TRINITY COLLEGE DUBLIN

Access-metro convergence in next generation broadband networks

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CONNECT Networks of the Future

OFC 2016

Content

- Why Access/Metro Convergence, why now?
  - Current network architecture
  - End-user requirements
  - Stake older requirements

- Access/Metro convergence
  - Network consolidation
  - Service multiplexing
  - Multi-tenancy
  - Is SDN the glue element for true access/metro convergence?

Acknowledgments

Much of the material is from the DISCUS project (www.discus-fp7.eu to see the full list of partners and deliverables), but results and ideas from other sources are also included.

Prof. David B. Payne from Trinity College Dublin.

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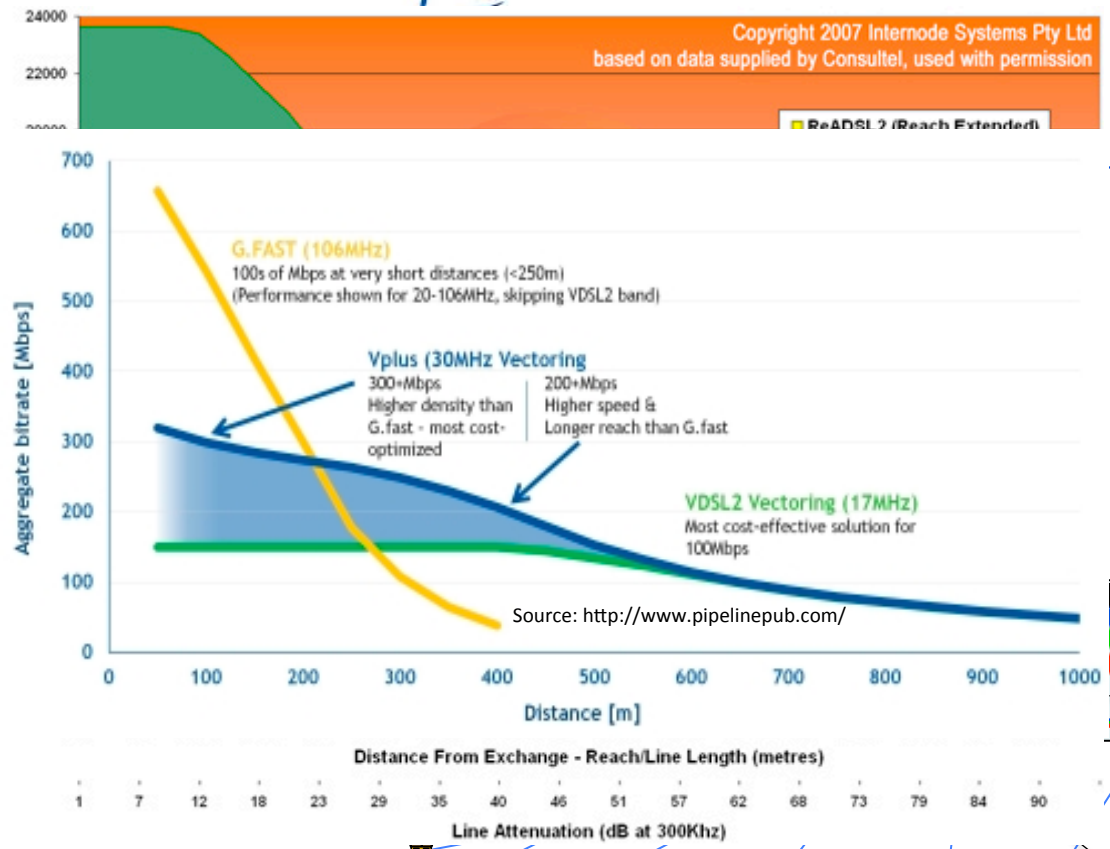
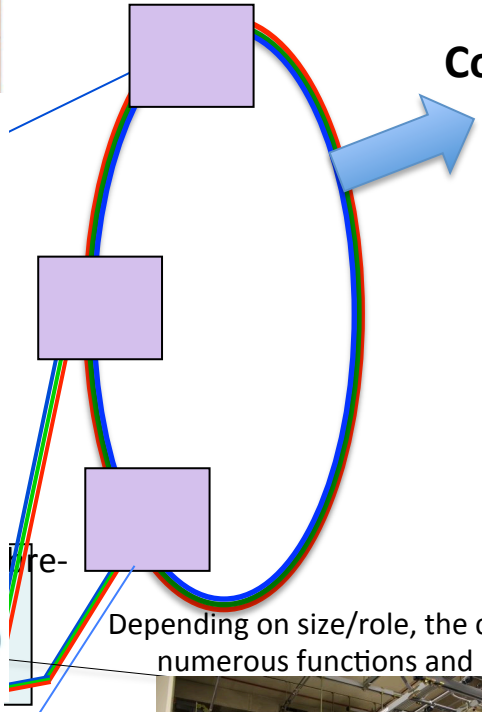
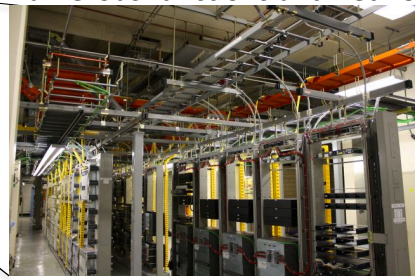
Access and metro network view





Core or Backbone network

Depending on size/role, the central office hosts numerous functions and network boxes



1G/10G Ethernet,
ADSL/VDSL
SDH
GPON/EPON
POTS
…

BRAS, PE Router
SGSN/GGSN (Mobile)
DPI
DSLAM
Carrier-grade NAT
MPLS
…

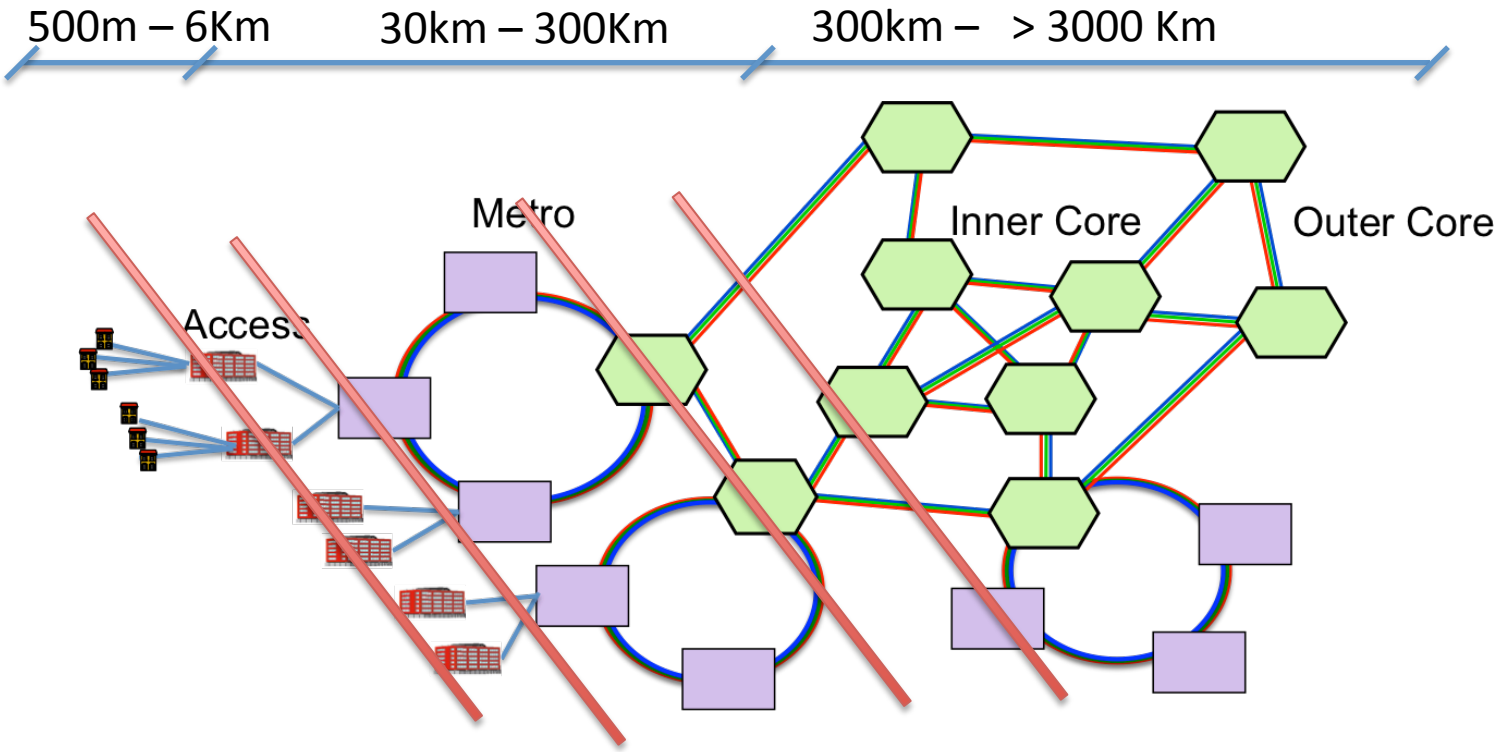
4G

Ptp Ethernet

Large business

DC

A telecommunications network (access/ metro/core view)



Based on progressive customer traffic aggregation through Optical-Electronic-Optical (OEO) conversion

Converging the access and metro networks

Much fuss about integrating metro and access networks today

- Why change it?
- What's different today?
- What are the drivers?

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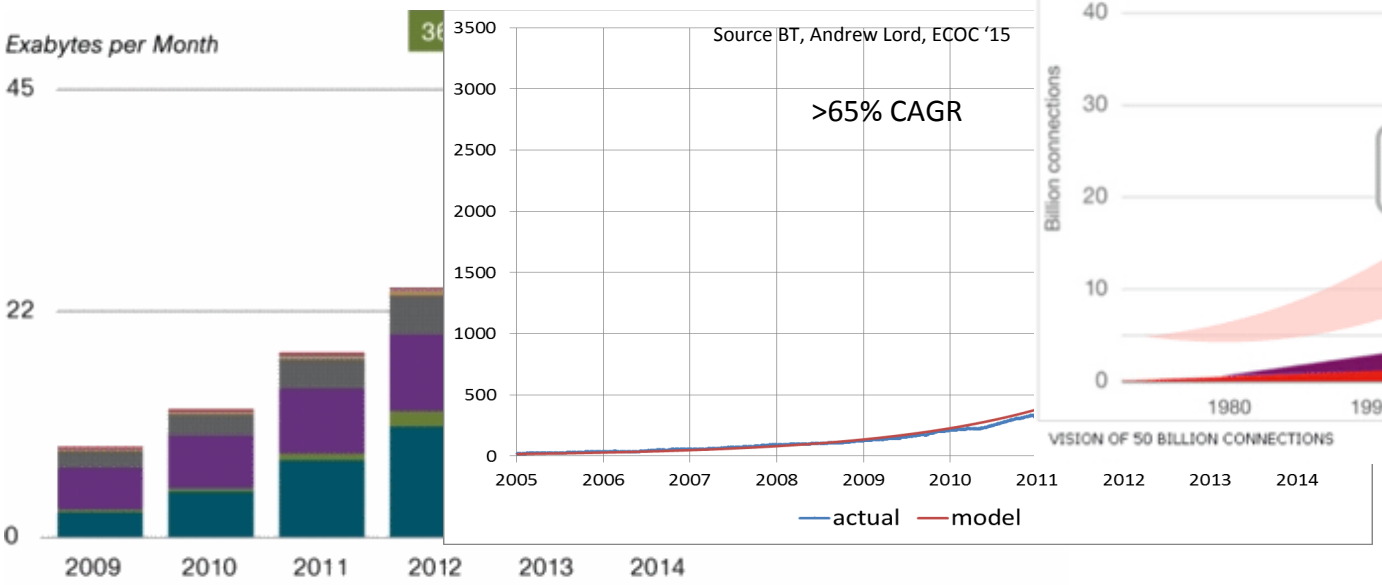
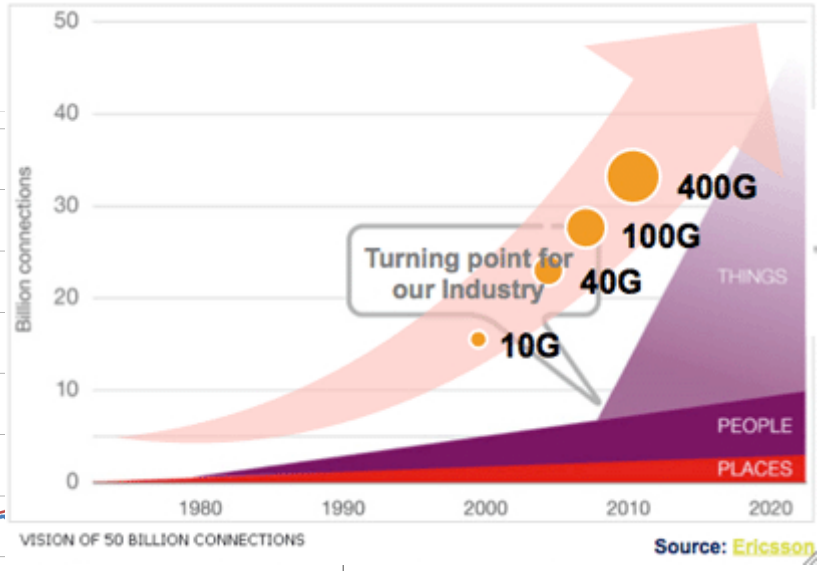
Change in traffic requirements

Internet traffic keeps growing



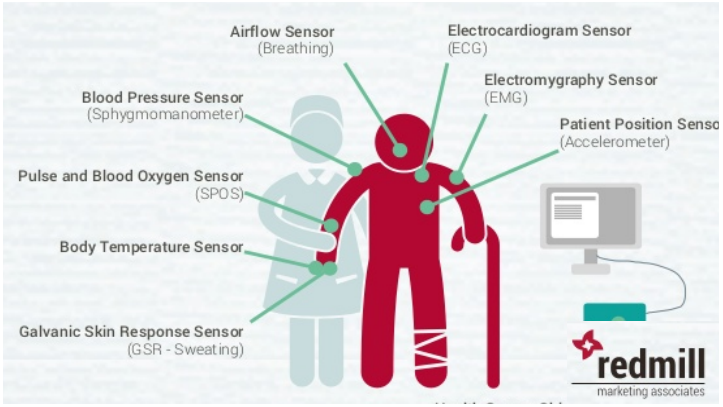
Source: Cisco VNI, 2010



Cisco VNI 2014-2019	North America			Western Europe			Middle East and Africa		
CAGR Average / Busy hour	26%		30%	23%		29%	47%		52%
Daily FTTx user download 2014 / 2019 / CAGR	5.4GB	9 GB	18%	3GB	5GB	10.7%	1.2GB	3.8GB	26%
Daily mobile connection download 2014 / 2019 / CAGR	49MB	255MB	39%	21.5MB	131MB	43.5%	5.6MB	65.5MB	63.5%

It's more than bare capacity

- Bit/service disassociation: value in the service not in the bits



- Any content at a click's reach: immersive interaction

Augmented Reality

Virtual Reality

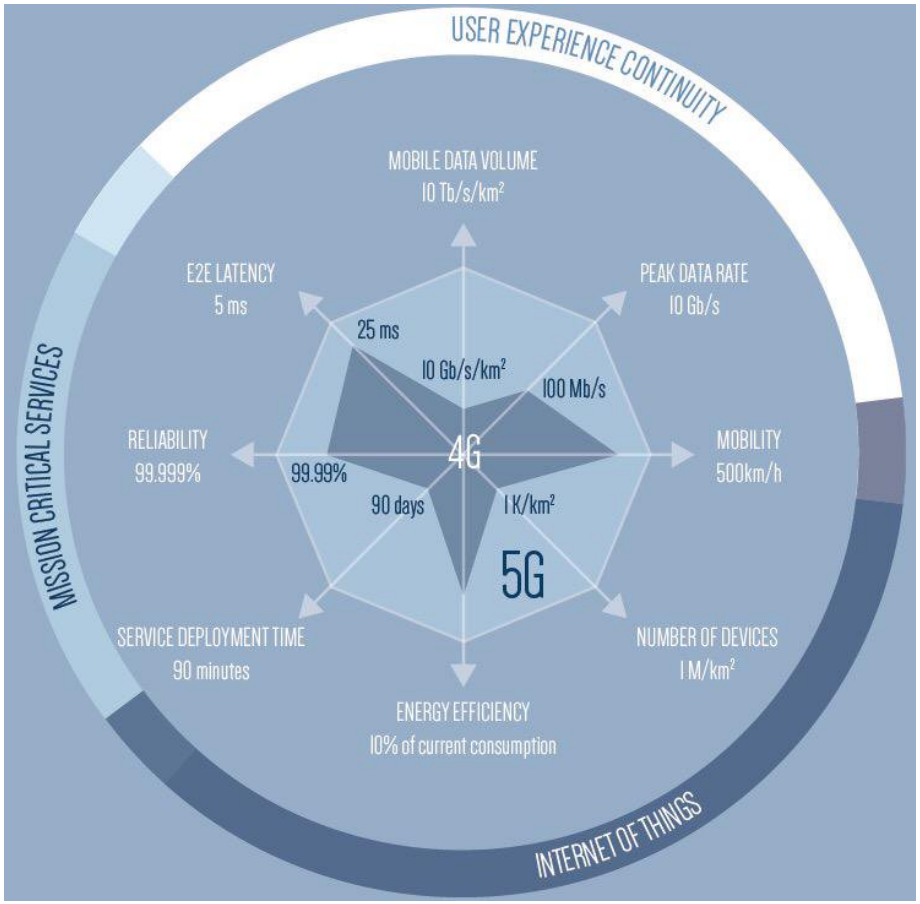
OFCity challenge

- Smart location and transportation

- Smart health

- Smart education

5G requirements



Source: GPPP, "5G Vision," available on www.5g-ppp.eu

5G is not 4G + 1G

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!

