TRINITY COLLEGE DUBLIN

Access-metro convergence in next generation broadband networks

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

CONNECT Networks of the Future

Background

- Assistant Professor in Optical Network architecture at Trinity College Dublin (TCD), Ireland
  - Carrying out my research at the CONNECT Telecommunications Research Centre (in TCD) www.connectcentre.ie

- Technical coordinator of European project DISCUS (End-to-end architecture and technology for next generation optical broadband networks) - 2012-2015

www.discus-fp7.eu

- Principal Investigator of national project O'SHARE (Open-access SDN architecture enabling multi-operator and multi-service convergence in shared optical access networks) 2015 – 2019

www.oshare.ie

- Partner in other projects on fixed/mobile convergence and next generation optical datacentre

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

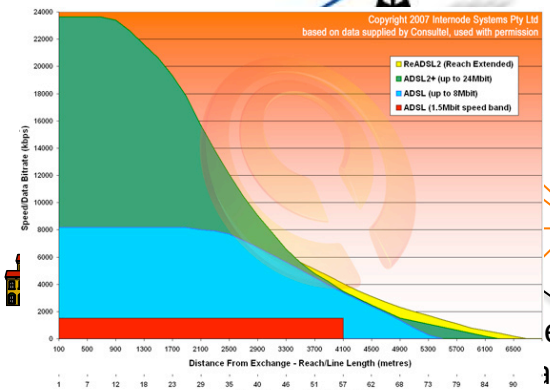
Much of the material is from the DISCUS project (www.discus-fp7.eu to see the full list of partners and deliverables), but results and ideas from other sources are also included.

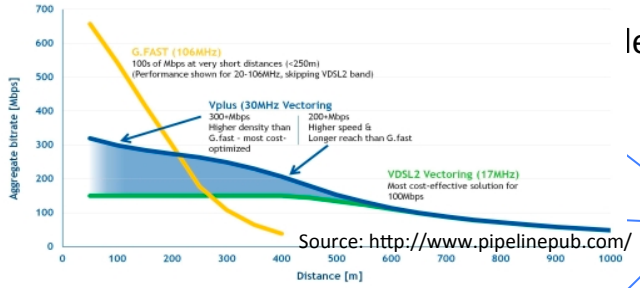
Content

- 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?

Access and metro network view





Source: http://www.pipelinepub.com/

Local Exchange with DSL customers

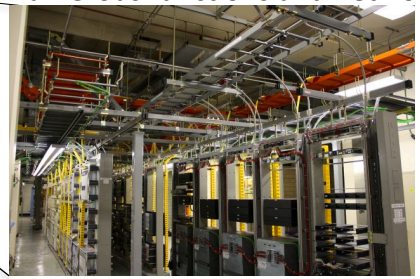
eet cabinets, copper cable
anching

le

Local Exchange with Fibre-to-the-cab customers

Core or Backbone network

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



FTTH

Ptp Ethernet

4G

DC

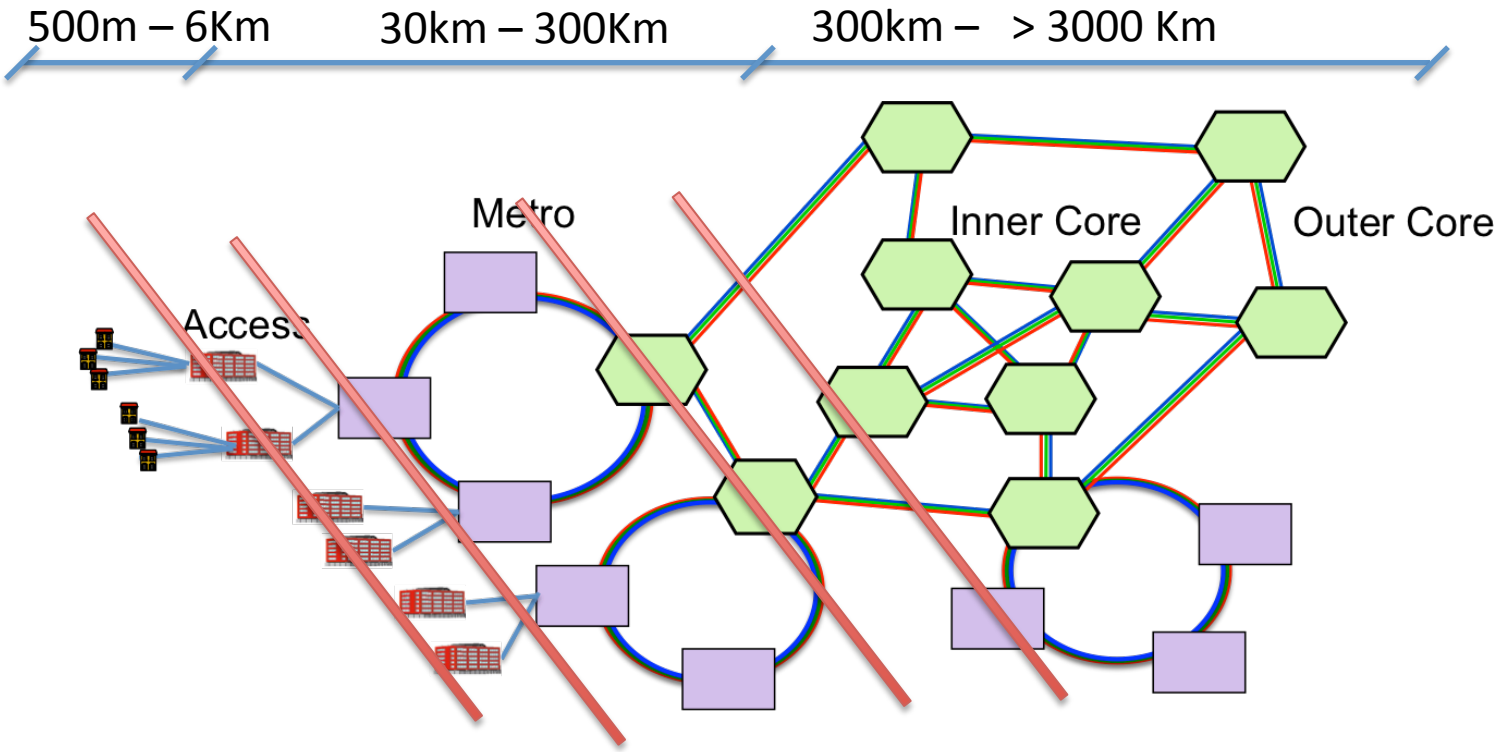
Large business

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

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

CONNECT Networks of the Future

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?

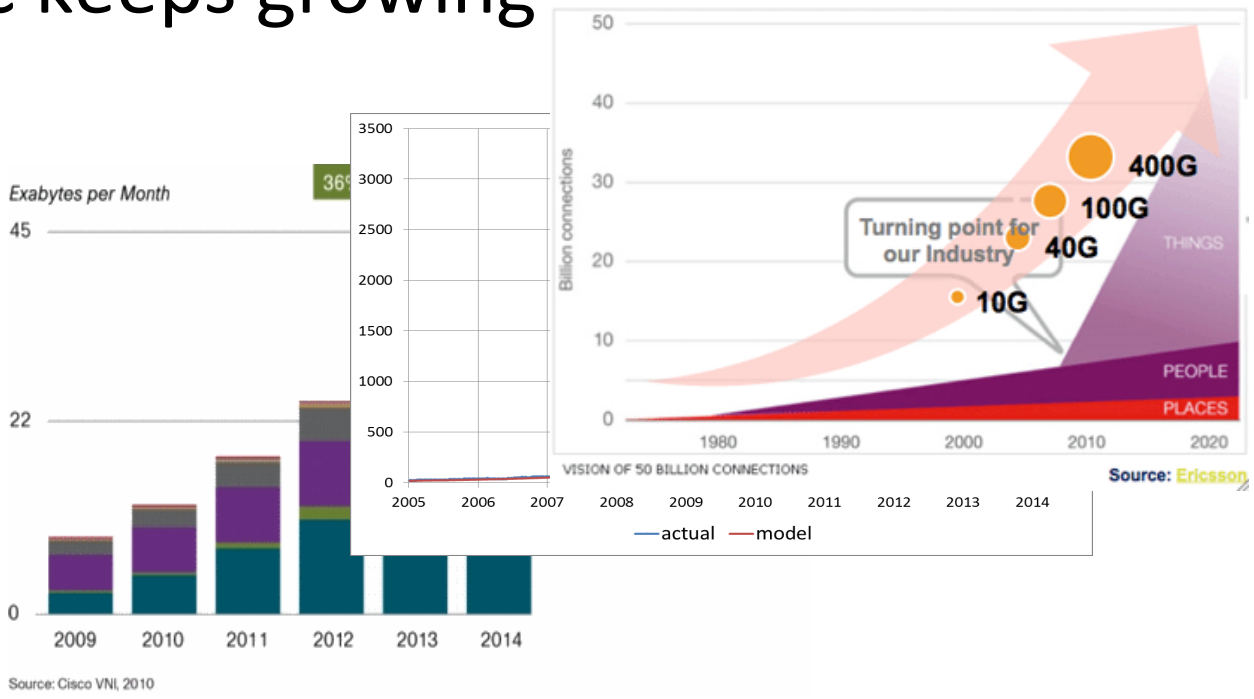
Content

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

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

Change in traffic requirements

Internet traffic keeps growing



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 just bits

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

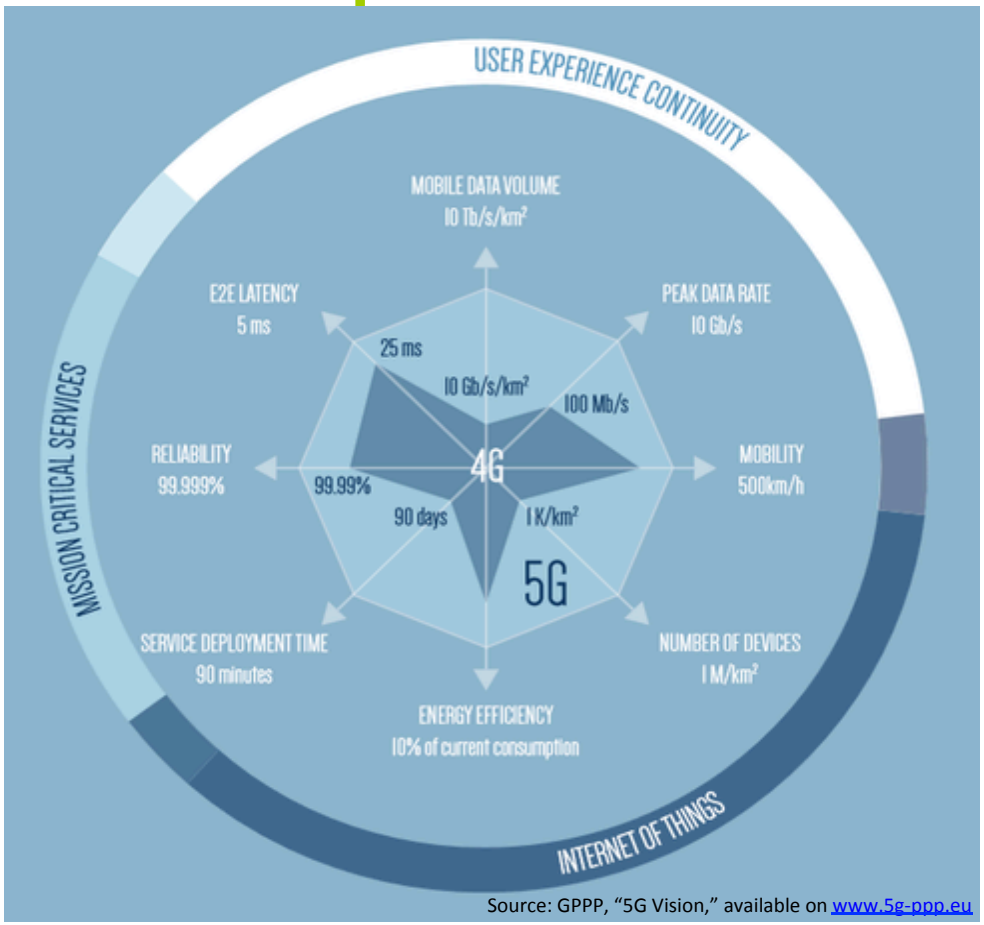
Different rate requirements, same value, same expectations

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

Augmented Reality

Virtual Reality

5G requirements



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

5G is not the evolution of 4G

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!

