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Trinity College Dubli
Coláiste na Tríonóide, Baile Átha Clia
The University of Dublin

CONNECT
Centre for Future Networks

Embedding SDN and virtualisation into 5G telecommunications networks and beyond

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CONNECT and IPIC research centres

Trinity College Dublin
The University of Dublin

KYP Talks
IEEE Young Professionals affinity group , Kharagpur Section
24th August 2020,

Science Foundation Ireland sfi For what's next

IPIC
BRINGING PHOTONICS TO LIFE

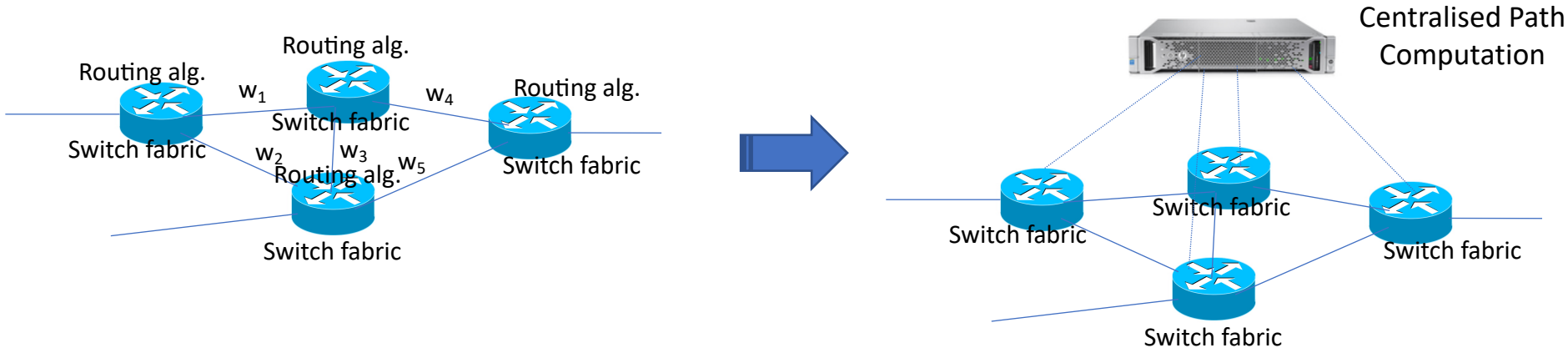
Content of the talk

TRINITY COLLEGE DUBLIN

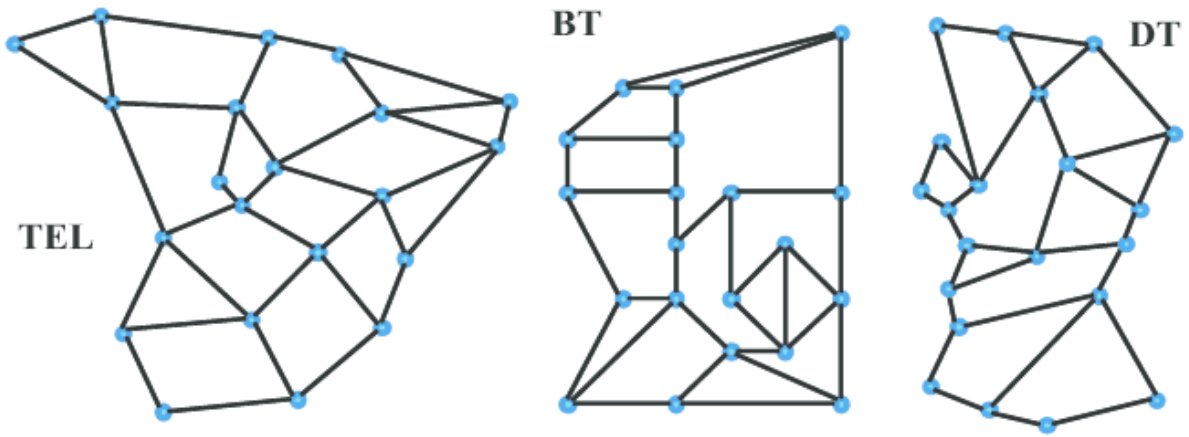
- OpenFlow and Software Defined Networks
- Network virtualisation and network function virtualisation technology (NFV)
- SDN and NFV gest applied to telecommunications networks
  - Cloud RAN
  - Central Office Cloudification (CORD)
  - The Fully virtualised PON
    - Multi-service and multi-tenancy performance
    - The optical-wireless convergence
    - The edge problem
- Disaggregating the optical layer
  - What is optical layer disaggregation?
  - Adding intelligent to disaggregation
  - Mininet-Optical
- Conclusions
  - DubliNets: enabling end-to-end control plane research across access and metro networks

Software Defined Networks

- Move from a system where routers run independent (but converging algorithms) to a system where all routes are decided by a central entity



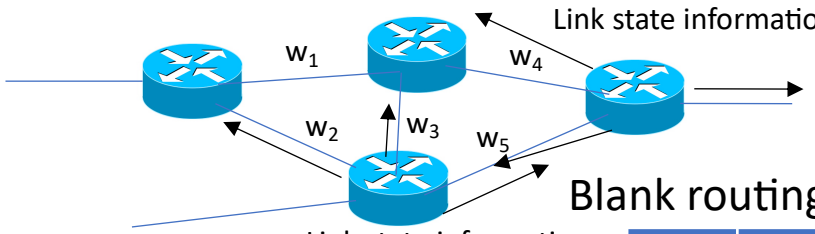
- Advantages:
  - More flexibility in deciding routes
  - The system opens up and facilitate development of integrated software



OpenFlow example

- Distributed approach:

Link state broadcast



Blank routing table

Destination	Use port

Shortest path calculation

Shortest path calculation

```
function Dijkstra(Graph, source):

    create vertex set Q 4 5
    for each vertex v in Graph:
                    ……..
```

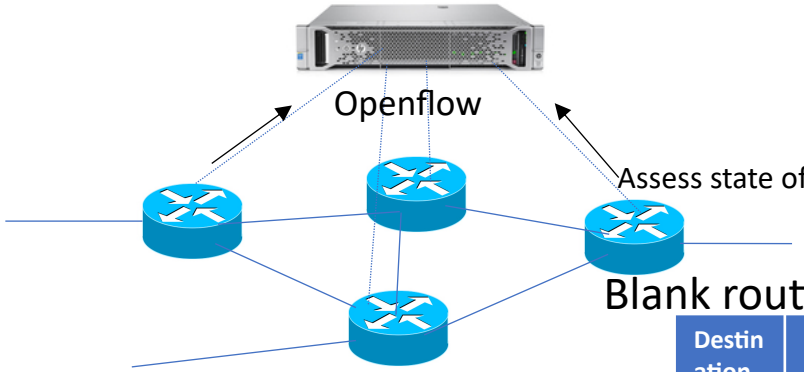
Routing table update

Destination	Use port
A	1
B	2
C	2

Routing table update

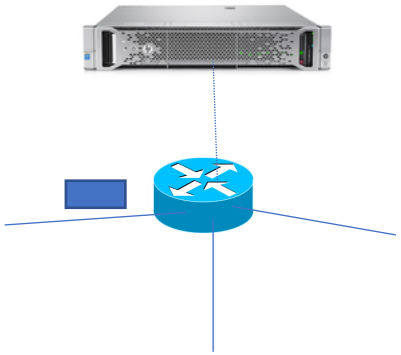
Destination	Use port
A	3
B	3
C	1

- Openflow centralized (reactive) approach

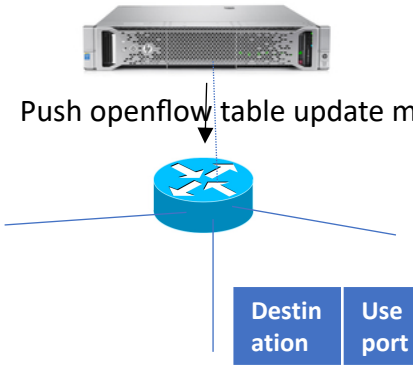


Blank routing table

Destination	Use port



Push openflow table update message



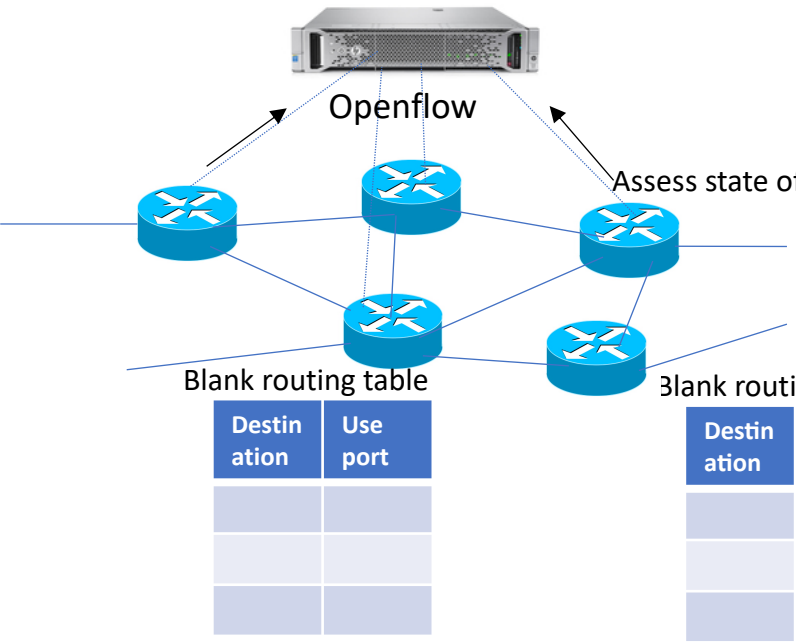
Destination	Use port
A	3

Destination	Use port
A	3

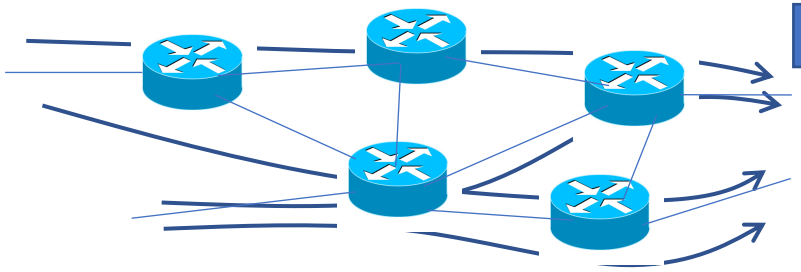
CONNECT Networks of the Future

OpenFlow example

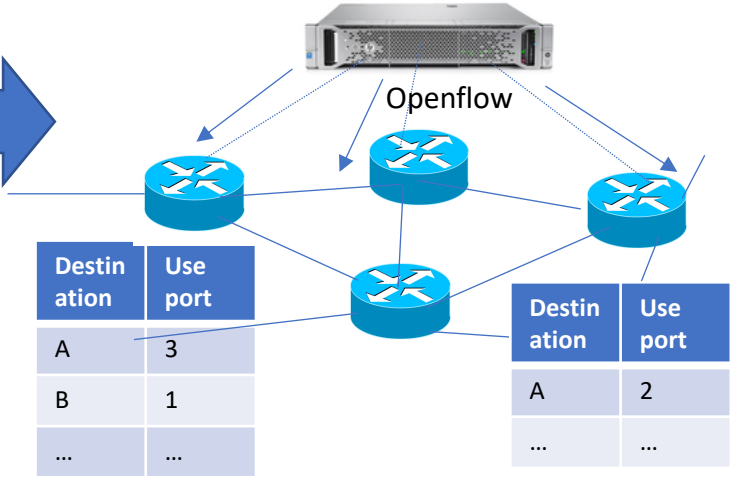
- Openflow centralized (proactive) approach



Optimal routes calculation

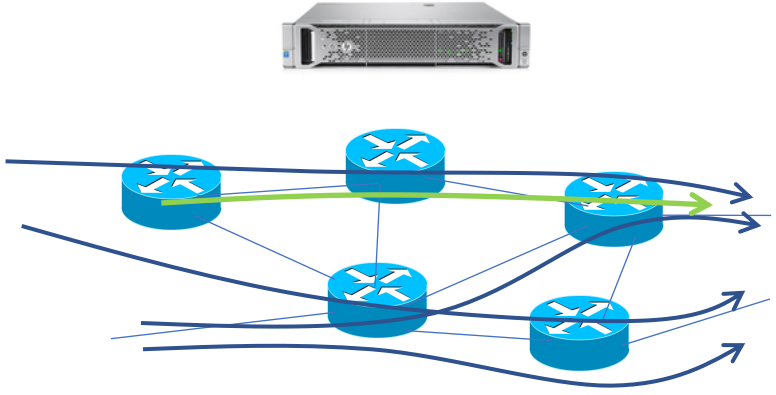


Routing table update

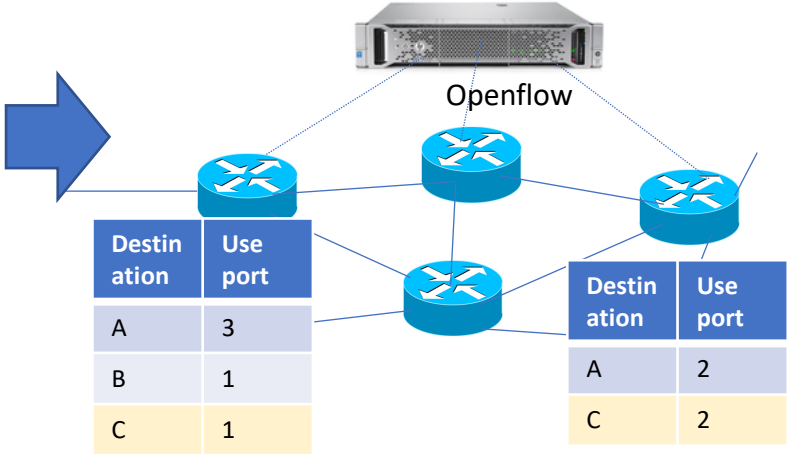


New user path request: A→C @1.5 Gb/s

Optimal routes calculation



Routing table update



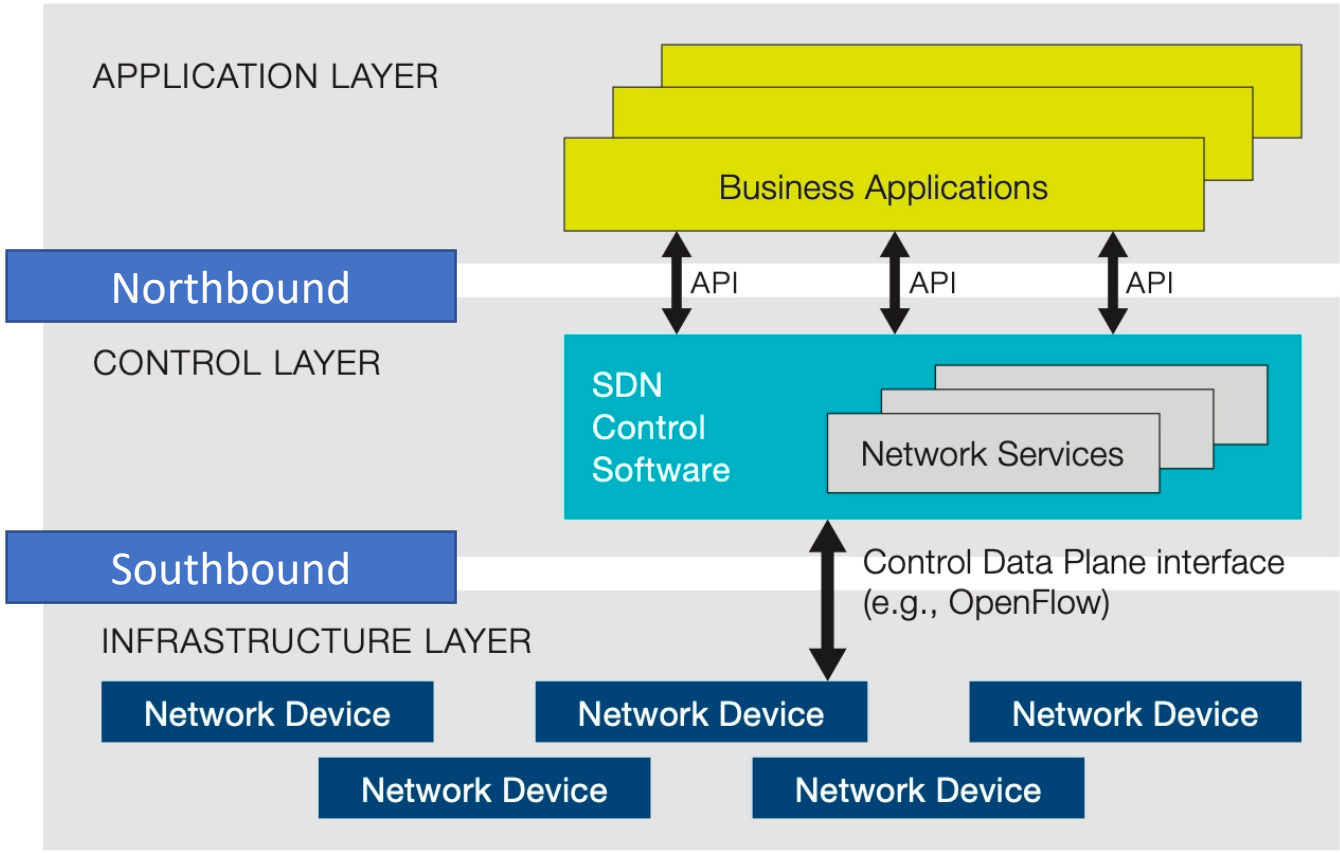
An SDN architecture

The control plane (controller) becomes the Operating System for the network.

Programmability requires well defined and standardized interfaces:

- Southbound interface to send instructions to network devices (think of hardware drivers)
- Northbound APIs are used by applications (e.g., the entity setting up a service) to express their intent

The controller transforms abstract, high-level intents into physical layer commands



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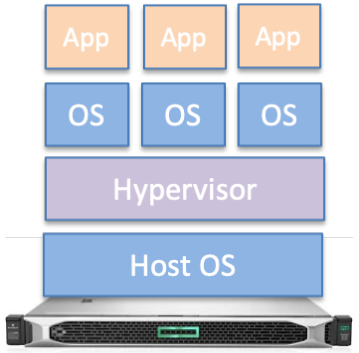
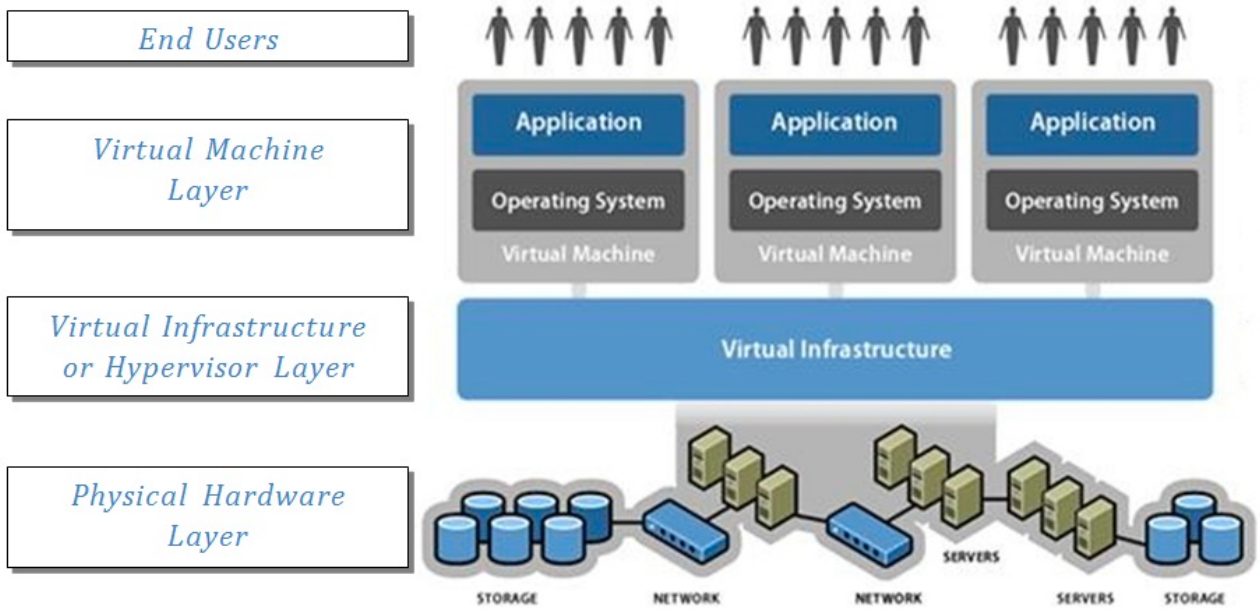
Virtualisation

Virtualisation gives the illusion of obtaining control of a physical entity or resource.



