Access-metro convergence in next generation broadband networks

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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?
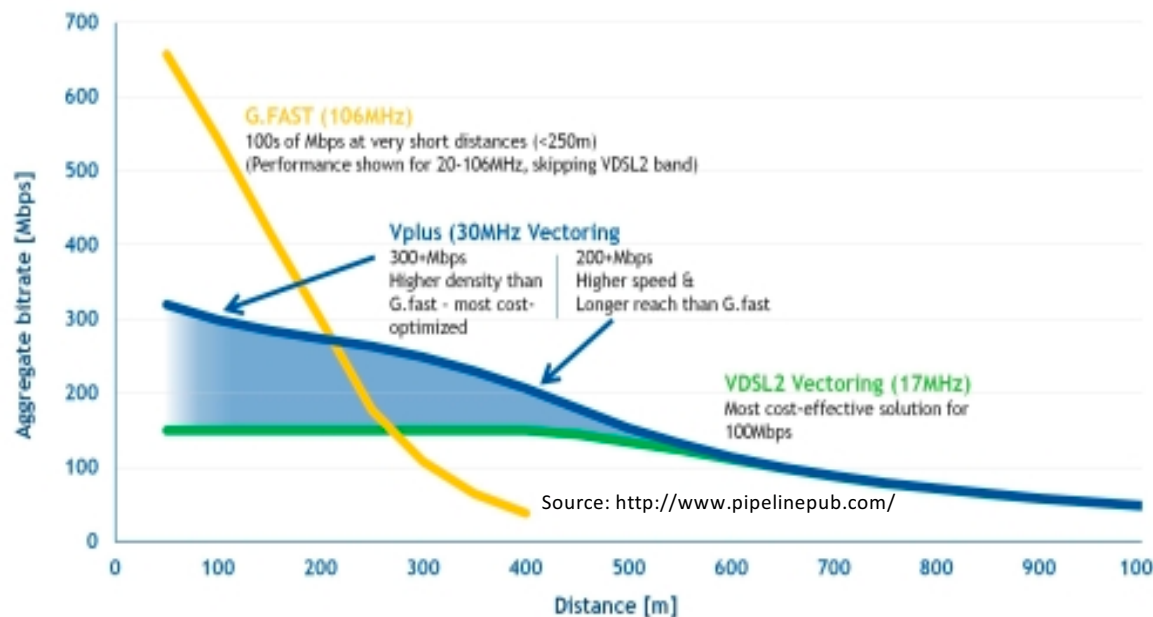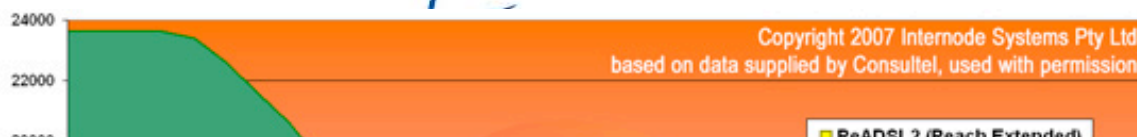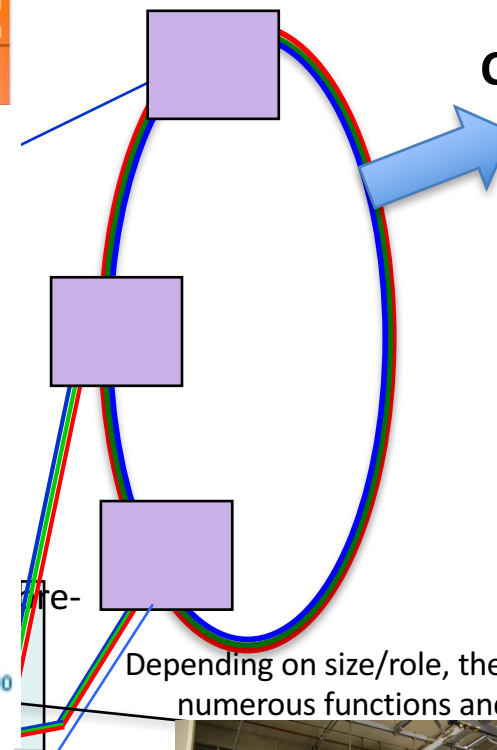

Acknowledgments

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Access and metro network view

Copyright 2007 Internode Systems Pty Ltd
based on data supplied by Consultel, used with permission

ReADSL2 (Reach Extended)

G.FAST (106MHz)
100s of Mbps at very short distances (<250m)
(Performance shown for 20-106MHz, skipping VDSL2 band)

Vplus (30MHz Vectoring
300+Mbps
Higher density than
G.fast - most cost-
optimized

200+Mbps
Higher speed &
Longer reach than G.fast

VDSL2 Vectoring (17MHz)
Most cost-effective solution for
100Mbps

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

Aggregate bitrate [Mbps]

Distance [m]

Distance From Exchange - Reach/Line Length (metres)

Line Attenuation (dB at 300Khz)

