

Network convergence for high performance and sustainable 5G networks

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CONNECT / The centre for future networks and
communications

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MINISTRY OF
SCIENCE, TECHNOLOGY,
INNOVATIONS AND
COMMUNICATIONS



Summary

- Intro to network convergence
 - What, why, how?
- Multi-dimensional convergence
 - Service/space dimension
 - Networking dimension
 - Ownership dimension
- Vision

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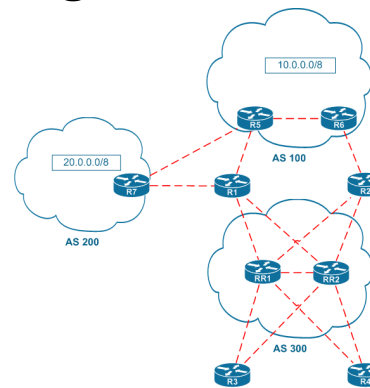
What is convergence?

- Merriam-Webster definition applied to technology:
“the merging of distinct technologies, industries, or devices into a unified whole”

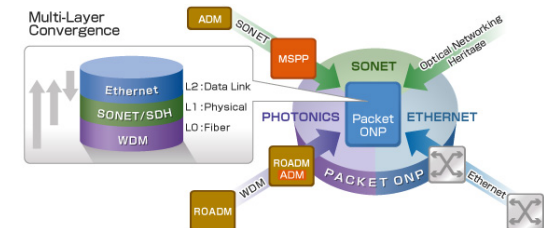
A better definition: what does Google thinks about it? Search results for “network convergence”



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



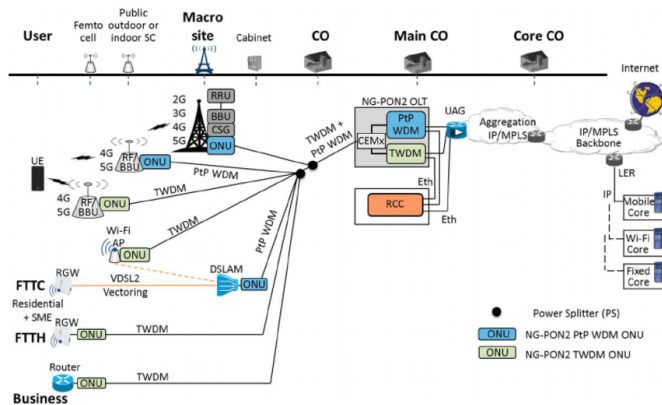
IP heads perspective:
convergence of
distributed protocols



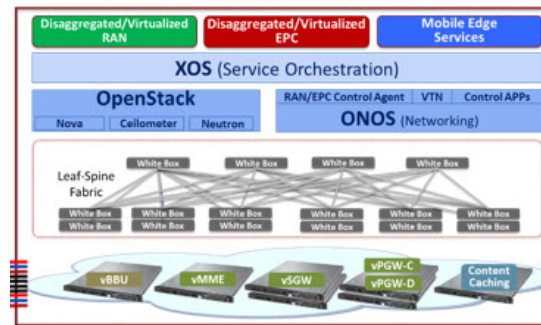
Telco vendors perspective:
packet-optical convergence

What does it mean for us

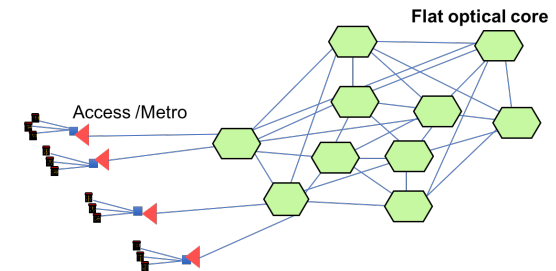
- Our research community (e.g., conferences... up to standardisation – apologies for any bias :)



Convergence of fixed and mobile networks



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



Convergence of access and metro networks

- ...please tell me more

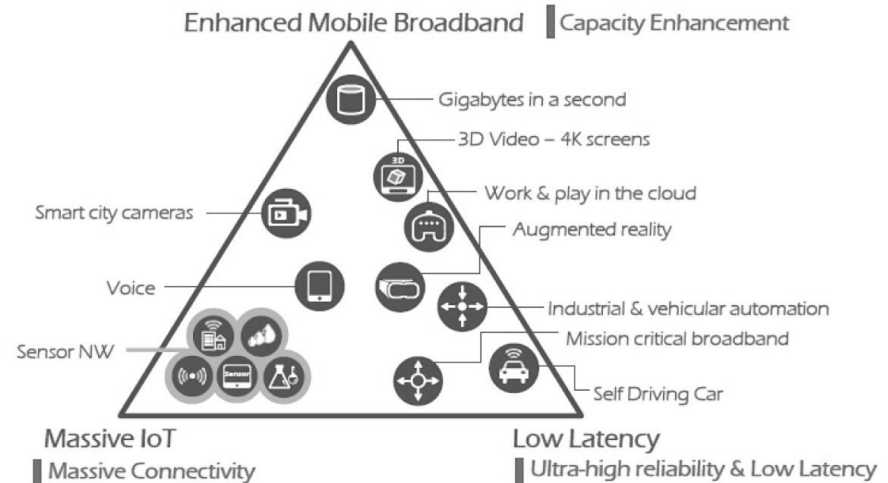
What is it for?

- 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

More revenue generating apps

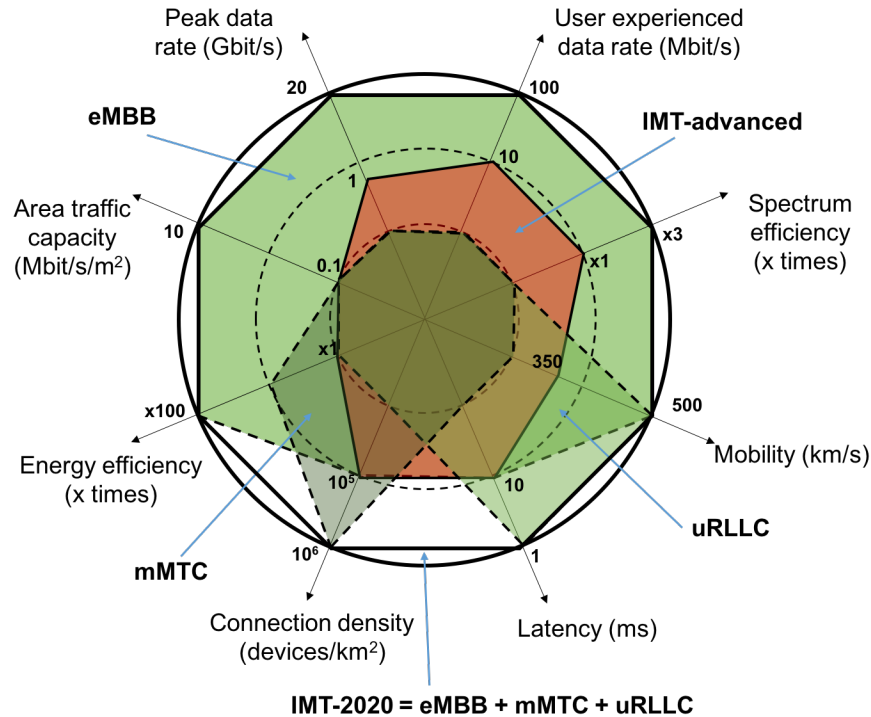
- Think real-time high capacity...



- Think real-time interaction



5G requirements



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!

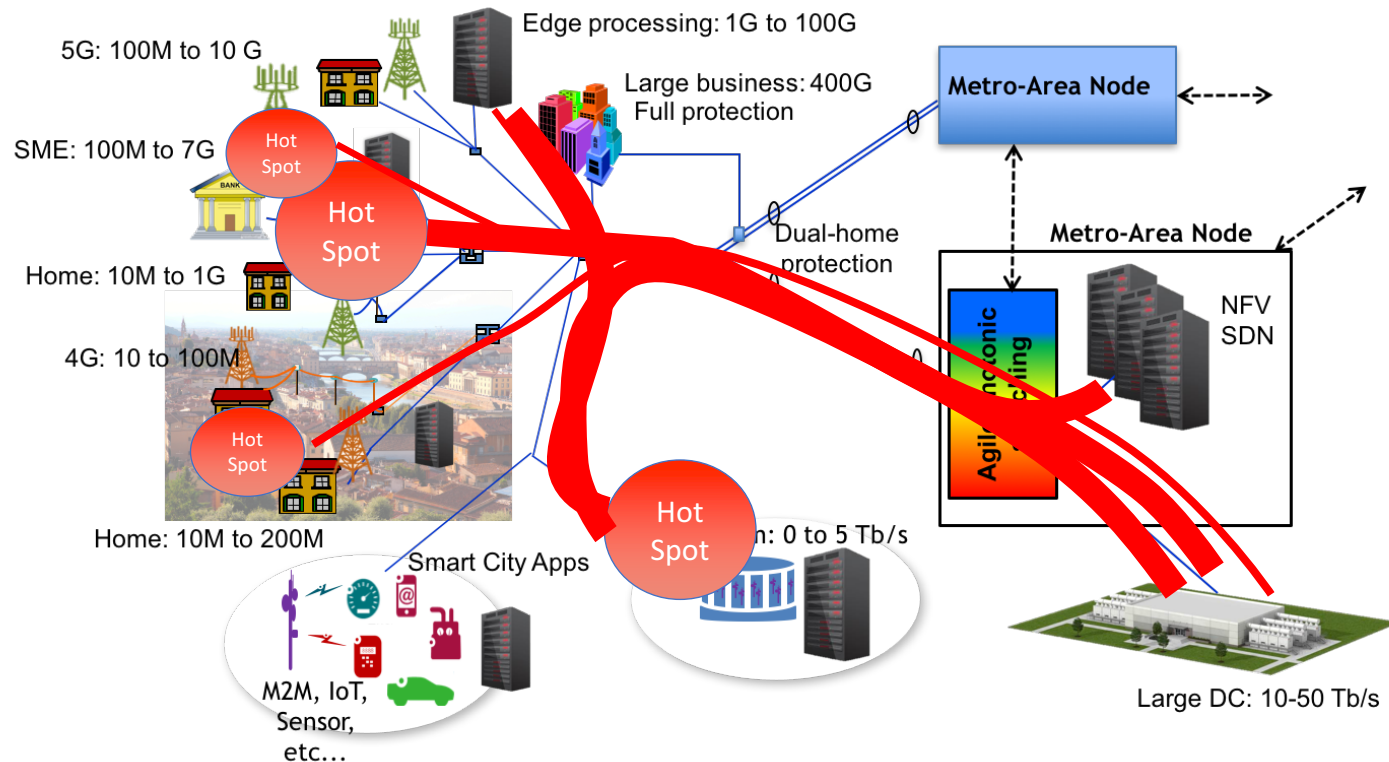
Even ITU has realized that!

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: a lot of it and and reconfigurable
 - Higher performance: low latency, low jitter
- 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

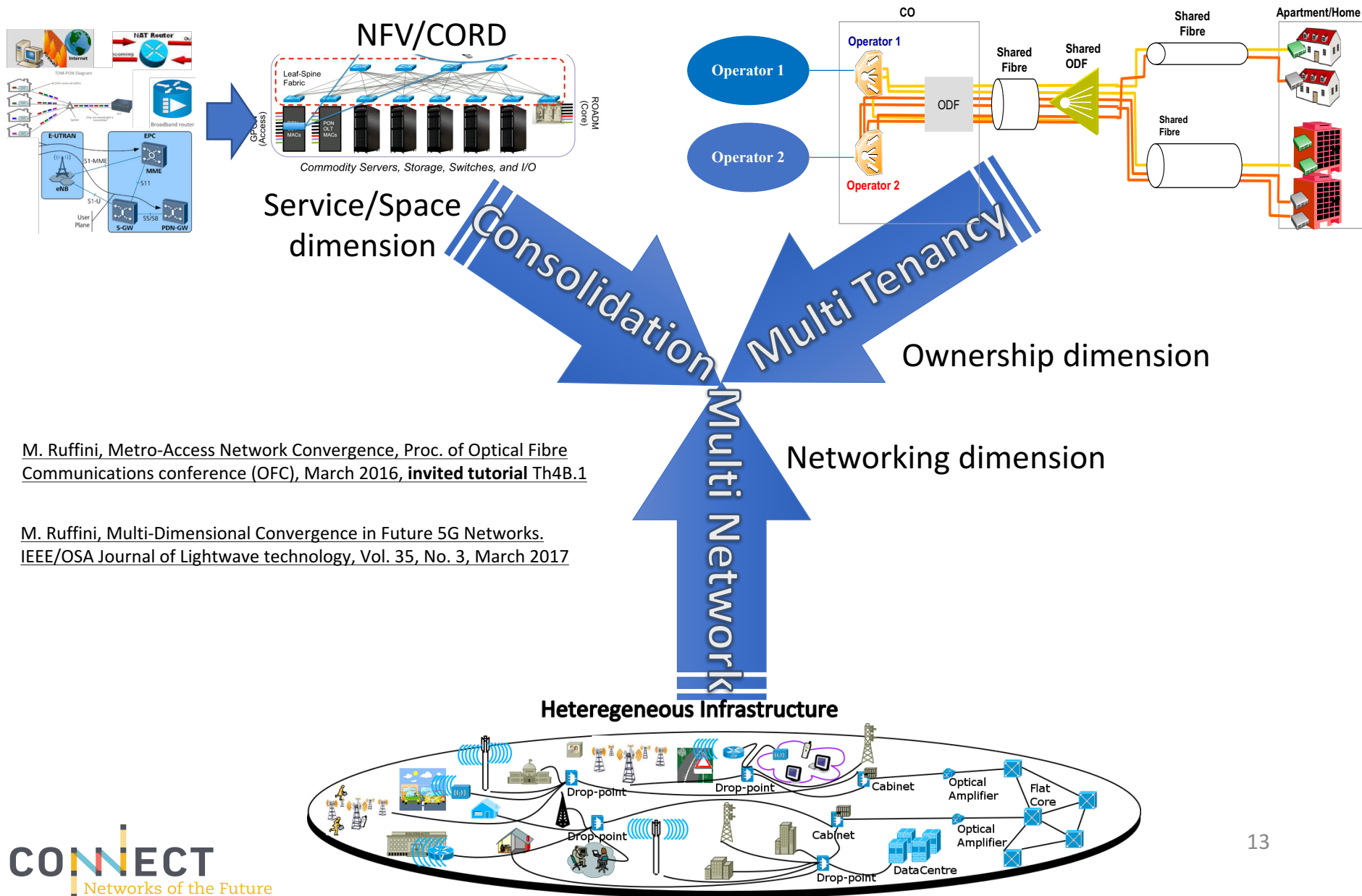


- Capacity:
 - dense wireless access point deployment
- Performance: heterogeneous data storage/processing locations
- Reliability and cost-effectiveness: dynamic end-to-end resource orchestration