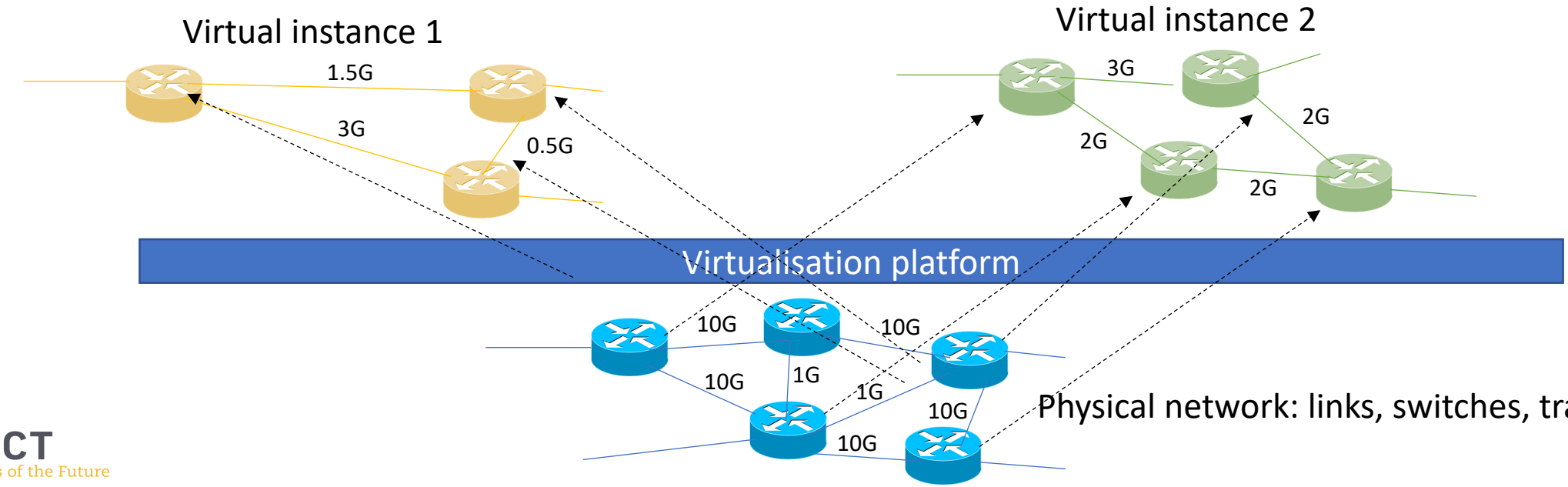
In Data centres the principle extends to the whole infrastructure

Completely decouple end user resources from physical hardware resources:
Increase in efficiency, lower energy usage, lower capital costs,…



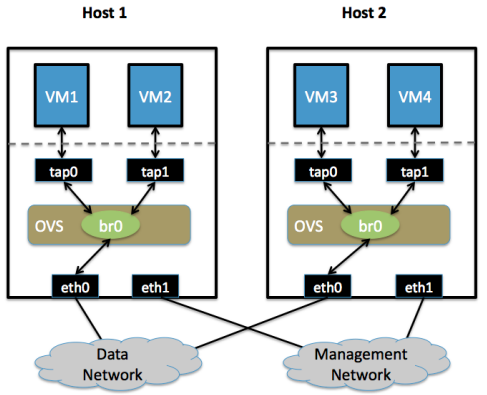
Network Virtualisation

- In networks, virtualisation could be seen as using software to abstract the functionality of a piece of hardware infrastructure.
  - 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

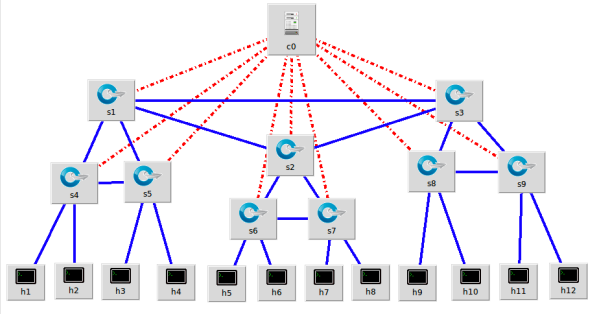


Some examples of network virtualisation testbeds

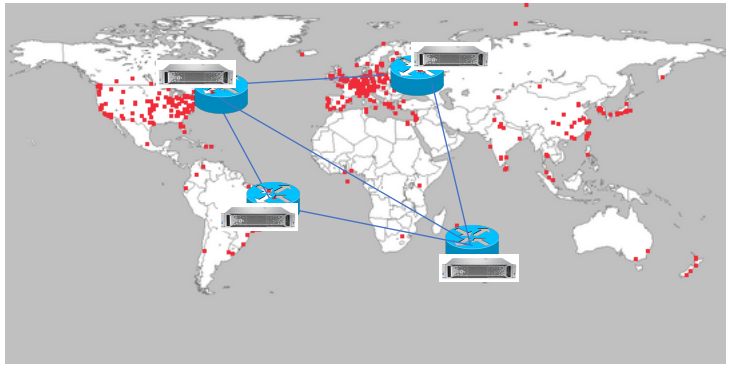
- From local scale:
  - OpenvSwitch (OvS): a virtual packet switch operating in Linux environment



  - Mininet: emulation platform comprising of virtual switches, hosts, and links
    - Can be used to test SDN controllers behaviour



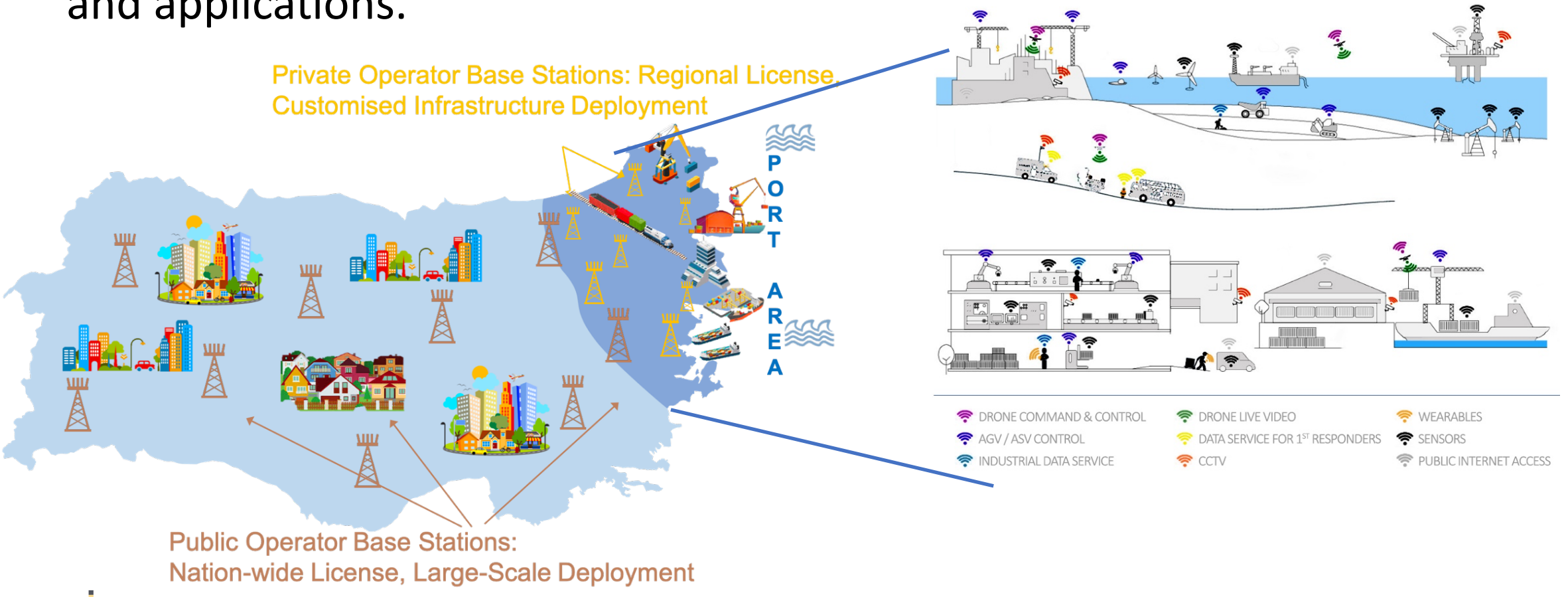
- To global scale:
  - Planetlab applies the idea of virtualisation using nodes and links spread out across the globe



- Today many others exist, including wireless and optical domains

Network slicing

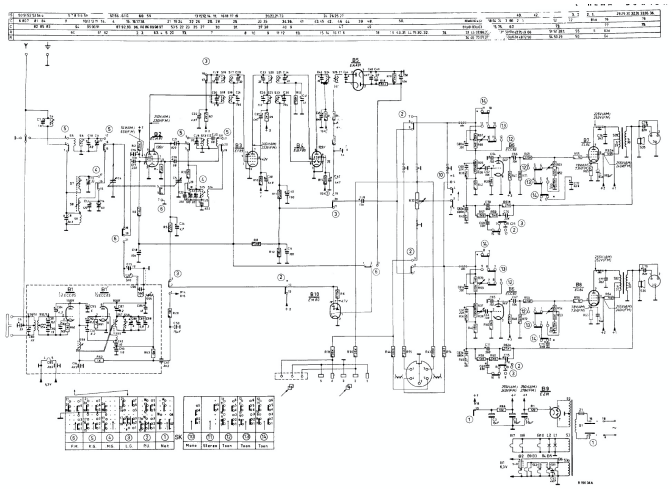
Virtualisation enables slicing, meaning that you can take a network infrastructure and partition it dynamically to serve different use cases and applications.

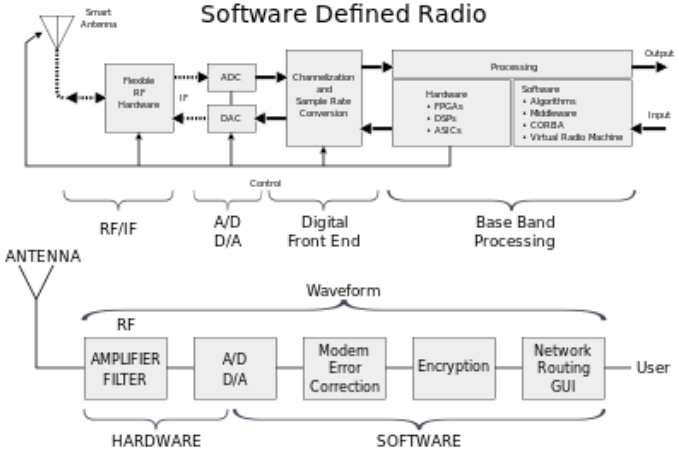


From virtualisation to network function virtualization (NFV)

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

Software Defined Radio is an early example: GNU radio

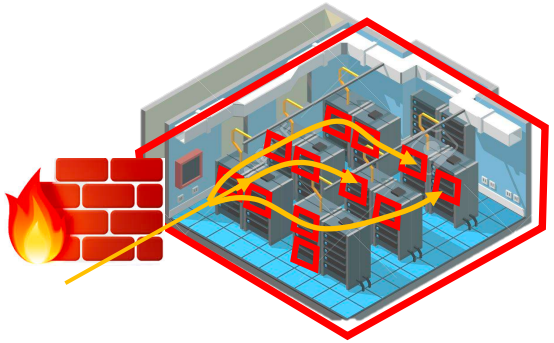




- Advantages:
  - flexibility of adapting transmission format to environment and application
  - coordination with other radios (either distributed or centralized)
  - Integration with other software components…

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 o vBRAS): aggregates incoming access connections, enforces QoS, provides layer 3 (IP) connectivity
  - Customer Premises Equipment (vCPE): operates routers, firewalls, VPNs, NAT

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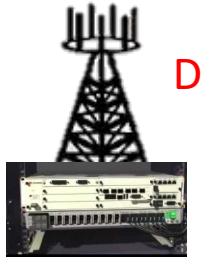
SDR in today's telcos

- SDR today stronger than ever:
  - C-RAN based on SDR ➔ srsLTE, Amarisoft, Flexran, OpenAirInterface, OpenLTE, or the implementations based on GNU radio,…
  - Enabling flexibility in resource allocation, statistical multiplexing,…
  - Also, integration with other elements for convergence with other technologies, joint orchestration,…

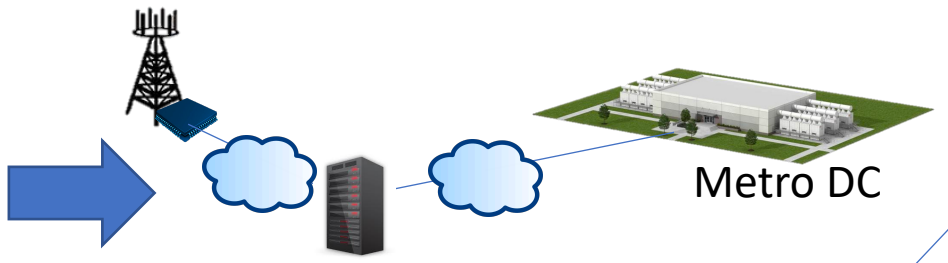


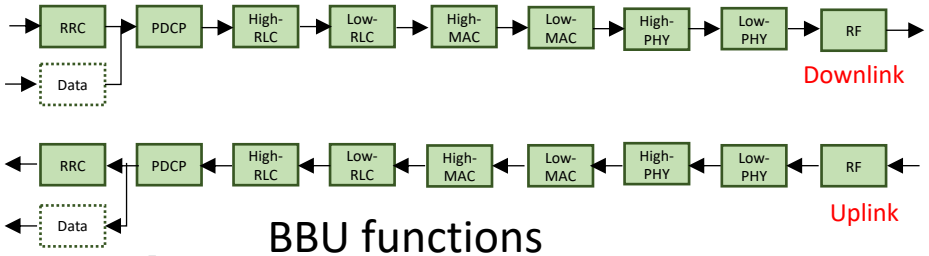
Distributed RAN

Hardware baseband unit (BBU)

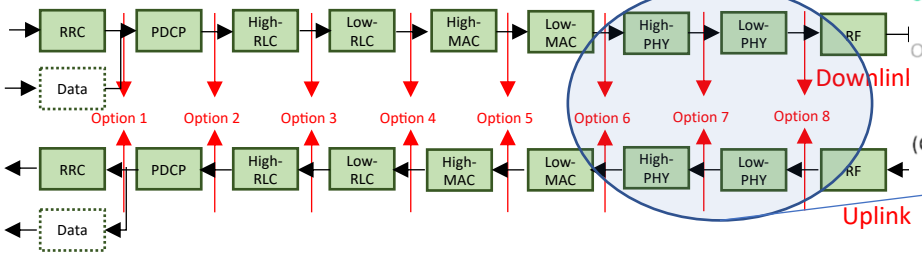
Remote Radio Unit (RRU)

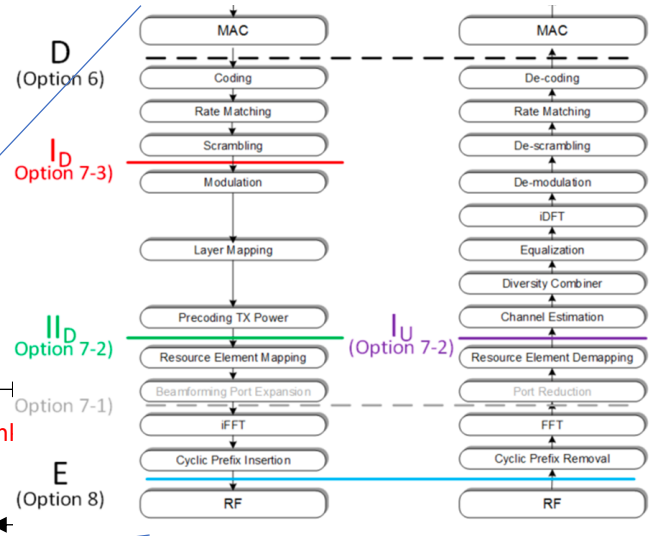
Centralised RAN





BBU functions

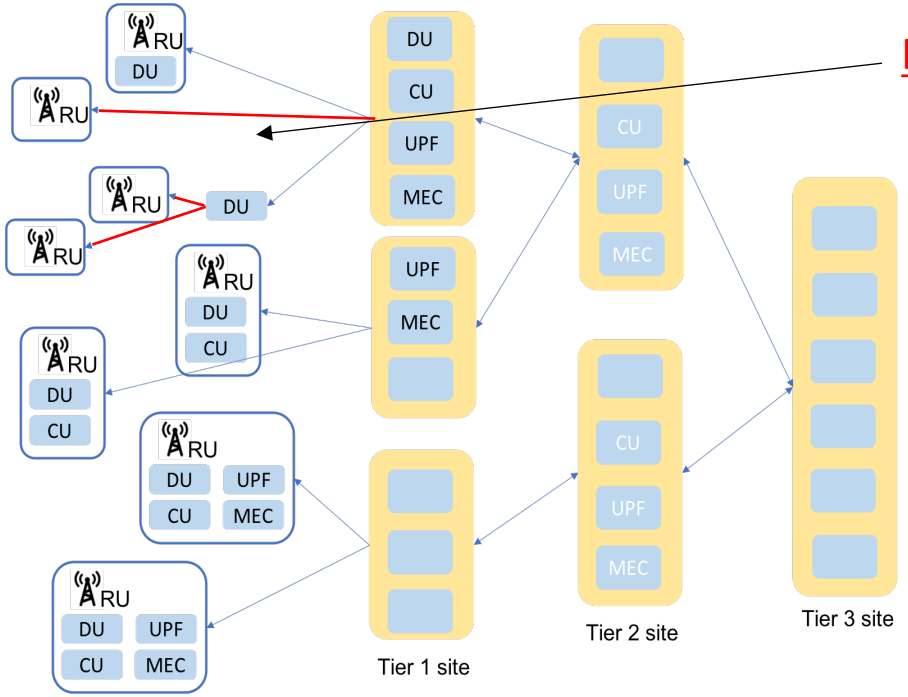




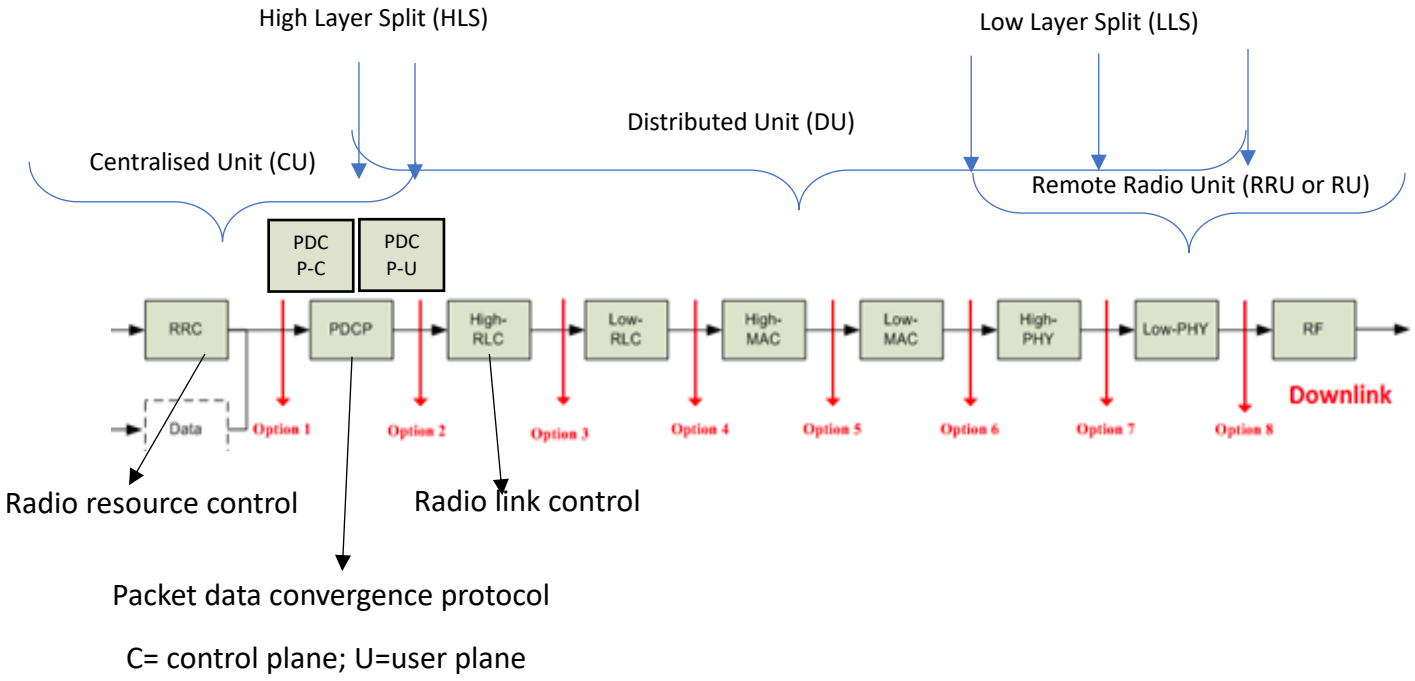
Source: Next Generation Mobile Network (NGMN) alliance. NGMN Overview on 5G RAN Functional Decomposition. Feb., 2018

