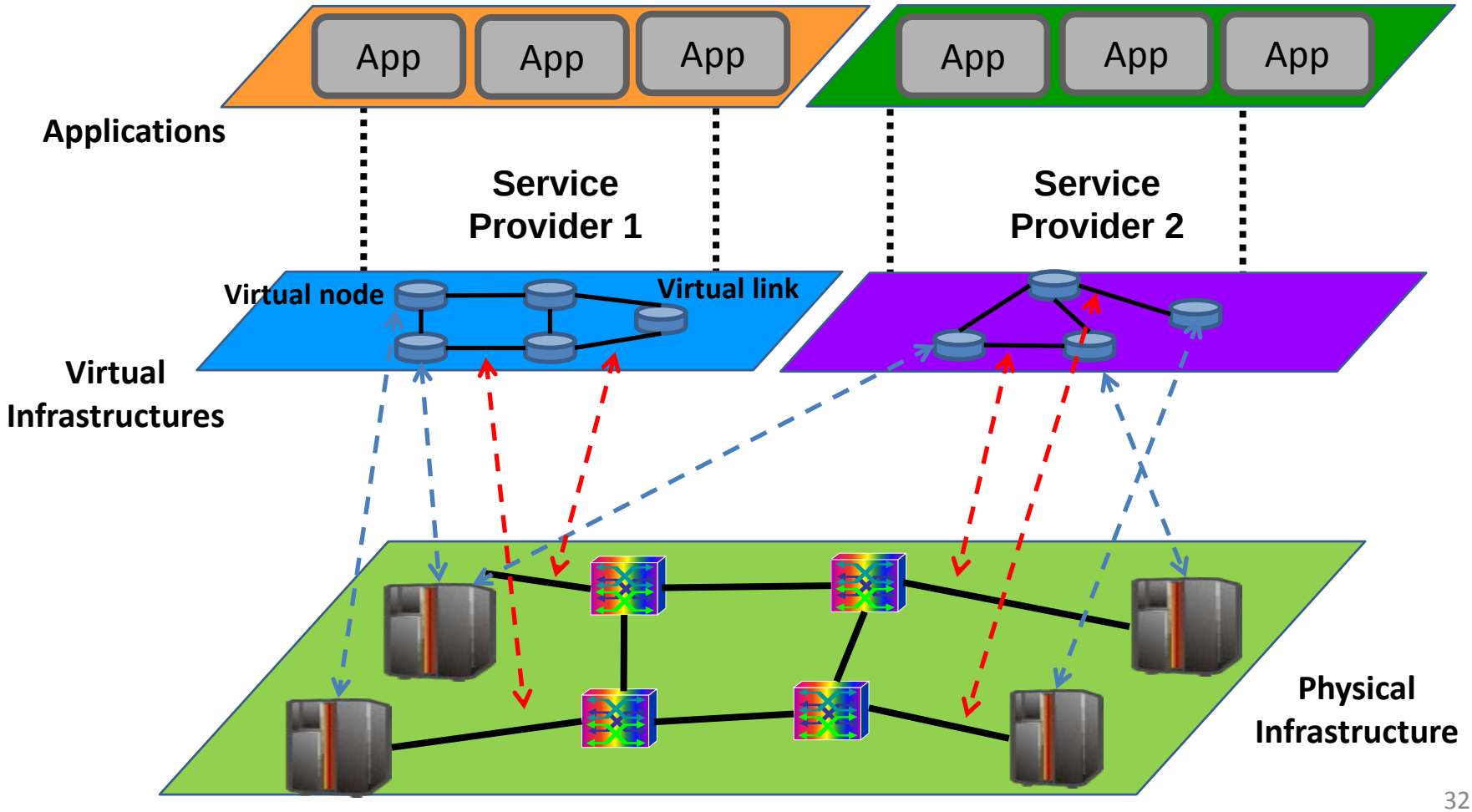
- The COSIGN project provided a **novel DC architecture** using optical technologies for the DCN, a SDN-based control plane and an **Orchestration** plane for coordinated service provisioning
- **Innovation** in three main directions
  - Improved **optical switching technologies** for increased bandwidth, reduced power consumption and high re-configurability
    - **High radix** optically enabled Ethernet switches, **SDM** and **Fast optical switches**
  - Enhanced **SDN controller** for network programmability and dynamic service configuration
  - DC **Orchestrator** to provide **network and IT virtualization** allowing service programmability
    - Joint optical and IT infrastructure orchestration for complex service provisioning → **Virtual Data Center** (VDC) use case

The orchestration layer

- SDN provides an efficient way to configure connectivity services across OF-enabled optical networks, independent of the underlying optical nodes
- However, SDN is not sufficient to achieve an optimization of the network resources
  - Presence of multiple data plane technologies. Which one to choose?
  - Multiple independent SDN-controlled infrastructures. How are resources provisioned across?
    - A global view of the whole infrastructure is needed
  - Provisioning of IT and network resources. How is it coordinated?
    - VDC, Cloud, …
  - Etc.

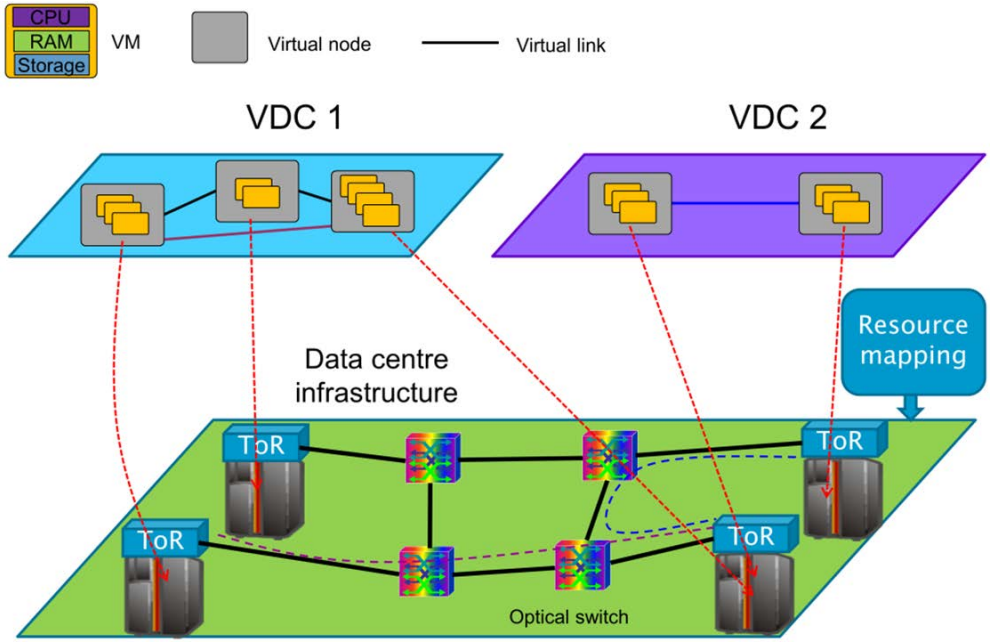
Resource orchestration in optical networks

- Example of IaaS achievable through resource orchestration:



VDC provisioning

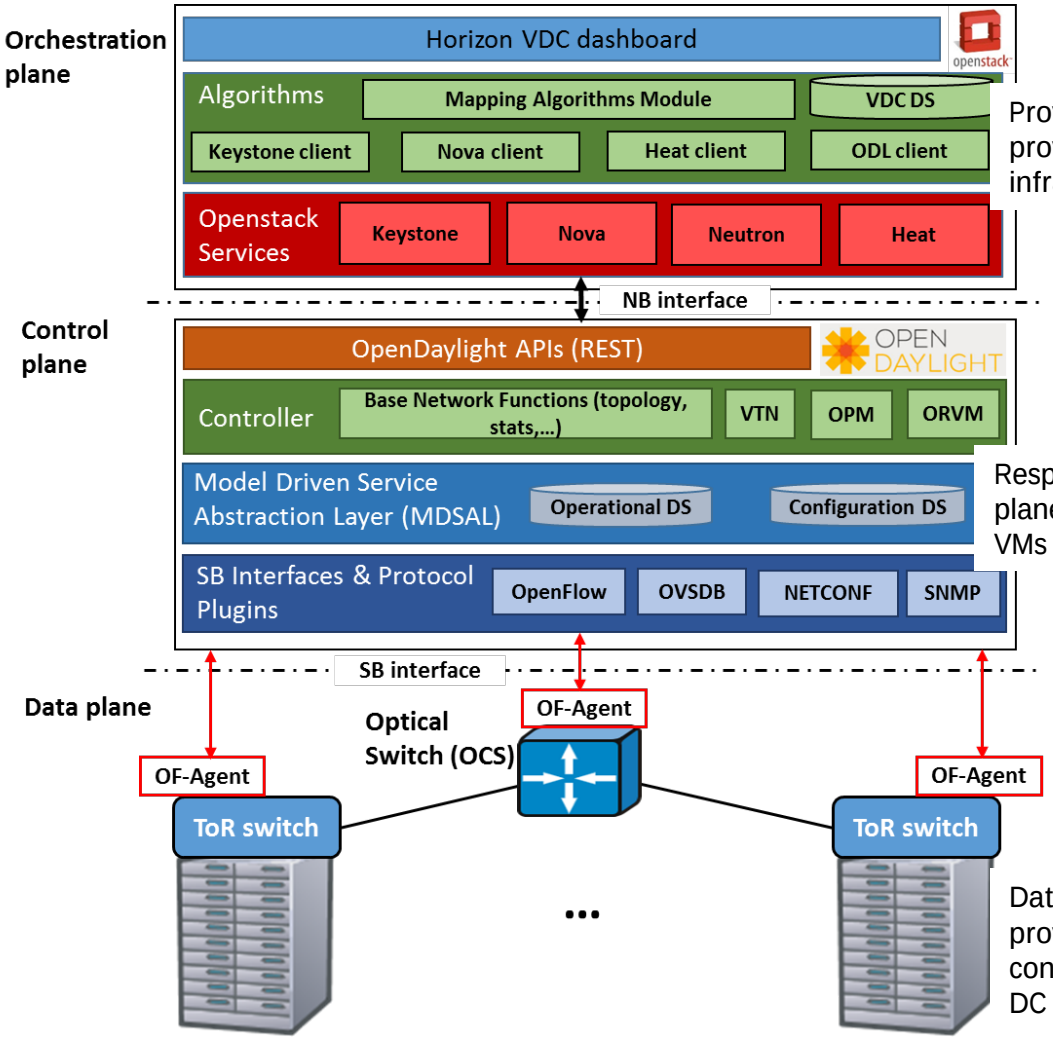
- The **Virtual Data Center** (VDC) has emerged as a service to cope with the **multi-tenancy** requirements faced by the DC operators
- A VDC is a form of Infrastructure as a Service (**IaaS**) where a **tenant** (i.e. DC client) asks for an infrastructure composed of computing capabilities (e.g. Virtual Machines, **VMs**), interconnected through a **virtual network**
- Tenants use the VDC infrastructure as a support to develop their own business models



VDC provisioning

- Virtualization techniques are the foundation of the VDC service
- Upon a VDC request, the provisioning of both VMs and virtual network connecting them must be done
- Such process is complex and entails both the **mapping of VMs onto servers** in the DC and the **virtual links onto physical network resources** in the DC network (DCN)
- In the framework of COSIGN, novel DC solutions that jointly and automatically configure both computing and network resources for efficient VDC provisioning were designed and implemented
- The **Orchestrator** is the key entity in this context

COSIGN architecture overview



Provides functionalities such as coordinated service provisioning according to the status of the physical infrastructure and the requests coming from external users

Responsible for configuring the network devices of the data plane to setup high-capacity connectivity services between VMs

Data plane based on optical switching technologies that provide high-bandwidth, low-latency and low-power consumption connectivity between servers and ToRs in the DC

COSIGN SDN controller

- The control plane is based on **OpenDaylight** (ODL) SDN platform in its Lithium release
- ODL was extended to control and configure the optical DCN
  - OCS extensions implemented in the OF protocol and the OF plugin of ODL
  - Extended to support optical data plane infrastructure
    - Inventory, Topology Manager, Optical Provisioning Manager, Path Computation Manager
  - Extended to support pure optical transmission devices virtualization
    - Optical Resource Virtualization Manager
  - Extended Northbound connectivity to the Orchestration layer for VDC provisioning
    - Neutron, Virtual Tenant Network

COSIGN Orchestrator

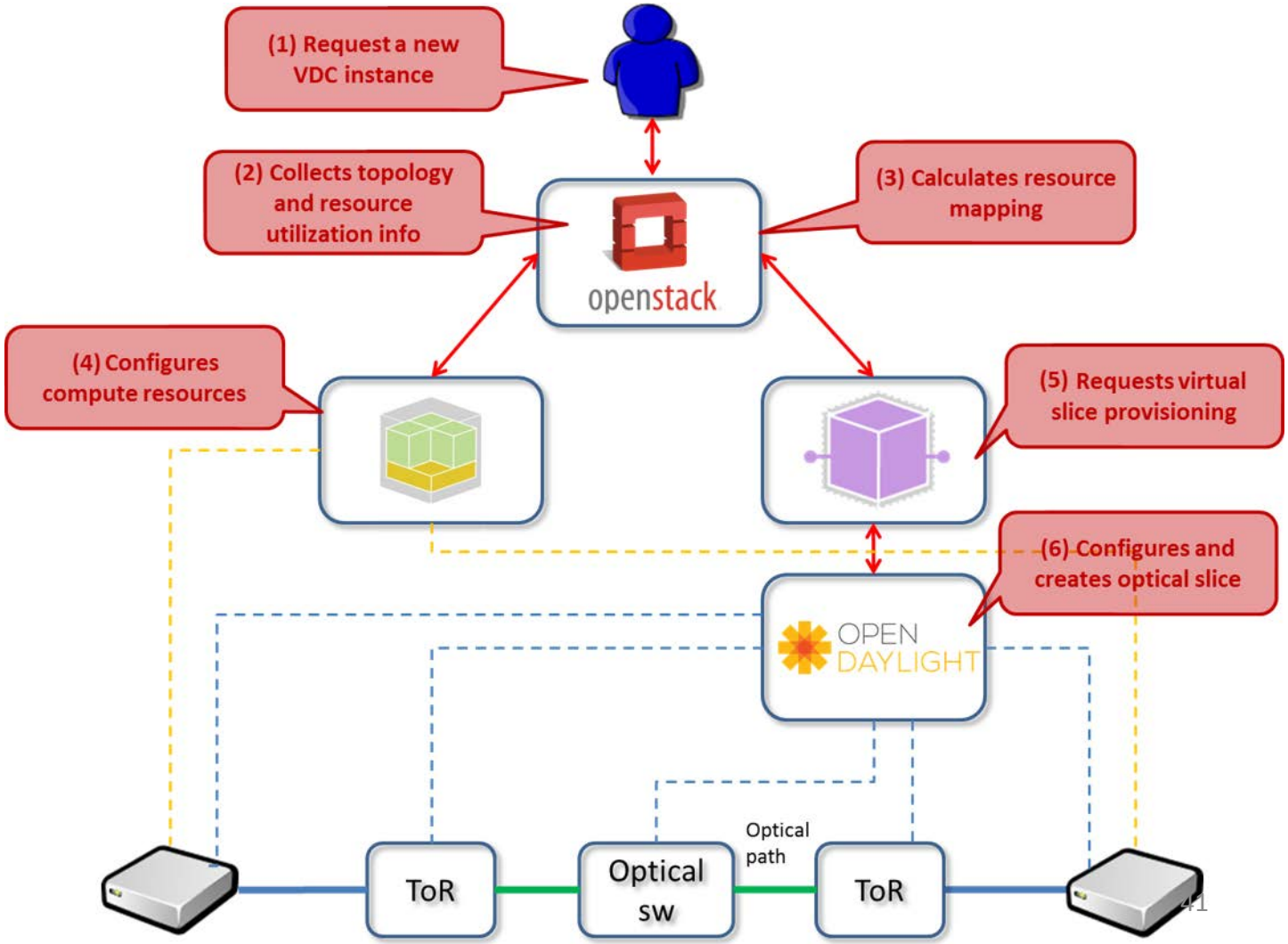
- Based on **OpenStack**:
  - Horizon service for the VDC dashboard
  - Nova service for VM configuration
  - Neutron service for IP network configuration
  - Heat service for stack orchestration
- A new Algorithms module was specially designed and integrated in the architecture:
  - It implements several algorithms that compute the optimal mapping of the VDC resources onto physical DC resources: servers for the VMs and optical resources for the virtual network
  - Several RESTful servers and clients were implemented for the communication between the algorithms and OpenStack core services