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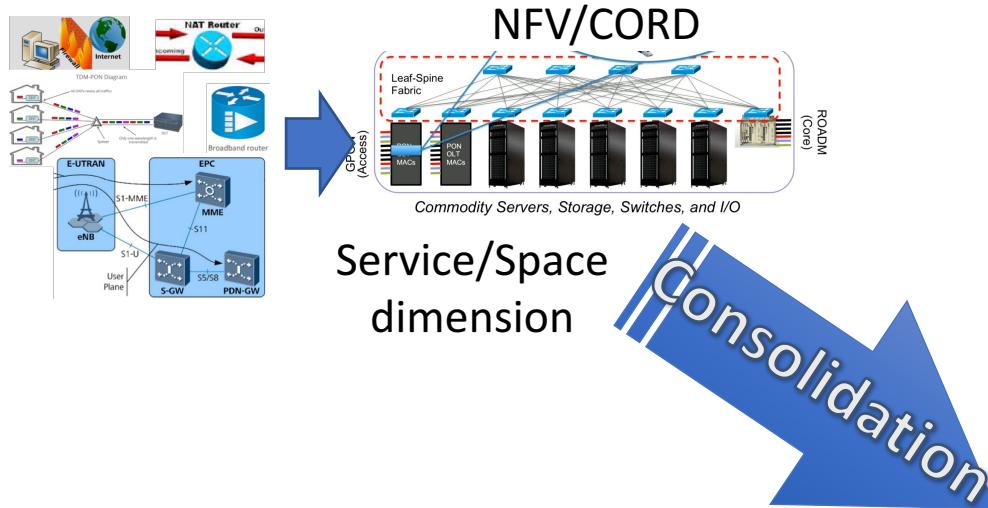
Multi-dimensional convergence



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

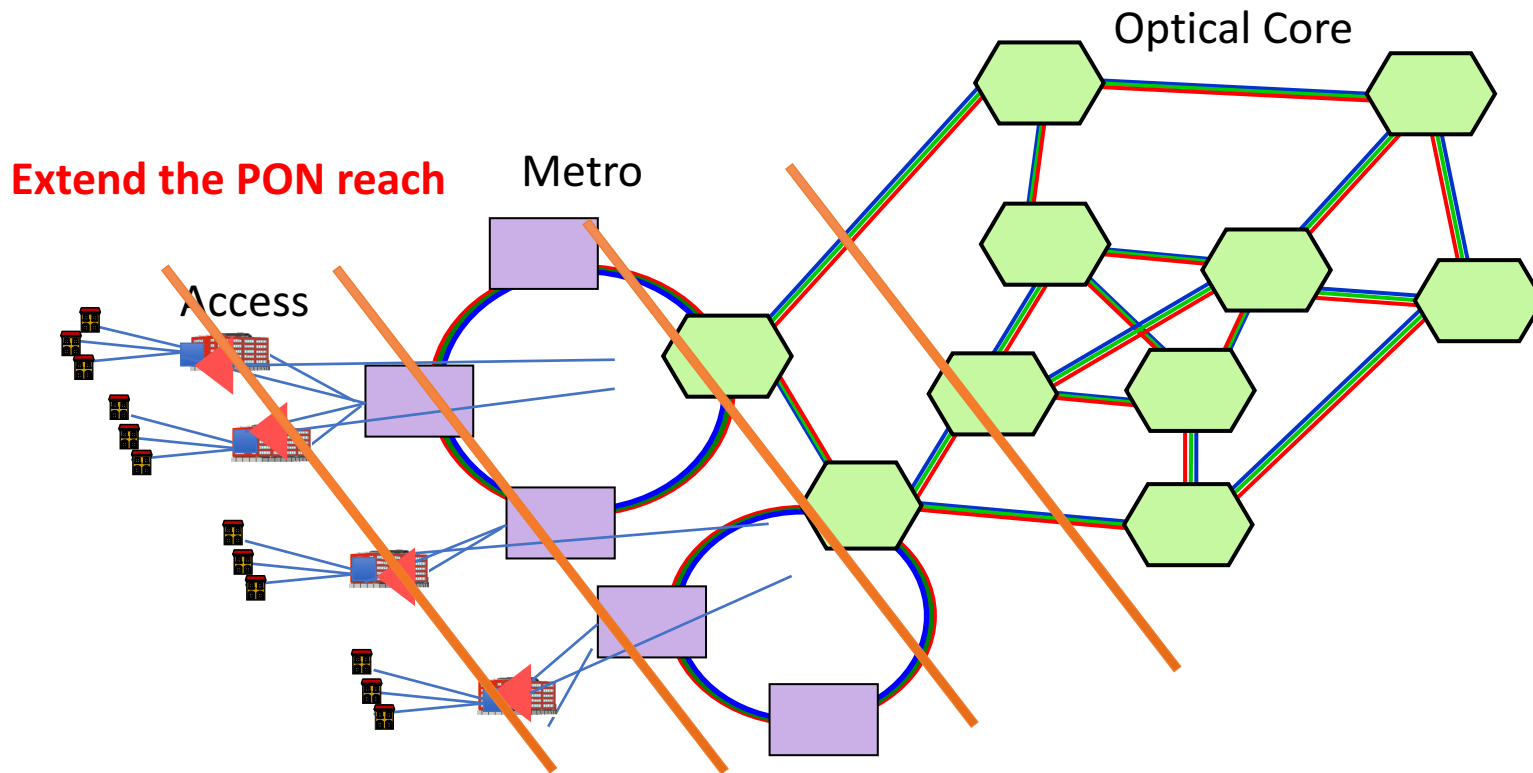
M. Ruffini, Multi-Dimensional Convergence in Future 5G Networks. IEEE/OSA Journal of Lightwave technology, Vol. 35, No. 3, March 2017

Consolidation: service/space dimension



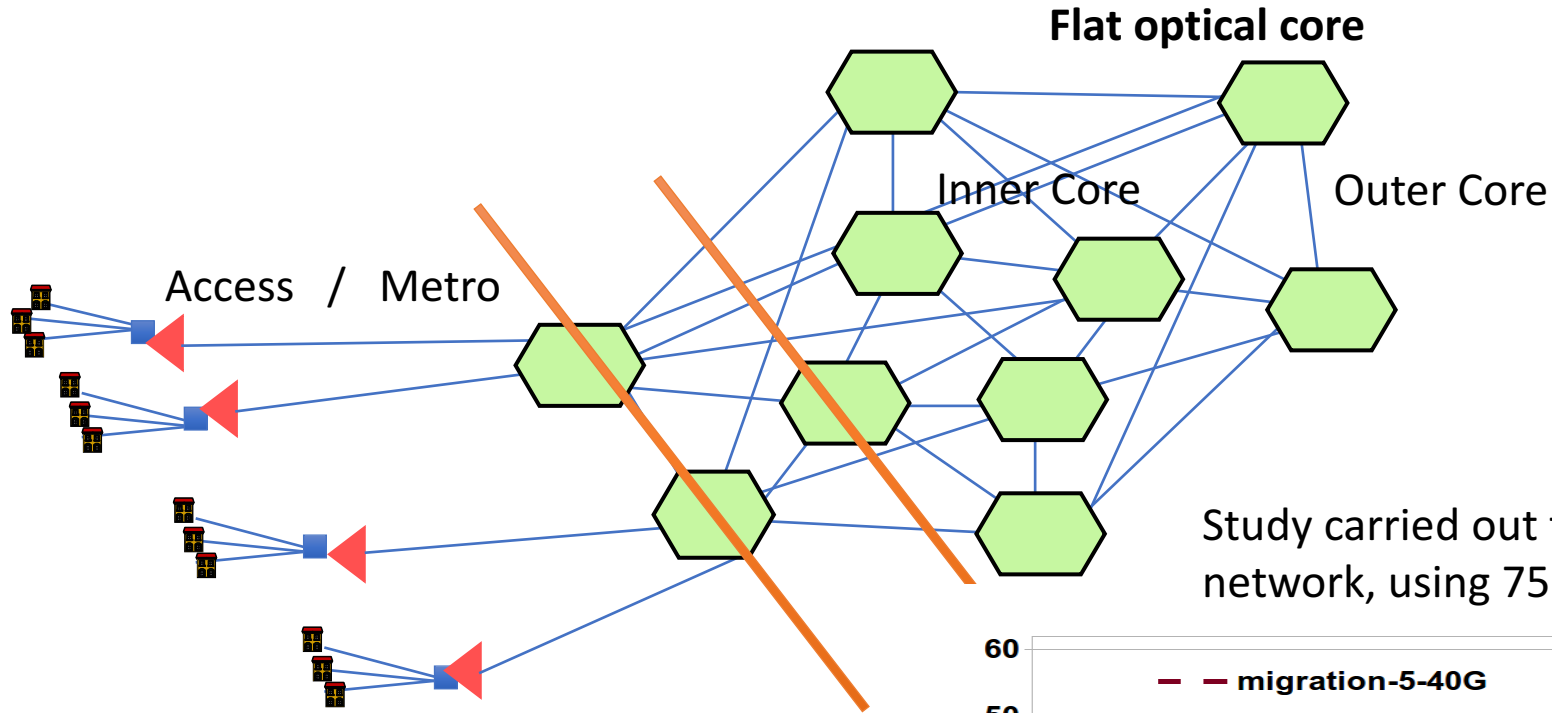
Access-metro convergence I

- Our previous work on spatial consolidation in EU FP7 DISCUS:
 - Extend optical access reach to reach core: reach up to >100Km



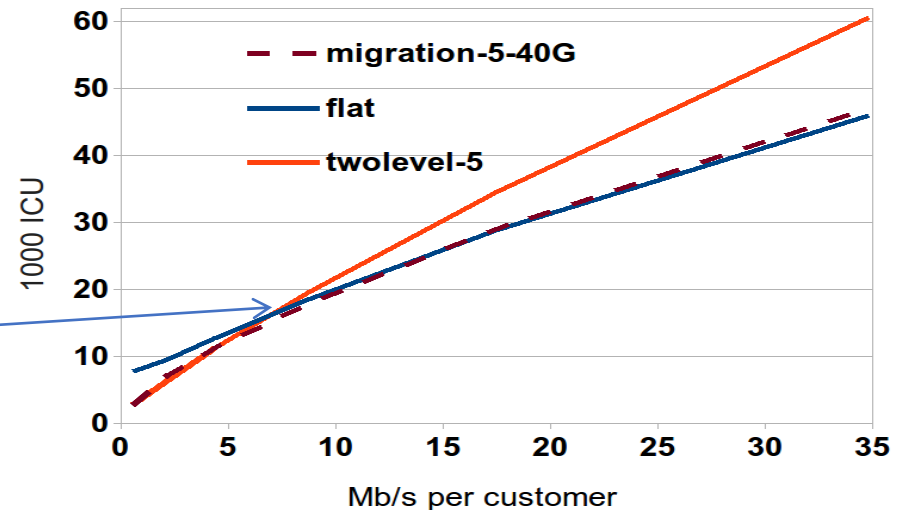
M. Ruffini, L. Wosinska, M. Achouche, J. Chen, N. J. Doran, F. Farjady, J. Montalvo, P. Ossieur, B. O'Sullivan, N. Parsons, T. Pfeiffer, X.-Z. Qiu, C. Raack, H. Rohde, M. Schiano, P. Townsend, R. Wessaly, X. Yin, D. B. Payne, DISCUS: An end-to-end solution for ubiquitous broadband optical access. *IEEE Com. Mag.*, vol. 52, no. 2, February 2014