Core or Backbone network

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

4G

Ptp Ethernet

DC
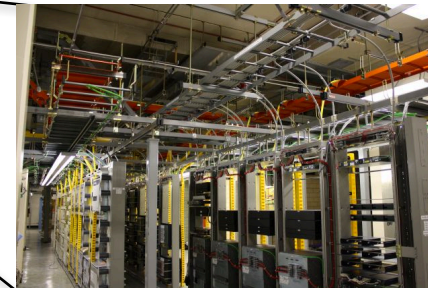
Large business

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

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

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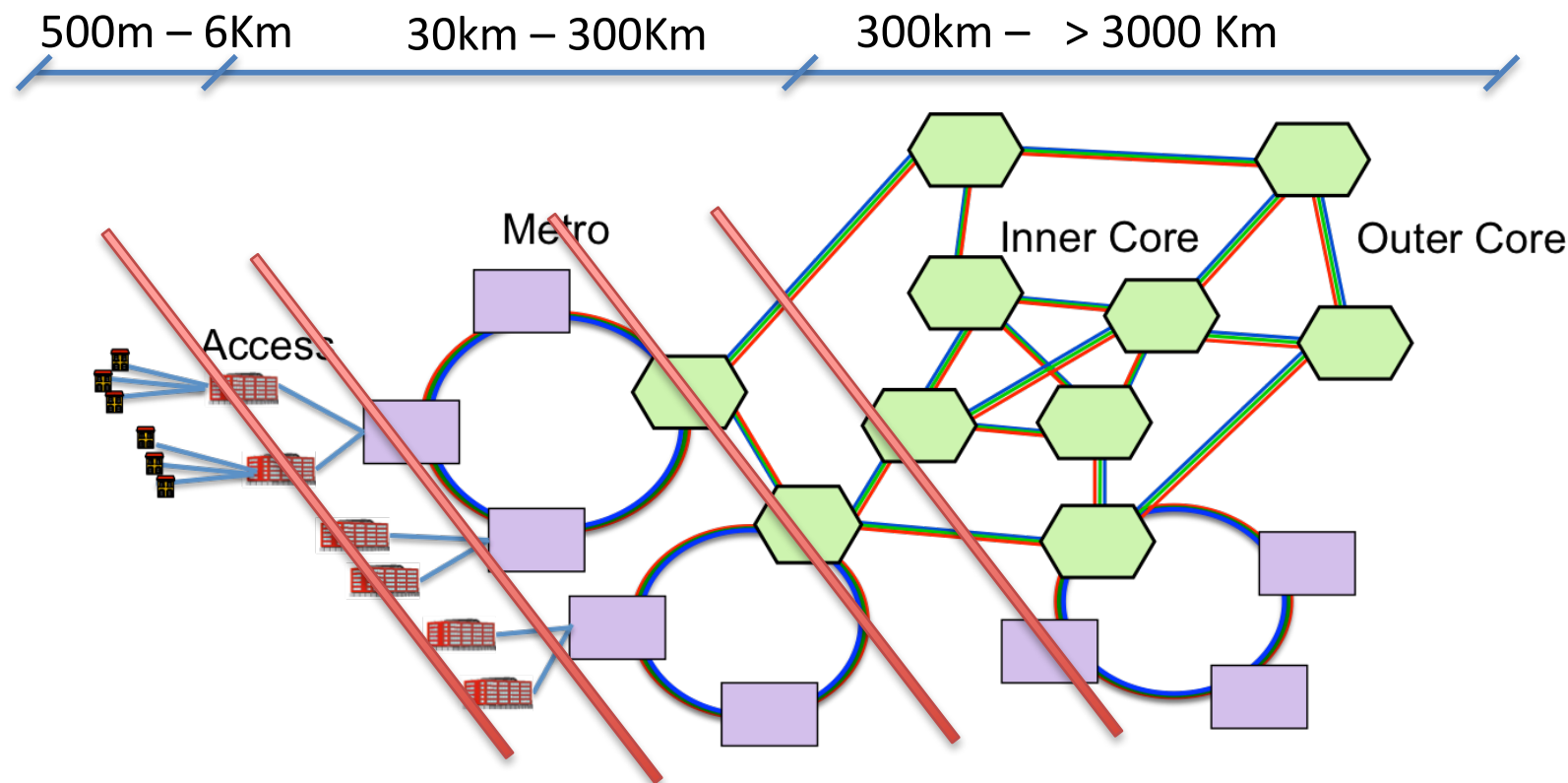
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4
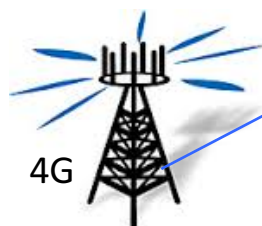
A telecommunications network (access/metro/core view)

500m – 6Km   30km – 300Km   300km –   > 3000 Km

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

Converging the access and metro networks

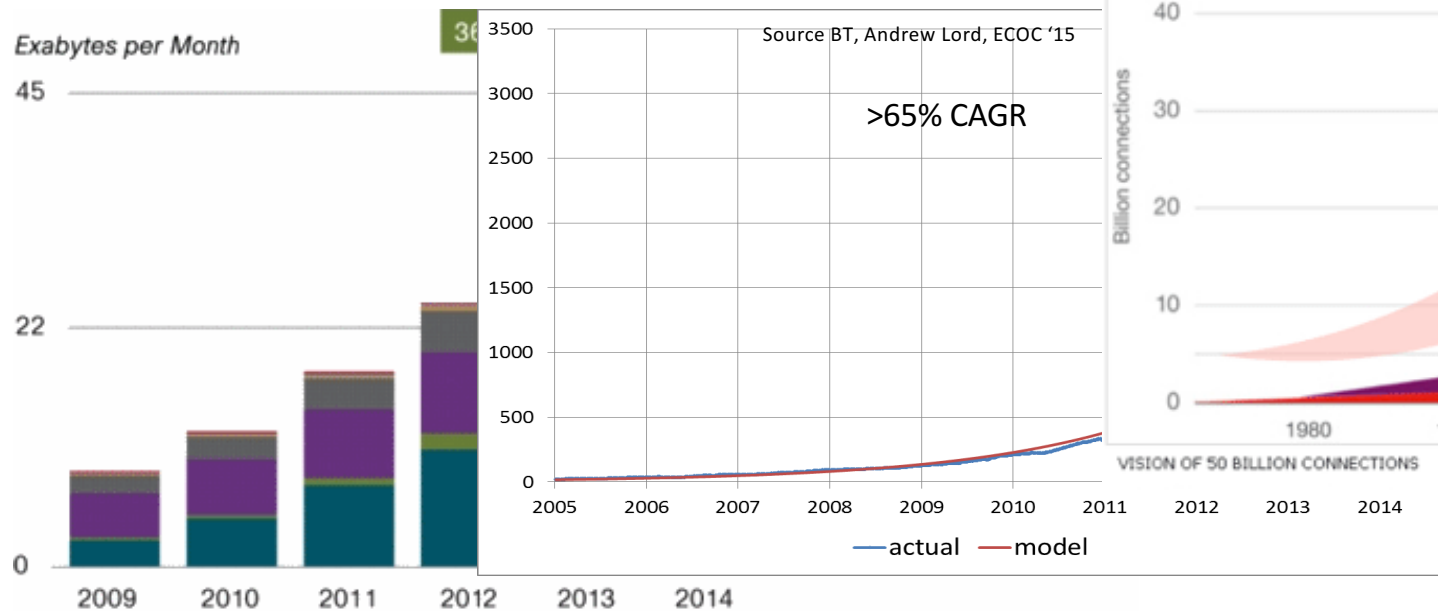Much fuss about integrating metro and access networks today