Physical disaggregation of the mobile network

- The different pieces (functions) of the mobile stack can be disaggregated and placed in different locations



LLS is the low latency interface, between RRU and DU

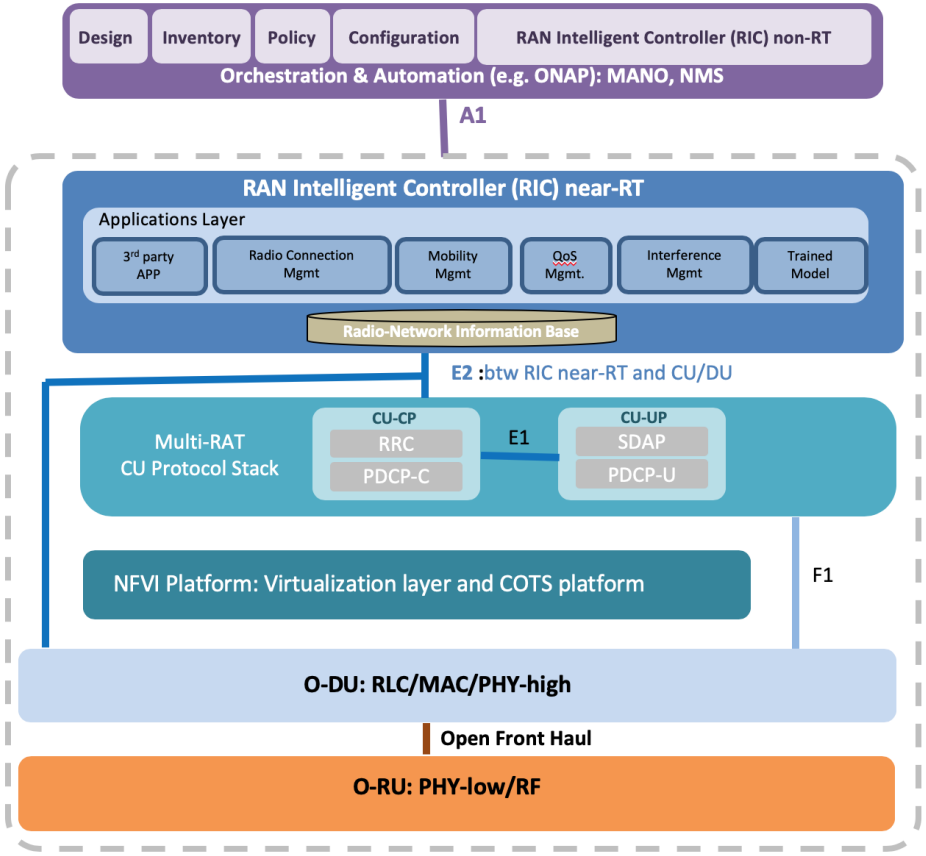


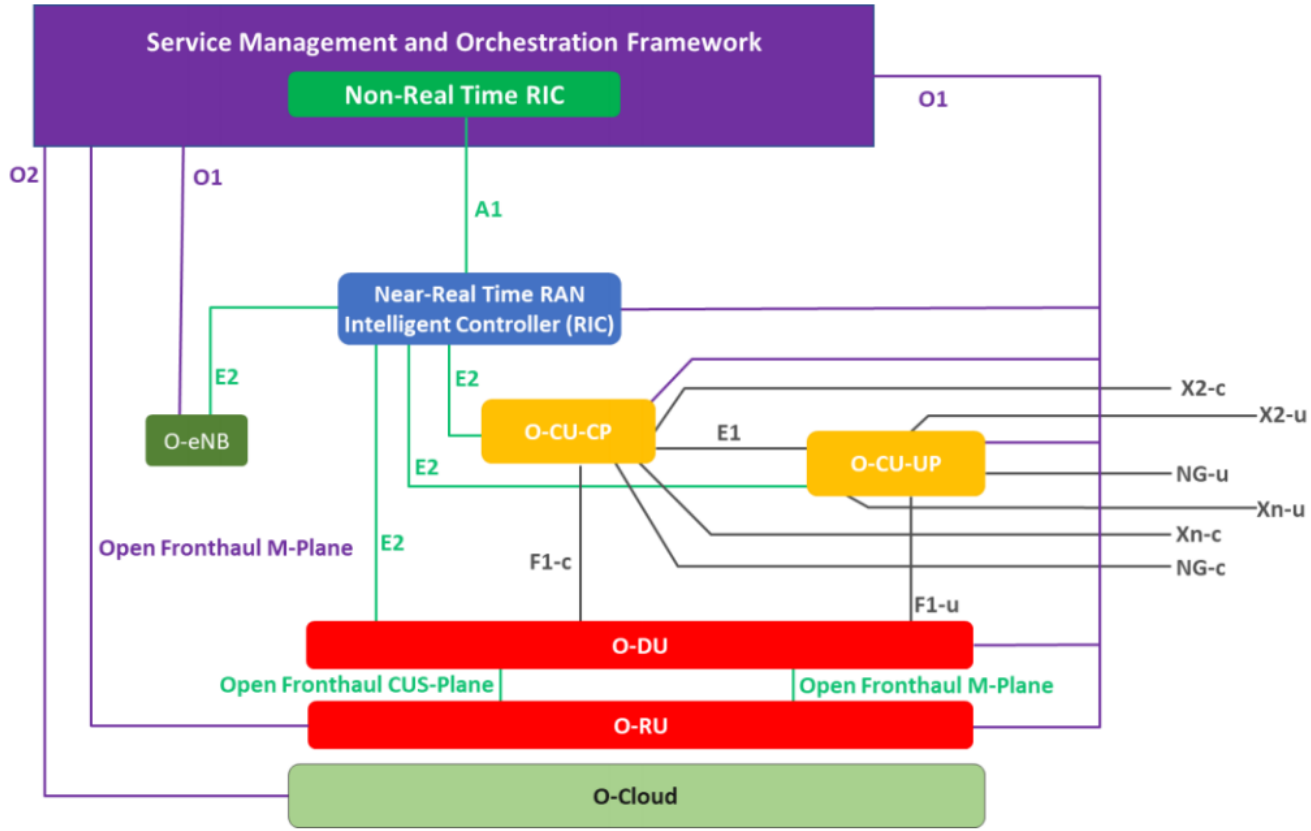
UPF Location	Tier 1	Tier 2	Tier 3
Relative number of sites	1000	100	10
Transport latency (1-way)	0.6 ms	1.2 ms	4.2 ms
Estimated 5G latency (RTT)	9.2 ms [eMBB]	10.4 ms [eMBB]	16.4 ms [eMBB]
	2.2 ms [URLLC]	3.4 ms [URLLC]	9.4 ms [URLLC]

Source: NGMN

O-RAN

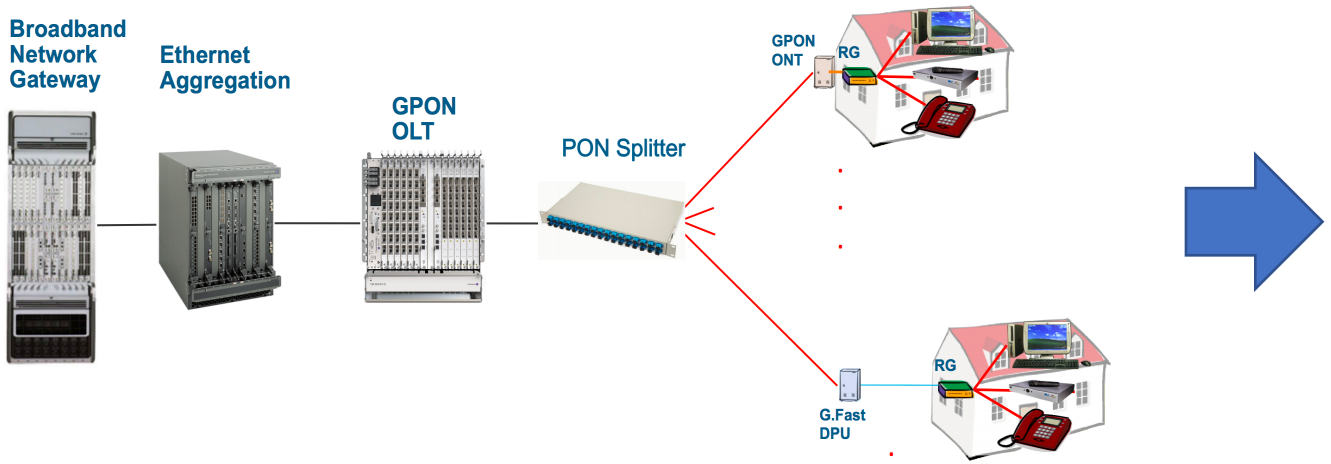
- Split 7.2 being standardised, so you can go and buy an RU and then install the rest as opensource software
- O-RAN is providing standardisation of several interfaces, so the system can be fully open

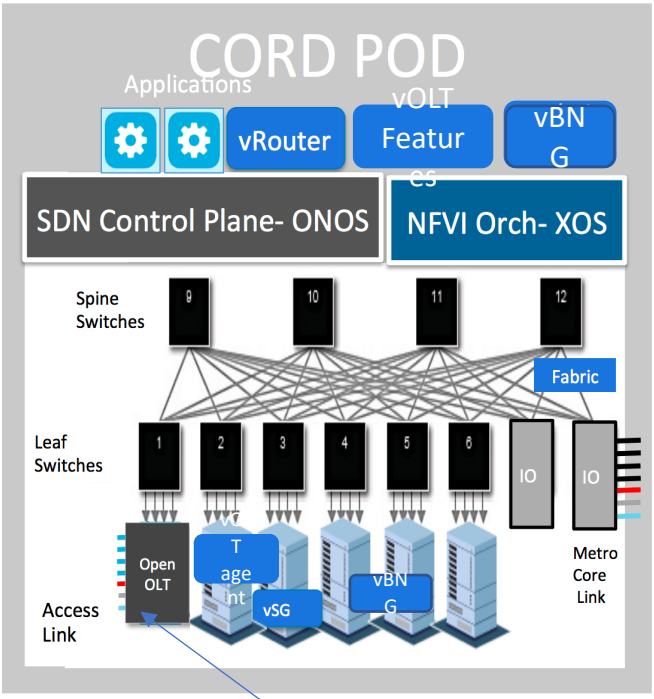




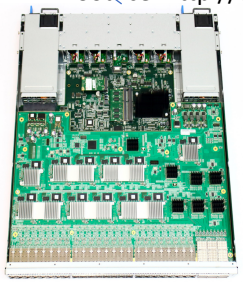
Central Office Virtualisation

- Getting SDN and NFV into the central office:



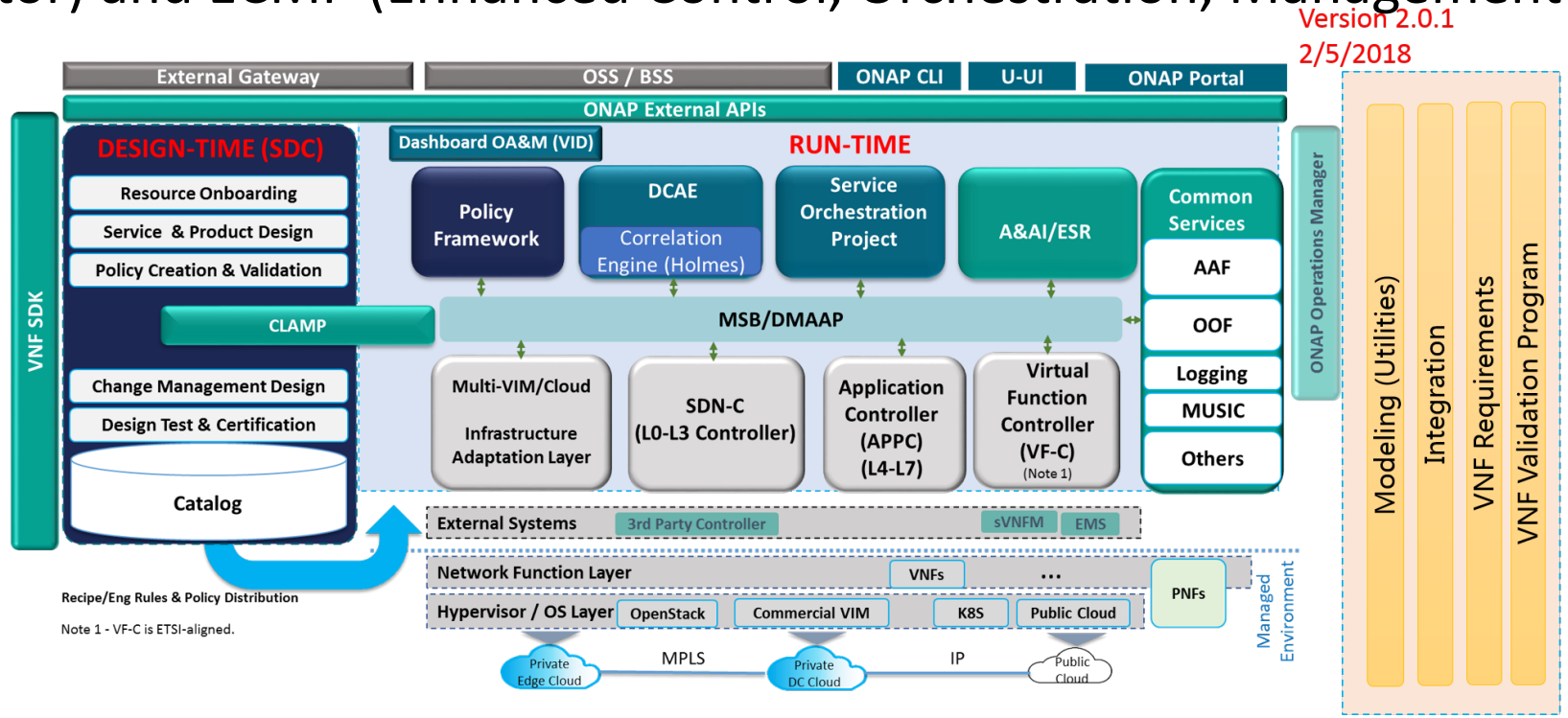


- Latest architecture called “SDN Enabled Broadband Access (SEBA)”
- Being trialed by several operators world-wide
  - E.g., AT&T recently carried out trials on XGS-PON using OLT white boxes



But there's more to NFV than CORD…

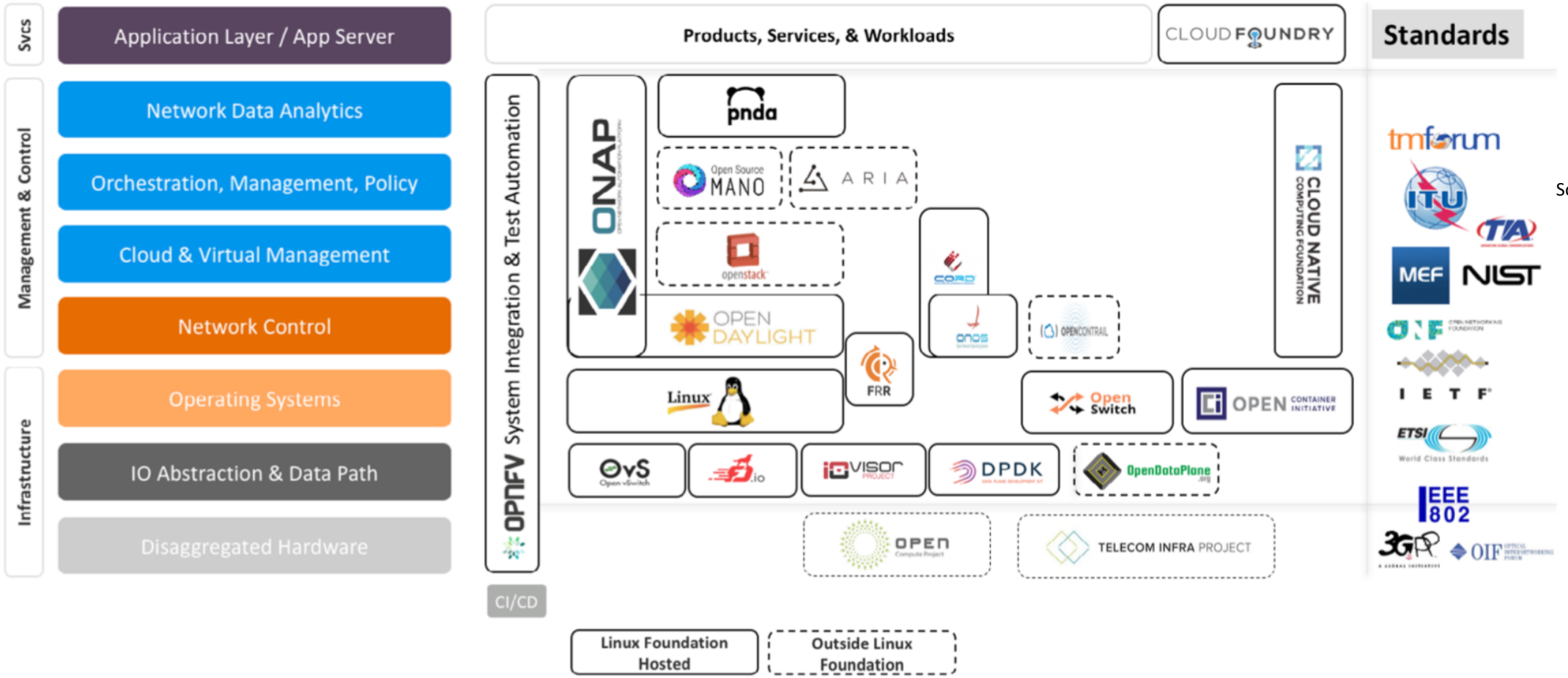
ONAP: The Open Network automation Platform: recently formed by the fusion of OPEN-O (Open Orchestrator) and ECMP (Enhanced Control, Orchestration, Management and Policy)