Content

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

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

Operators/Providers Requirements I

- 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

- Charge for services, not bit pipes:
  - The value is in the service (type of application delivered, where and when) not in the bits transported

    ➔Bridge gap between user and network: take high-level request and figure out the details, hiding complexity to the user

  - Flexibility: from 10Tb/s during an event to 0 a few hours later

Operators/Providers Requirements II

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

- 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"

Summary of requirements

Application-oriented approach to deliver better 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 need to work 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 by providing more and faster services
- Reduce energy consumption

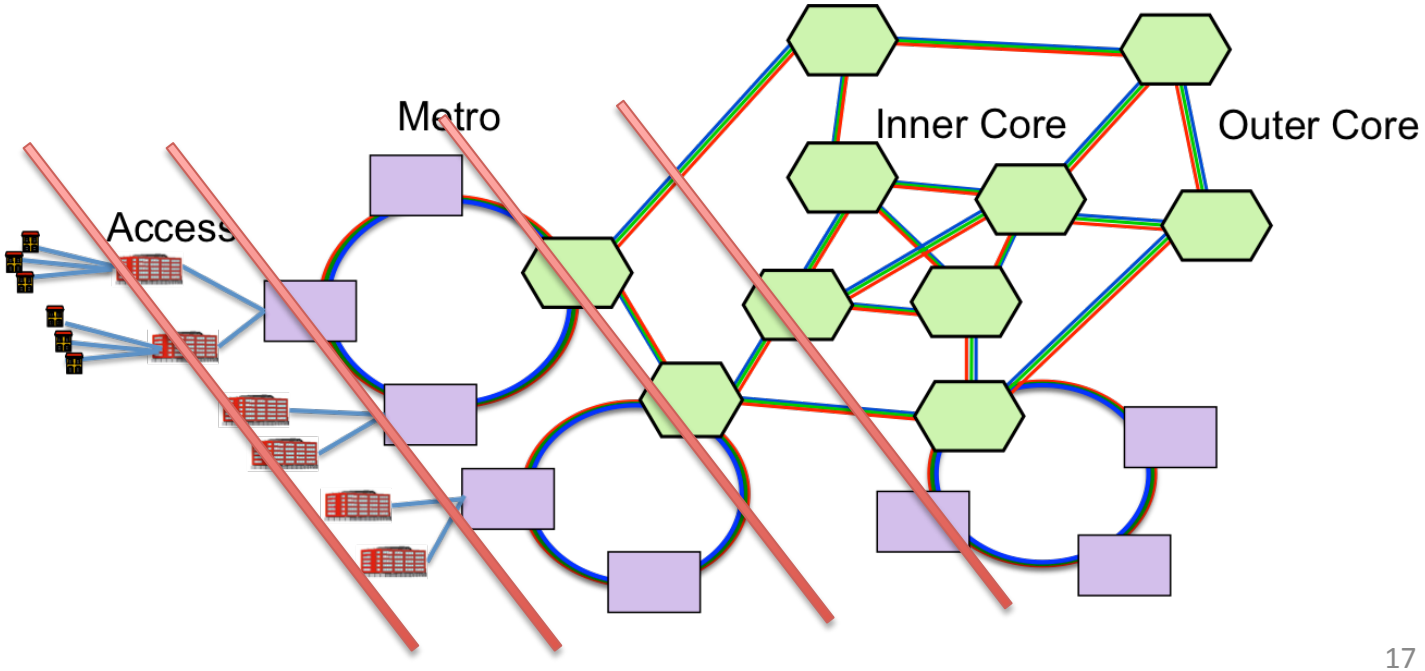
Content

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

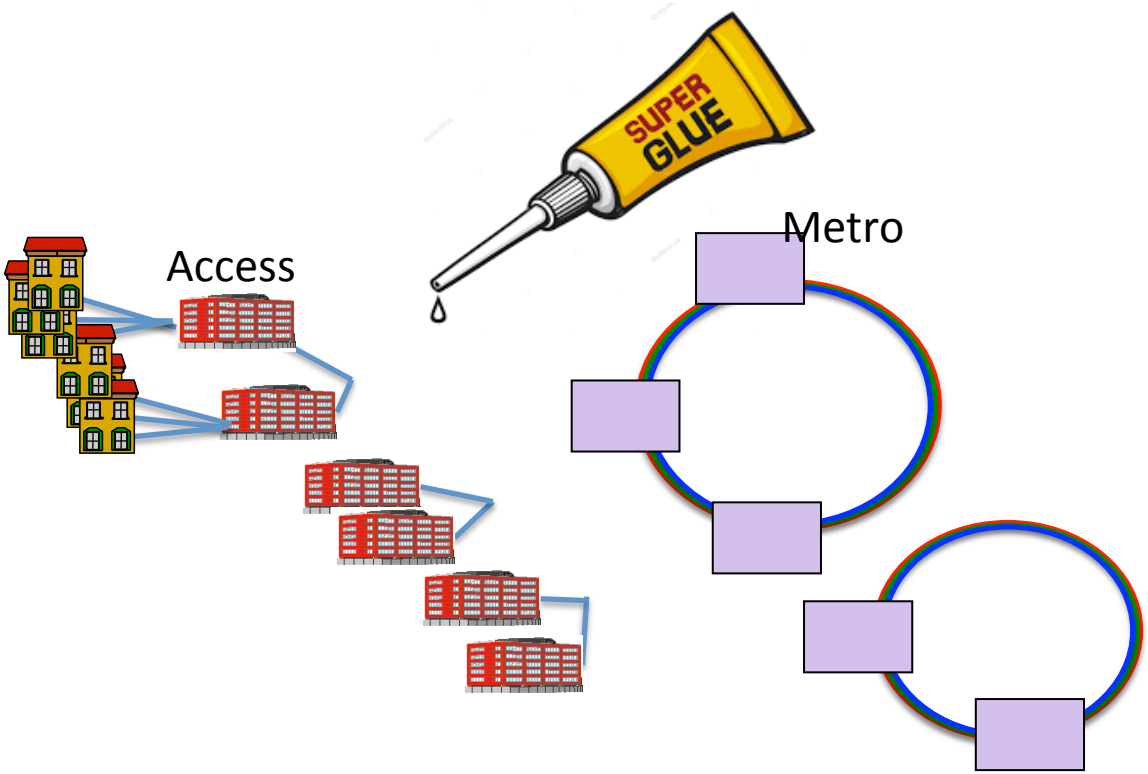
- Access/Metro convergence
  - Network consolidation
  - Service multiplexing
  - Multi-tenancy
  - Is SDN the glue element for true access/metro convergence?

Need for change?

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

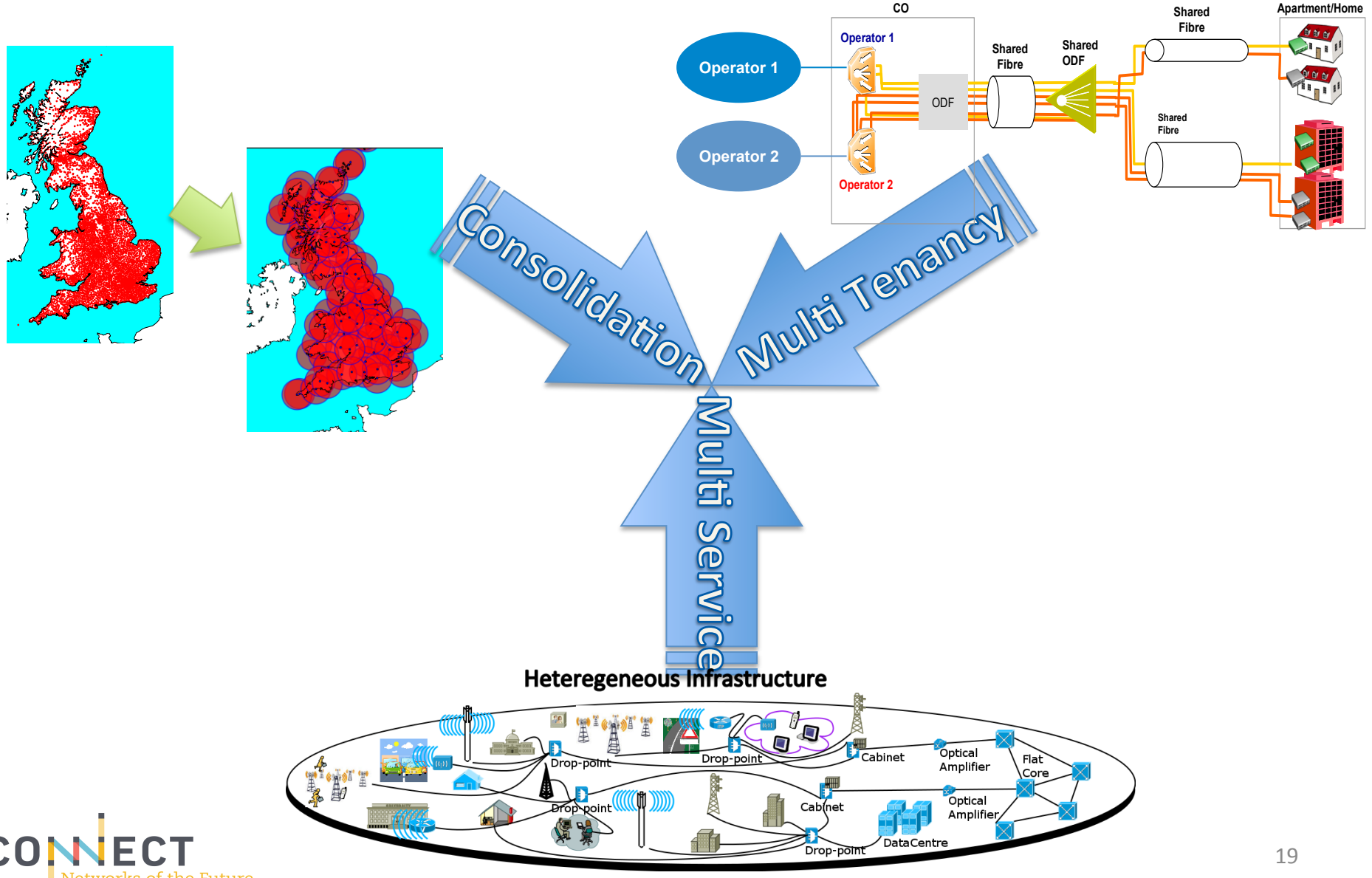


What is access-metro convergence?