Access-metro convergence II



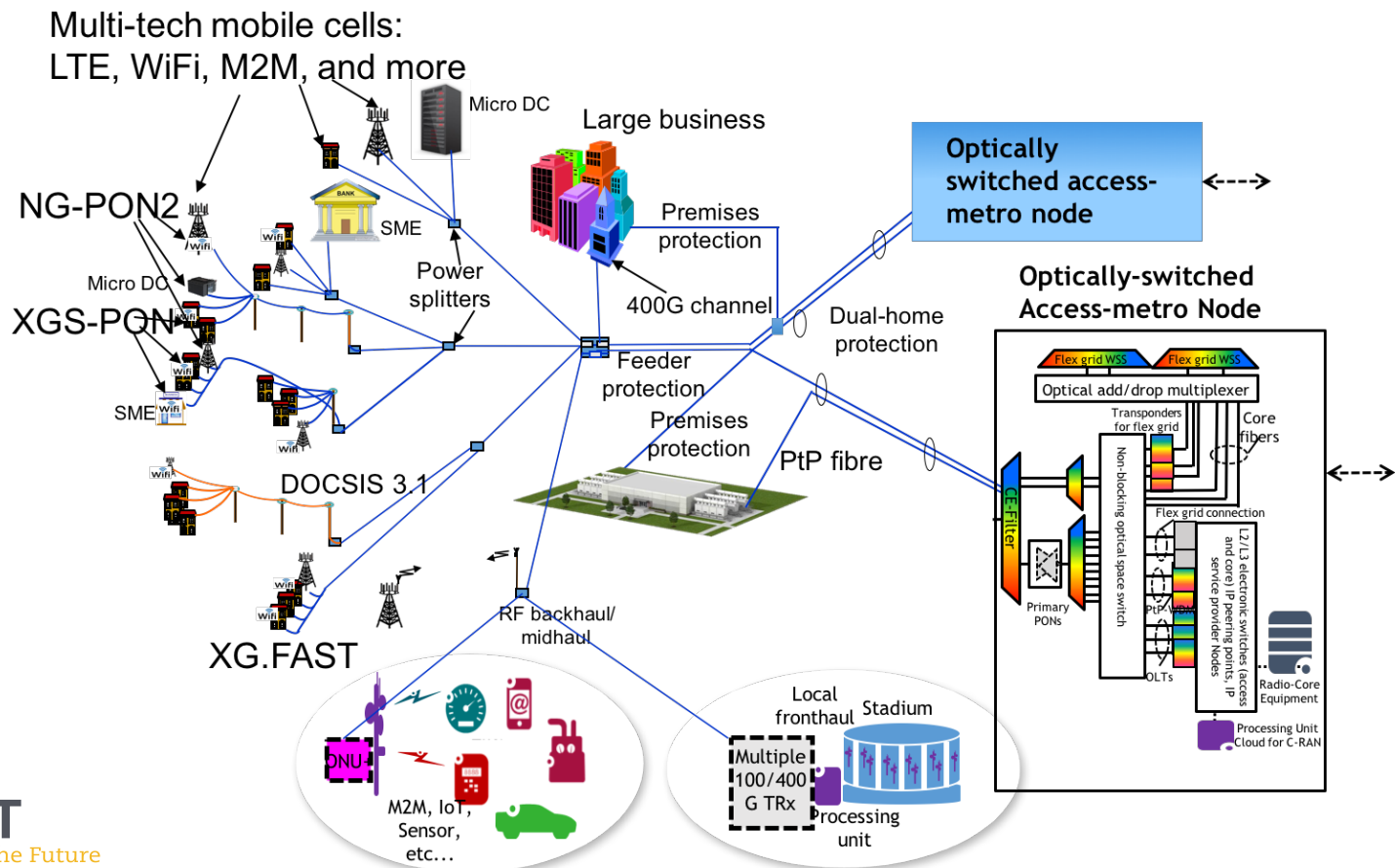
Study carried out for UK network, using 75 MC nodes

Flat core becomes the cheaper option when traffic is above a given threshold



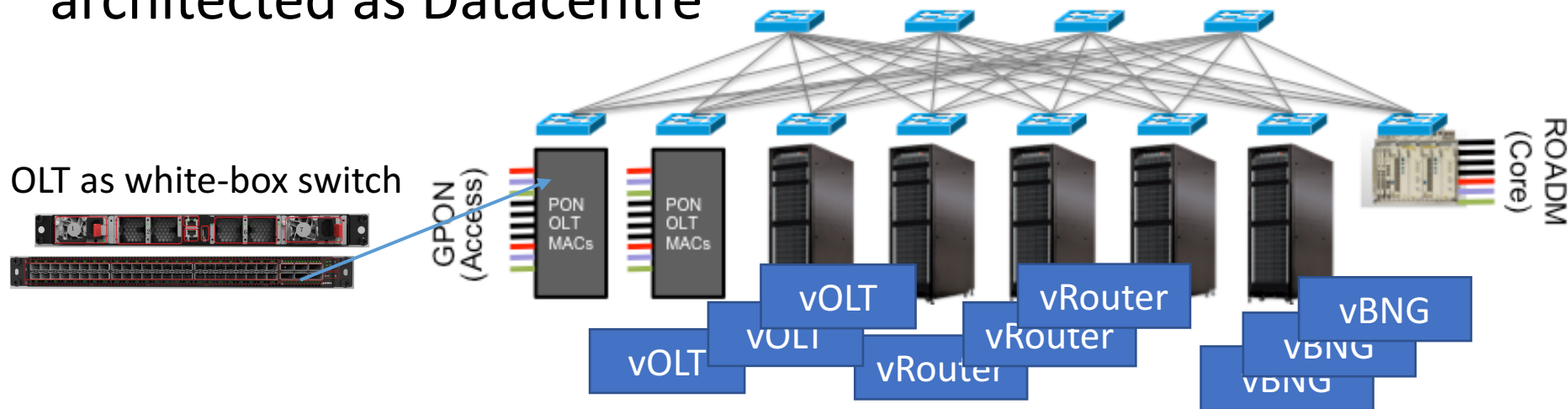
Access-metro convergence today

- Fronthaul poses latency constraints restricting optical reach.
- Spatial convergence more confined to the metro area



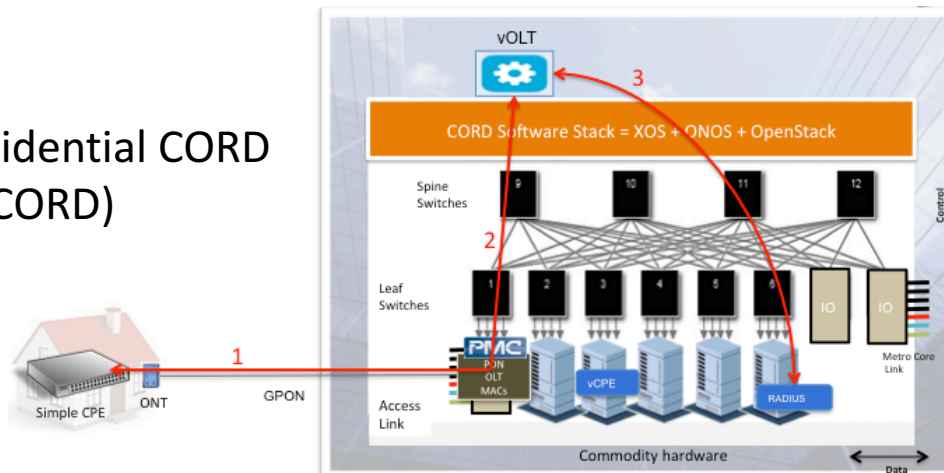
NFV and service convergence

AT&T and On.Lab OpenCORD – Central Office Re-architected as Datacentre



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

Residential CORD (R-CORD)



Source: white paper Central Office Re-architected as Datacentre (CORD), wiki.opencord.org

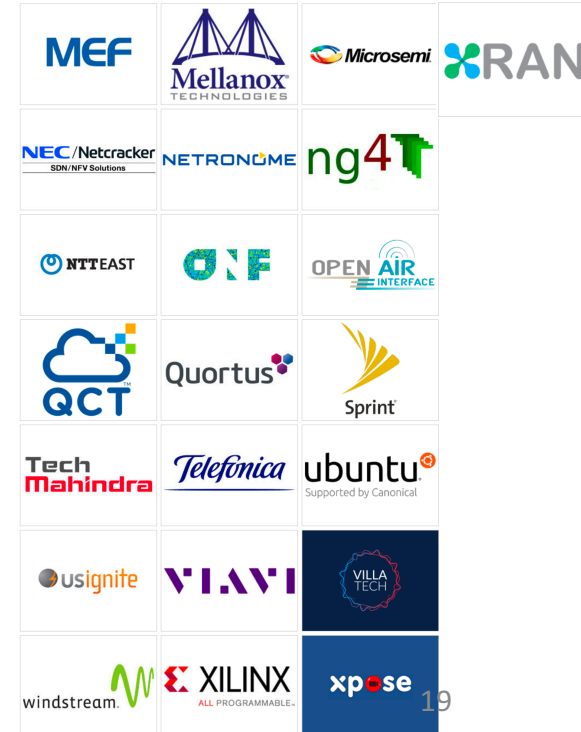
NFV and service convergence

- OpenCORD progressing fast.. First heard in 2015, is now at v3.0
 - Started between AT&T and ON.Lab and now involves all major telco industry

Partners

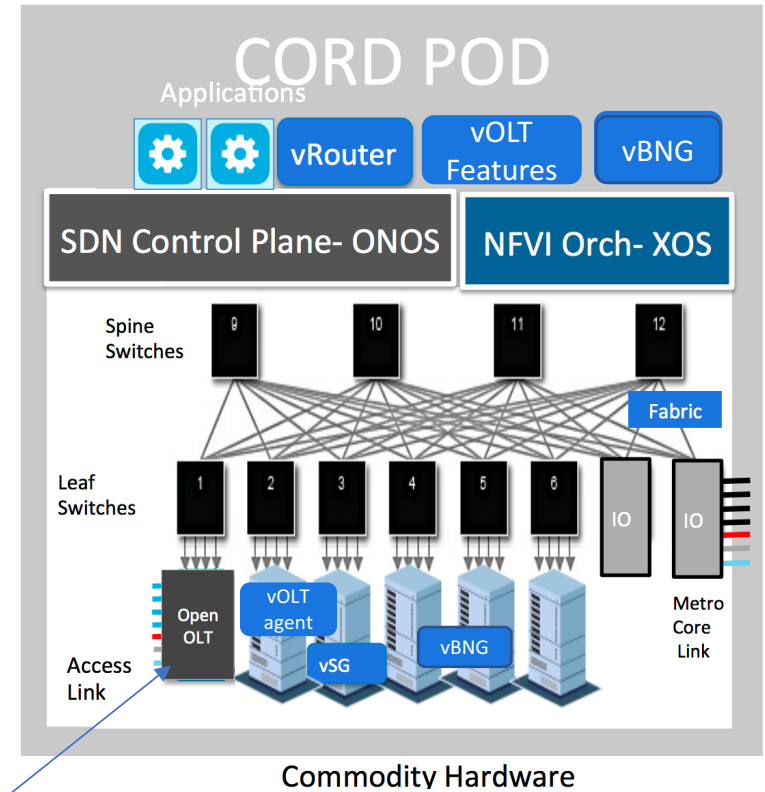
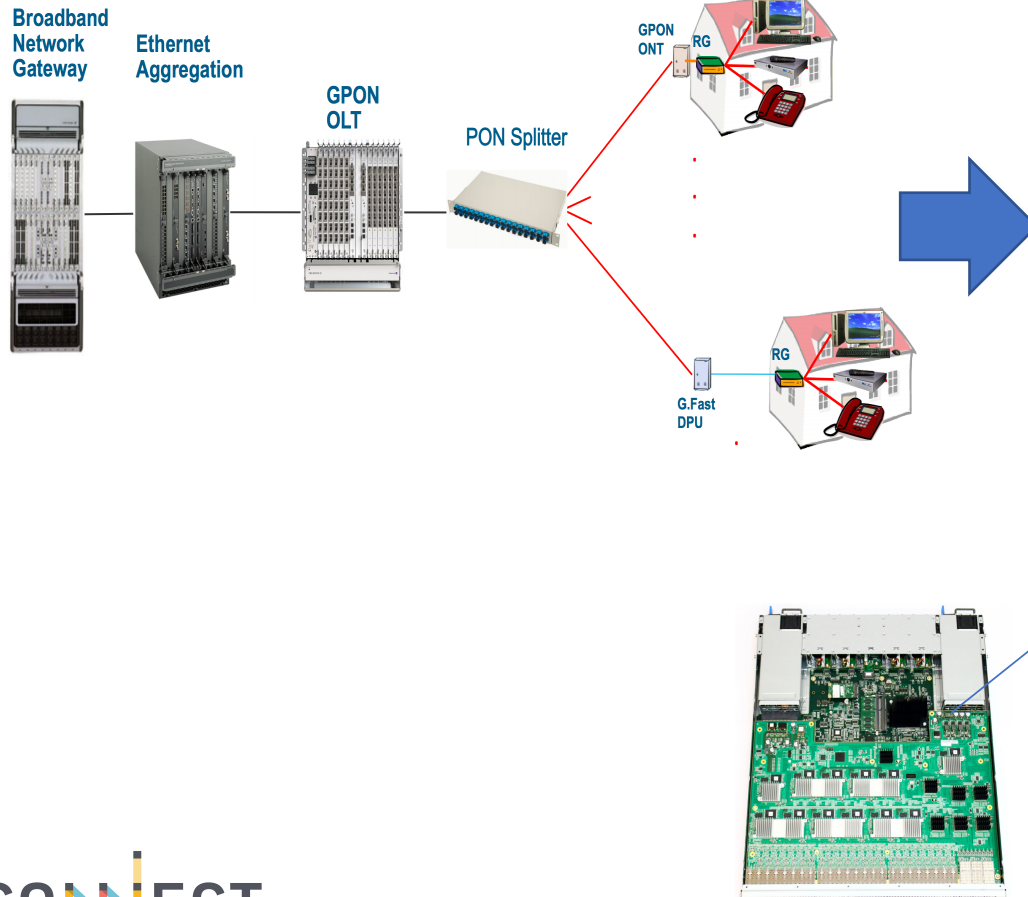