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Operators/Providers Requirements I

- Survival requires network simplification
  - Lower cost of running the network
  - Run multiple services in the same network infrastructure (existing and new ones)
  - Lower energy consumption
  - Enable the 5G vision: capacity anywhere to anything
    - Work with heterogeneous requirements (latency, capacity, reliability)

- Become a Virtual Network Operator: control network (capacity, QoS, connection availability) without owning it

  ➔ Build up required end-to-end connectivity pooling together virtual network instances from multiple and diverse resources

"The new status symbol isn't what you own—it's what you're smart enough not to own"

Operators/Providers Requirements II

- Speed up service provisioning time:

  ▸ CARRIER SDN / SDN ARCHITECTURES

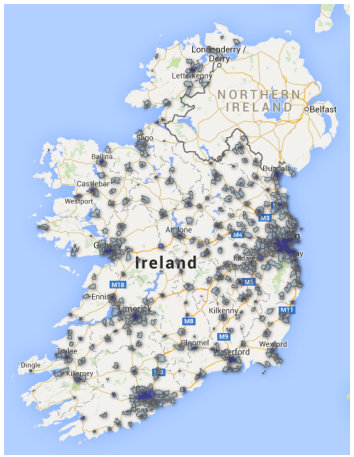
  AT&T: SDN Is Slashing Provisioning Cycle Times by up to 95%

  Source: Lighreading, August 12th 2015

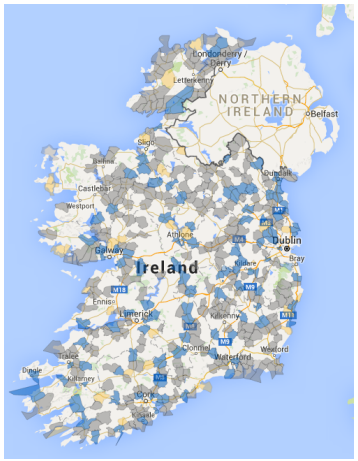
- Cost-effective flexibility: no capacity most of the week, to 10Tb/s for a few hours during an event

Government Requirements

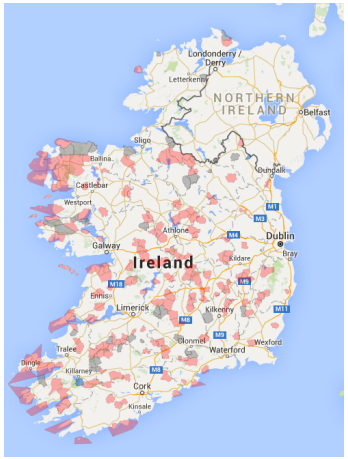
- Broadband is a commodity in our information age
- Digital divide is a big social issue for all government and EU has a 2020 target of 30Mb/s to **every** household



Population and urban areas

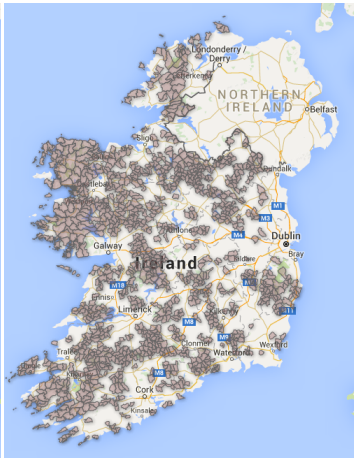


FTTCab blue= available today



Area with no DSL

Planned FTTH



National Broadband Plan ➔ state intervention

70% of population in 17% of territory

30% of population spread over 83% of territory

- Lower cost technology means reduce the areas of state intervention
- Open-access models are very important for national broadband plans

Summary of requirements

Application-oriented approach to deliver real value

- Reliable applications (reliable capacity, latency, survivability,…)
- Application availability anytime anywhere (really ubiquitous network access)

5G requirements:

data rate, latency, mobility, connections, energy, reliability,..

- Multiple technologies working seamlessly together
- Prepare for the unknown as most 5G applications are still unknown…

Improve network business case

- Reduction of network operating cost
  - Lower capital cost for network equipment
  - Sharing cost of ownership
- Increase revenues with more and faster services
- Reduce energy consumption

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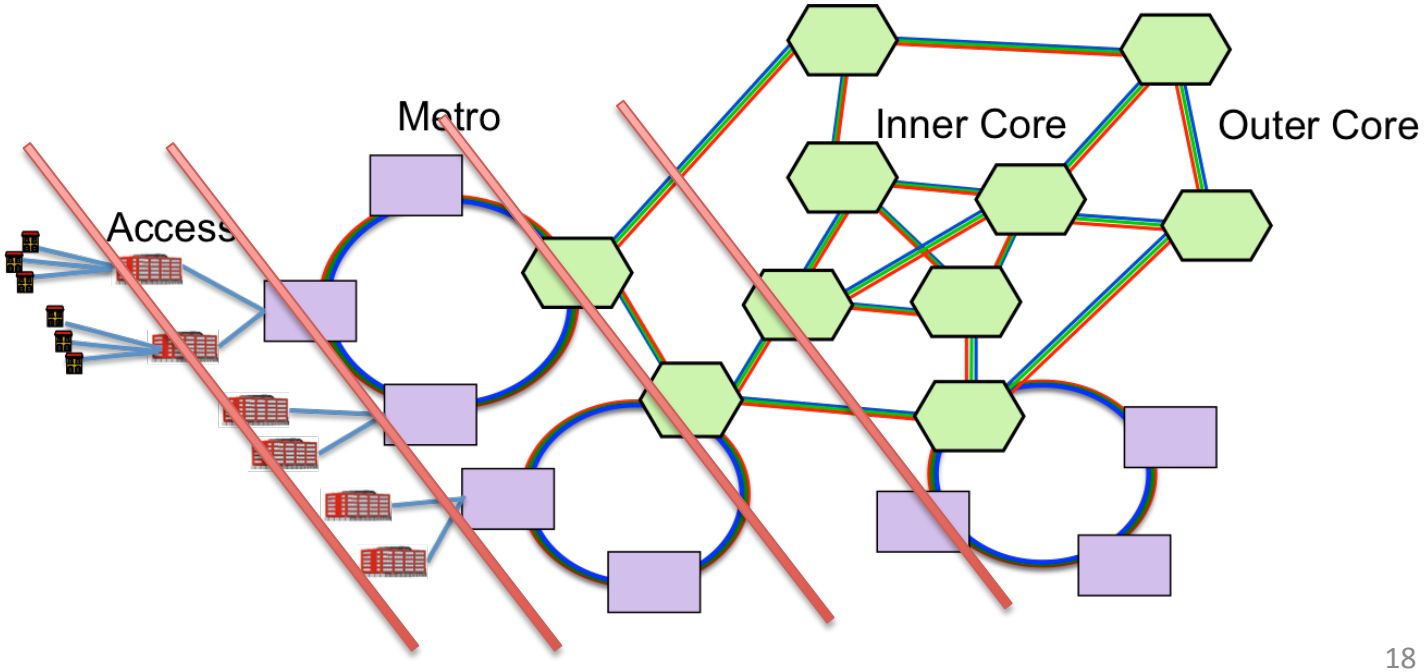
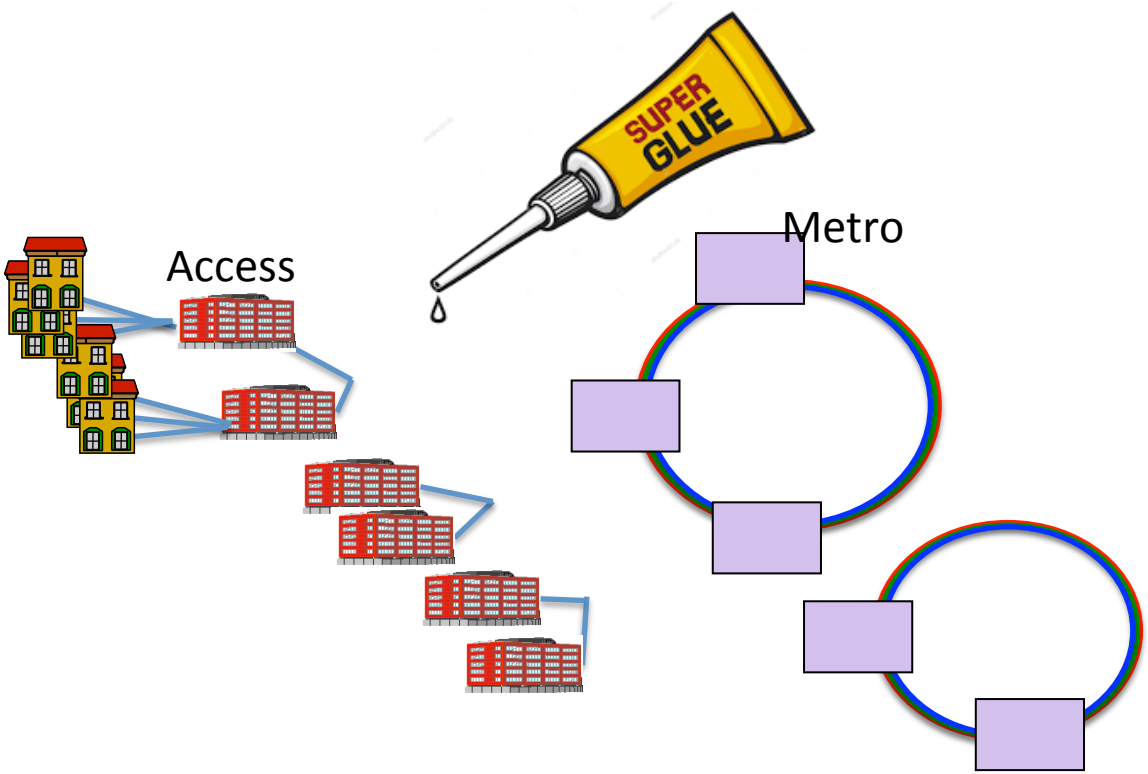
Need for change?

- Considering these requirements:
  - Is this model obsolete?
  - Is access-metro convergence the solution? Why?
  - What is access/metro convergence???

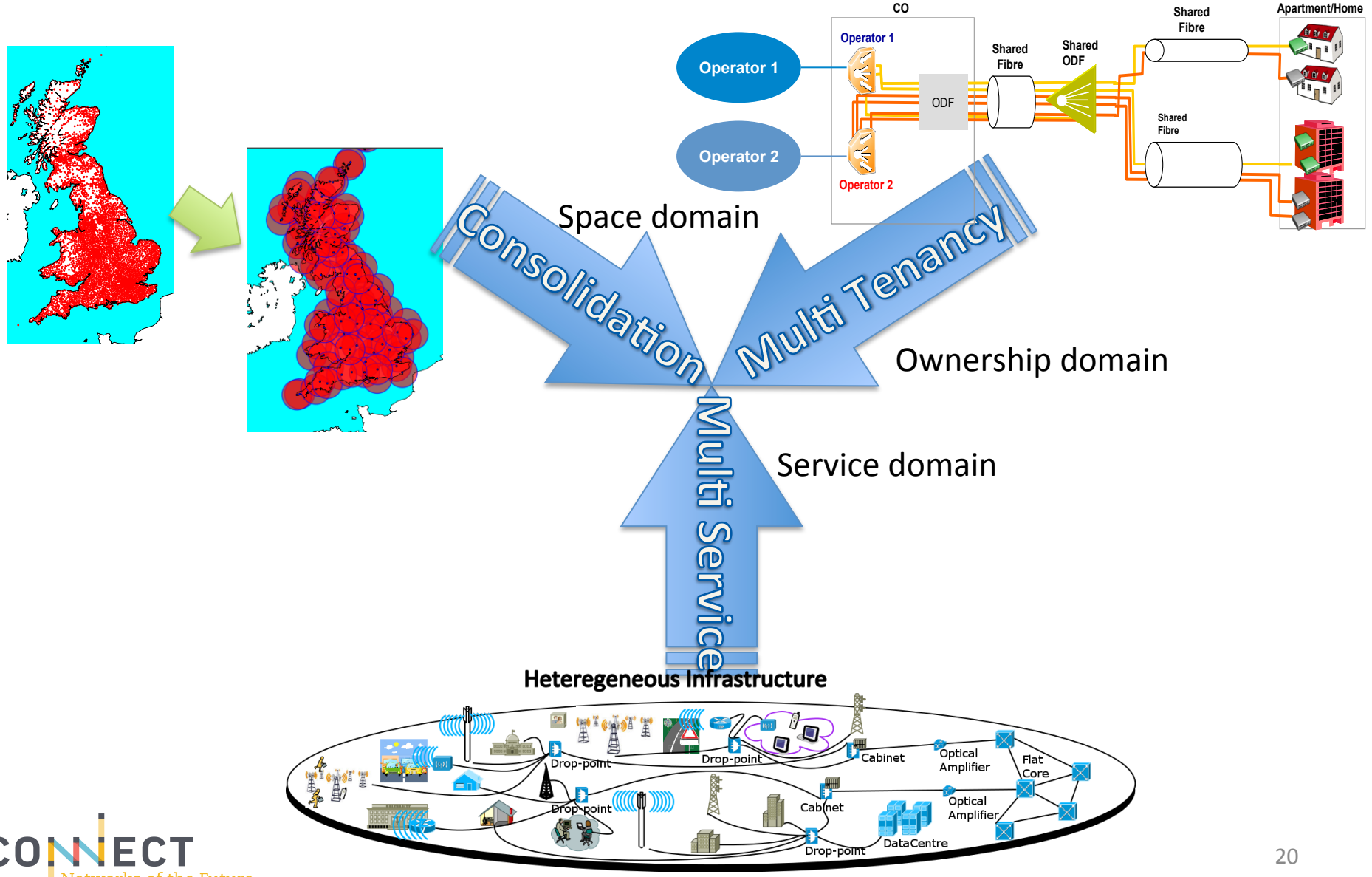


What is access-metro convergence?