Live VDC provisioning demonstration

- COSIGN designed and implemented an OpenStack-based orchestrator plus an SDN-enabled controller allowing for the creation of VDC slices on top of a physical optically interconnected DC infrastructure:
- To showcase the full workflow involving the whole COSIGN architecture, live provisioning of several VDC instances (**stacks**) where performed in aims to highlight the following:
  - Full dynamic, automated and transparent deployment of VDC instances
  - Enhanced graphical specification of VDC instances
  - Automated stack creation and mapping thanks to the Algorithm module
  - On-demand configuration of optical paths thanks to ODL controller
  - Exploitation of the multi-technology optical data plane
  - Simple and on-demand tear-down of deployed VDC instances

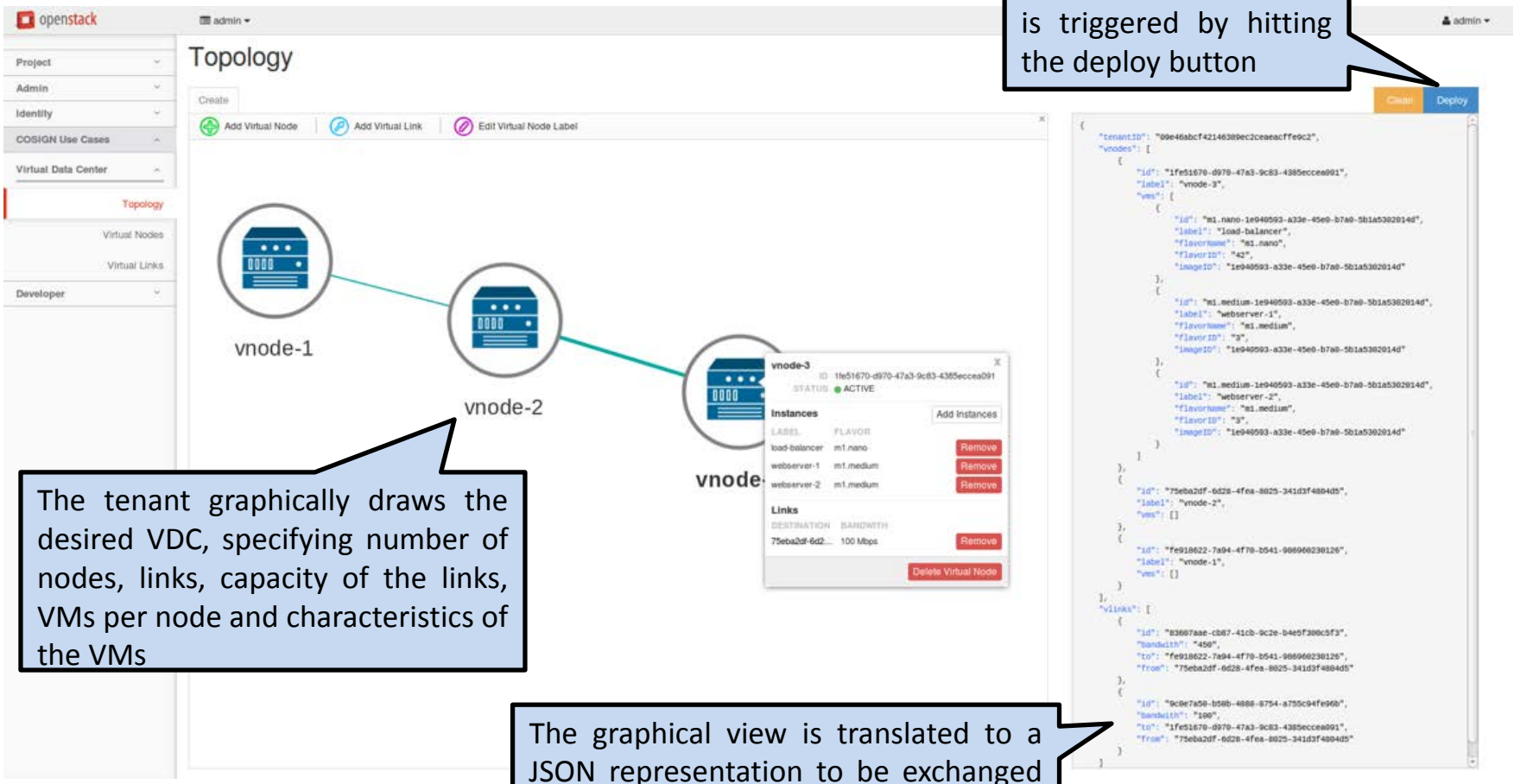
Live VDC provisioning demonstration

- Overall VDC provisioning workflow:



Live VDC provisioning demonstration

- The VDC provisioning process starts at the extended Horizon dashboard:



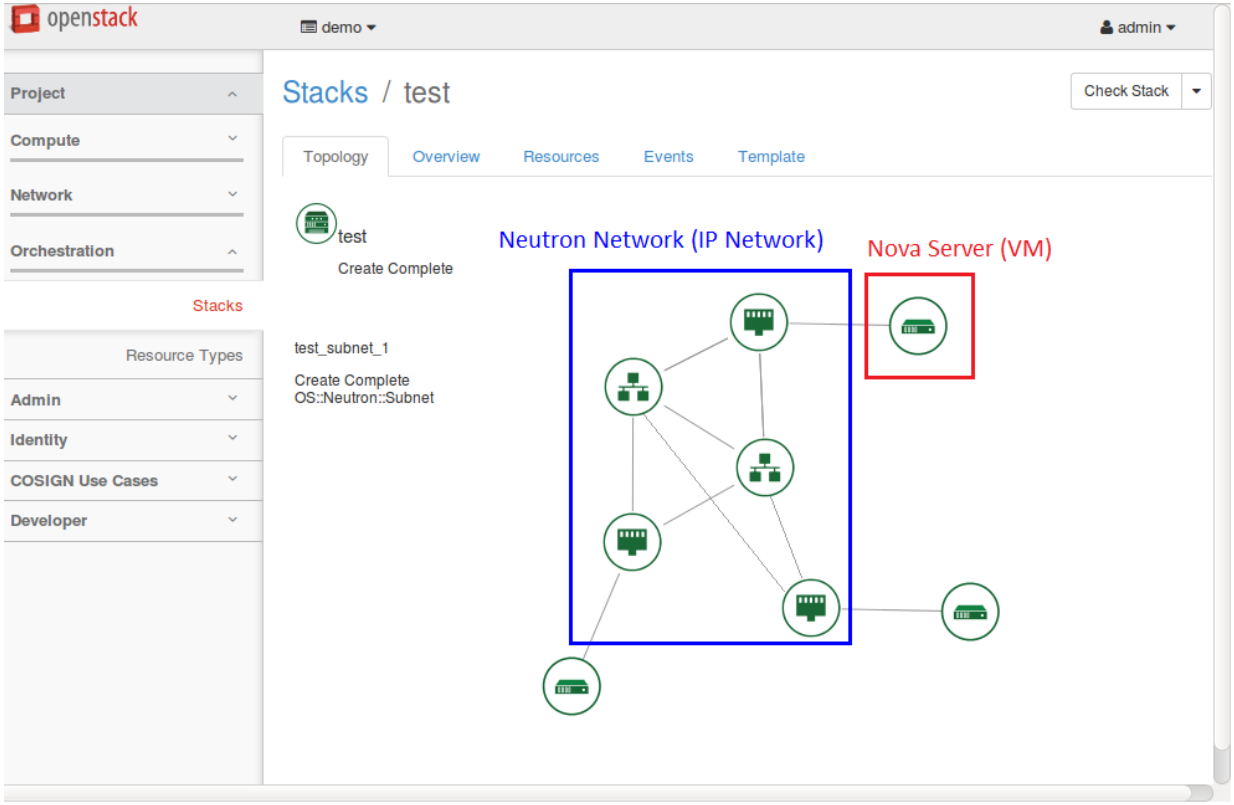
Finally, the provisioning is triggered by hitting the deploy button

The tenant graphically draws the desired VDC, specifying number of nodes, links, capacity of the links, VMs per node and characteristics of the VMs

The graphical view is translated to a JSON representation to be exchanged with lower modules/layers

Live VDC provisioning demonstration

- At the end of the process, the full stack has been created automatically (network + IT), with VMs being able to exchange information thanks to the configured optical routes:



Example of VDC stack

Live VDC provisioning demonstration

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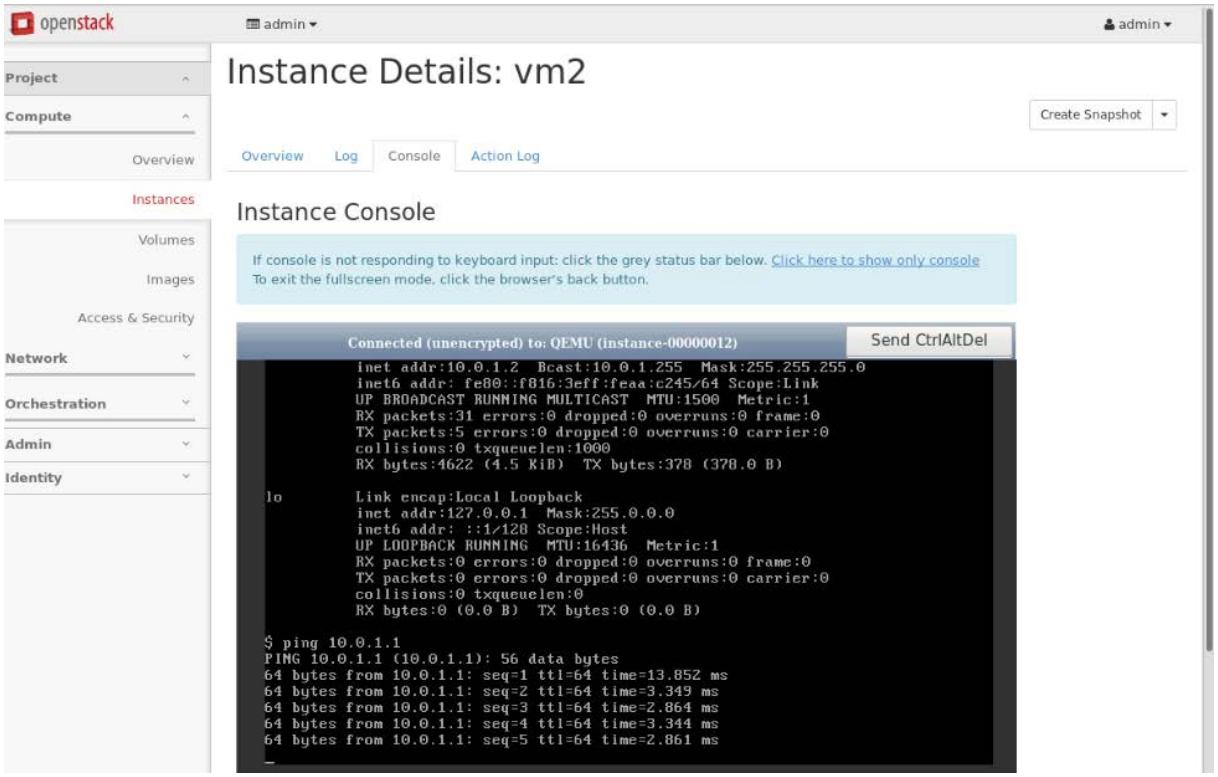
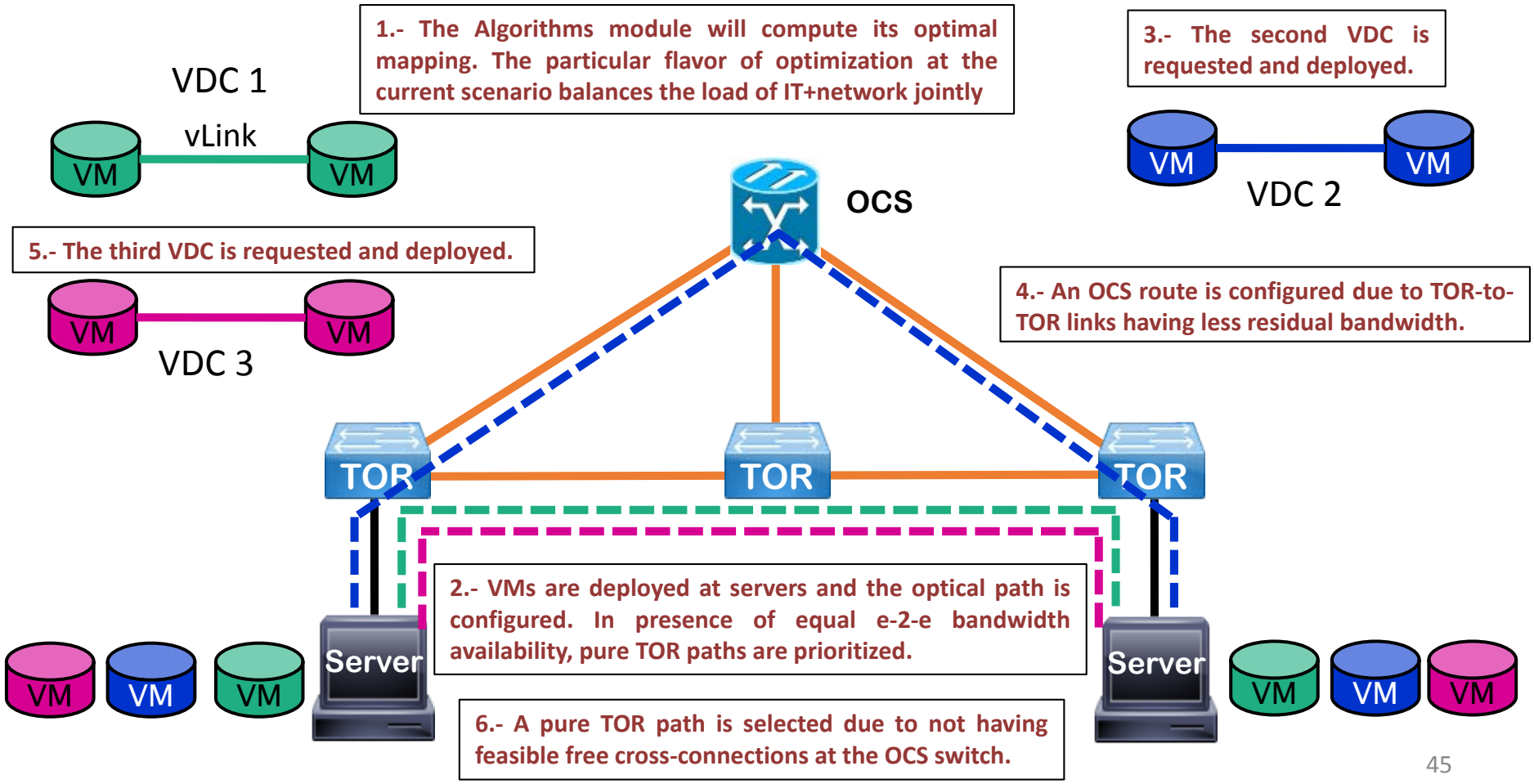


