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Science Foundation Ireland sfi For what's next

CONNECT Centre for Future Networks

The role of Optical Networks in 5G convergence

Presenter: Prof Marco Ruffini

Trinity College Dublin
The University of Dublin

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European Union
European Regional Development Fund

Science Foundation Ireland sfi For what's next

Summary

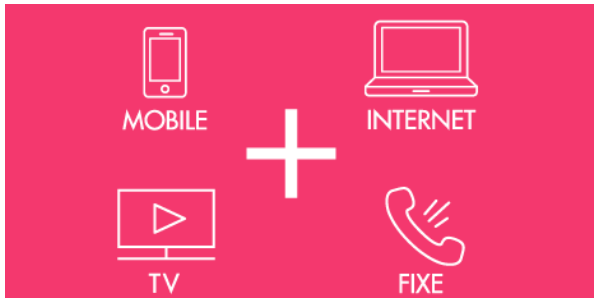
- Intro to network convergence
  - What, why, how?

- Multi-dimensional convergence
  - Service/space dimension
    - Central Office Re-architected as a Data Centre (or Cloud CO)
    - Access network virtualization activities
    - Our work on OLT virtualization: theory and experiments
  - Networking dimension
    - Multi-tenancy in Cloud CO
    - Our work on sharing incentives
  - Ownership dimension
    - Fixed/mobile, access/metro, network/DC convergence
    - Our work on variable fronthaul: experiment and theory
    - Integration of data centre/ cloud into fully converged network view

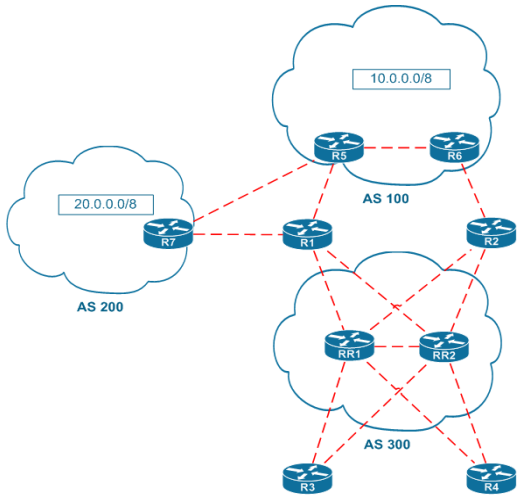
- Vision

What is convergence?

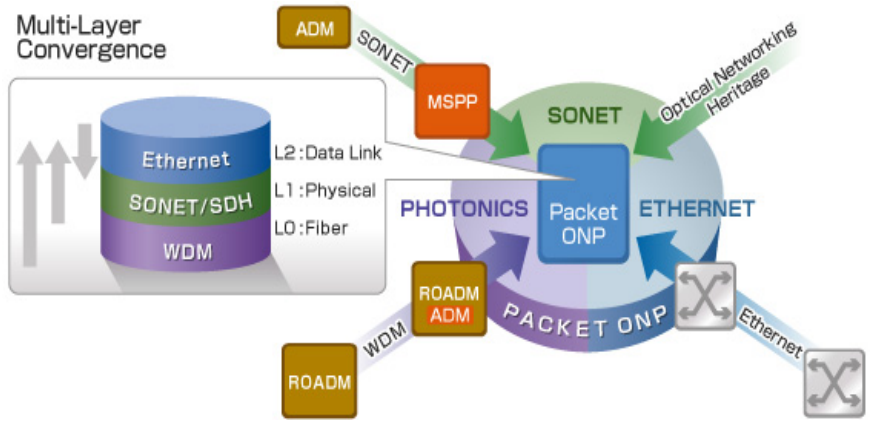
This is what Google thinks about it:



Telco heads perspective: triple/quadruple play and voice/data (also Wikipedia)



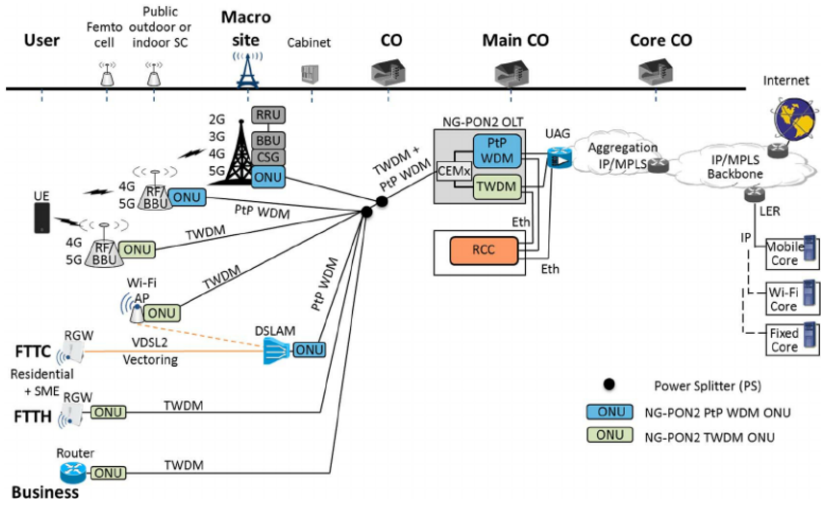
IP heads perspective: convergence of distributed protocols



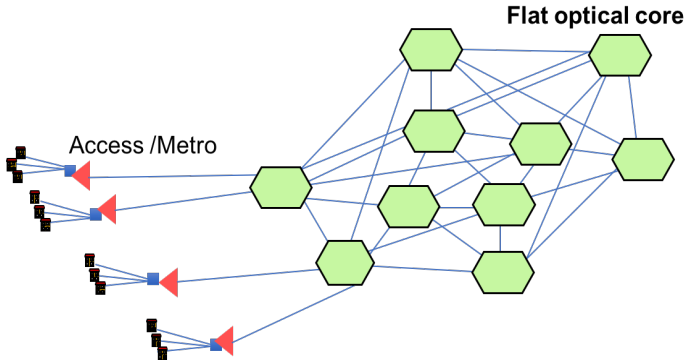
Telco vendors perspective: packet-optical convergence

What does it mean for us

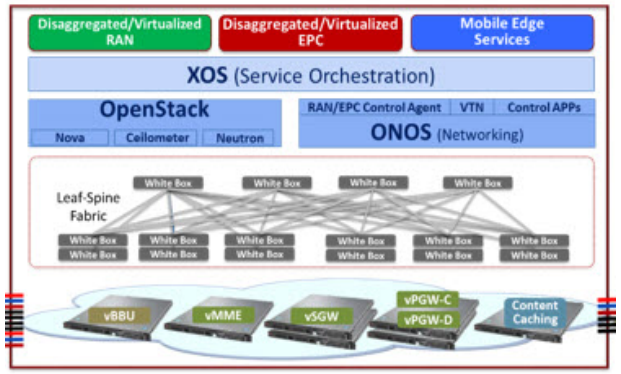
- Our research community (e.g., conferences… up to standardisation)



Convergence of fixed and mobile networks



Convergence of access and metro networks



Convergence of networking functionalities and services into Data centre (e.g., NFV)

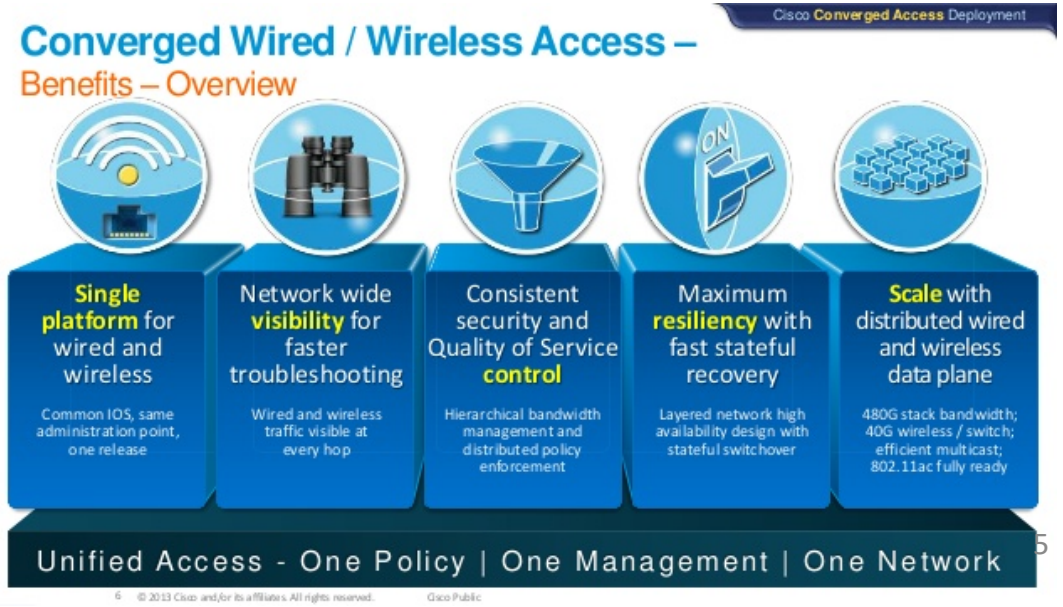
- **…please tell me more**

What is it for?

- Look back at all definitions:
  - It's about making one network or system do multiple things…
  - …without loss in performance!

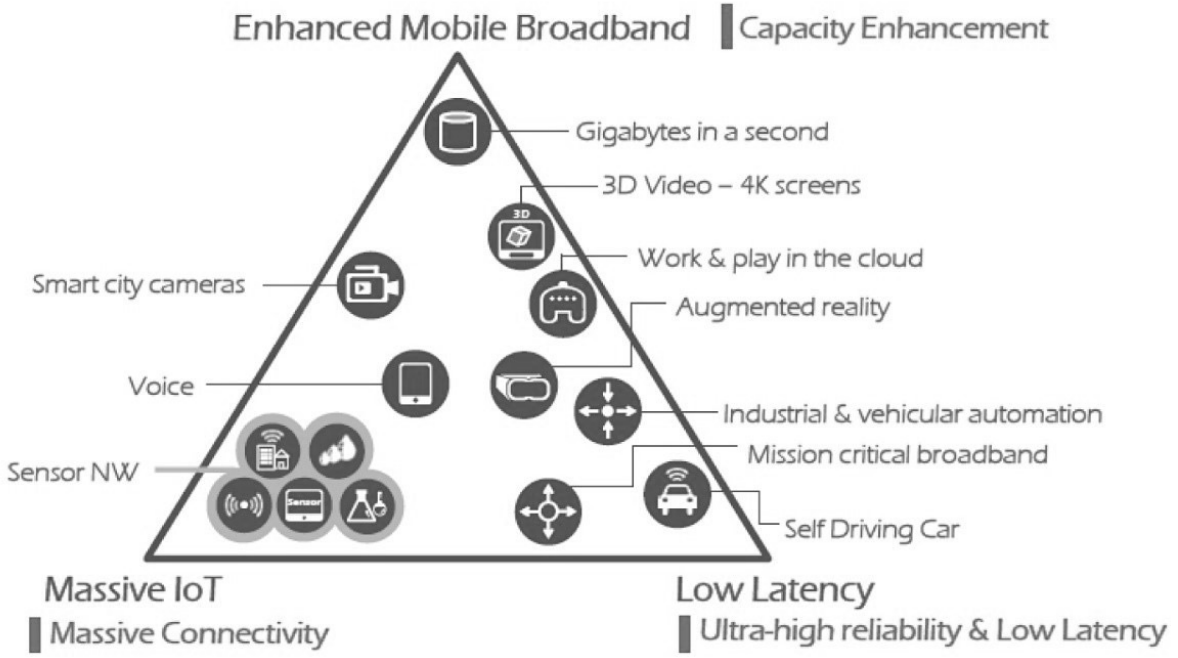
  - Save capital costs:
    - use less infrastructure (more efficiently)

  - Save operational costs :
    - number of personnel with different skills,
    - training involved
    - cross-domain experts,…



Let's talk 5G

- We have all seen this:



(Source: ETRI graphic, from ITU-R IMT 2020 requirements)

- Of course Enhanced mobile broadband is where we see the capacity challenge coming from…
- … but the low latency and ultra reliability is the real challenge especially at intersection with mobile broadband
- … indeed it is recognised by NGMN as the part that can generate new revenue for the network

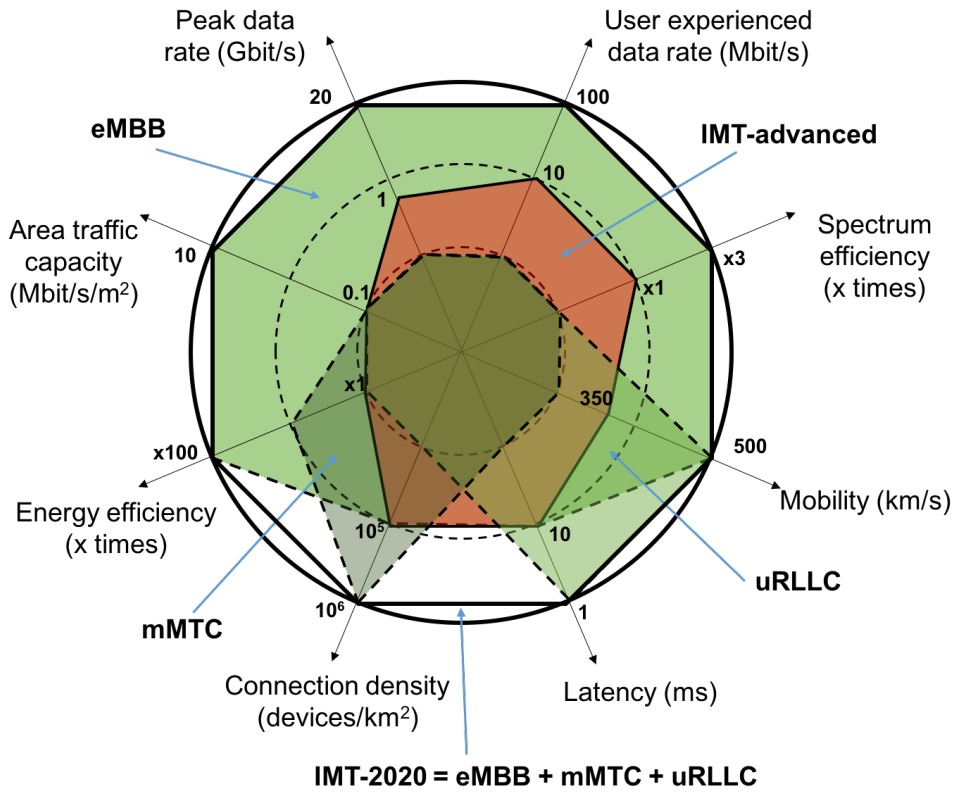
NGMN Alliance White Paper, 5G Prospects. Key Capabilities to Unlock Digital Opportunities. July 2016, available at: https://www.ngmn.org/uploads/media/160701_NGMN_BPG_Capabilities_Whitepaper_v1_1.pdf

More revenue generating apps (see OFCity 2016-2017 workshops)

- Think real-time high capacity…

- Think real-time interaction

5G requirements



Source: IMT Vision - Framework and overall objectives of the future development of IMT for 2020 and beyond

5G ≠ 4G + 1G

5G = convergence

5G is the full integration of end-user applications and network, and the network is a seamless convergence of different communications technologies, fixed and wireless!

