



Tutorial We4D.1: Moving the Network to the Cloud: Multi-Tenant and Multi-Service Cloud Central Office

Marco Ruffini



Summary

- Some history of programmable networks:
 - from active networks to Openflow
- Network virtualisation:
 - from Network function virtualisation to the cloud central office
 - CORD, ONAP, OPNFV,...
- SDN, NFV, cloud-CO application to future networks
 - Future wireless/optical/cloud use cases
 - Joint fixed/mobile orchestration enabled by virtualisation
- Optical layer disaggregation
 - Open Line system, OpenROADM, ONF Open and Disaggregated Transport Network (ODTN), use of machine learning.
- Future challenges

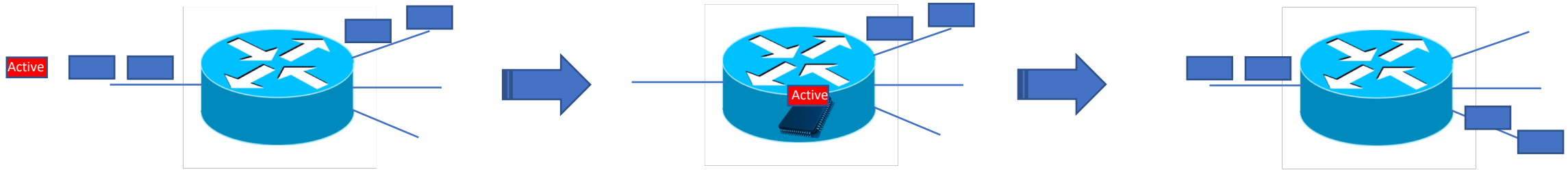
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History of programmable networks:

1) Active Networks

- Ideas on programmable networks date back to the late '90
- Active networks was one of the first (SwitchWare, Smart Packets, NetScript):
 - Network nodes would expose resources through programming interfaces
 - Packets entering nodes could carry code that would change the behaviour of the router
 - This could be achieved in band (capsule model) or out of band (programmable router model)

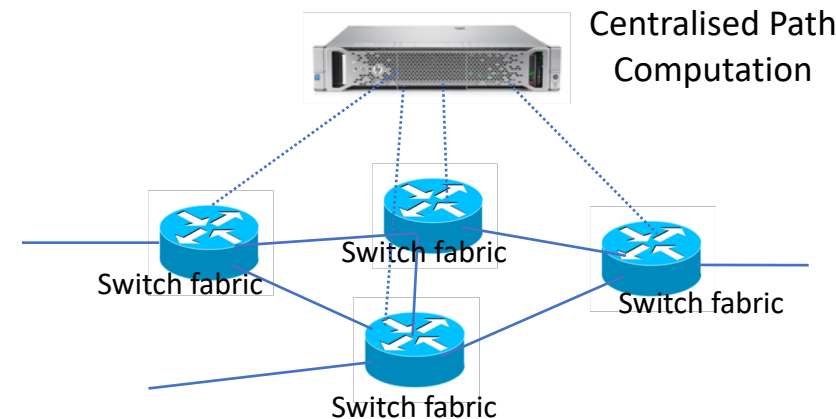
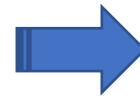
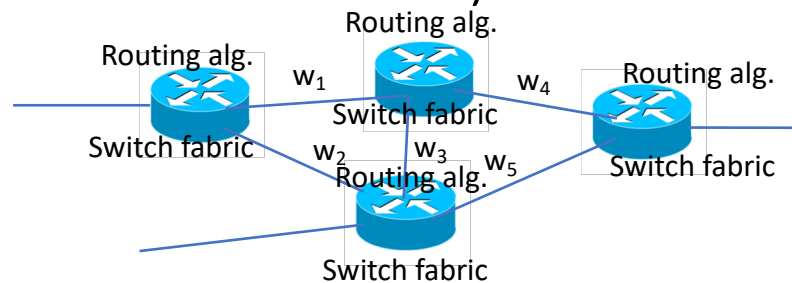


- Interesting to examine drivers (compare them to SDN):
 - Technology: cost reduction of processing power in routers, new programming languages
 - Usage: reduce long provisioning times of legacy technology, unify control of middle boxes (firewalls, proxies,...)

History of programmable networks:

2) Separation of control and data planes

- This occurred at the beginning of decade 2000s
- Development of open interfaces between control and data plane (e.g., IETF Forwarding and Control Element Separation - ForCES)
- Development of centralized network control (Routing Control Platform - RCP, SoftRouter, Path Computation Element - PCE)



- Drivers:
 - Technology:
 - hardware (ASIC) data plane implementation already started separation with software control plane;
 - Commodity GPP has more memory and power than dedicated router processors
 - Use: demand for higher capacity leads operators to seek more control for traffic engineering
 - Users requiring services such as VPNs..
 - Legacy techniques of changing link weight to influence distributed routing protocols suboptimal and unpredictable
 - MPLS being developed to create tunnels that could be centrally organized

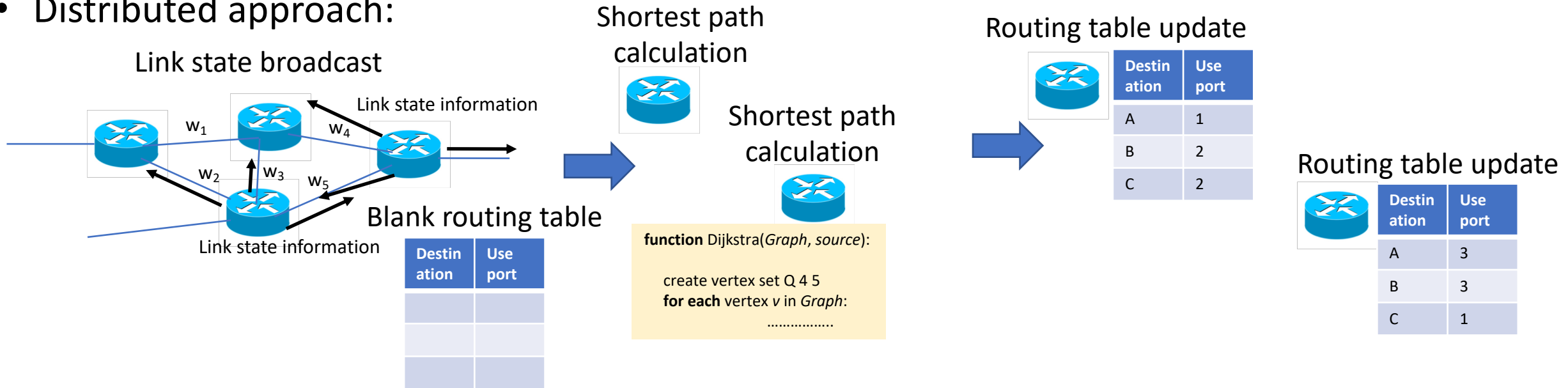
History of programmable networks:

3) OpenFlow

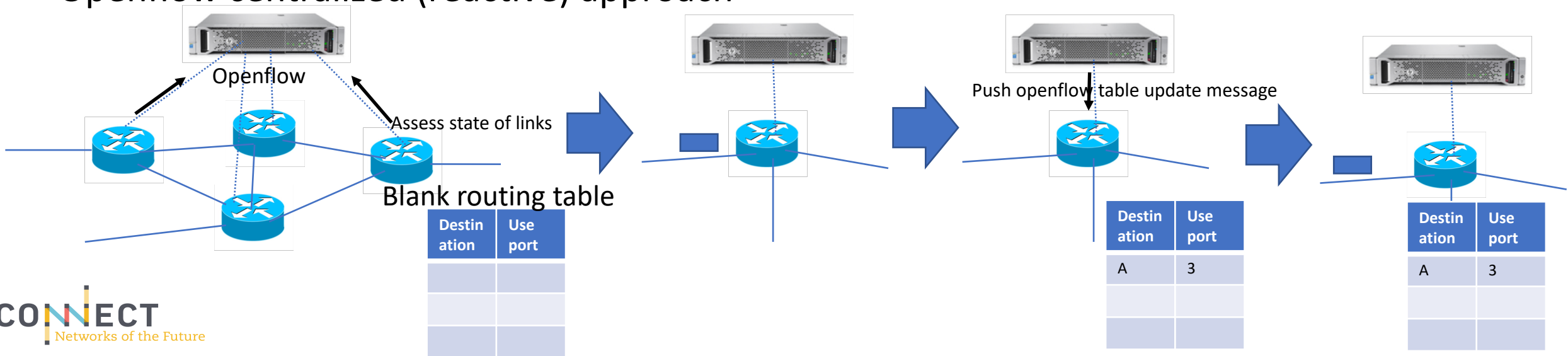
- OpenFlow succeeded in trade-off between full programmability and real-world deployment
 - Use of existing switch hardware (merchant silicon)
 - Fast moving move from academic to industry/application environment
 - API between control plane software (opensource as NOX, POX) and switch hardware:
 - Allowed basic functionalities such as: Pattern matching, counters, actions...
 - Several developments since first release in 2009, to include meter tables, pipeline of tables, addition of optical interfaces, etc.
- Drivers:
 - Technology:
 - availability of merchant silicon (same chip for several manufacturers)
 - OpenFlow initially only required firmware upgrade
 - Use: Data centre community could use software engineers to write network control code (gained more control and quicker development time)
 - Controlled environment (homogeneous network, one domain, controlled traffic)

OpenFlow example

- Distributed approach:

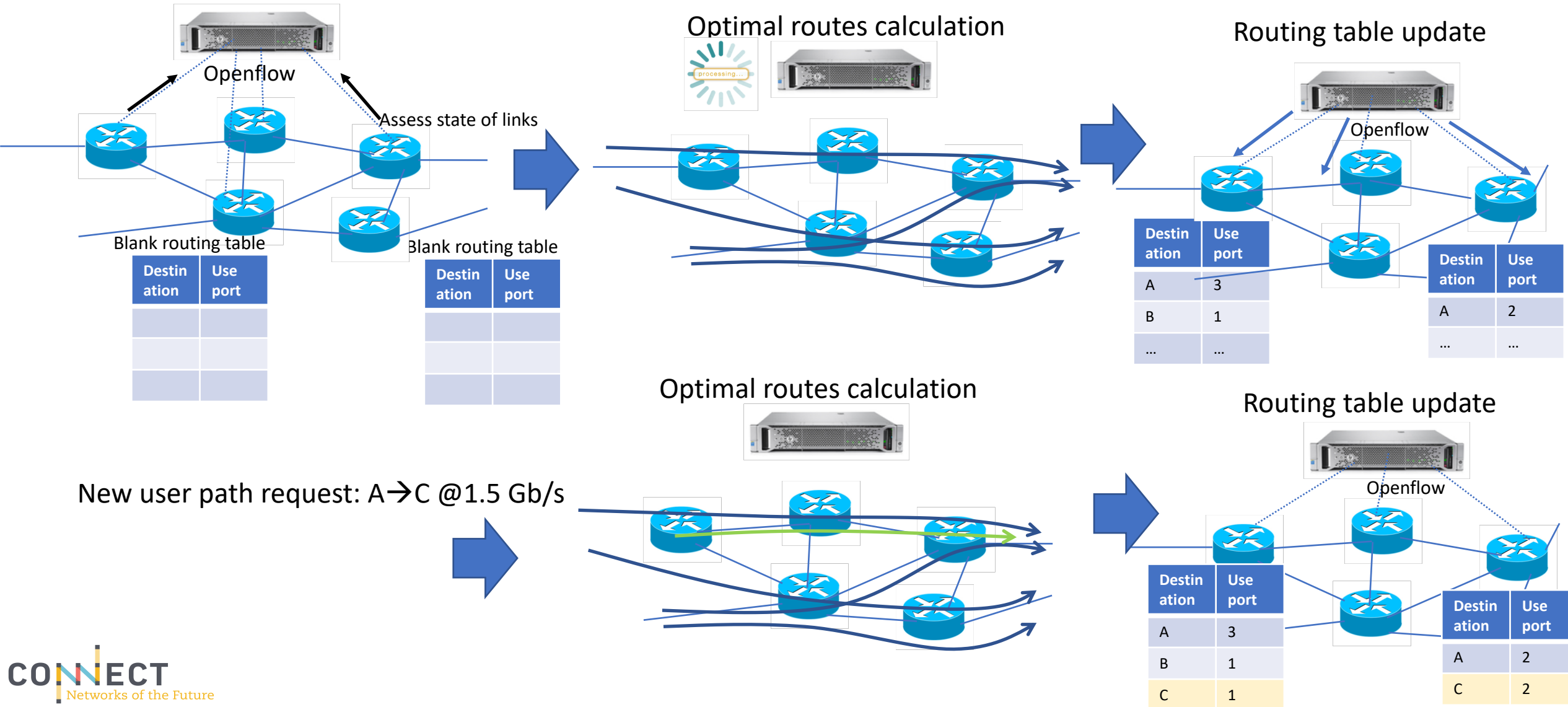


- Openflow centralized (reactive) approach



OpenFlow example

- Openflow centralized (proactive) approach



Summary

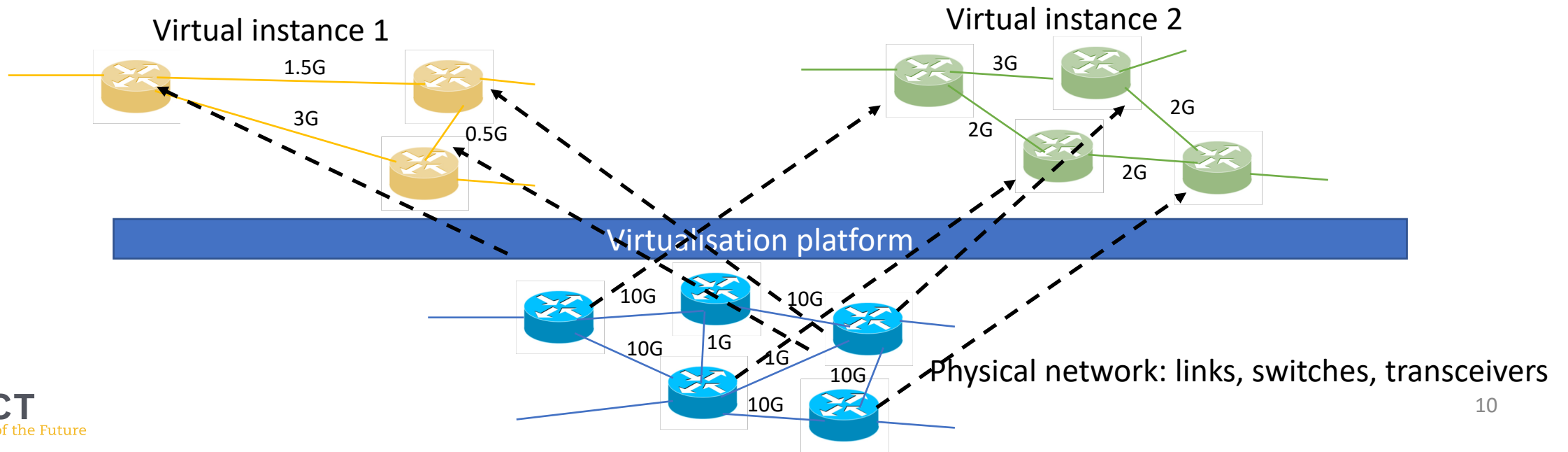
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History of programmable networks:

4) Virtualisation

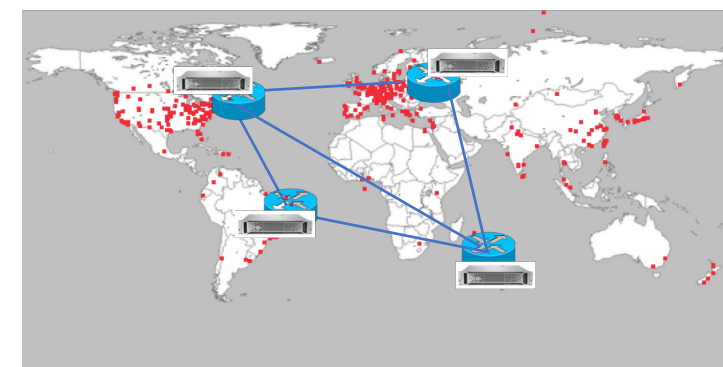
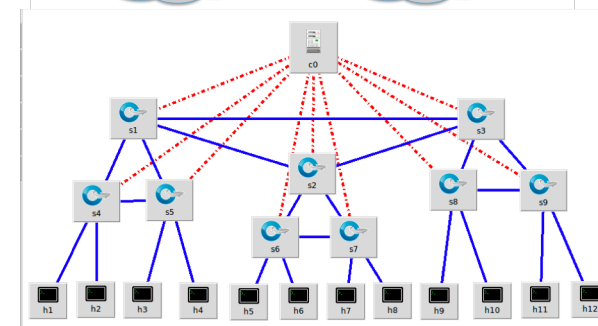
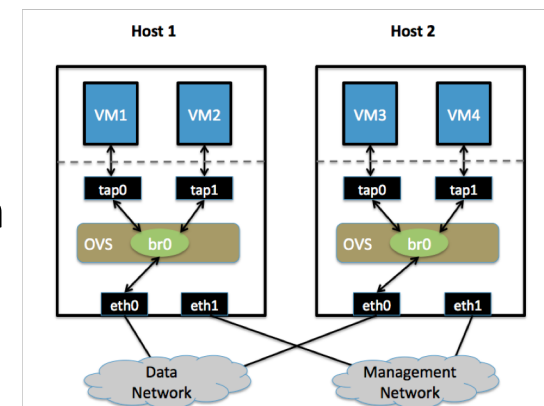


- Virtualisation is the illusion of obtaining control of a physical entity or resource.
- In networks, virtualisation could be seen as abstracting the functionality of a piece of hardware infrastructure into software.
 - relies on a virtualisation platform to associate the virtual network with real hardware links
 - can provide the ability to instantiate an entire network overlay in software



Some examples of network virtualisation

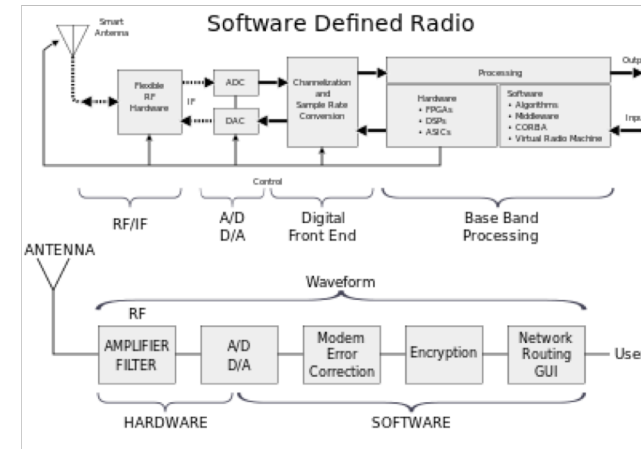
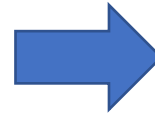
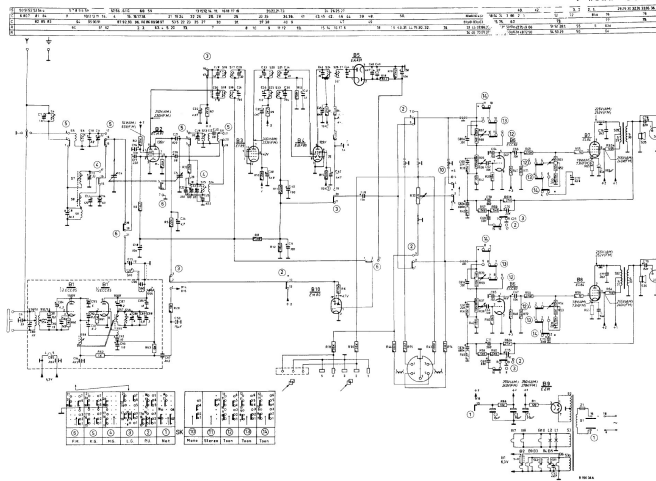
- From local scale:
 - OpenvSwitch (OvS): a virtual packet switch operating in Linux environment
 - Mininet: emulation platform comprising of virtual switches, hosts, and links
 - Can be used to test SDN controllers behaviour
- To global scale:
 - Planetlab applies the idea of virtualisation using nodes and links spread out across the globe
- Today many others exist, including wireless and optical domains




From virtualisation to network function virtualization (NFV)

- NFV moves functions from dedicated hardware to software running on commodity servers

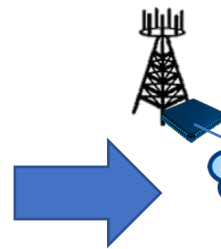
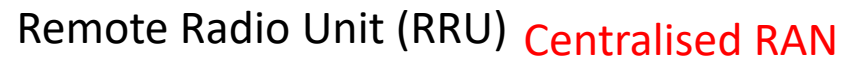
Software Defined Radio is an early example: GNU radio



- Advantages:
 - flexibility of adapting transmission format to environment and application
 - coordination with other radios (either distributed or centralized)
 - Integration with other software components...

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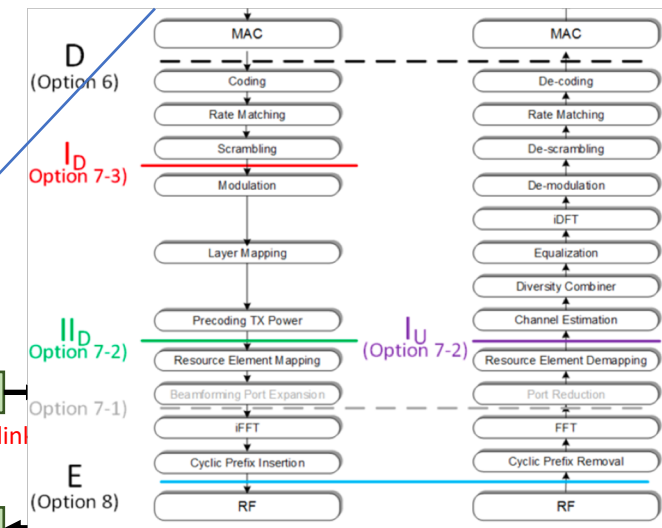
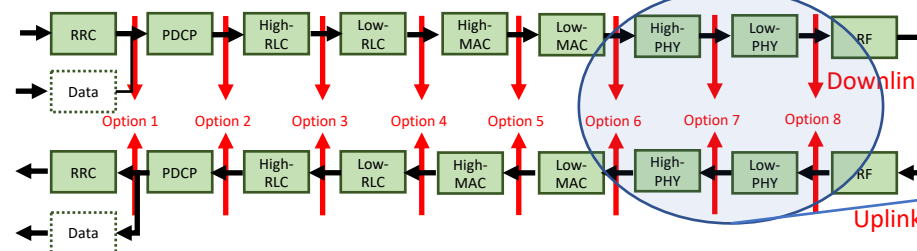
Hardware baseband unit (BBU)



Edge cloud node



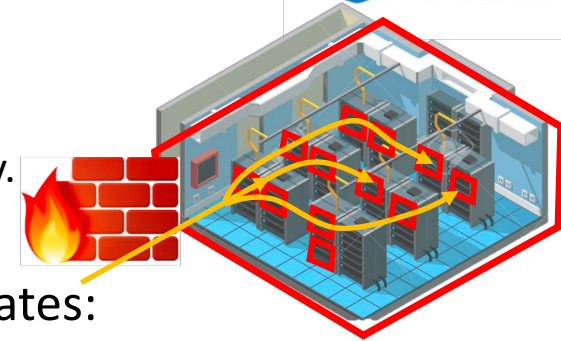
Metro DC



CONNECT
Networks of the Future

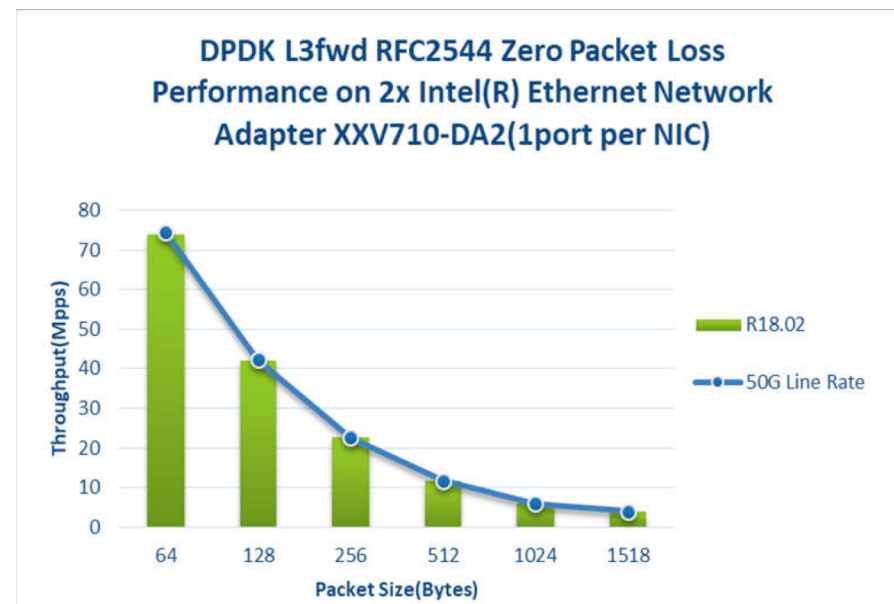
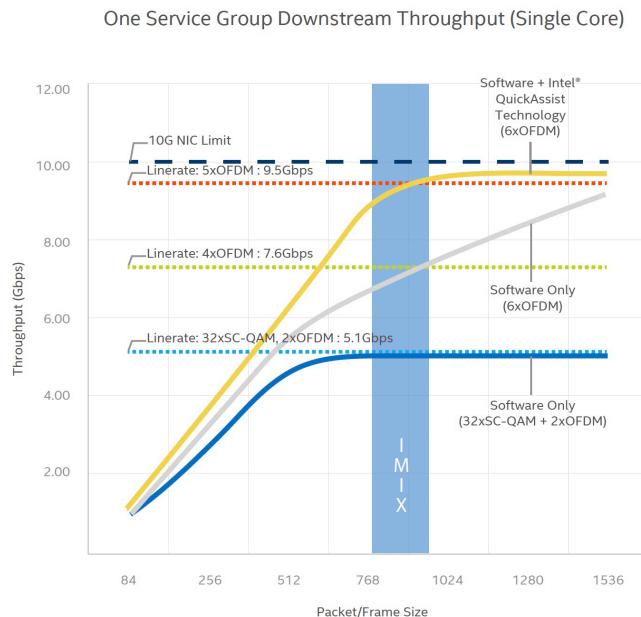
Network functions

- The NFV concept applies to several other telco functions:
 - Firewall: in VMware NSX it's integrated in each VM, for better customization, flexibility, security.
- In general all functions that require packet processing and switching are good candidates:
 - Service Gateway (vSG): e.g., route the request to the specific service provider
 - Broadband Network Gateway (vBNG or vBRAS): aggregates incoming access connections, enforces QoS, provides layer 3 (IP) connectivity
 - Customer Premises Equipment (vCPE): operates routers, firewalls, VPNs, NAT
- Highly improved packet processing/switching performance (e.g., Data Plane Development Kit – DPDK)



Full MAC of DOCSIS3.1 in single core of Xeon processor.

Source: M. O'Hanlon, B. Ryan. Maximising the performance of DOCSIS 3.0/3.1 processing on Intel Xeon processors, 2017.

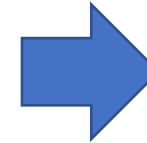
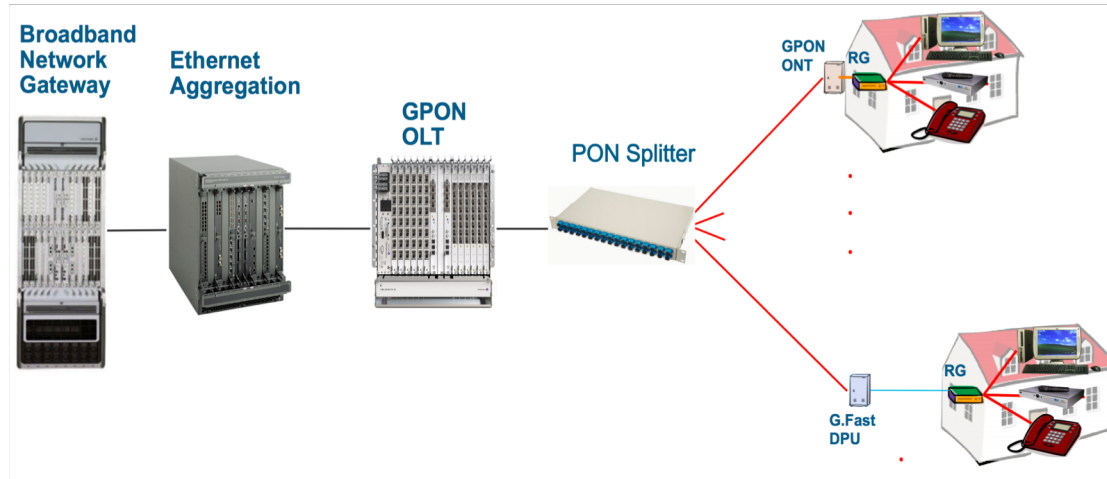


Packet switching performance on Xeon processor

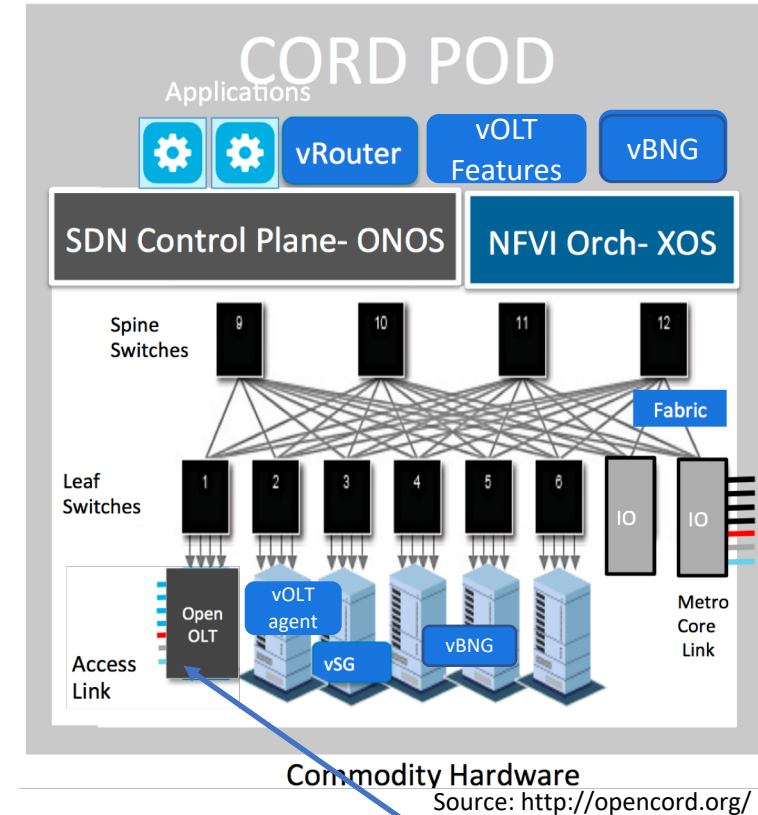
Source: DPDK Intel NIC Performance Report Release 18.02, May 2018