Ping exchange between VMs at a created VDC instance

Live VDC provisioning demonstration

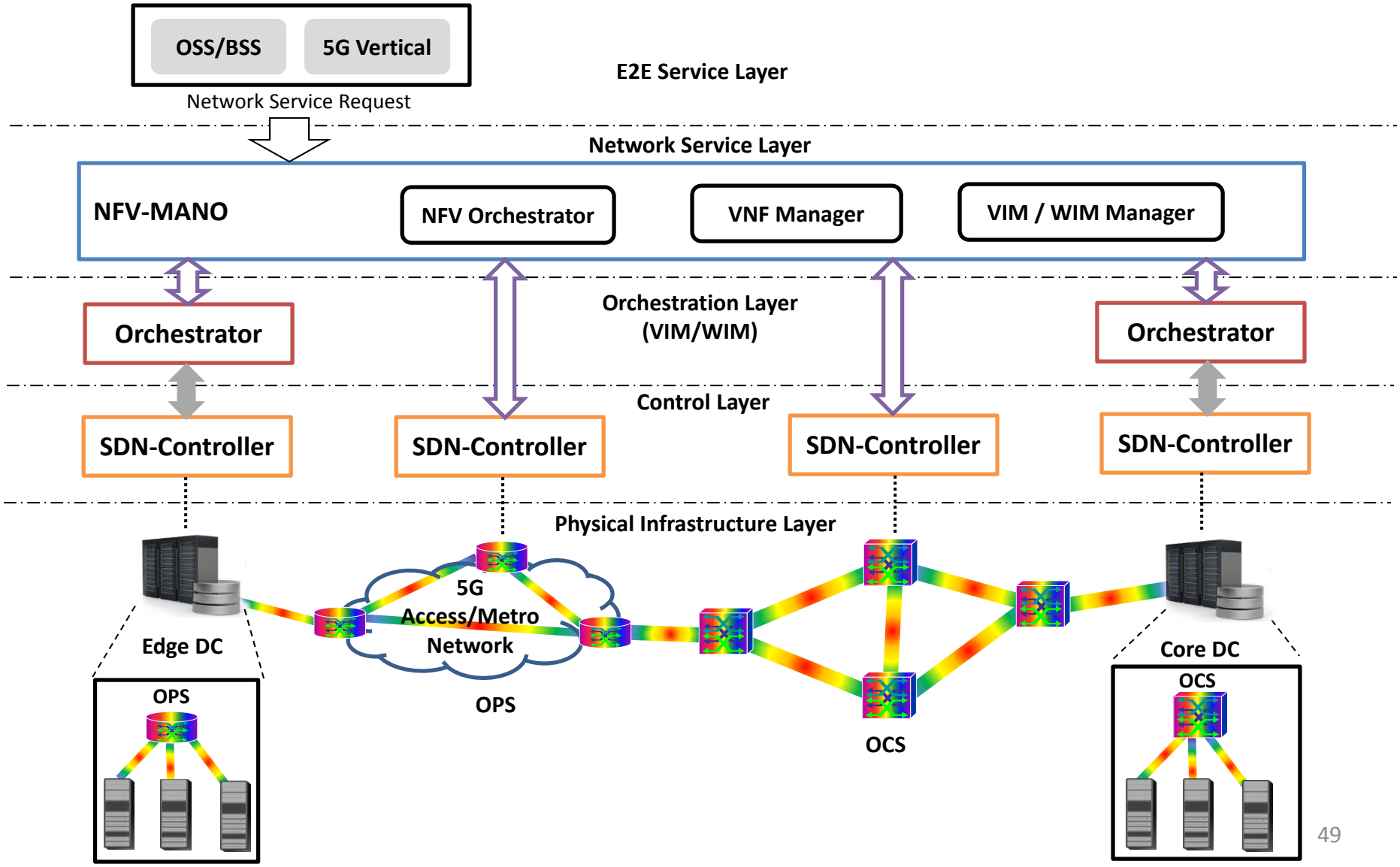
- Several concurrent VDC instances were deployed, each one representing requests from different tenants:



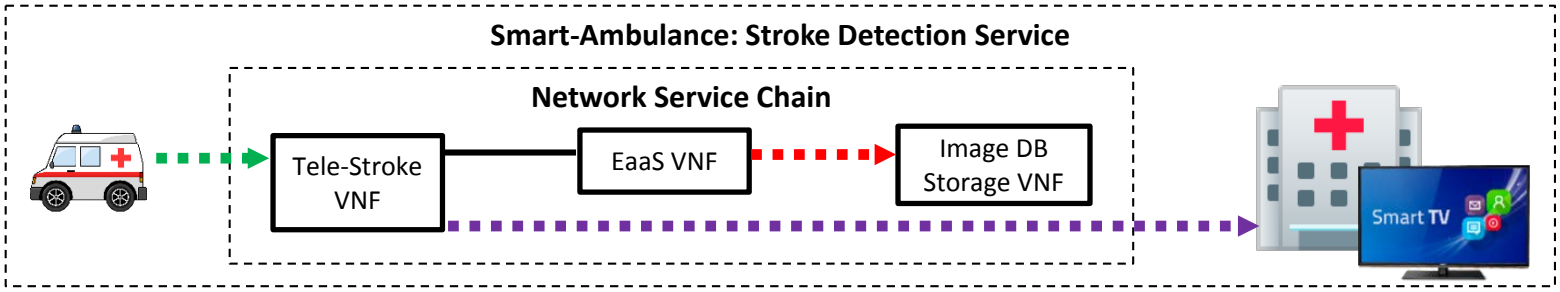
Conclusions

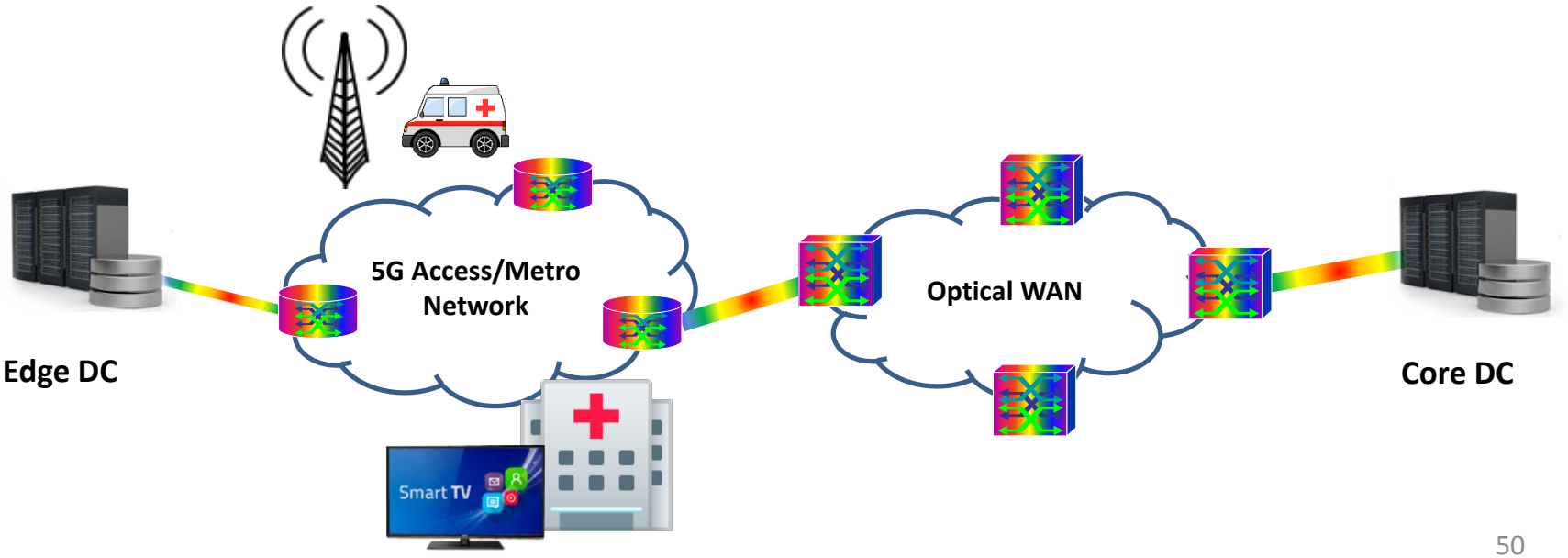
- Optical transport technologies are applied to the DCN infrastructure to cope with the requirements of current and forth-coming applications
- SDN has been presented as a valid paradigm to implement the control of such networks
- Two practical use cases have been presented
  - The LIGHTNESS project demonstrated an implementation of the SDN-based control of a hybrid OCS/OPS DCN to provide virtualized DCN infrastructures → Foundations for the Network Slicing
  - The COSIGN project demonstrated a fully orchestrated optical DC infrastructure → The VDC Use Case paved the way for the NFV-MANO and End-to-End Slicing (5G)

NFV MANO over an optical infrastructure



5G services over an optical infrastructure





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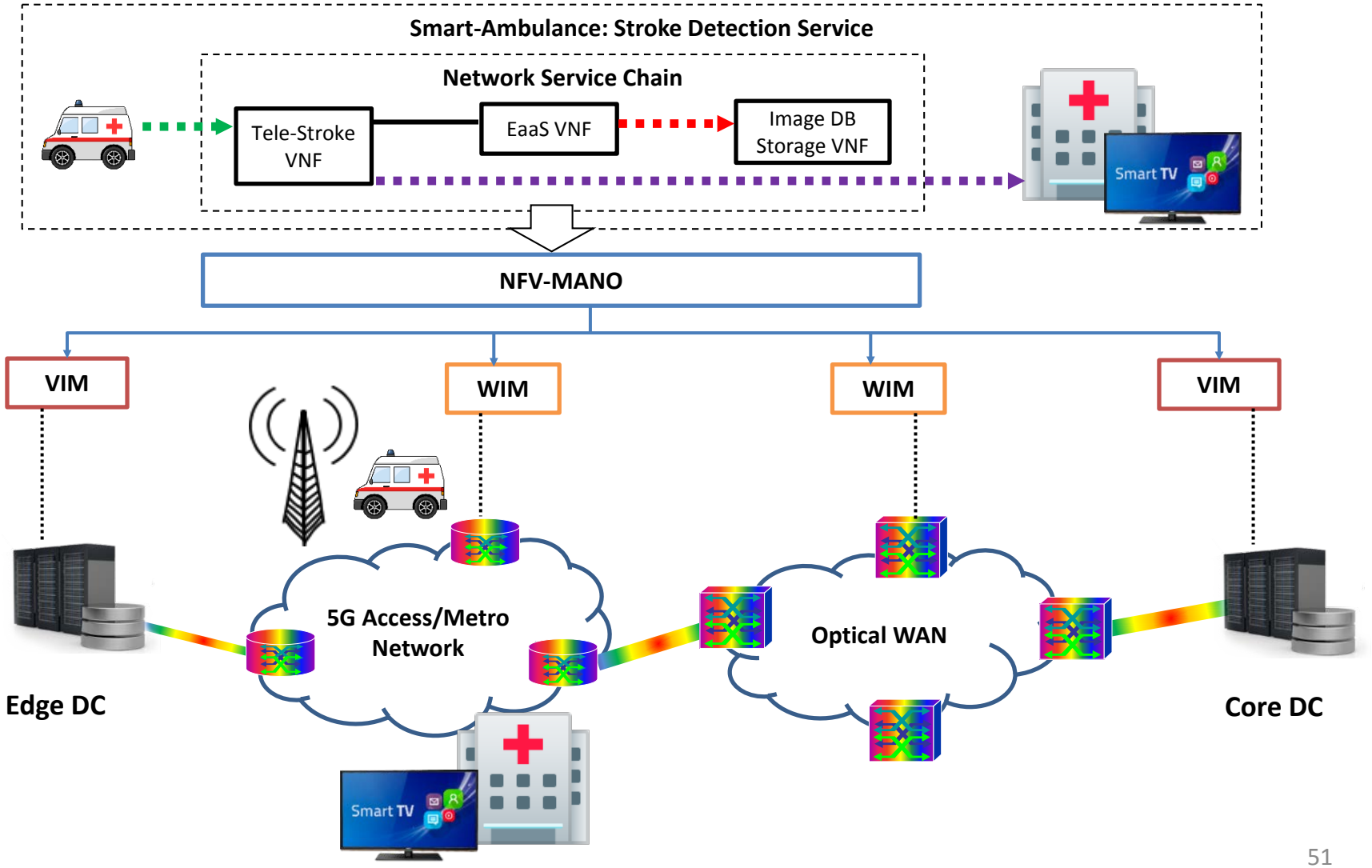