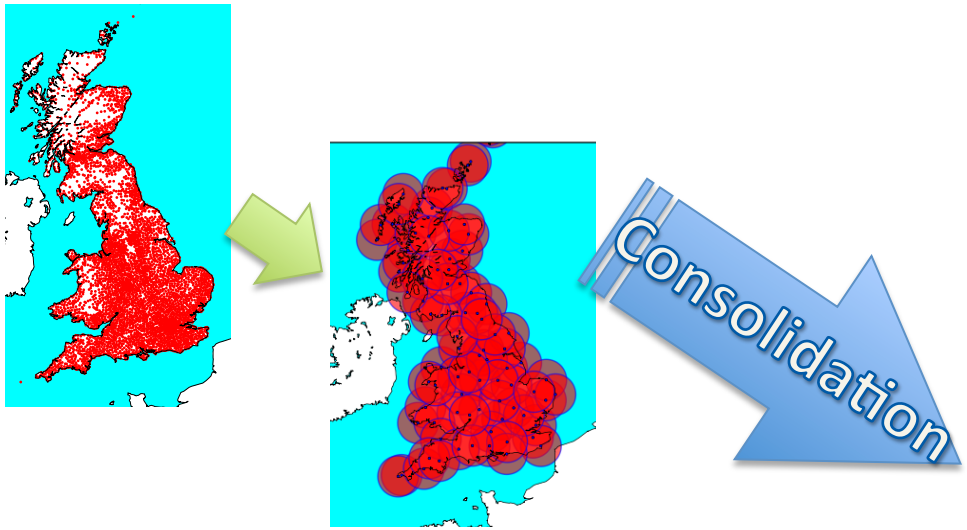


Much more than the integration of access and metro transmission technologies

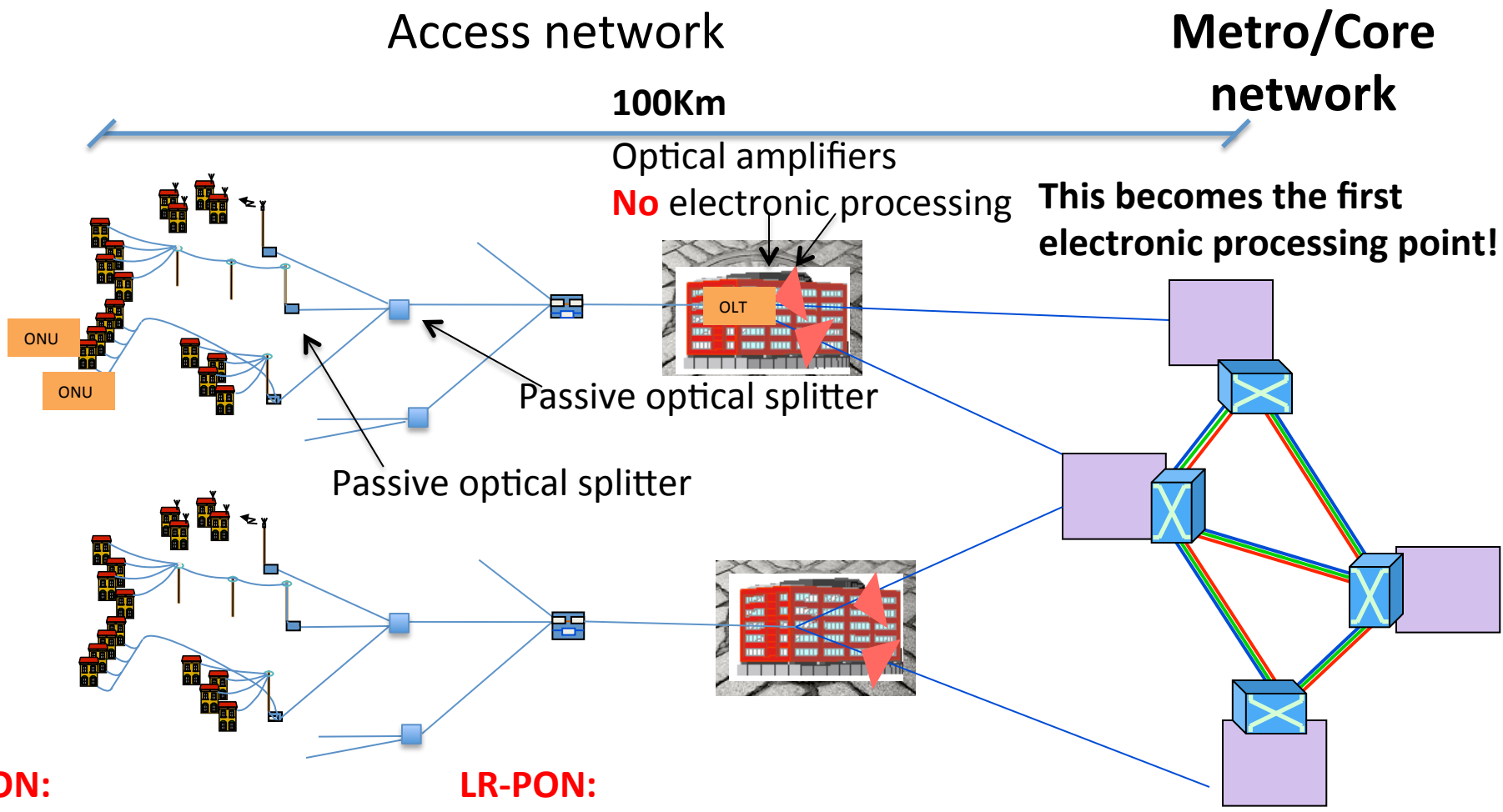
Access/Metro Convergence



Access/Metro Convergence



GPON and LR-PON



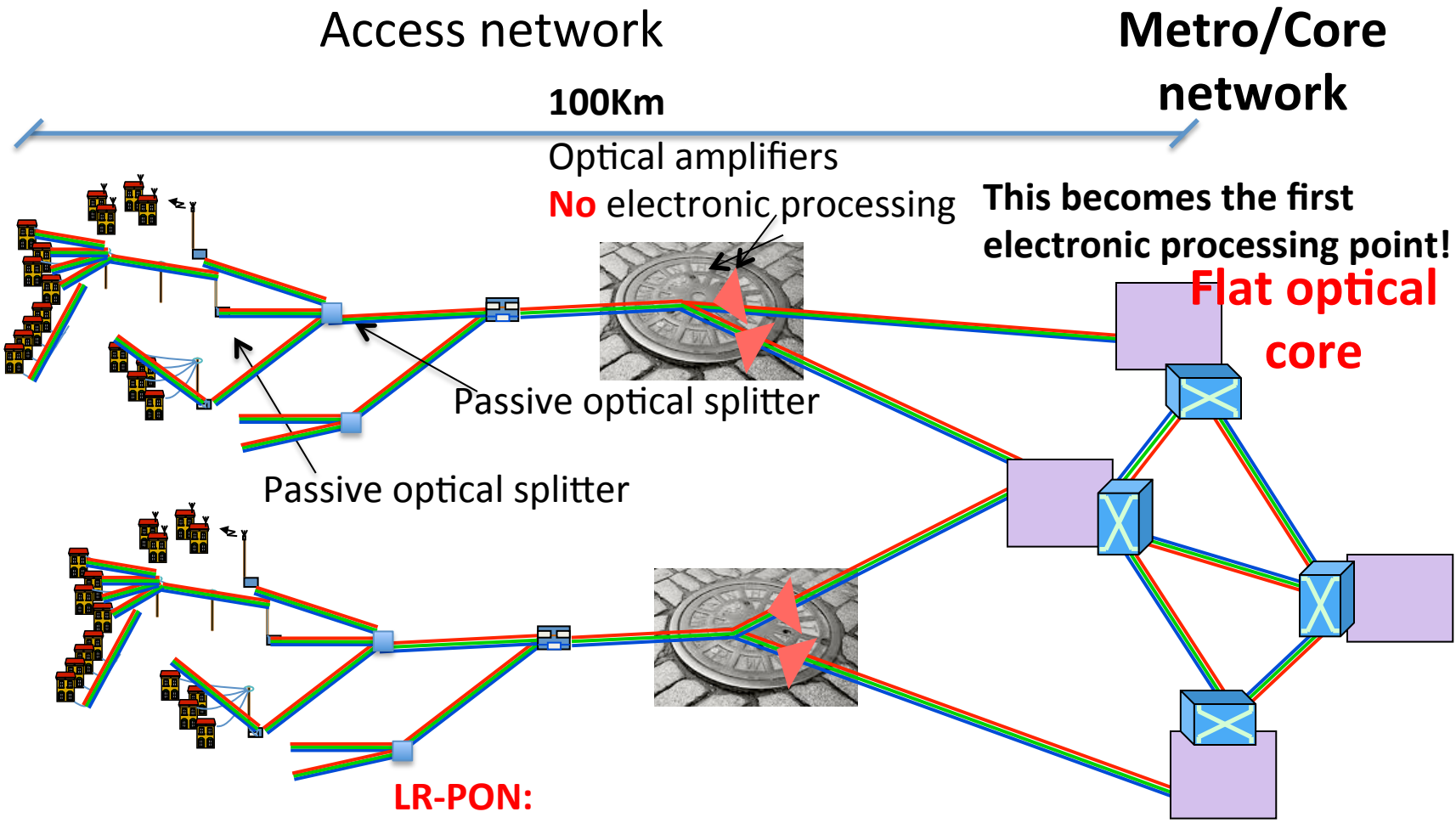
GPON:

- **32 users per OLT**
- **distance up to 20Km**

LR-PON:

- **512 users per OLT**
- **distance above 100 km**
- **10Gb/s peak per user**
- **Possibility of 100s Gb/s per user**

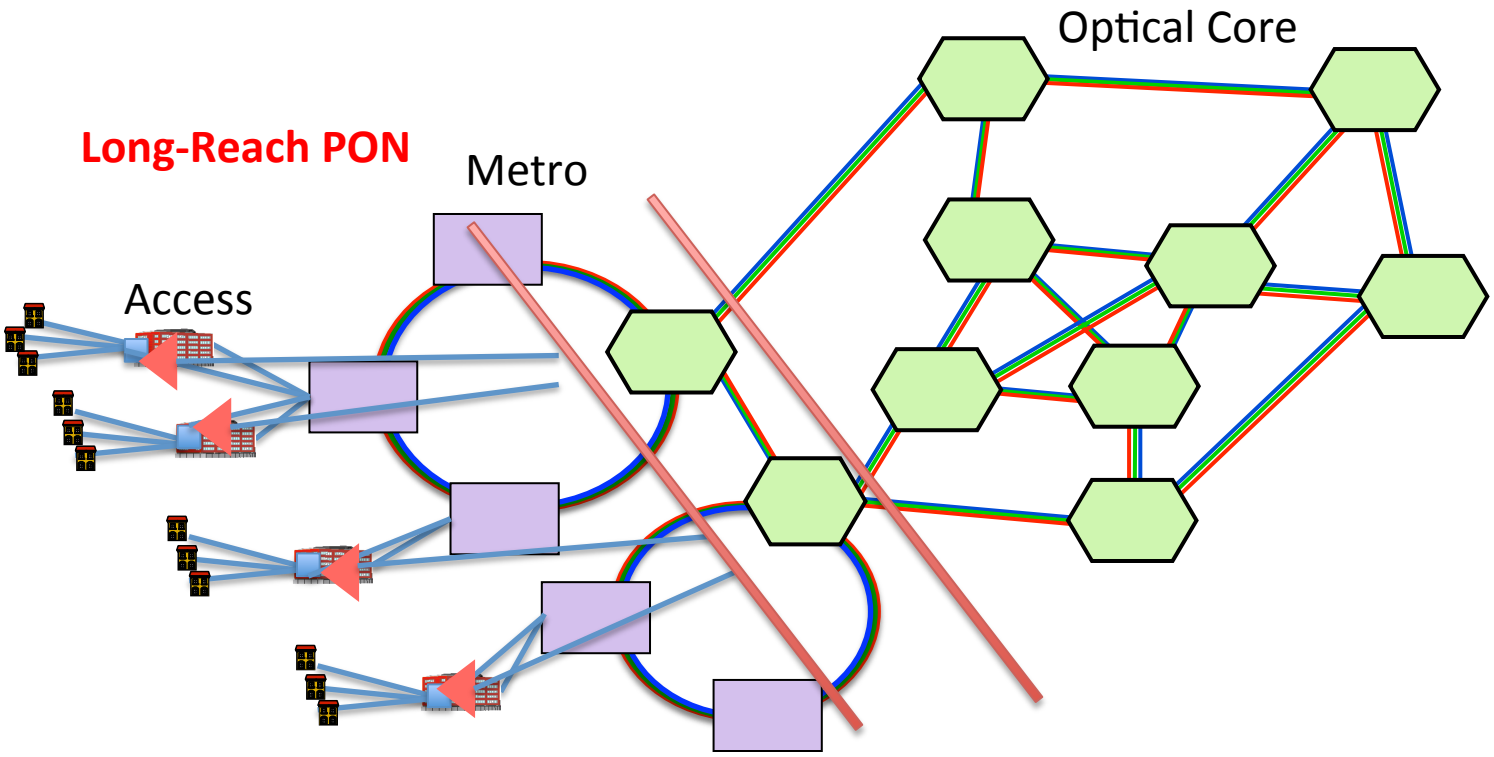
Multi-λ LR-PON



LR-PON:

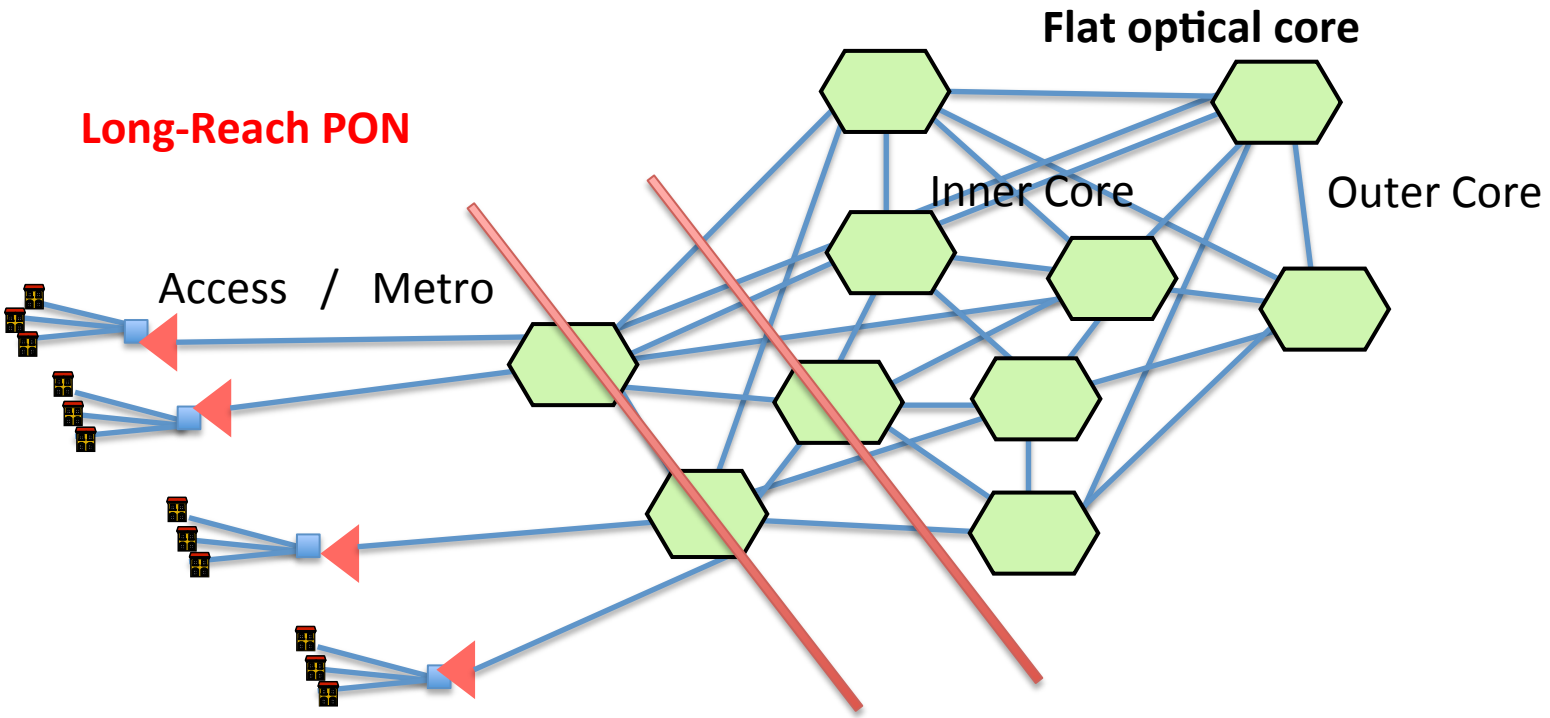
- **512 users per OLT**
- **distance above 100 km**
- **10Gb/s peak per user**
- **Possibility of 100s Gb/s per user**