Collaborators



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

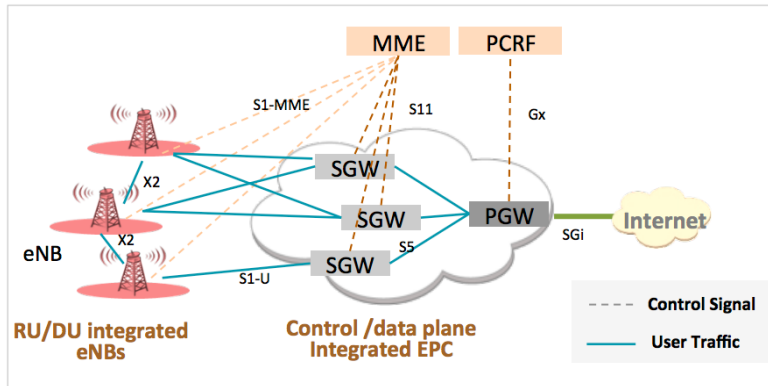
Residential-CORD



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

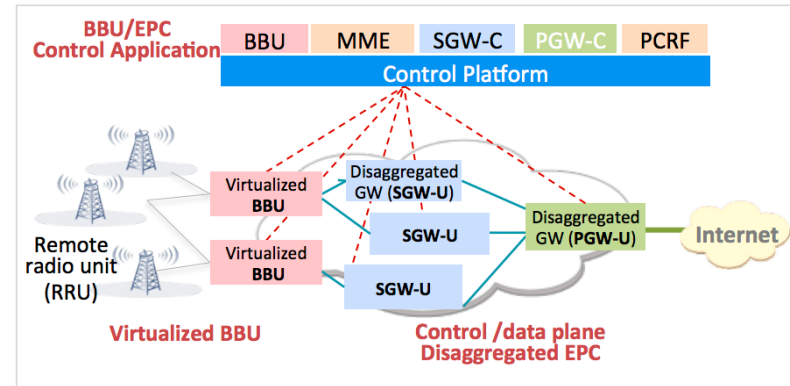
Mobile-CORD

Traditional Architecture

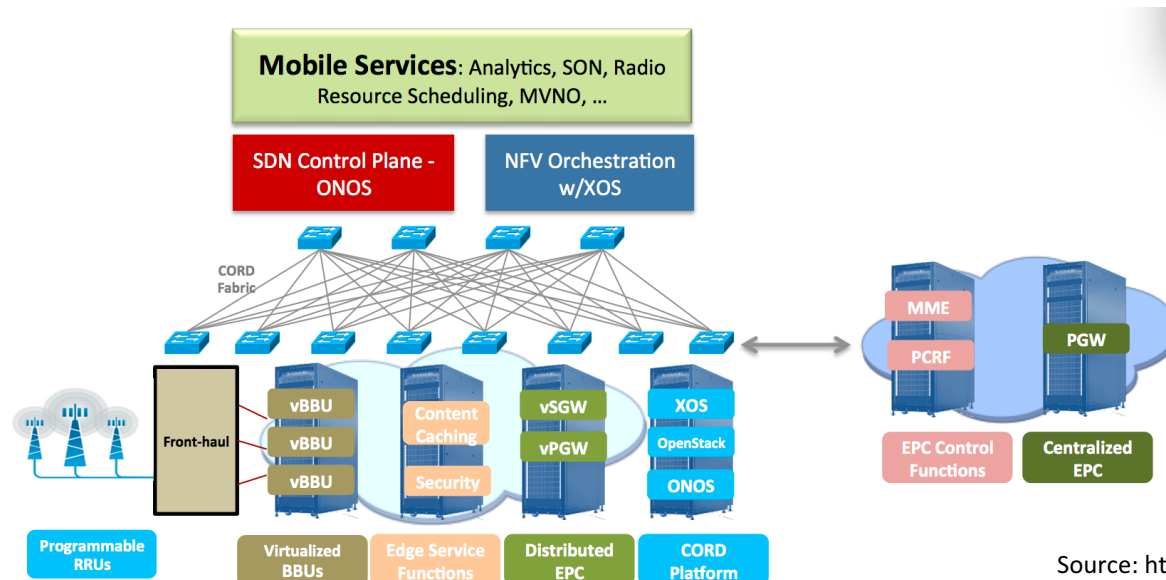


with proprietary boxes & solutions

Target Architecture



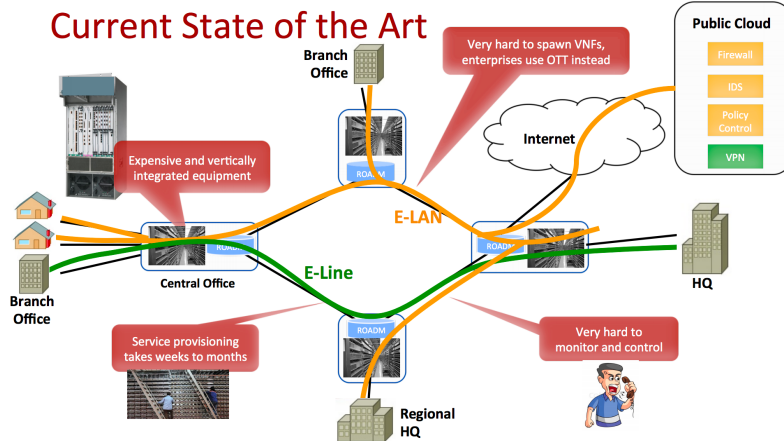
with commodity H/W & open source/open API



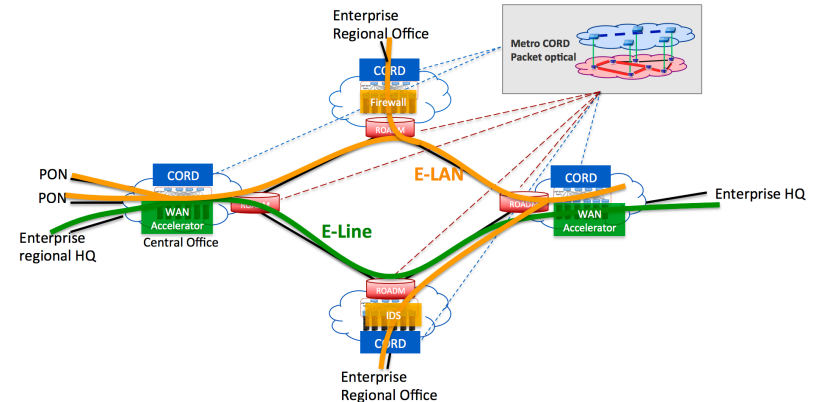
Source: <http://opencord.org/>

Enterprise-CORD

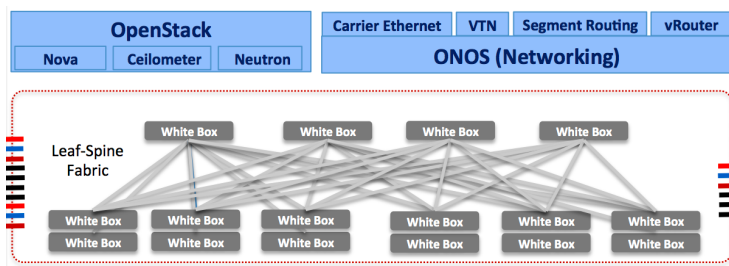
Current State of the Art



E-CORD in Metro



Access



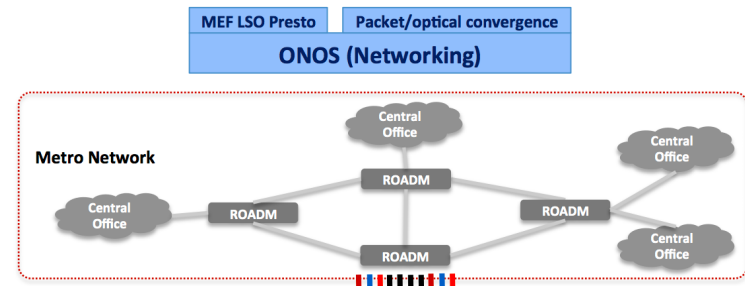
Virtual Network On-Demand

Customer Control

Enterprise WAN Services

CORD Controller (XOS)

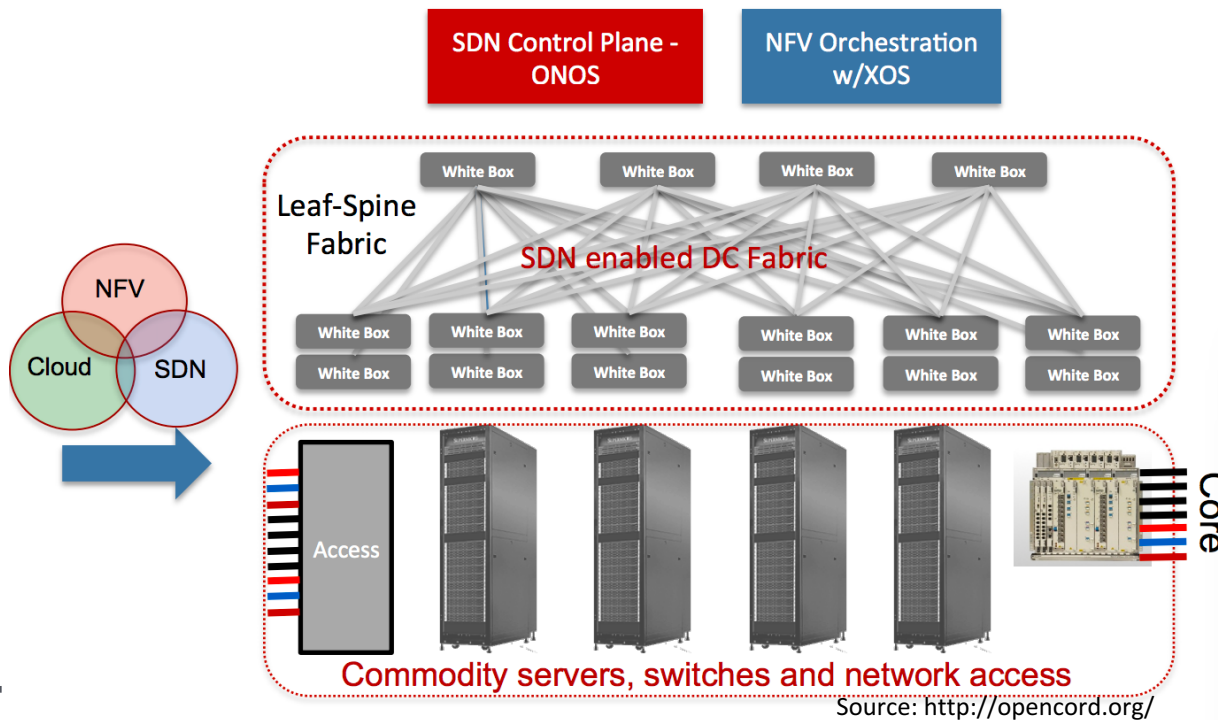
Metro



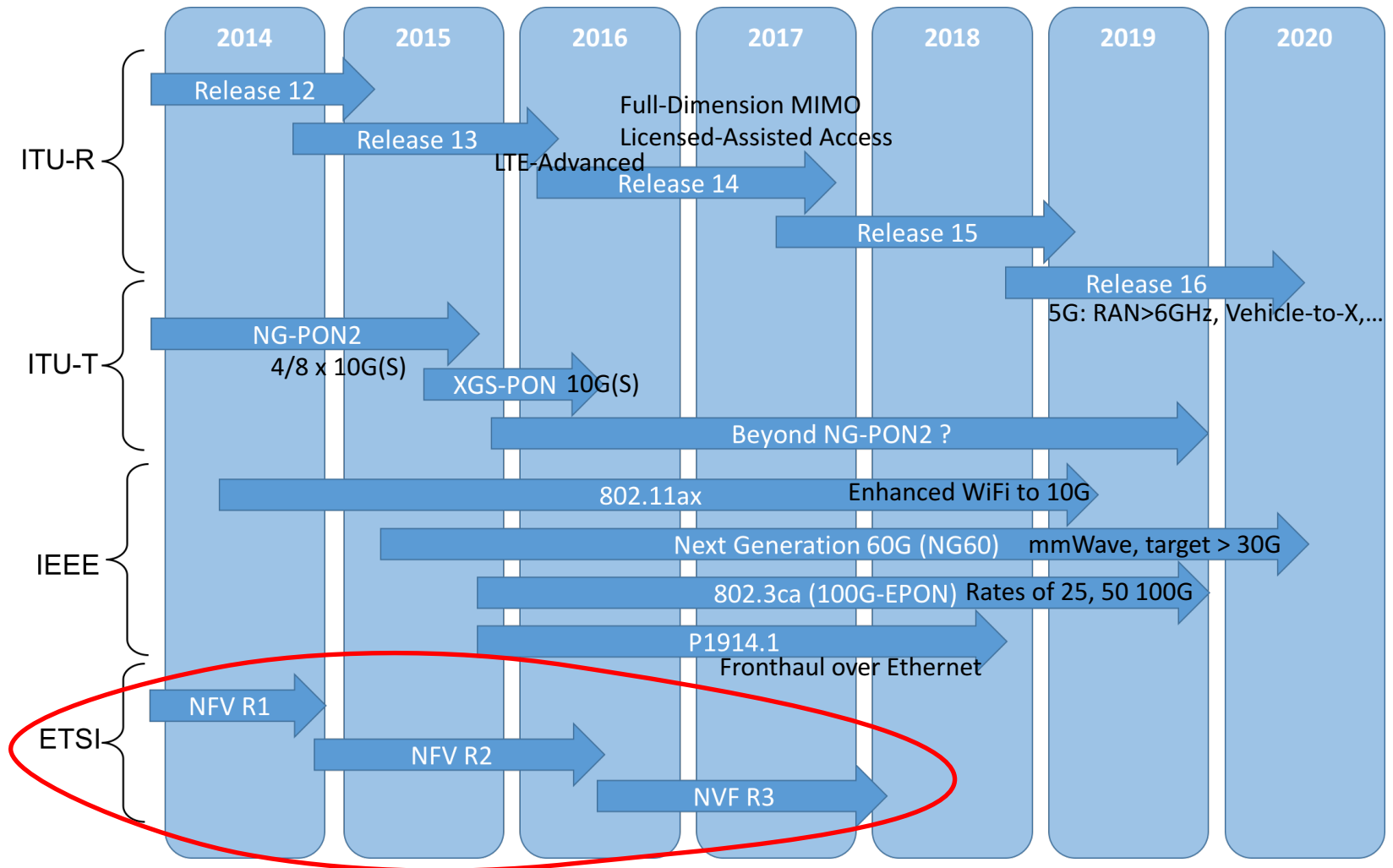
Source: <http://opencord.org/>

CORD convergence

- You might have noticed that R-CORD, M-CORD, E-CORD are based on similar components...
- CORD converging R/M/E-CORD into one?