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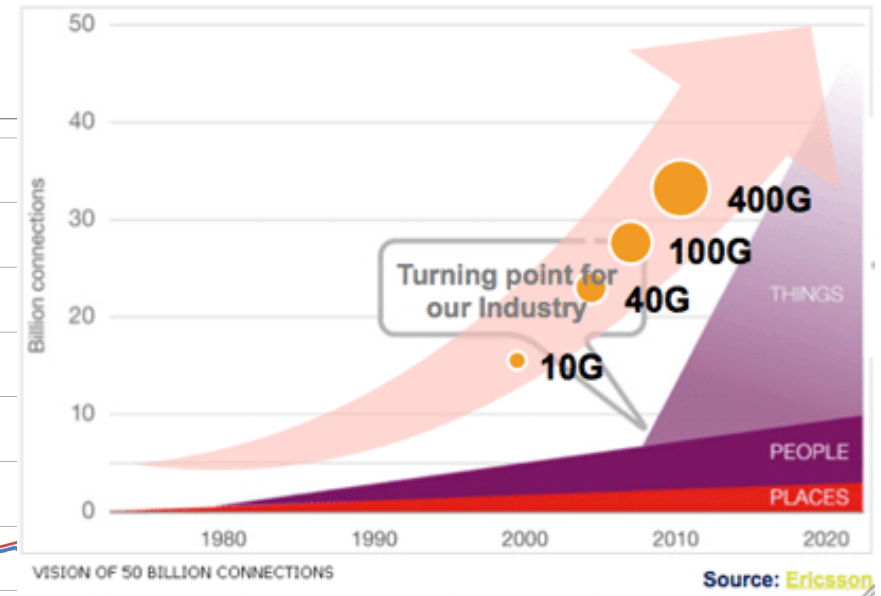- What's different today?
- What are the drivers?

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Change in traffic requirements

Internet traffic keeps growing

Exabytes per Month

Source: Cisco VNI, 2010

Source BT, Andrew Lord, ECOC '15

>65% CAGR

actual — model

VISION OF 50 BILLION CONNECTIONS

400G
100G
40G
Turning point for our Industry
10G
THINGS
PEOPLE
PLACES

Source: Ericsson

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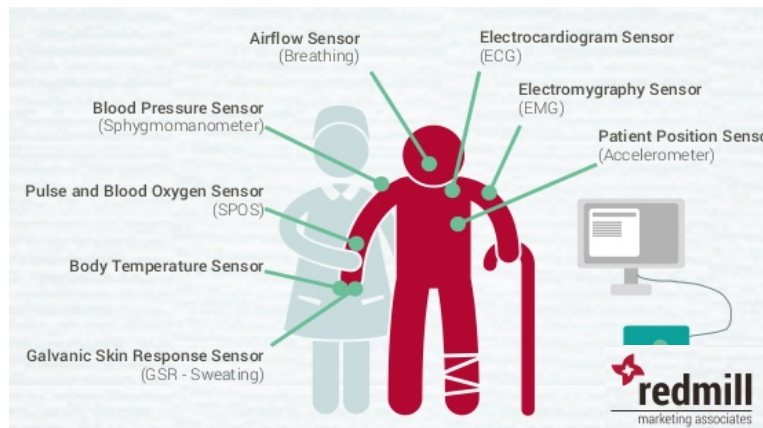
- Any content at a click's reach: immersive interaction