LR-PON enabling node consolidation



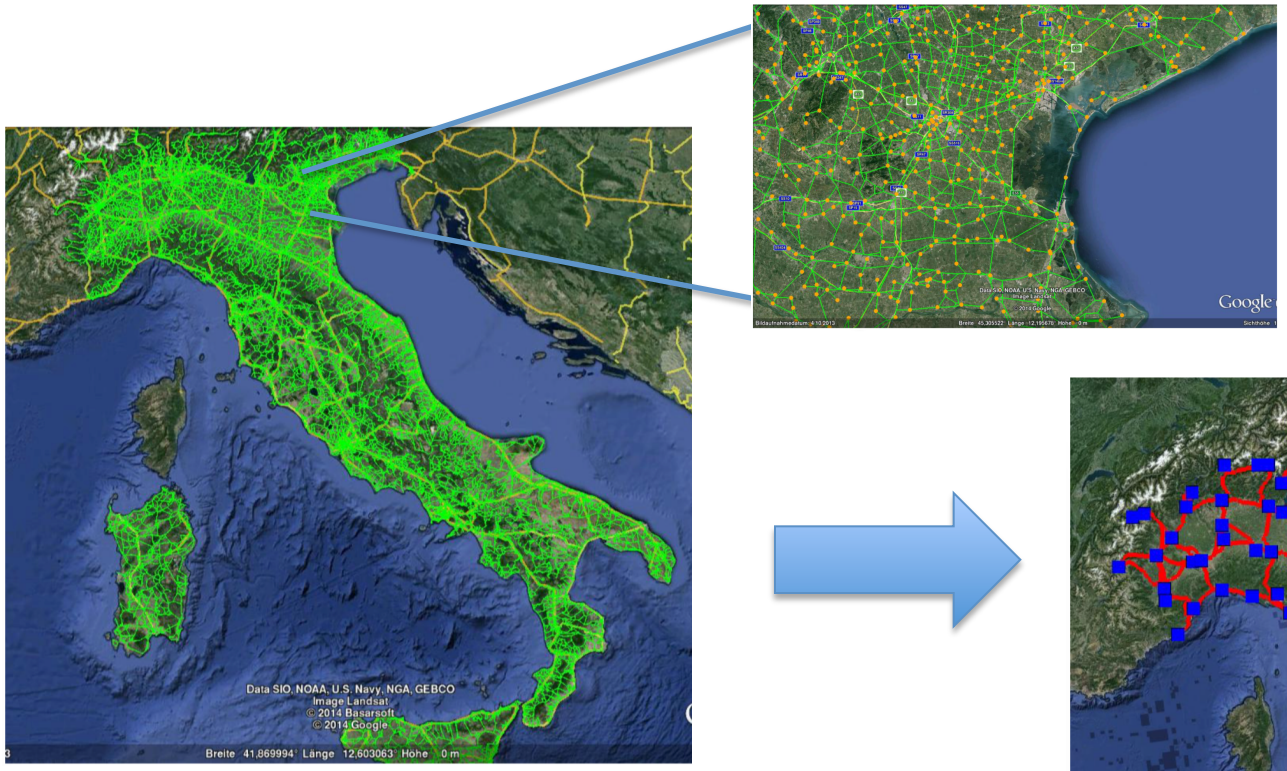
Once you start the convergence process you need to rethink of all network boundaries: What defines access-metro, metro-core, inner core?

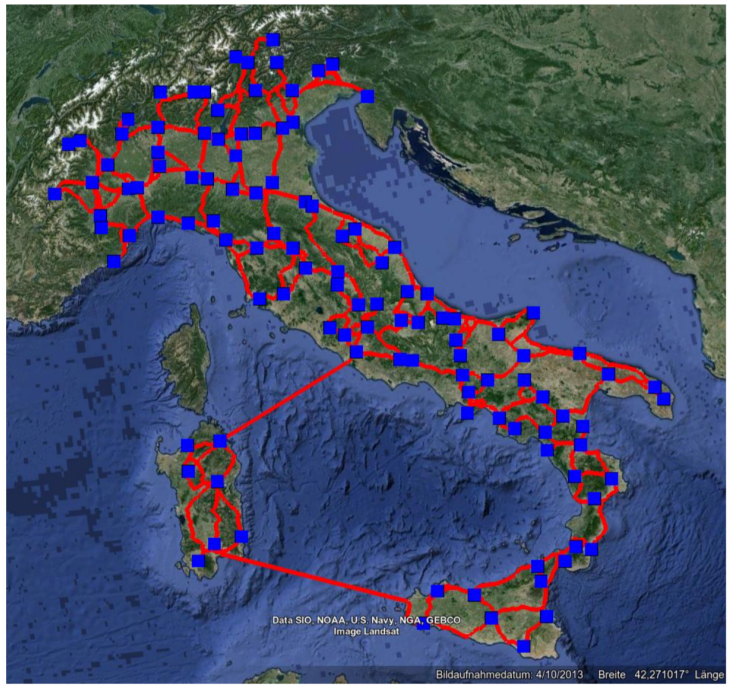
Flat core



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

Node consolidation studies

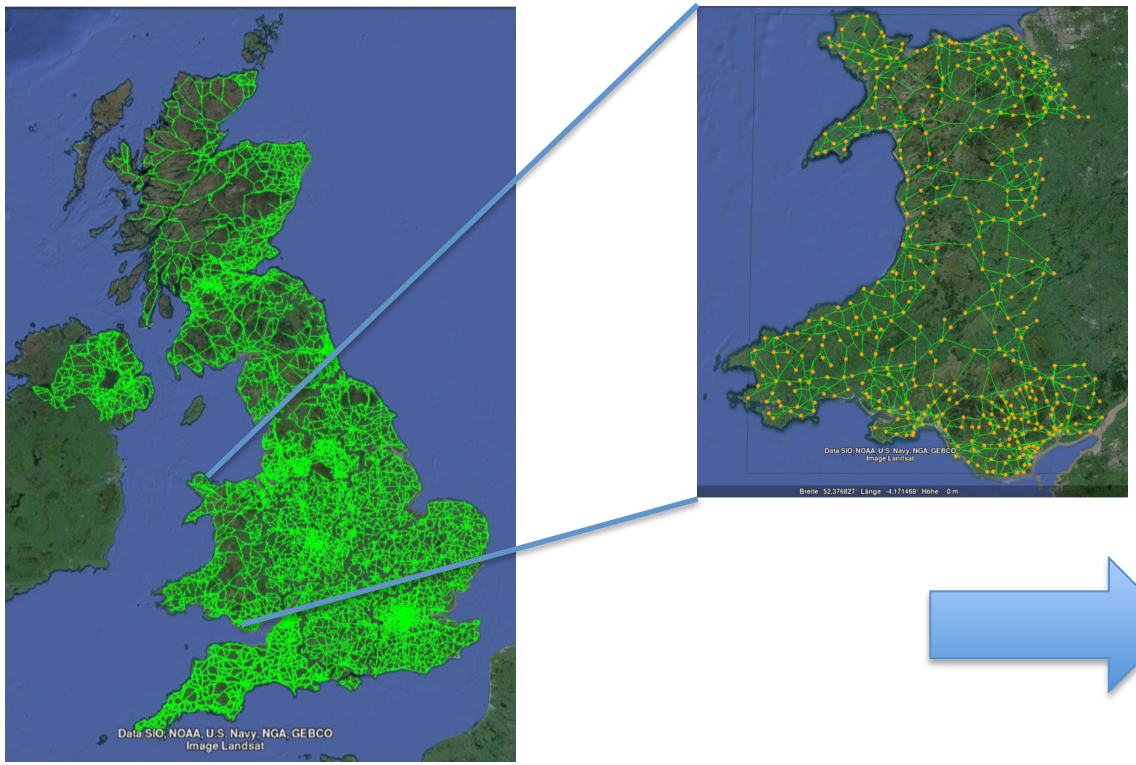


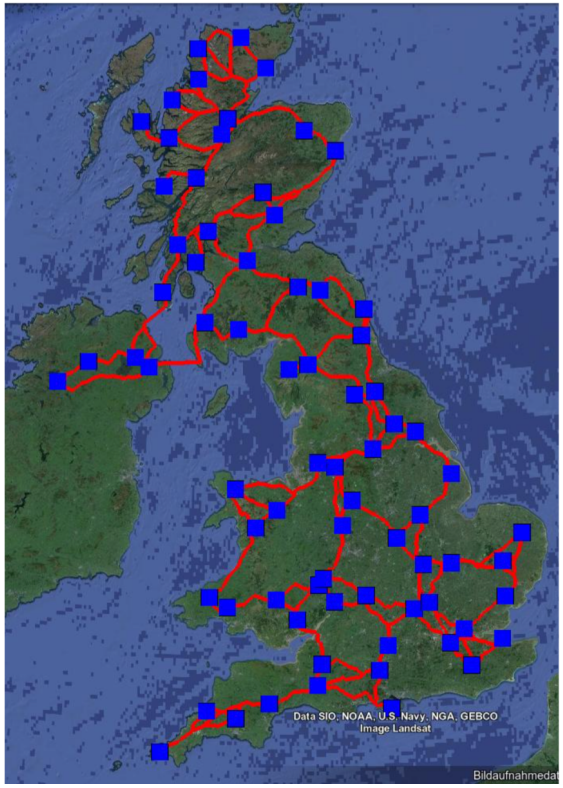


Country	Instance $\max_{Km}$	# MC nodes	# Fiber links
UK	110 km	75	137
Italy	115 km	116	219
Spain	115 km	179	321