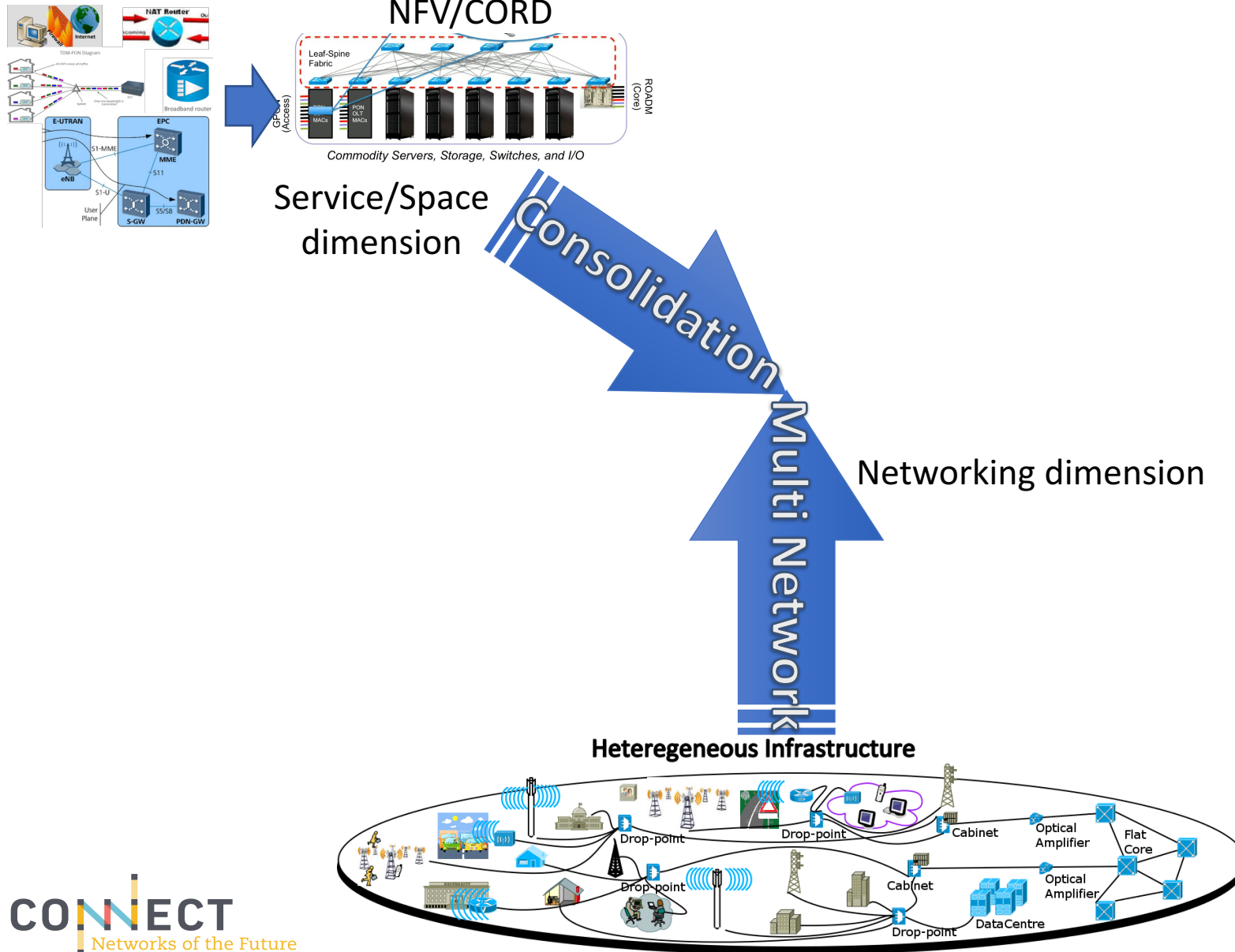


Standards



ONF: constant new releases on OpenFlow, v 1.3.x, 1.4.x, 1.5.x; Of-Config 1.2, SDN architecture...

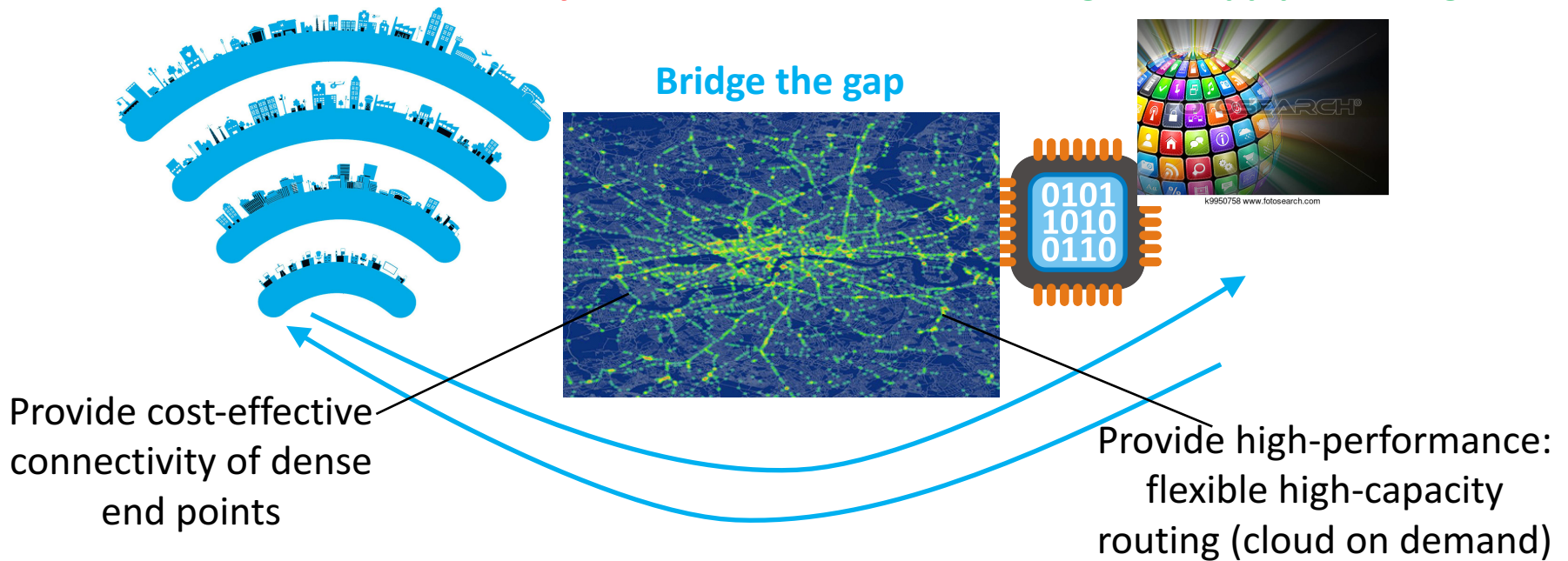
Multi-dimensional convergence



Why fixed/mobile/DC convergence?

Service delivery to end users

Data storage and app processing

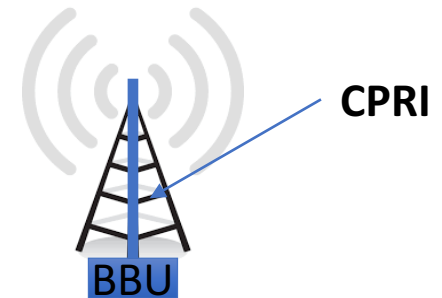


End-to-end reliability, repeatability (haptic feedback, front/X-hauling)

Cloud RAN

Placing Base Band Unit (BBU) at different location than the Remote Radio Unit (RRU).

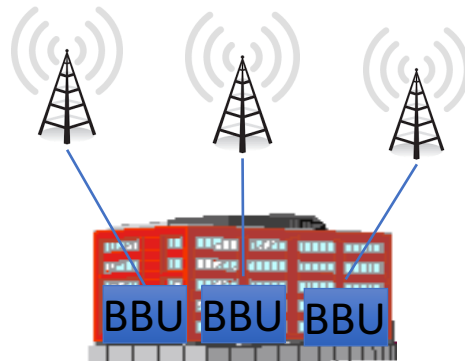
A well-known interface for this “Fronthaul” transmission is the Common Public Radio Interface (CPRI)



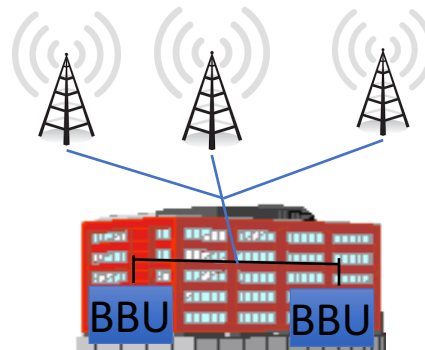
This gave the idea to move the BBU further out giving rise to the Cloud RAN concept

Examples of Fronthaul architectures

One virtual BBU to many RRU



BBU hoteling



BBU pooling



BBU cloud

Fronthaul

Problems:

$$1. \text{ High capacity: } B = R_s \times N_q^{\text{bits}} \times N_a^{\text{Antennas}} \times N_b^{\text{bands}} \times R_c \times R_l^{\text{ratio}}$$

Sampling rate Word control ratio

Examples:

- Take a macro cell: 8x8 MIMO, 3 sectors, 5 x 20MHz channels
 ➔ backhaul rate (64-QAM): 9 Gb/s ➔ fronthaul rate 148 Gb/s
- Take a small cell: 2x2 MIMO, 1 sector, 20 MHz channel
 ➔ backhaul rate (64-QAM) 150 Mb/s ➔ fronthaul rate 2.5 Gb/s

This is independent of usage... it's a sustained rate!

2. Strict latency requirements, 3 ms due to HARQ

- ➔ considering this is the total latency budget, typically only a few hundreds micro seconds left for optical transport ➔ 20-40Km max

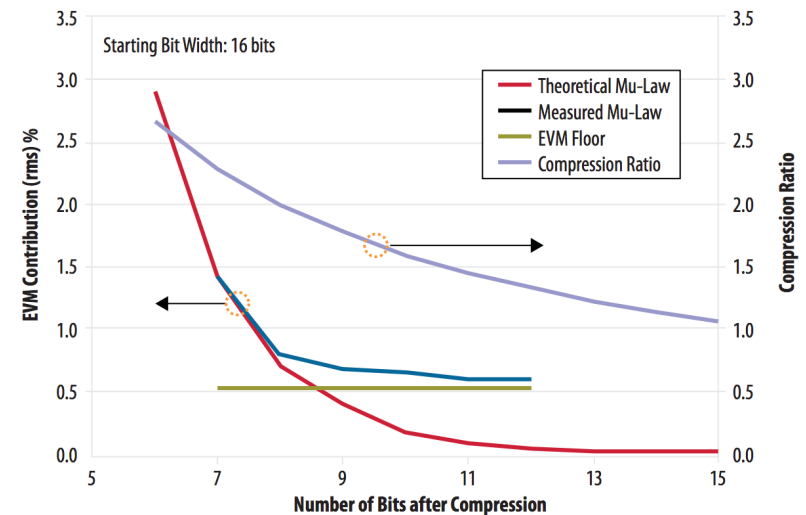
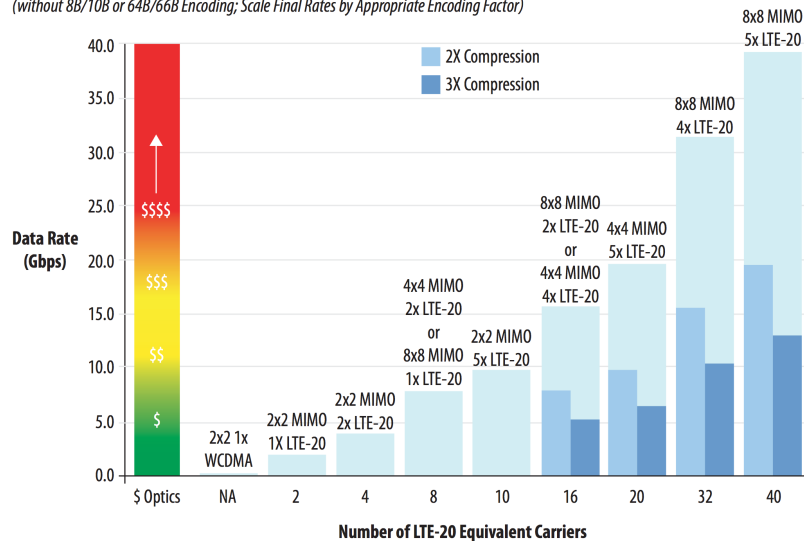
Fronthaul capacity issue and solutions

Issues arise when the fronthaul capacity goes above 10G (also the max capacity of CPRI)

- Solution 1: compression

Raw CPRI Data Rate vs. MIMO and Carrier Aggregation (per Sector)

(without 8B/10B or 64B/66B Encoding; Scale Final Rates by Appropriate Encoding Factor)