Augmented Reality

Virtual Reality

OFCity challenge

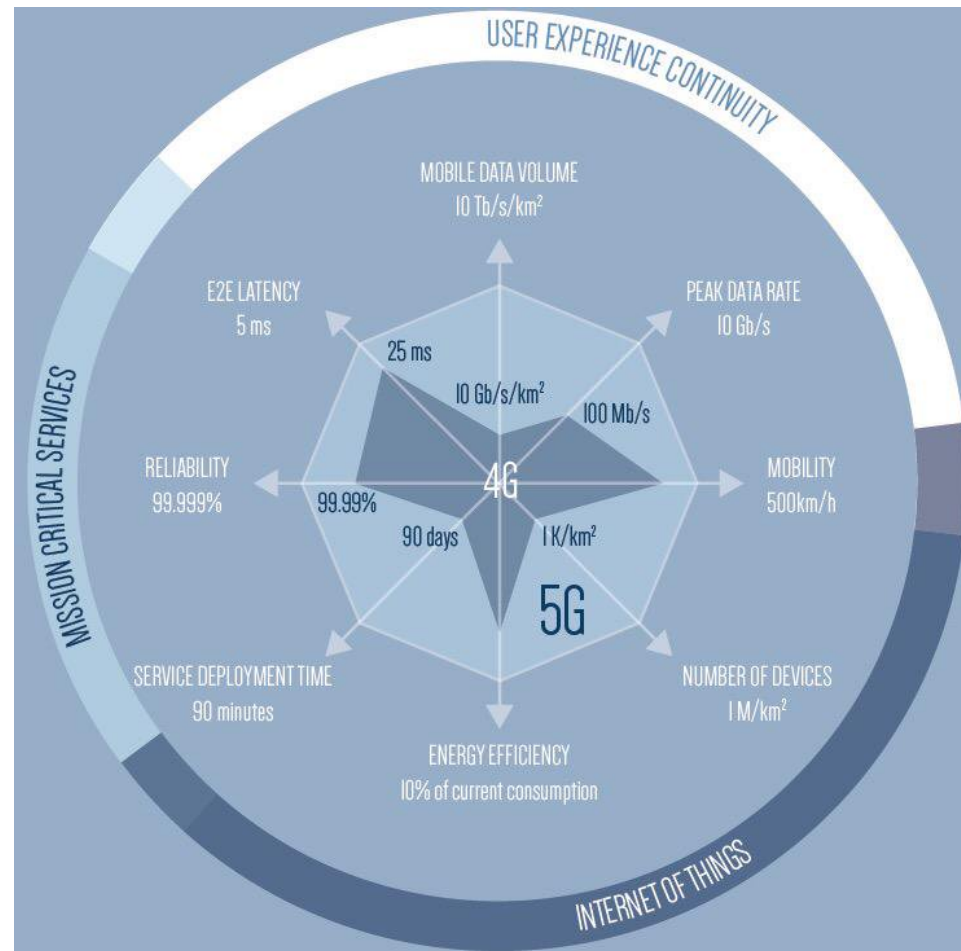- Smart location and transportation

- 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

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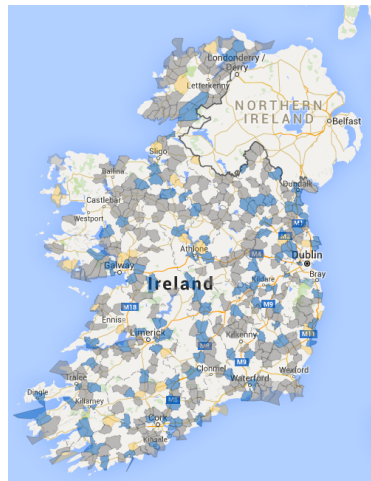
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Government Requirements

- 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
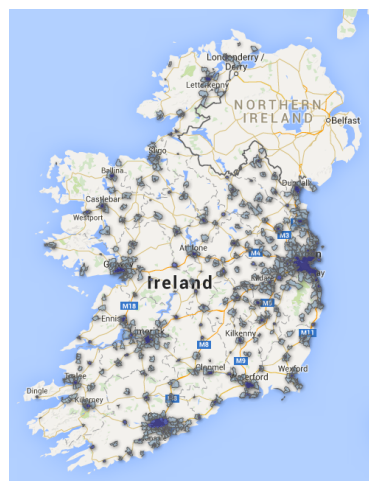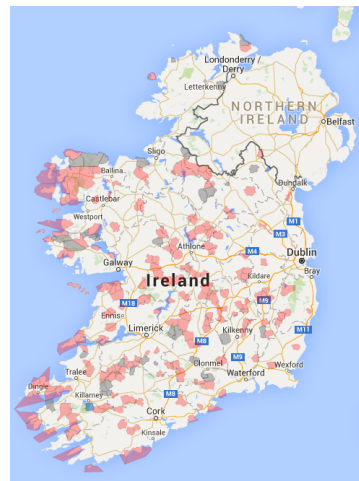
Population and urban areas	FTTCab blue= available today	Area with no DSL	Planned FTTH	National Broadband Plan ➔ state intervention

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
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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???