Even ITU has realized that!

ITU's secretary-general, Houlin Zhao,: "Air interfaces and radio access networks are progressing rapidly, but there is a need to devote more attention to the networking aspects of IMT-2020. Wireline communications will transform significantly in support of IMT-2020, and the coordination of ITU's standardization and radiocommunication arms will ensure that the wireline and wireless elements of future networks develop in unison."

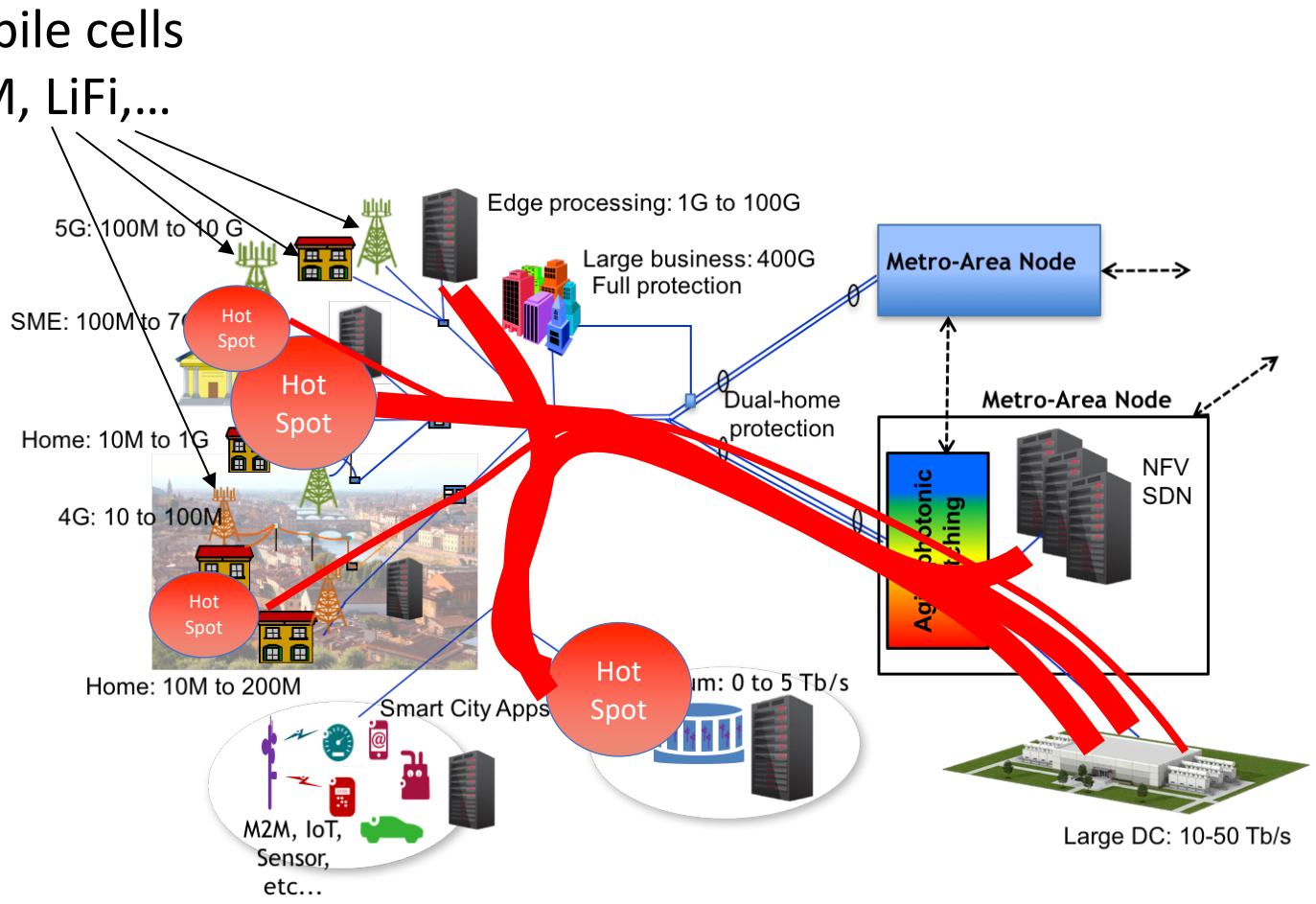
How do we get there

- What is it about?
  - Capacity:
    - Obviously more, but the key work is end-to-end availability/reliability
    - Reconfigurable for cost-efficiency (e.g., make strong use of statistical multiplexing)
  - Low latency, low jitter
    - End-to-end availability/reliability is even more obvious here!

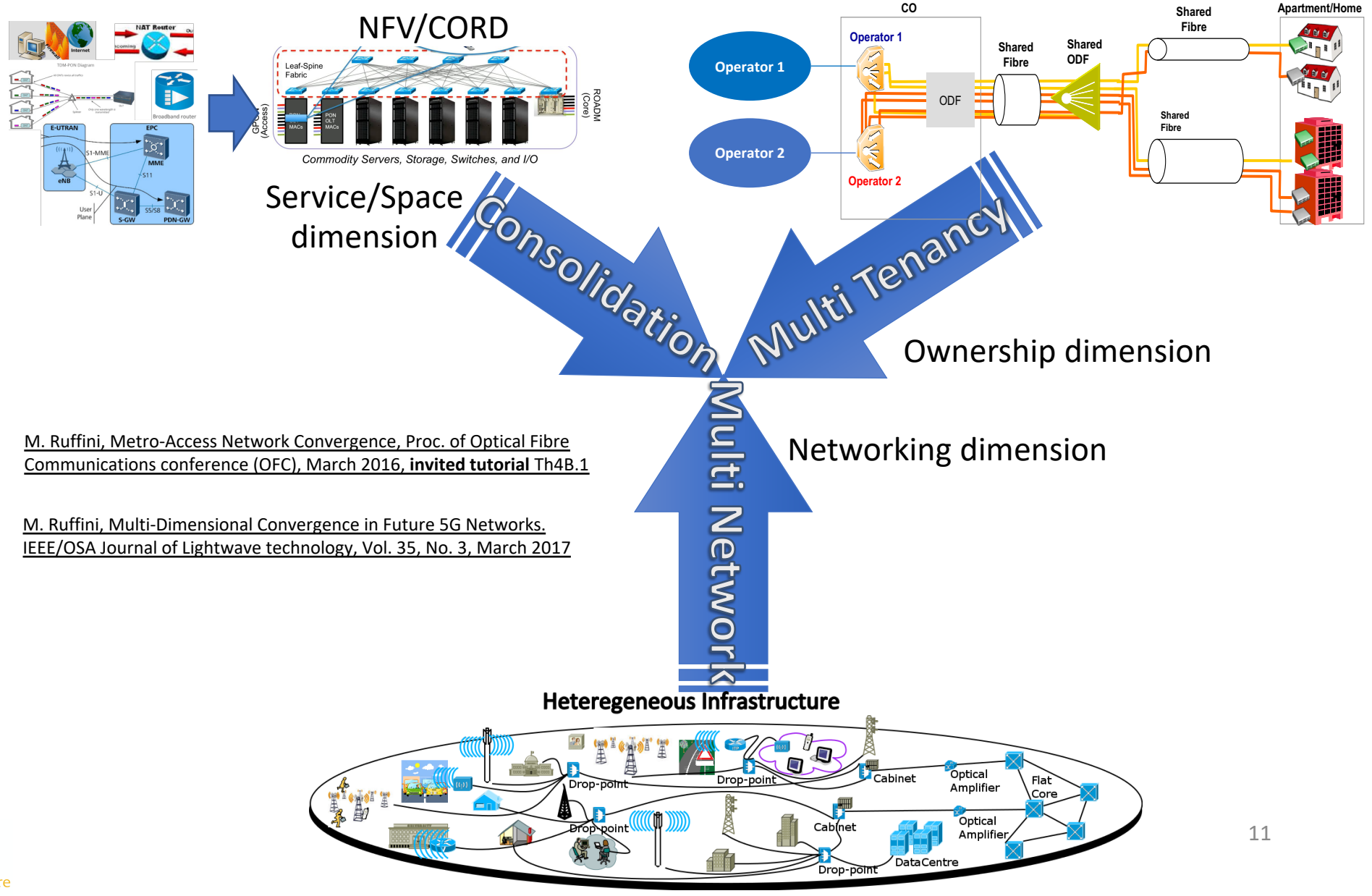
- It is an immense task:
  - We barely managed convergence before 5G when the KPI were much more relaxed
    - We really only managed to put voice and data together… …and even then not so much (think how many time skype, conf call system provide unsatisfactory service, but even see VoLTE)
  - Now we want convergence with many more applications and much more restrictive parameters

The Converged Network

- Capacity:
  - dense wireless access point deployment
- Performance: heterogeneous data storage/processing locations
- Reliability and cost-effectiveness: dynamic end-to-end resource orchestration



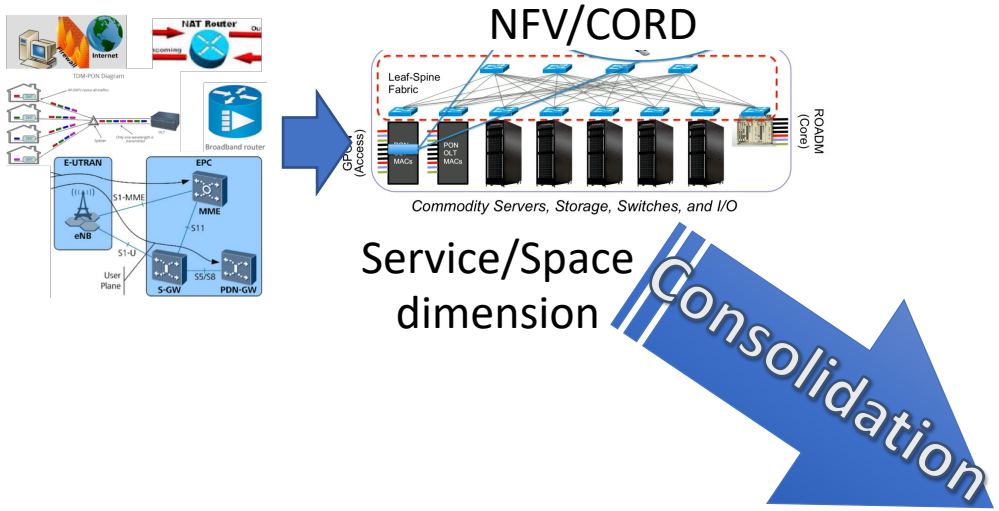
5G vision: Multi-dimensional convergence



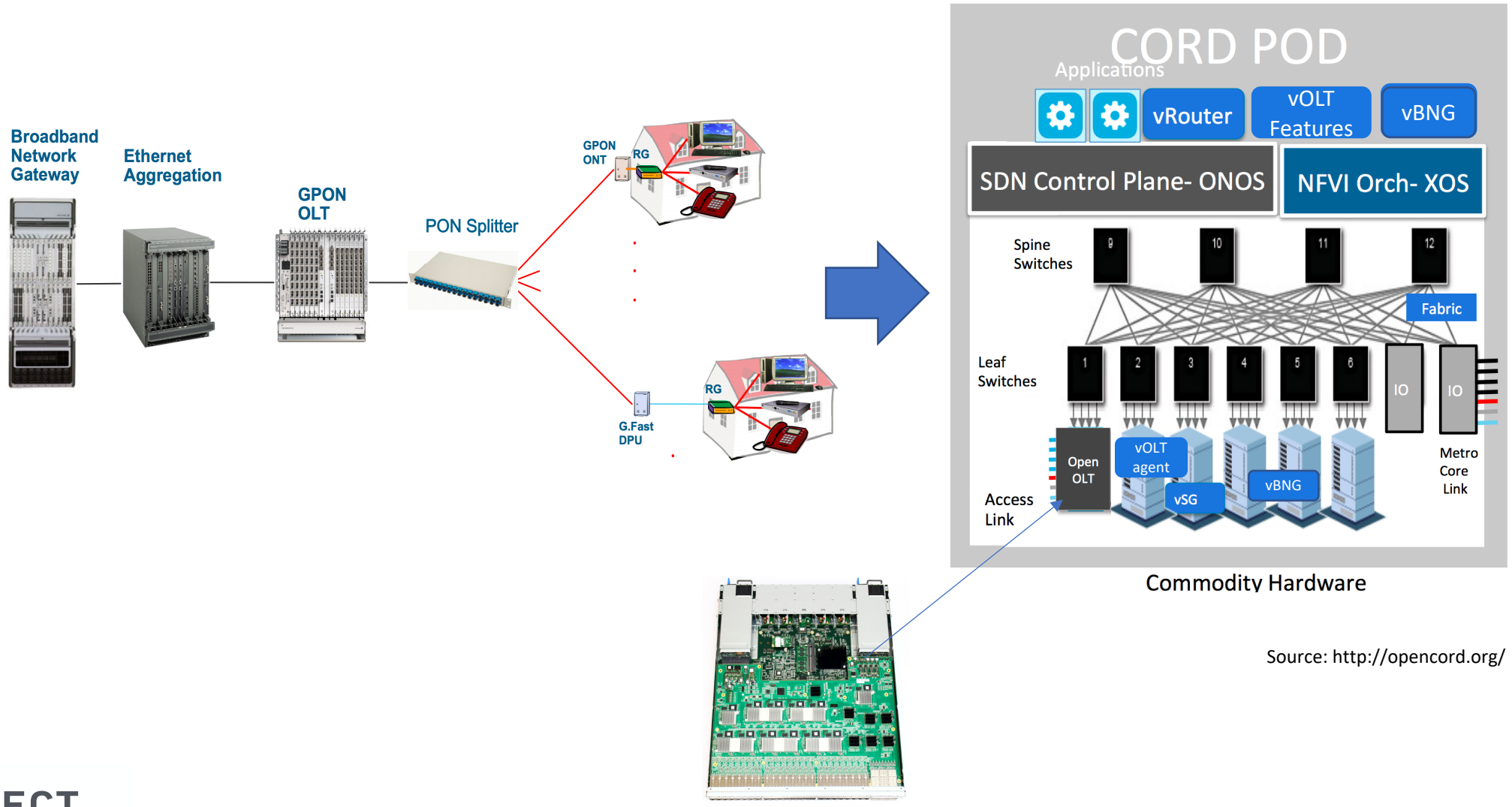
M. Ruffini, Metro-Access Network Convergence, Proc. of Optical Fibre Communications conference (OFC), March 2016, **invited tutorial** Th4B.1

M. Ruffini, Multi-Dimensional Convergence in Future 5G Networks. IEEE/OSA Journal of Lightwave technology, Vol. 35, No. 3, March 2017