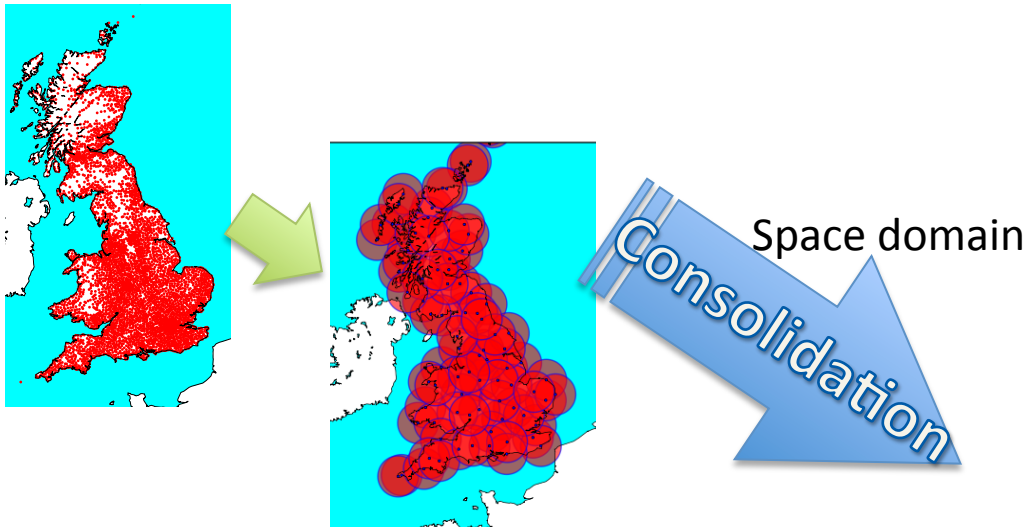


Much more than the integration of access and metro transmission technologies

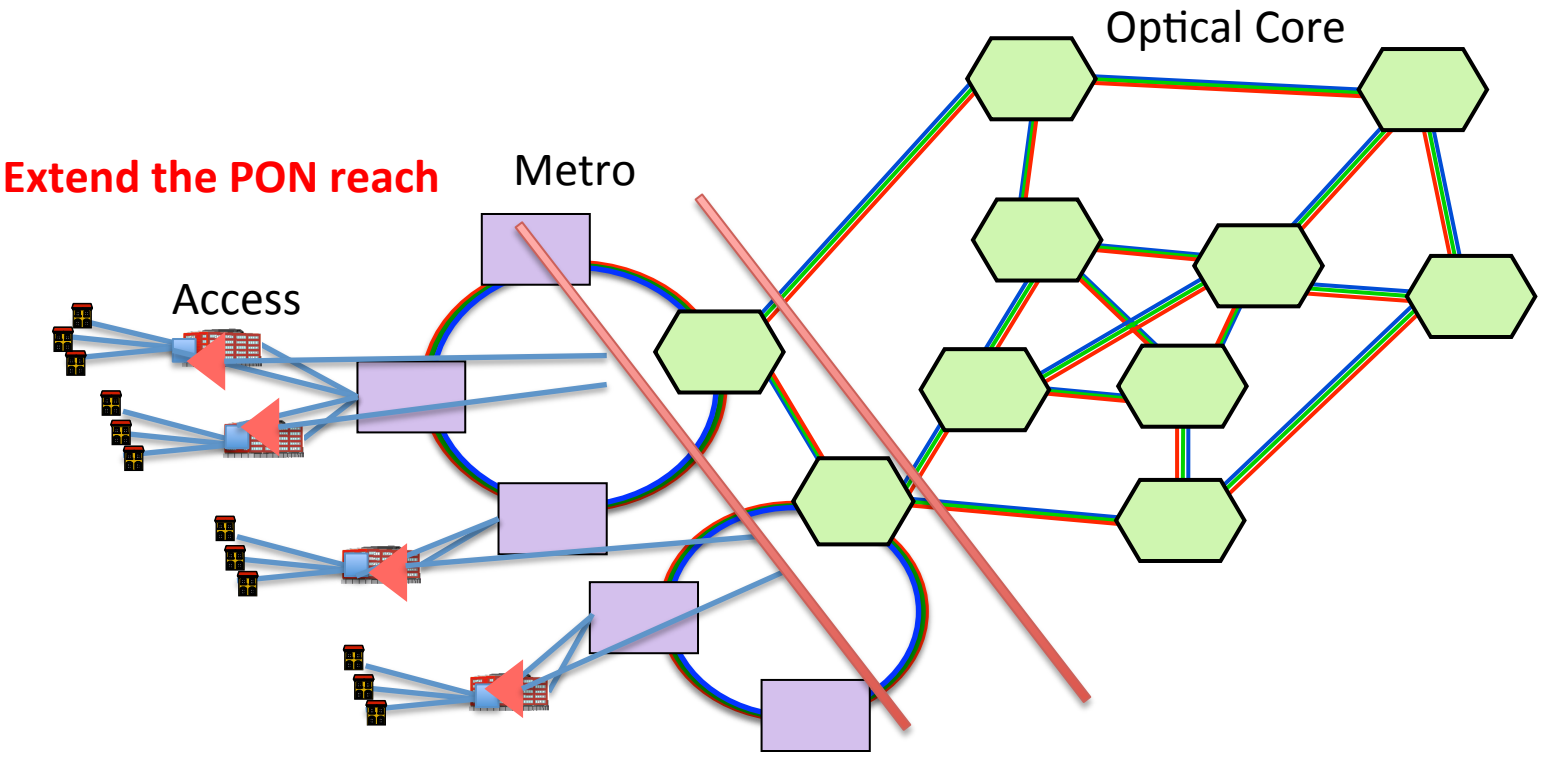
Access/Metro Convergence



Access/Metro Convergence

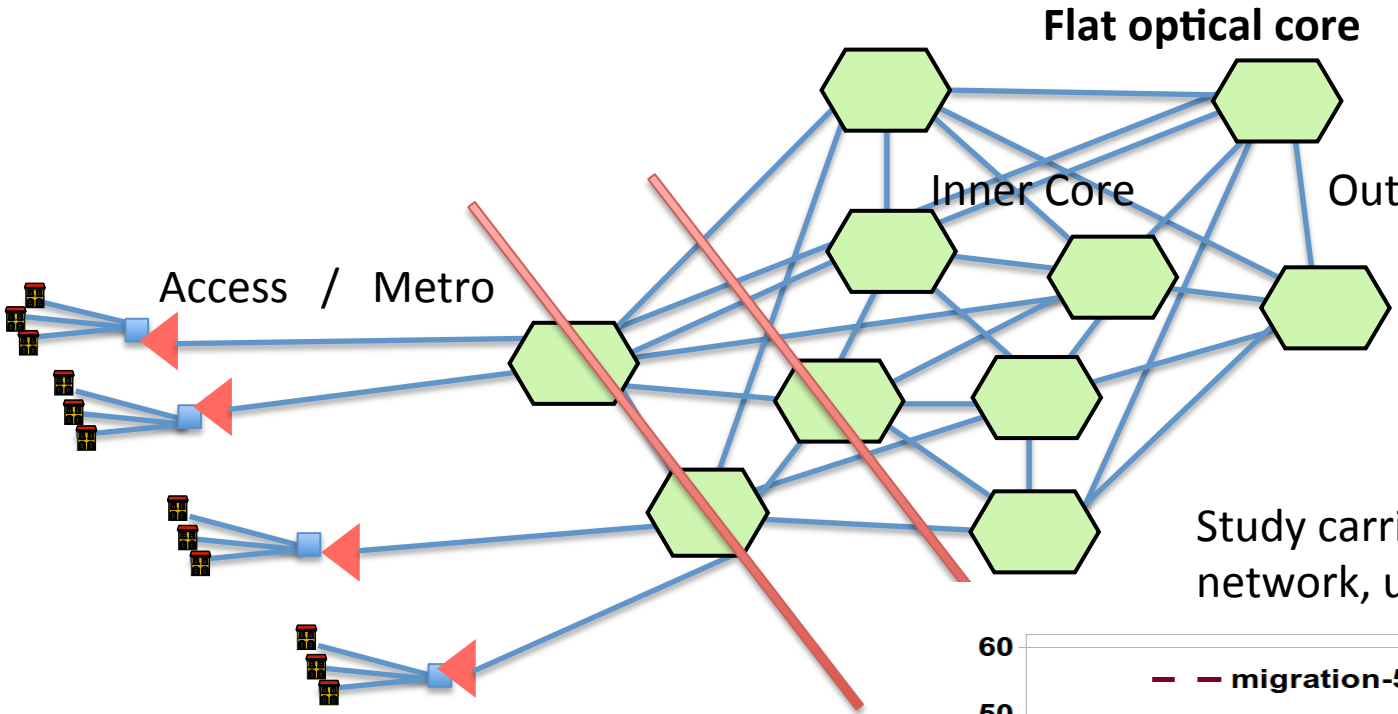


DISCUS PON architecture enabling node consolidation

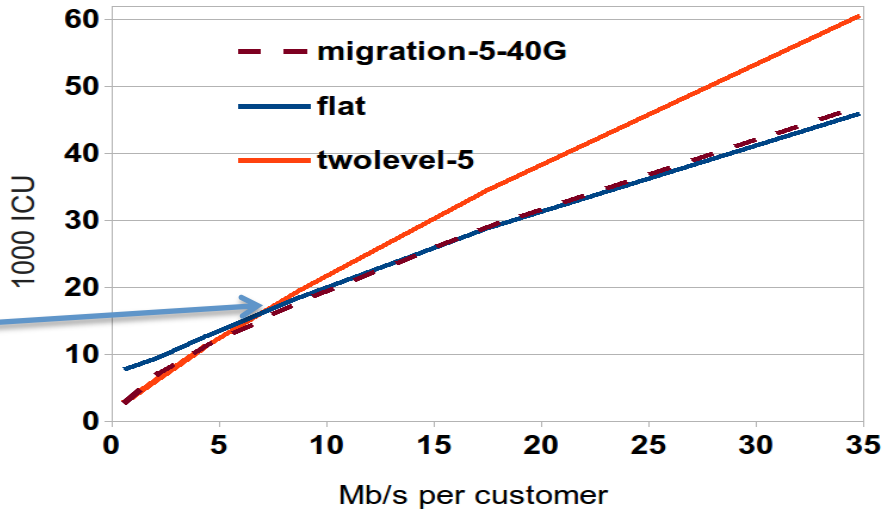


Once you start the convergence process you need to rethink of all network boundaries: What defines access-metro, metro-core, inner core?

From hierarchical to flat core



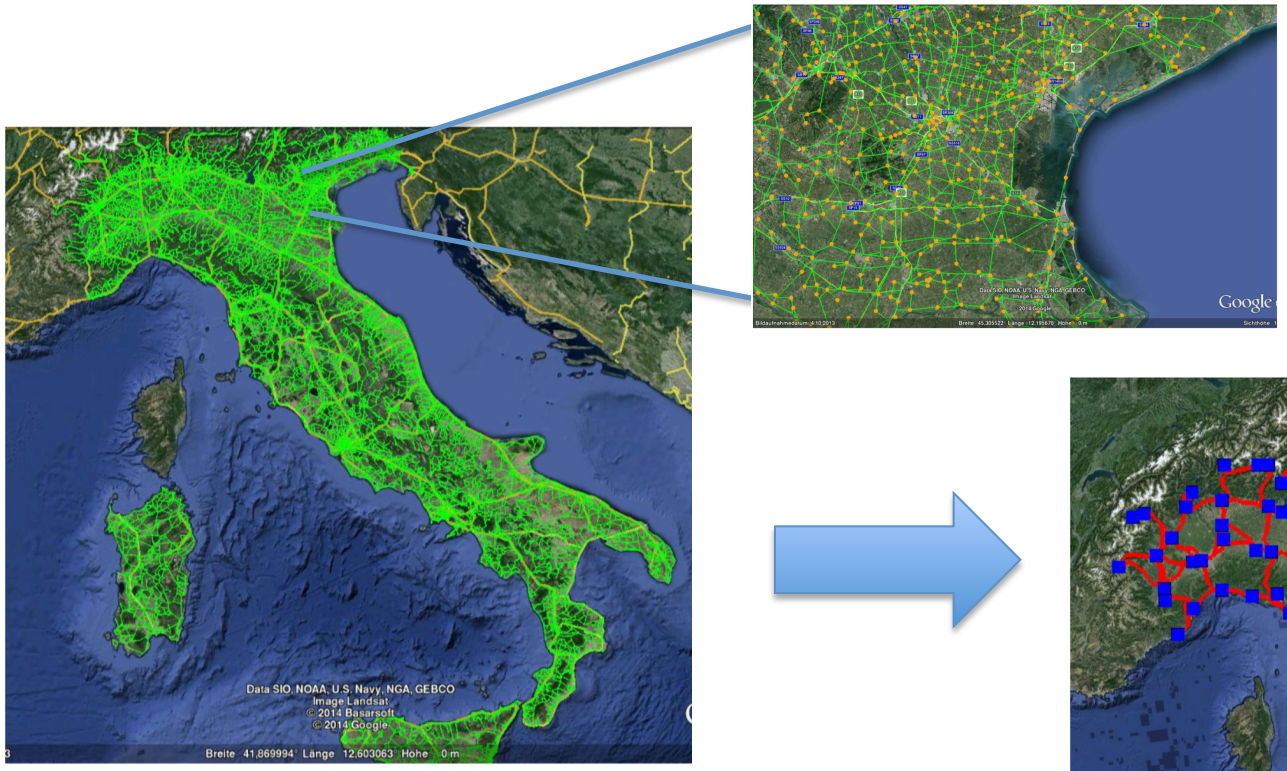
Study carried out for UK network, using 75 MC nodes

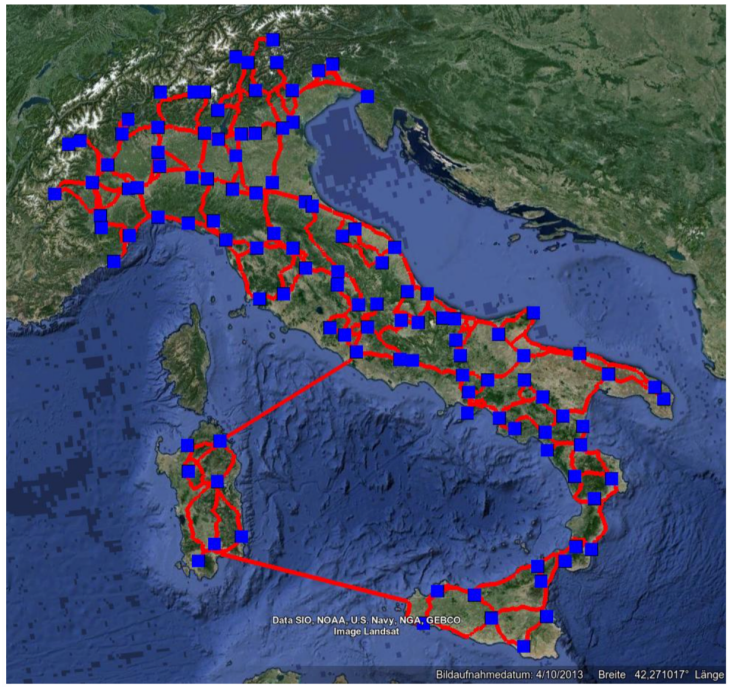


Flat core becomes the cheaper option when traffic is above a given threshold

C. Raak et al., Hierarchical Versus Flat Optical Metro/Core Networks: A Systematic Cost and Migration Study, ONDM 2016

Node consolidation studies

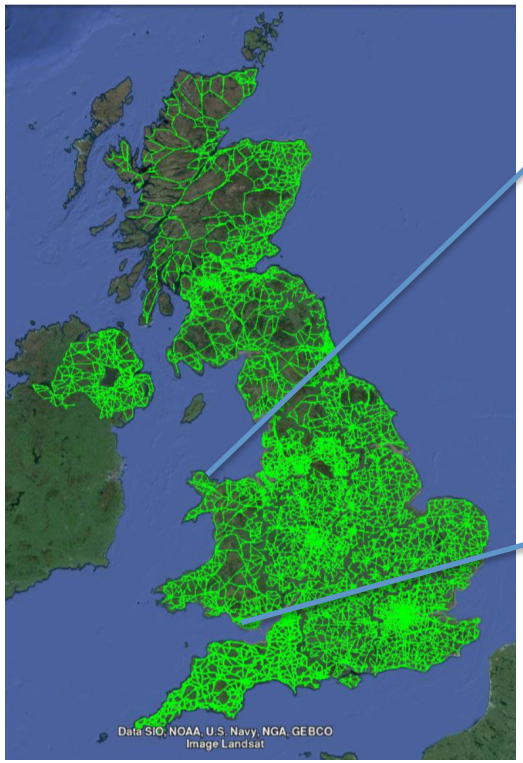


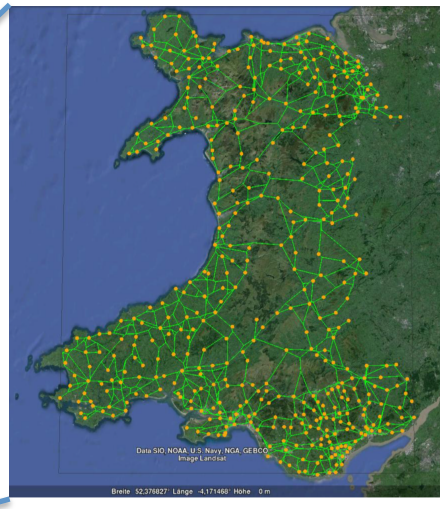


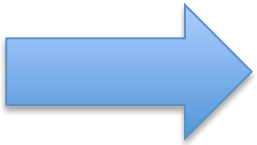
Country	Instance $\max_{Km}$	# MC nodes	# Fiber links
UK	110 km	75	137
Italy	115 km	116	219
Spain	115 km	179	321