Central Office Virtualisation

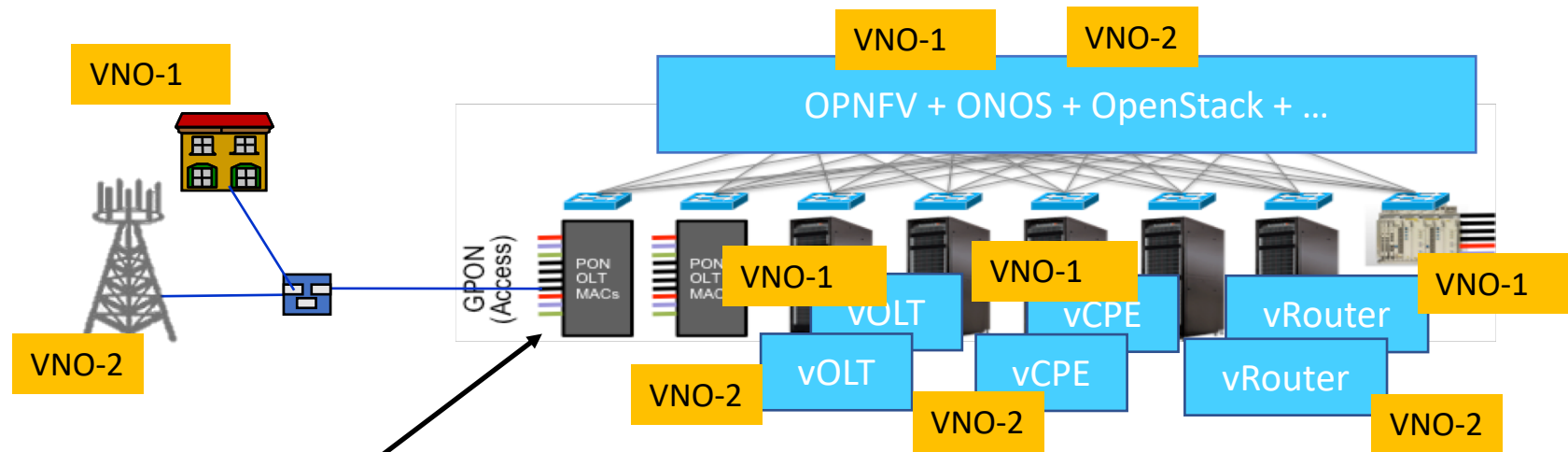
- Getting SDN and NFV into the central office:



- Driven by development, not by standard
- Being trialed by several operators world-wide
 - E.g., AT&T recently carried out trials on XGS-PON using OLT white boxes

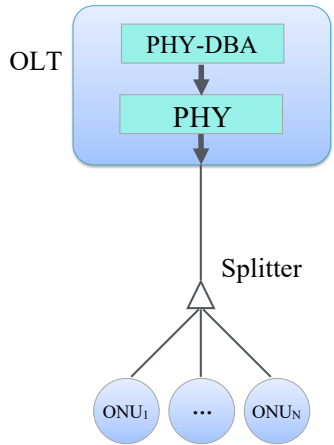


Enabling multi-tenancy

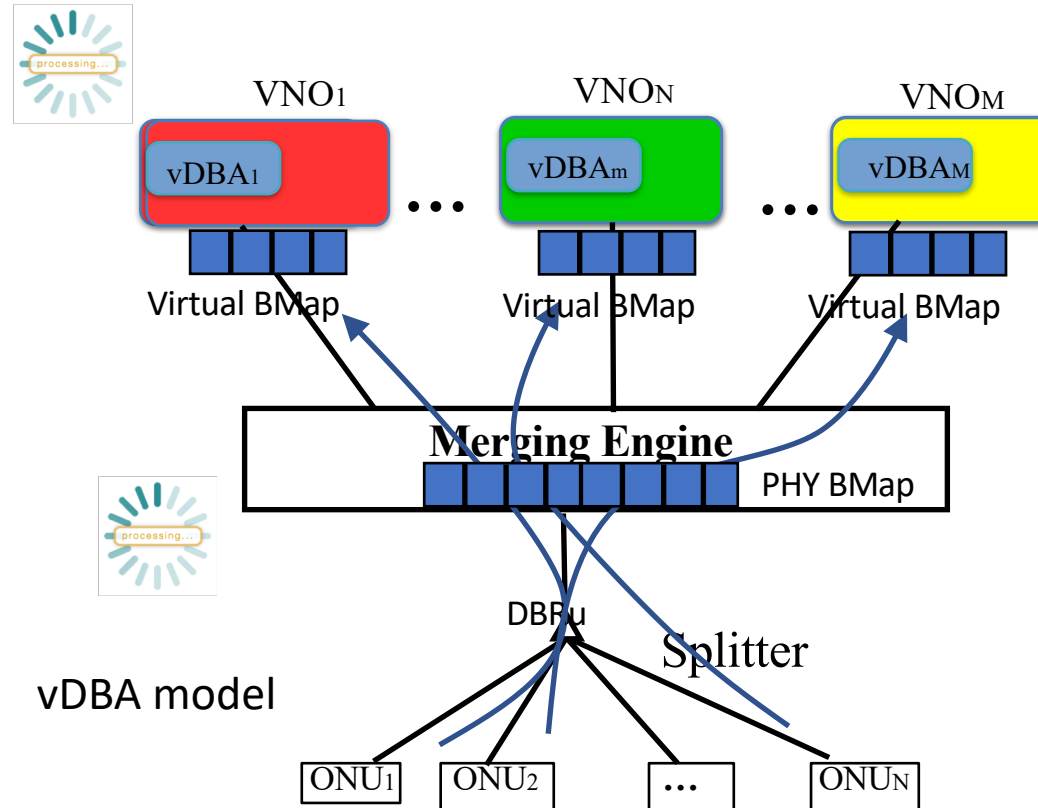


- Functions are virtualized and multiple instances can be assigned to different Virtual Network Operators (VNOs)
- ... but for example Dynamic Bandwidth Allocation (DBA) is carried out in hardware

Full disaggregation of the OLT



Current physical DBA model



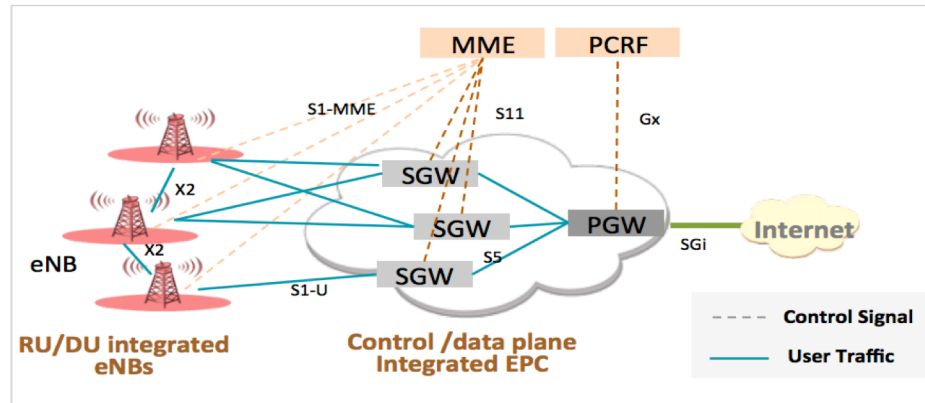
vDBA model

Demo session TuDS.16 “Experimental Demonstration of DPDK Optimised VNF Implementation of Virtual DBA in a Multi-Tenant PON”

- Work on DBA virtualization to enable fine-grained control to different tenants.
- Also other use cases: e.g., for service differentiation, for mobile front haul (more on this later)
- Both recently included in BBF WT-402 “PON Abstraction Interface for Time-critical Applications”

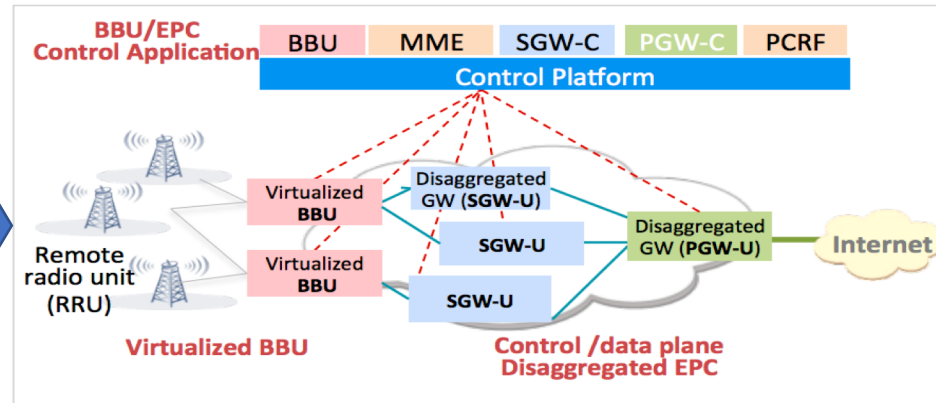
Multi-service example: Mobile-CORD

Traditional Architecture



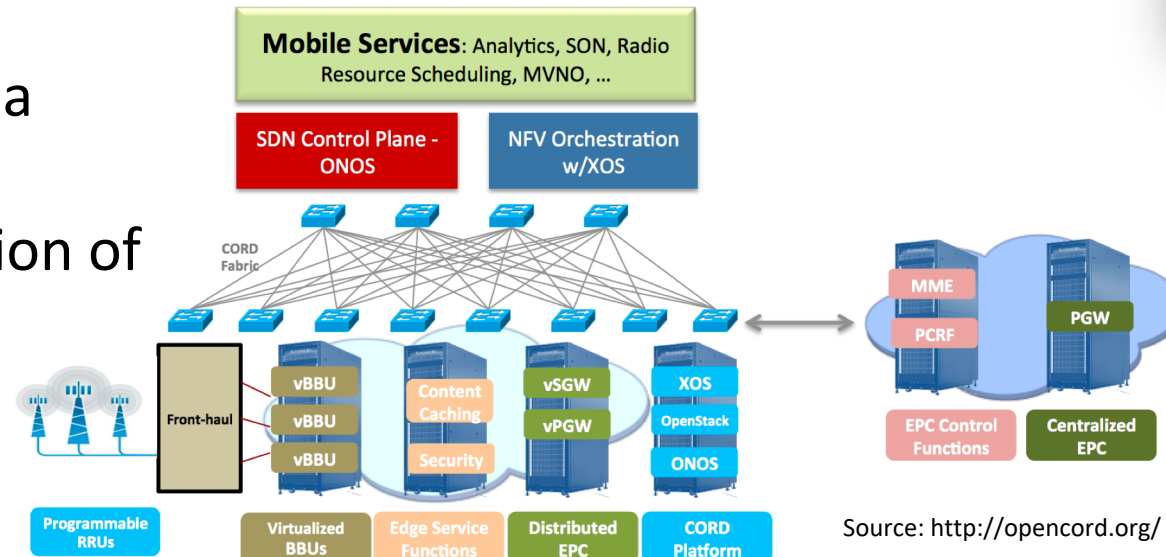
with proprietary boxes & solutions

Target Architecture



with commodity H/W & open source/open API

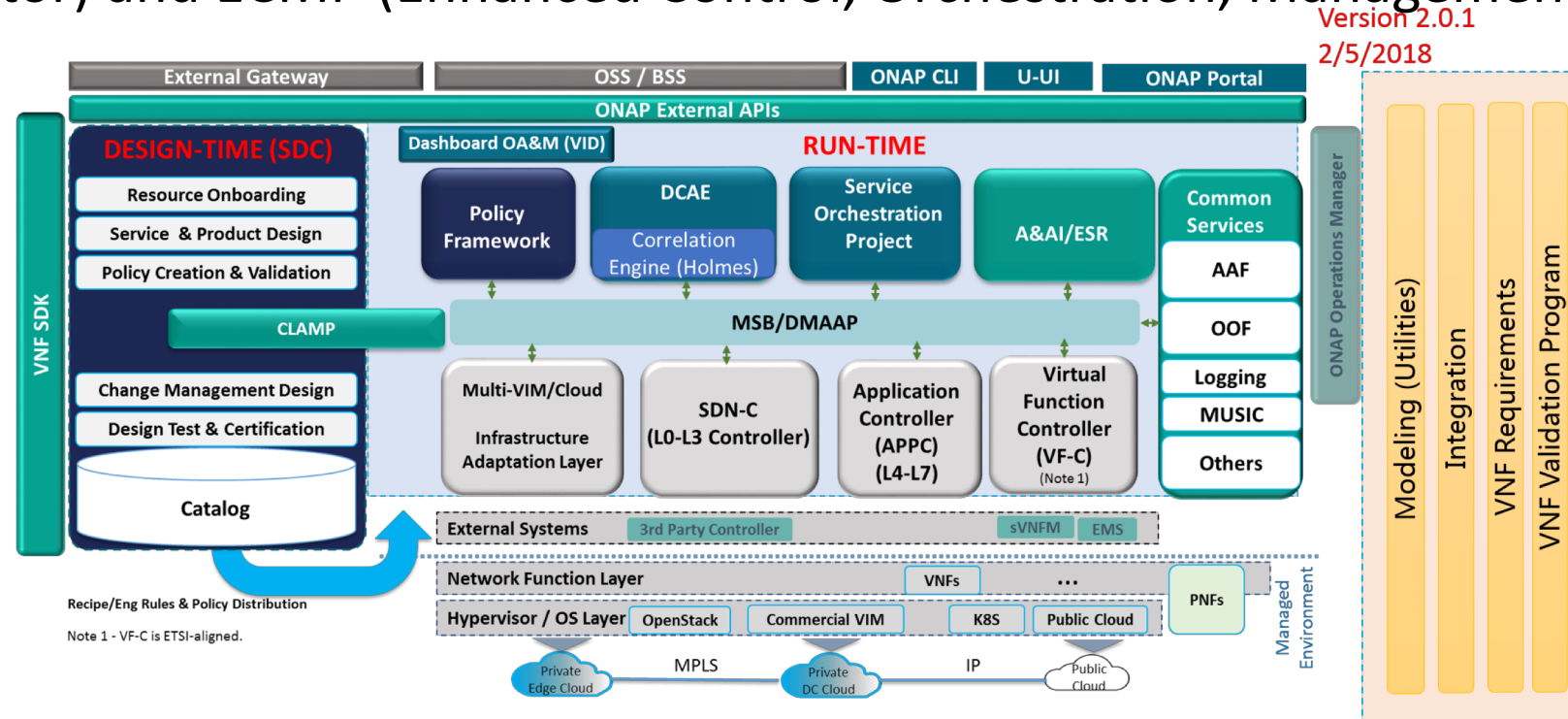
- Software and programmability a main enabler of convergence
- E.g., enables tighter orchestration of resources (see fixed/mobile)



Source: <http://opencord.org/>

But there's more to NFV than CORD...