5G vision: Multi-dimensional convergence



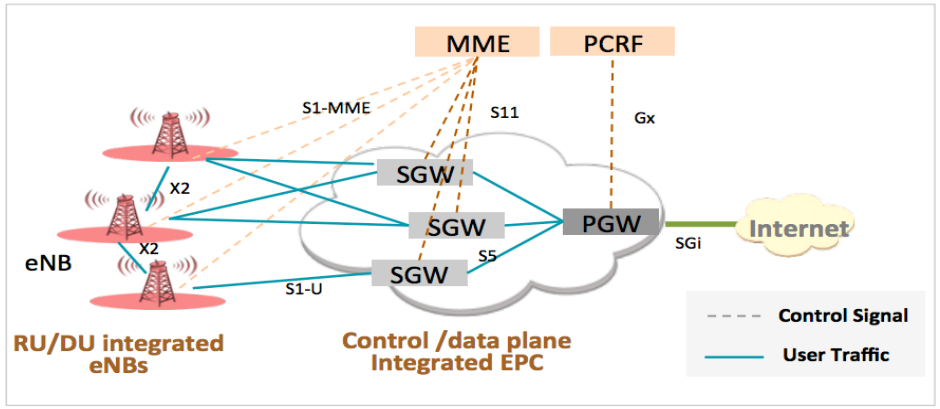
Residential-CORD
Central Office Re-architected as a Data Centre



Source: http://opencord.org/

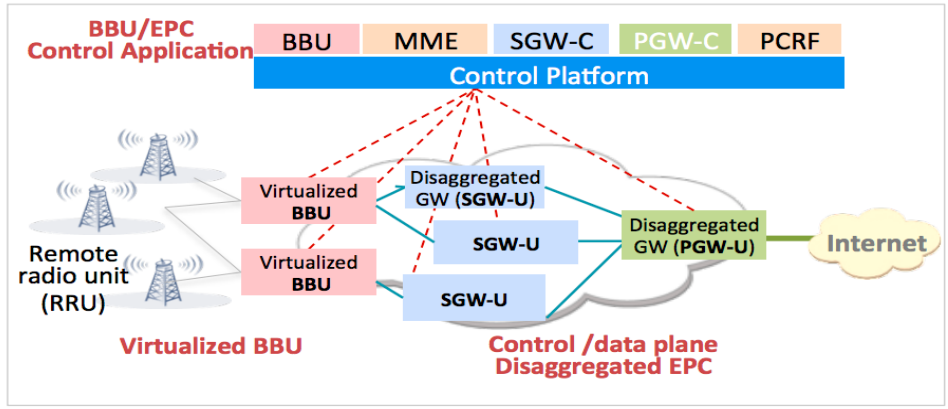
Mobile-CORD

Traditional Architecture

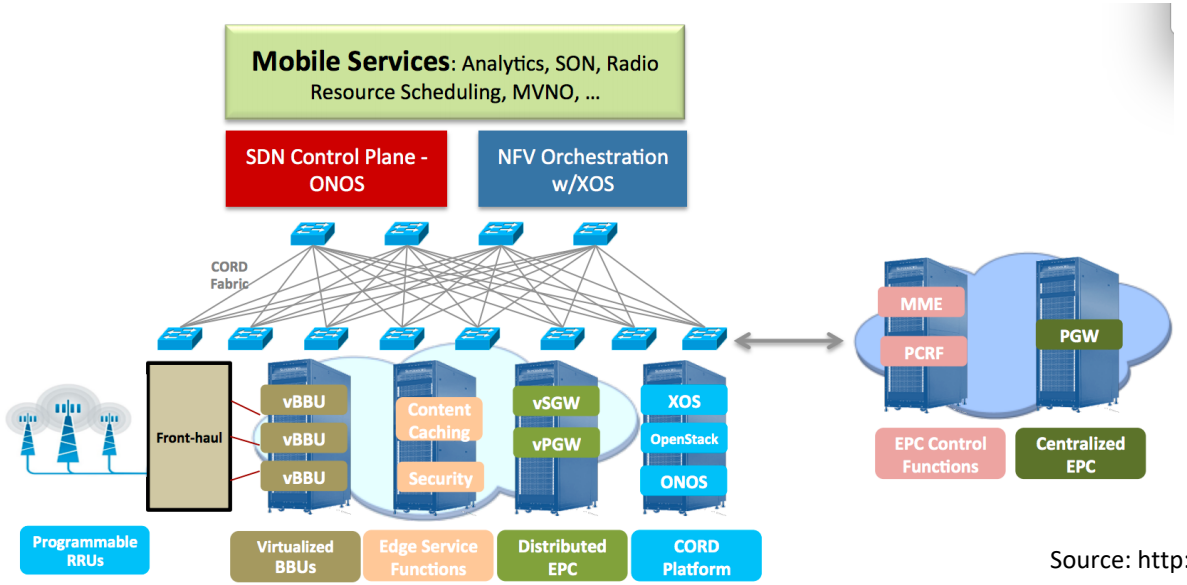


with proprietary boxes & solutions

Target Architecture

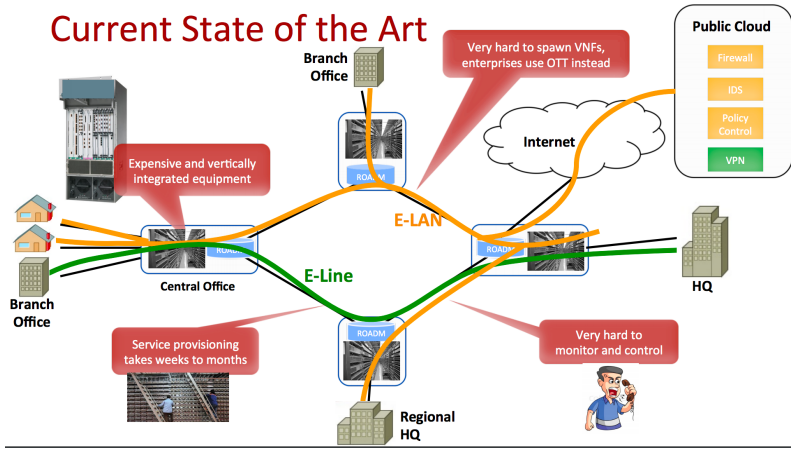


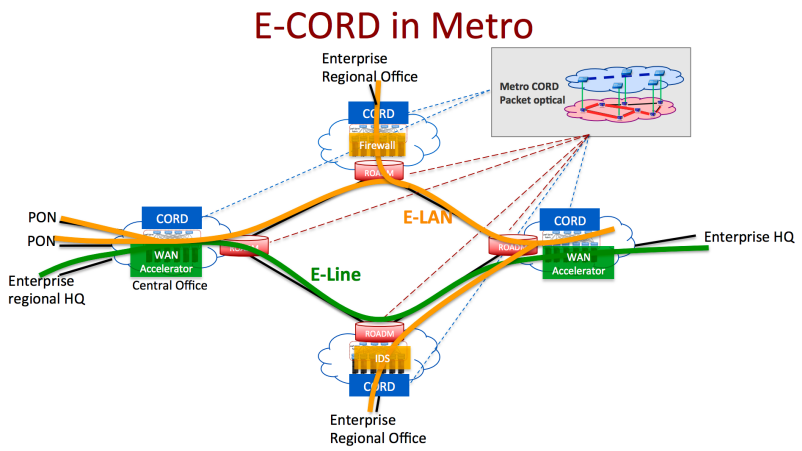
with commodity H/W & open source/open API

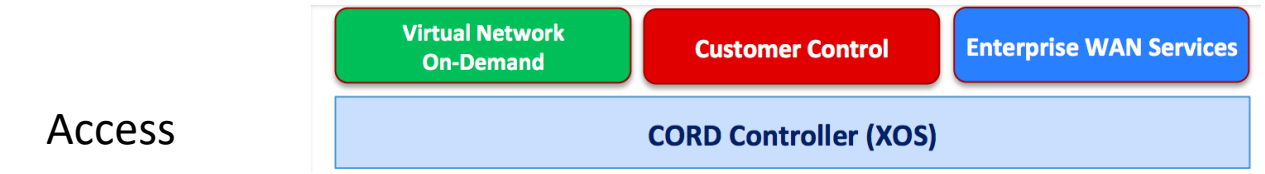


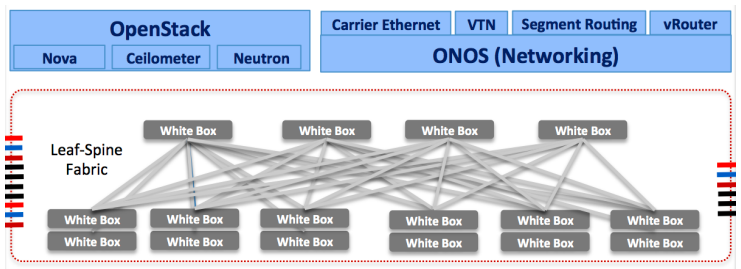
Source: http://opencord.org/

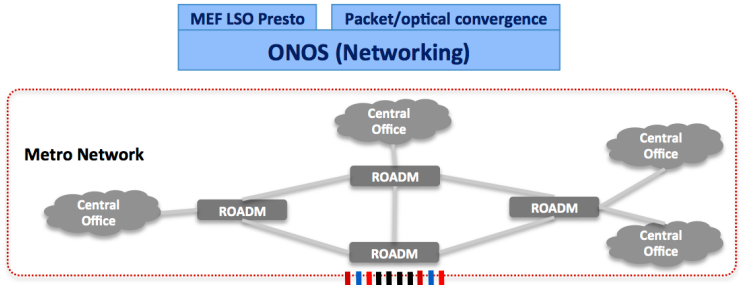
Enterprise-CORD







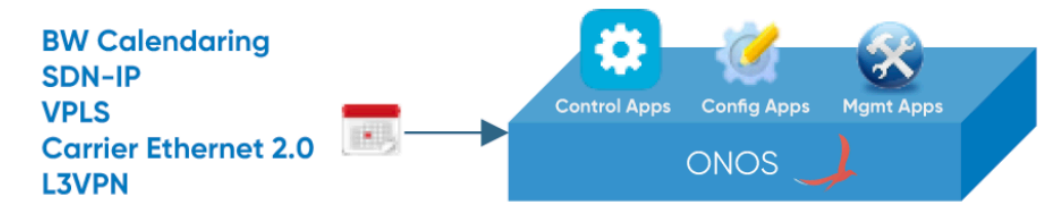




Source: http://opencord.org/

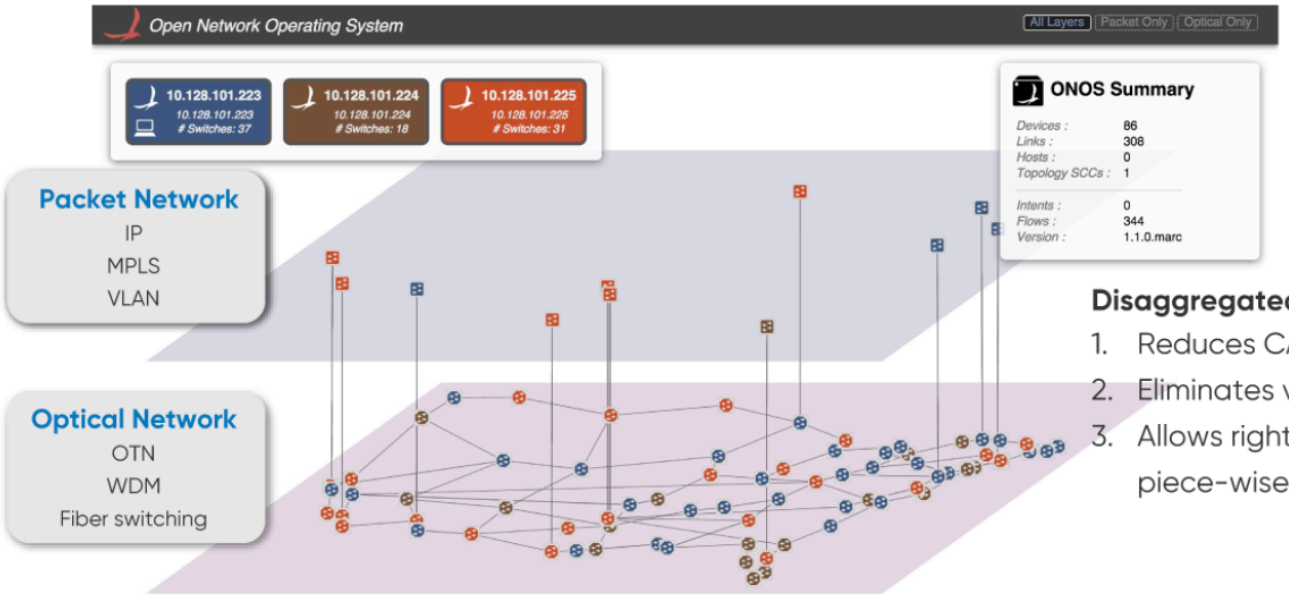
New: Open Disaggregated Transport Network

Multi-layer SDN Control of Packet and Optical Networks for an Agile, Efficient WAN