- 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

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

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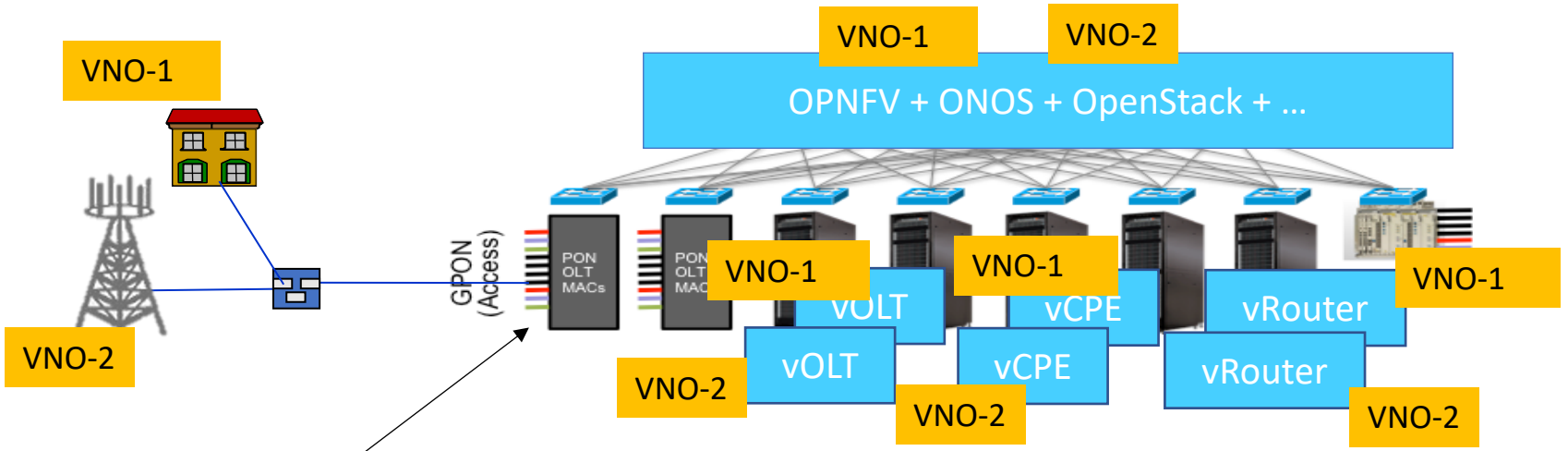
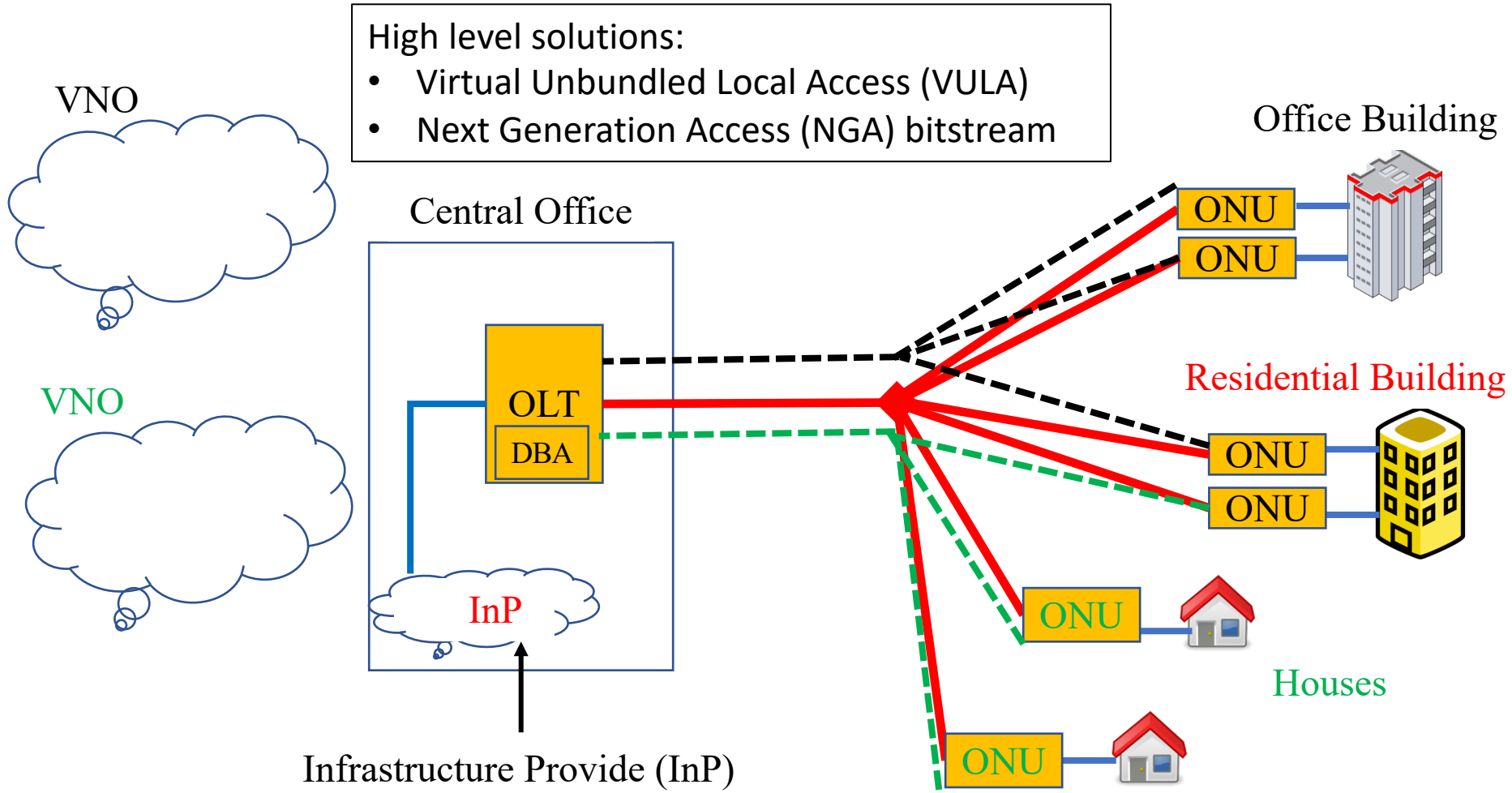
Is CORD virtualization enough for PONs?

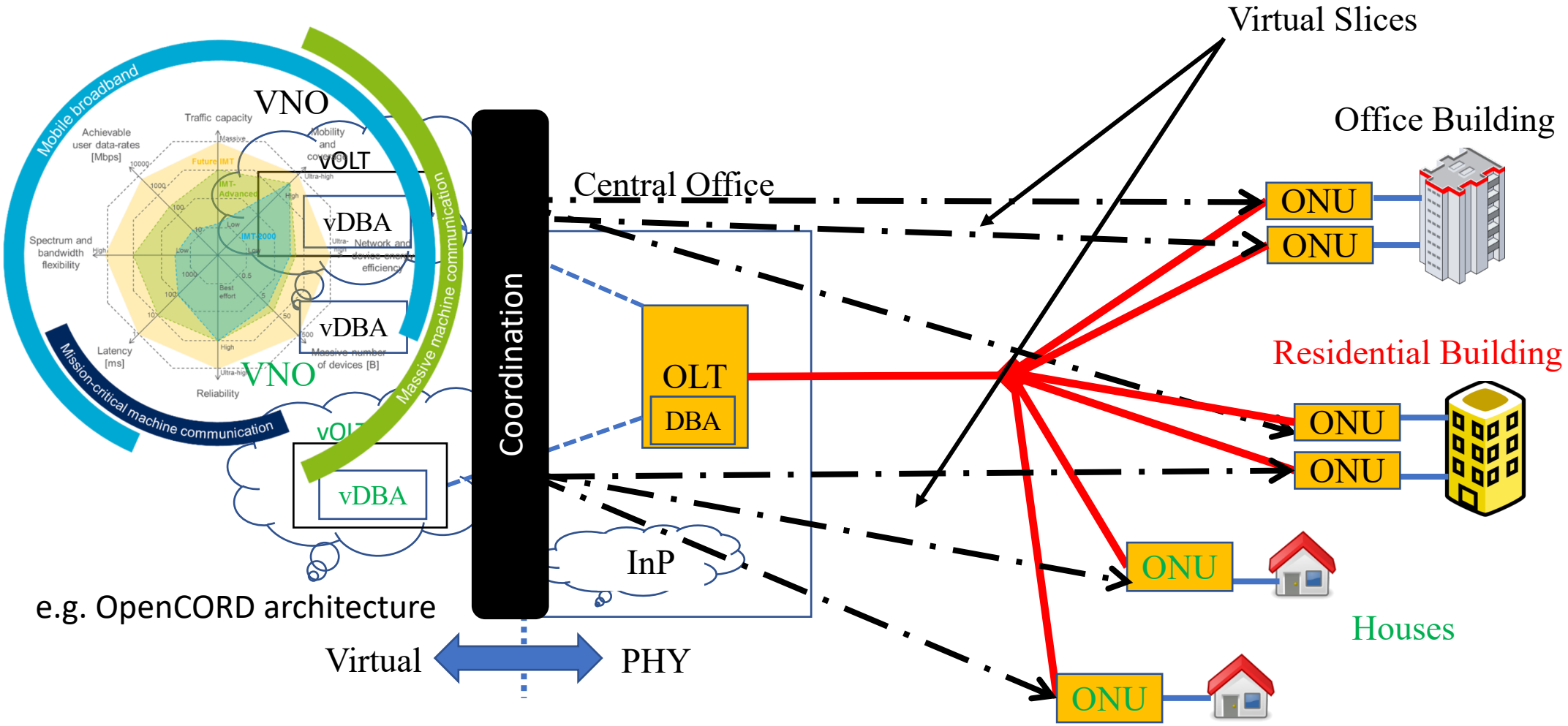


- Functions are virtualized and multiple instances can be assigned to different Virtual Network Operators (VNOs)
- … but for example Dynamic Bandwidth Allocation (DBA) is carried out in hardware

This is the current PON Multi-Tenancy



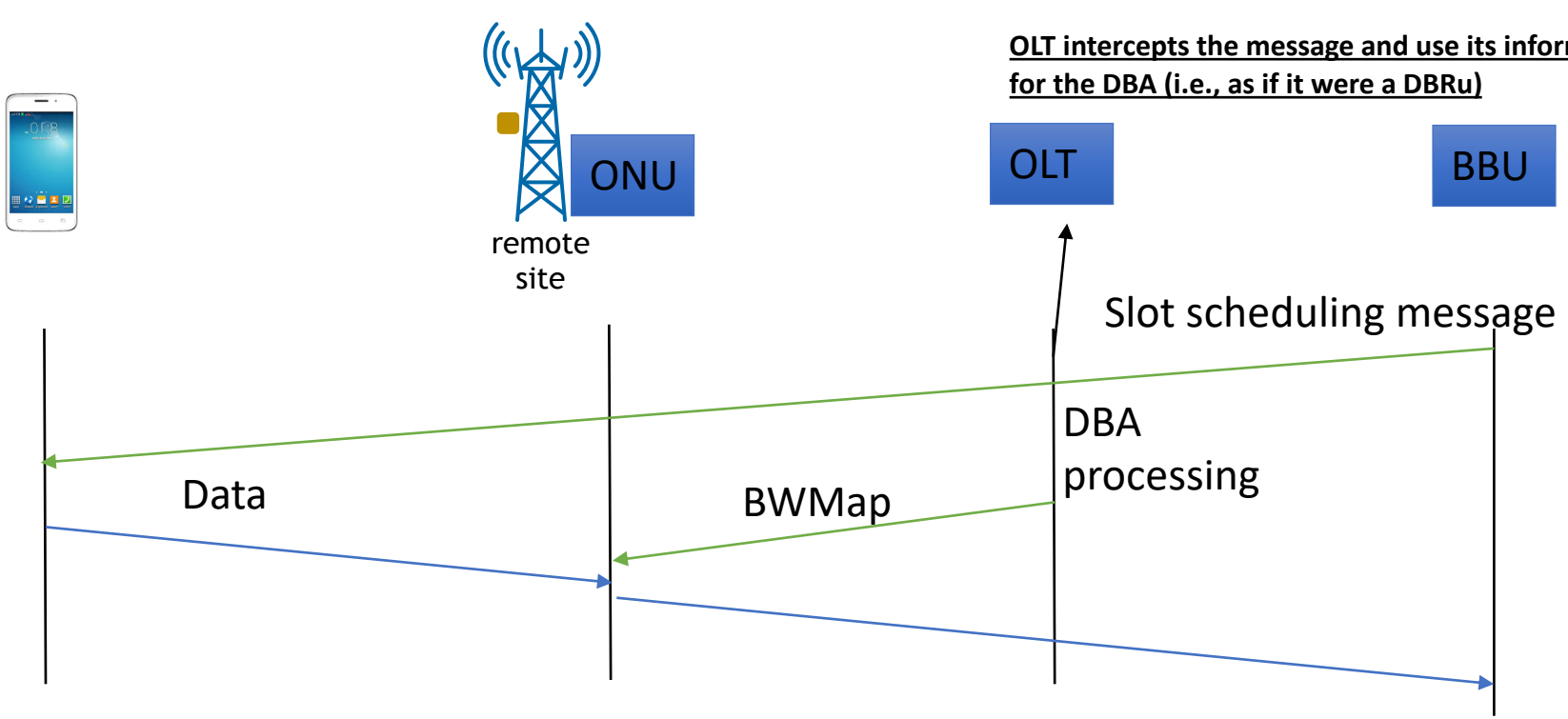
This is True PON Multi-Tenancy



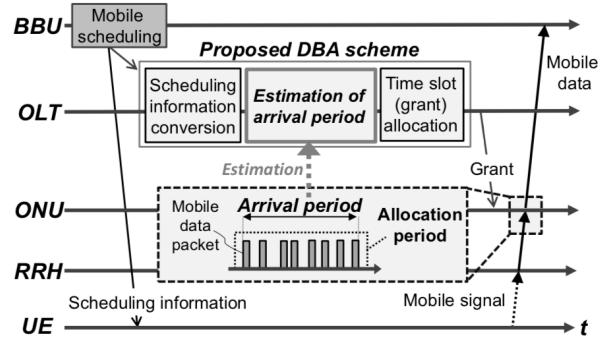
- M. Ruffini, A. Ahmadi, S. Zeb, N. Afraz and F. Slyne. **The Virtual DBA: Virtualizing Passive Optical Networks to Enable Multi-Service Operation in True Multi-Tenant - Environments.** OSA Journal of Optical Communications and Networking, No.4, Vol.12, April 2020
- M. Ruffini, F. Slyne. Moving the Network to the Cloud: the Cloud Central Office Revolution and its Implications for the Optical Layer. IEEE/OSA Journal of Lightwave Technology, Vol. 37, No 7, April 2019

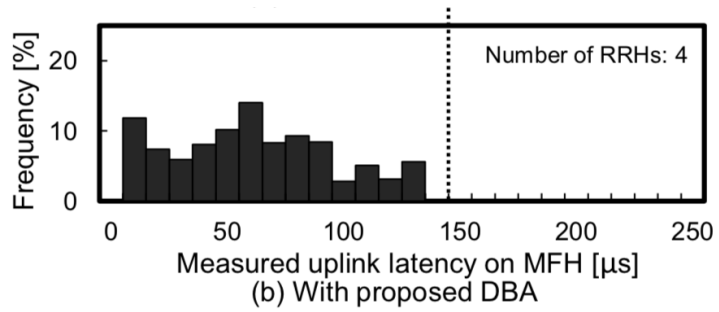
C-RAN requires deep virtualization

- CORD virtualizes the PON management and all other aggregation, routing, service layers …**BUT**… The MAC and PHY are in hardware.
- Operating a PON in low latency mode requires access to scheduling



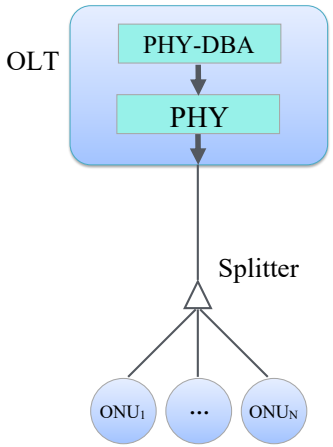
Standardised in ITU-T G.989.3Am1



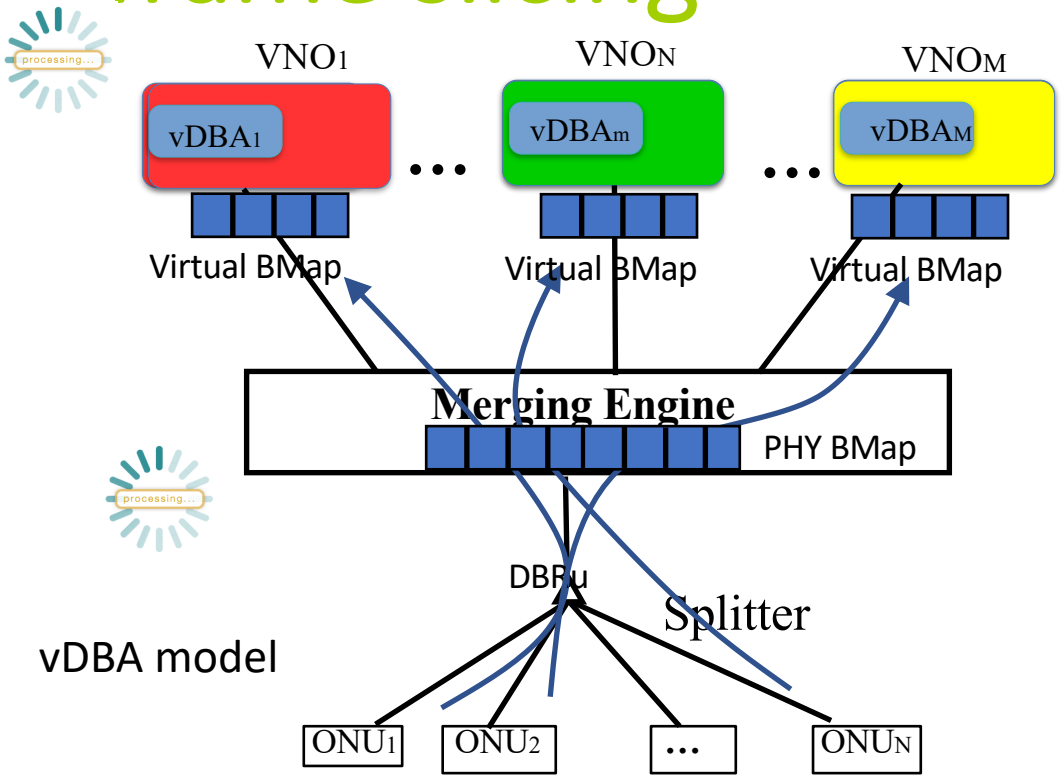


Source: H. Uzawa, et al. Practical Mobile-DBA Scheme Considering Data Arrival Period for 5G Mobile Fronthaul with TDM-PON. ECOC 2017.