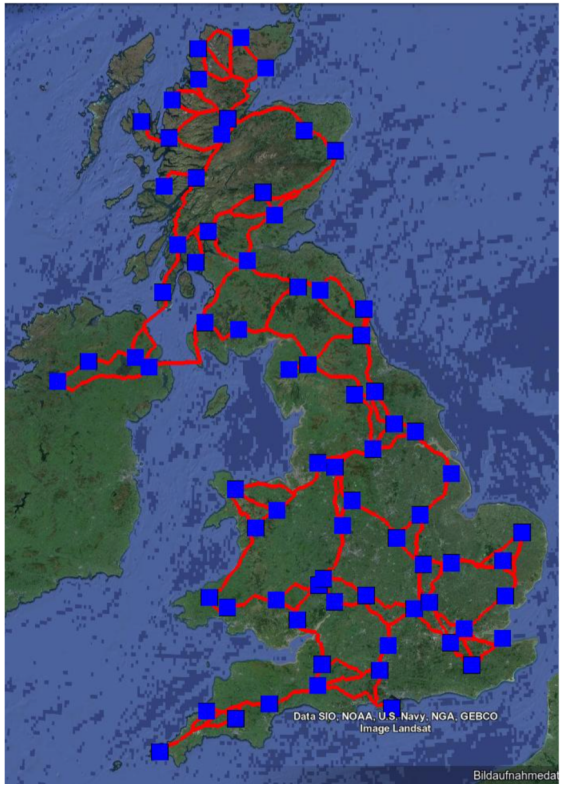
Dual-homed PON protection with maximally disjoint fibre routes

Node consolidation studies









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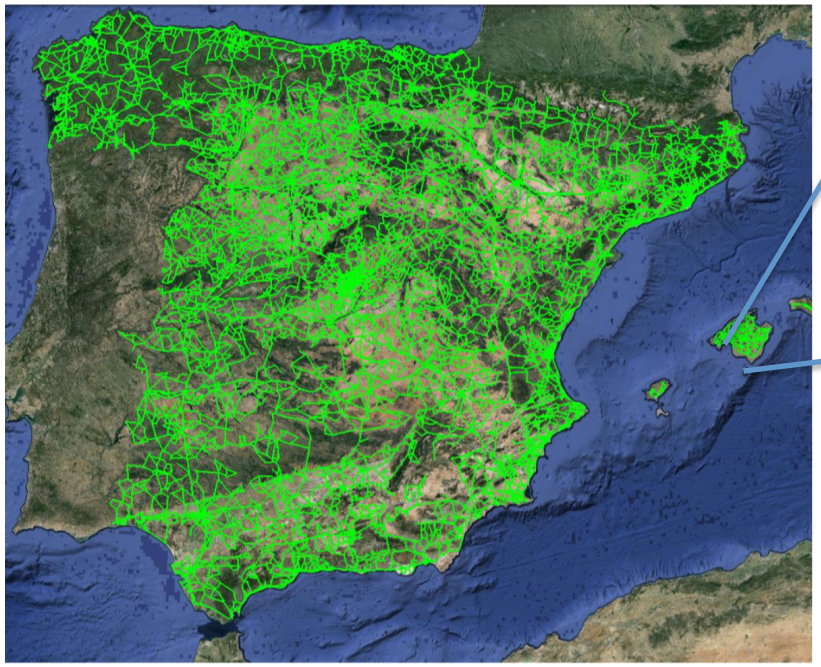

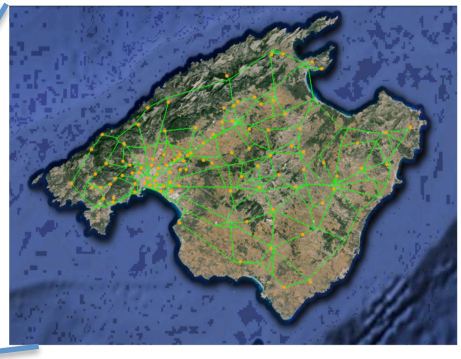

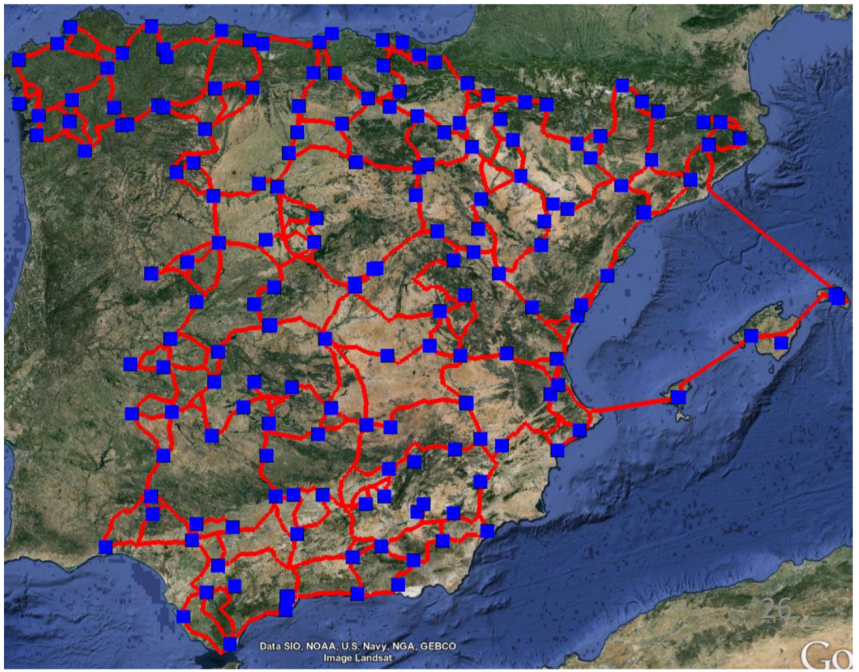

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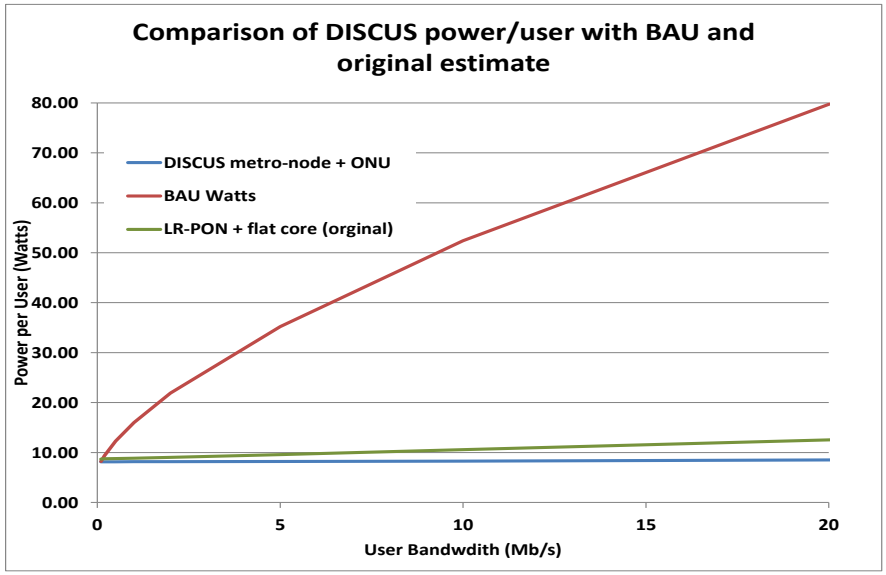
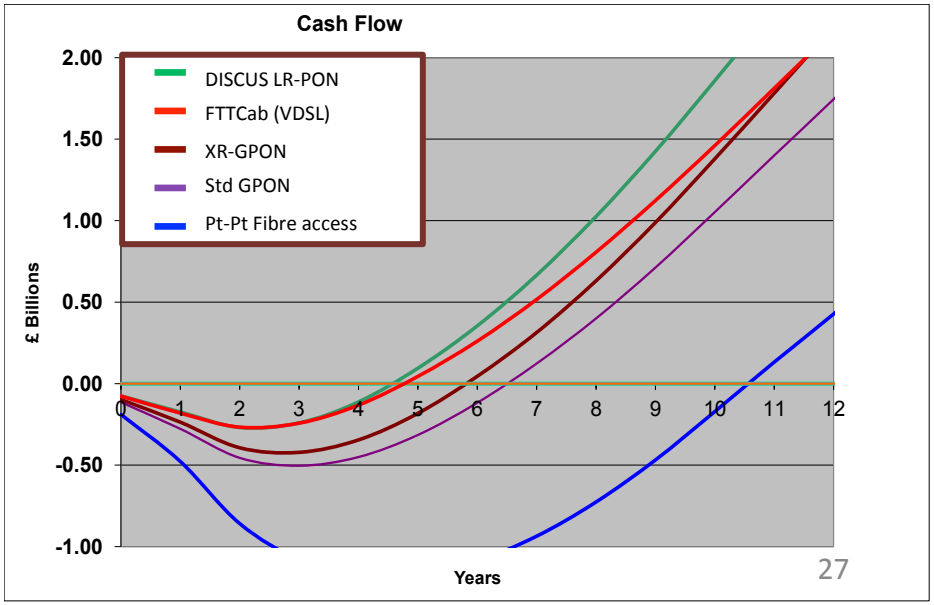
Architectural results

- 10x decrease in power consumption compared to Business as Usual (BAU)



- Lower cost compared to other optical access technologies



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Improve network business case

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Requirements enabled by consolidation

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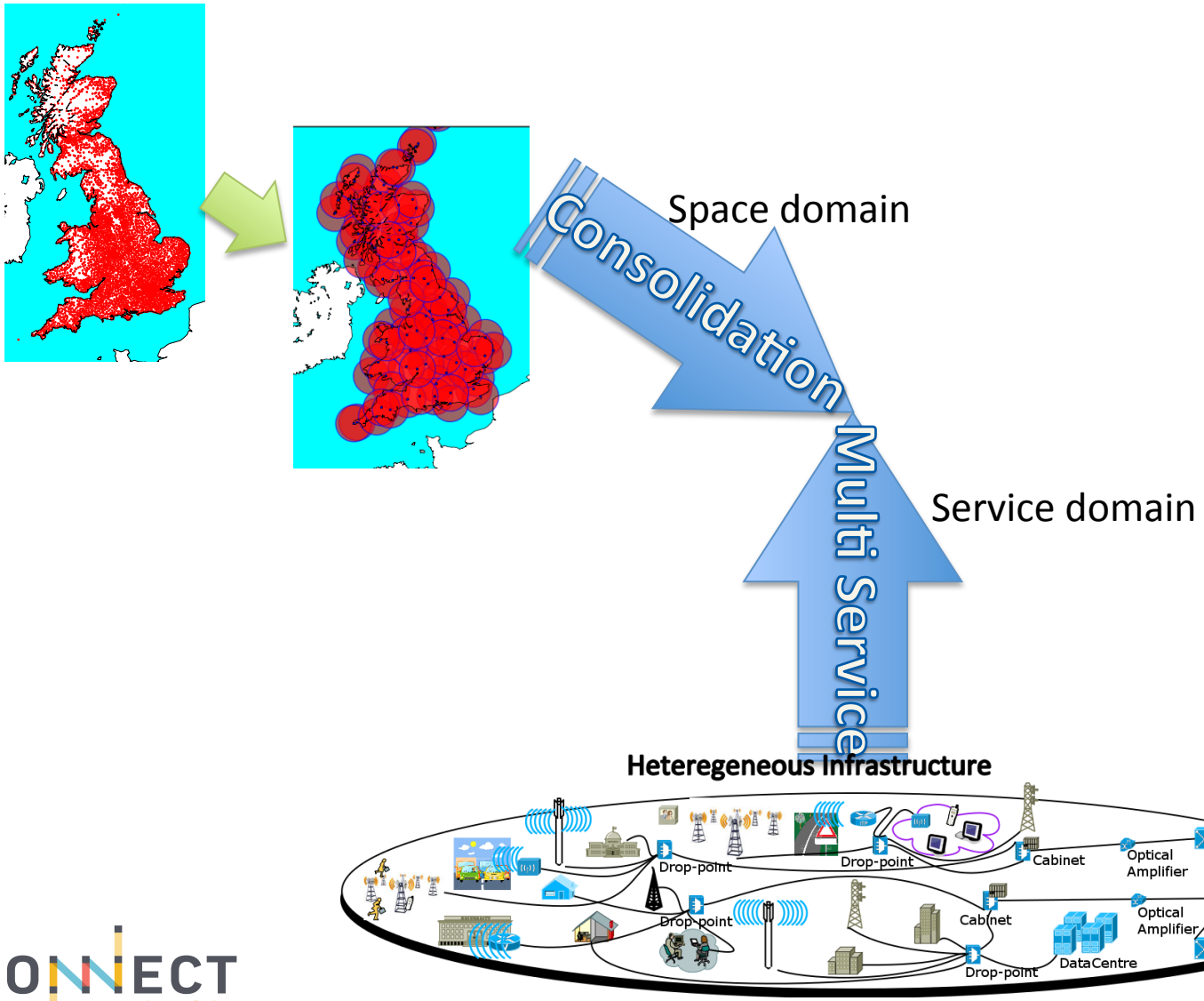
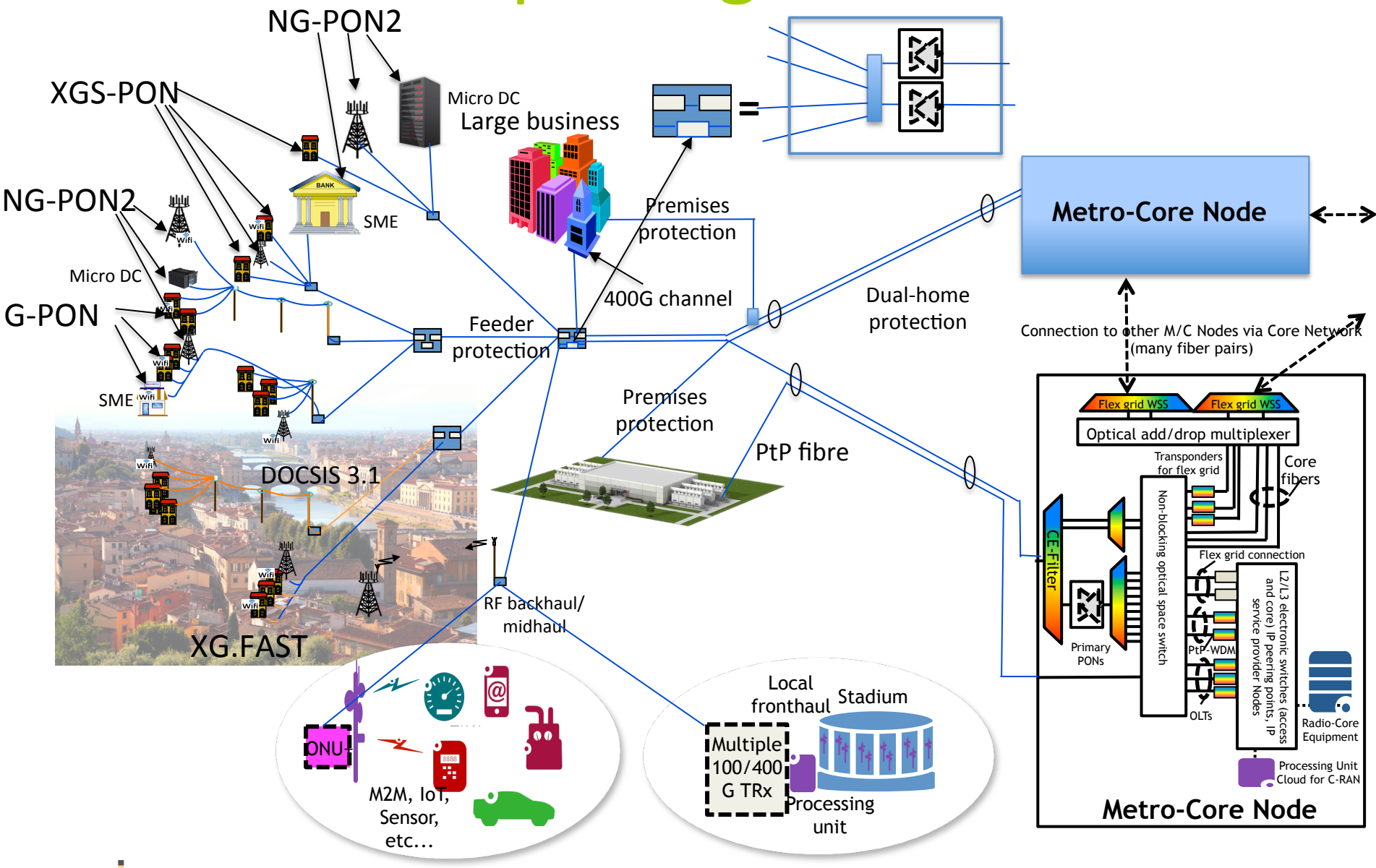


Service Multiplexing



G. Talli et al., Demonstration of SDN Enabled Dynamically Reconfigurable High Capacity Optical Access for Converged Services . PDP paper Th5B.1

Fixed-mobile convergence

Question: how to increase mobile capacity by 1000 times (by 2020??)