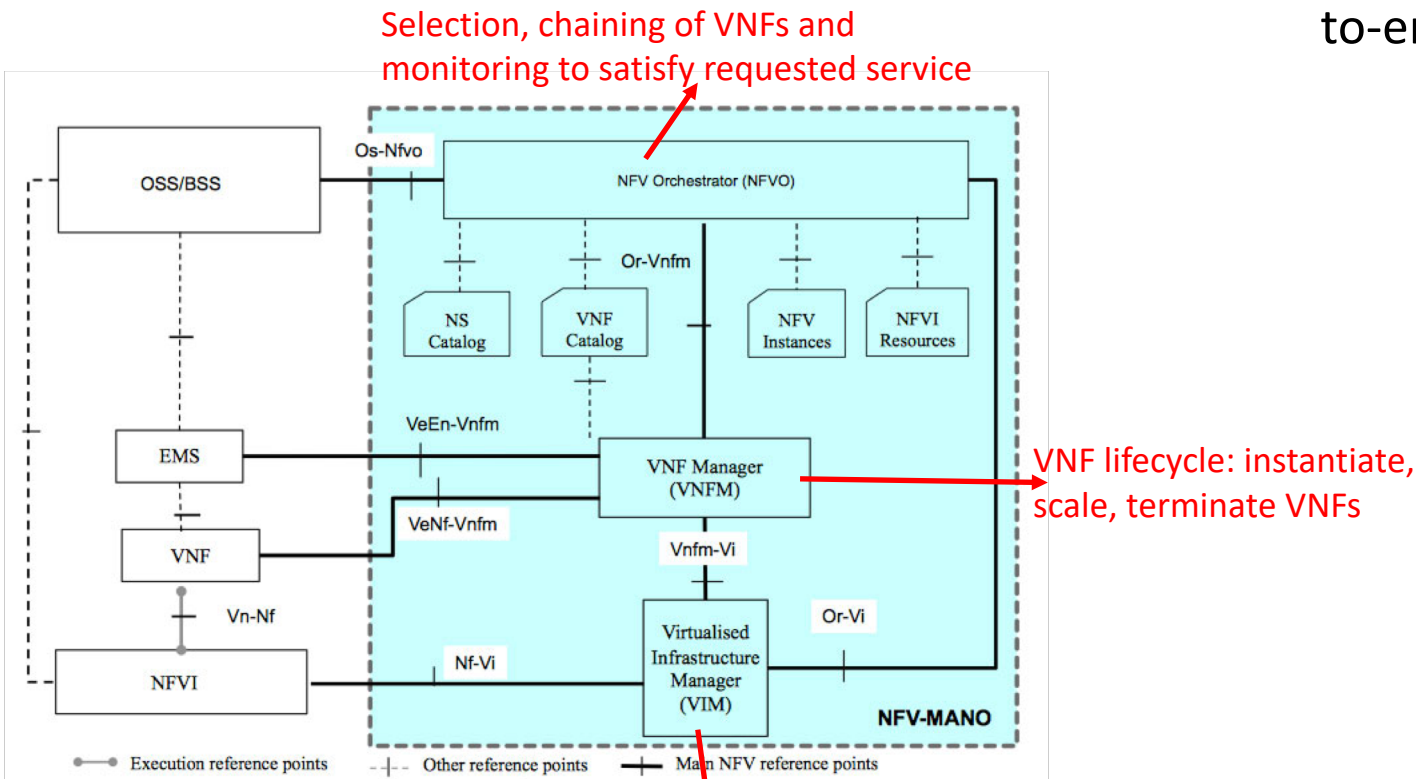
ONAP: The Open Network automation Platform: recently formed by the fusion of OPEN-O (Open Orchestrator) and ECMP (Enhanced Control, Orchestration, Management and Policy)



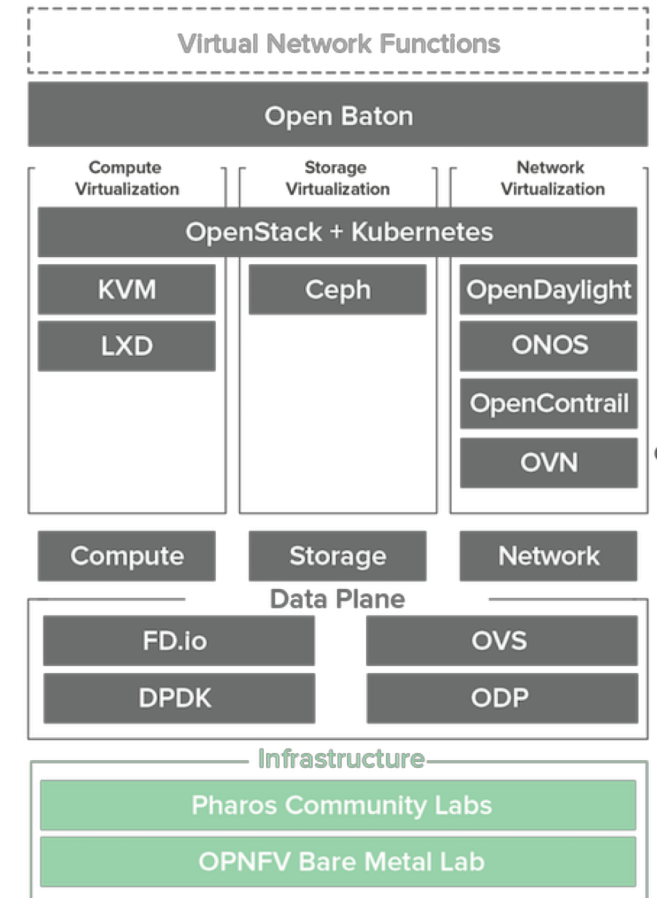
- Focuses on aspects such as data analytics, orchestration, policy, virtual management and network control
 - Ability to specify orchestration and control frameworks to automatically instantiate services
 - Offers analytic framework for monitoring performance associated to the service created

... much more

- The Open Source MANO (OSM)
 - implementation of the NFV "Management & Orchestration" reference architecture (ETSI)

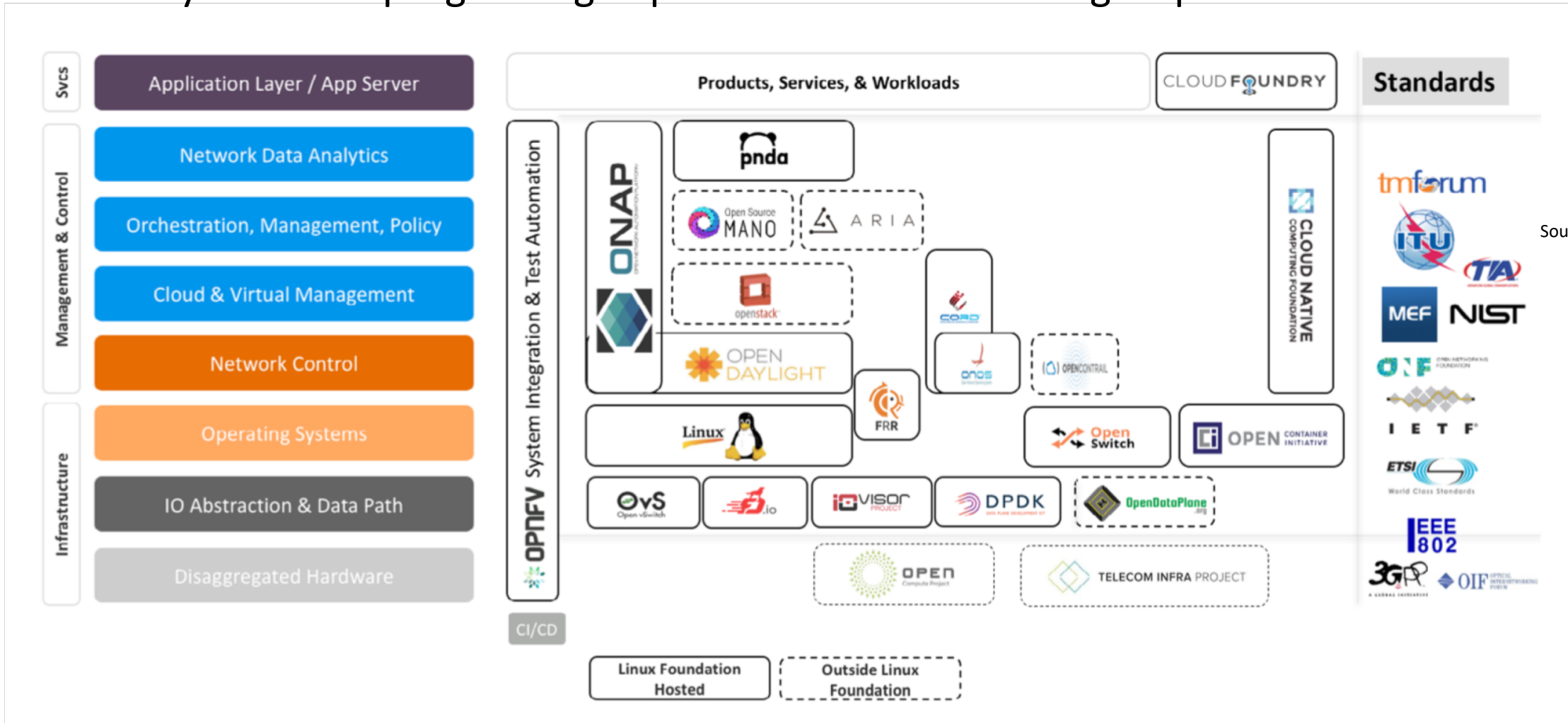


- The Open Platform for NFV (OPNFV)
- Carrier-grade open source reference platform for NFV
- Brings together several NFV components and provides an environment for assuring interoperability and end-to-end testing



Let's try to manage the confusion...

- Many activities progressing in parallel across different groups... here's an overview

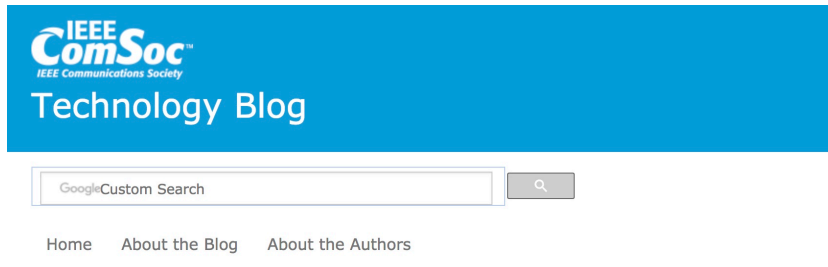


Source: the Linux foundation

P.S.: This mapping is not part of a masterplan, rather a post-processing mapping exercise to try and show similarity and differences between systems currently being developed

Some business projections

- There is high expectation for NFV...



IHS-Markit Forecast: Carrier NFV at \$37B in 2021 for a CAGR of 30% from 2016-2021

...service provider SDN and NFV investments will grow at a CAGR of approximately 45% between 2017 and 2020, eventually accounting for nearly \$22 Billion in revenue by the end of 2020...

Source: "SDN, NFV & Network Virtualization Ecosystem Market" from SNS Telecom & IT

...global market for virtual customer-premises equipment (vCPE) infrastructure will exceed \$3 billion by 2022...

Source: "Worldwide vCPE/uCPE Forecast, 2017–2021: NFV at the Network Edge" from IDC.

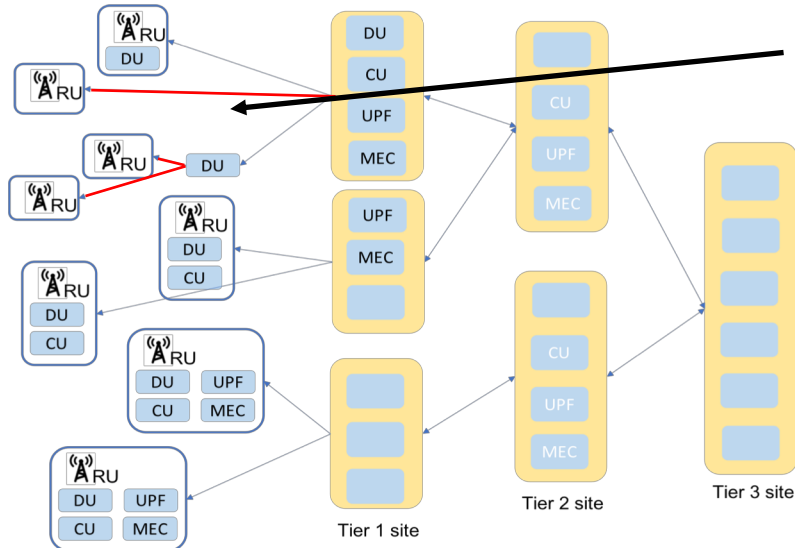
- Still early to project for the virtual CO, but most operators are exploring, trialing, ...

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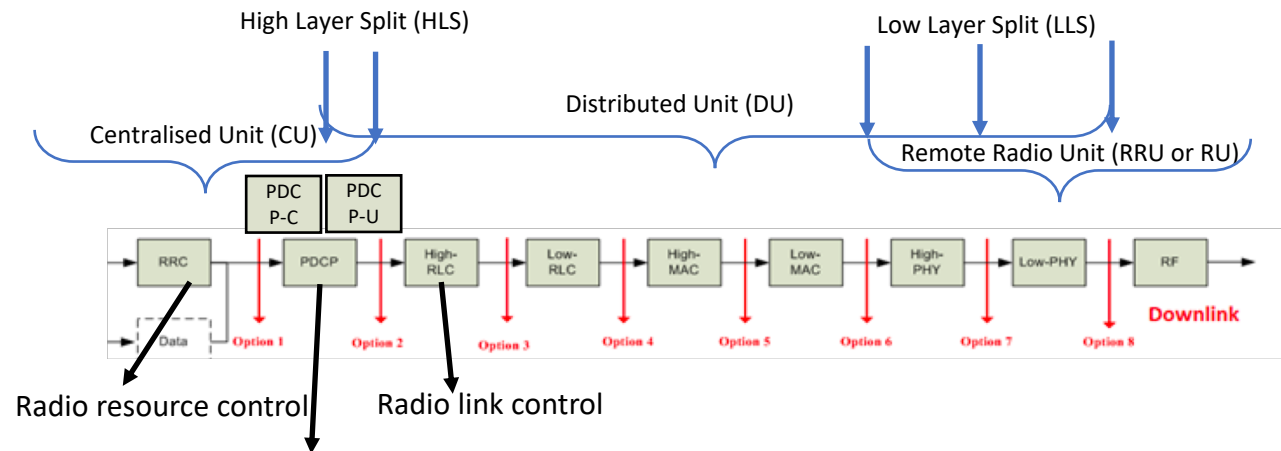
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SDN, NFV and 5G

- Does 5G need SDN/NFV? Is it a coincidence their occurrence at the same time?
- Did SDN/NFV happen because of the 5G drive? ... or vice versa?
- There are signs of mutual influence:
 - 5G initially considered as Radio Access Network (RAN) technology evolution
 - Today the main challenges revolving around 5G now include virtualization and network slicing aspects
 - Fixed/mobile, access/metro convergence are two strong use cases for SDN/NFV in 5G
- The SDN/NFV is also reshaping the network architecture...