Access

Metro

Inner Core

Outer Core
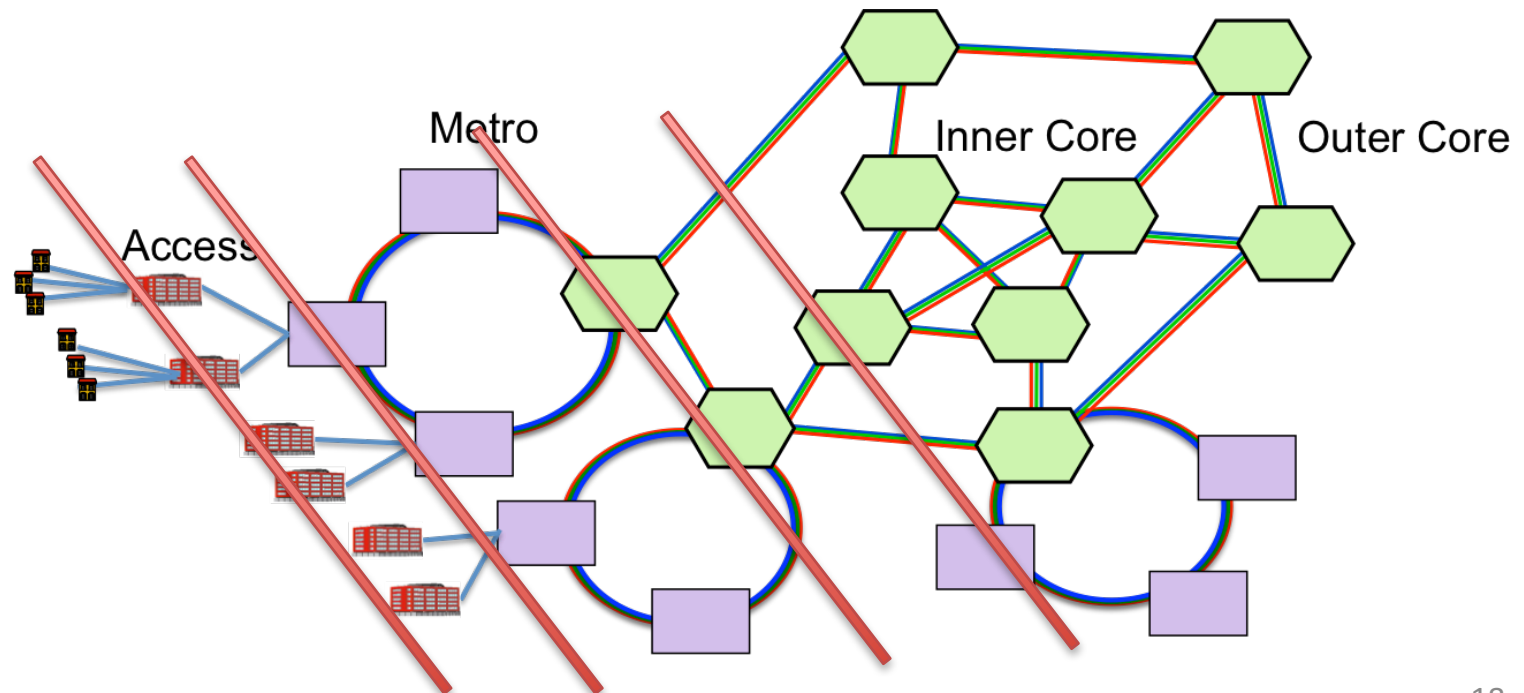
What is access-metro convergence?
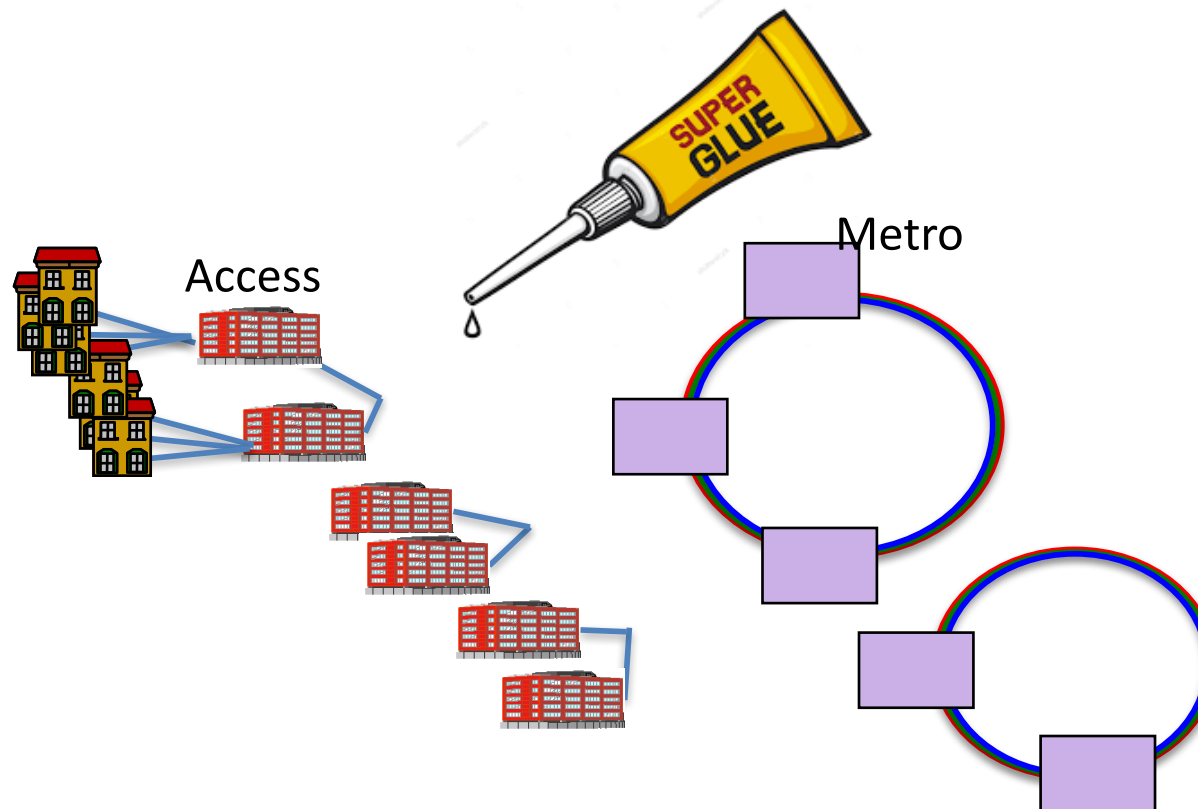
Much more than the integration of access and metro transmission technologies