Some popular estimates of factors for capacity increase:

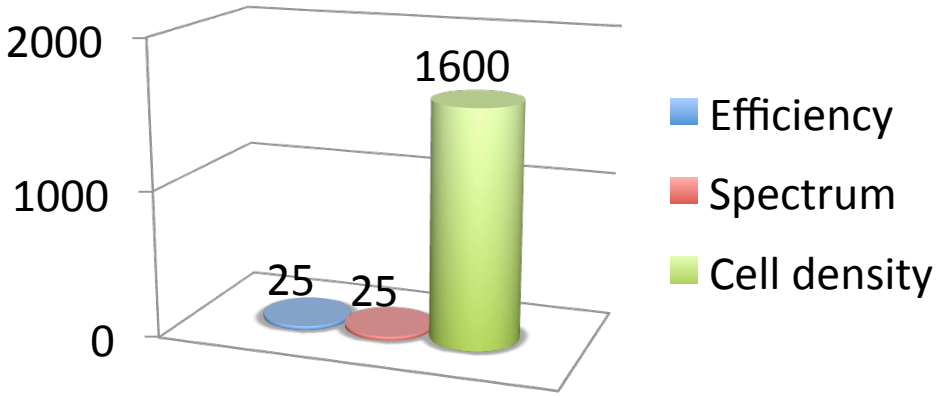
- Efficiency (MIMO, Smart scheduling, enhanced-CoMP) -> x3
- Spectrum (Carrier Aggregation, New Bands, Authorized Shared Access) -> x2
- **Density (Advanced Macros, HetNet management, Flexible small cells)**

➔ $\frac{1000}{2 \cdot 3} = 167$

Source: Nokia, enhance mobile networks to deliver 1000 times more capacity by 2020

This is in line with what happened in the past:

Cooper's law (of spectral efficiency): 1 million times improvement in the past 45 years



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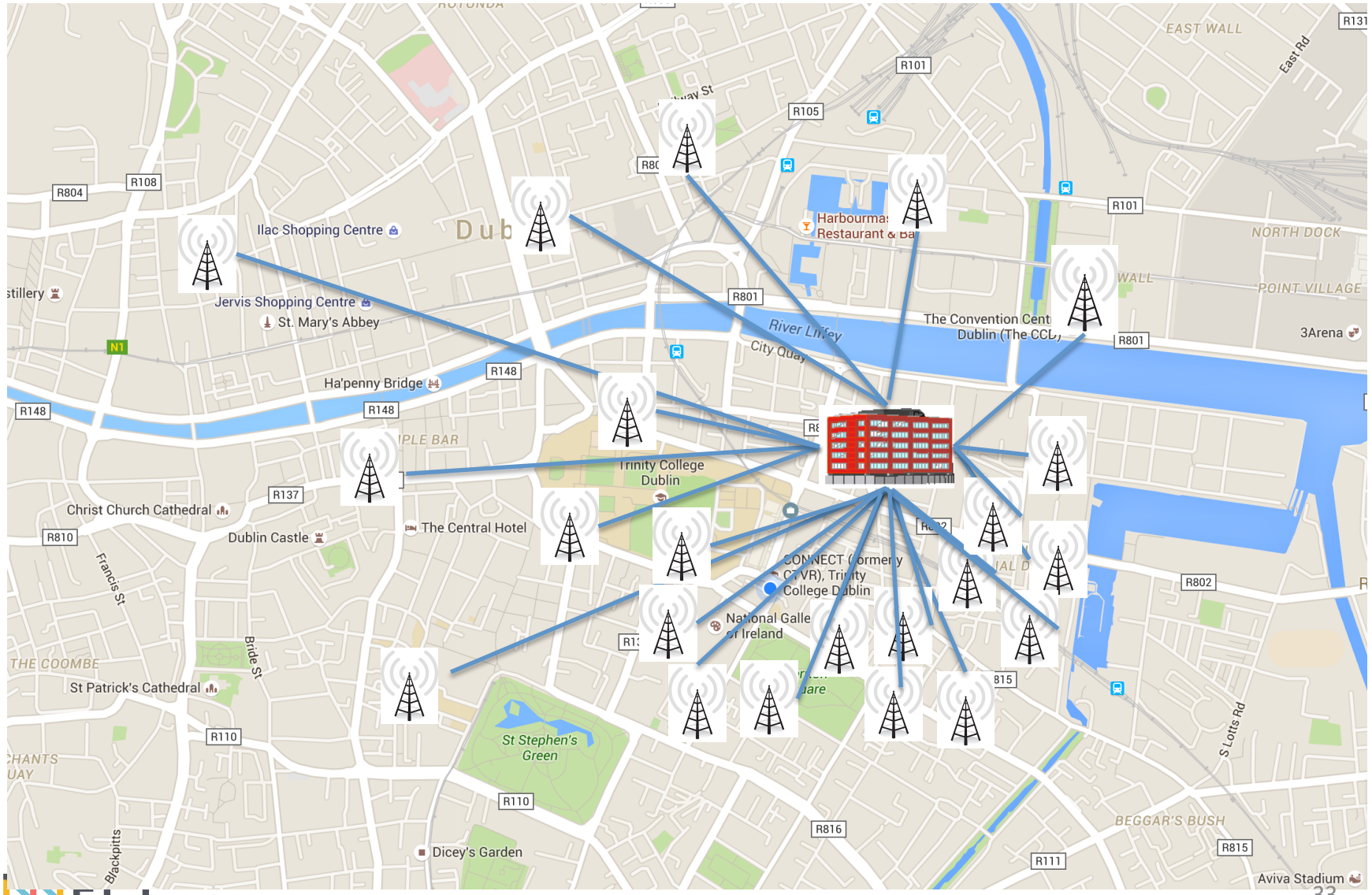
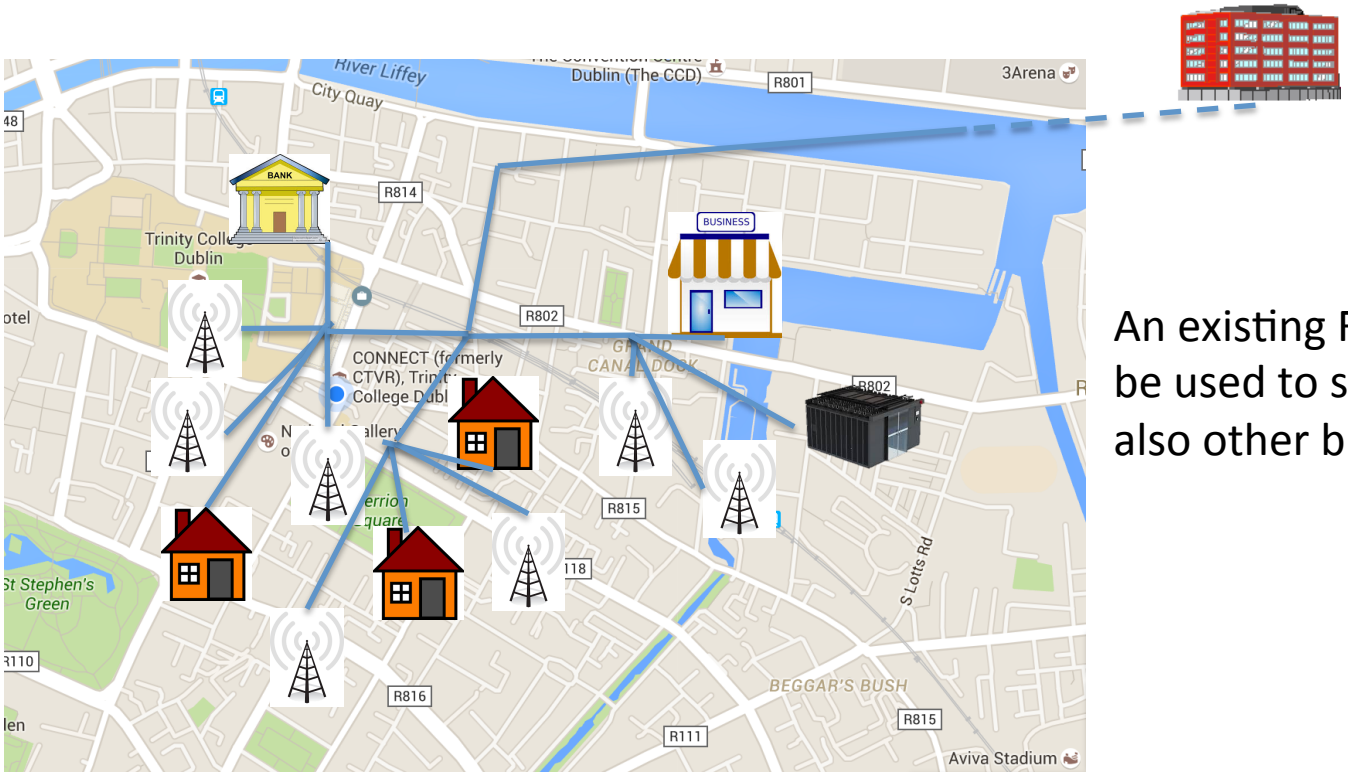
Higher Cell Density



Shared PON for mobile backhauling



An existing FTTH infrastructure can be used to serve mobile cells, but also other businesses

An optical access network, if well architected can allow service multiplexing:
any access point (a home, a macro cell, a small cell, a business, a micro cache or small data center) can request assured capacity from the low Mb/s to multiple 100s Gb/s.

But things change quickly… i.e. Cloud RAN came into play chaning latency requirements

Cloud RAN

Great example of changing requirements and need for flexible network architecture

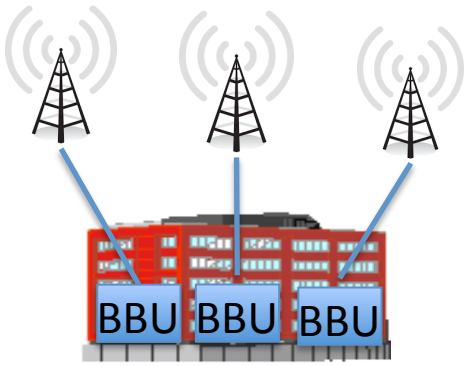
Placing Base Band Unit (BBU) at different location than the Remote Radio Unit (RRU).

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

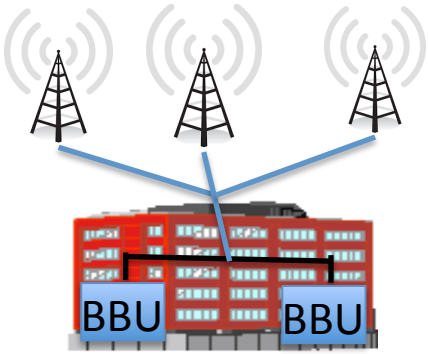
This gave the idea to move the BBU further out giving raise to the Cloud RAN concept

Examples of Fronthaul architectures

One virtual BBU to many RRU



BBU hoteling



BBU pooling

BBU cloud

Fronthaul

Problems:

1. High capacity: $B = R_s \times N_q \times N_a \times N_b \times R_c \times R_l$

Sampling rate; Quantization bits; Antennas; Frequency bands; Word control ratio; Line coding ratio

J-I Kani et al., Options for future mobile backhaul and fronthaul, Elsevier OFT issue on access networks, November 2015

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

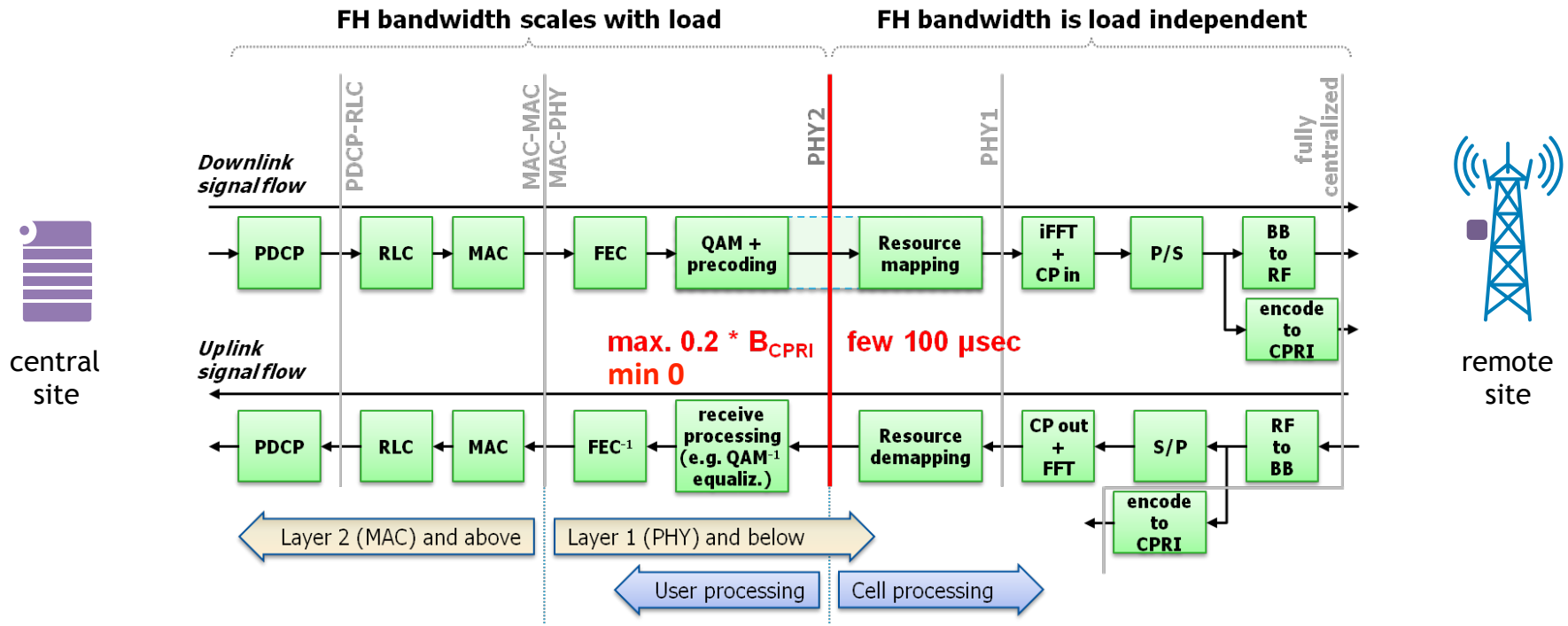
This is independent of usage… it's a sustained rate!