LLS is the low latency interface, between RRU and DU



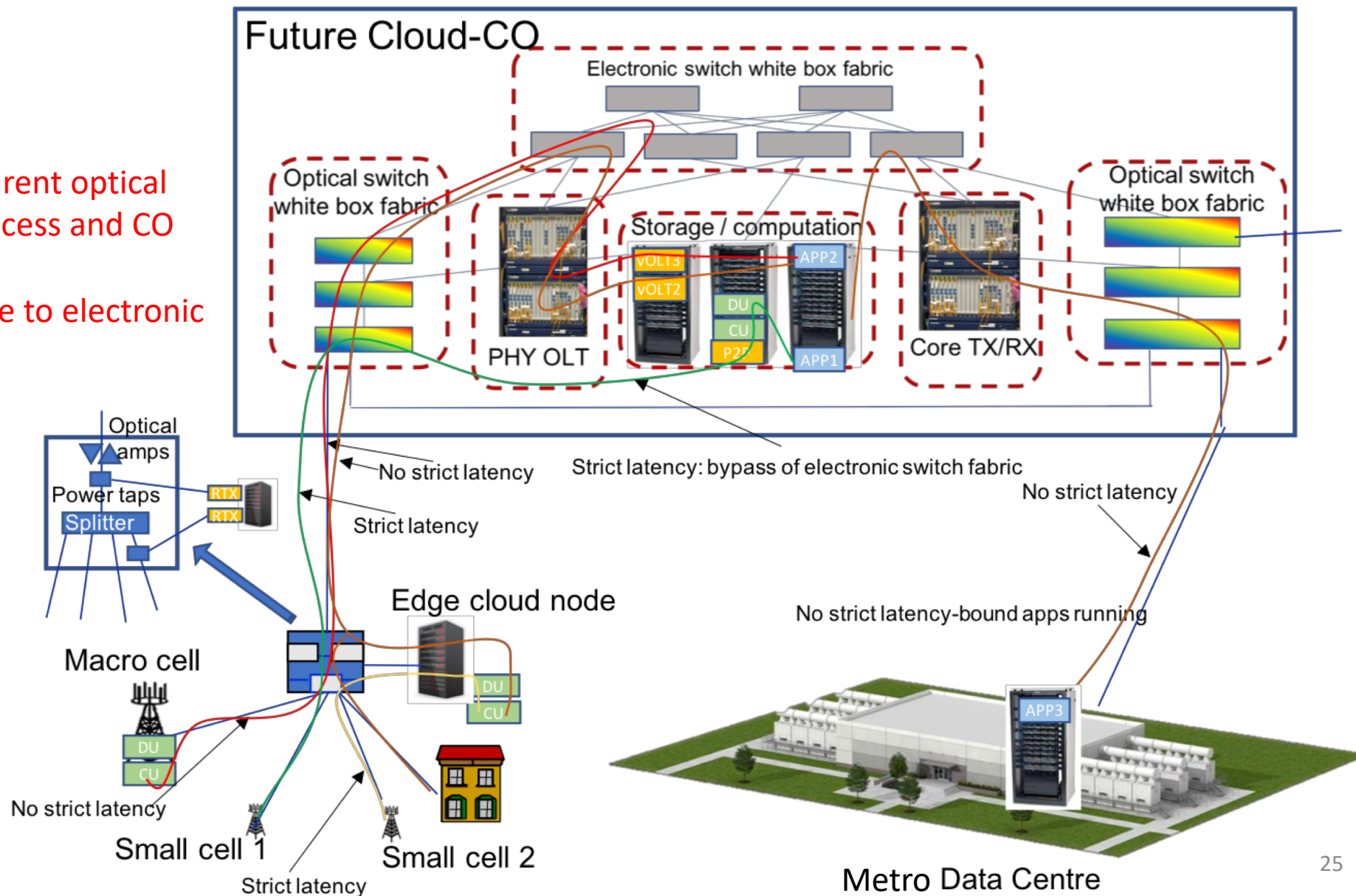
UPF Location	Tier 1	Tier 2	Tier 3
Relative number of sites	1000	100	10
Transport latency (1-way)	0.6 ms	1.2 ms	4.2 ms
Estimated 5G latency (RTT)	9.2 ms [eMBB]	10.4 ms [eMBB]	16.4 ms [eMBB]
	2.2 ms [URLLC]	3.4 ms [URLLC]	9.4 ms [URLLC]

Source: NGMN

Sample use case: convergence of mobile, optical and cloud

Orchestration of transparent optical connections between access and CO

Reduce latency/jitter due to electronic switching, etc.



Sample use case... cont'd

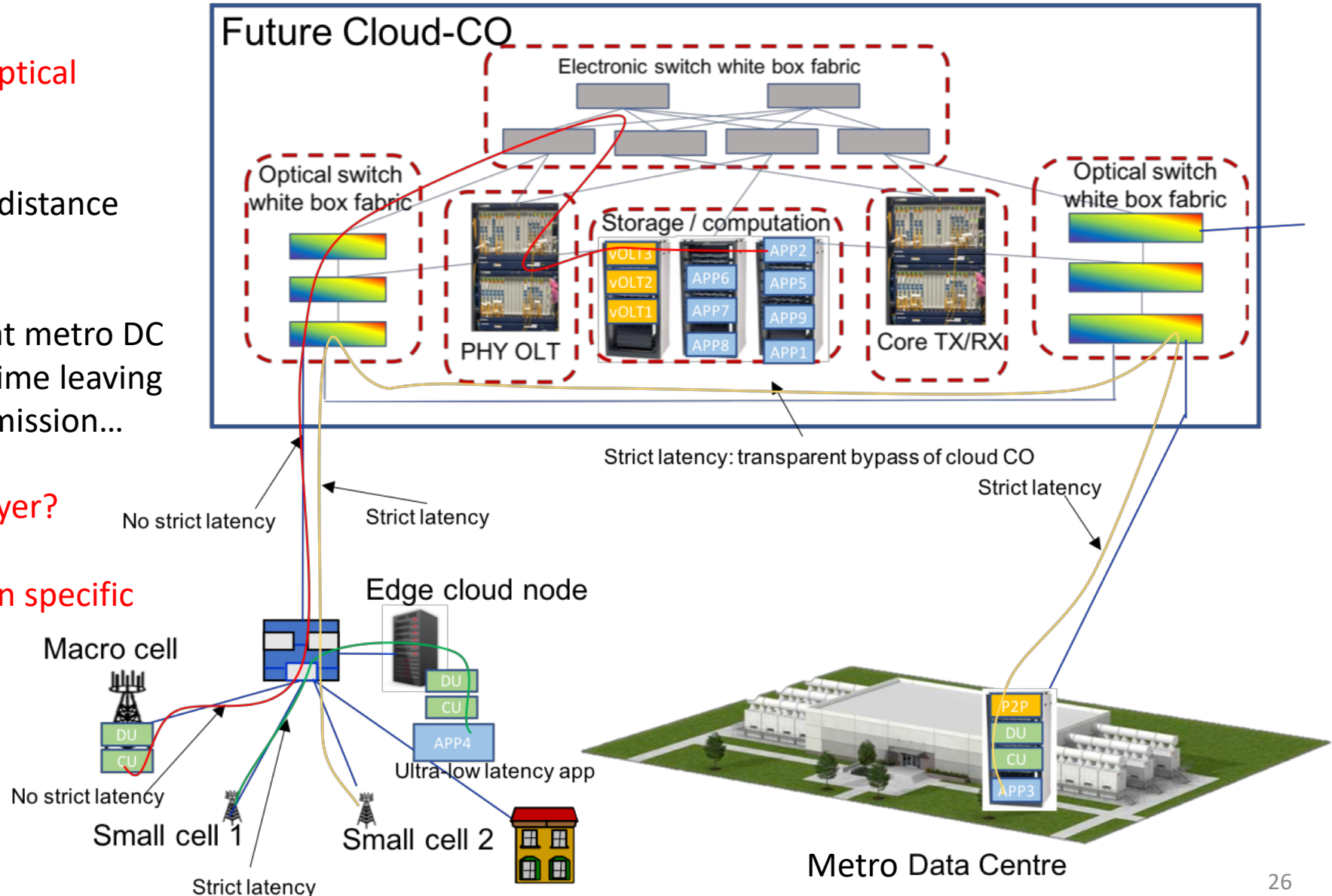
Orchestration of transparent optical connections across the metro

In principle metro data centre distance limited to 40 km by latency...

...but more processing power at metro DC can decrease VNF processing time leaving more latency budget for transmission...

Need to open up the optical layer?

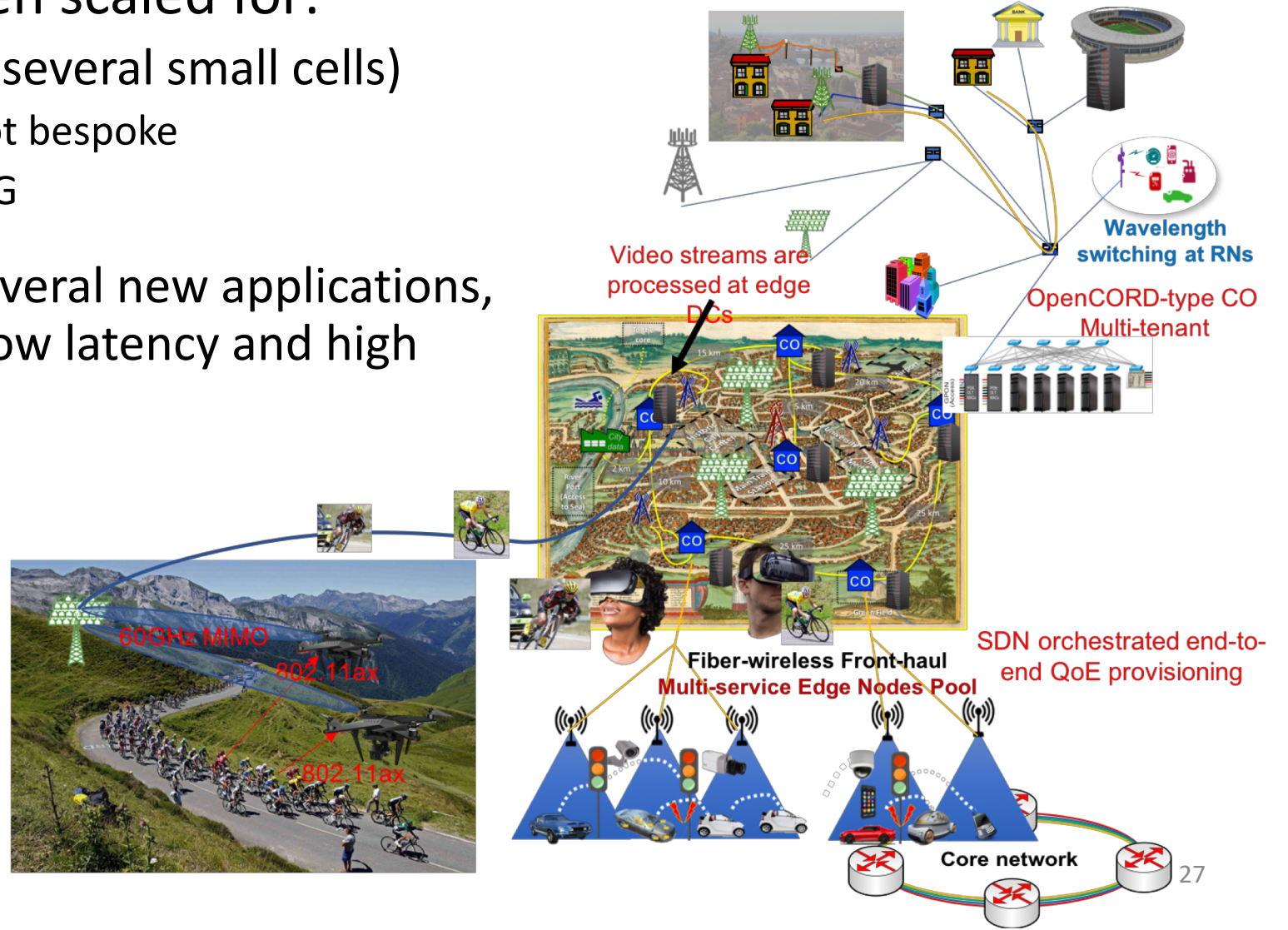
Surely need to be able to assign specific (e.g., powerful) resources as needed



Scalability

- How does this look like when scaled for:
 - High densification scenario (several small cells)
 - need for scalable solution, not bespoke
 - > 10 cells per km² each @ 10G
 - Multiple diverse services, several new applications, some of which will require low latency and high capacity guarantee
 - Multi-tenancy

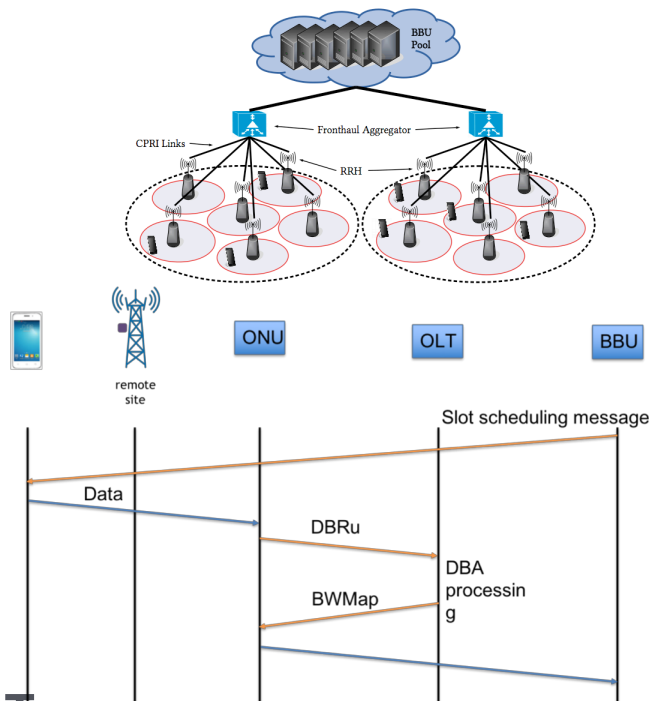
Source: OFCity '17, team ALIVE



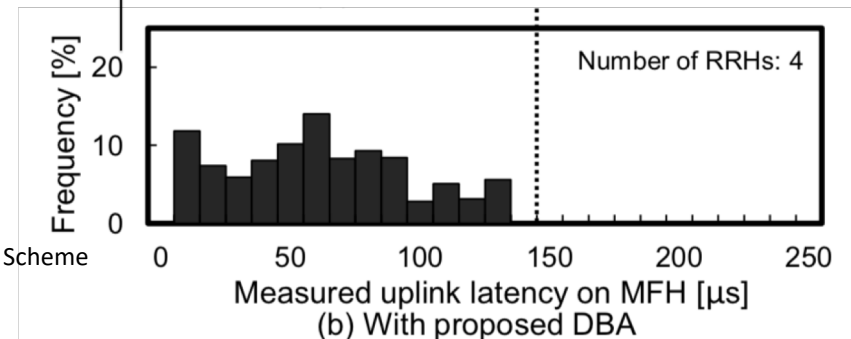
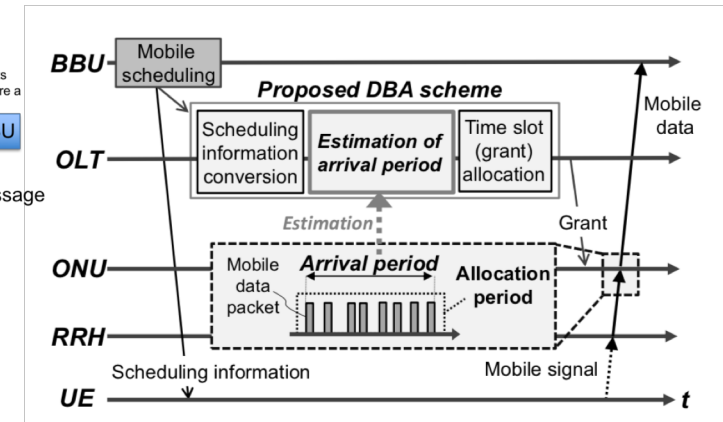
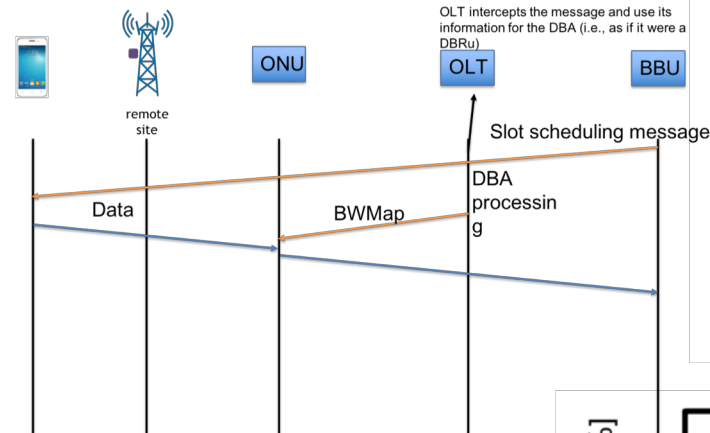
Virtualisation enabling joint orchestration: Fixed-mobile convergence I