Logically Centralized Control

1. Optimize resource usage
2. Dynamic traffic provisioning
3. Multi-layer resiliency



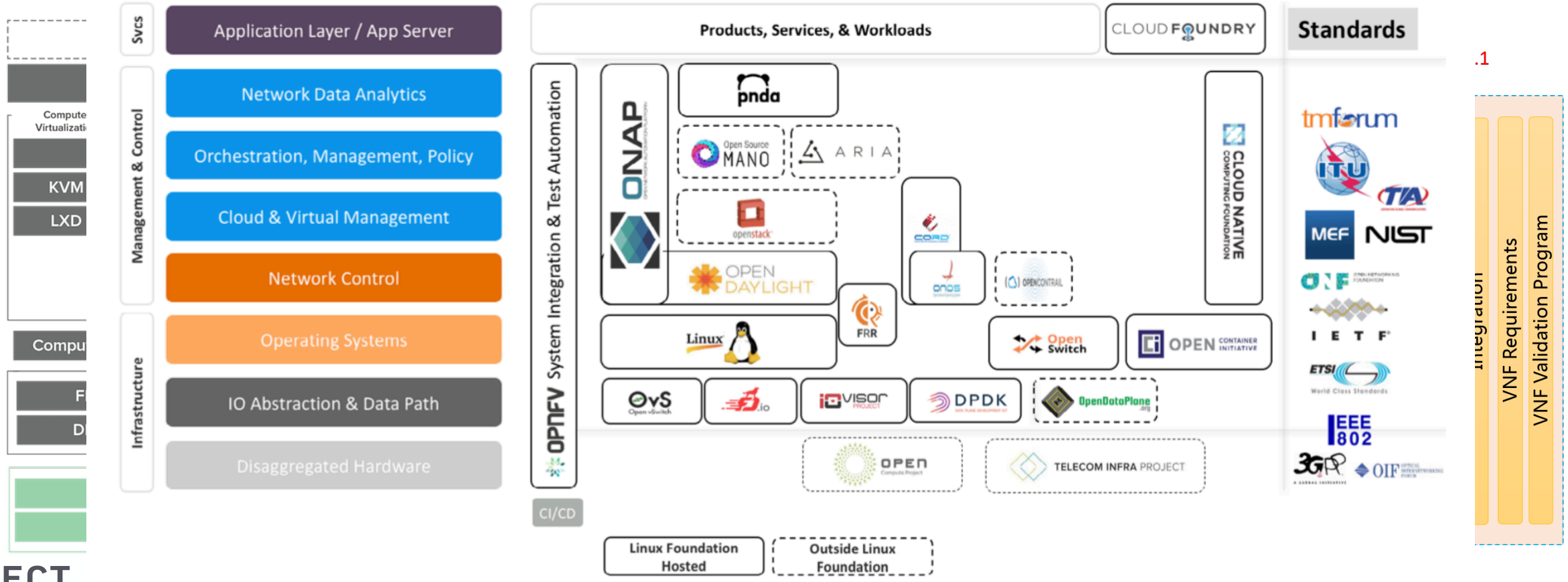
Disaggregated Transport Network

1. Reduces CAPEX & OPEX
2. Eliminates vendor lock-in
3. Allows rightsizing and piece-wise upgrades

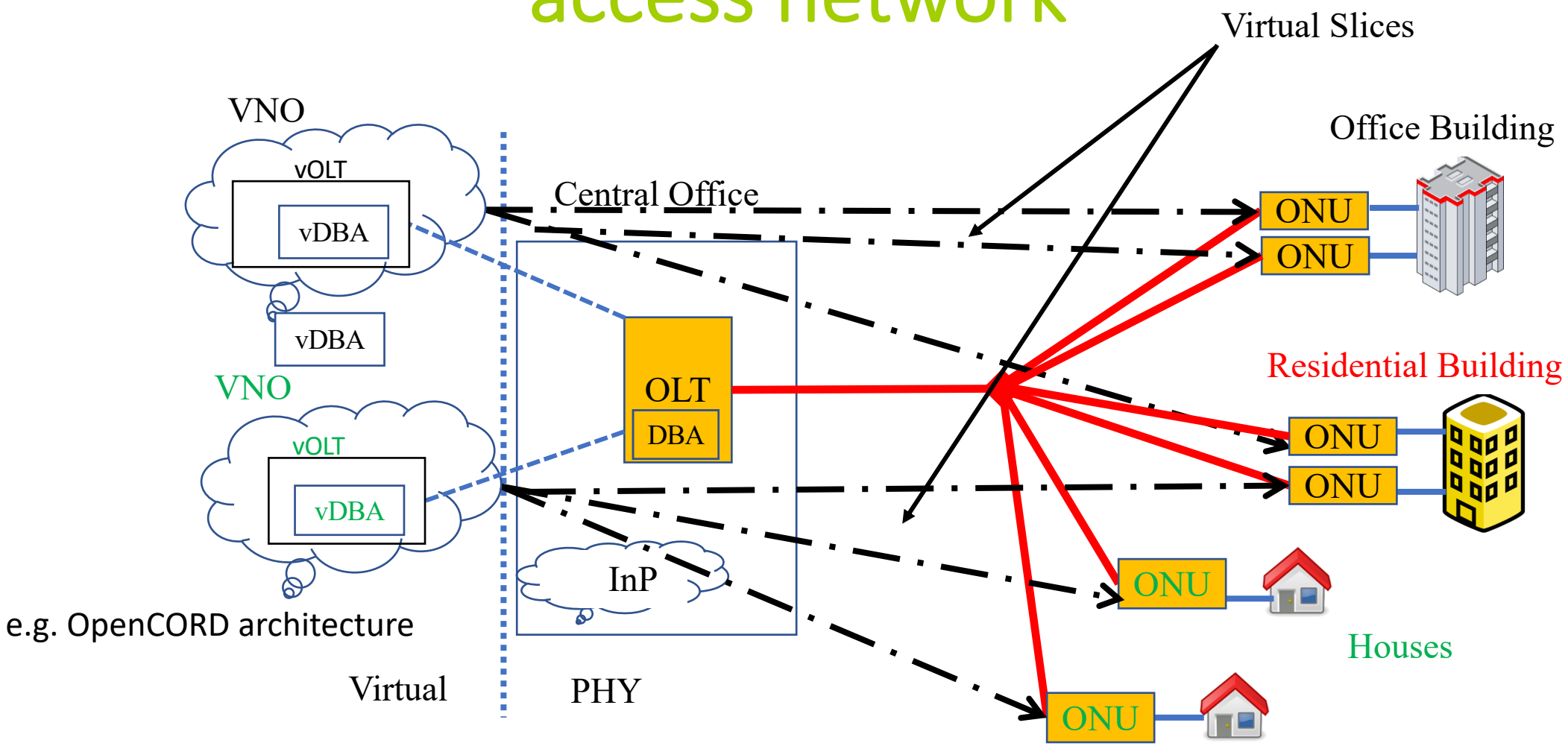
Source: https://www.opennetworking.org

Activities in network virtualisation

- Standardisation of the Cloud Central Office Concept (BroadBand Forum)
- Although it's really when you see the design associated with a software implementation that this starts making more sense…



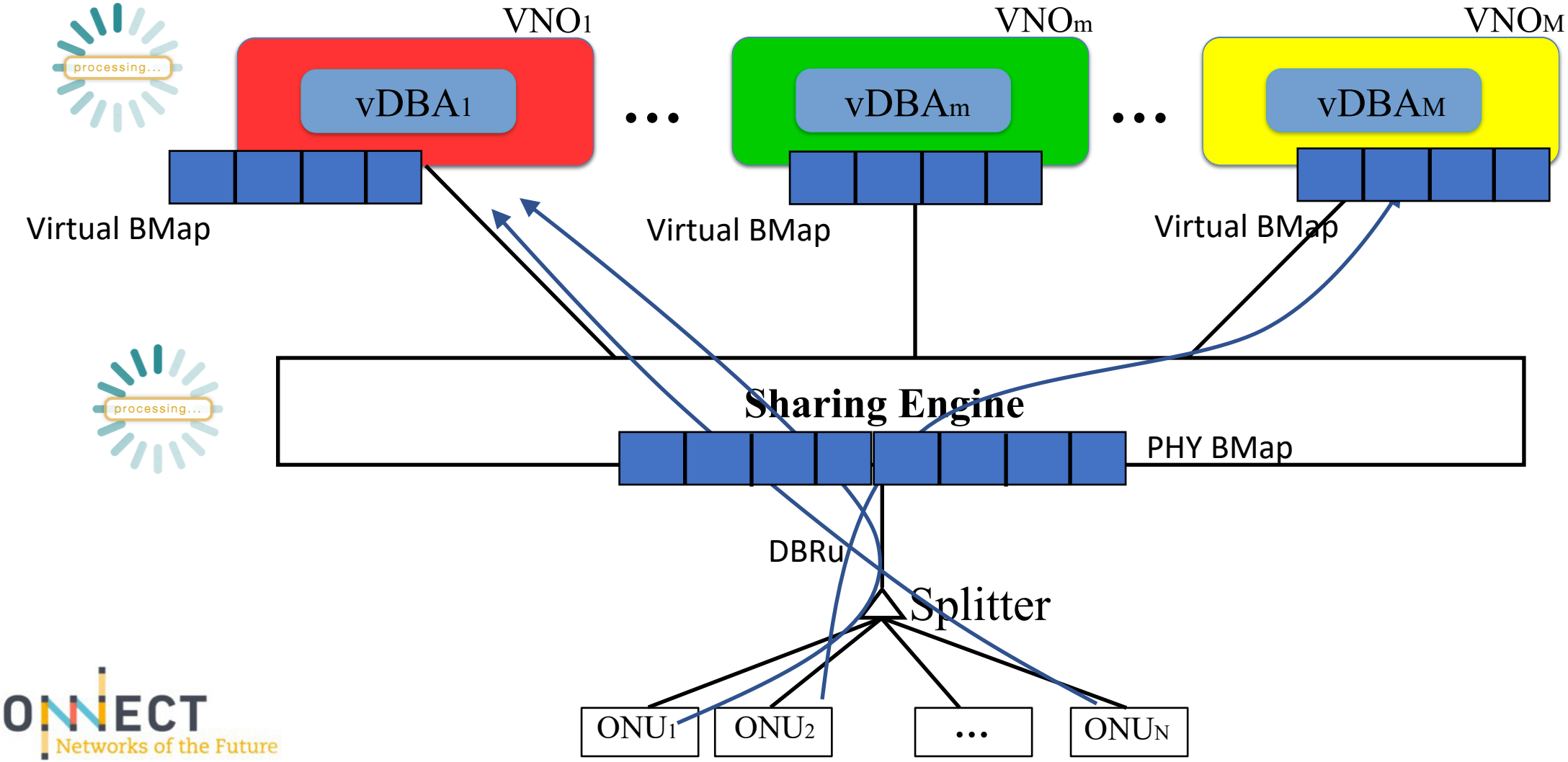
Our work: virtualisation of the optical access network



Amr Elrasad and Marco Ruffini, Frame Level Sharing for DBA Virtualization in Multi-Tenant PONs. Proc. Of Optical Networks Design and Modeling (ONDM), May 2017

Amr Elrasad, Nima Afraz, and Marco Ruffini, Virtual Dynamic Bandwidth Allocation Enabling True PON Multi-Tenancy. Proc. of Optical Fibre Communications conference (OFC), March 2017

Virtual PYH-layer interactions



vOLT performance: comparison to previous work

TRINITY COLLEGE DUBLIN

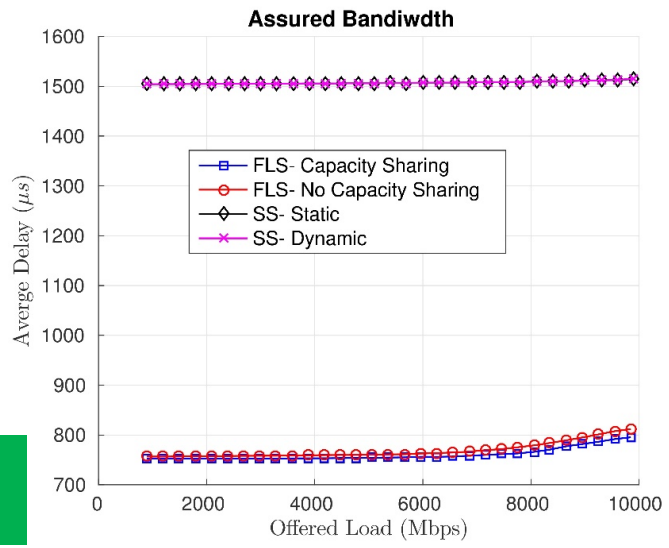
VNOs have same load

VNOs load ratio 1:2

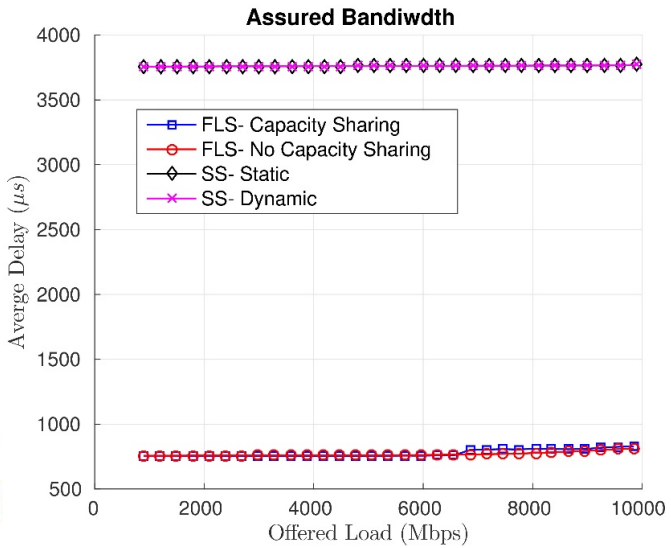
scalability

Service Isolation

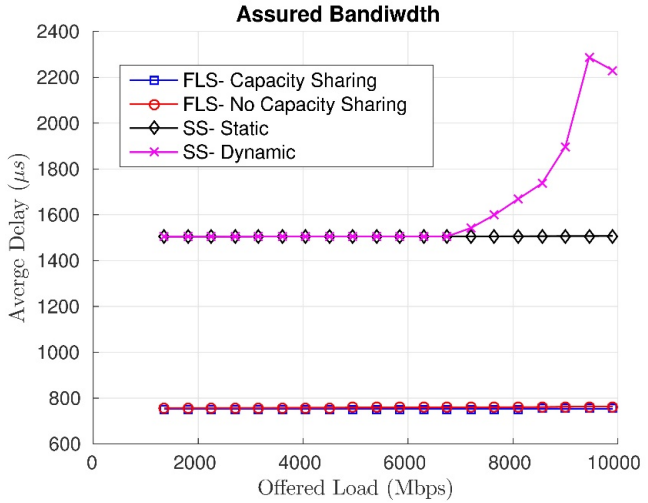
2 VNOs, balanced



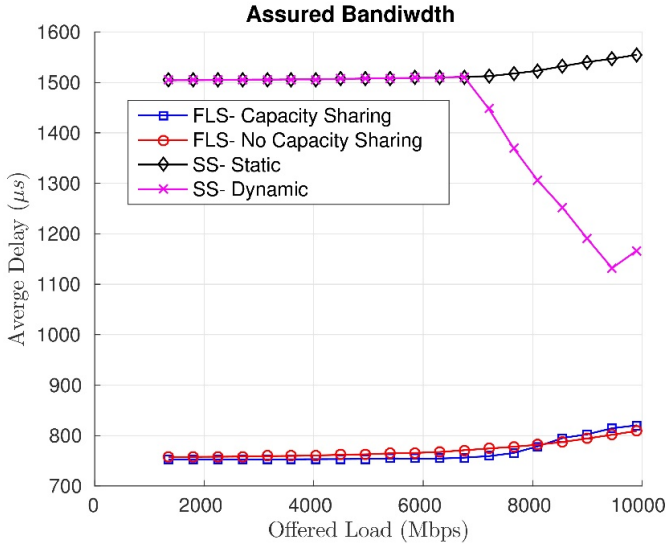
5 VNOs, balanced



2 VNOs, low loaded

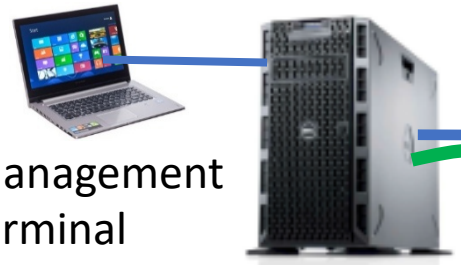


2 VNOs, high loaded



CONNECT Networks of the

Demonstration at OFC, San Diego, March 2017



Management terminal

DBRU Emulation Server

OPNFV

Orchestration and Management (MANO)

Virtual Network Functions

VNO1 vOLT vDBA

VNO2 vOLT vDBA

VNO3 vOLT vDBA

Mergine Engine

Compute Virtualisation Control

Storage Virtualisation Control

Network Virtualisation Control

OpenStack

KVM

CEPH

ONOS

Data Plane Acceleration

DPDK

DBRU

BWMap

Frank Slyne, Amr Elrasad, Christian Blumm and Marco Ruffini, Demonstration of Real Time VNF Implementation of OLT with Virtual DBA for Sliceable Multi-Tenant PONs. Accepted for OFC 2018 SDN/NFV demo session