Dual-homed PON protection with maximally disjoint fibre routes

Node consolidation studies

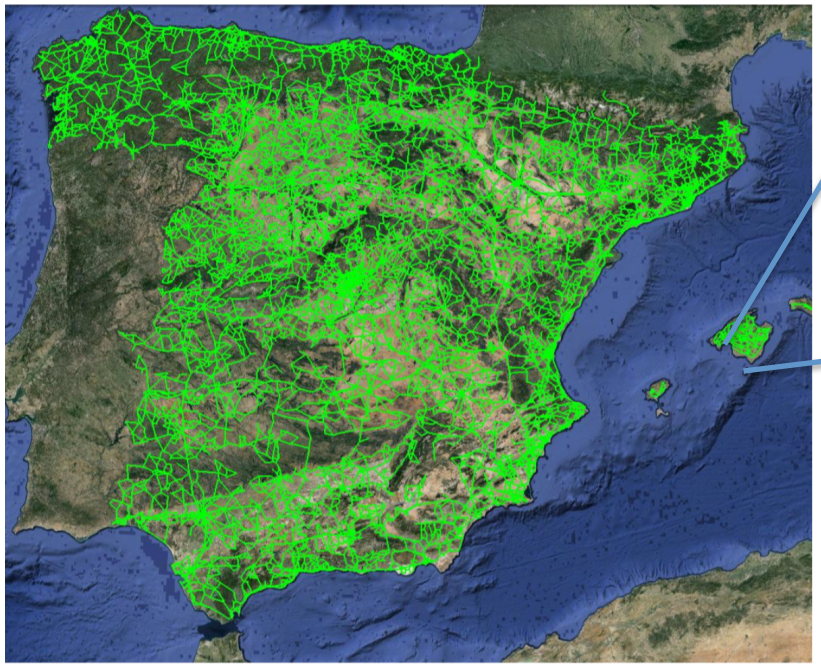


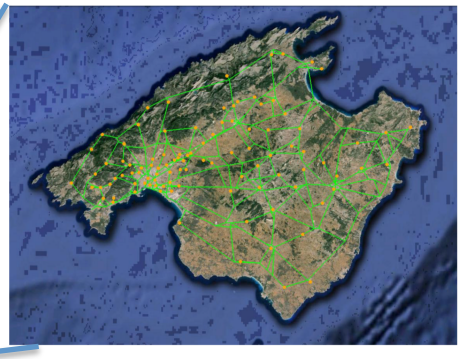


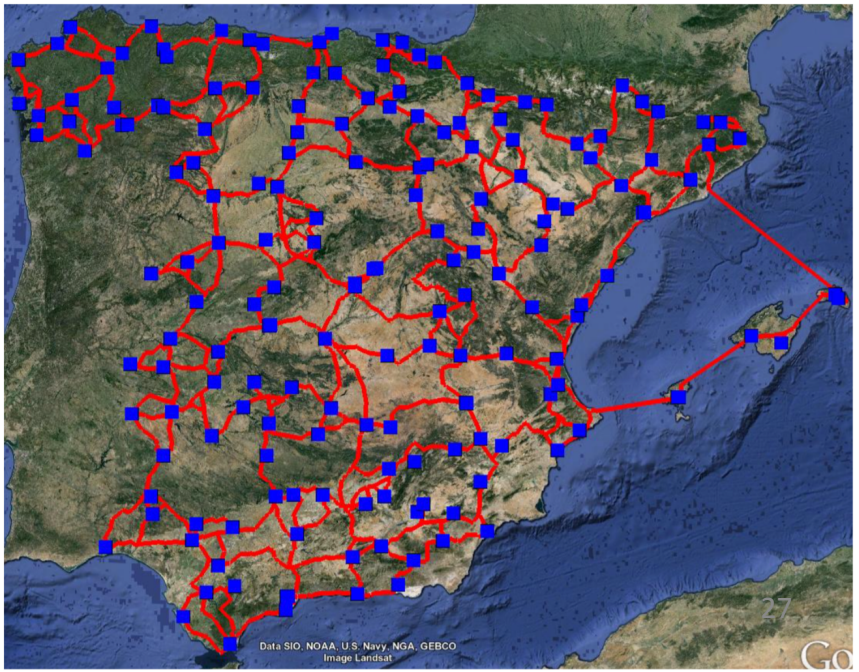
Country	Instance $\max_{Km}$	# MC nodes	# Fiber links
UK	110 km	75	137
Italy	115 km	116	219
Spain	115 km	179	321

TRINITY COLLEGE DUBLIN

Node consolidation studies



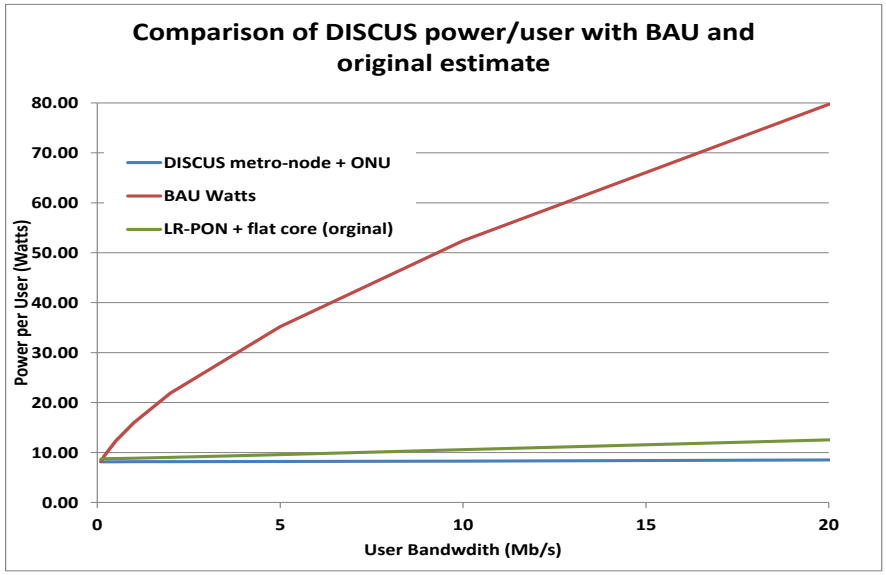


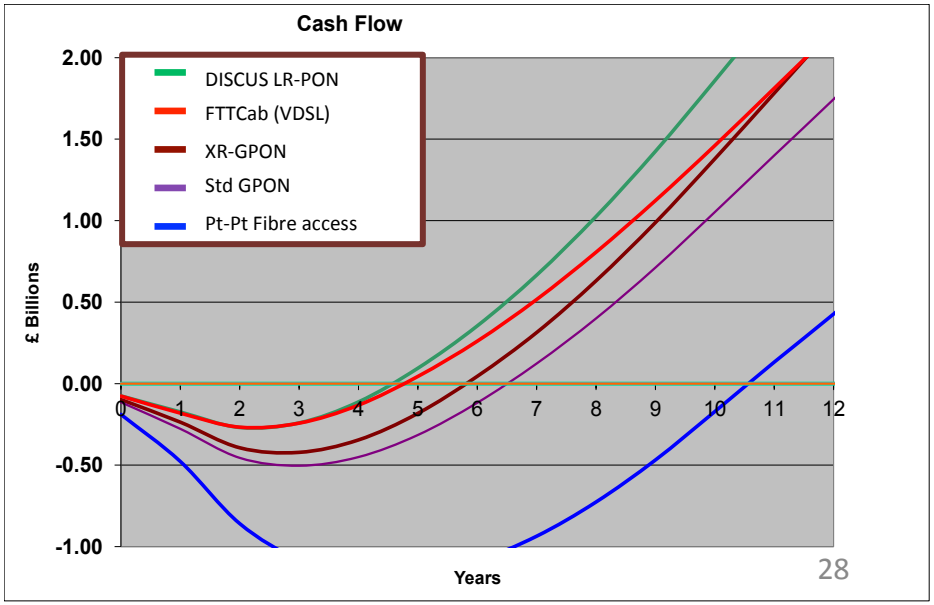


Country	Instance $\max_{Km}$	# MC nodes	# Fiber links
UK	110 km	75	137
Italy	115 km	116	219
Spain	115 km	179	321

Architectural results

- 10x decrease in power consumption compared to Business as Usual (BAU)
- Lower cost compared to other optical access technologies





Access/Metro centric architectures

Keeping traffic within the metro is 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%

Summary of requirements

Application-oriented approach to deliver better 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 need to work 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 by providing more and faster services
- Reduce energy consumption

Requirements enabled by consolidation

Application-oriented approach
to deliver better value

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

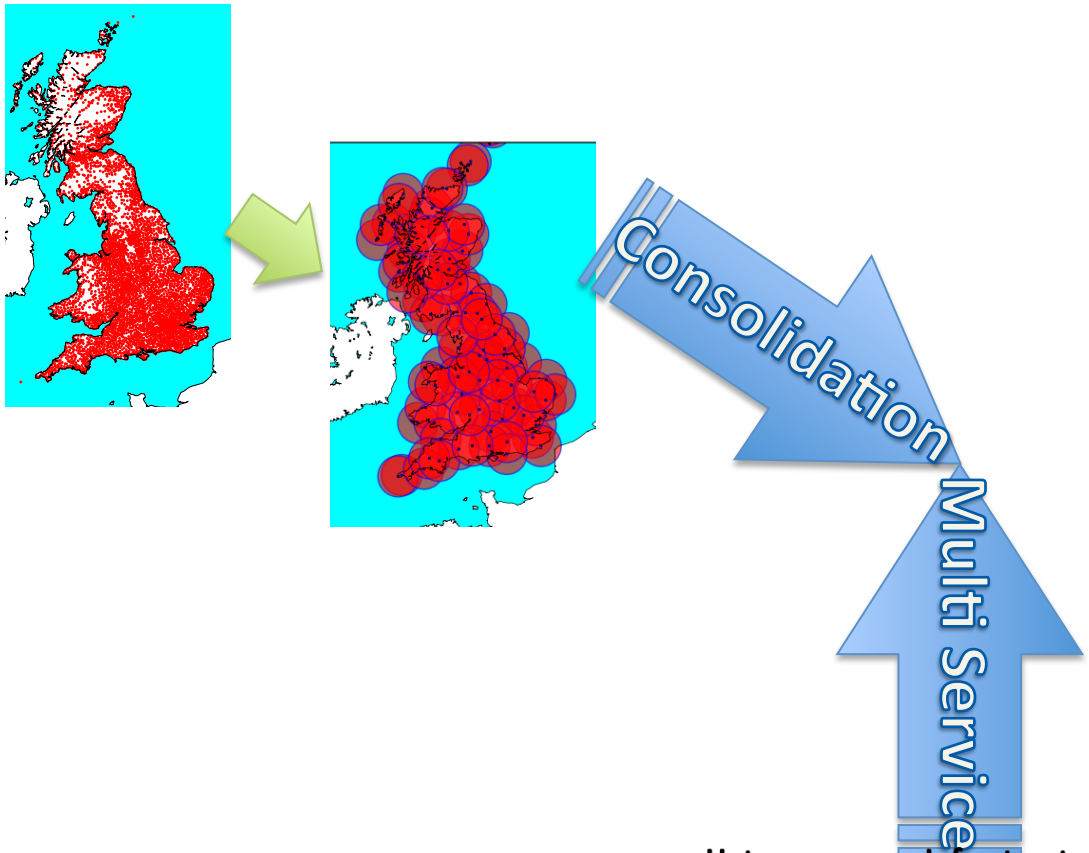
5G requirements:
data rate, latency, mobility, connections, energy, reliability,..

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

Improve network business case

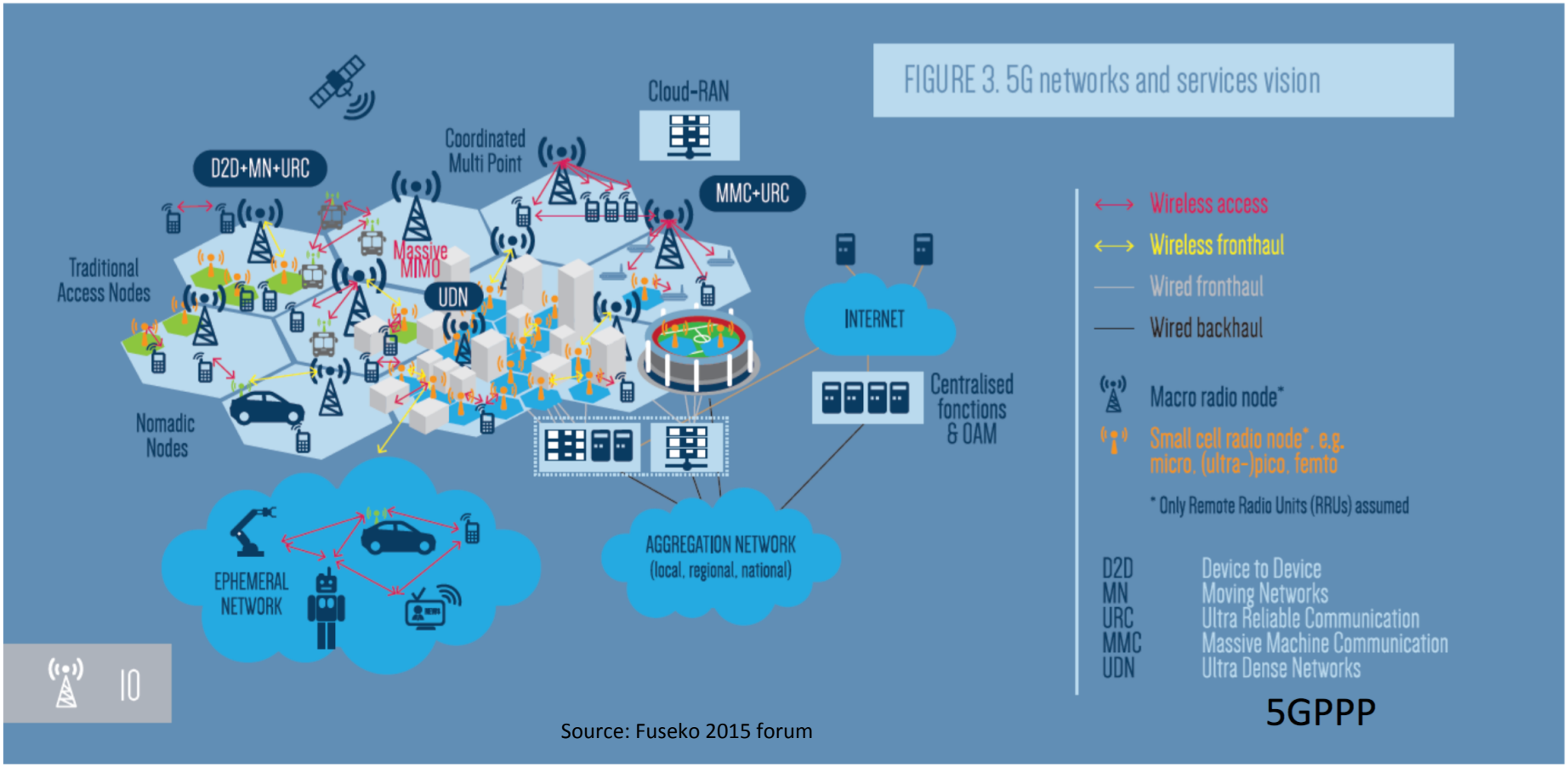
- Reduction of network operating cost
  - Lower capital cost for network equipment
  - Sharing of cost of ownership
- Increase revenues by providing more and faster services
- Reduce energy consumption