- Important feature of virtualization: easy to exchange information between systems, e.g., mobile and PON backhaul
- Joint upstream scheduling of mobile and PON capacity to reduce latency
 - i.e., the BBU tells the OLT in advance when packets will arrive from BS to ONU
 - the OLT synchronizes its scheduling so that an upstream slot will be immediately available

Problem



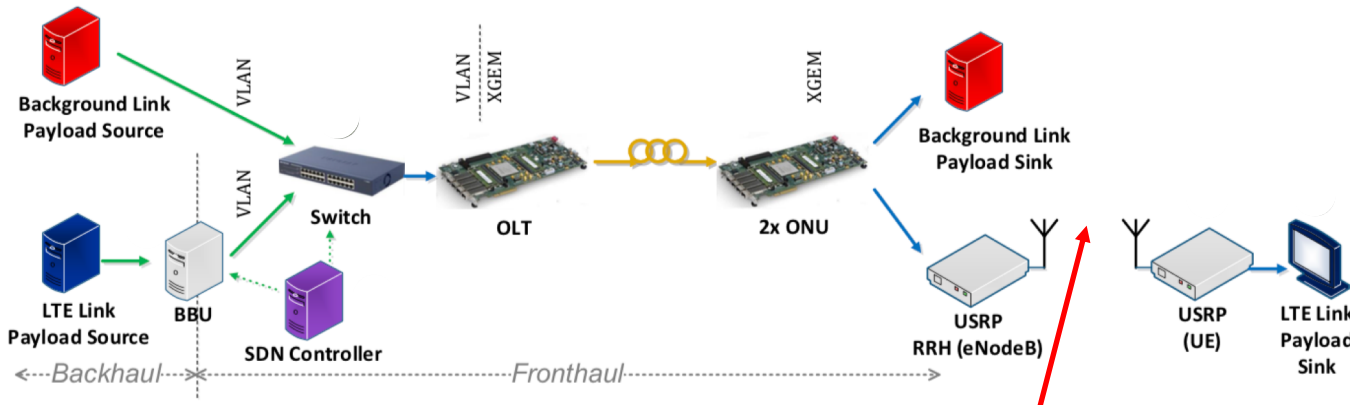
Solution



Source: H. Uzawa, et al. Practical Mobile-DBA Scheme Considering Data Arrival Period for 5G Mobile Fronthaul with TDM-PON. ECOC 2017.

F/M convergence II: variable rate fronthaul

Adapt wireless bandwidth to required cell capacity
 ➔ Fronthaul rate is reduced proportionally



1. BBU ➔ SDN: Assess capacity used by the cell
2. SDN ➔ BBU: Adaptation of wireless bandwidth
3. SDN ➔ PON: Adaptation of reserved PON capacity to new fronthaul rate

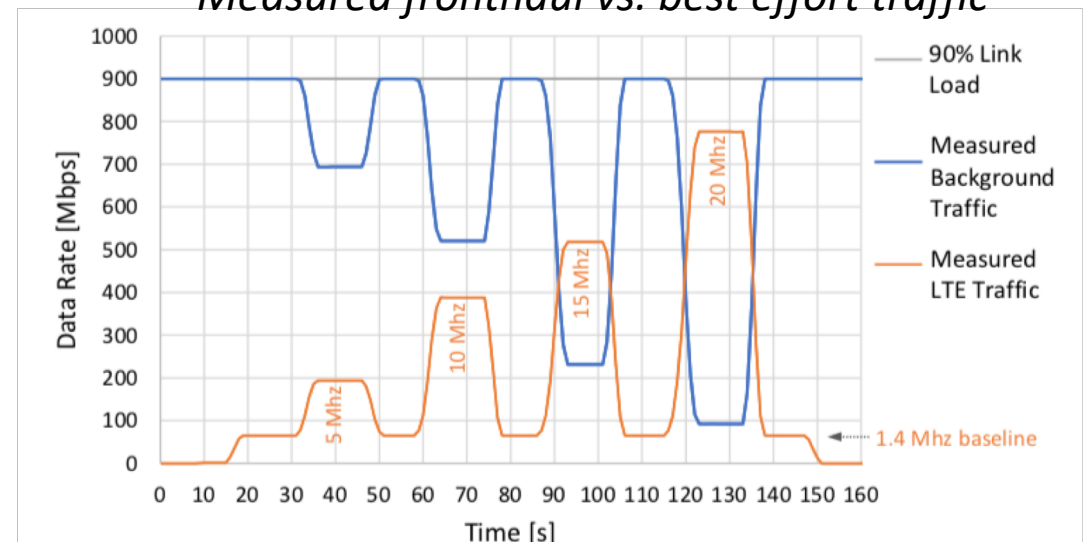
Possible use cases:

- Mix fronthaul with other low priority traffic
- Statistical multiplex across adjacent small cells

Adaptive cell bandwidth

Wireless Bandwidth	PRB Number	Fronthaul Rate	Max Cell Capacity
1.4 MHz	6	61 Mbps	1.8 Mbps
3 MHz	15	121 Mbps	4.584 Mbps
5 MHz	25	182 Mbps	7.736 Mbps
10 MHz	50	364 Mbps	15.264 Mbps
15 MHz	75	485 Mbps	22.92 Mbps
20 MHz	100	730 Mbps	30.576 Mbps

Measured fronthaul vs. best effort traffic

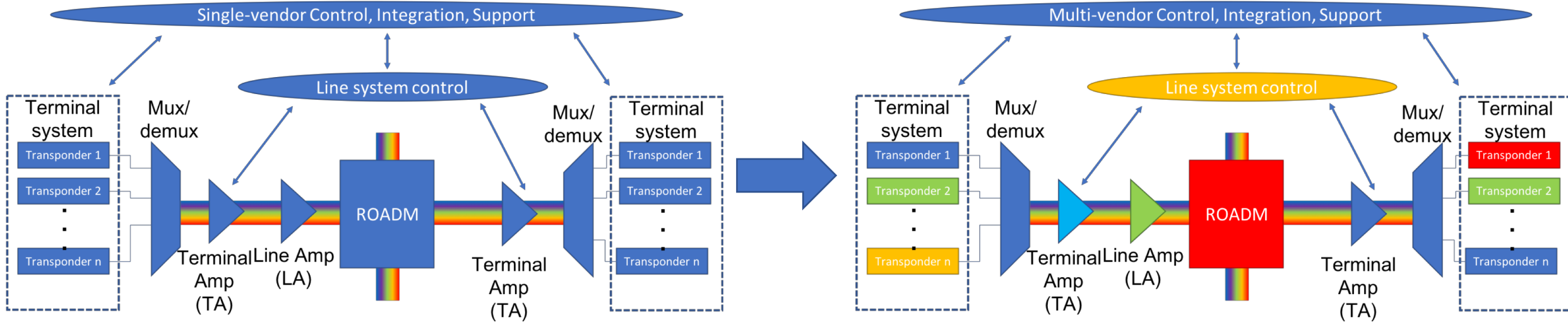


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Optical layer disaggregation

- With CORD, etc. the NFV paradigm was pushed down to the MAC layer of optical technologies (e.g., in PON with the VOLTHA)..
- ..and for wireless technologies down to the physical layer (software radio implementation of LTE)
- So, what about the optical transmission layer?

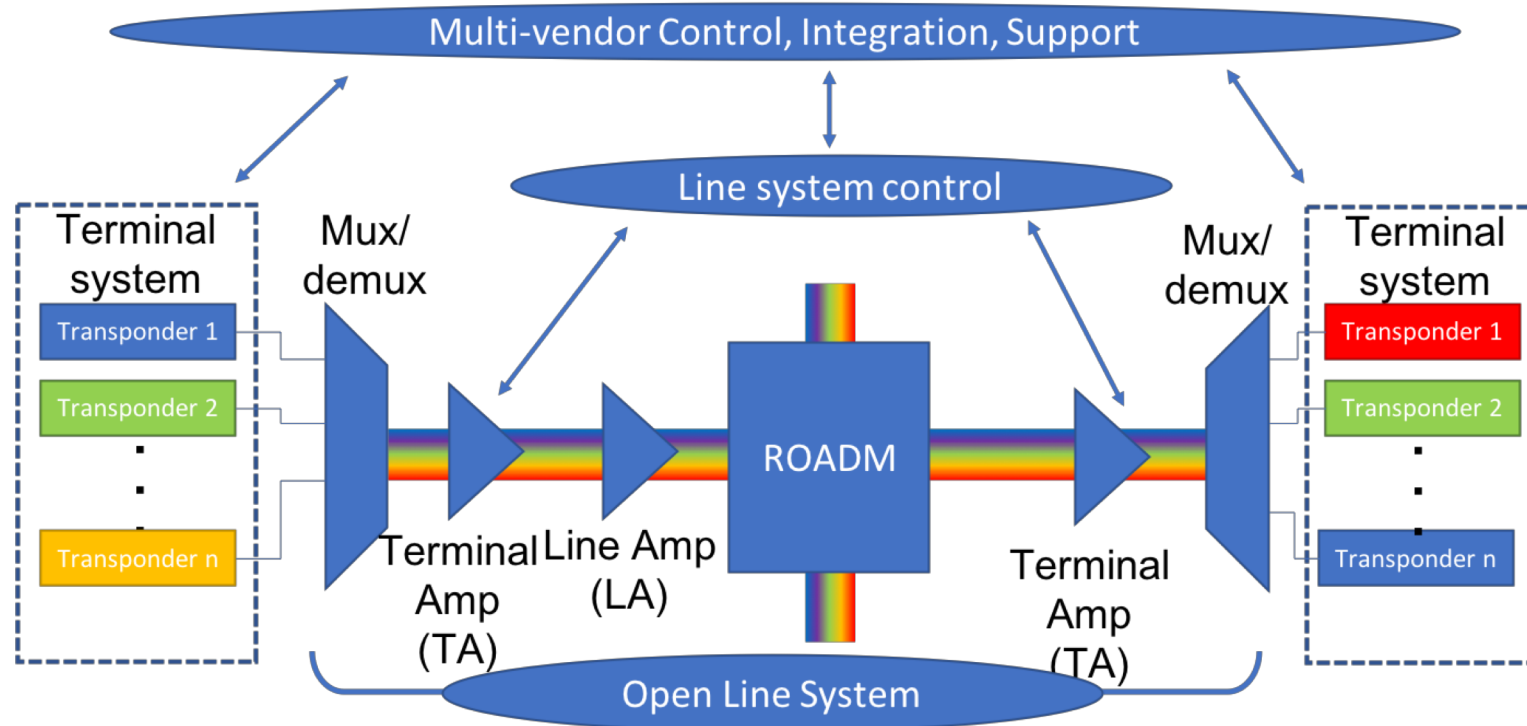


- What it means:
 - Mix and match transponders, amplifiers, ROADMs, control loops, optical control plane ...

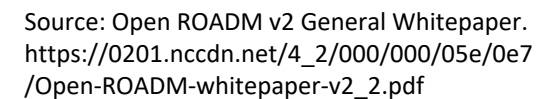
Work ongoing: Open Line System

Part of the Telecom Infra Project (TIP)

- Aim at decoupling the line system from the transponders
 - The line system is closed but should operate with any transponders
 - The transponders should operate over any line system



- Agreement between manufacturers to make products that are compatible across vendors
- Operates functional disaggregation of the ROADM system, providing abstraction for optical functions: ROADM, transponder, pluggable optics, in line amplifiers and Muxponders (OTN)
- The specification provides access to those through a standard API using NETCONF with YANG based data model providing a generic representation to the controller



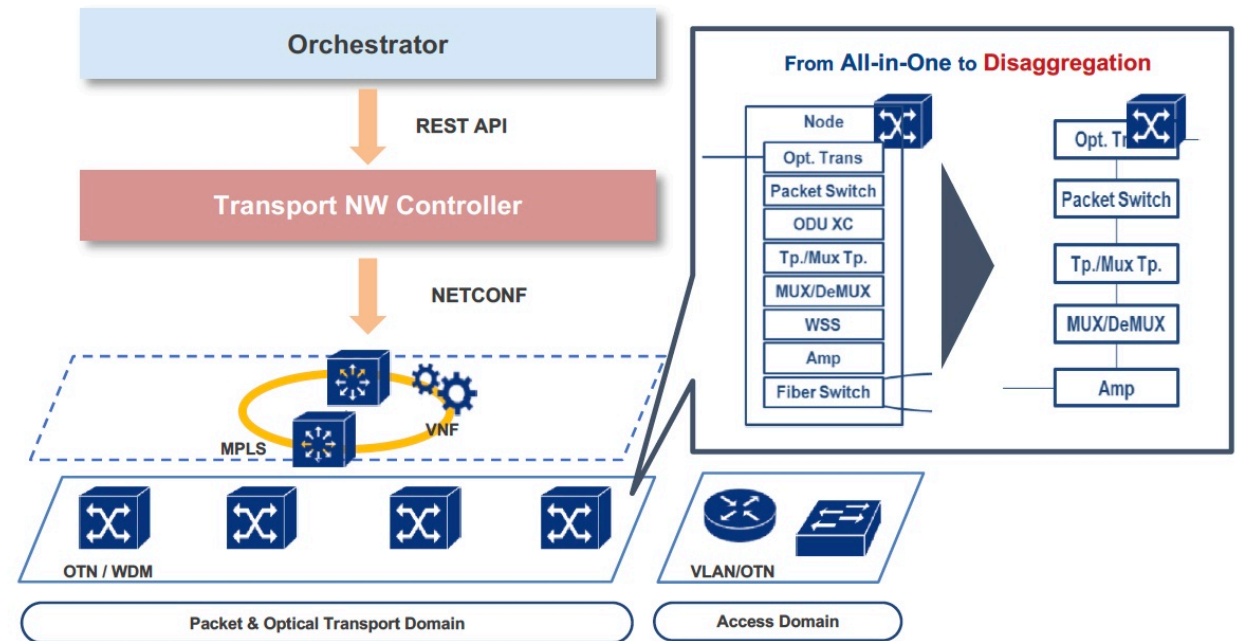
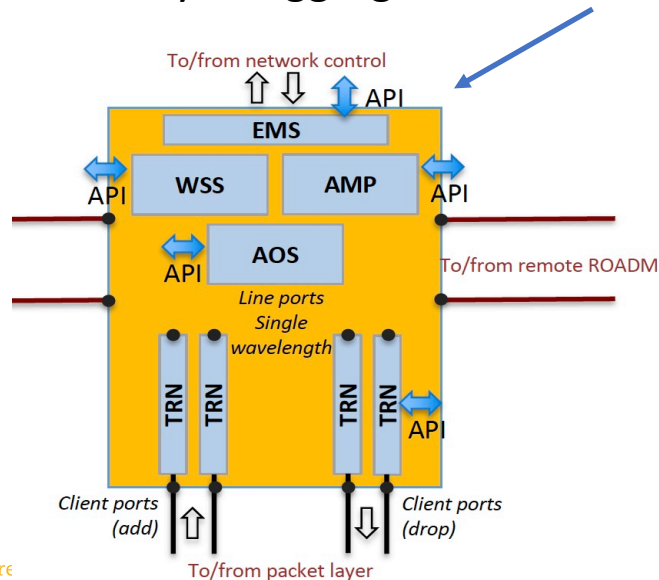
Work ongoing: Open and Disaggregated Transport Networks (ODTN)