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

Solution for Fronthaul capacity issue

- Signal compression: bandwidth reduction by factor of 2-3 but deterioration of SNR
- Split processing or midhauling:

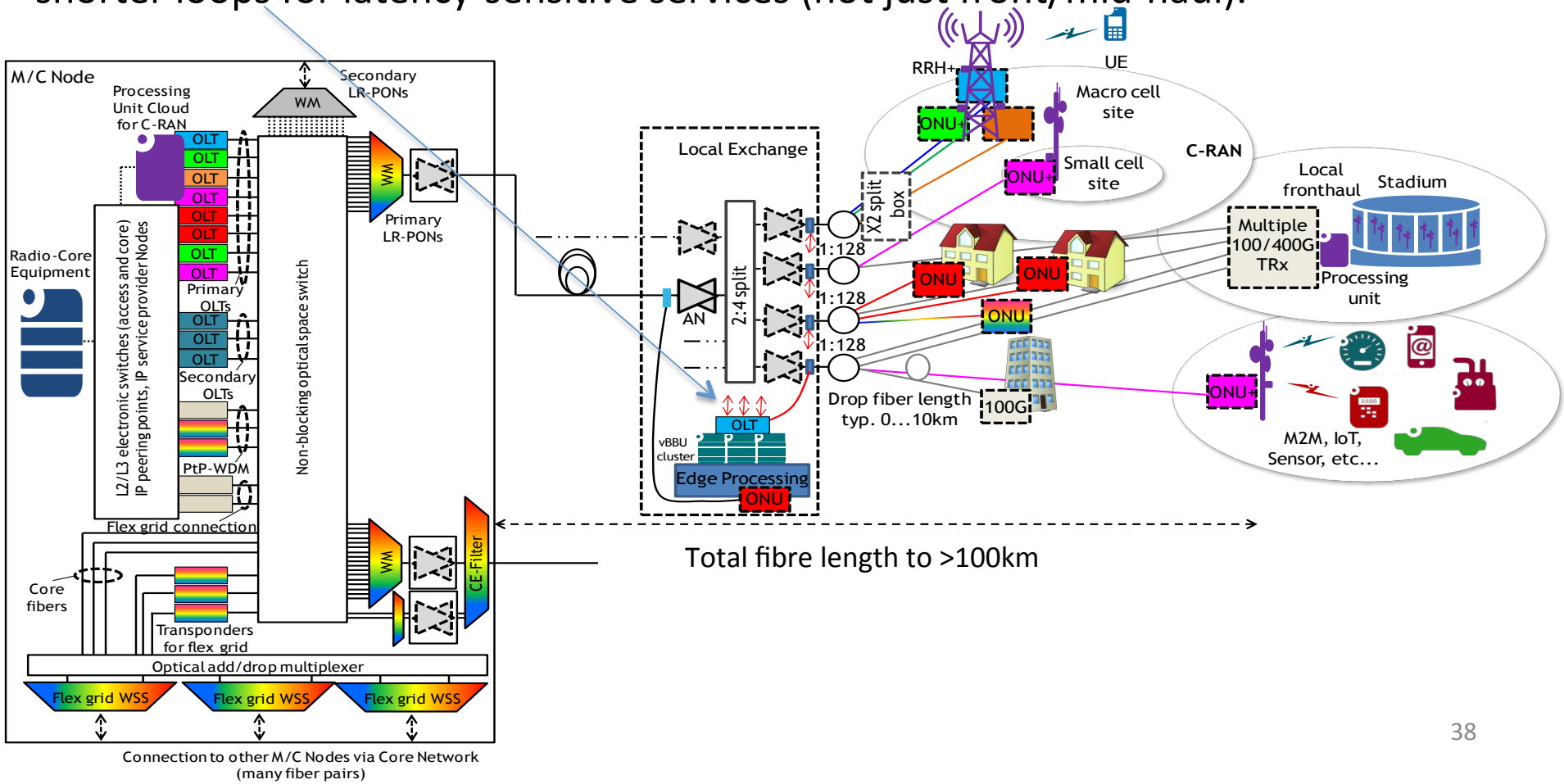


Source: Thomas Pfeiffer, Next Generation Mobile Fronthaul and Midhaul Architectures. IEEE/OSA JOCN 7(11), Nov 2015. Original work from: U. Dotsch, et al., Quantitative Analysis of Split Base Station Processing and Determination of Advantageous Architectures for LTE

Flexible architecture

- Latency from front/mid-haul can restrict PON reach
- Latency-sensitive 5G applications might impose even tighter distance constraints

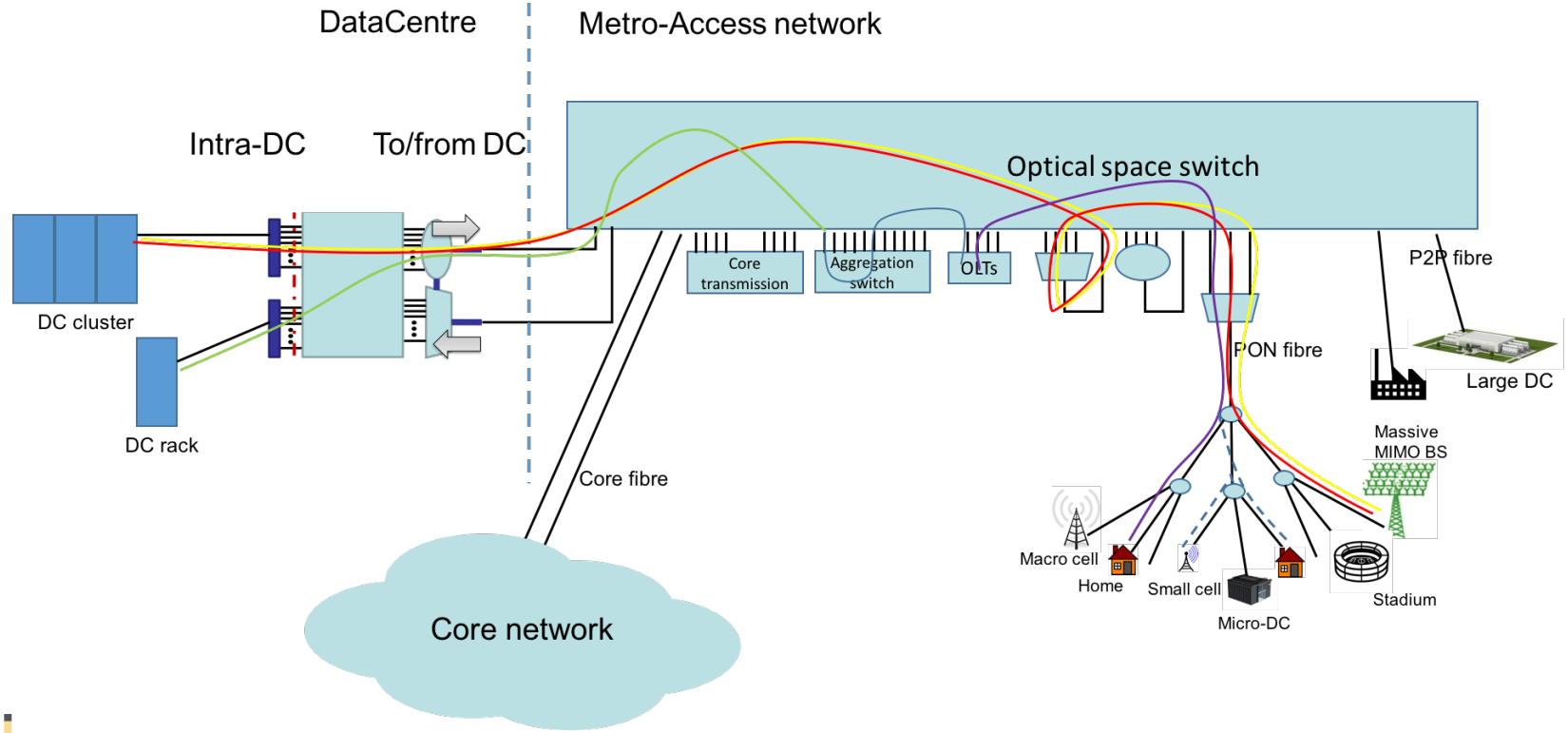
➔ Flexibility: build overall network to target majority of applications, but allow shorter loops for latency-sensitive services (not just front/mid-haul).



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



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

Summary of requirements

Application-oriented approach to deliver real value

- Reliable applications (reliable capacity, latency, survivability,…)
- Application availability anytime anywhere (really ubiquitous network access)

5G requirements:
data rate, latency, mobility, connections, energy, reliability,..

- Multiple technologies working seamlessly together
- Prepare for the unknown as most 5G applications are still unknown…

Improve network business case

- Reduction of network operating cost
  - Lower capital cost for network equipment
  - Sharing of cost of ownership
- Increase revenues with more and faster services
- Reduce energy consumption

Requirements enabled by consolidation, service multiplexing

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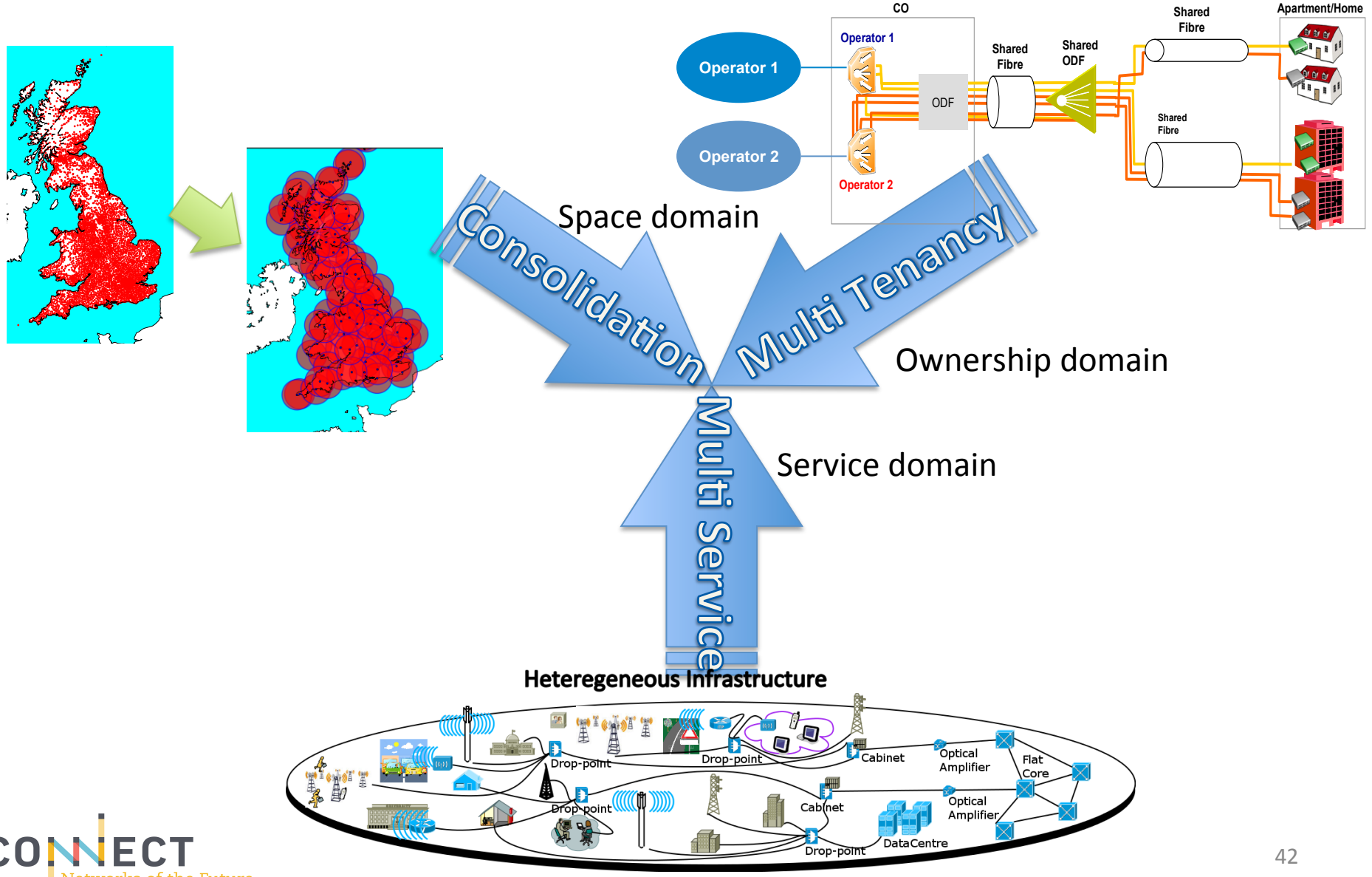
Access/Metro Convergence



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.

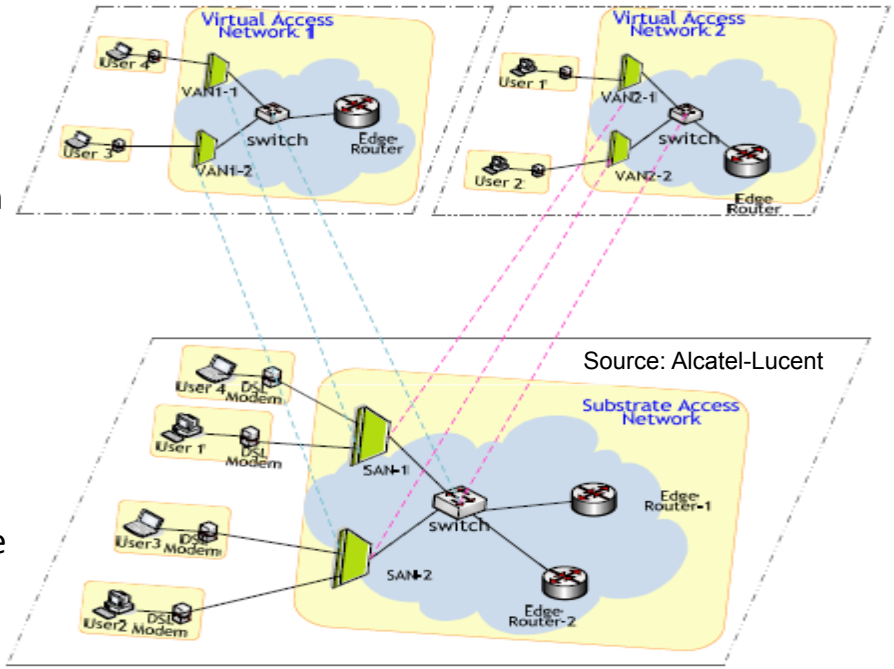
Risk of creating de-facto monopoly

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

Benefit from fast dynamics and innovation brought by fully open market

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 (IP)**
  - 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 SD-351, Analysis of Fixed Access Network Sharing (FANS), Jun. 2015

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Requirements enabled by

consolidation, service multiplexing, multi tenancy

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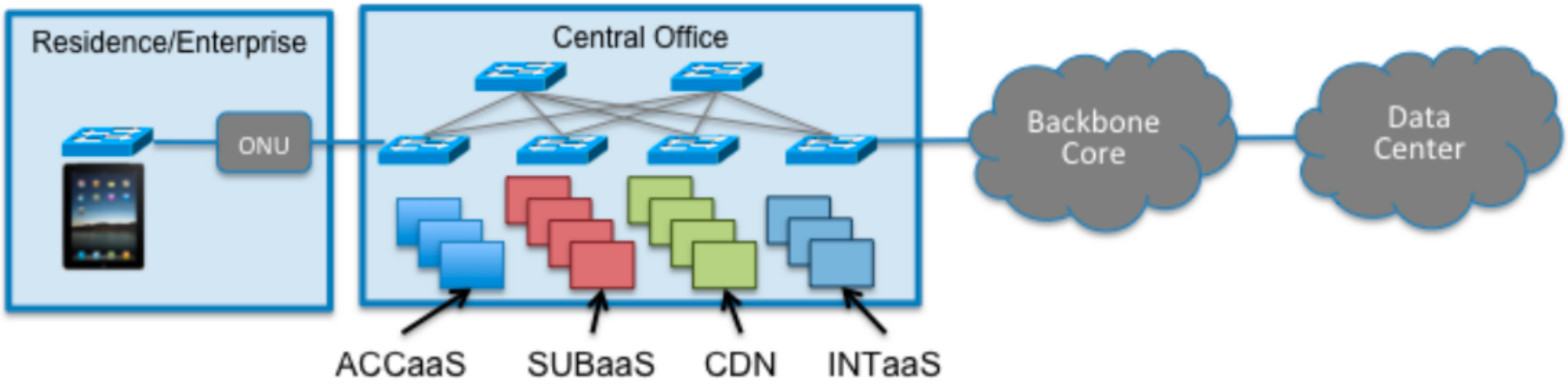
Is SDN **the glue** to enable true access/metro convergence?