Full disaggregation of the OLT with upstream frame slicing



Current physical DBA model



vDBA model

- 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)
- Also included in BBF TR-402 “PON Abstraction Interface for Time-critical Applications” and recently in TR-370i2 “Fixed Access Network Sharing (FANS)

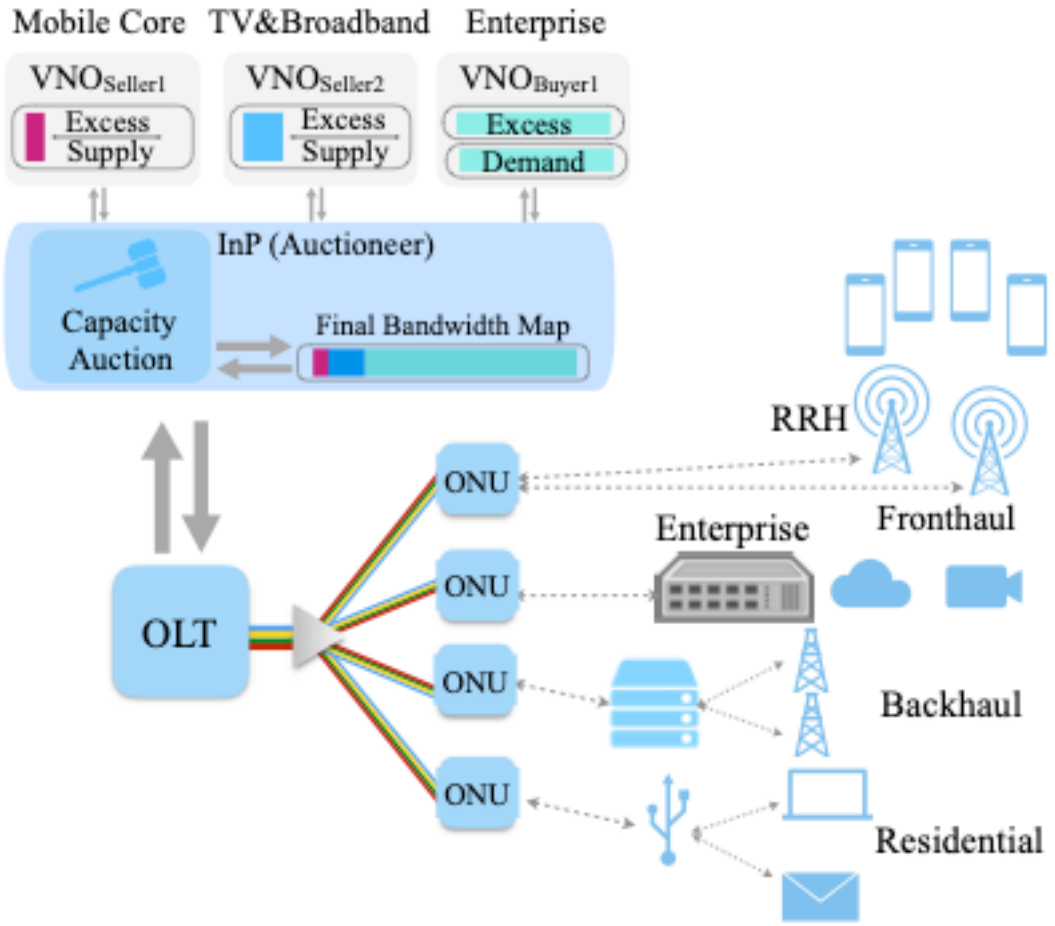
Solution: Multi-Tenant PON Market

Incentive Solution:

- Monetary Compensation for Excess Bandwidth

Market features:

- Multiple traders (sellers, buyers) on both sides
- Multiple Identical frame units to trade
- Roles change in each frame



Improved McAfee Double Auction

A Multi-Item Double Auction Mechanism:

- Meets desirable economic properties:
  - Truthfulness
  - Individual Rationality
  - Budget Balance

Algorithm 1: Multi-Item Double Auction

1 Sort sellers ascending so $v_1^B > v_2^B > ... > v_m^B$

2 Sort buyers descending so $v_1^S < v_2^S < ... < v_n^S$

3 Find $max(S_L, B_K)\ \forall\ v_L < v_K$ **and** $\sum_1^K q_j^B \leq \sum_1^L q_i^S$

4 $\gamma = \frac{1}{2} \times (v_{L+1} + v_{K+1})$

5 **if** $\gamma \in [v_L, v_K]$ **then**

6 $\quad \Theta_{Pr} = \min(\sum_1^{i=L} q_i, \sum_1^{j=K} q_j)$ — Quantity

$\quad p^B = p^S = \gamma$ — Pricing

8 **else if** $\gamma \notin [v_L, v_K]$ **then**

9 $\quad \Theta_{Pr} = \min(\sum_1^{i=L-1} q_i, \sum_1^{j=K-1} q_j)$ — Quantity

10 $\quad p^B = v_K$

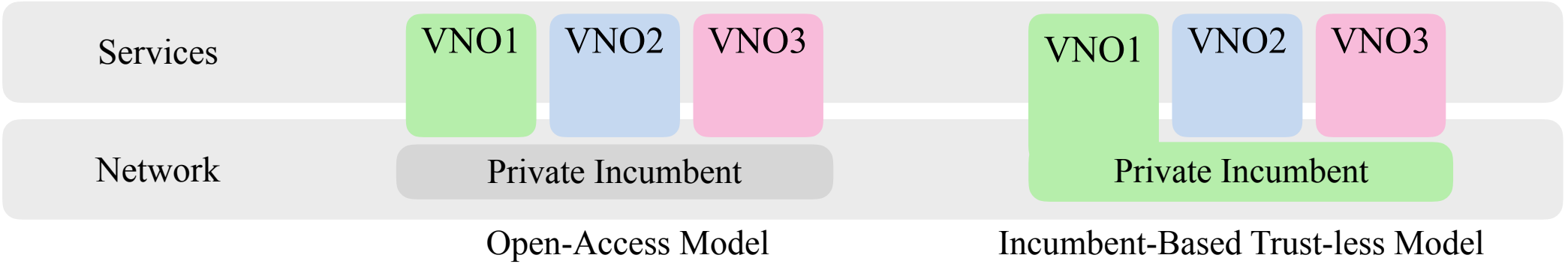
11 $\quad p^S = v_L$ — Pricing

N. Afraz and M. Ruffini, "A Sharing Platform for Multi-Tenant PONs," in Journal of Lightwave Technology, vol. 36, no. 23, pp. 5413-5423, 1 Dec.1, 2018.

The problem with Incumbent access networks

- The previous work however requires that all VNOs trust the infrastructure provider (OK in open access model)

- However today the incumbent-based model is widespread

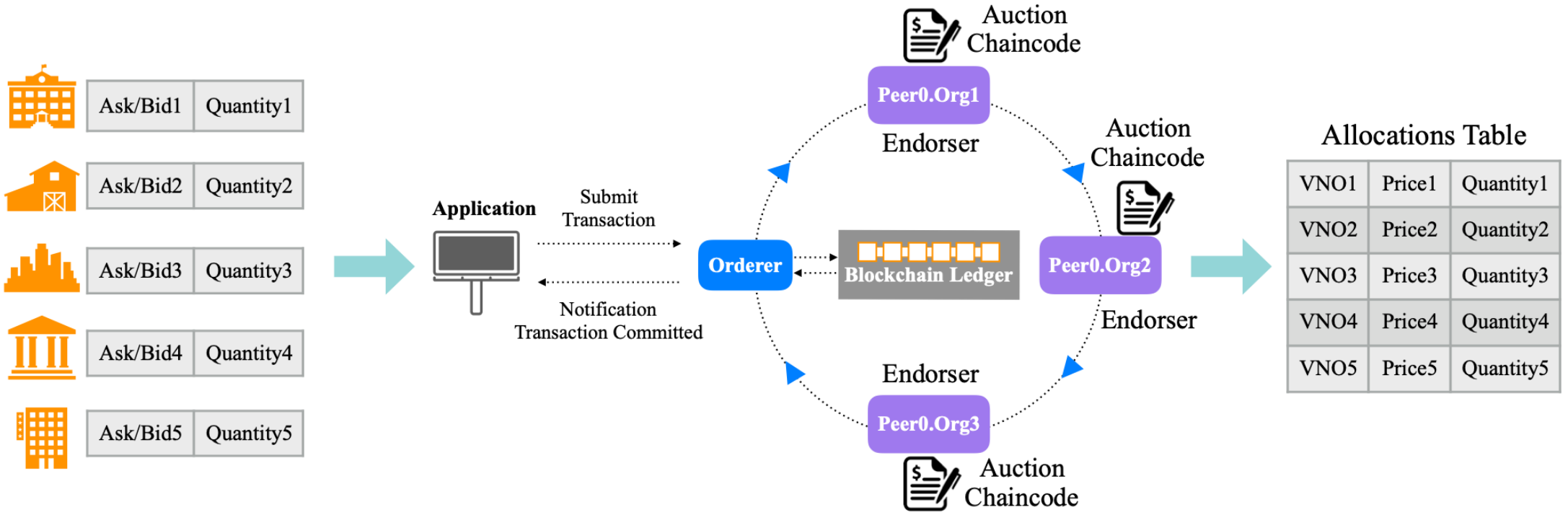


Open-Access Model

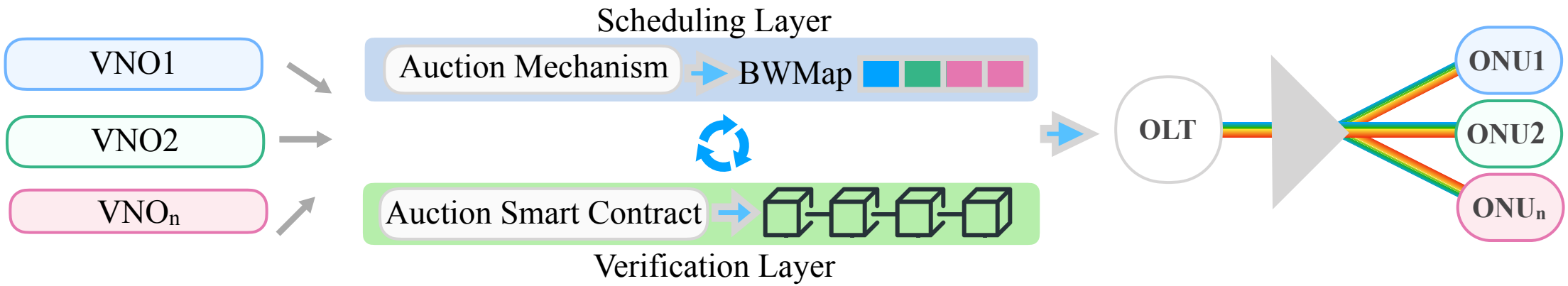
Incumbent-Based Trust-less Model

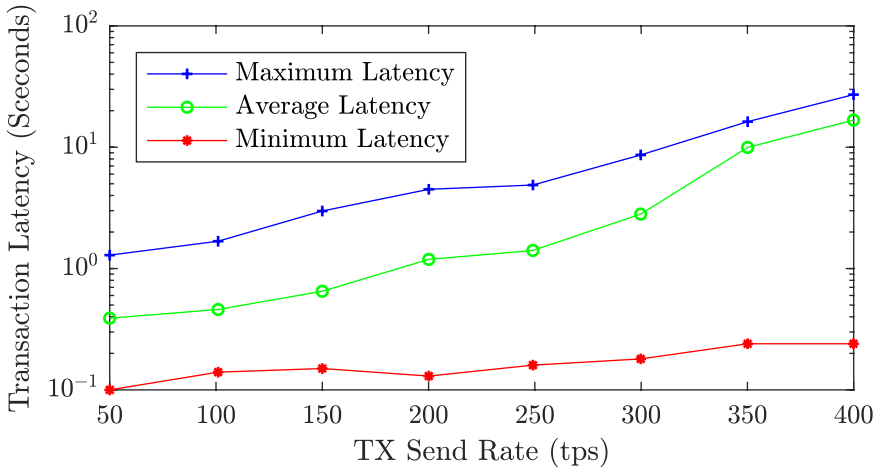
Distributed Market on Blockchain

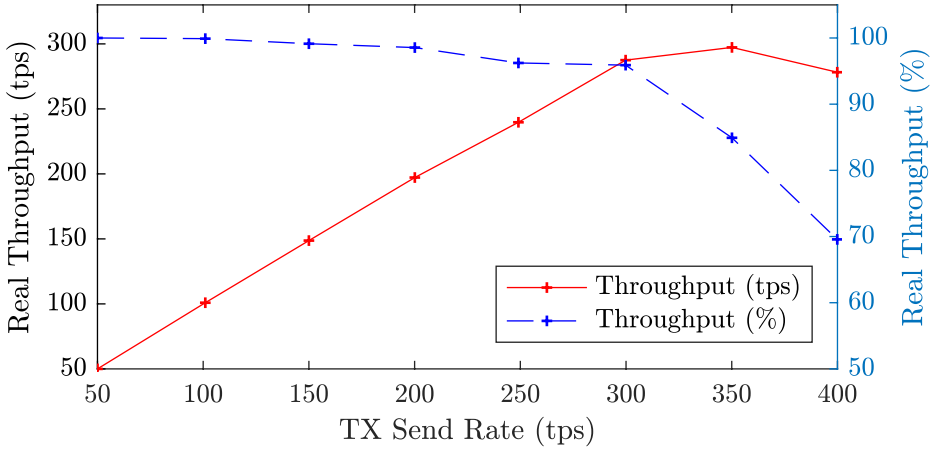
Fault Tolerant distributed record-keeping
- Distributed ledger technology
Manipulation-proof distributed Auction
- Smart Contract technology



Blockchain as verification mechanism







- N. Afraz and M. Ruffini. A Distributed Bilateral Resource Market Mechanism for Future Telecommunications Networks. Proc. of IEEE Globecom 2019.
- N. Afraz, M. Ruffini. 5G Network Slice Brokering: A Distributed Blockchain-based Market. IEEE EuCNC, June 2020

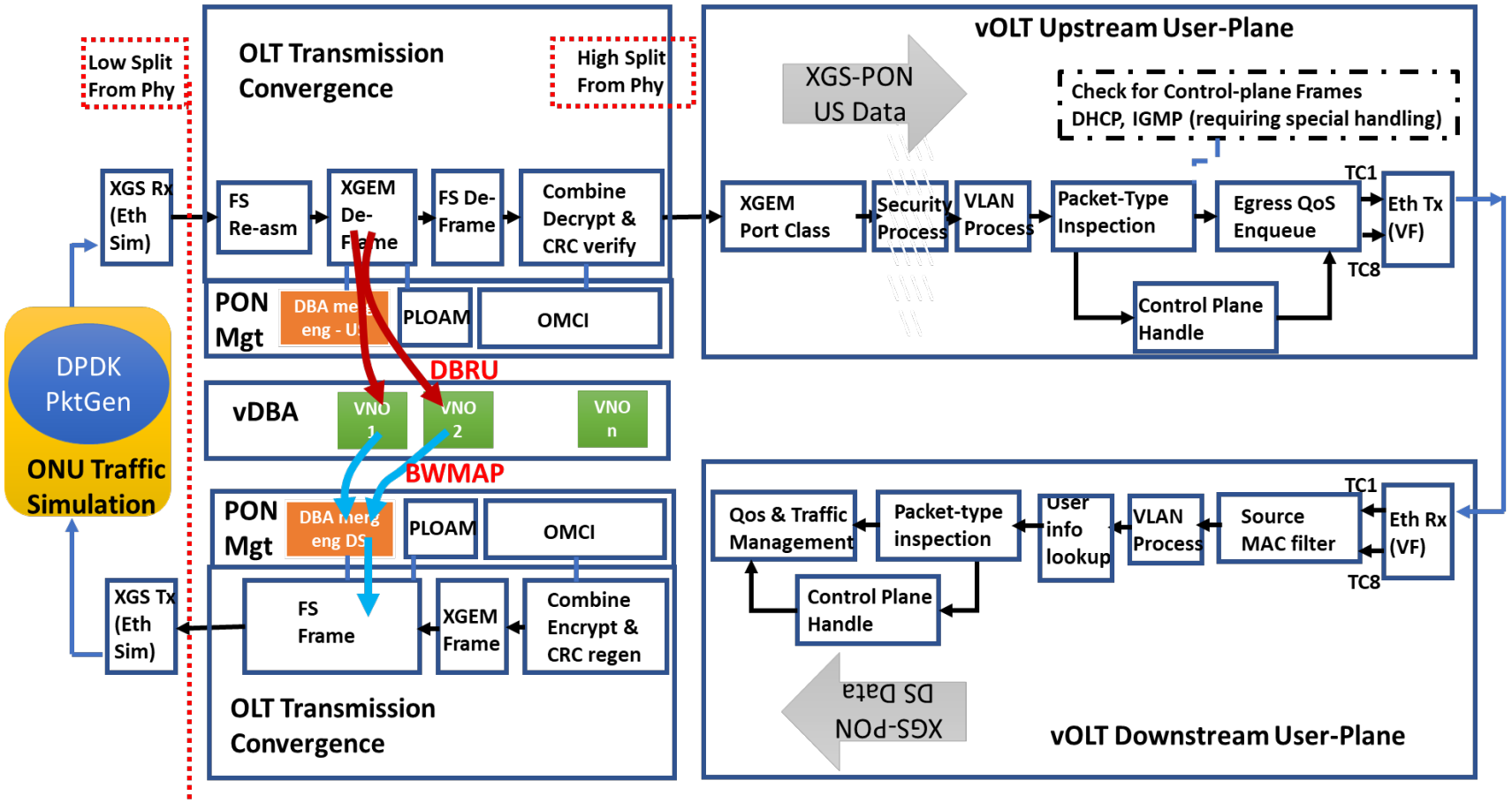
The virtual PON implementation

XGS-PON compliant protocol implemented in software

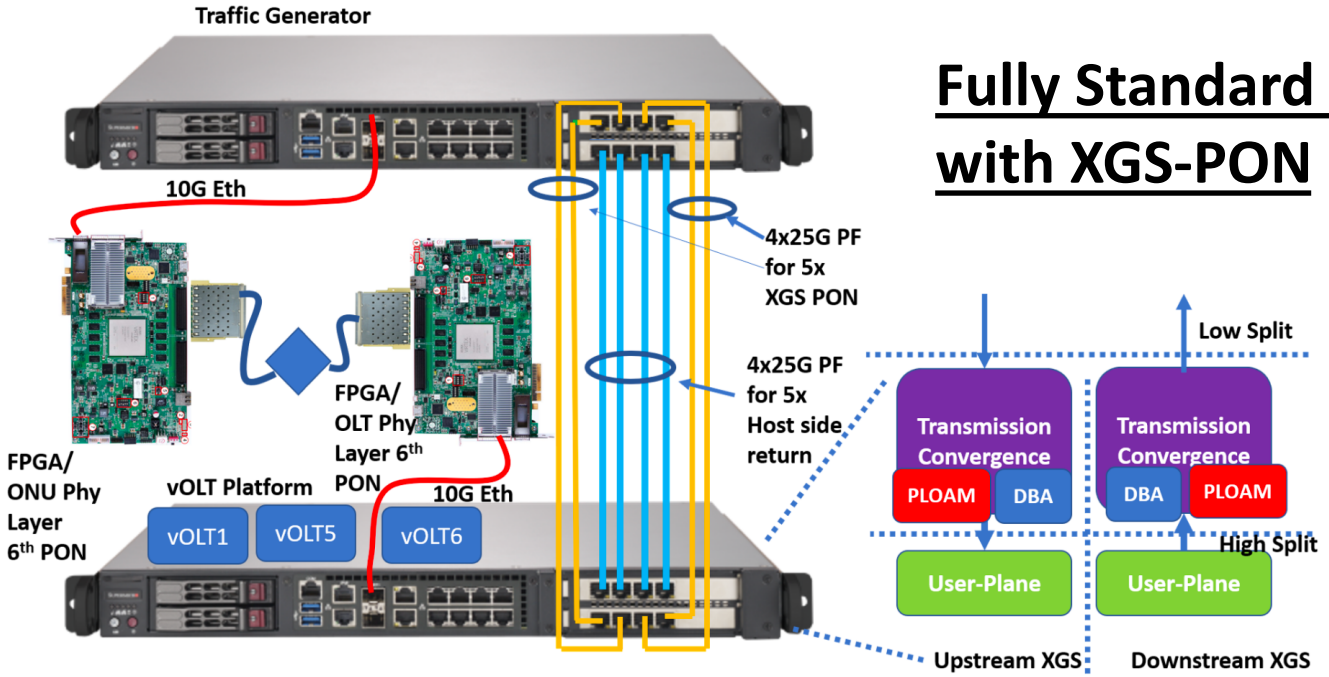
Two implementations:

- High split: part of the protocol in GPP (i.e., Intel Xeon) software, part in dedicated programmable hardware (FPGA)
- Low-split: all is done in the GPP