TCONT#13 Fixed

TCONT#11 Assured

TCONT#12 Unassured

TCONT#13 Best Effort

TCONT#21 Fixed Assured

TCONT#22 Unassured

TCONT#23 Best Effort

Traffic Generator

ONU1

ONU2

VC709

Physical PON

DBRU

BWMap

Foreground traffic

Eth0

Data Plane

OVS

Eth1

OLT

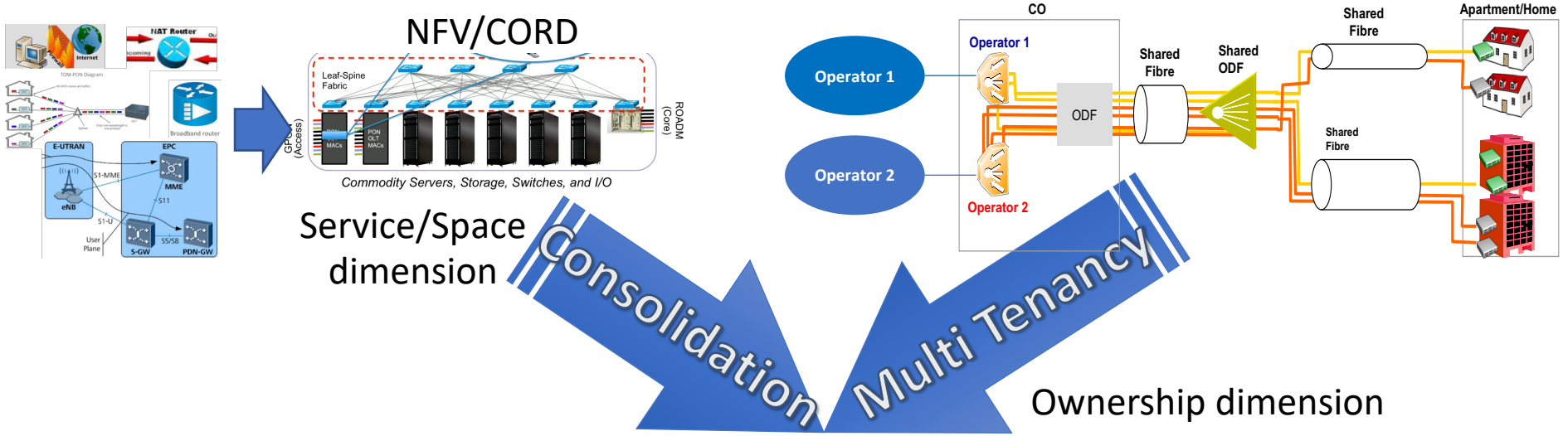
VC709

Return traffic

TRINITY COLLEGE DUBLIN

Networks of the Future

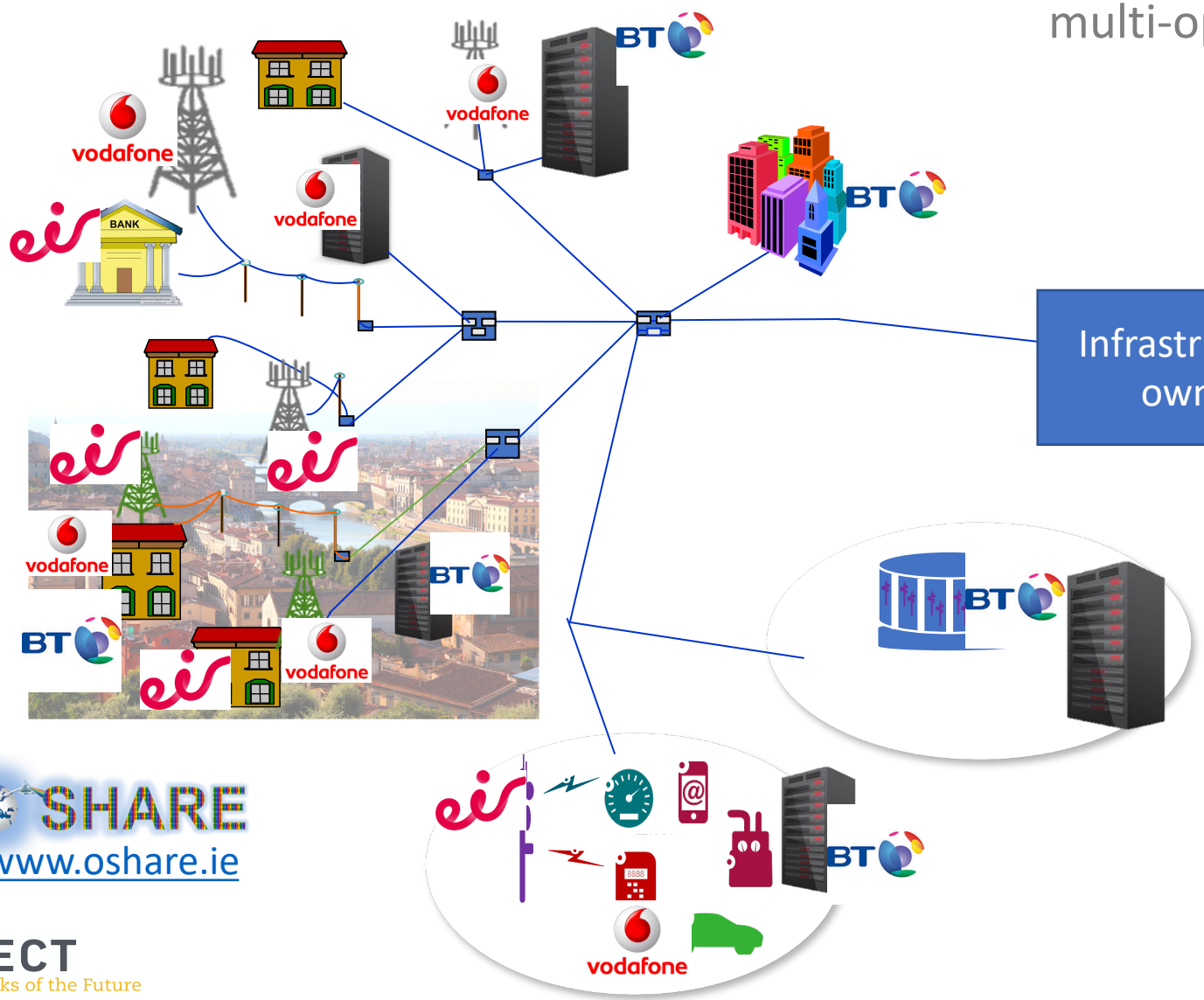
5G vision: Multi-dimensional convergence



Multi-tenancy aspect

TRINITY COLLEGE DUBLIN

An open access SDN-driven architecture enabling multi-operator and multi-service convergence in shared optical access networks



Infrastructure owner

vodafone

BT

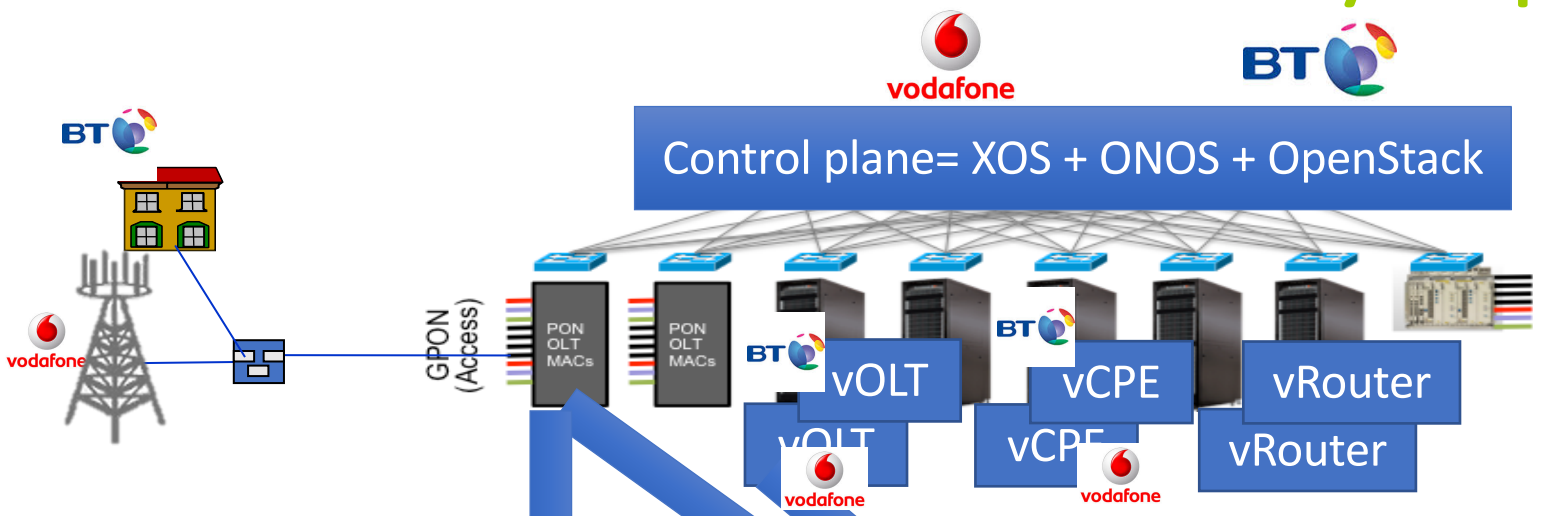
Allow virtual service provider to have full control in access capacity allocation.

Enable coexistent of multiple services, from best effort to strict-QoS

SHARE
www.oshare.ie

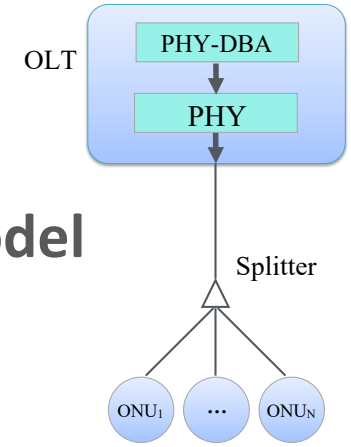
CONNECT
Networks of the Future

Multi-tenancy aspect



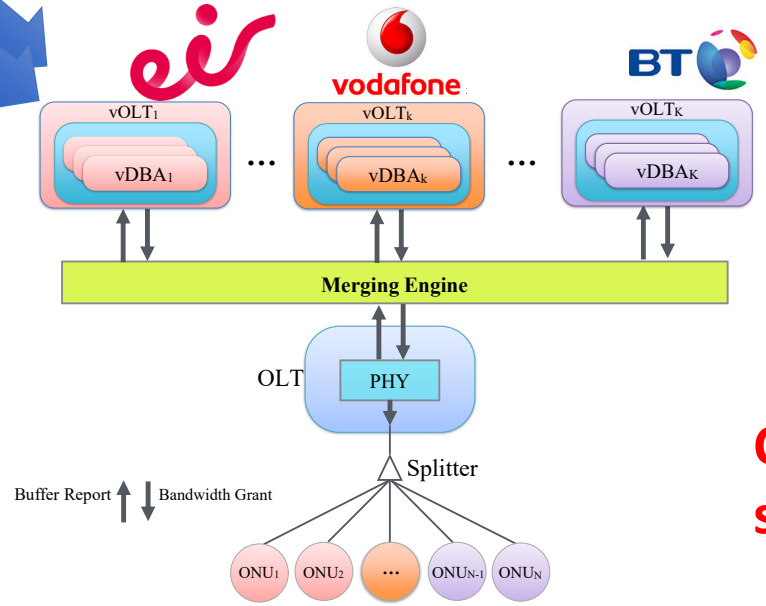
Push virtualisation down to data plane/scheduling

give SPs the illusion of complete physical control of shared physical infrastructure



Current model

O'SHARE model



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Amr Elrasad and Marco Ruffini, Frame Level Sharing for DBA Virtualization inMulti-Tenant PONs. ONDM, May 2017.

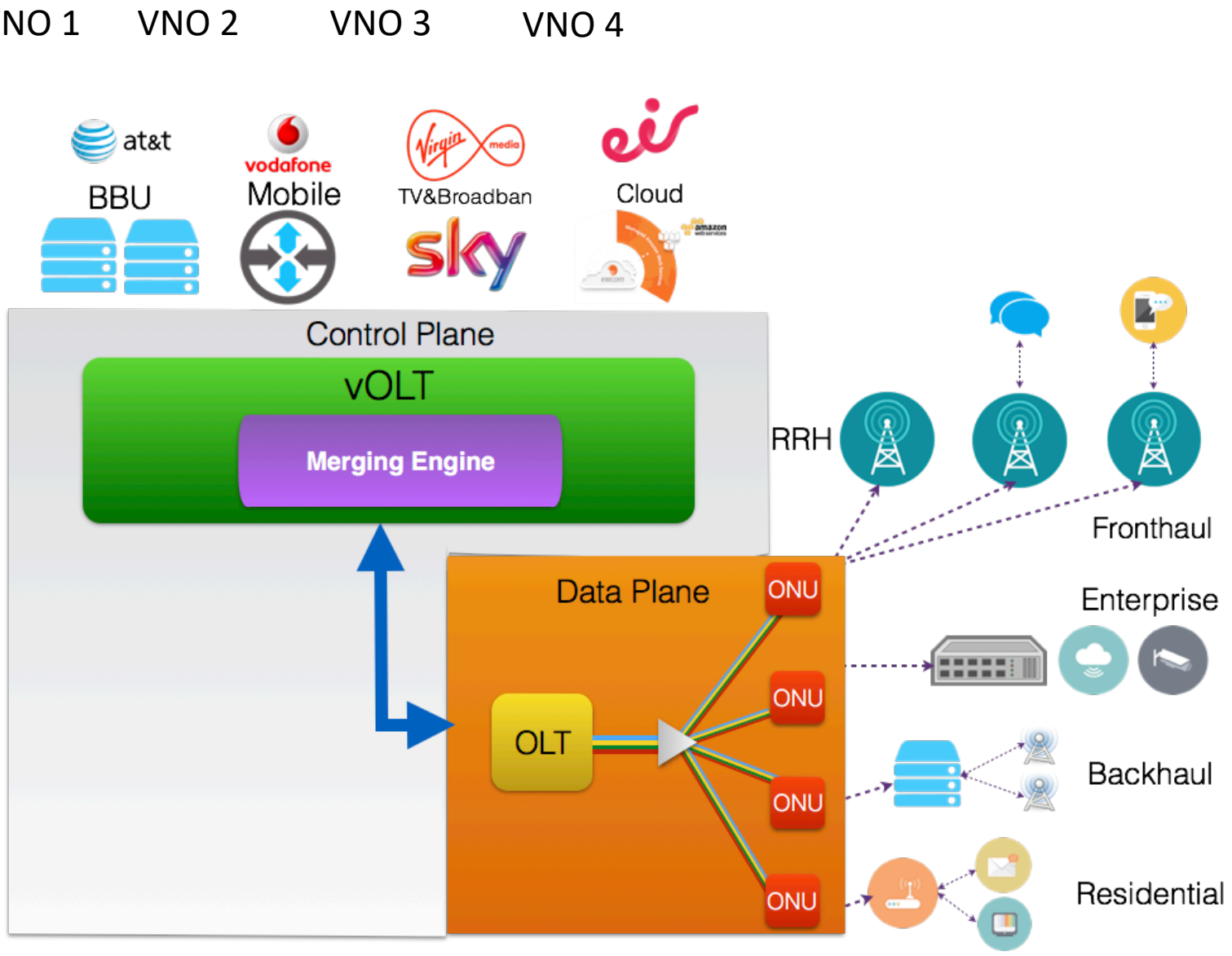
Contributing to BBF standardisation forum

CONNECT Networks of the Future

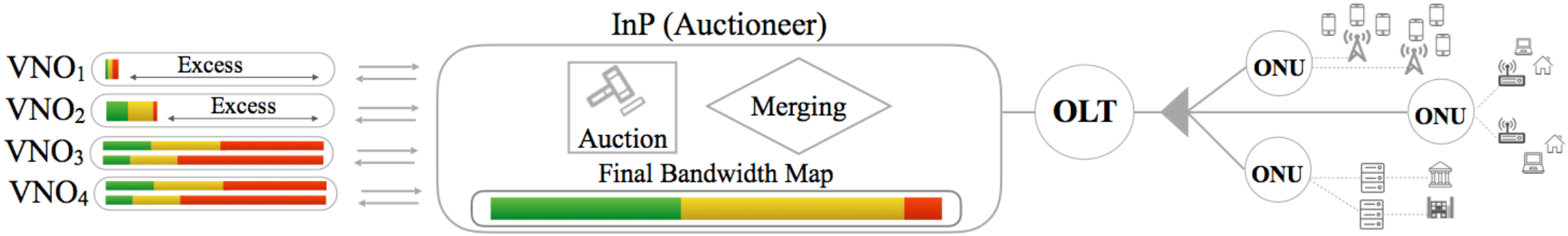
Our work: Sharing incentives

- Why would a VNO share excess bandwidth with other VNOs instead of blindly assigning it to its own users?