Promises full programmability through open and standardized interfaces (e.g., web server APIs)

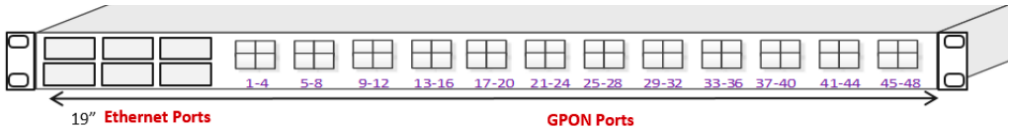
"Softwarization" is key to tackle the complexity and dynamic requirements of a converged access/metro infrastructure

AT&T DOMAIN 2.0 – SDN-based multi-service multi-tenant platform

AT&T CORD – Central Office Re-architected as Datacentre



OLT as white-box switch

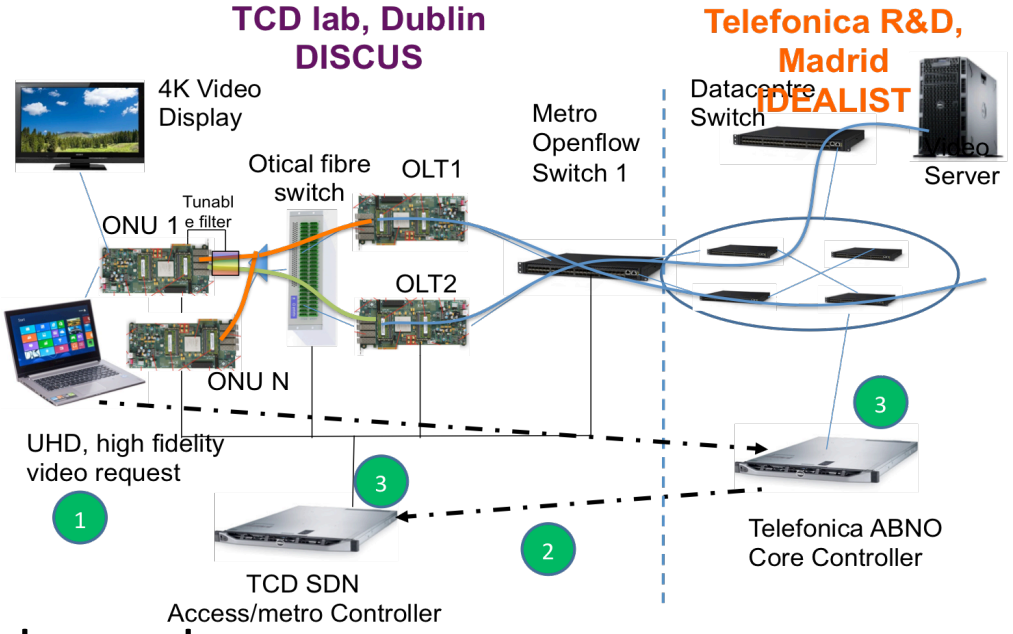


Source: white paper Central Office Re-architected as Datacentre (CORD), onosproject.org

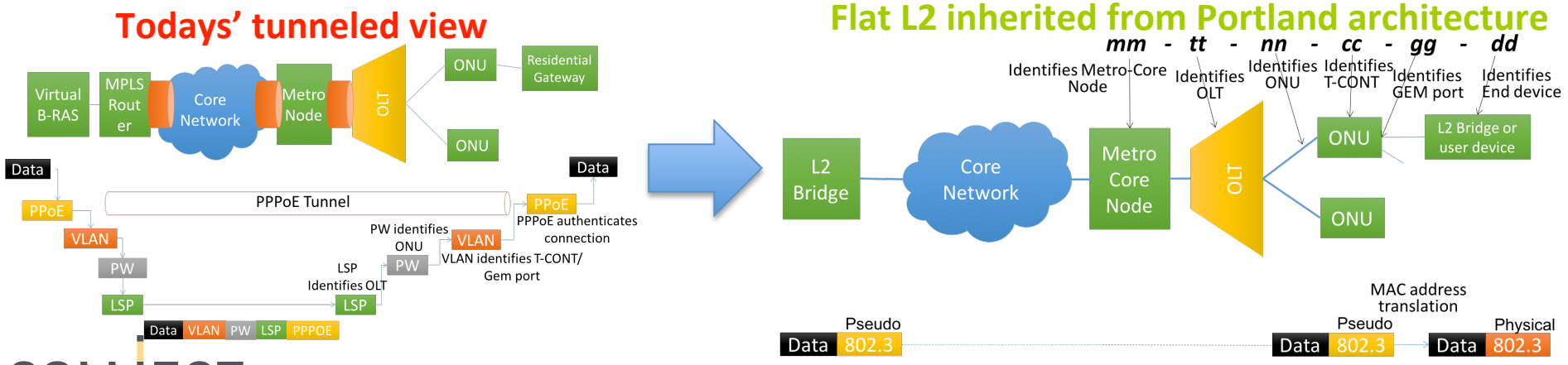
SDN enabling innovation and convergence

- SDN speeds up research on control plane integration…
  - DISCUS-IDEALIST-STRAUSS control plane integration

Source: J.M. Gran Hosa et al., End-to-end Service Orchestration From Access to Backbone, to appear in ONDM 2016



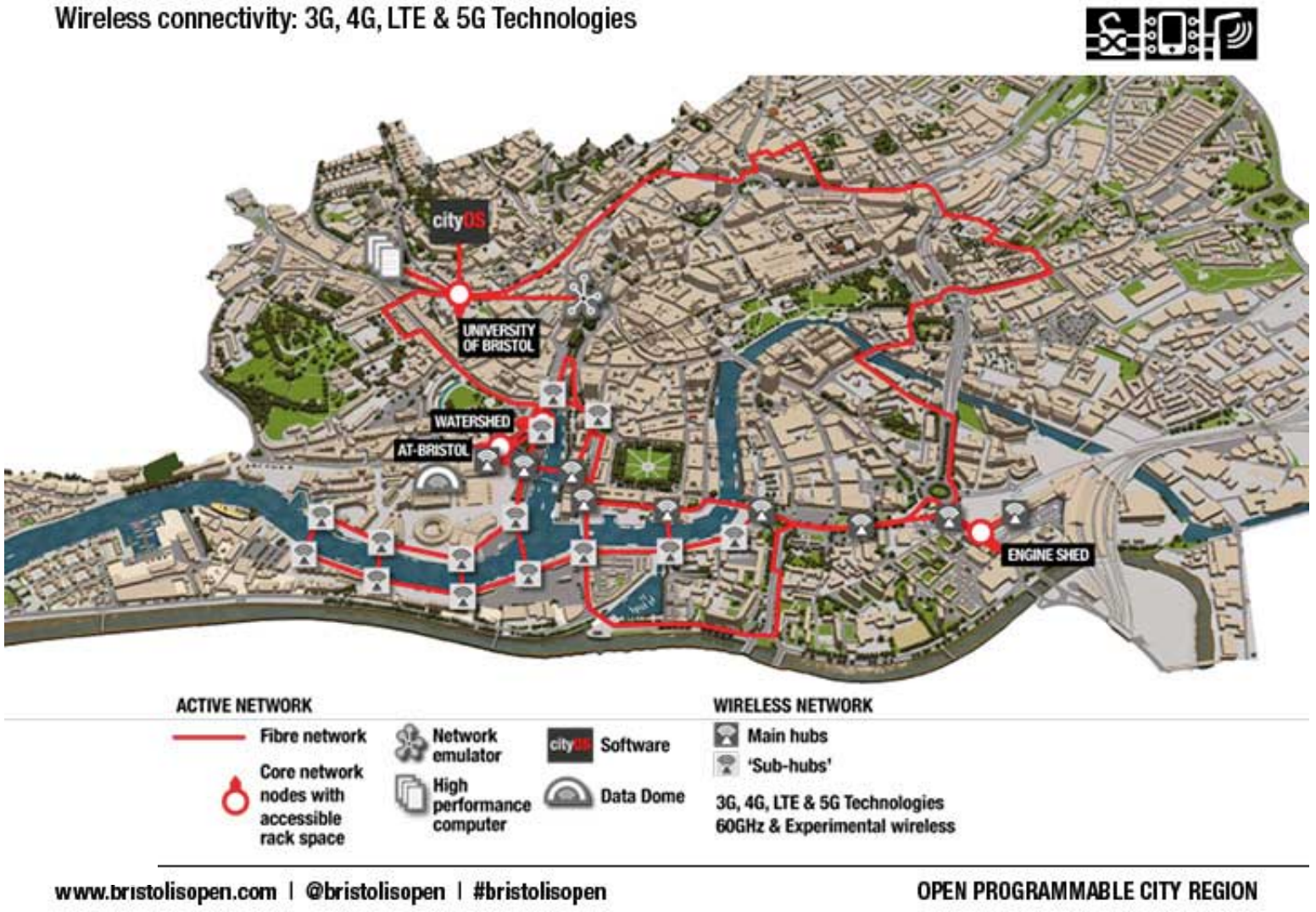
- Access/metro re-architected as a data centre
  - Flat LAyer Two Large-scale Network (FLATLANd)



Source: F. Slayne et al., FLATLANd: A Novel SDN-Based Telecoms Network Architecture Enabling NFV and Metro-Access Convergence, to appear in ONDM 2016

CONNECT Networks of the Future

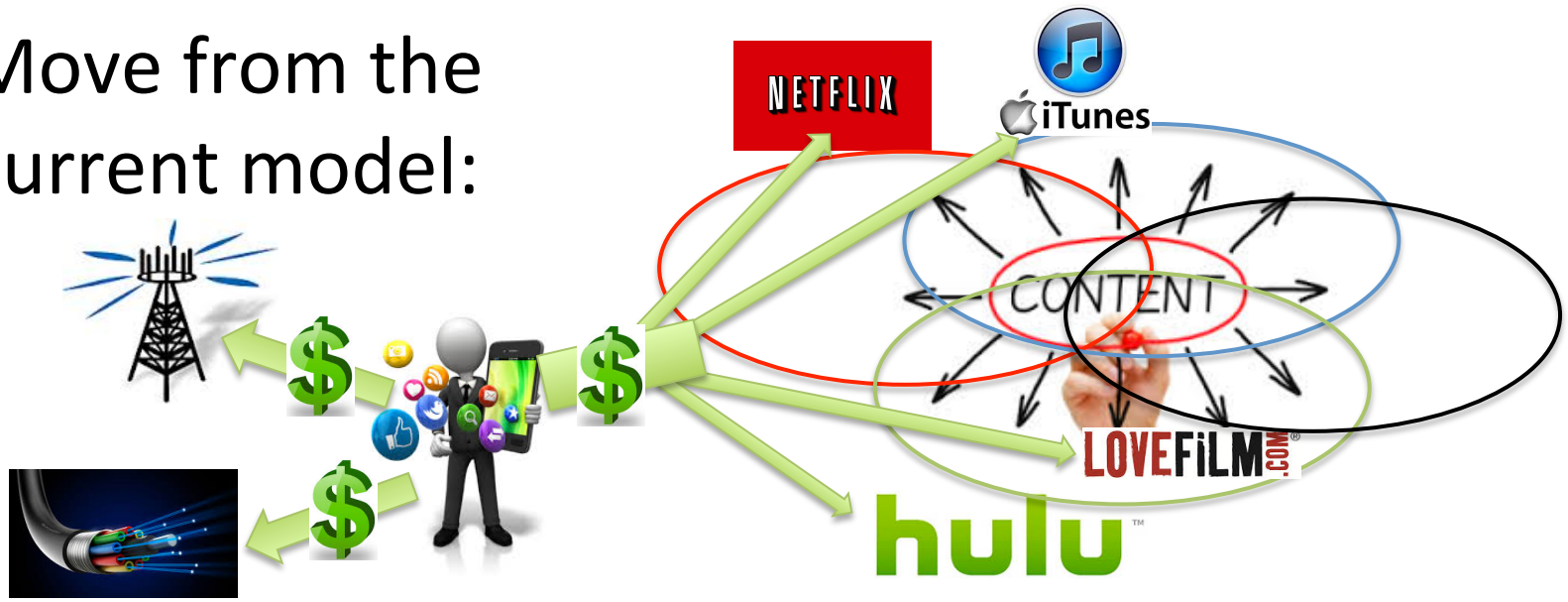
Bristol is open



~~Conclusions~~ Vision

Content-focused business models

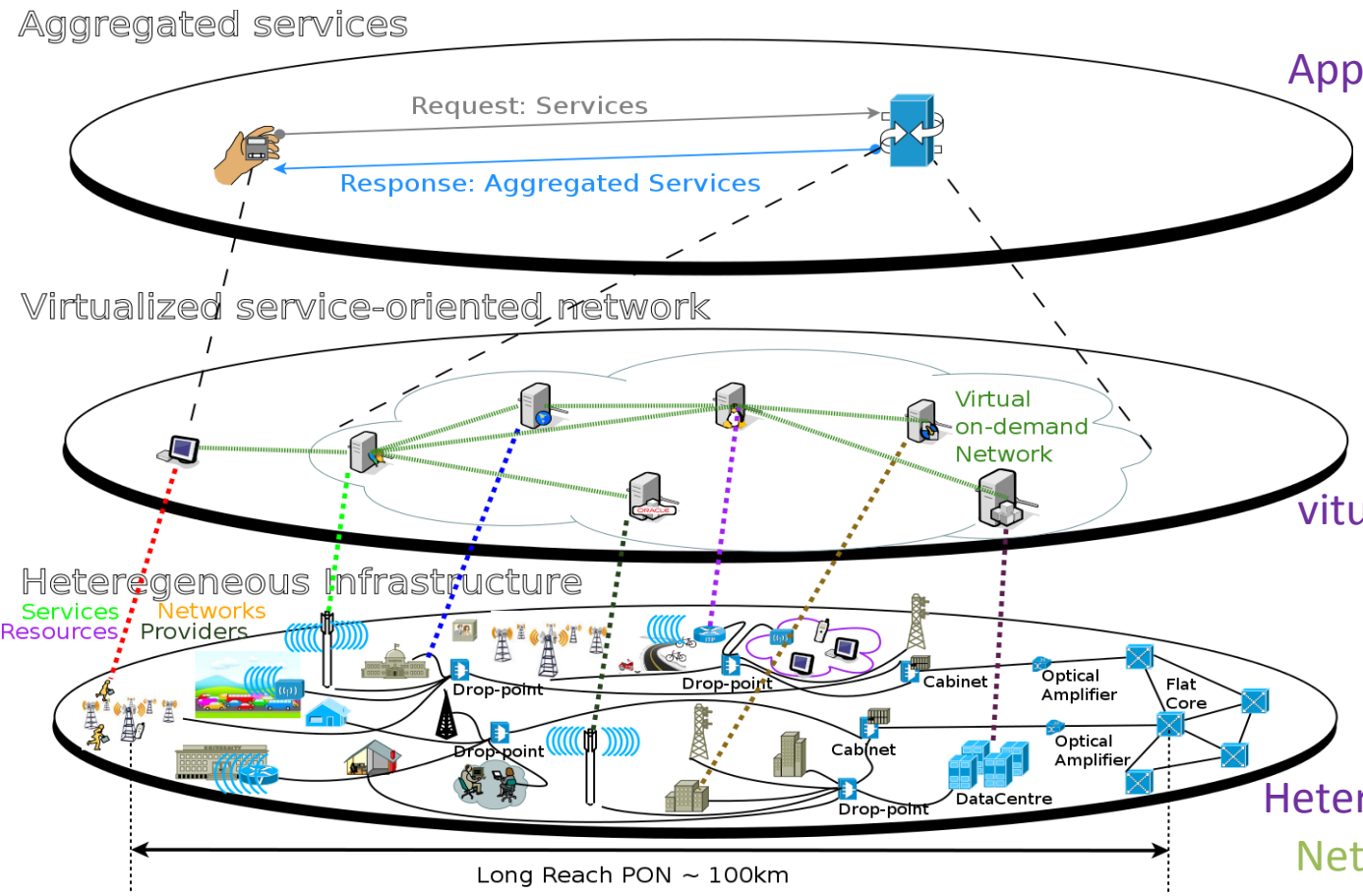
Move from the current model:



To a service-driven model:

Example: Amazon Kindle 3G

End-to-end ephemeral network



Application-oriented service provisioning

Ephemeral network connection

Brokerage of pool of vitualized network resources

SDN orchestration

Heterogeneous physical layer

Networks without borders

L. Doyle, et al., Spectrum Without Bounds, Networks Without Borders. Proceedings of the IEEE, Vol. 102, No. 3, March 2014

K. Katsalis, et al., Wireless Network Virtualization: The CONTENT Project Approach. IEEE CAMAD 2014.

J. M., Marquez-Baria, Ephemeral wireless networks. http://www.slideshare.net/JohannMMarquezBarja/ephemeral-wireless-networks

(Open) questions

- How much fonthaul will we need?
  - Will front-hauled small cells really displace simpler Wi-Fi or Li-Fi?
- Will access SDN stand the challenge of gluing together apps and networks to enable true access/metro convergence?
- If the appetite is all for being a virtual operator, who will maintain the physical infrastructure?
  - Back to state-owned infrastructure?
  - Or can a content-focused model pour enough revenue into the physical infrastructure?
- Full open access vs. vertical integration?!?