Access/Metro Convergence

Space dimension

Consolidation

Multi Tenancy

Ownership dimension

Service dimension

Multi Service

Heteregeneous Infrastructure

CO

Operator 1

Operator 2

Operator 1

Operator 2

ODF

Shared Fibre

Shared ODF

Shared Fibre

Shared Fibre

Apartment/Home

Drop-point

Drop-point

Cabinet

Optical Amplifier

Flat Core

Drop-point

Cabinet

Optical Amplifier

Drop-point

DataCentre

Access/Metro Convergence

Space domain

Consolidation

DISCUS PON architecture enabling node consolidation

Extend the PON reach

Metro

Access

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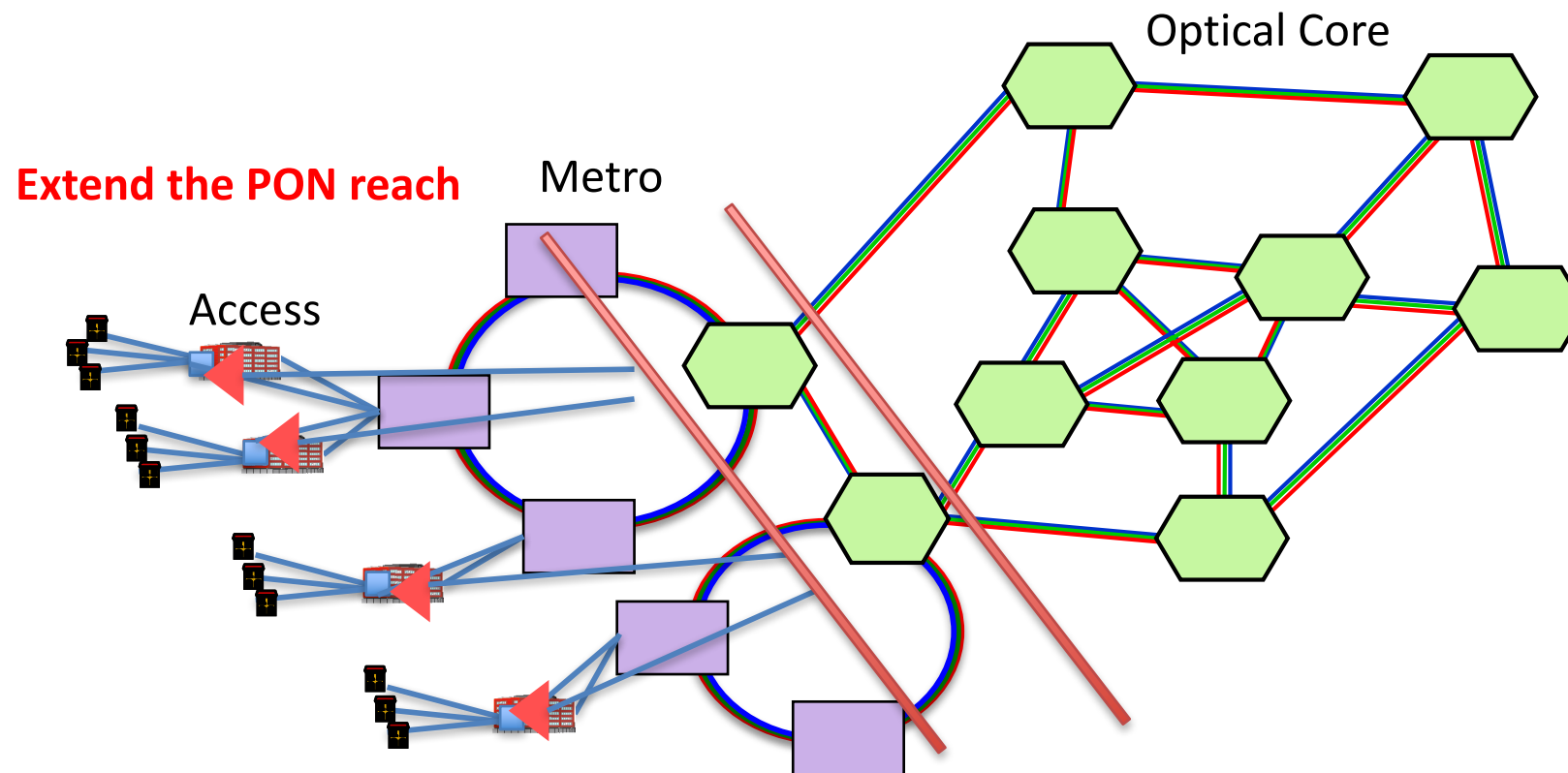
Once you start the convergence process you need to rethink of all network boundaries:
What defines access-metro, metro-core, inner core?