Access/Metro Convergence



Service Multiplexing

Converging business services into PON broadband network essential for cost sharing



Source: Fuseko 2015 forum

Fixed-mobile convergence

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

Some popular estimates of factors for capacity increase:

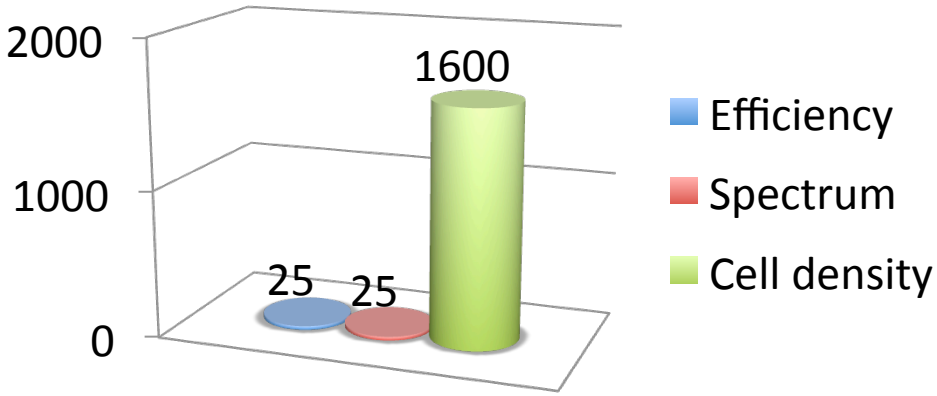
- Efficiency (MIMO, Smart scheduling, enhanced-CoMP) -> x3
- Spectrum (Carrier Aggregation, New Bands, Authorized Shared Access) -> x2
- **Density (Advanced Macros, HetNet management, Flexible small cells)**

➔ $\frac{1000}{2 \cdot 3} = 167$

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

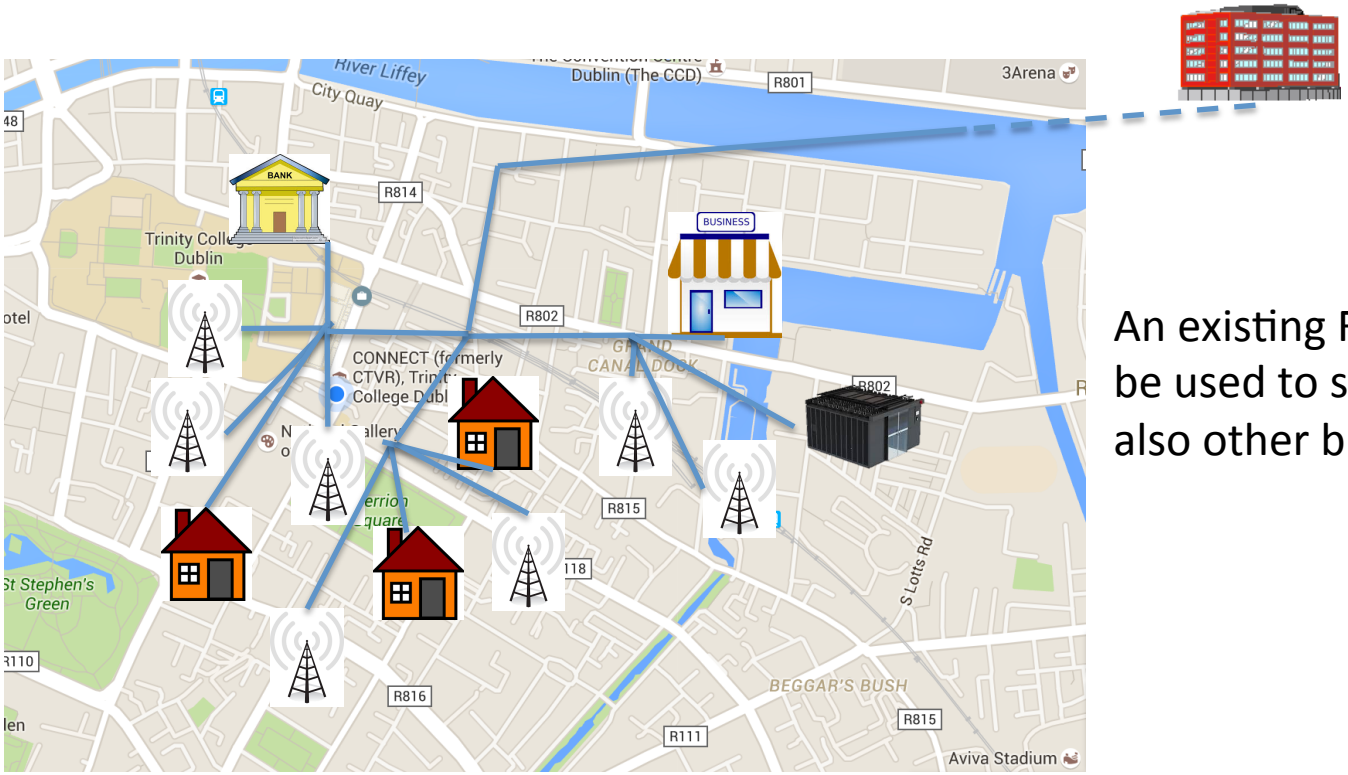
This is in line with what happened in the past:

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



Higher Cell Density

LR-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

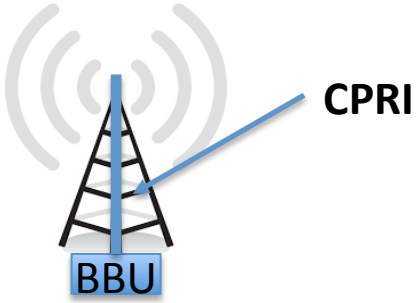
Cloud RAN

Serves as good example of constantly changing requirements, and need for flexible network architecture

The idea is to have Base Band Unit (BBU) processing located at different location than the mast.

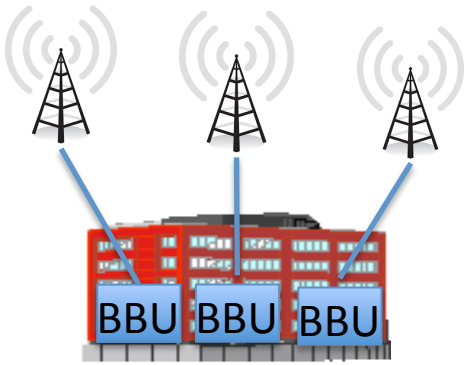
This was initially applied to connect antenna at top of mast with BBU in the ground to avoid using very expensive coaxial cables.

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

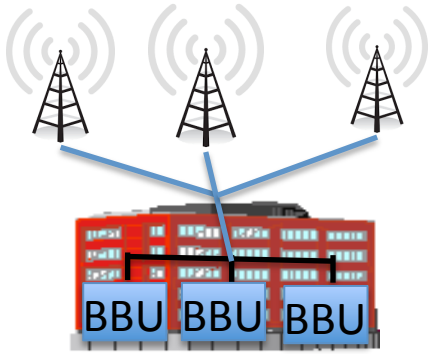


This gave the idea to move the BBU further out giving raise to the Cloud RAN concept

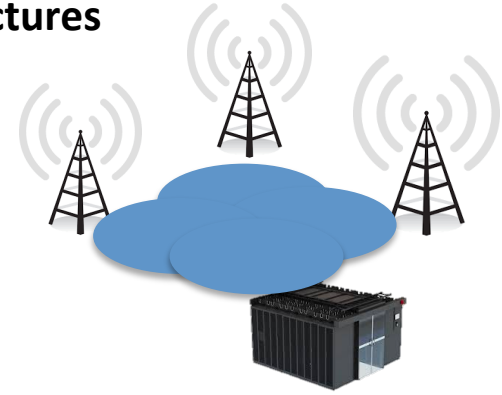
Examples of Fronthaul architectures



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

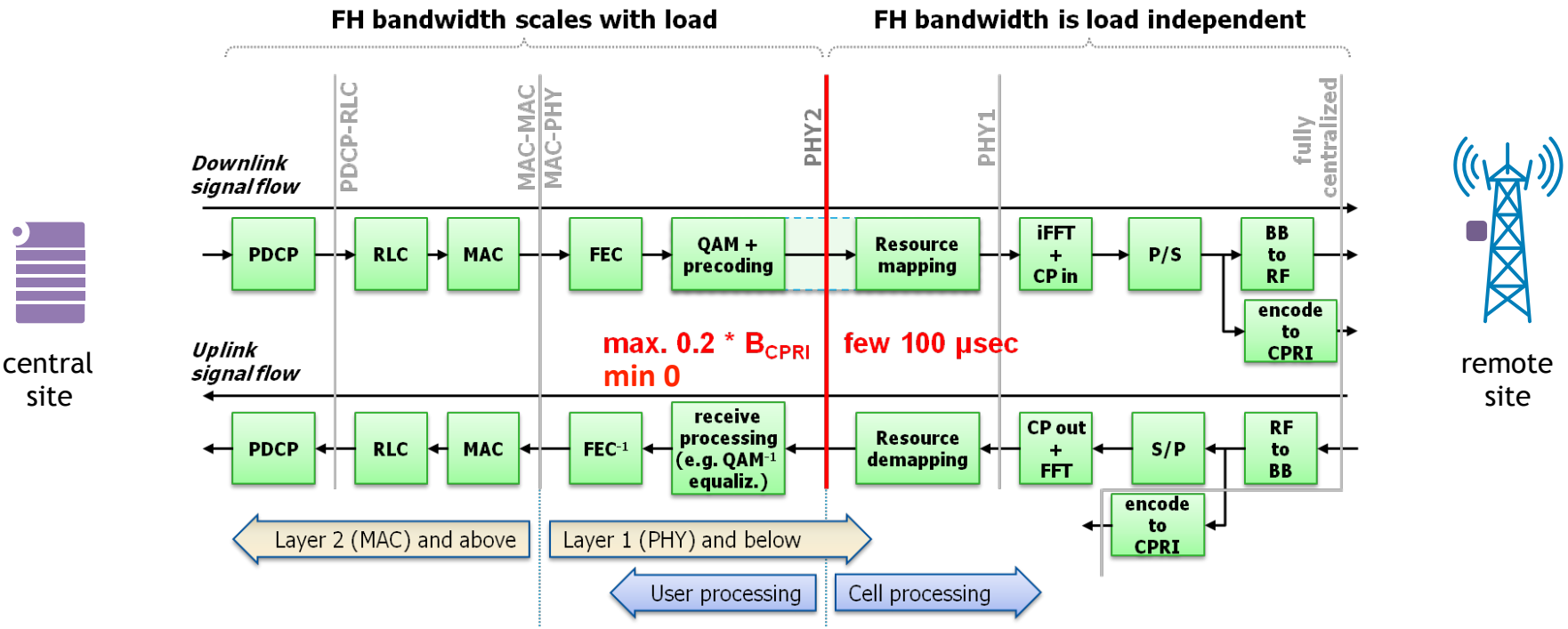
This is independent of usage… it's a sustained rate!