ONF's version of the disaggregated optical network architecture

- Build reference implementation using open source and open standards
- Making use of largely adopted interfaces, OpenConfig, Transport API (TAPI), NETCONF, and ONOS controller

Three phases:

- First phase focusing on point-to-point (completed)
- Second phase will include ROADMs
- Third phase on fully disaggregated ROADM



Source: <https://www.opennetworking.org>

Open Roadmap

- Stage 1: Open Line System
 - The line system is closed but should operate with any transponders
 - The transponders should operate over any line system
- Stage 2: Open APIs and SDN control
 - Open to external controllers and orchestrators
 - OpenROADM and ODTN (ONF) working on this
- Stage 3: Disaggregate the OLS
 - Have also in-line amplifiers and ROADMS from different vendors
 - OpenROADM working on this, planned in ODTN
- Stage 4: Full end-to-end integration of the open system
 - The optical system is full disaggregated and open to external control
- Question is who provides the end-to-end integration: one of the components vendors, the orchestration vendor or the operator itself...?

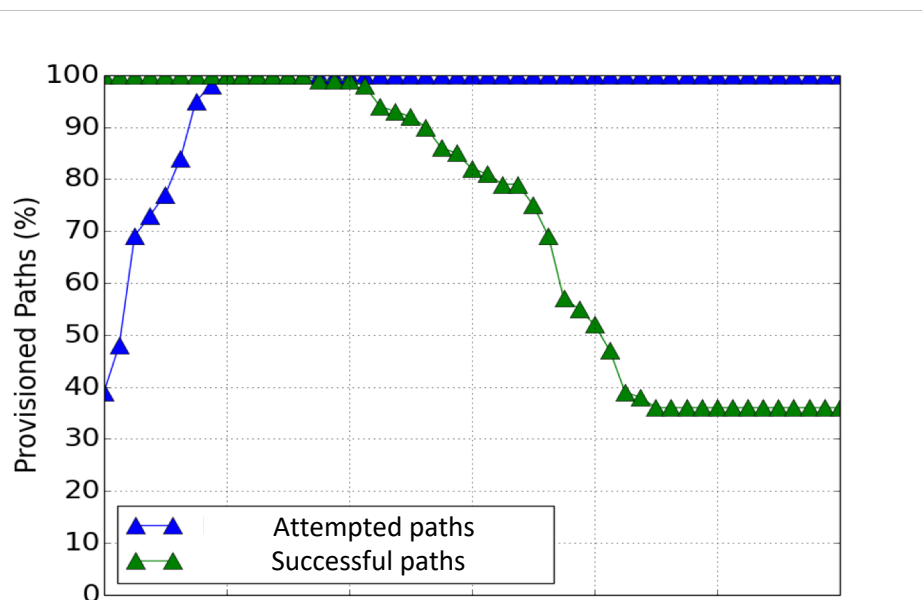
... or the network becomes so intelligent and does it by itself..?

Pros and challenges

- Fast evolution: in 5 years went from being unacceptable ... to hot topic
- Pros:
 - Open market of components from multiple vendors brings cost down
 - No vendor lock-in, faster network upgrades
 - Possibility of full integration with other control layers to achieve dynamic, fast, end-to-end optical re-configurability → previous mobile, optical, cloud use case
- Challenges:
 - Working on analog system with physical parameters and impairments...
...notice that a digital system is also built upon a physical analogue layer, but there we have a better abstraction built over 50 years of evolution in computing systems
 - A system engineered by a one vendor producing is more predictable and requires lower optical margins → higher efficiency/lower cost
 - Business-oriented:
 - Who provides system integration?

Metro vs core

- Meaning of effect on margins:

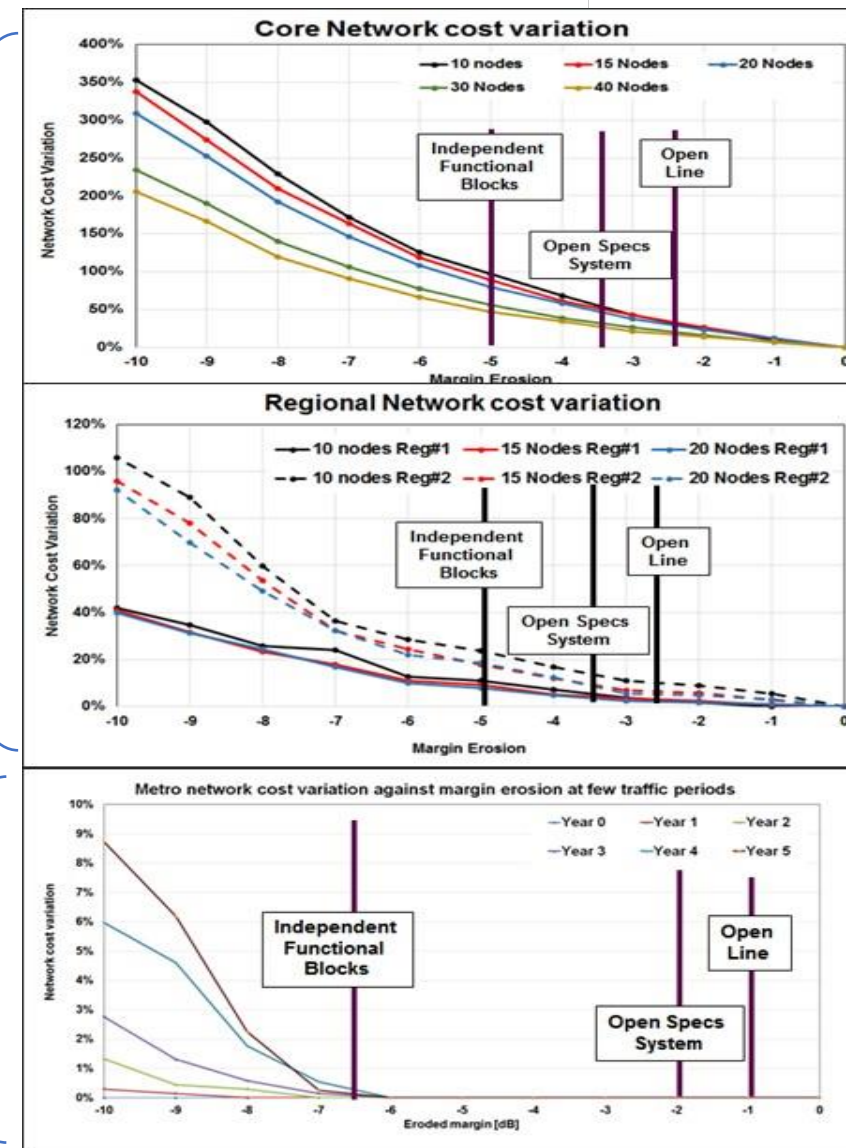


More conservative

More aggressive

X axis: how conservative are the margins

Effect on cost of core and regional network shown to be substantial due to low available margins



Effect on metro though is negligible, as the metro has larger margins

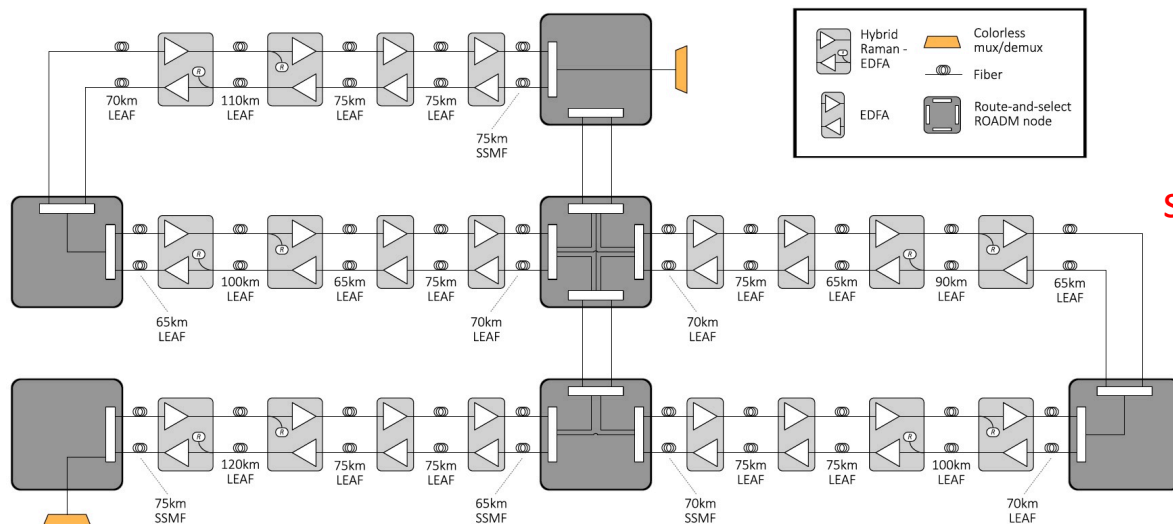
QoT estimation from TIP project

Work from the Open Optical Packet Transport (OOPT) group Physical Simulation Environment (PSE) subgroup, part of the Telecom Infra Project (TIP)

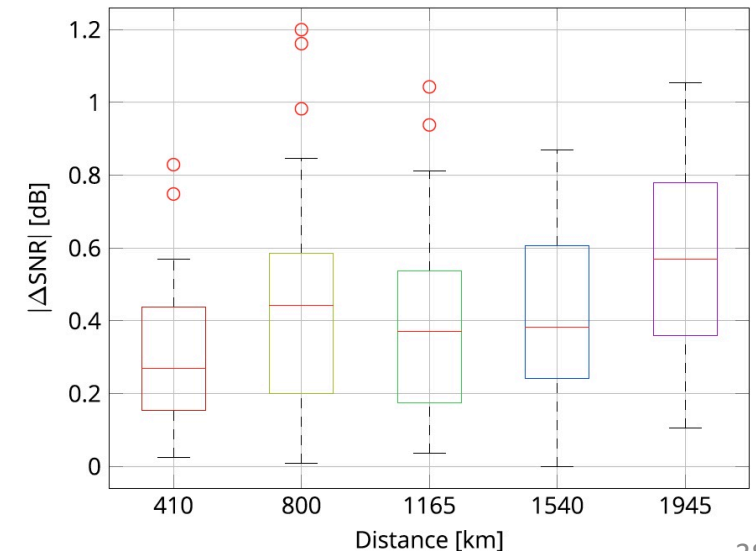
- PSE aims at developing opensource tools for QoT assessment in disaggregated optical systems
- Different transponders characteristic provided by the vendors by vendors
- Takes into account ASE noise and nonlinear impairment as Gaussian Noise (GN)

Simplifications:

- Other effects assumed to be compensated by receiver (dispersion, phase noise)
- Power profile info at every node fed to eliminate amplifier ripple issue

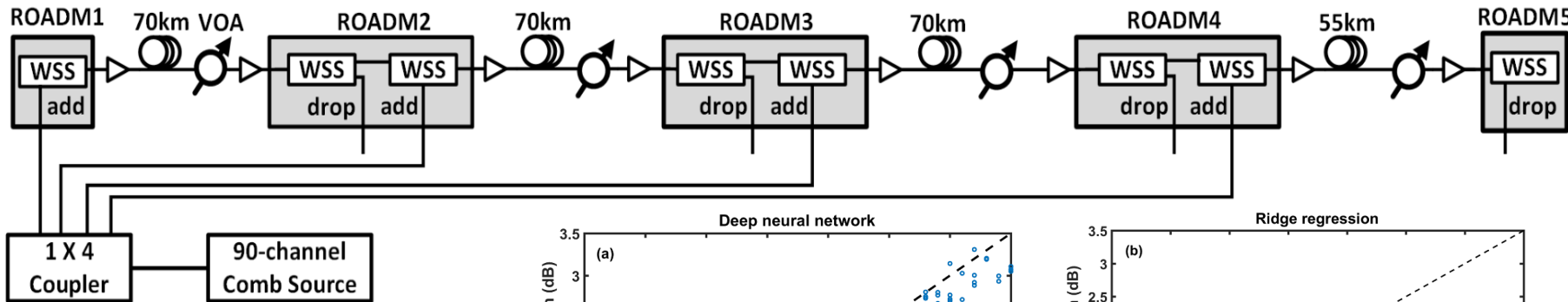


Measured vs.
simulated results



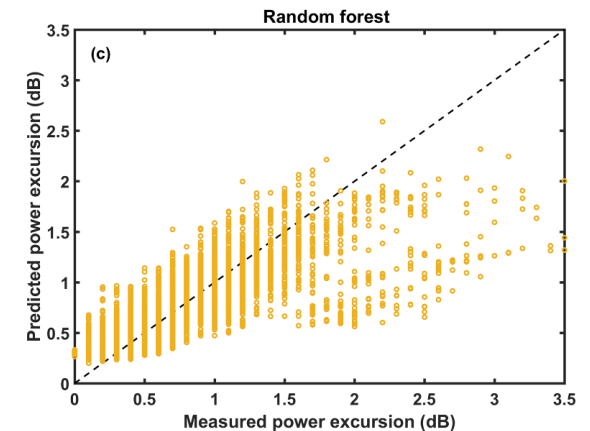
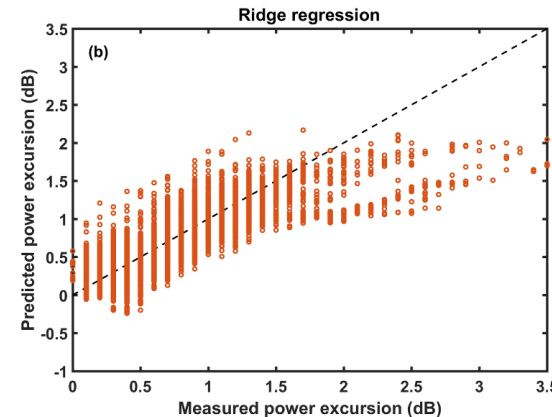
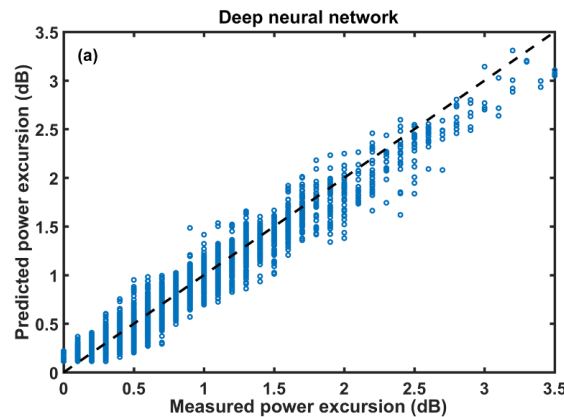
Machine learning to the rescue...