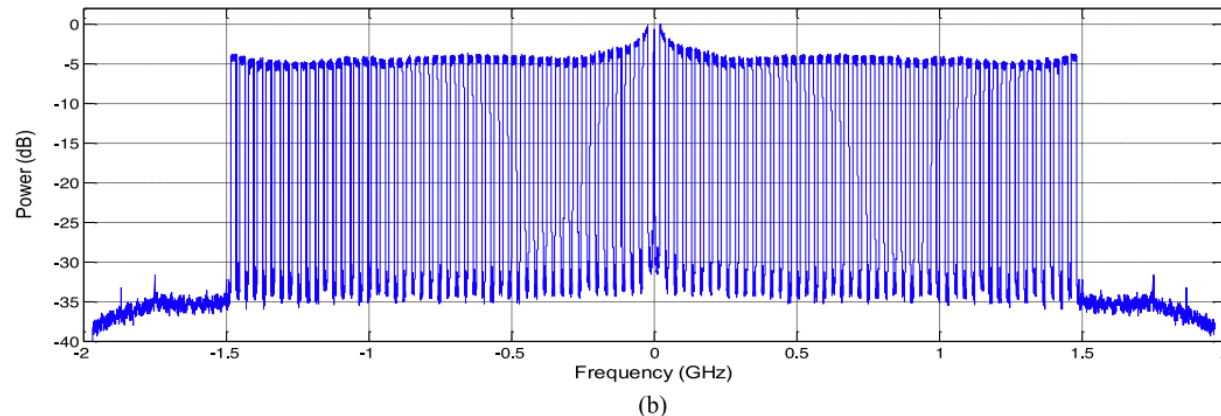
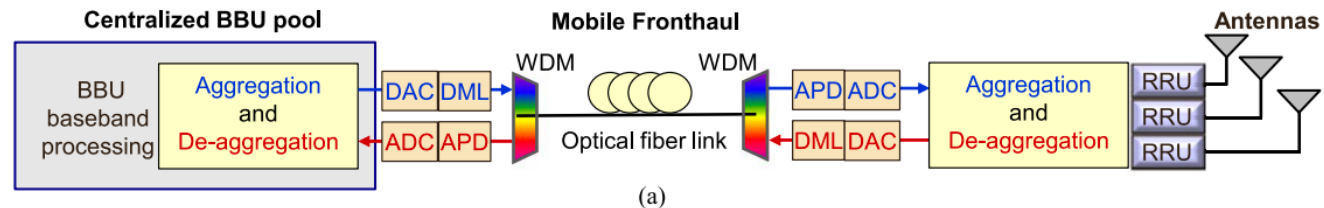


Compression will introduce some latency. Typically lossy compression is used

Fronthaul capacity issue and solutions

- Solution 2: Analogue radio over fibre
 - Especially when considering massive MIMO cases:
 - E.g., 64x64 MIMO with 200MHz bandwidth for 3 sectors would give 2.4 Tb/s in CPRI-equivalent rates
 - 32 x 200MHz channels over single wavelength were demonstrated (equivalent of 400Gb/s CPRI)

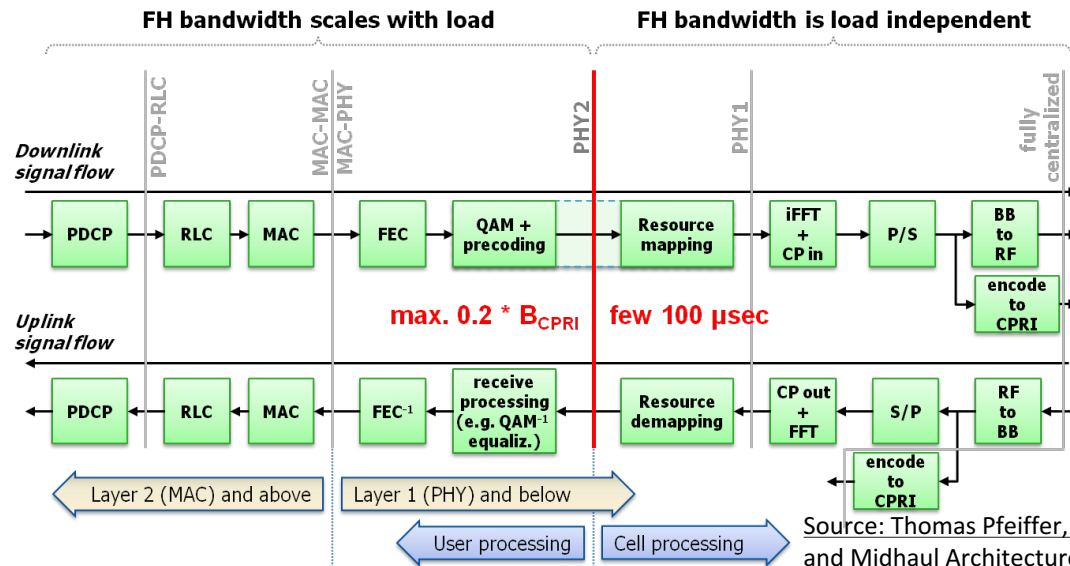
X. Liu et al., Efficient Mobile Fronthaul via DSP-Based Channel Aggregation, JLT, VOL. 34, NO. 6, March 2016



Midhaul or NG Fronthauls

- Solution 3: the split can be done in different parts, in the PHY (split-PHY) or in the MAC (Split-MAC)

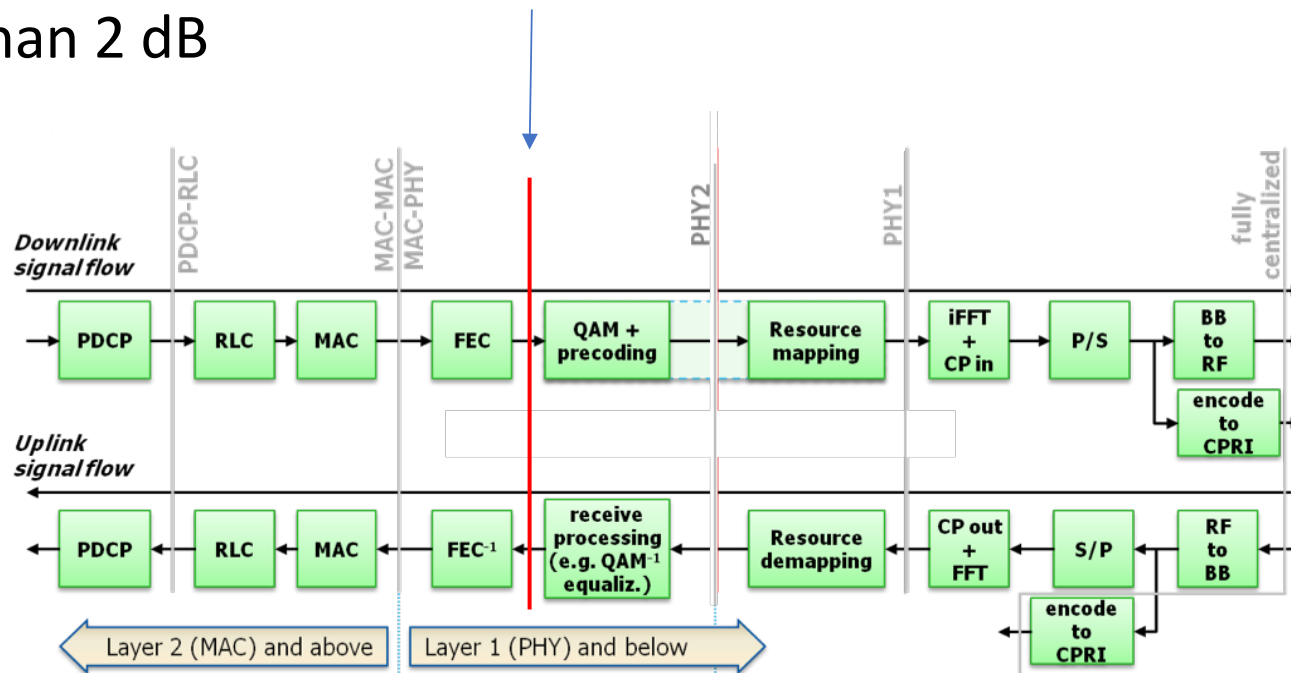
Midhaul restores relation between cell utilization and optical transport rate



- One issue that arises is that the closer the split is to the MAC the less information I send, and some types of Coordinated Multipoint (CoMP) cannot be done (e.g., MIMO)

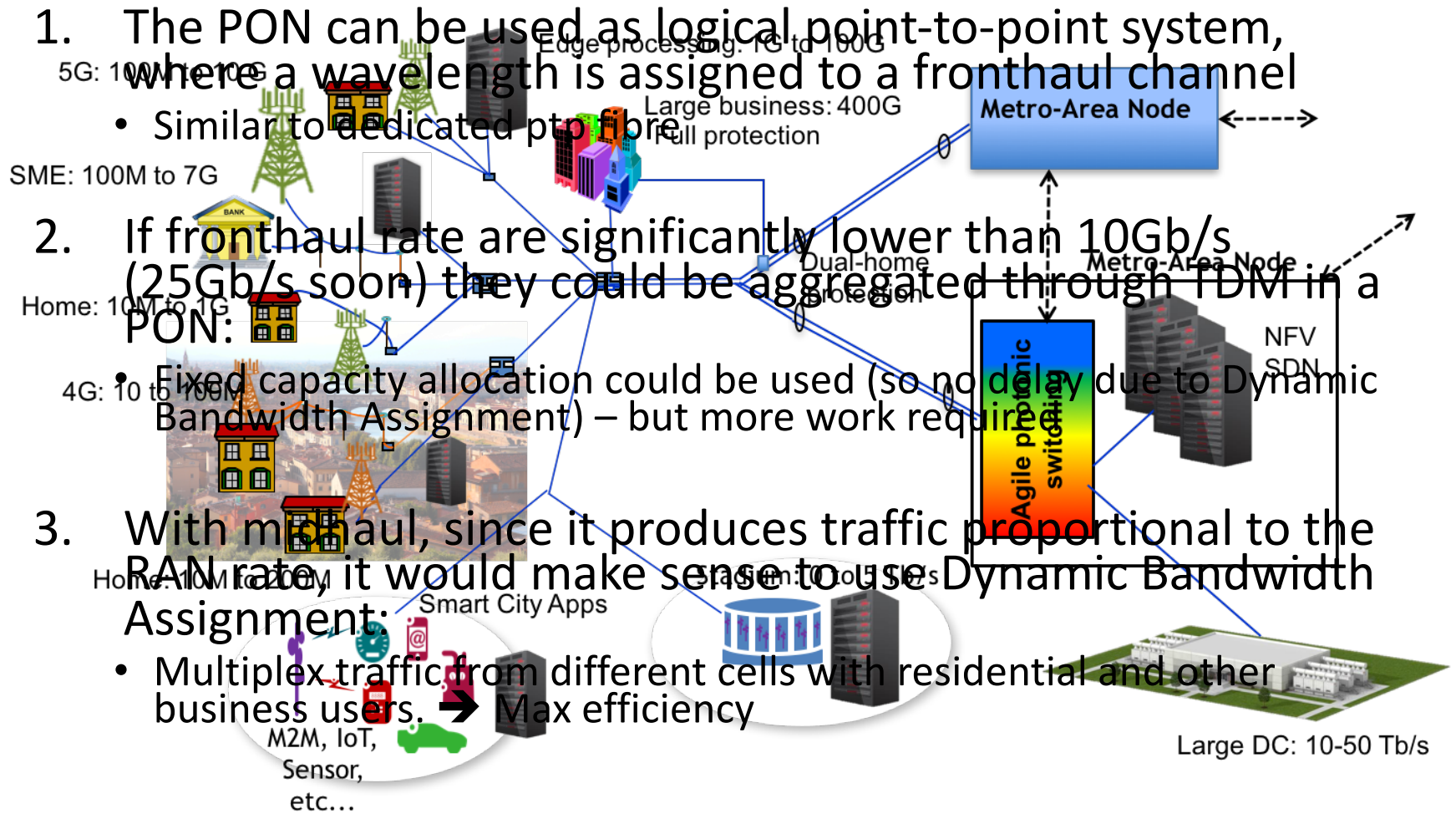
Midhaul and MIMO

- However solutions are already coming up
 - It was demonstrated that MIMO could be carried out effectively from this split, showing SNR penalties of less than 2 dB



K. Miyamoto et al., Performance Evaluation of Ethernet-Based Mobile Fronthaul and Wireless CoMP in Split-PHY Processing. JOCN VOL. 9, NO. 1, Jan 2017

Transport over PON



Optical transmission rate

- MIMO systems with large bandwidth driving the need for PON access > 10 Gb/s
- For TDM PON:

X. Liu and F. Effenberger, Emerging Optical Access Network Technologies for 5G Wireless [Invited]
JOCN, VOL. 8, NO. 12, Dec 2016

COMPARISON OF DOWNSTREAM MODULATION AND DETECTION OPTIONS FOR PON

Option	Modulation at OLT	Detection at ONU	Pros	Cons
1	NRZ (EML, DML) ^a	Analog DD (APD)	+ Cost effective	<ul style="list-style-type: none"> – Low bandwidth efficiency – Low dispersion tolerance – O-band operation only for 25+ Gb/s
2	Optical duobinary (Laser+MZM)	Analog DD (APD)	+ Higher dispersion tolerance than Option 1 (by ~2.5×)	<ul style="list-style-type: none"> – MZM needed (more expensive) – High modulation loss (optical booster amplifier needed)
3	DSP-assisted NRZ/PAM-4 (EML, DML)	DSP-assisted DD (linear APD)	<ul style="list-style-type: none"> + Higher dispersion tolerance than Option 1 (by ~2.5×) + Higher bandwidth efficiency than Option 1 (by ~2×) 	<ul style="list-style-type: none"> – High-speed DAC/ADC/DSP needed – Linear APD needed – DSP power consumption an issue
4	DSP-assisted DMT	DSP-assisted DD (linear APD)	<ul style="list-style-type: none"> + Higher dispersion tolerance than Option 1 (by ~2.5×) + Higher bandwidth efficiency + Flexible modulation formats 	<ul style="list-style-type: none"> – High-speed DAC/ADC/DSP needed – Linear APD needed
5	IQ modulation (IQ-MZM)	DD (APD)	<ul style="list-style-type: none"> + Dispersion precompensation + Bandwidth-efficient modulation 	<ul style="list-style-type: none"> – DSP power consumption an issue – High cost due to IQ-MZM – DAC/ADC/DSP needed for advanced formats

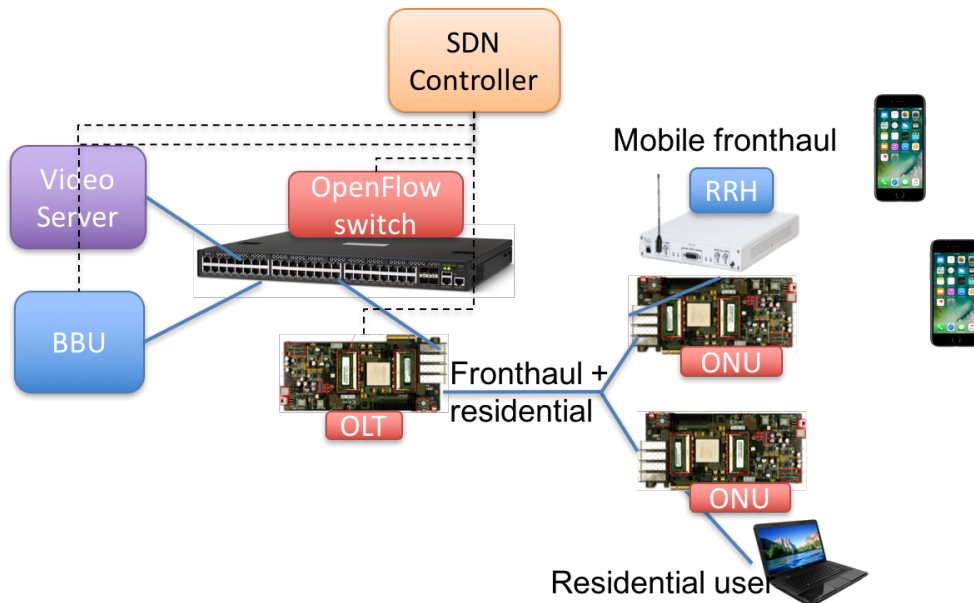
^aEML, electro-absorption modulated laser; DML, directly modulated laser.