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:

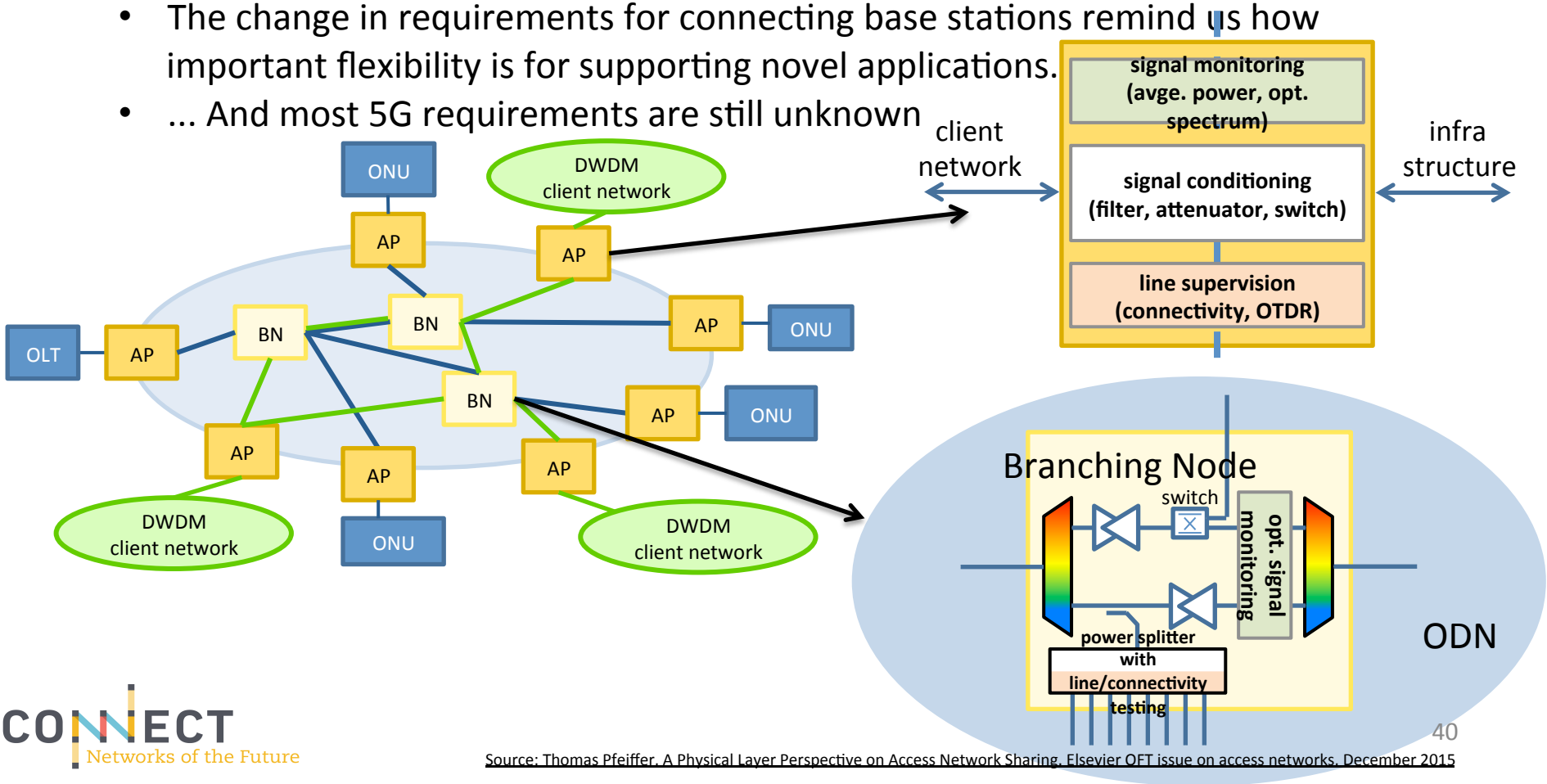


Source: Thomas Pfeiffer, Next Generation Mobile Fronthaul and Midhaul Architectures, IEEE/OSA JOCN 7(11), Nov 2015.
Original work from: U. Dotsch, et al., Quantitative Analysis of Split Base Station Processing and Determination of Advantageous Architectures for LTE

Flexible architecture

- Latency remains an issue for LR-PON, where the lenght is above 40Km

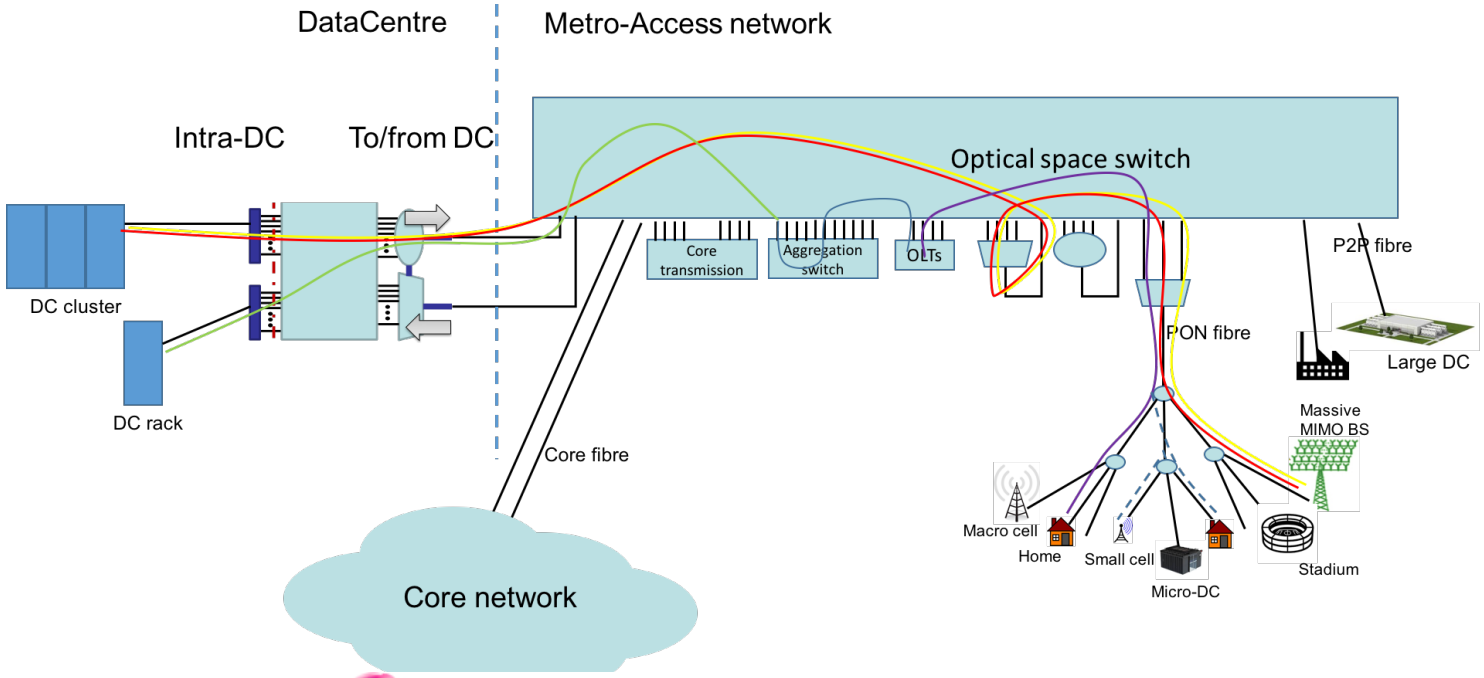
- LR-PON architecture can be updated to include more intelligent branching nodes where required: allow local optical branching, allow local monitoring
- Such flexibility is of paramount importance
  - The change in requirements for connecting base stations remind us how important flexibility is for supporting novel applications.
  - ... And most 5G requirements are still unknown



Source: Thomas Pfeiffer, A Physical Layer Perspective on Access Network Sharing, Elsevier OFT issue on access networks, December 2015

Data centre integration

- Seamless connectivity of data centres in the access/metro convergence story
  - 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 from directly to DC cluster or rack



Summary of requirements

Application-oriented approach
to deliver better 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 need to work 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 by providing more and faster services
- Reduce energy consumption

Requirements enabled by consolidation, service multiplexing

Application-oriented approach
to deliver better value

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

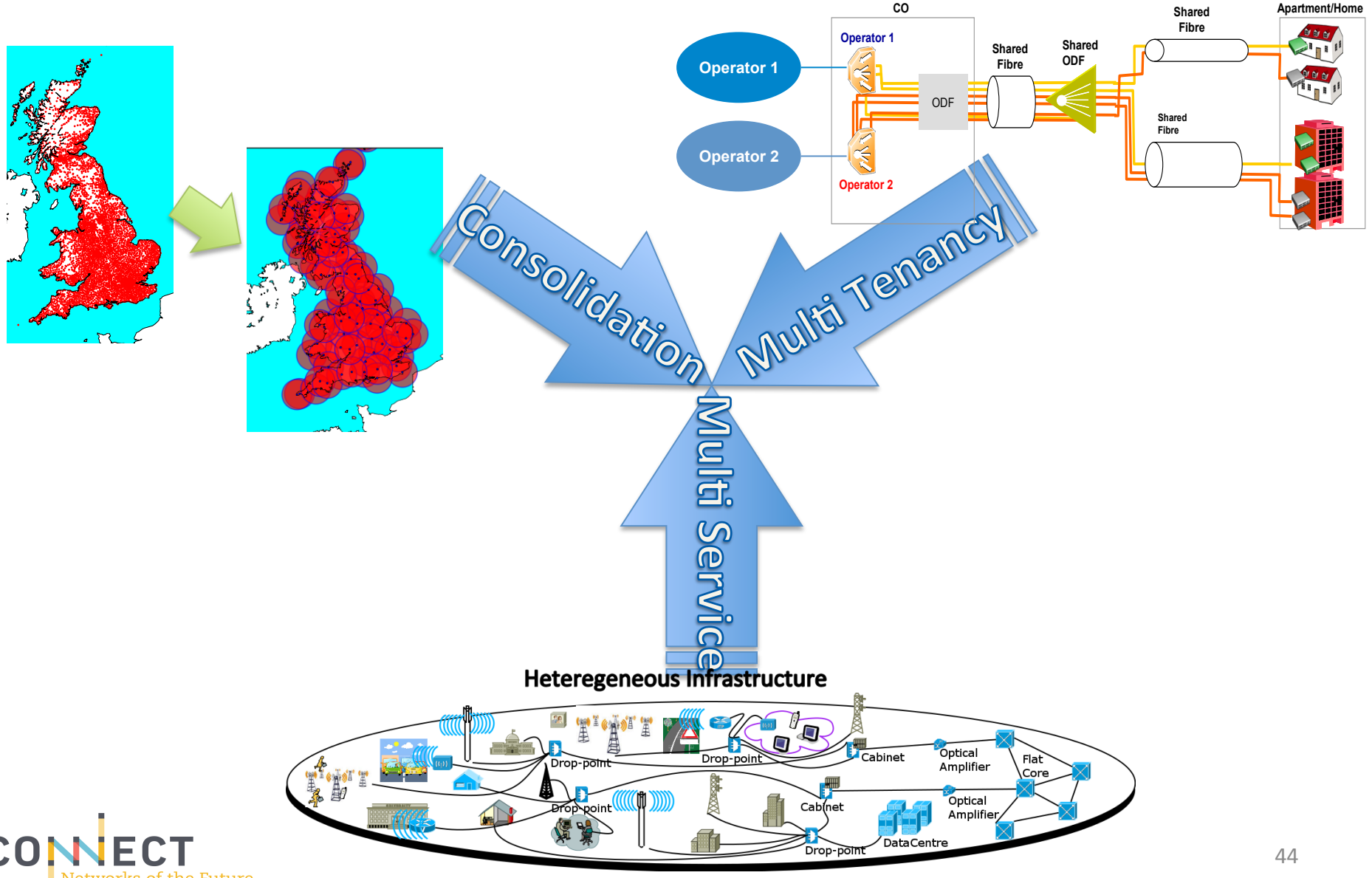
5G requirements:
data rate, latency, mobility, connections, energy, reliability,..

- Multiple technologies need to work 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 by providing more and faster services
- Reduce energy consumption

Access/Metro Convergence



Multi tenancy

A PON network 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??