From hierarchical to flat core

Flat optical core

Inner Core

Outer Core

Access / Metro
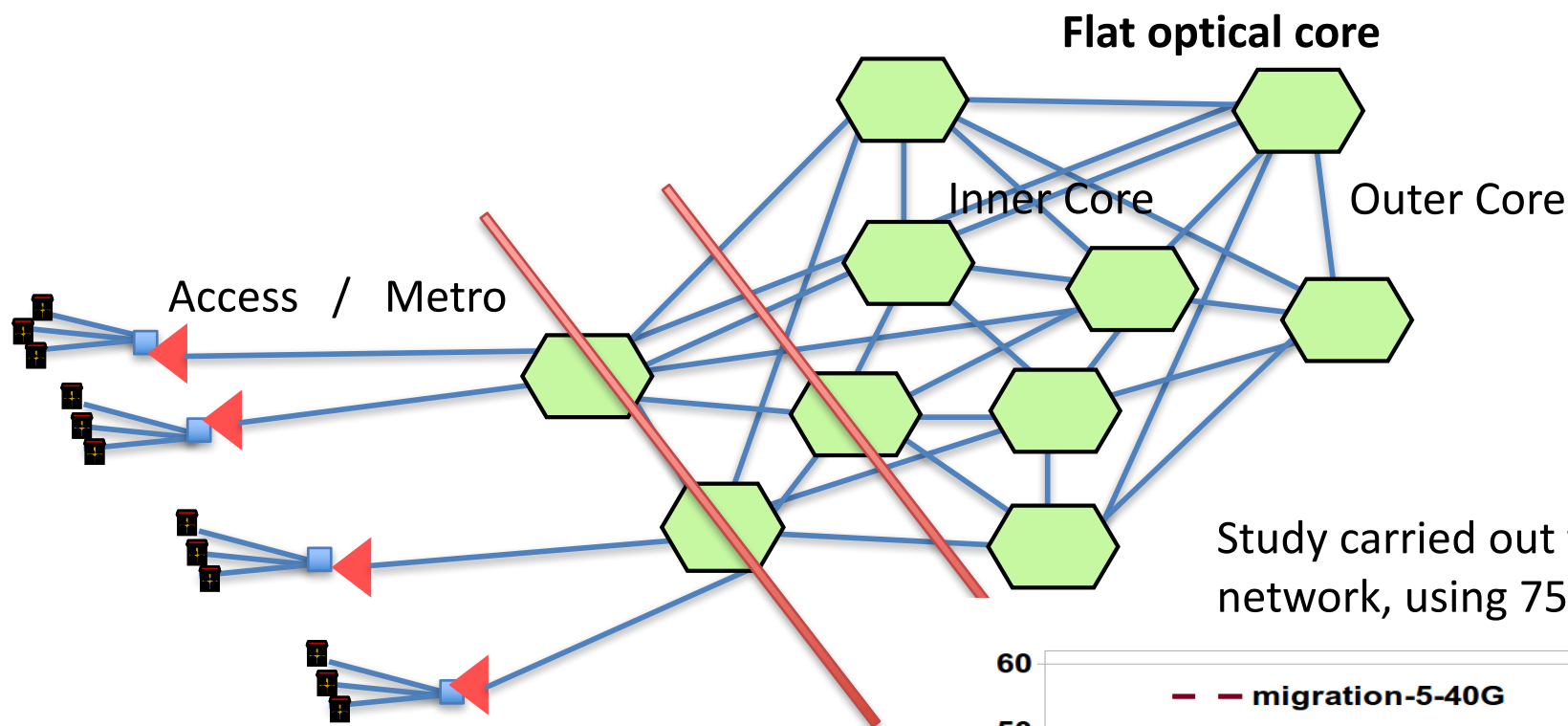
Study carried out for UK network, using 75 MC nodes