- Opening up metro network good trade-off, as that's where a dynamic optical layer can provide more benefit..
- ... however more work on QoT estimation could change such figures also in regional and core.
- Much work being carried out in the use of machine learning techniques



Amplifier power
excursion prediction

Source: W. Mo, et al., Deep Neural Network Based Wavelength Selection and Switching in ROADM Systems. JOCN Vol. 10, No 10, 2018.

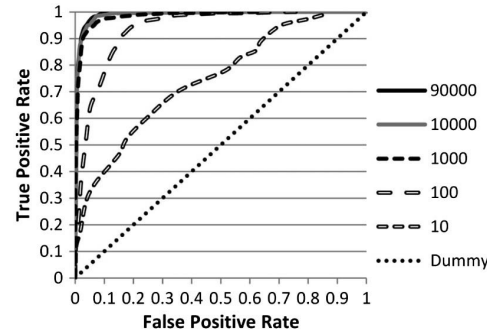
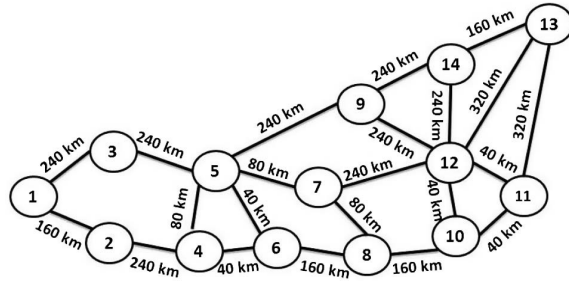


Deep learning (left) shown to accurately predict optical signal power which is main determinant of signal quality, based on the channel configuration alone.

More ML

QoT prediction using random forest ML algorithm

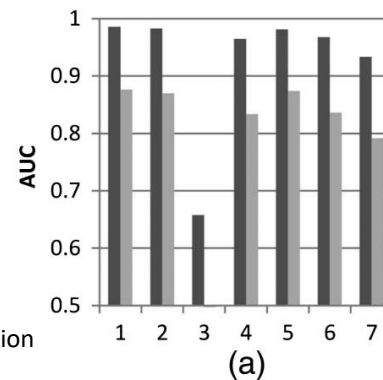
Dependency on training set size



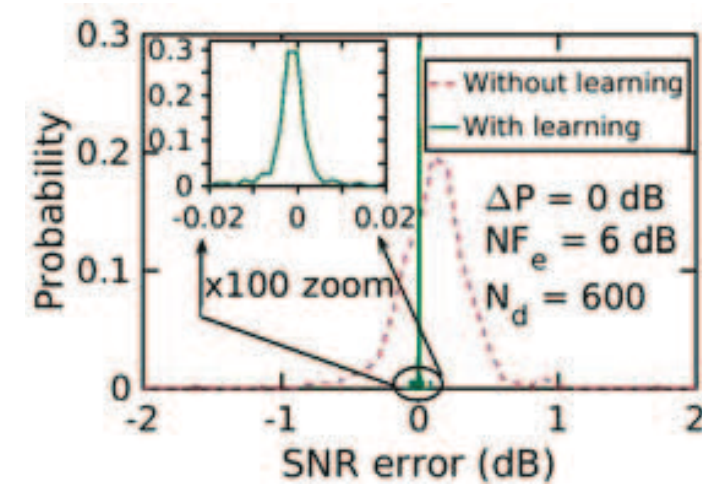
Relevance of different features

CONSIDERED FEATURE SUBSETS							
	S1	S2	S3	S4	S5	S6	S7
Number of links	✓	✓	✓	✓			
Lightpath length	✓	✓	✓	✓	✓	✓	
Length of longest link	✓	✓	✓	✓			
Traffic volume	✓	✓	✓		✓		✓
Modulation format	✓	✓		✓	✓	✓	✓
Guardband, modulation format, and traffic volume of nearest left and right neighbor	✓						

Source: C. Rottondi, et al. Machine-learning method for quality of transmission prediction of unestablished lightpaths. JOCN Vol. 10, No. 2, Feb. 2018



Using gradient descent on input parameters of QoT tool to reduce uncertainty on margins.



Source: E. Seve, J. Pesic, C. Delezoide, and Y. Pointurier. Learning process for reducing uncertainties on network parameters and design margins. OFC 2017.

• There are still issues:

- Scalability for large network systems need to be addressed, black box ML not a good option
- Data collection, storage and sharing is still the main problem

Summary

- Some history of programmable networks:
 - from active networks to Openflow
- Network virtualisation:
 - from Network function virtualisation to the cloud central office
 - CORD, ONAP, OPNFV,...
- SDN, NFV, cloud-CO application to future networks
 - Future wireless/optical/cloud use cases
 - Joint fixed/mobile orchestration enabled by virtualisation
- Optical layer disaggregation
 - Open Line system, OpenROADM, ONF ODTN, use of machine learning.
- Future challenges

Conclusions and Challenges

- SDN control across all layers can create great opportunities
 - The network really needs new revenue streams (.. to pay for 5G, etc.)
➔ Which new applications and services brought to the network??
- Providing new performance is a good start..
 - Low latency, bounded latency and availability
 - Virtualisation for customization of network service (like in the DC but over the network scale)
- The NFV/SDN approach has the ability to bring this through automation, but...
 - ...Higher reconfigurability brings higher complexity in decision making
 - How to decide and define exact requirements (processing power, latency, bandwidth)?
 - Scalability issues to be addressed
 - How to scale QoS for individual flows?

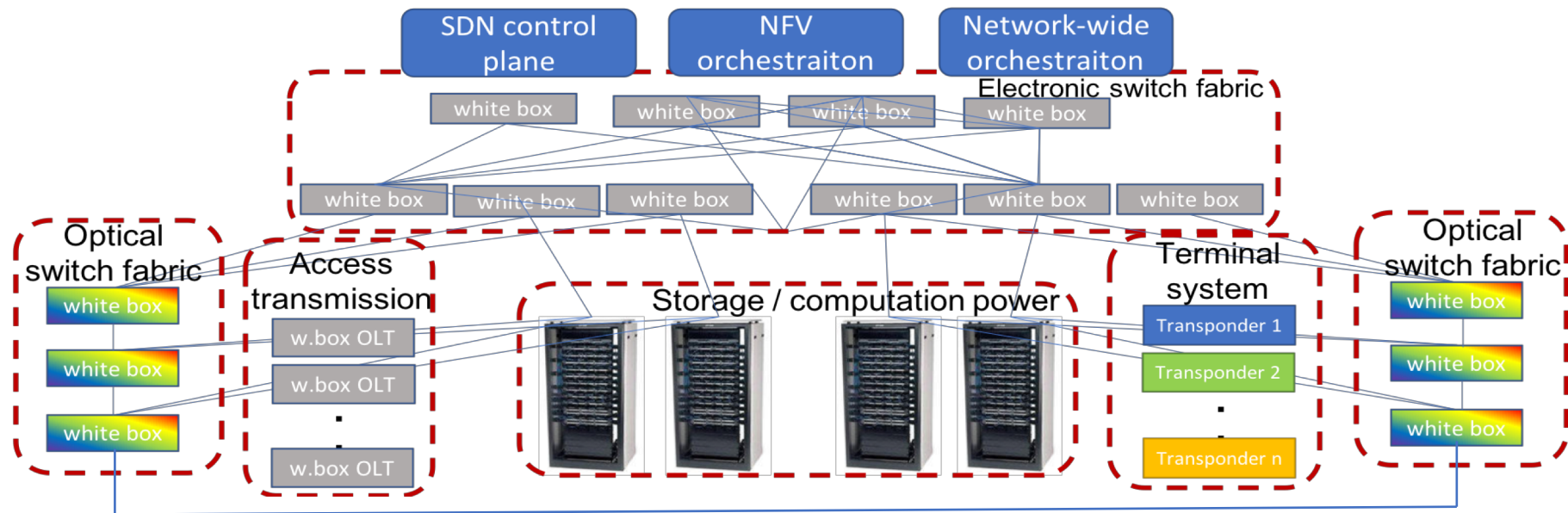


Future cloud CO: break the optical boundary

- Hybrid electronic/optical switching enabling optical bypass (e.g. direct link to rack or server) intra and inter CO: create low-latency paths when needed
 - Open optical system to enable physical layer orchestration with access, edge compute nodes, metro transmission, metro DC, etc.

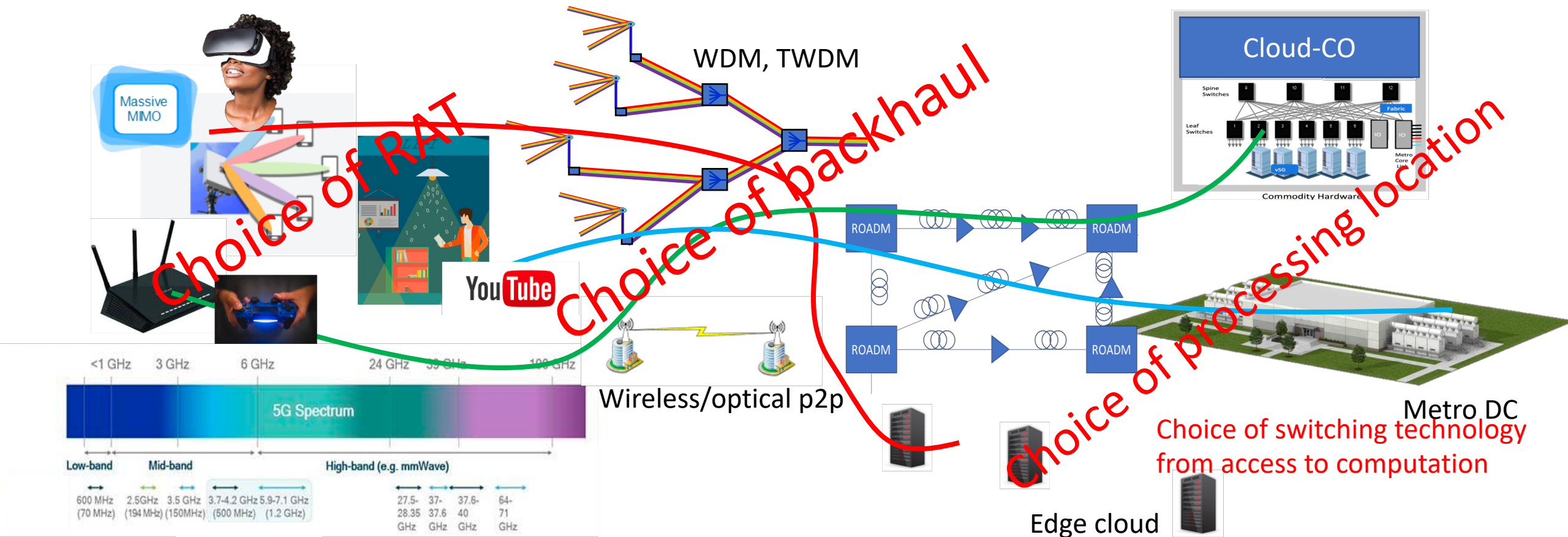
In addition to:

- Better control over individual flow performance (especially latency)
- Provide ability to map low-latency functions into appropriate hardware through suitable VNF location



We are considering the horizontal orchestration

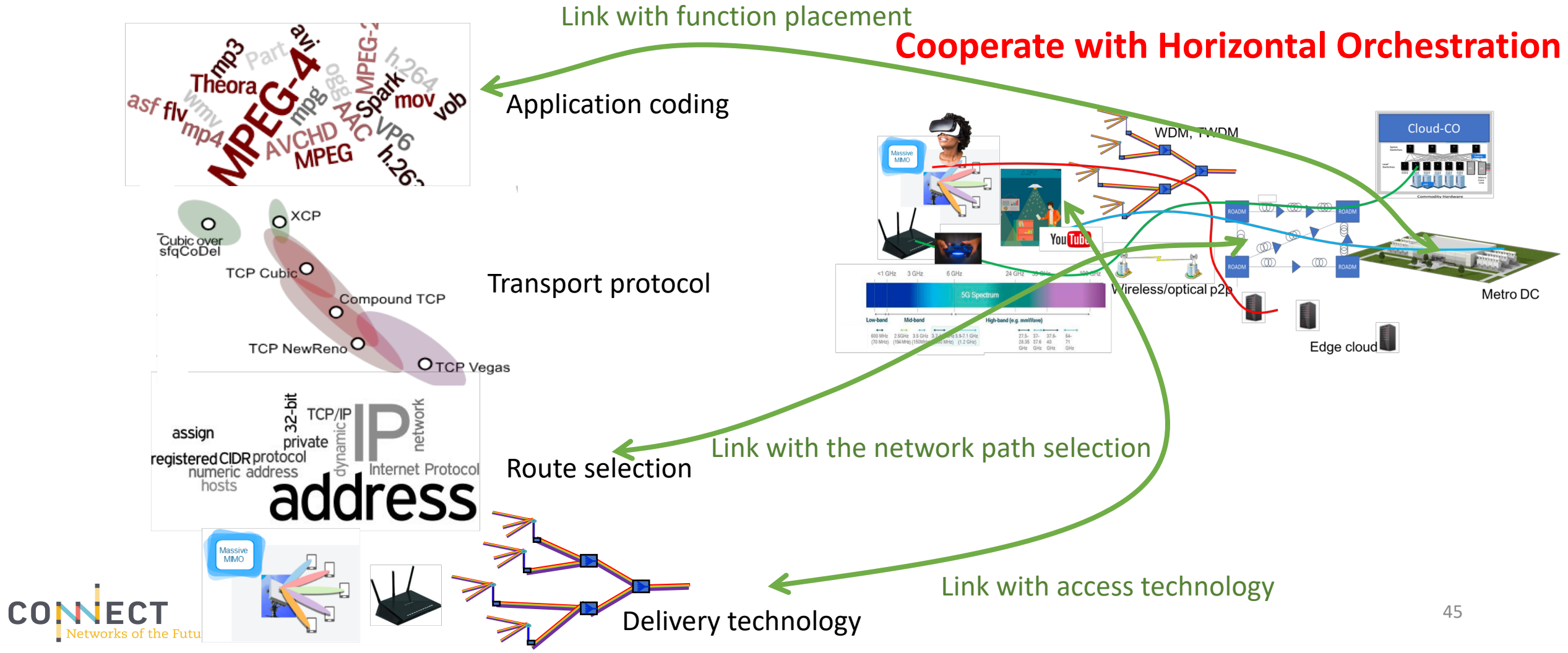
- Interconnect multiple domains, each with multiple technologies



Technologies are so different and variable that end-to-end statistical characterisation might be the only option

What about the vertical orchestration?

In addition to orchestrating physical domains.. orchestrate the protocol stack...





Thank you for your attention!

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