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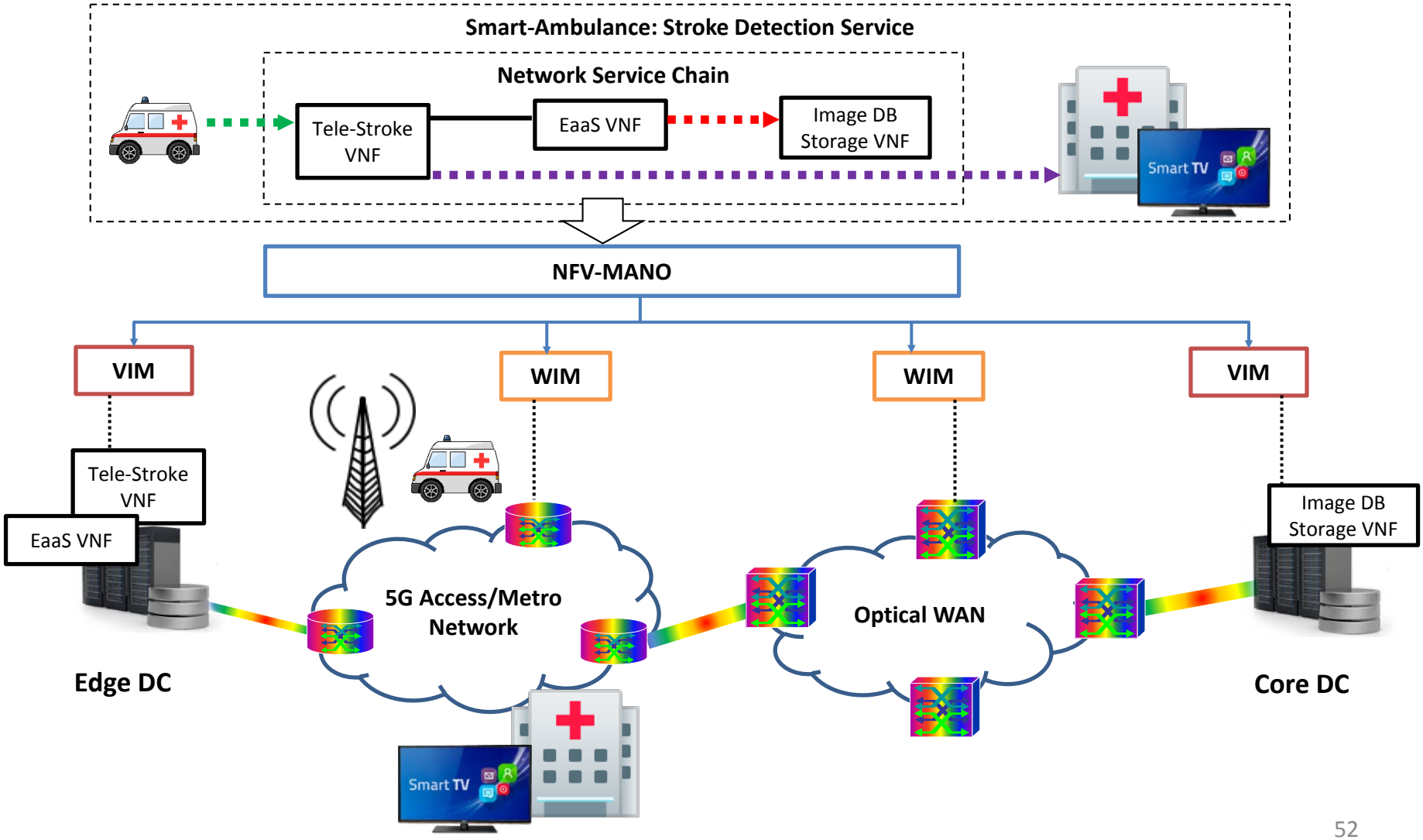

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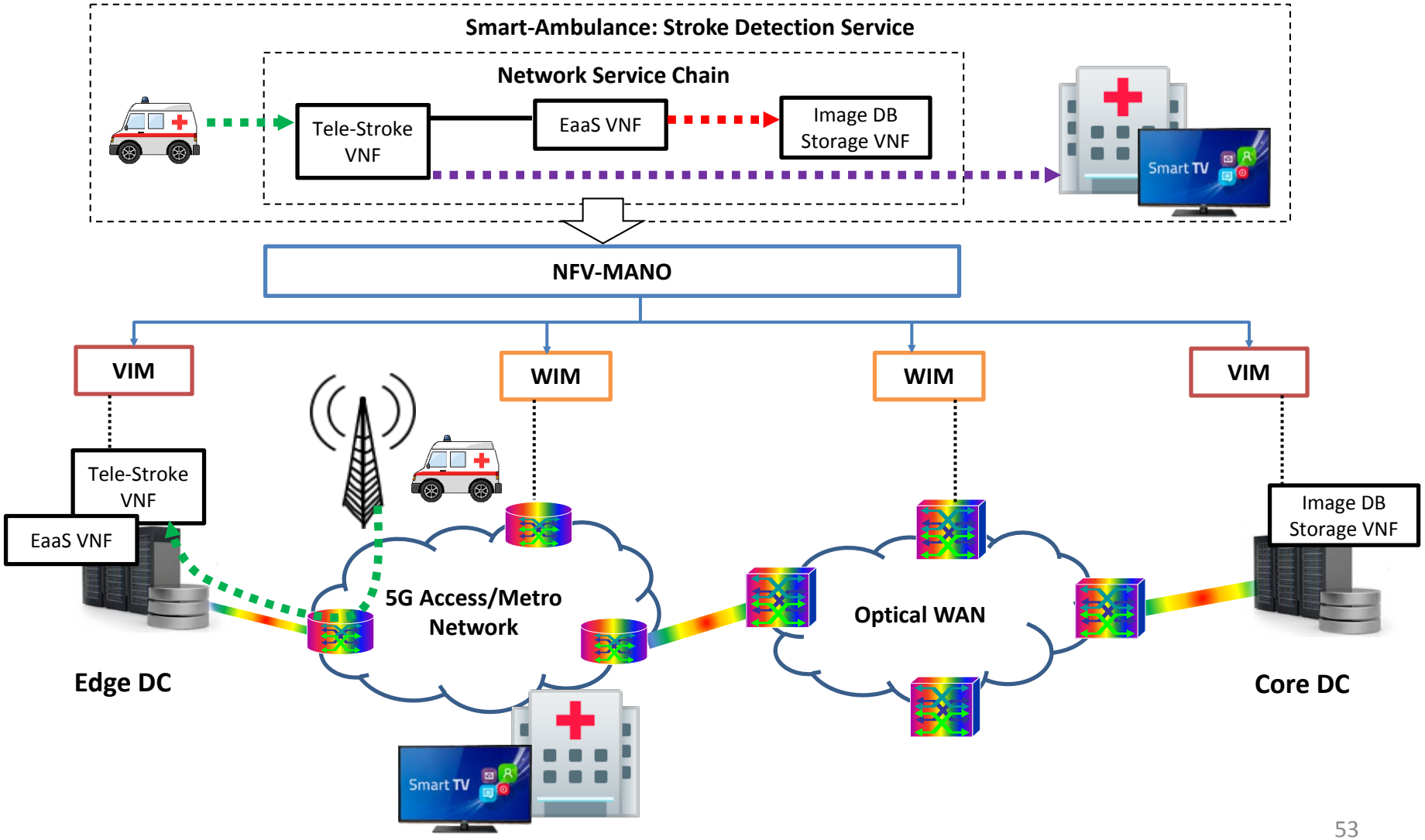