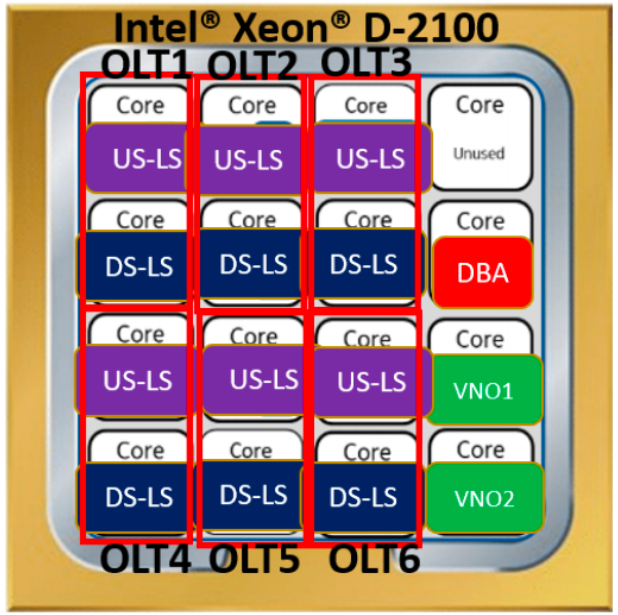
<u>The DBA is in GPP software in both cases</u>

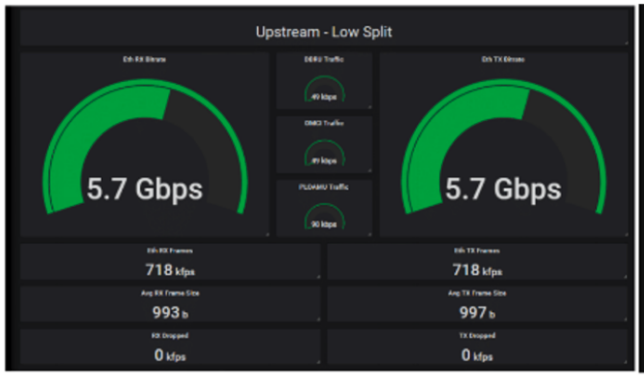


The virtual PON in performance



Fully Standard compliant with XGS-PON

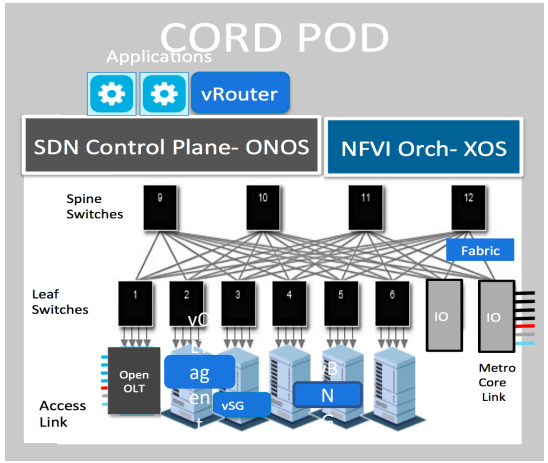


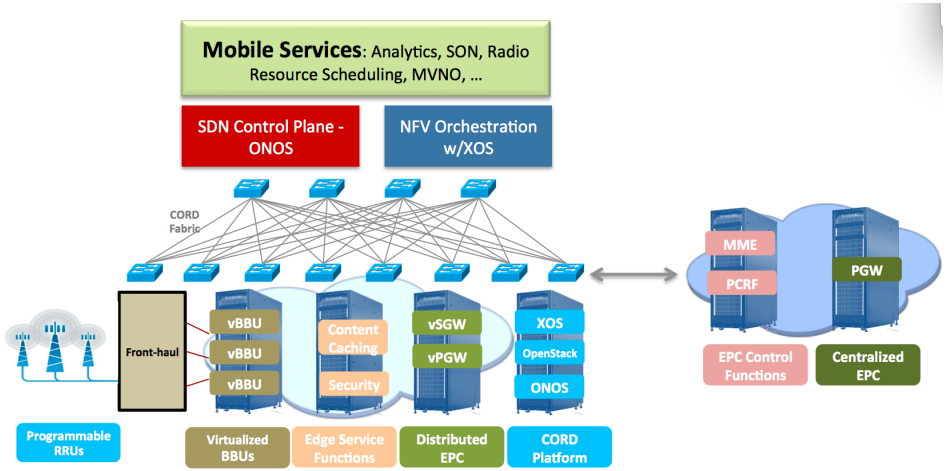


- F. Slyne et al., Experimental Demonstration of multiple Disaggregated OLTs with Virtualised Multi Tenant DBA, over General Purpose Processor. OFC 2020, Paper M3Z.11
- F. Slyne, J. Singh, R. Giller and M. Ruffini, Experimental Demonstration of DPDK Optimised VNF Implementation of Virtual DBA in a Multi-Tenant PON. Proc. of ECOC 2018

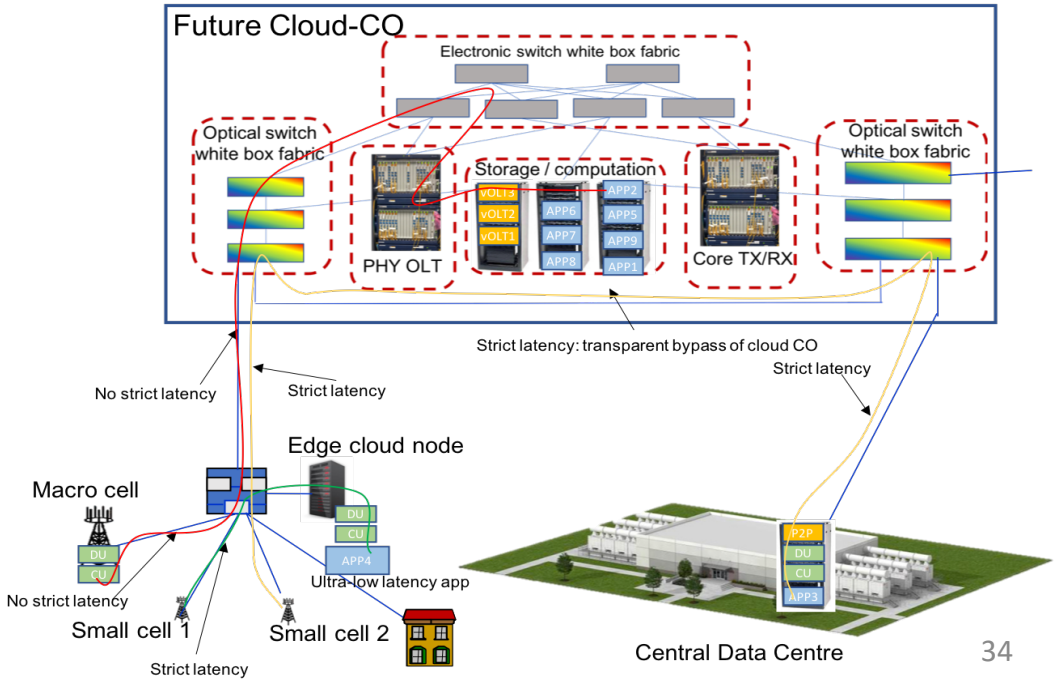
Virtualisation enables convergence

- Ability to run fixed access and mobile in same CO
- Enable use of cooperative DBA (synchronise PON and Mobile schedulers)





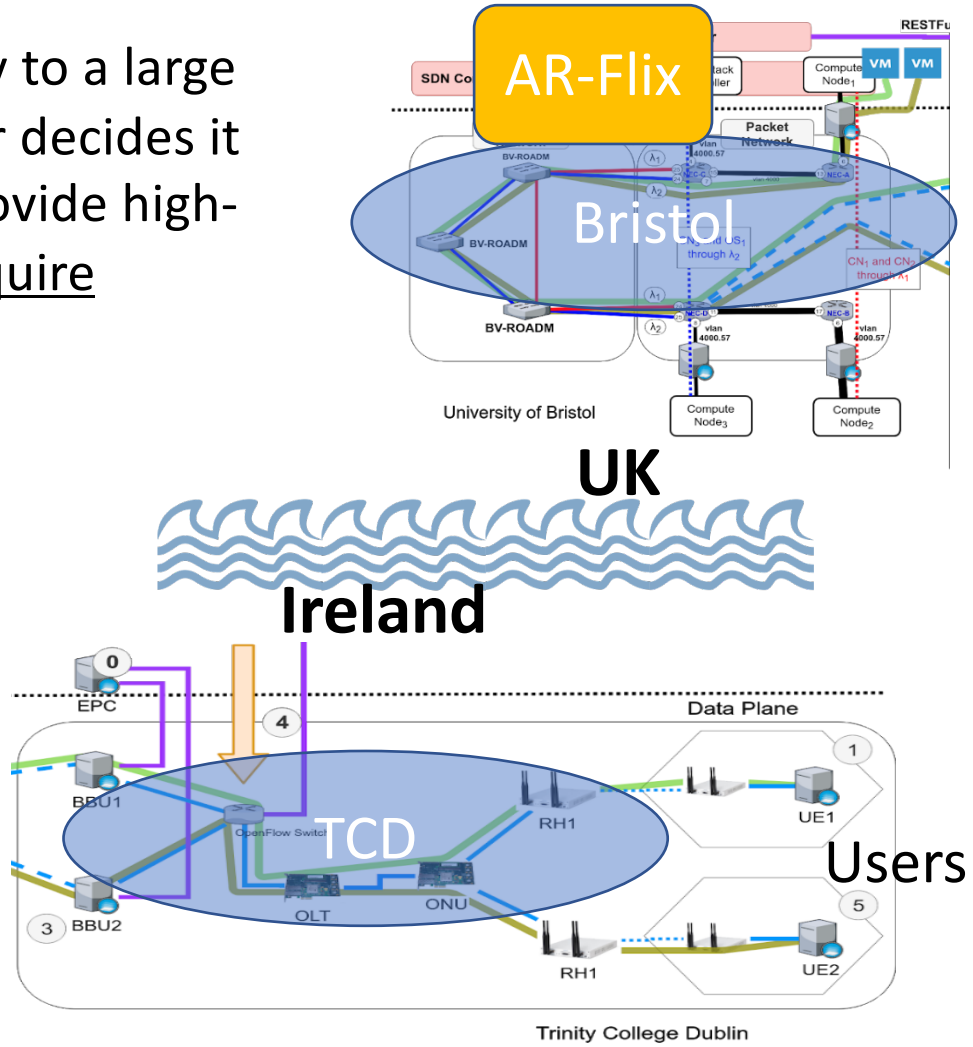
- Convergence of optical access, mobile and compute (edge and cloud) enables flexibility of resource allocation:
  - Time and wavelength capacity across edge and cloud (as optical switching moves into the computing nodes) provide high flexibility in resource allocation



Practical use case demonstration

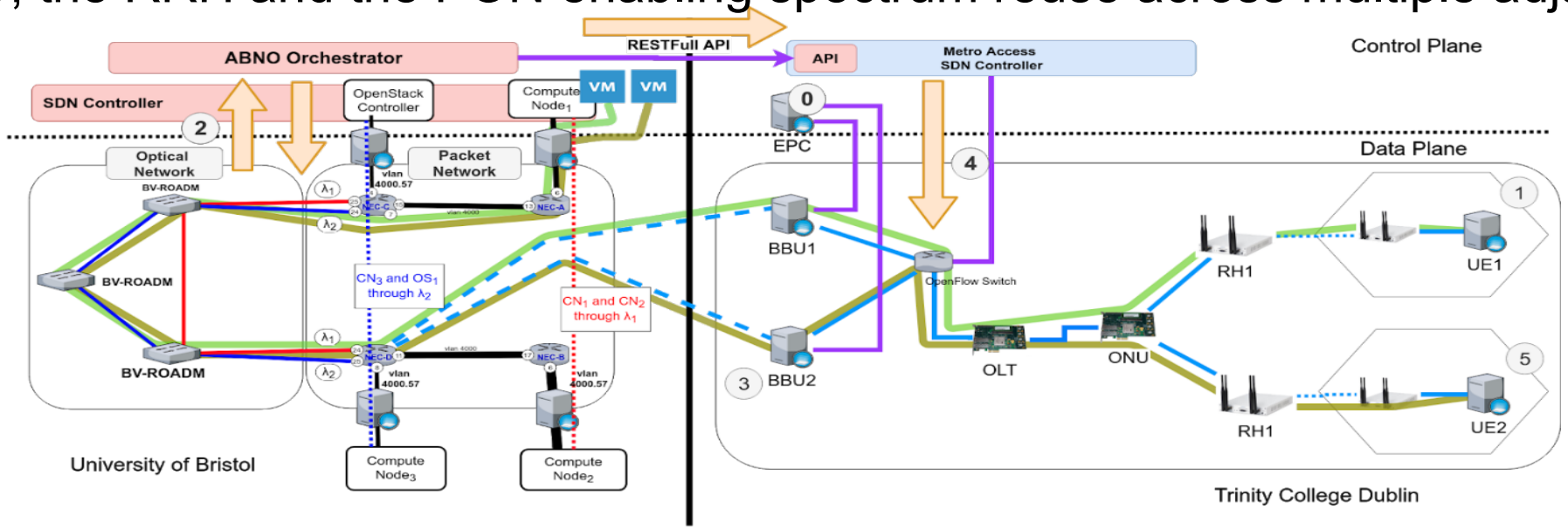
- A large UK Operator (Bristol) provides network connectivity to a large content providers (AR-Flix) in the UK. The content provider decides it also wants to access the Irish market and asks Bristol to provide high-QoS connectivity to wireless users in Ireland. Its service require "guaranteed performance" to work seamlessly.

- Bristol thus leases wireless capacity from TCD (which owns the wireless license in Ireland), but it wants to minimise its leasing cost, thus dynamically request only the capacity (wireless spectrum and optical bandwidth) that is actually required by the users, while the remaining is allocated to users of local content.



DEMO Setup

- Optical core network connected to servers representing content providers (UnivBris)
- Wireless edge network with fronthaul operating over fibre access PON (TCD)
- SDN system controlling:
  - optical core path and computing resources (UnivBris);
  - liaise with TCD controller for configuring TCD access network: adaptation between the BBU, the RRH and the PON enabling spectrum reuse across multiple adjacent cells.



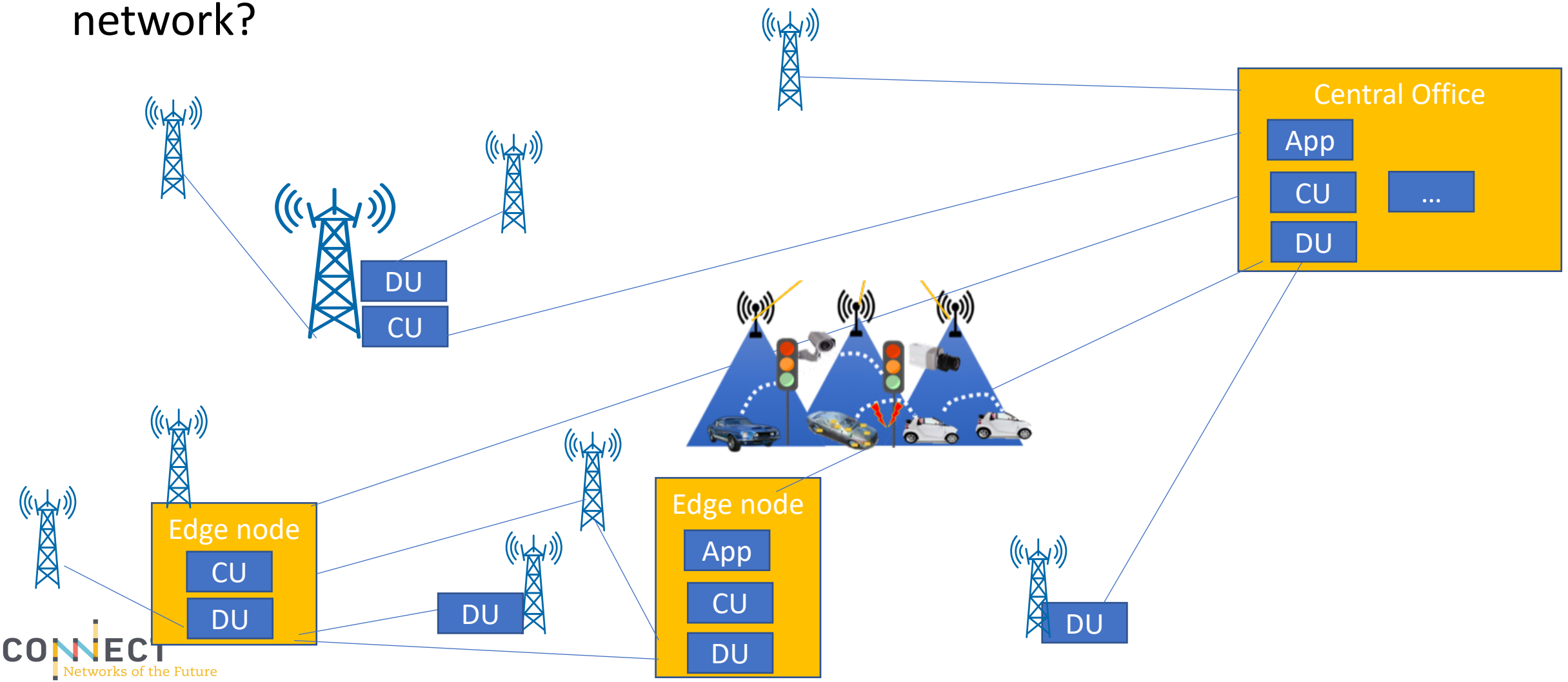
F. Slyne, R.S. Guimaraes, Y. Zhang, M. Martinello, R. Nejabati, M. Ruffini and L.A. DaSilva. Coordinated fibre and wireless spectrum allocation in SDN-controlled wireless-optical-cloud converged architecture. Proc. of European Conference on Optical Communications – ECOC, September 2019

Demo live

https://www.dropbox.com/s/tvp6il8dbol60em/ECOC%202019%20OW%20Demo.avi?dl=0

The Edge Problem…

- How to create connections with low latency and low cost across the access network?