Thank you for your attention!

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skype: ruffinim

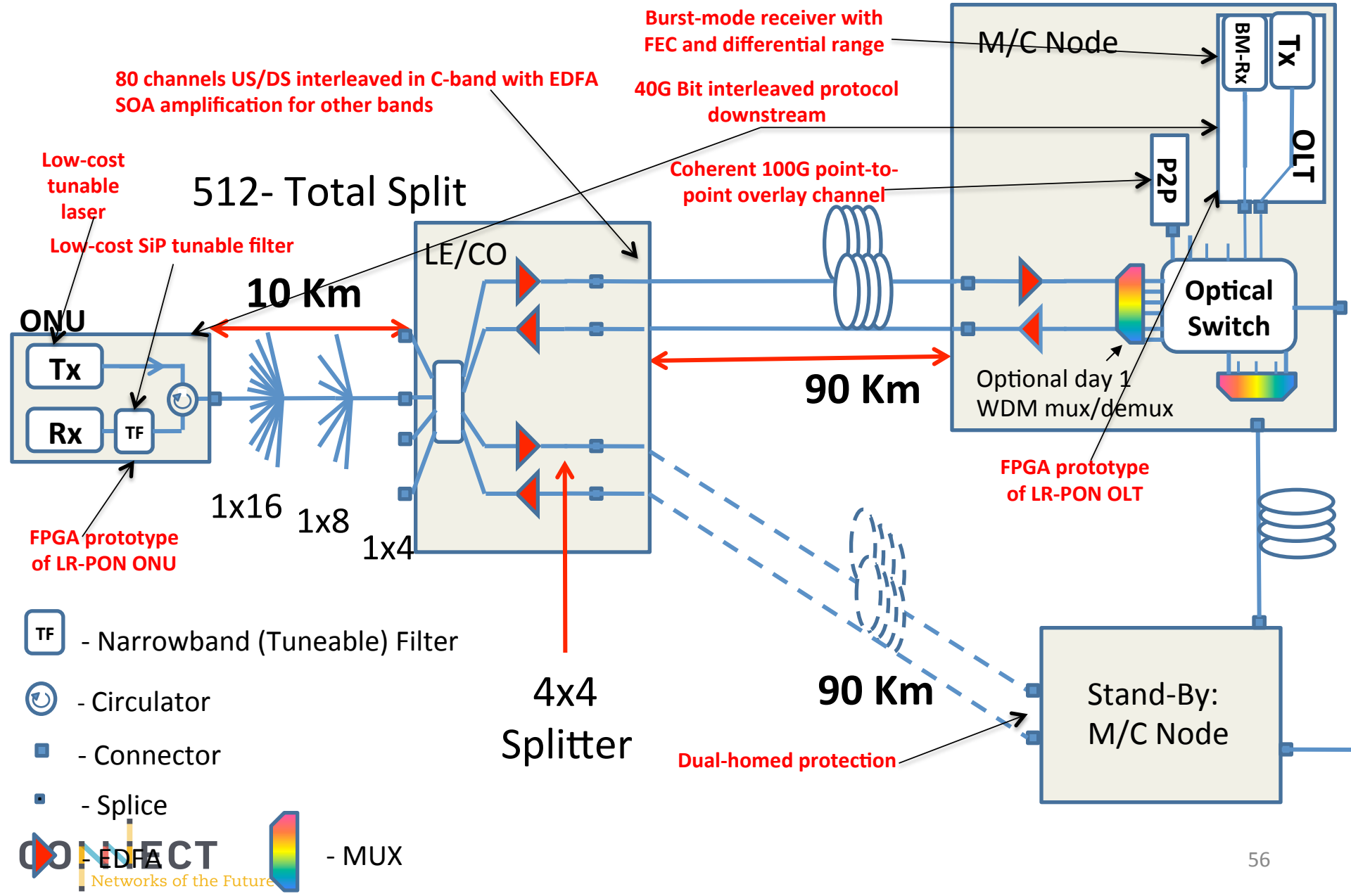
Architectural changes

Access/Metro centric architectures: keep the traffic in the metro and avoid the core as much as possible.

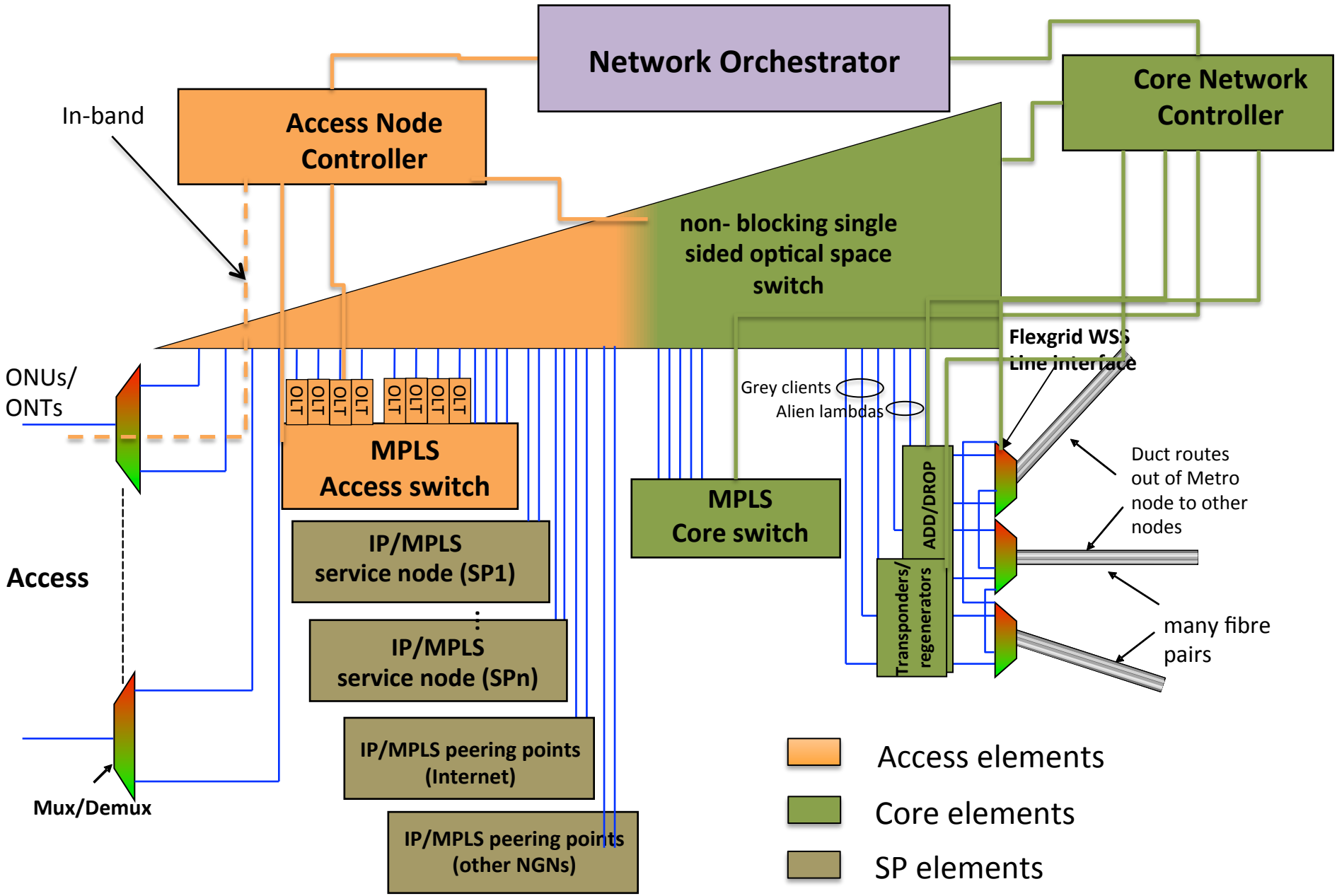
Indeed already a well **consolidated trend**..

Cisco VNI 2014-2019	North America			Middle East and Africa			Western Europe		
	Traffic PB-2015	Traffic PB-2019	CAGR 2014-2019	Traffic PB-2015	Traffic PB-2019	CAGR 2014-2019	Traffic PB-2015	Traffic PB-2019	CAGR 2014-2019
Metro	18,402	45,012	25%	384	2,838	67%	6,920	19,700	29%
Long-haul	5,150	4,708	0%	1,796	6,573	38%	4,311	4,980	4%

Some of the issues addressed



DISCUS Multi-service Metro-Core Node



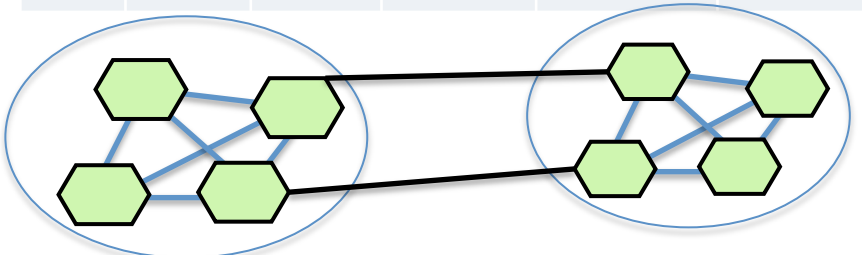
Flat optical core

For further decreasing electronic packet processing

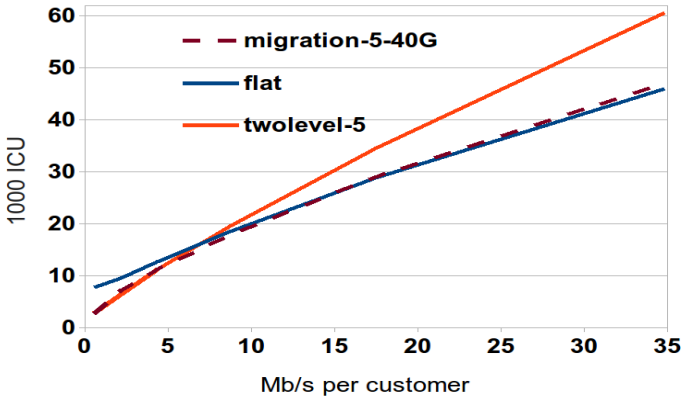
- Optical reach feasible

Signal	Data rate	No of 37.5 GHz Slots	G.652 reach (Km)	Modulation format	Spectral eff. Bit/s/ Hz
1	40	1	2430	DP-BPSK	2
2	100	2	2430	DP-BPSK	2
3	100	1	1170	DP-QPSK	4
4	100	1	500	DP-16QAM	8
5	400	4	1170	DP-QPSK	4
6	400	2	500	DP-16QAM	8

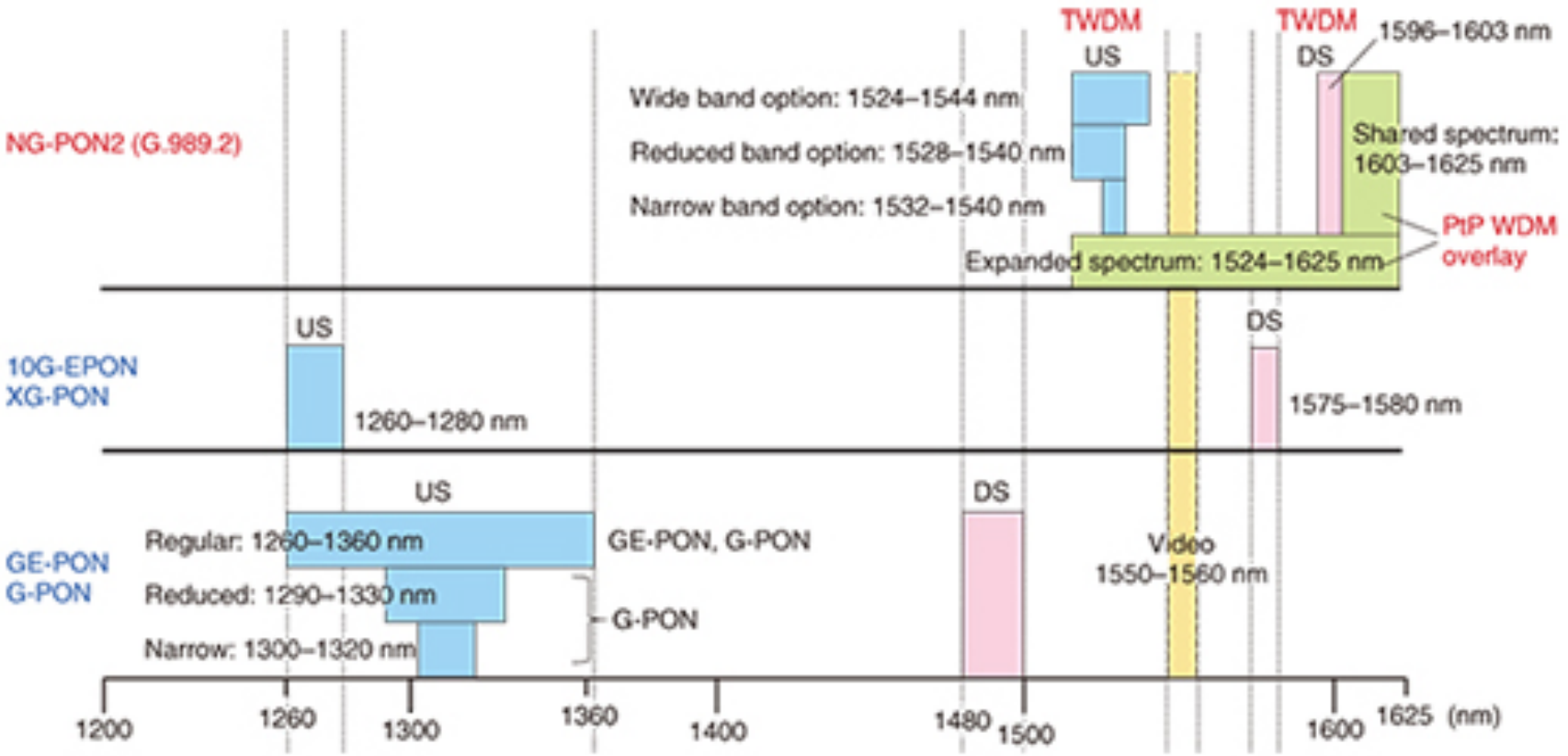
- Limitation in number of nodes in flat core due to mesh explosion
  ➔ concept of optical island



- Economical viability requires traffic between nodes to be above a given threshold



PON wavelength plan



Source: https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr201503gls.html