- VNOs can give economic advantage to competitors:
  - other VNOs gain economic benefit by under-provisioning their capacity (=lower cost) and taking advantage of unused capacity



Multi-tenant PON market



Desired auctions features

From an economist's point of view

- Truthfulness (Strategy-proofness)
  - Traders cannot manipulate the market by reporting untruthful values
- Individual Rationality
  - Traders will not regret participating in the auction
- Budget Balance

From engineering point of view

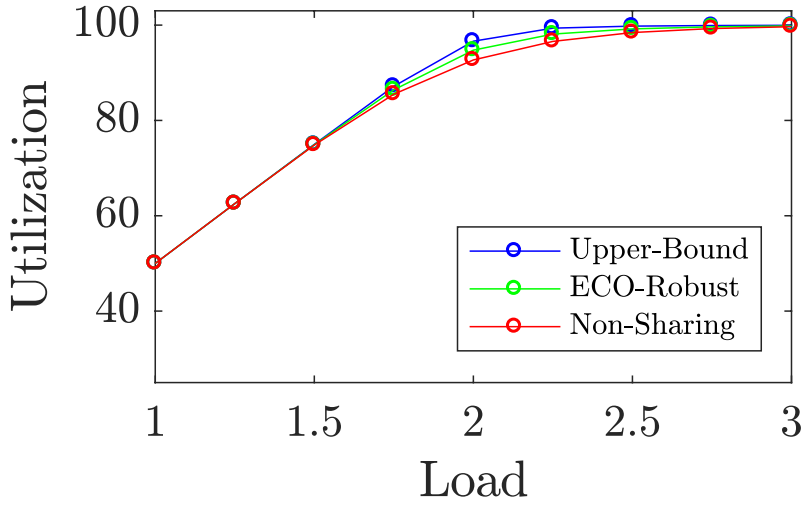
- Minimum communication between sellers, buyers, and infrastructure providers

Nima Afraz, Amr Elrasad, Marco Ruffini, DBA Capacity Auctions to Enhance Resource Sharing across Virtual Network Operators in Multi-Tenant PONs, Accepted for OFC 2018.

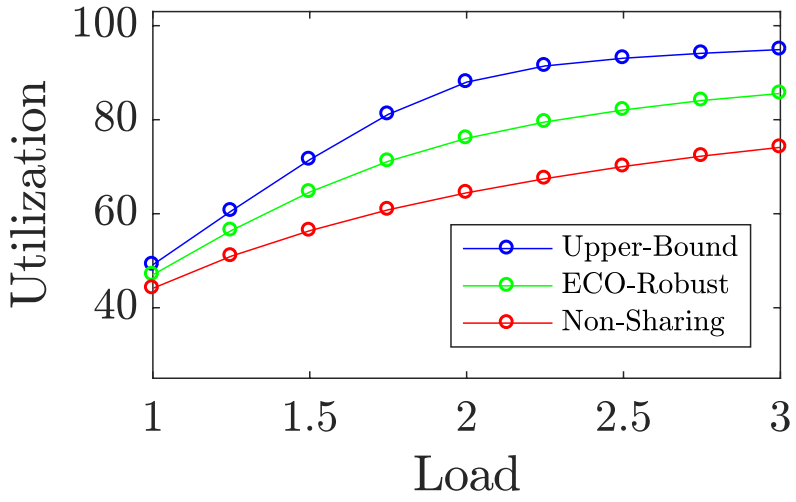
Nima Afraz, Amr Elrasad, Hamed Ahmadi and Marco Ruffini, Inter-Operator Dynamic Capacity Sharing for Multi-Tenant Virtualized PON. 28th International Symposium on Personal, Indoor and Mobile Radio Communication, PIMRC, Oct. 2017

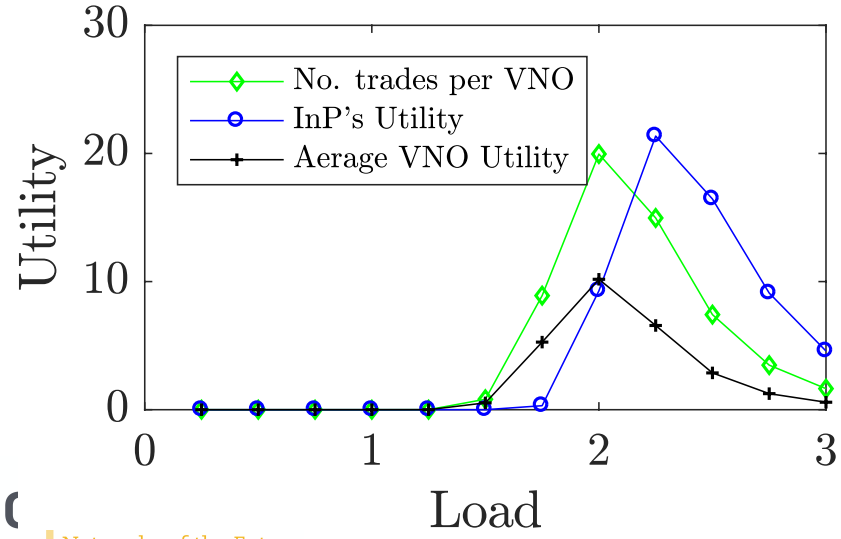
Some results

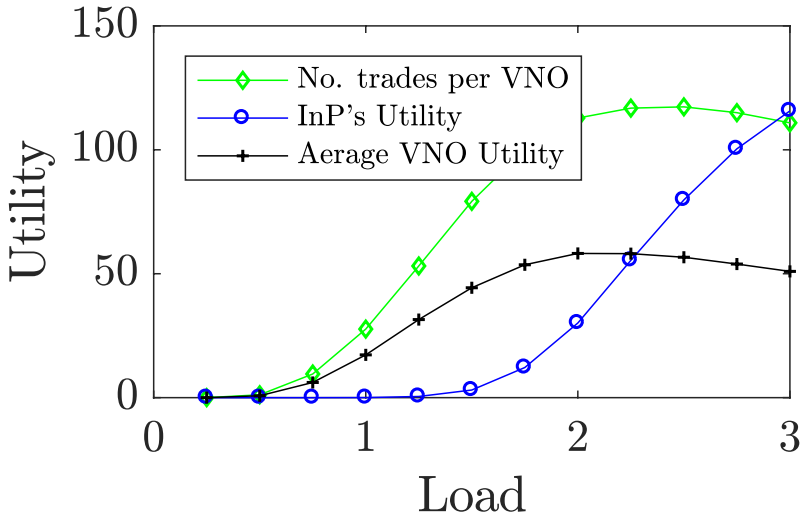
Balanced load



Unbalanced load

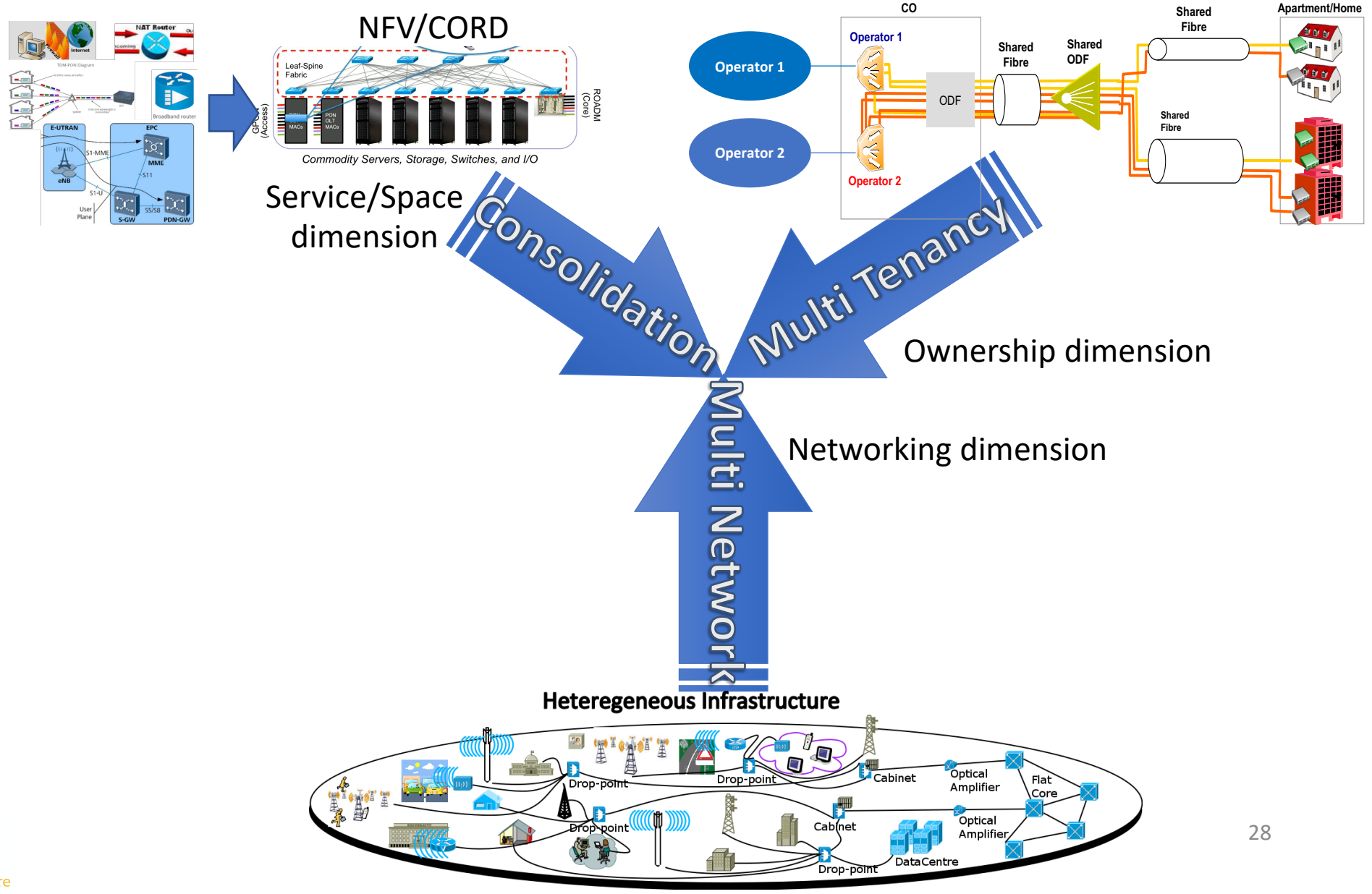




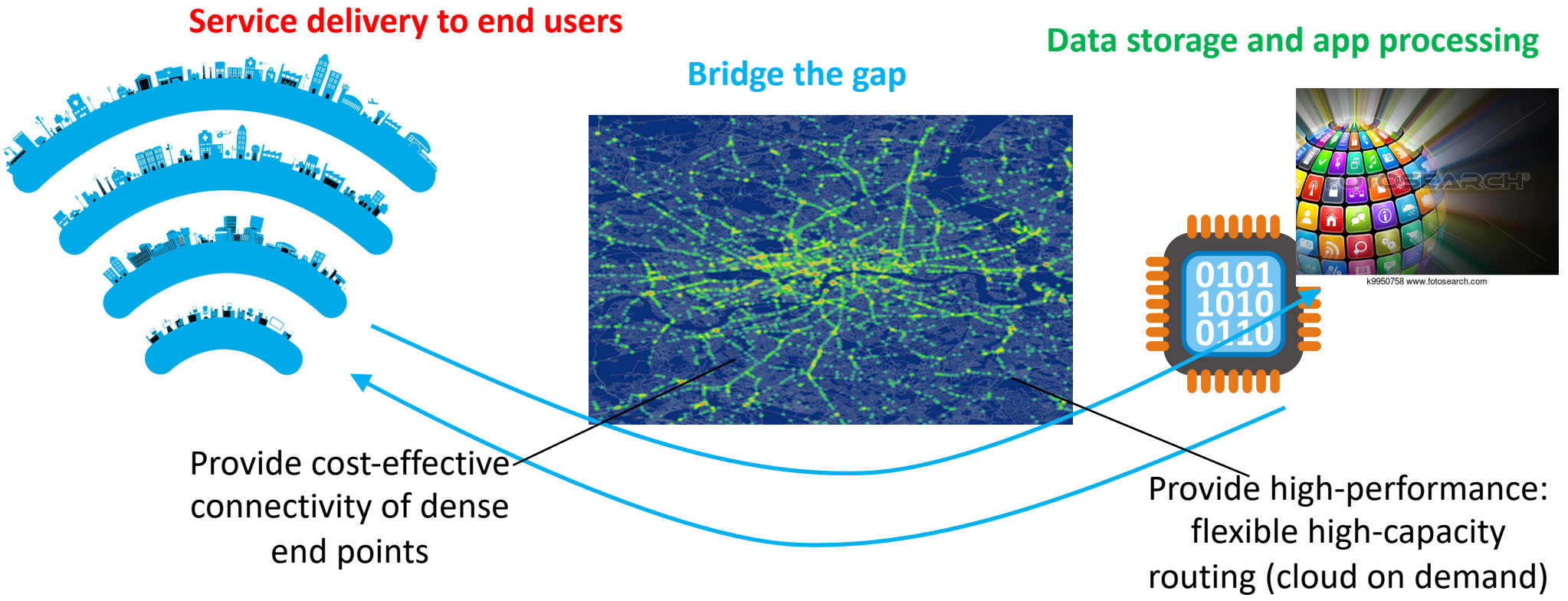


- Upper bound: the items from the cheapest sellers are sold to the highest offers for the reported values (i.e., perfect market with assumption of truthfulness - not economic-robust);

5G vision: Multi-dimensional convergence



Why fixed/mobile/DC convergence?