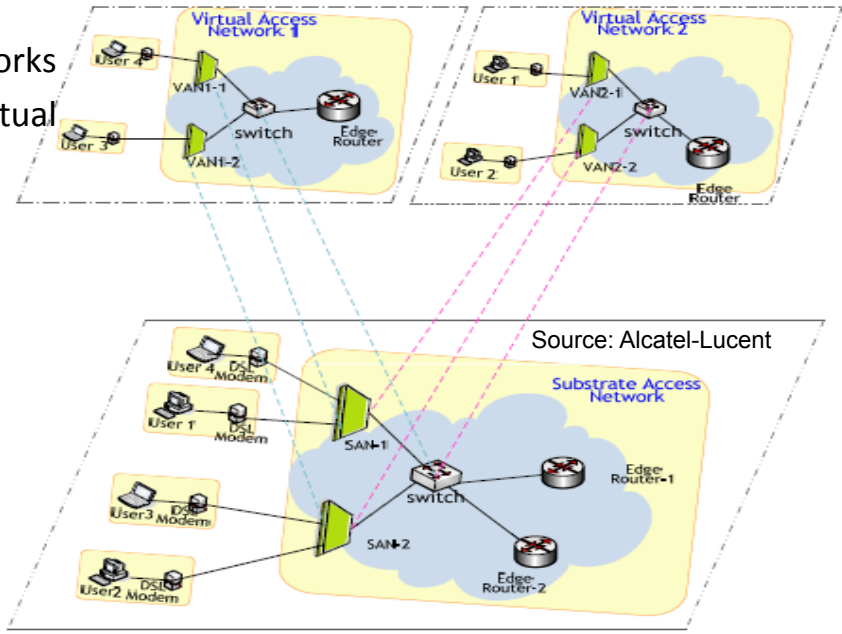
Open access

Avail of benefits derived from fast dynamics and innovation of an 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"

SHARE

www.oshare.ie

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

CONNECT Networks of the Future

Science Foundation Ireland sfi For what's next

Summary of requirements

Application-oriented approach
to deliver better value

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

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

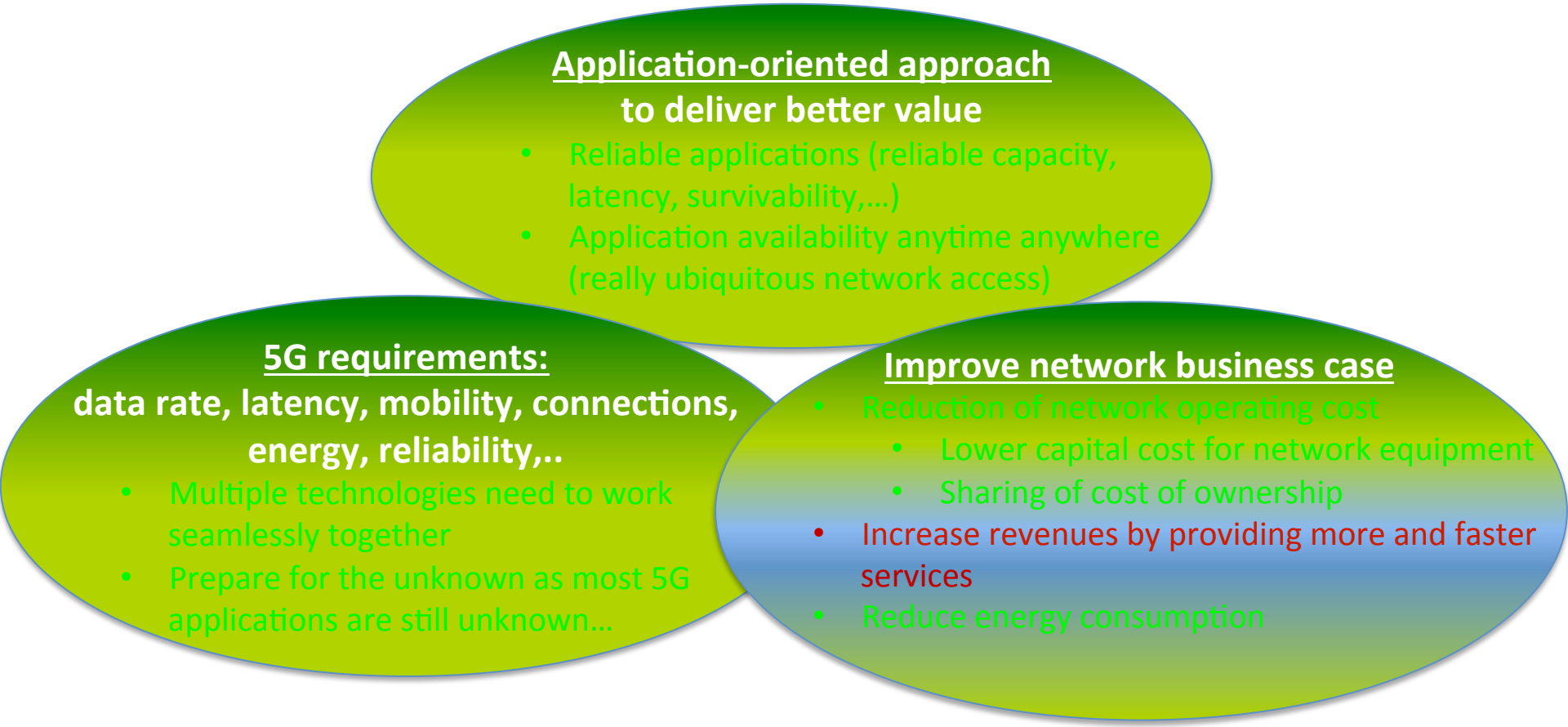
- Multiple technologies need to work seamlessly together
- Prepare for the unknown as most 5G applications are still unknown…

Improve network business case

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

Requirements enabled by

consolidation, service multiplexing, multi tenancy



Is SDN the glue element for true access/metro convergence?

Devised as a mechanism for separation of data and control plane

It now 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

Bringing SDN in the optical access – demo trials on virtualisation of ONU, OLT coming soon

Requirements enabled by

consolidation, service multiplexing, multi tenancy, SDN

Application-oriented approach
to deliver better 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 need to work seamlessly together
- Prepare for the unknown as most 5G applications are still unknown…

Improve network business case

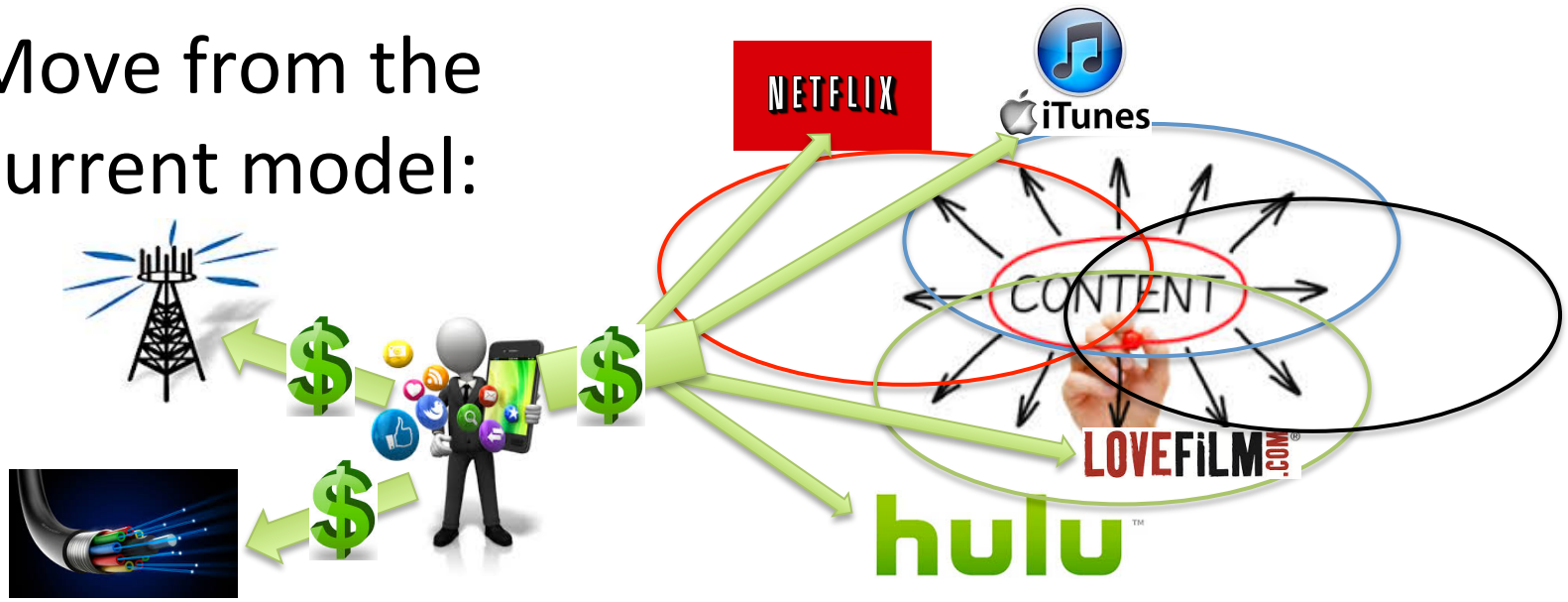
- Reduction of network operating cost
  - Lower capital cost for network equipment
  - Sharing of cost of ownership
- Increase revenues by providing more and faster services
- Reduce energy consumption

Conclusions

~~Conclusions~~ Vision

Content-focused business models

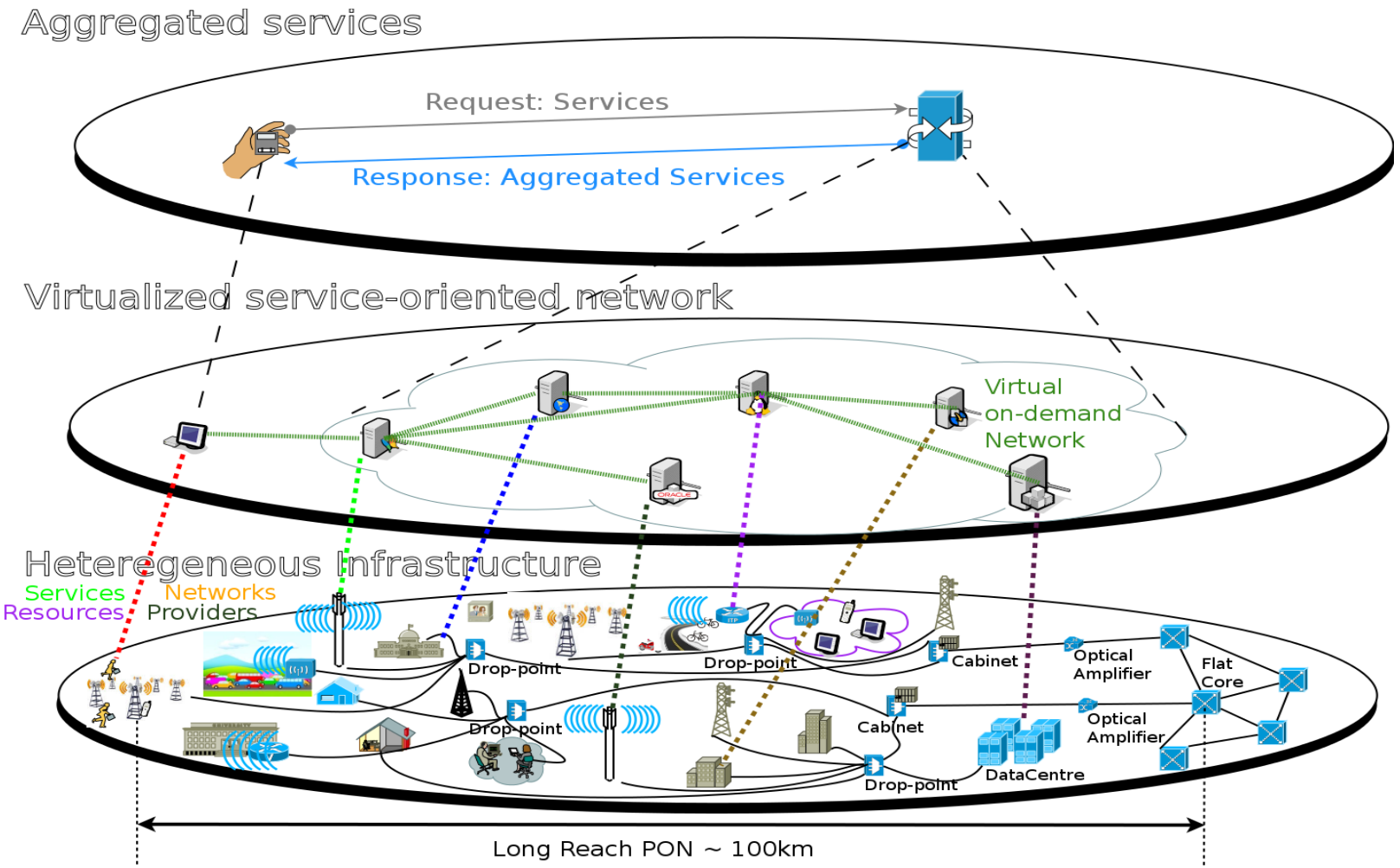
Move from the current model:



To a service-driven model:

Example: Amazon Kindle 3G

End-to-end centric network



Open questions

- 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

- Will access SDN stand the challenge of gluing together apps and networks to enable true access/metro convergence?

Thanks for your attention!

5G is not the evolution of 4G

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!