Joint FUTURE-CONNECT 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

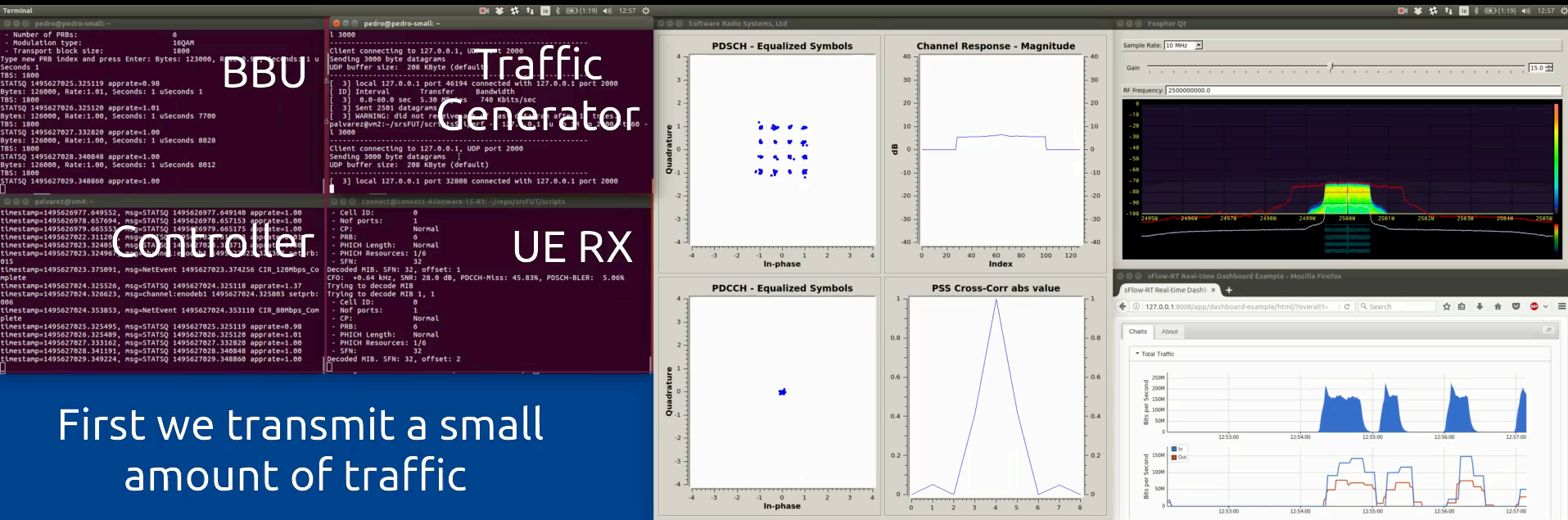
→ Fronthaul rate can be made dependent on actual usage



SDN orchestration of converged LTE/PON network:

1. BBU reports effective capacity to SDN
2. SDN reduce wireless bandwidth accordingly
3. SDN reduces PON bandwidth to fronthaul following reduction in I/Q samples
4. Saved capacity re-used by other PON users

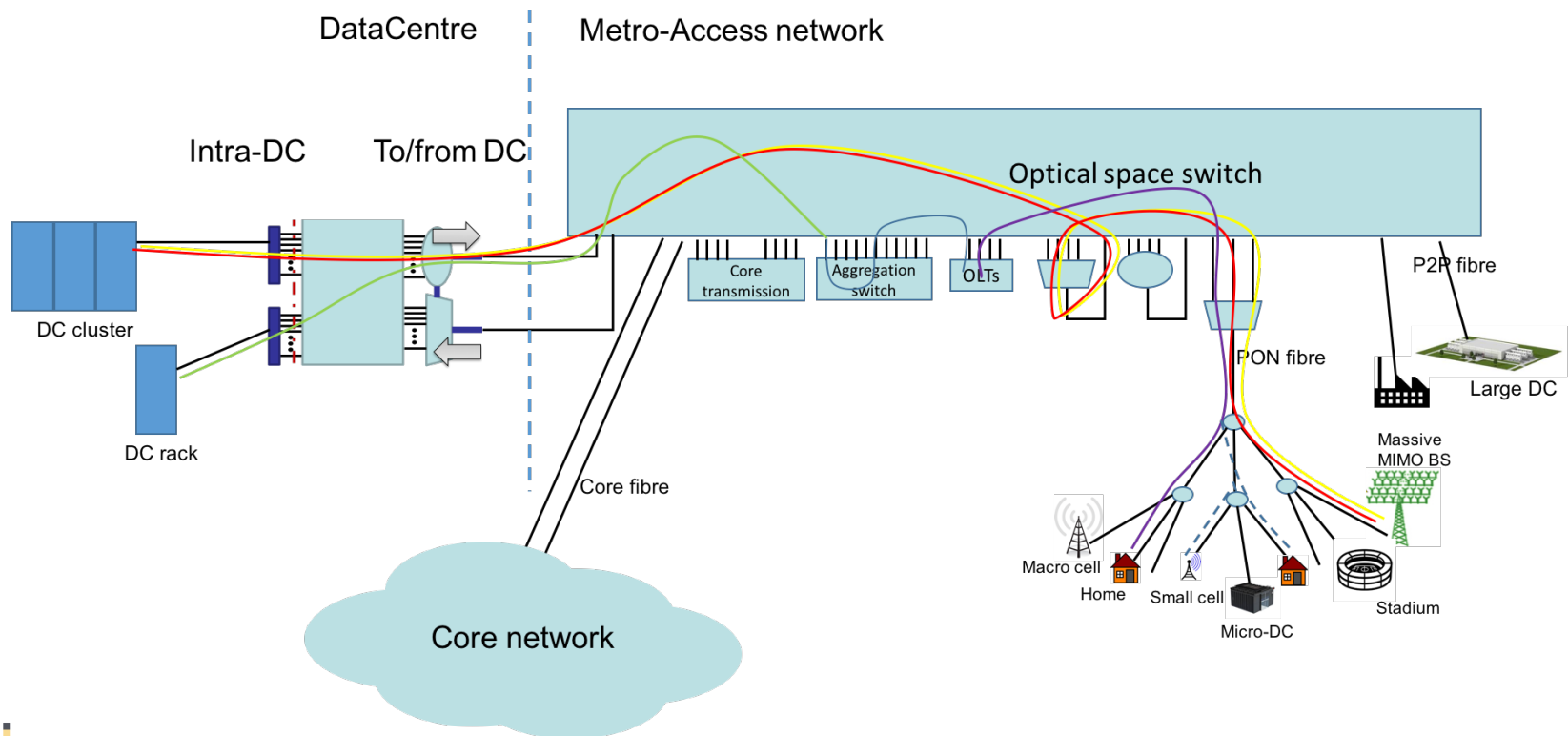
Joint FUTEBOL-CONNECT convergence demonstration: dynamic fronthaul over PON



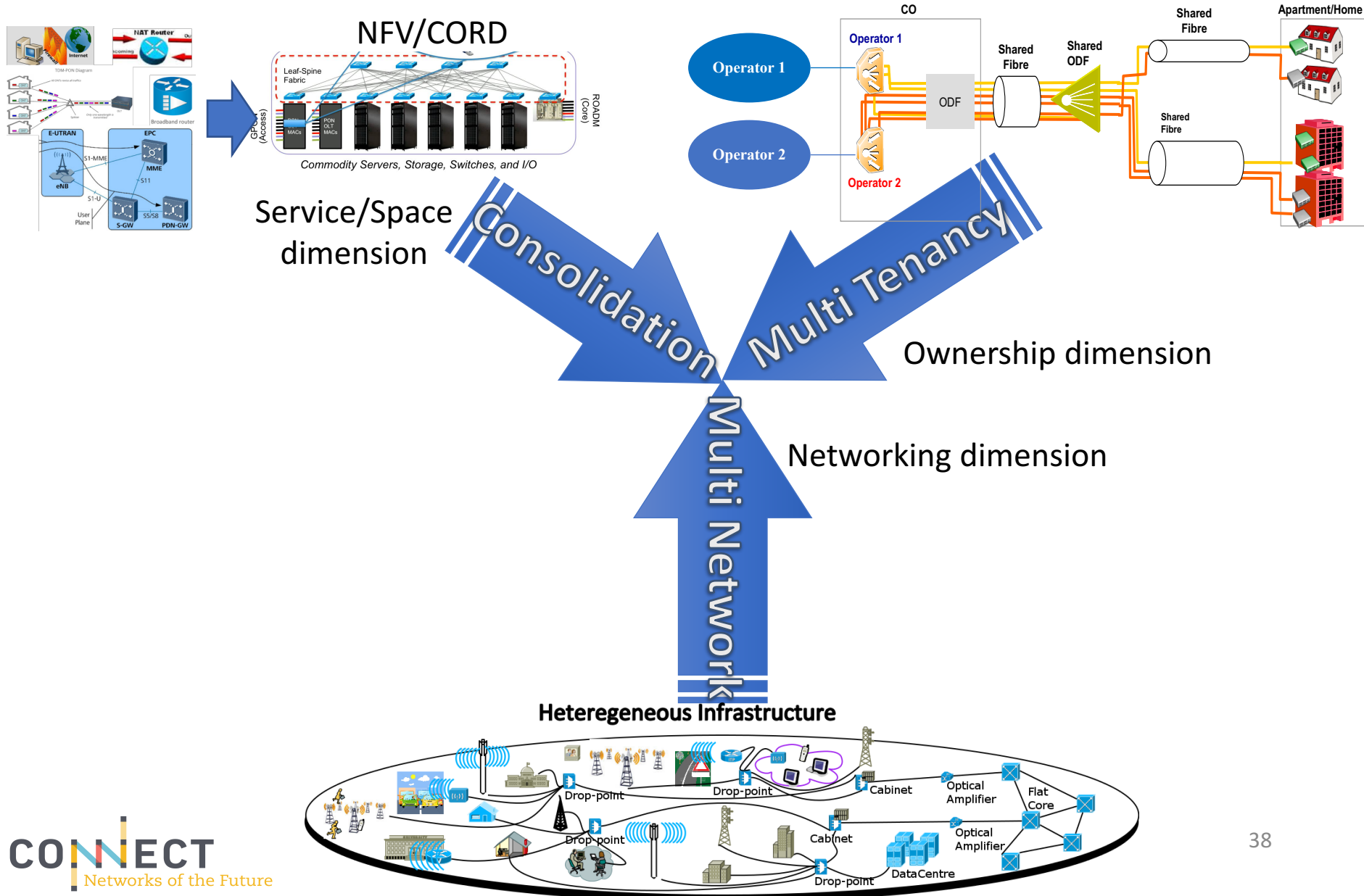
First we transmit a small amount of traffic

Data centre integration

- Seamless connectivity of data centres in the access/metro convergence
 - DCs have already moved to the metro to reduce latency and core traffic
 - 5G will see a mix of different size DCs from large to micro caches, it could also include home storage
- Transparent optical connection directly to DC cluster or rack



Multi-dimensional convergence



Multi tenancy

PONs can offer very large capacity but requires substantial effort (cash and resources)



Large operators can afford (typically only in urban areas) installation of a fibre access network.



Risk of creating de-facto monopoly

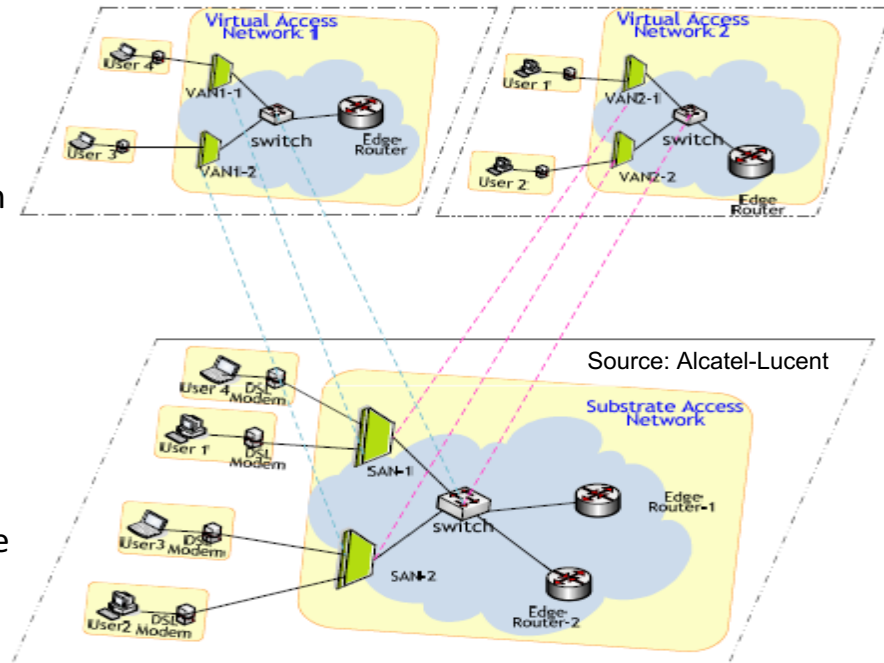
Can vertically-integrated operators support the diversity fostered by 5G??