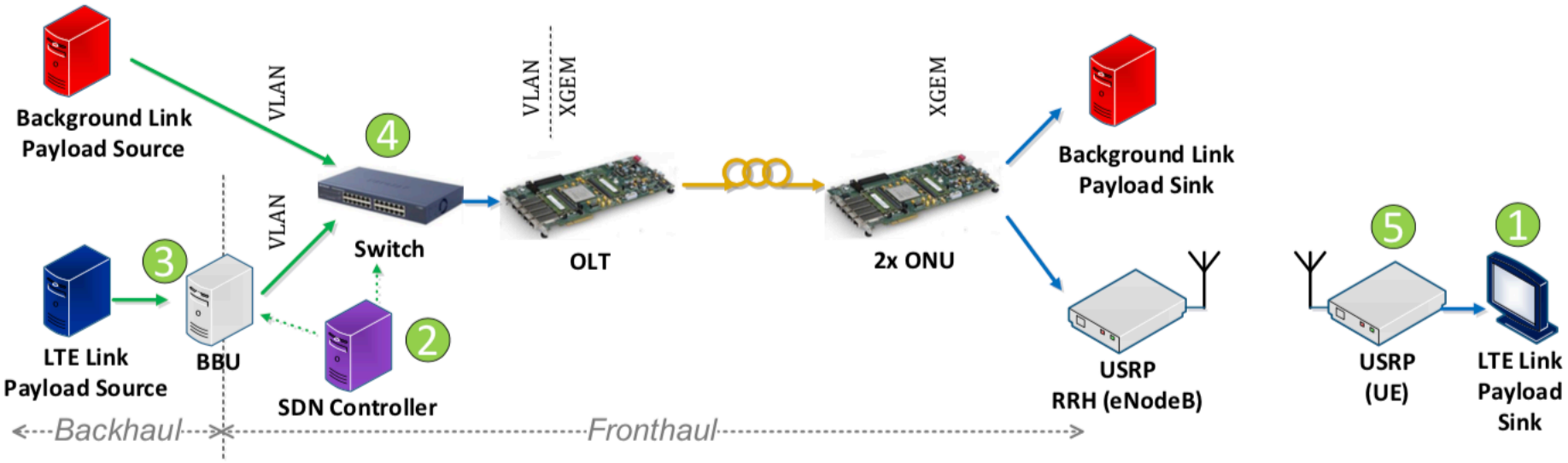
End-to-end reliability, repeatability (haptic feedback, front/X-hauling)

Our Work: Fixed-mobile LTE-PON convergence demonstration: dynamic fronthaul over PON

Fronthaul rate is fixed, independently of mobile user requirements

However if we dynamically change the wireless bandwidth we can change the sampling frequency

➔ Fronthaul rate can be made dependent on actual usage



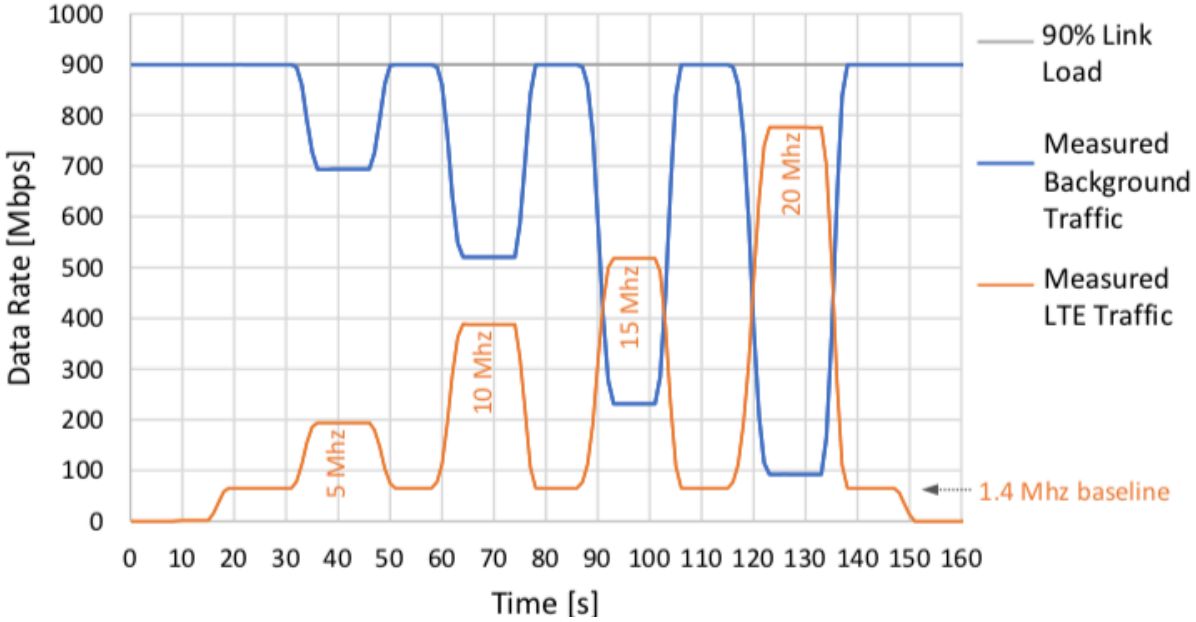
Events:

1. *Asynchronous change in foreground traffic demand*
2. *Synchronous reporting of application bit rate*
3. *Controller instructs BBU to alter I/Q rate*
4. *Controller alters committed data rate in the switch*
5. *UE resyncs*

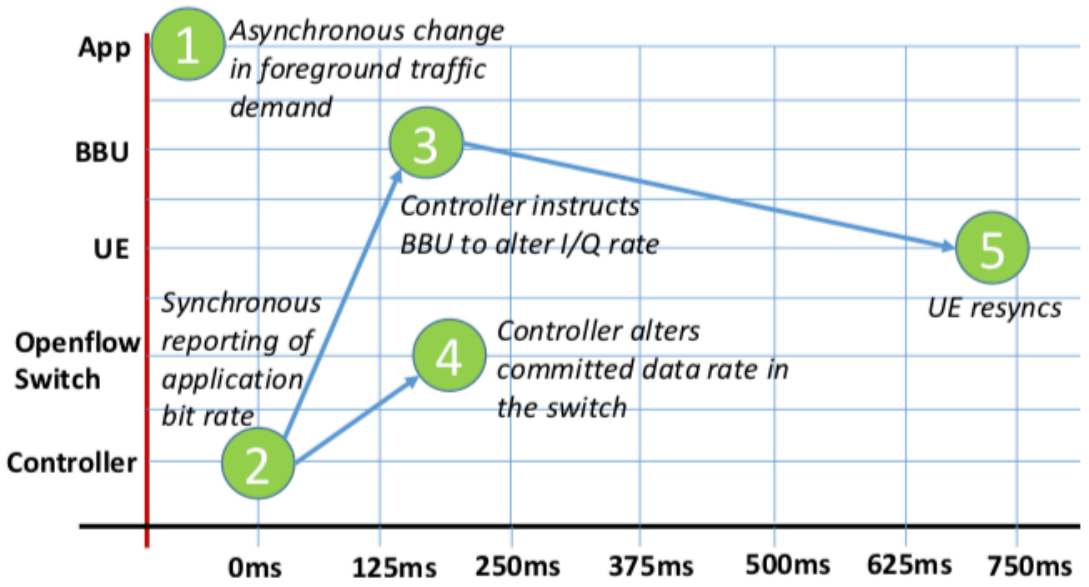
1G Ethernet
10G Ethernet
Fibre

CONNE Networks of the Future

Some experimental results



Measured fronthaul vs. best effort traffic

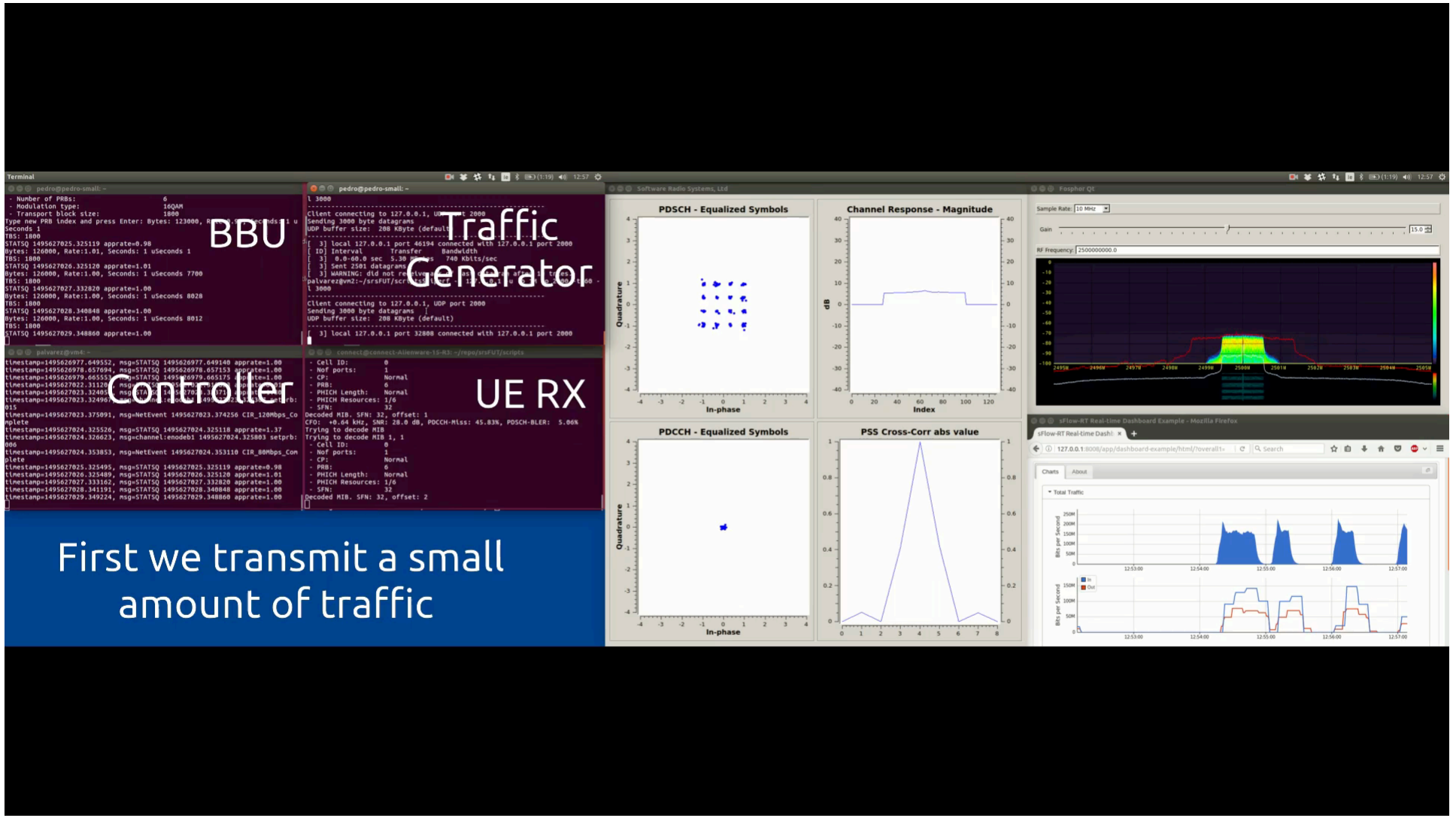


Time diagram of switching events

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

Pedro Alvarez, Frank Slyne, Christian Bluemm, Johann M. Marquez-Barja, Luiz A. DaSilva, Marco Ruffini, Experimental Demonstration of SDN-controlled Variable-rate Fronthaul for Converged LTE-over-PON. Accepted for OFC 2018

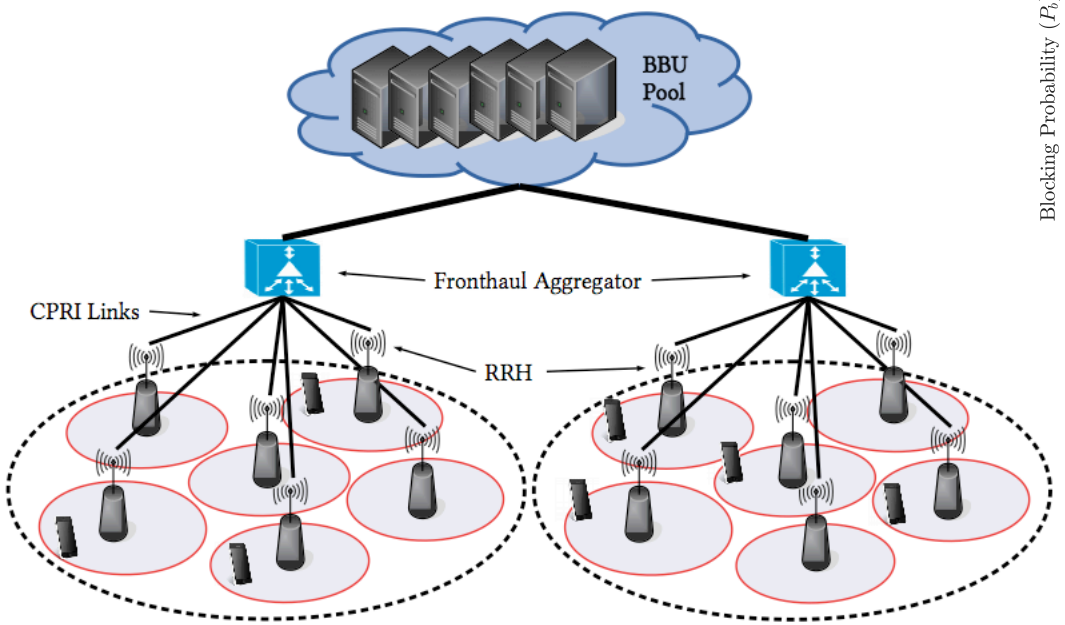
Demonstration: dynamic fronthaul over PON

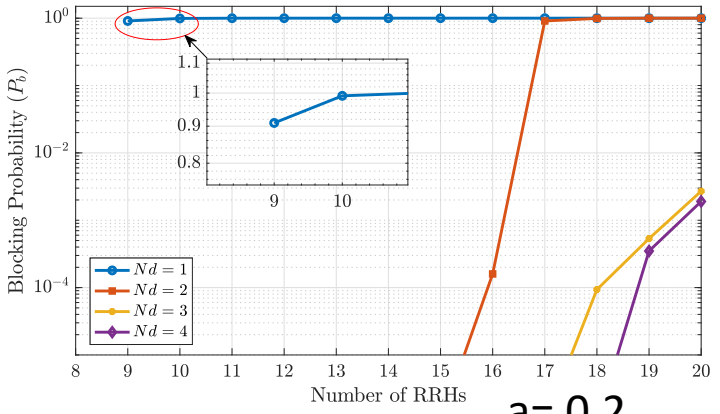


Our work: Variable rate fronthaul use cases

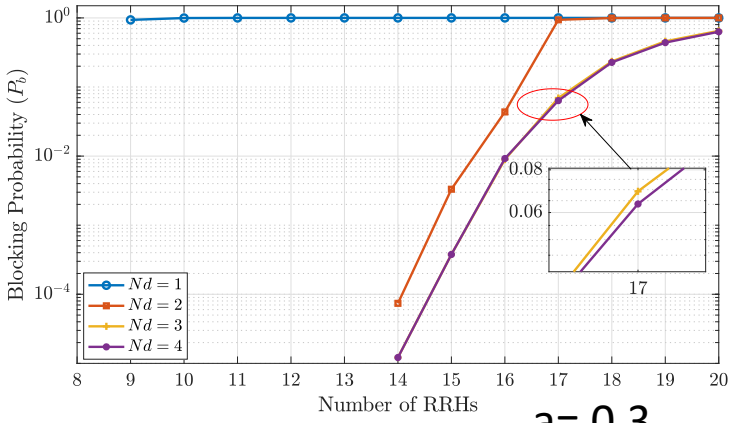
- Key goal is to re-instate the statistical multiplexing of base stations