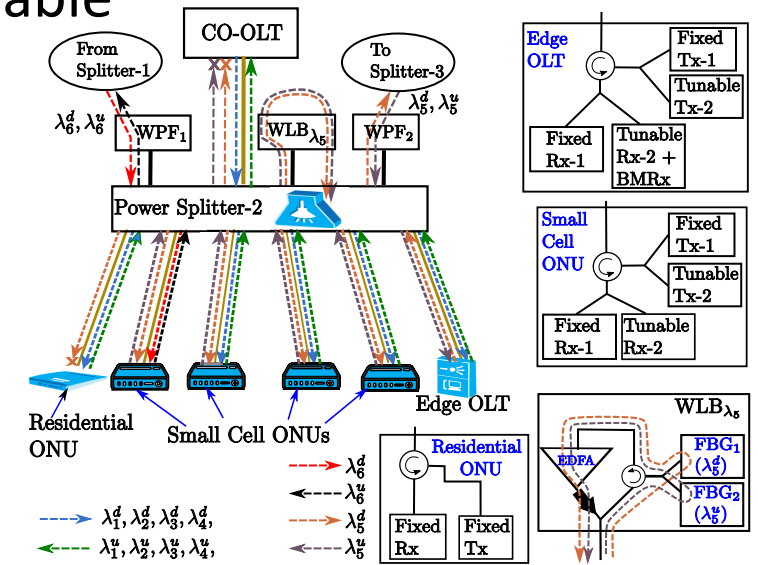


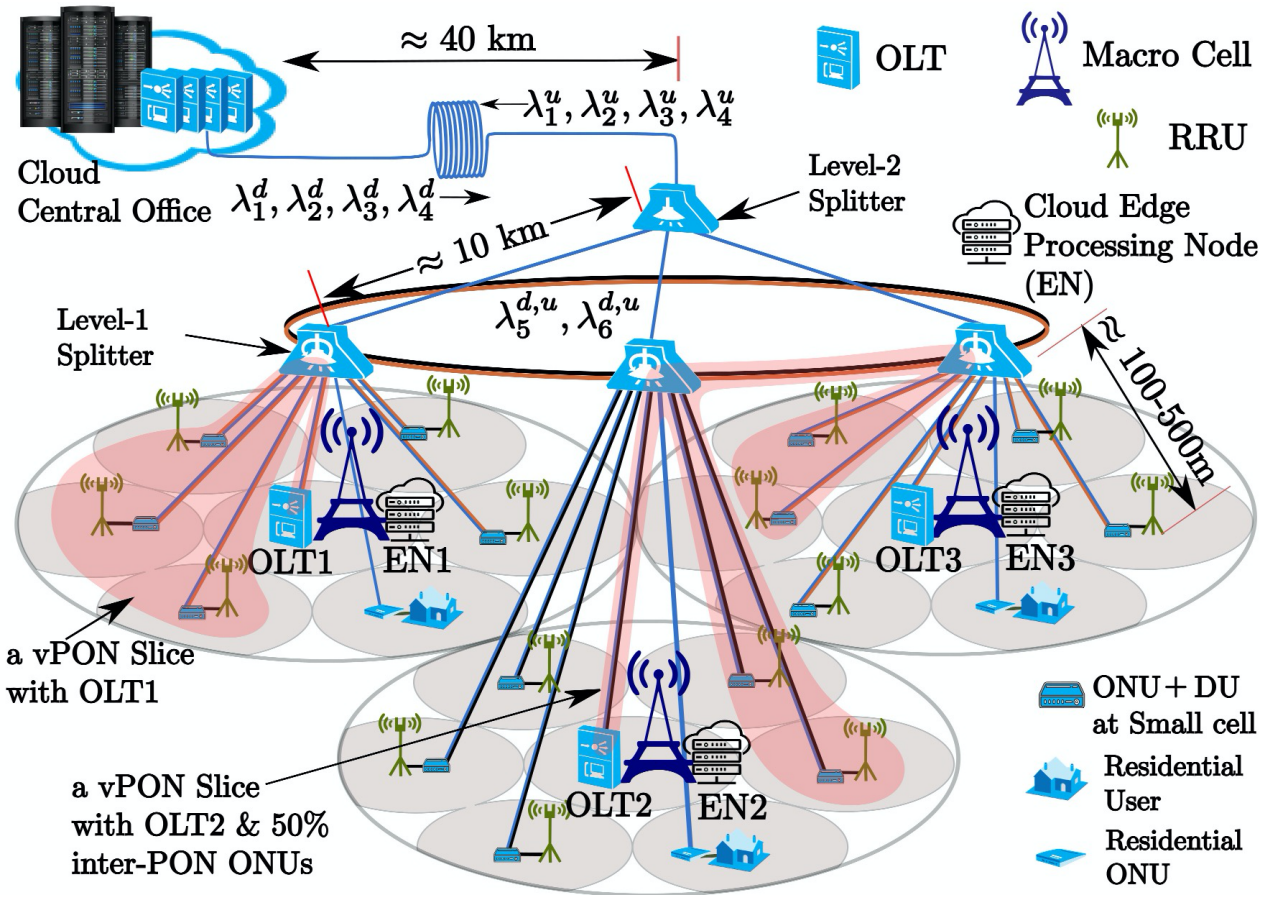
CONNECT Networks of the Future

Meshed PON architecture for edge cloud support

TRINITY COLLEGE DUBLIN

- PONs built for broadband delivery to residentials/ small business: hence the point-to-multipoint structure
- The new edge-oriented architecture is changing the access topology:
  - Edge nodes, such as base stations (Remote Units) need to be connected to other edge nodes (Distributed Units)
  - A mesh architecture that is dynamically reconfigurable





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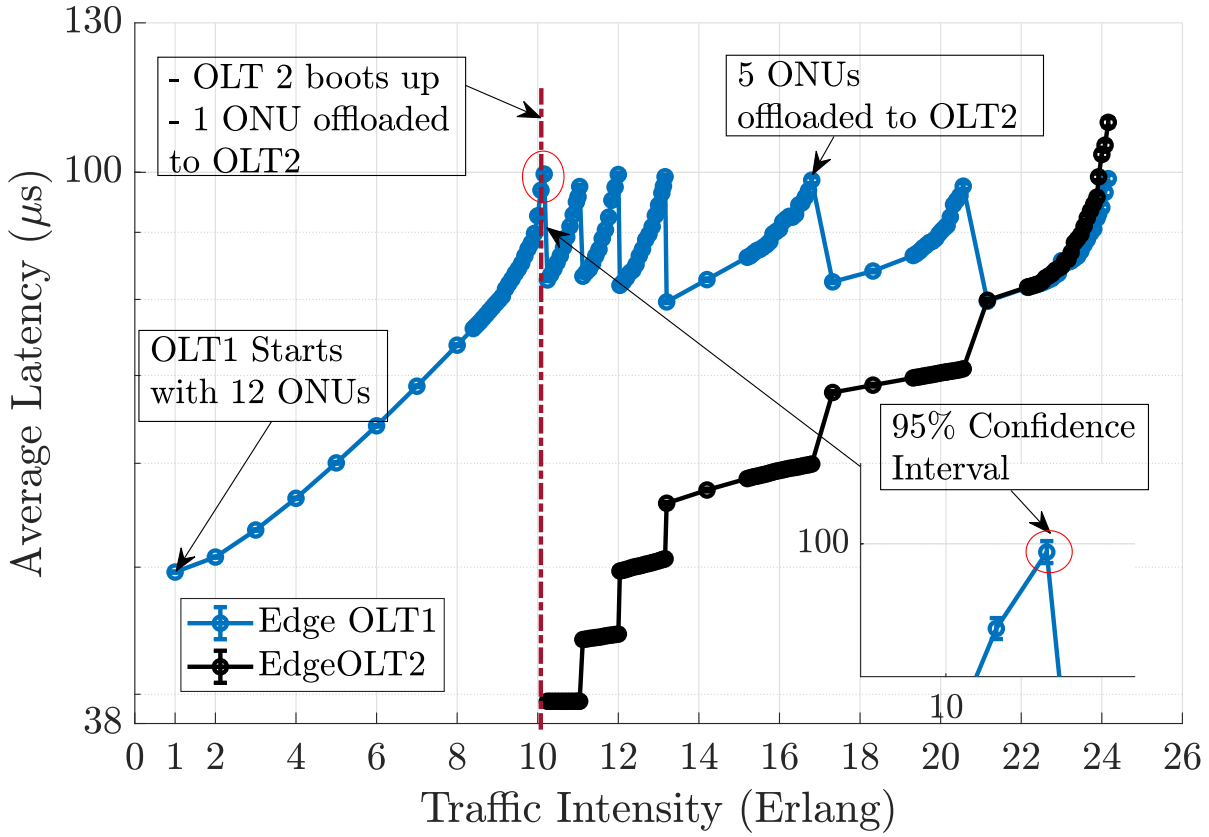
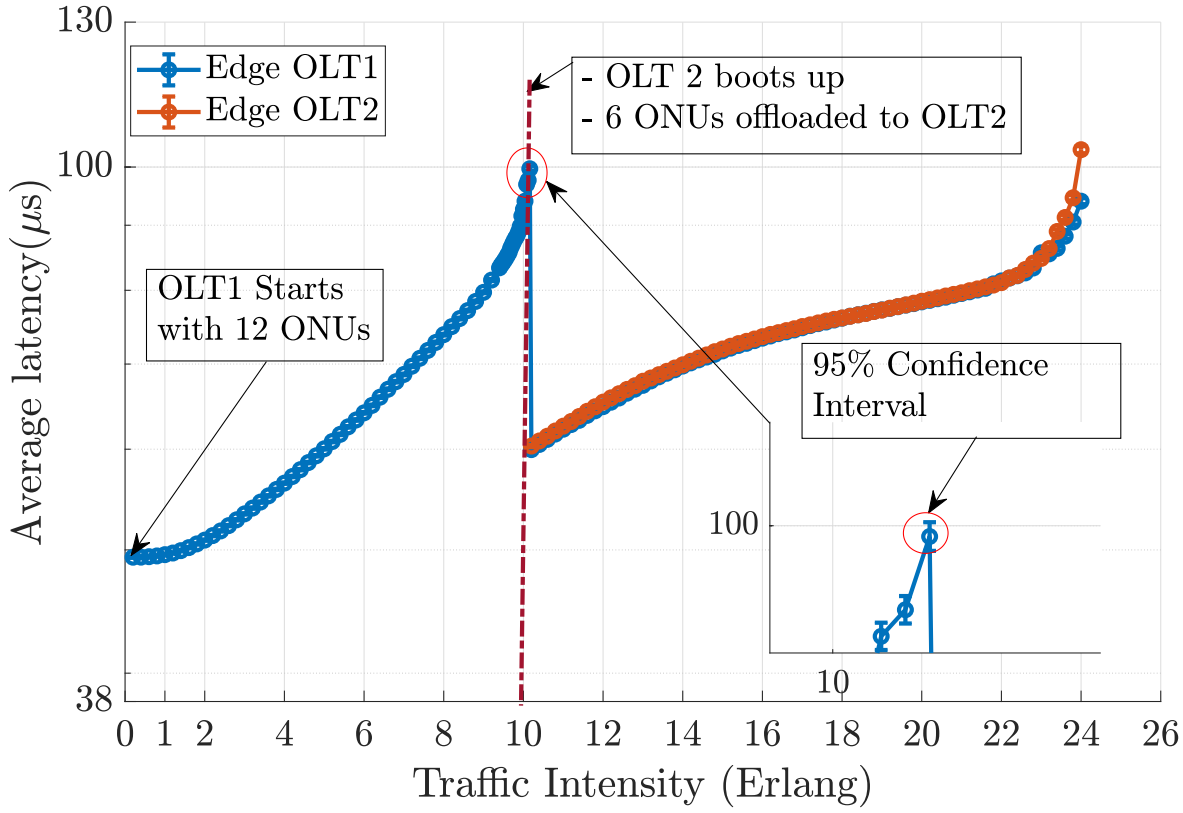
Dynamic virtual group reconfiguration for load balancing





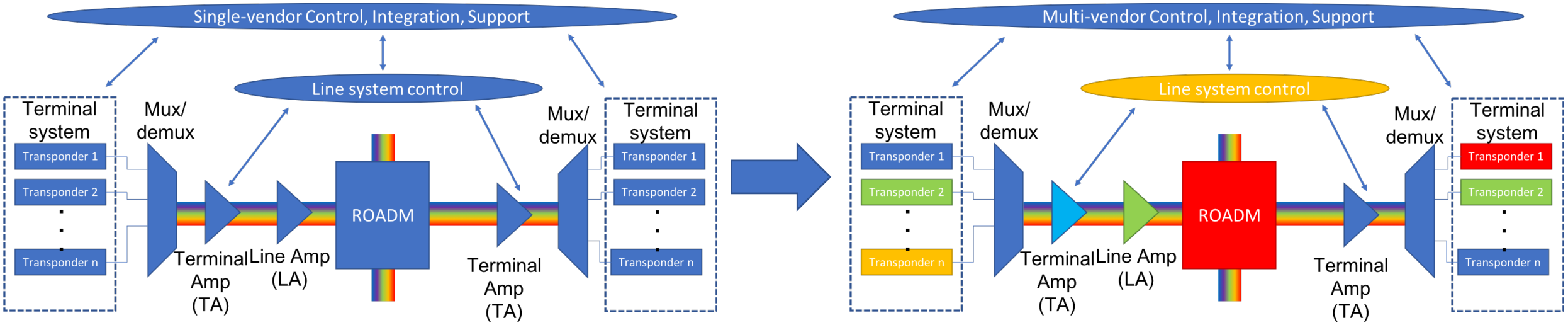
- S. Das, F. Slyne, A. Kaszubowska and M. Ruffini. Virtualised EAST-WEST PON Architecture Supporting Low-Latency communication for Mobile Functional-Split Based on Multi-Access Edge Computing. Accepted for OSA Journal of Optical Communications and Networking
- S. Das, M. Ruffini. PON Virtualisation with EAST-WEST Communications for Low-Latency Converged Multi-Access Edge Computing (MEC). OSA Optical Fiber Communications Conference (OFC), March 2020

Content of the talk

- OpenFlow and Software Defined Networks
- Network virtualisation and network function virtualisation technology (NFV)
- SDN and NFV gest applied to telecommunications networks
  - Cloud RAN
  - Central Office Cloudification (CORD)
  - The Fully virtualised PON
    - Multi-service and multi-tenancy performance
    - The optical-wireless convergence
    - The edge problem
- Disaggregating the optical layer
  - What is optical layer disaggregation?
  - Adding intelligent to disaggregation
  - Mininet-Optical
- Conclusions
  - DubliNets: enabling end-to-end control plane research across access and metro networks

What about the optical layer?

- 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)
- The optical layer has also started the disaggregation process:



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

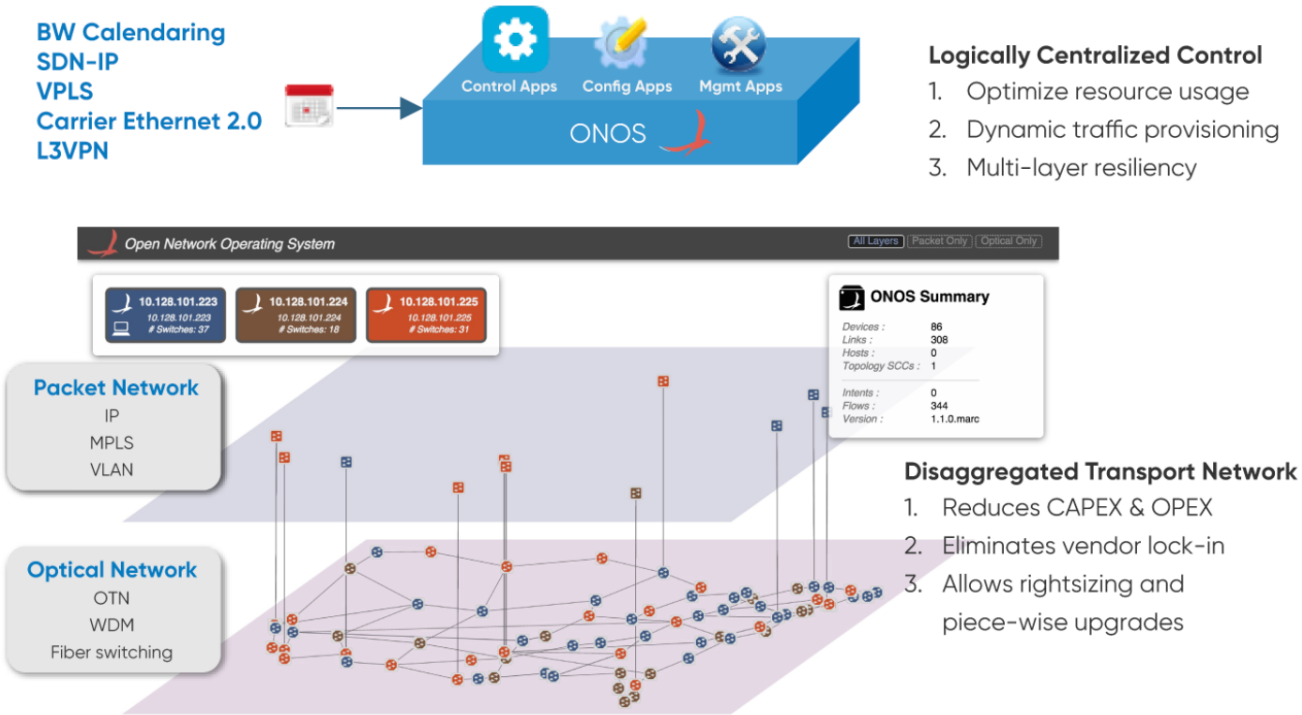
Open Disaggregated Transport Network (ODTN)

Pros:

- Open market of component from multiple vendors brings cost down
- No vendor lock-down, faster network upgrades
- Possibility of full integration with other control layers to achieve dynamic, fast, end-to-end optical re-configurability.

Challenges:

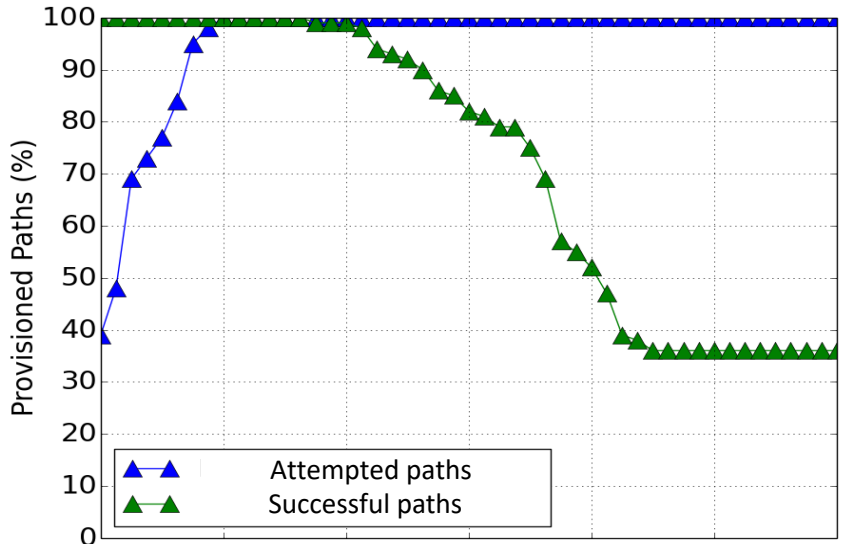
- Building an end-to-end analog system
  - How to do end-to-end system optimization with components whose behavior is not well known?
  - Avoid use of large margins
- Could this hinder research investment from transponder manufacturers?