Benefit from fast dynamics and innovation brought by
fully open market

Multi-tenancy and Access network virtualisation

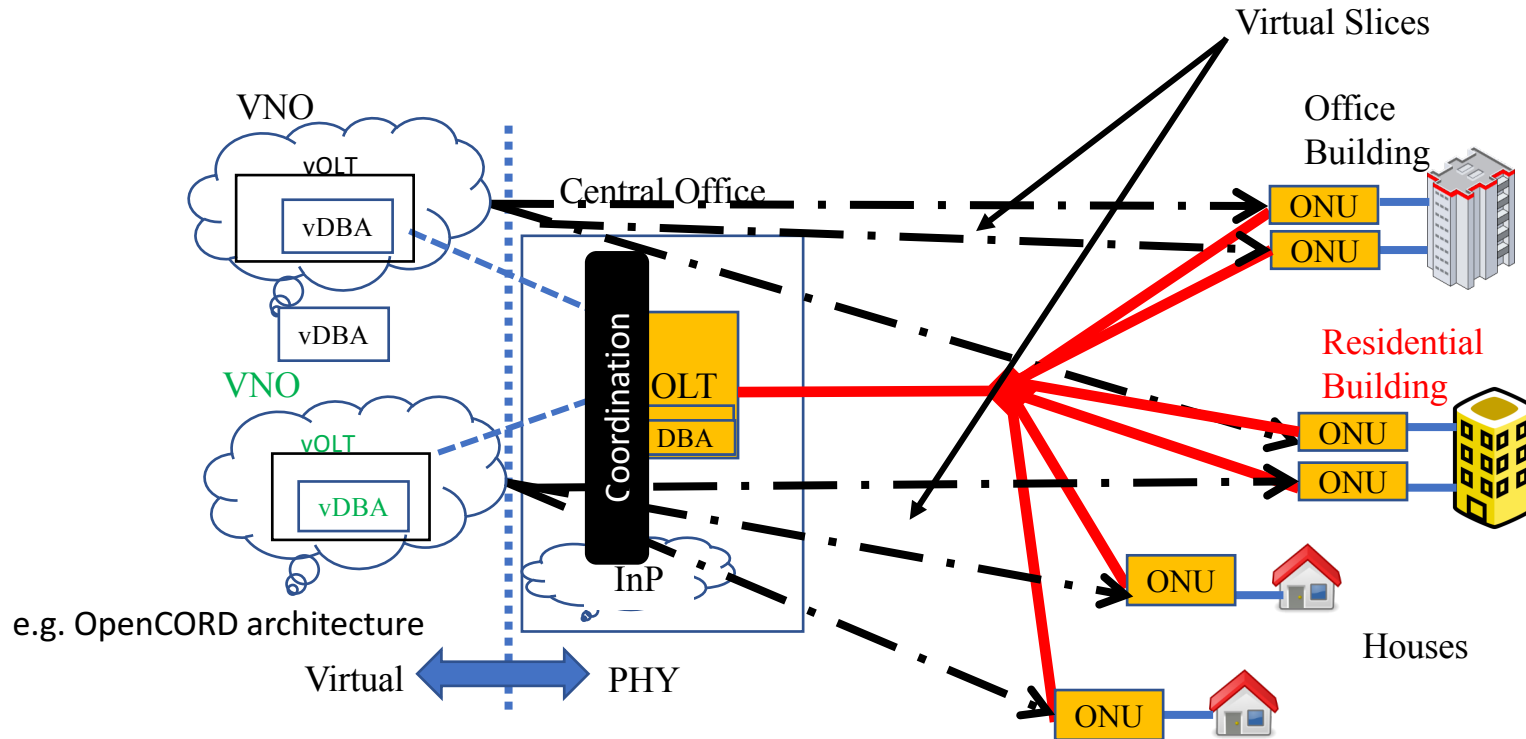
- **Virtual Network Operator (VNO)**
 - Operate, control, and manage its own virtual networks
 - Run/Re-design customized protocol in its own virtual networks
 - Provide specific and customized service through its own virtual networks
 - VNO saves deployment cost of network infrastructure
- **Infrastructure Provider (InP)**
 - Own and maintain physical networking resources
 - Enable physical resource virtualization and carry out the virtualization
 - Provide virtual resource controlling API to VNP/VNO
 - InP gets revenue from resource leasing



Source: Bruno Cornaglia (Vodafone) 2014 Broadband Forum presentation: "Fixed Access Network Virtualization"

BroadBand Forum WT-370, Fixed Access Network Sharing (FANS) - Architecture and Nodal Requirements, Dec. 2016

Our PON True Multi-Tenancy work

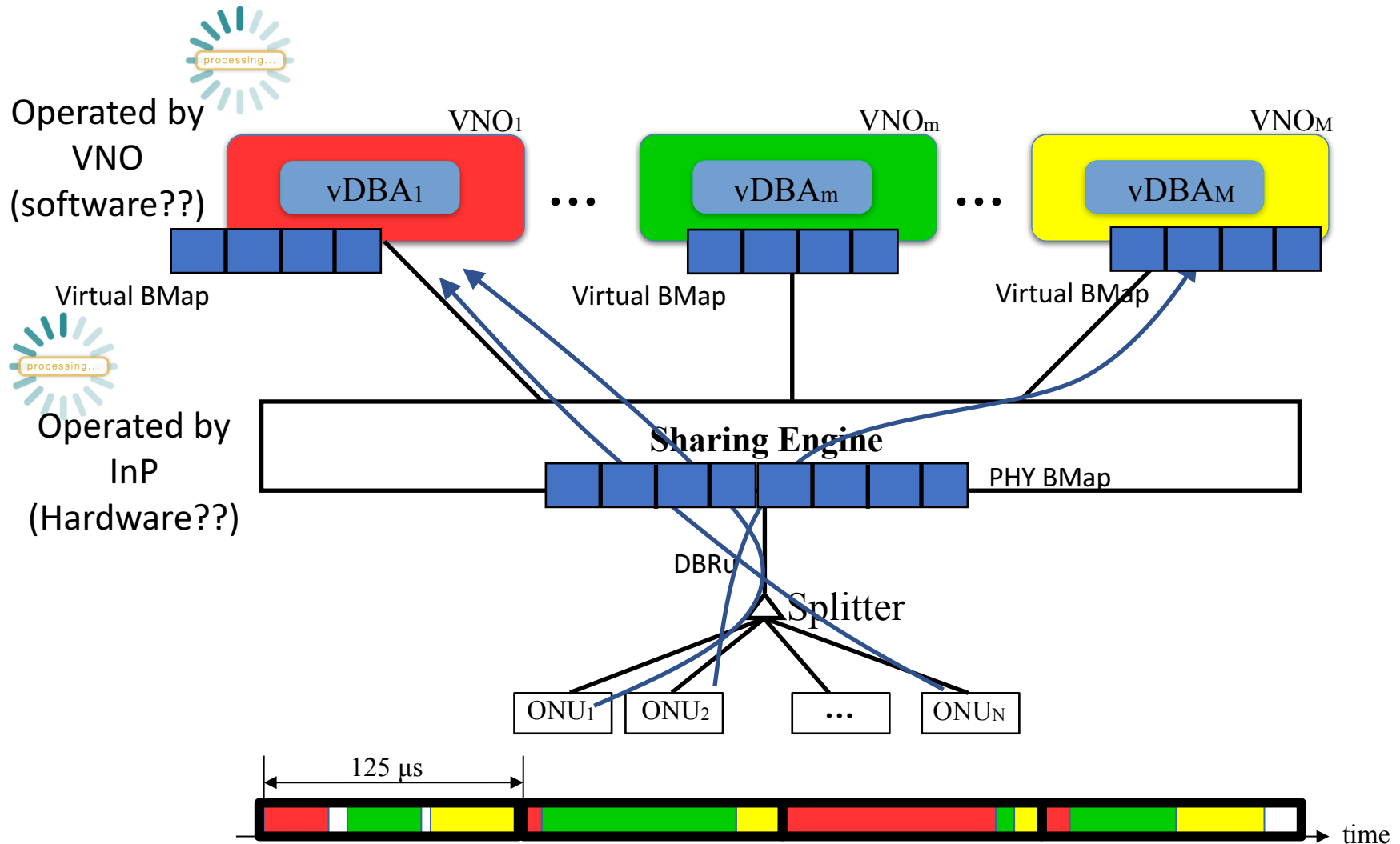


The O'SHARE project

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

www.oshare.ie

vDBA – sharing engine details



~~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-

5G: Another Next-Generation Disappointment?

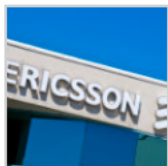
The forthcoming 5G standard sounds impressive, but it seems unlikely to reinvigorate the telco business.

Source: lightreading

connectivity and bit per second

speed?

Ericsson: 5G Heralds 'New' New Economy



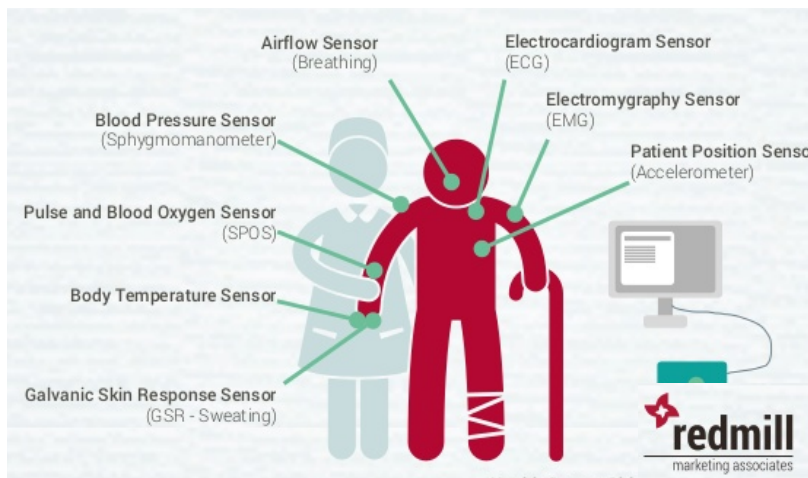
By MARI SILBEY, Senior Editor, Cable/Video, 1/12/2017

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



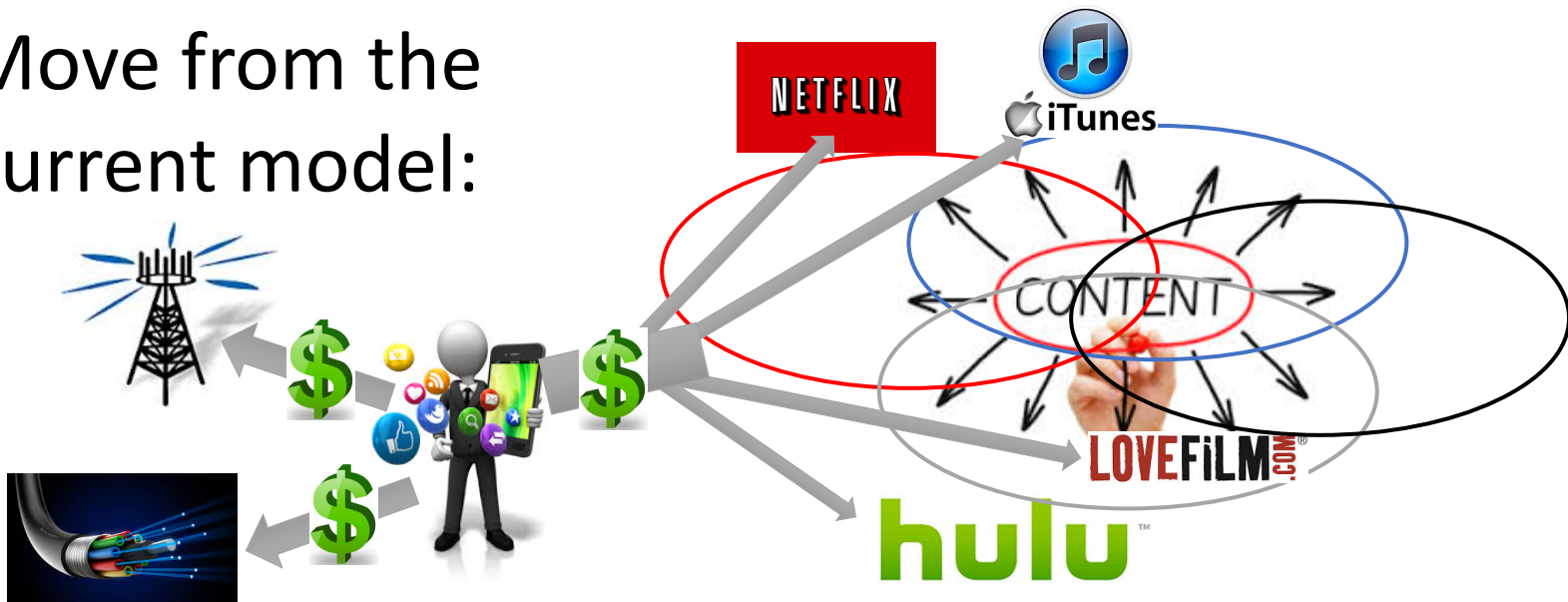
High value per bit



Low value per bit

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

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