➔ cells linked to a fronthaul aggregator (Ethernet switch or PON network)

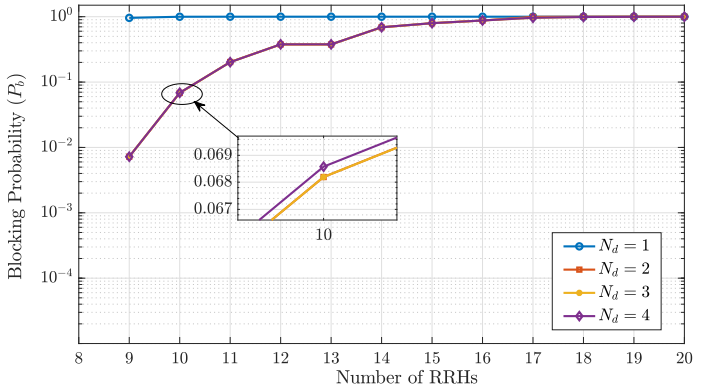




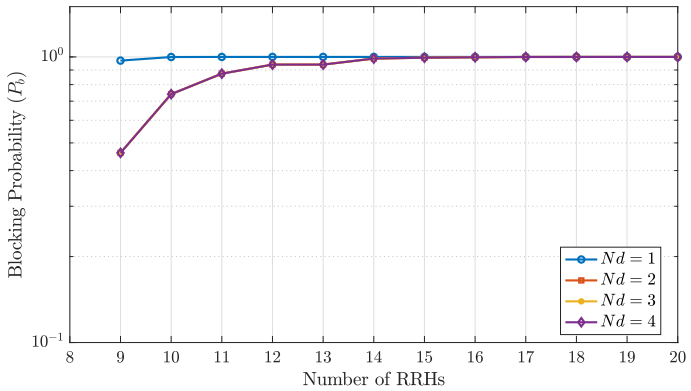
a= 0.2



a= 0.3



a= 0.5



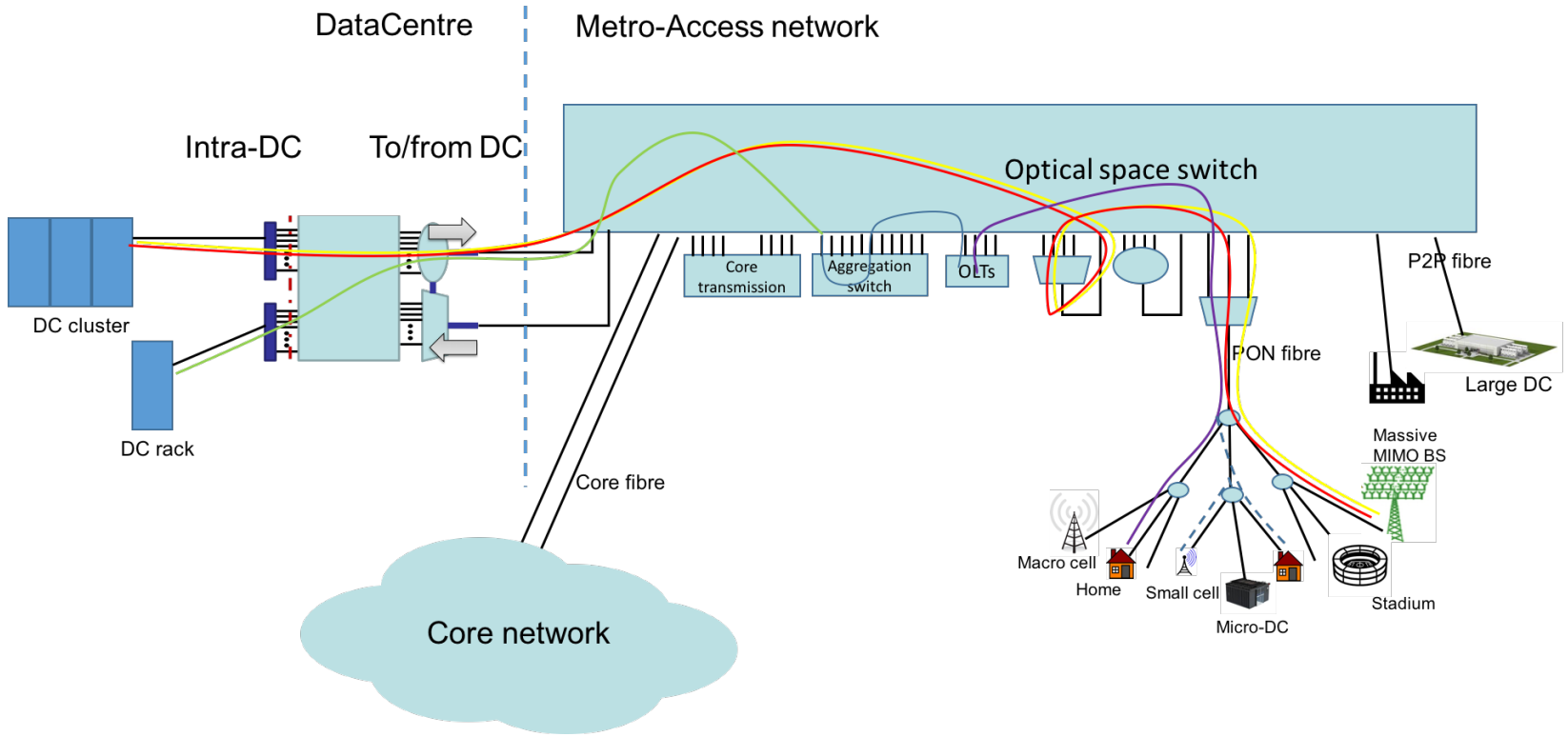
a= 0.7

a= incoming/served requests

Data centre and edge cloud integration

- Seamless connectivity of data centres in the access/metro convergence
  - DCs have already moved to the metro to reduce latency and core traffic
  - As COs turn into virtual/cloud Cos, we'll see a full integration of the DC type of nodes within the 5G ecosystem

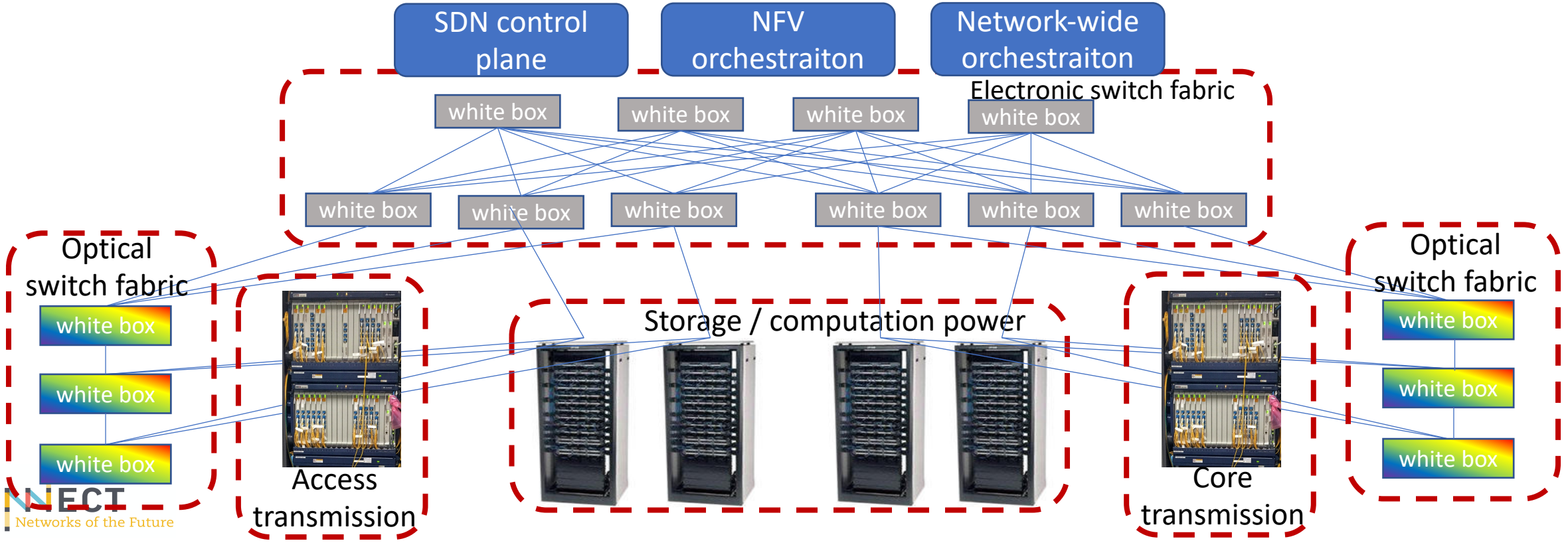
- Transparent optical connection directly to DC cluster or rack



Source: SFI/NSF project "*Agile cloud service delivery using integrated photonics networking*"

The fully converged view

- As central offices turn into Cloud CO, **everything (network/computation node)** will look more like a DC:
  - Core of servers/switches: *white boxes has brought much innovation already*
  - SDN/NFV/Orchestration control and management: *more to come, on per-flow availability/reliability*
  - Optical switching technology: *much more to come*
    - starting from highly reconfigurable ROADMs/metro transmission …
    - …to progressive integration with electronic switching fabric
  - Edge of few types of (optical) transmission technology: *more to come in photonic integration technology*



~~Conclusions~~ Vision

Is this it?
Will convergence enable 5G?

- There is much more that I haven't discussed and involves:
  - new services: how to bring more revenue to the system
  - infrastructure virtualisation and sharing: create virtual end-to-end networks on demand, possibly on a per-service basis
  - business models:
    - kee
    - do
    - is t

er second speed?

5G: Another Next-Generation Disappointment?

The forthcoming 5G standard sounds impressive, but it seems unlikely to reinvigorate the telco business.

Source: lightreading

Ericsson: 5G Heralds 'New' New Economy

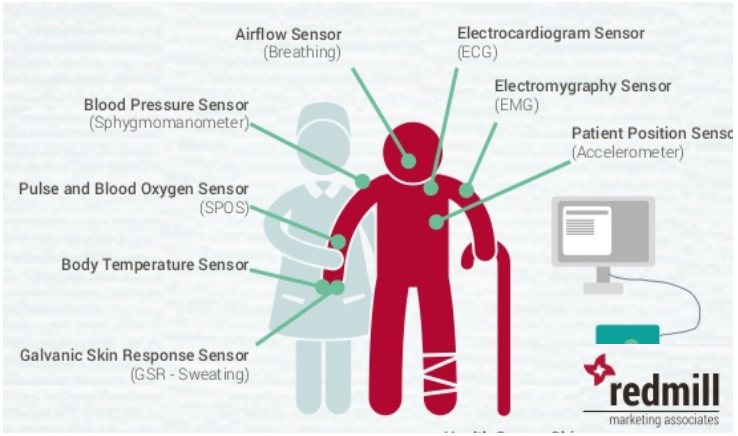
By MARI SILBEY, Senior Editor, Cable/Video, 1/12/2017

Just as the Internet ushered in a new digital economy in the late 20th century, Ericsson CTO Ulf Ewaldsson believes the advent of 5G wireless connectivity will fundamentally change business models once again.

Source: lightreading

5G is more than (G)b/s

- End users will pay more if a service is personalized and **it works** (requires end-to-end guarantee)
- The value (and willingness to pay) is not in the Gb/s but in service delivery



High value per bit

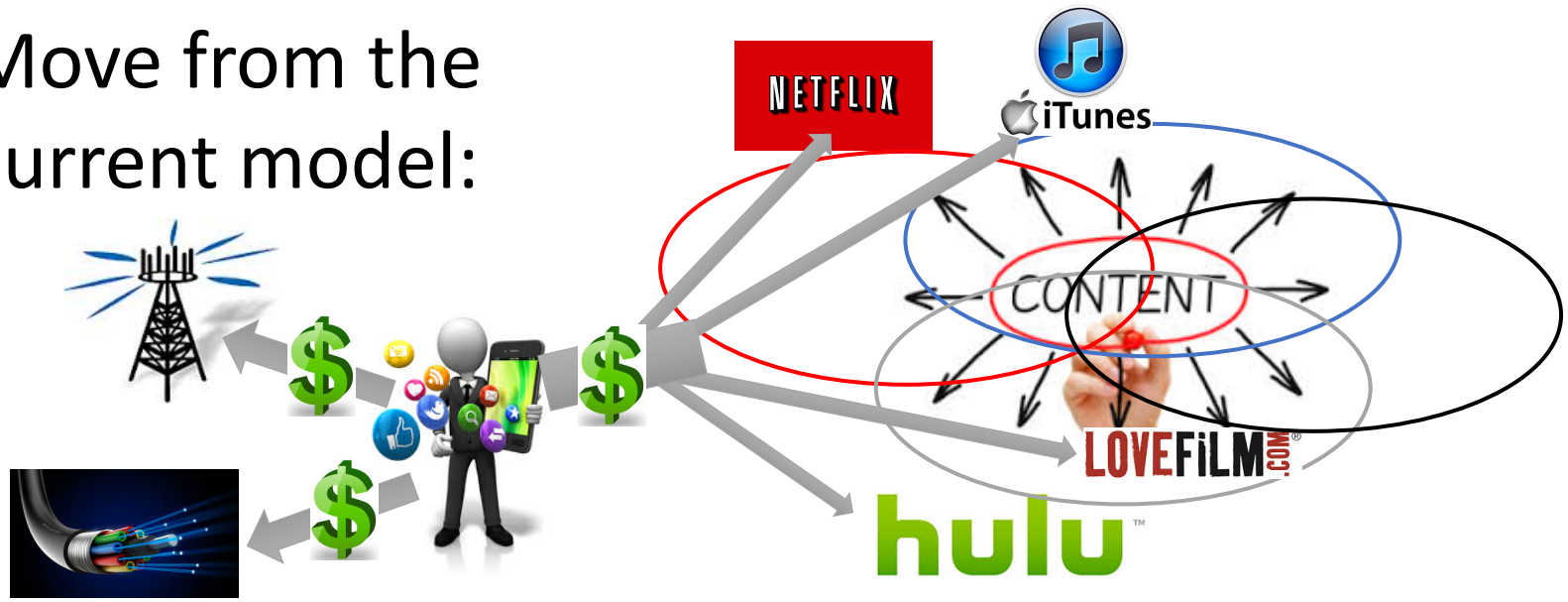
Low value per bit

Implications:

1. New high-value services to the users needed to bring more revenue into the network (e.g., redirect citizens spending towards services that use the network)
   ➔ I think there's novelty coming up with a reliable low-latency network
2. The current business model won't work, it does not have a clear chain of responsibility

Content-focused business models

Move from the current model:



To a service-driven model:

Example: Amazon Kindle 3G

Thank you for your attention!

Prof. Marco Ruffini
CONNECT / The centre for future networks and communications
The University of Dublin, Trinity College, Ireland
marco.ruffini@tcd.ie, www.marcoruffini.com
skype: ruffinim