Source: https://www.opennetworking.org

Metro vs core

- Meaning of effect on margins:

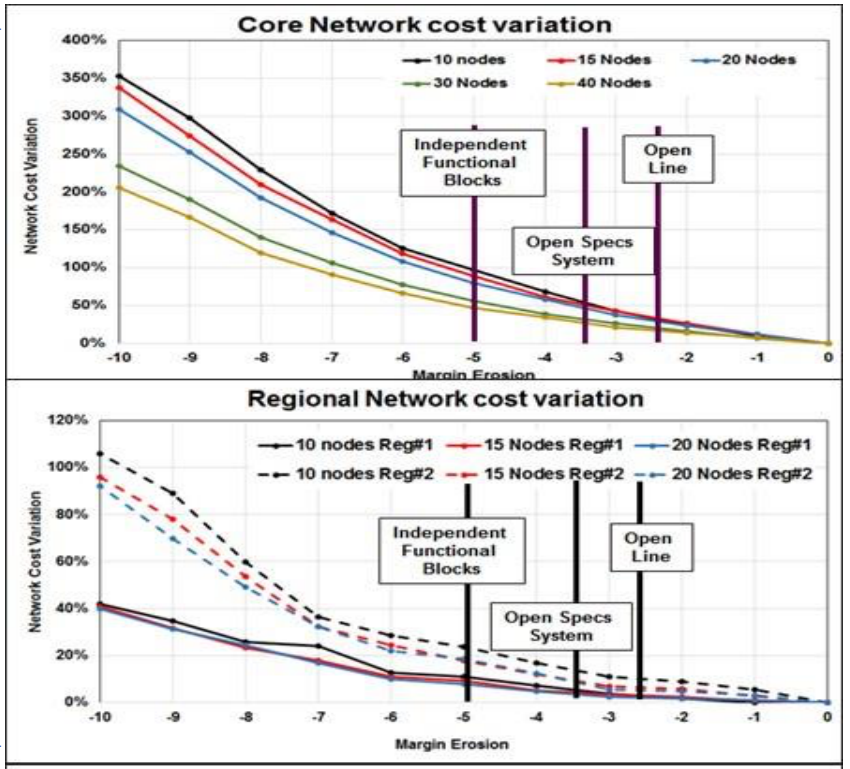


More conservative — More aggressive

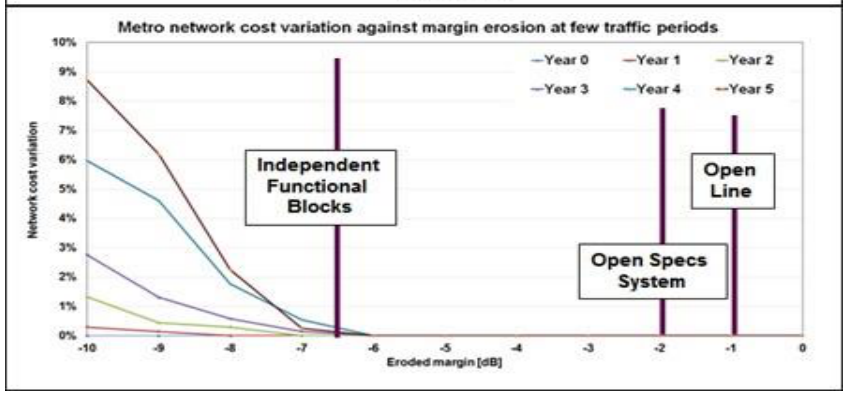
X axis: how conservative are the margins

Alan A. Díaz-Montiel, Jiakai Yu, Weiyang Mo, Yao Li, Daniel C. Kilper and Marco Ruffini. Performance Analysis of QoT Estimator in SDN-Controlled ROADM Networks. Proc. of Optical Network Design and Modeling conference (ONDM), May 2018

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

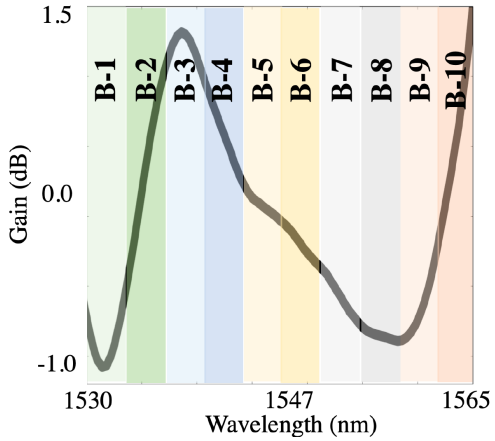


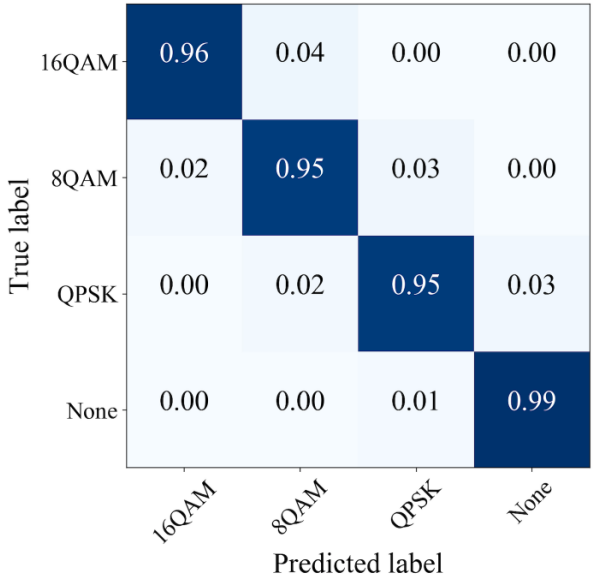
Source: M. Bleanger, M, O'Sullivan and P, Littlewood. Margin requirement of disaggregating the DWDM transport system and its consequence on application economics. M1E.2, OFC '18

Machine learning to the rescue

- Dynamic wavelength allocation suffers from impairments in optical amplifiers:
  - Amplifier gain is not perfectly flat across wavelengths and this function is not known and depends on amplifier, working point…

  ➔ Adding a wavelength channel can increase/decrease the power and OSNR of all other channel
- Quality of Transmission estimation is an important research area, and ML techniques have been used to provide such estimation
- Build multi-class SVM classifier to decide what modulation is possible (e.g., related to OSNR) with features: number of nodes, fibre length, launch power, EDFA gain, plus the number of wavelength channels already loaded in each of the 10 bins below.





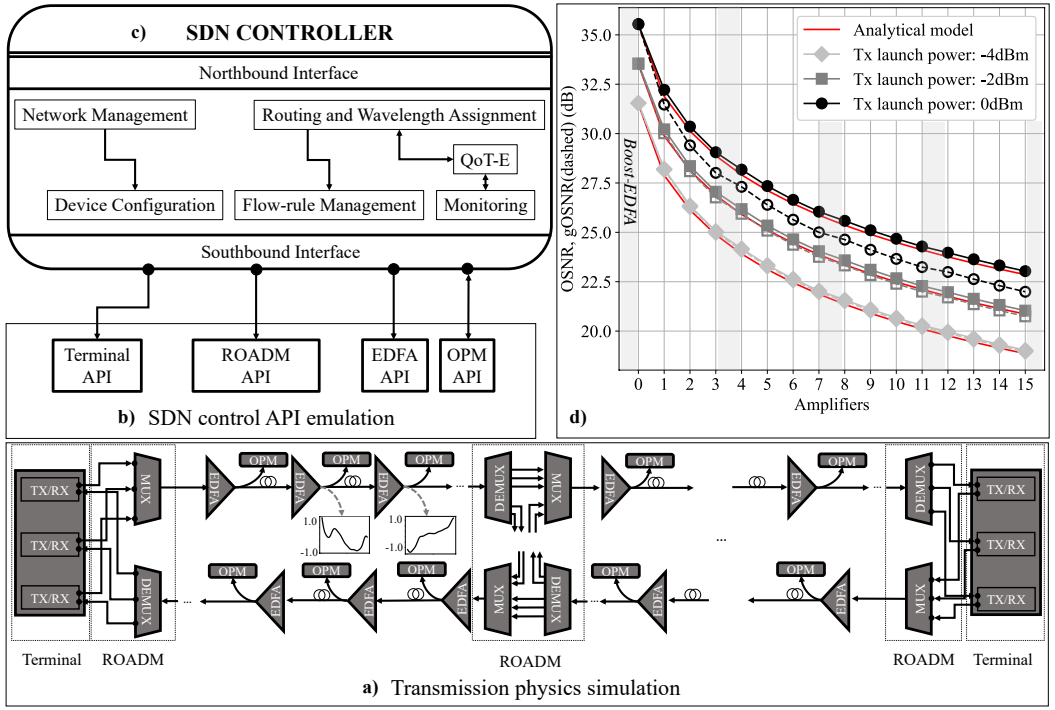
A. A. Dıaz-Montiel, S. Aladin, C. Tremblay and M. Ruffini. Active Wavelength Load as a Feature for QoTEstimation Based on Support Vector Machine. IEEE International Conference on Communications, May 2019

Mininet becomes Optical!

THE UNIVERSITY OF ARIZONA

TRINITY COLLEGE DUBLIN

- We have created **Mininet-Optical**: an SDN emulator that uses Mininet and additional physical layer optical simulation to emulate optical devices, such as ROADMs, amplifiers, transceivers, fibre propagation (including nonlinearities), etc.
- Now you can test an SDN control plane also on optical devices (i.e., ONOS-ODTN) on large scale networks

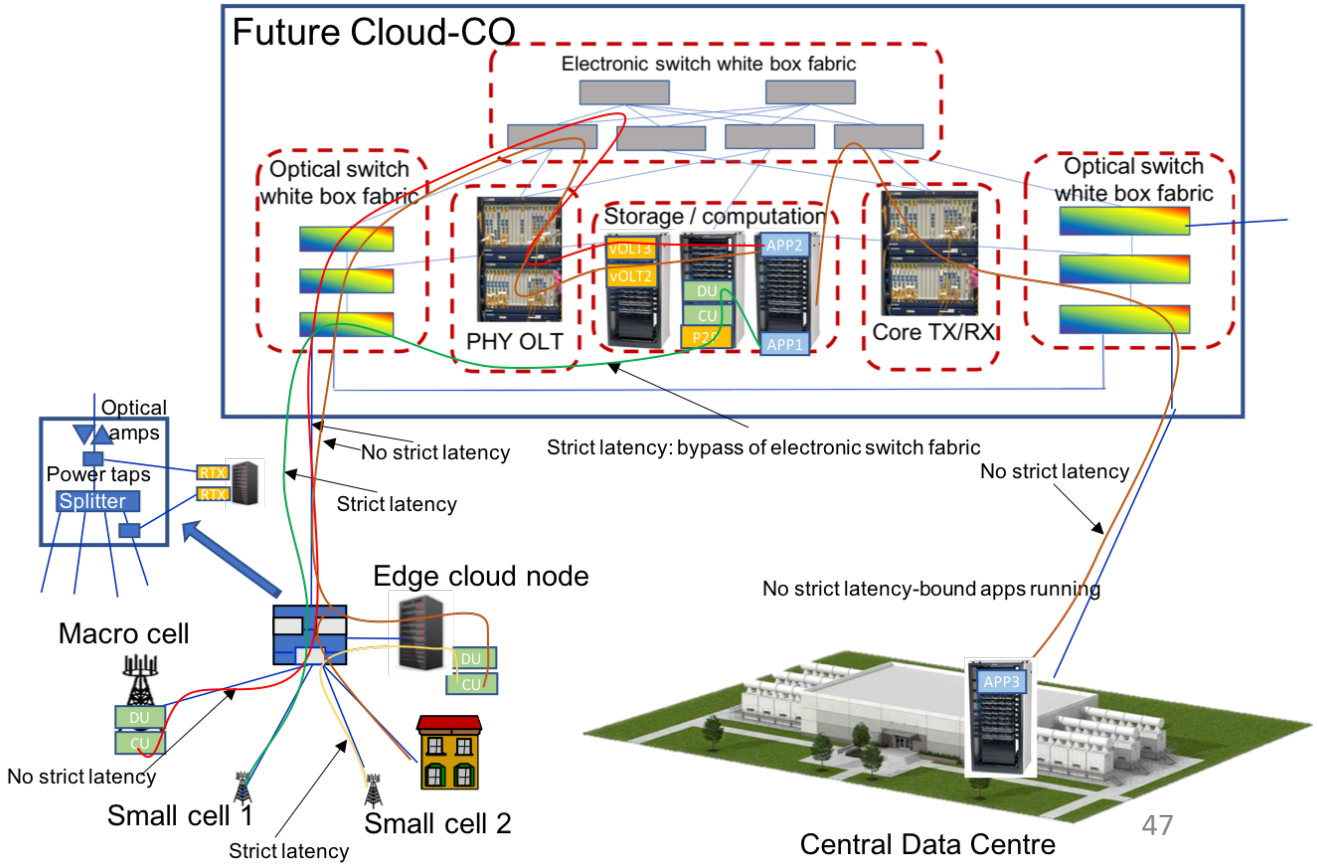


B. Lantz, A. Diaz-Montiel, J. Yu, C. Rios, M. Ruffini and D. Kilper. Demonstration of Software-DefinedPacket-Optical Network Emulation with Mininet-Optical and ONOS. OSA Optical Fiber Communications Conference (OFC), March 202

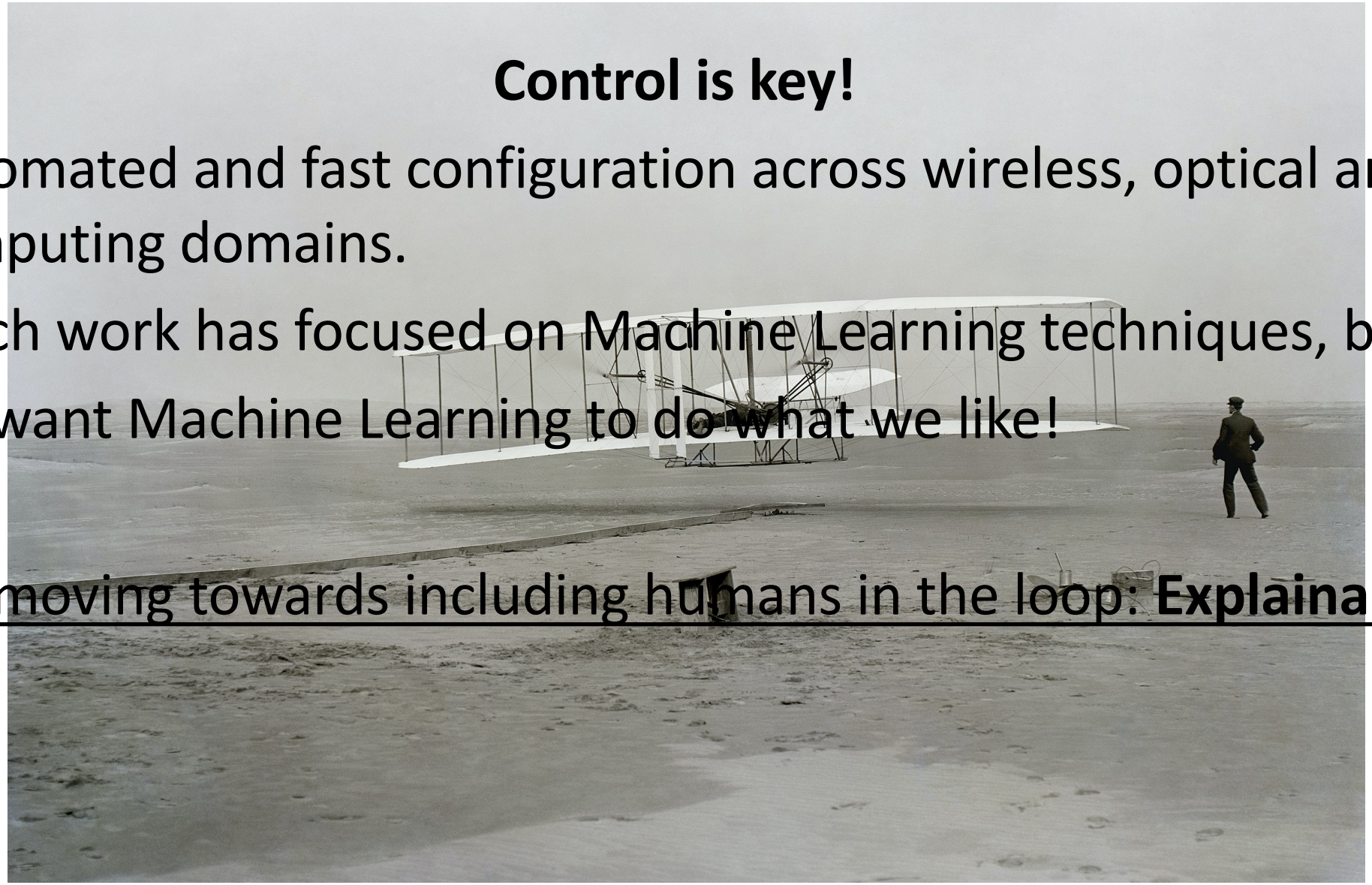
CONNECT Networks of the Future

Conclusions

- Disaggregation is happening everywhere in the network:
  - Standardisation is moving forward: ORAN, BroadBand Forum (BBF)…
- We have great physical layer technology that can provide much optical layer flexibility:
  - switching: flexgrid ROADMs, micro-ring resonator technology,…
  - transmission: coherent moving towards the access to provide higher power budget and wavelength flexibility



What's next?



Control is key!

- Automated and fast configuration across wireless, optical and computing domains.
- Much work has focused on Machine Learning techniques, but …

… we want Machine Learning to do what we like!

- ML moving towards including humans in the loop: **Explainable AI**

DubliNets

- **<u>Build a full end-to-end testbed based only on *open interfaces and open source software: show how it can all be integrated*</u>**
  - <u>Enable control plane and protocol level research across wireless, optical and compute domains in live city environment</u>

Outdoor 5G small cells in Cloud-RAN configuration

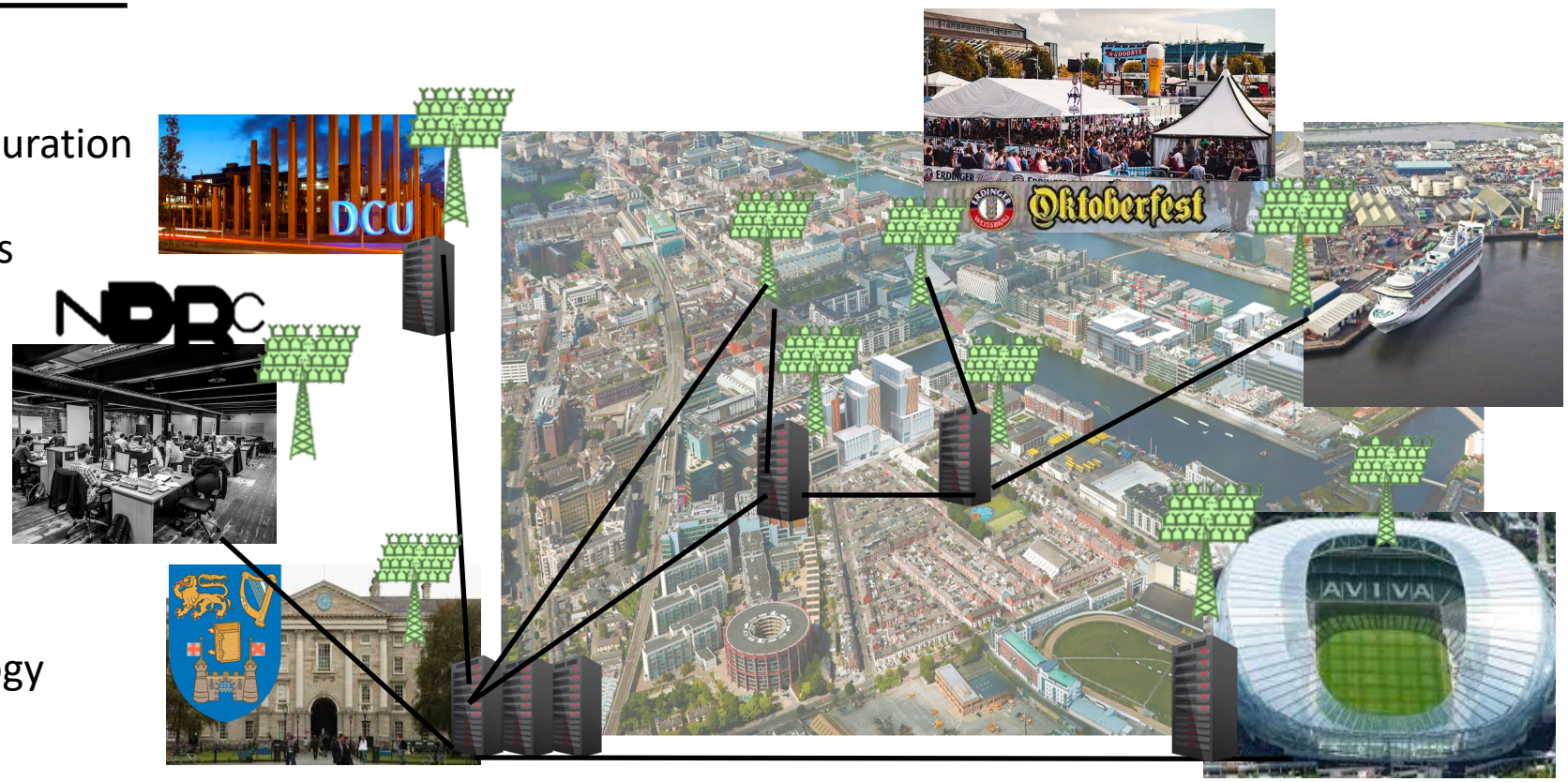
Edge and central computing features

Fully fledged reconfigurable optical metro network

Dark fibre connectivity across the city

>1,500 km of laboratory fibre

Virtual and mesh PON access technology



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Thank you for your attention!

…and we are now hiring PhD students!

Prof. Marco Ruffini

CONNECT / The centre for future networks and communications

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KYP Talks
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24th August 2020,

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