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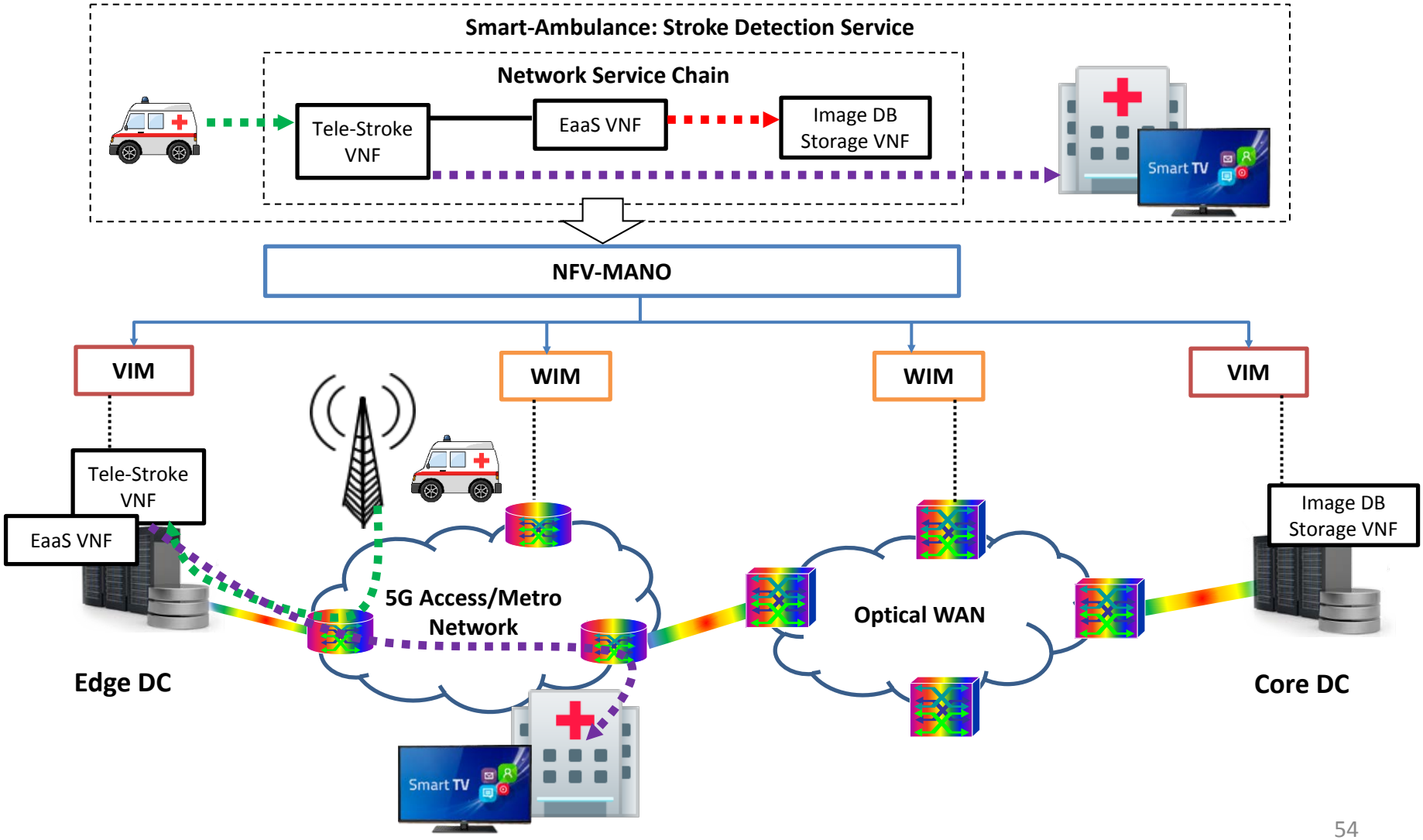

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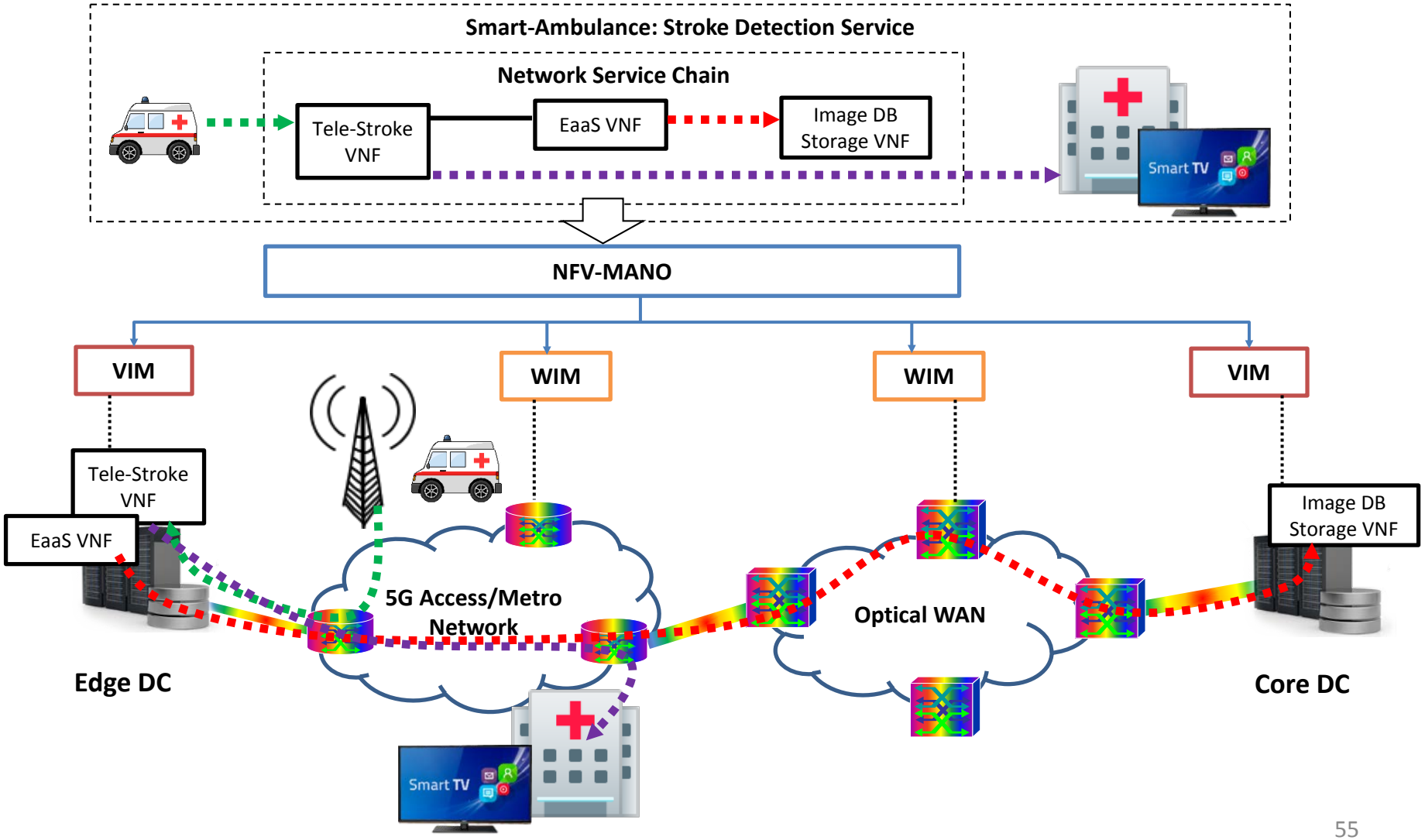

References

- Open Networking Foundation (https://www.opennetworking.org)
- OpenDaylight project (https://www.opendaylight.org)
- OpenStack (https://www.openstack.org)
- EU FP7 LIGHTNESS project (http://www.ict-lightness.eu)
- EU FP7 COSIGN project (http://www.fp7-cosign.eu)
- ETSI NVF Standards (http://www.etsi.org)
- EU H2020 SLICENET project (https://slicenet.eu)

Thank you!

Questions?

Fernando Agraz (agraz@tsc.upc.edu)

Future Internet Networks (FINE)

Master in Innovation and Research in Informatics (MIRI)