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

Instance Country	$\max_{Km}$	# MC nodes	# Fiber links
UK	110 km	75	137
Italy	115 km	116	219
Spain	115 km	179	321
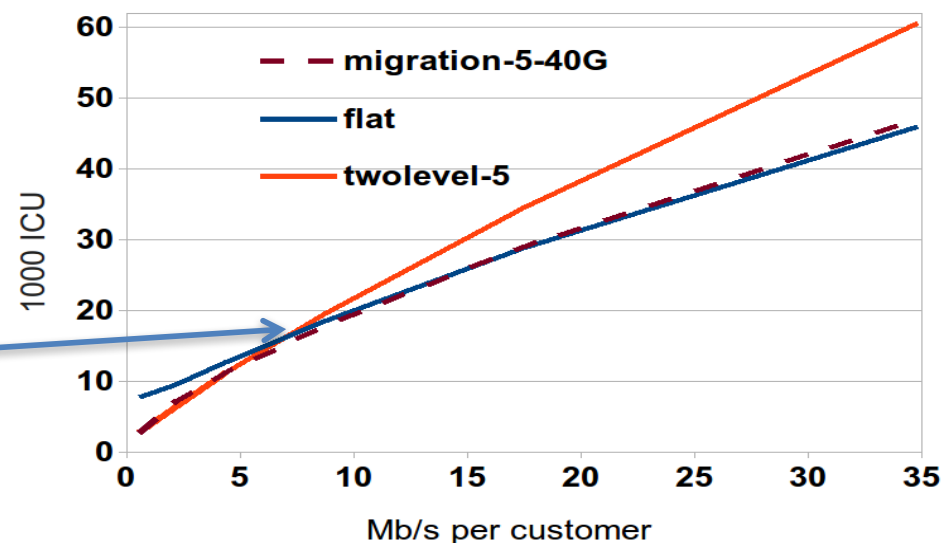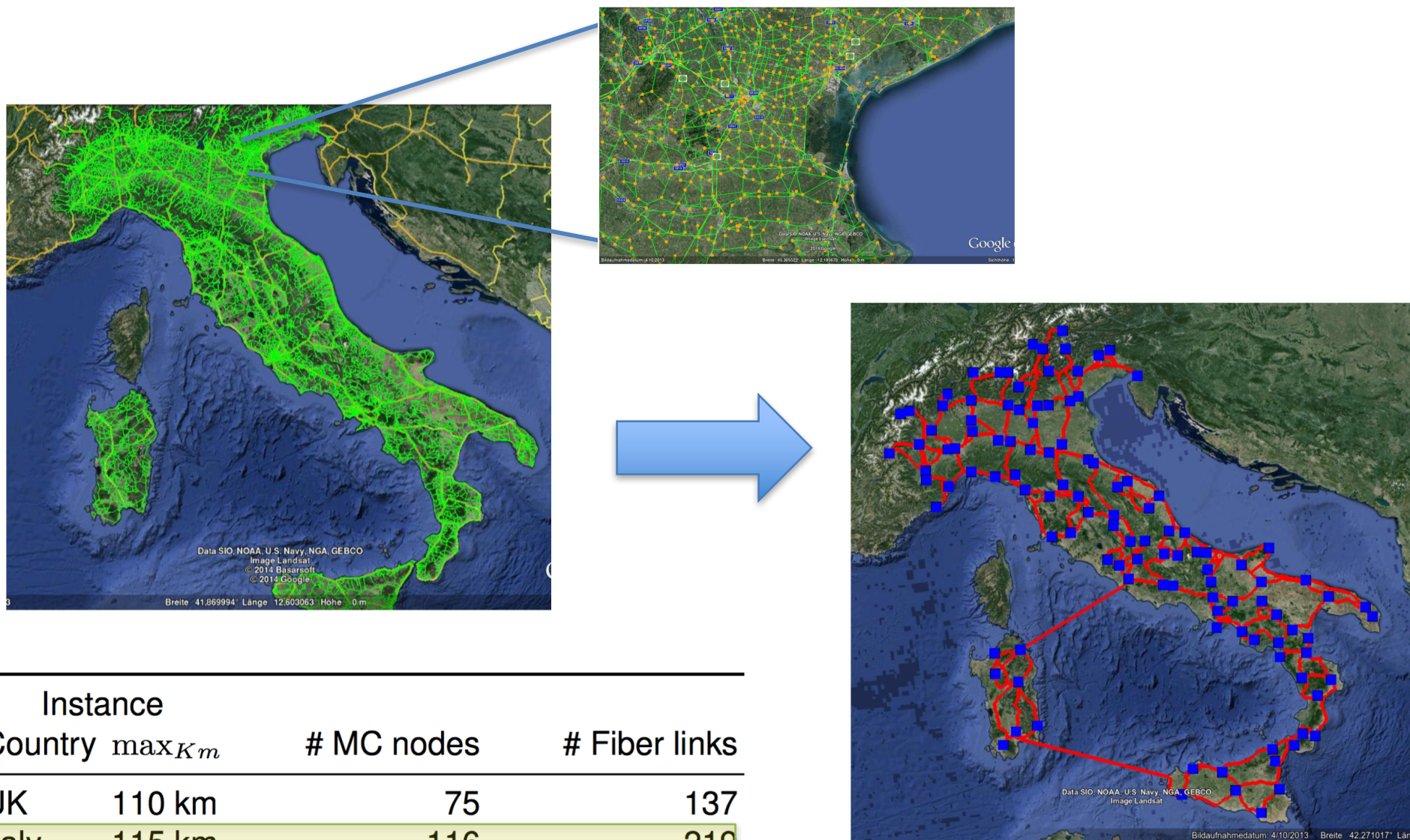
Dual-homed PON protection with maximally disjoint fibre routes
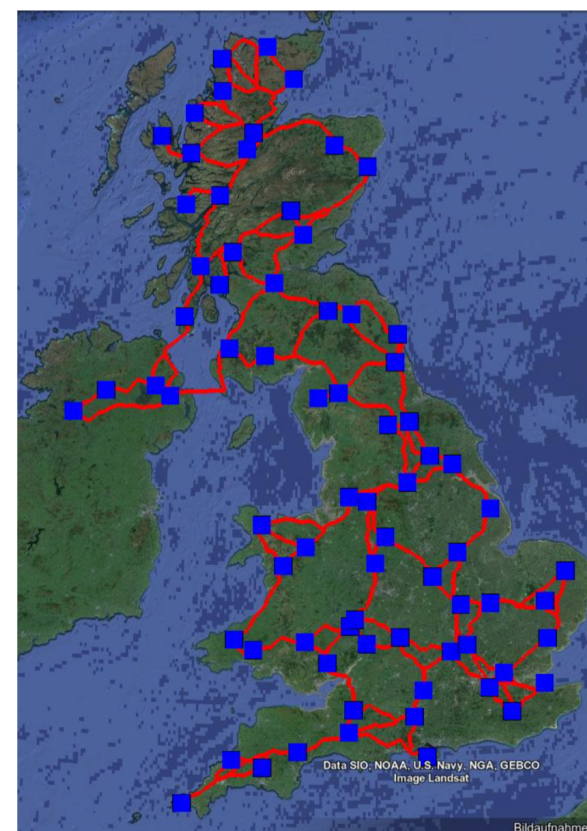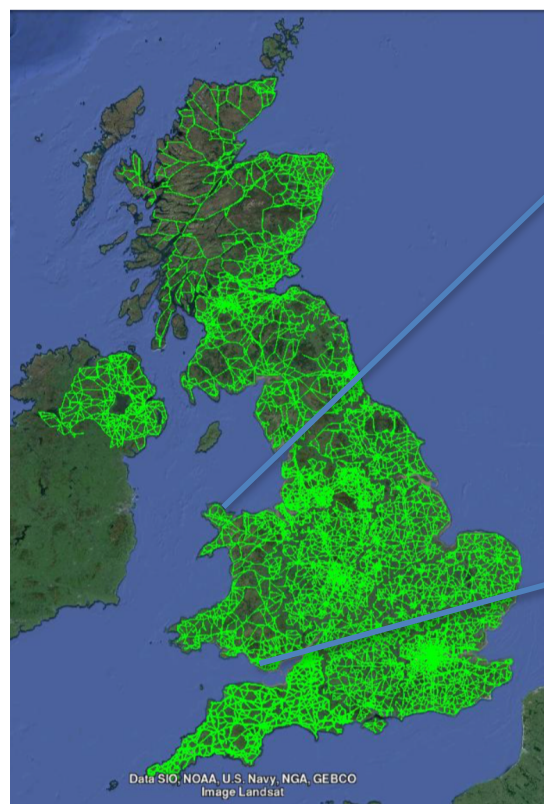
Networks of the Future

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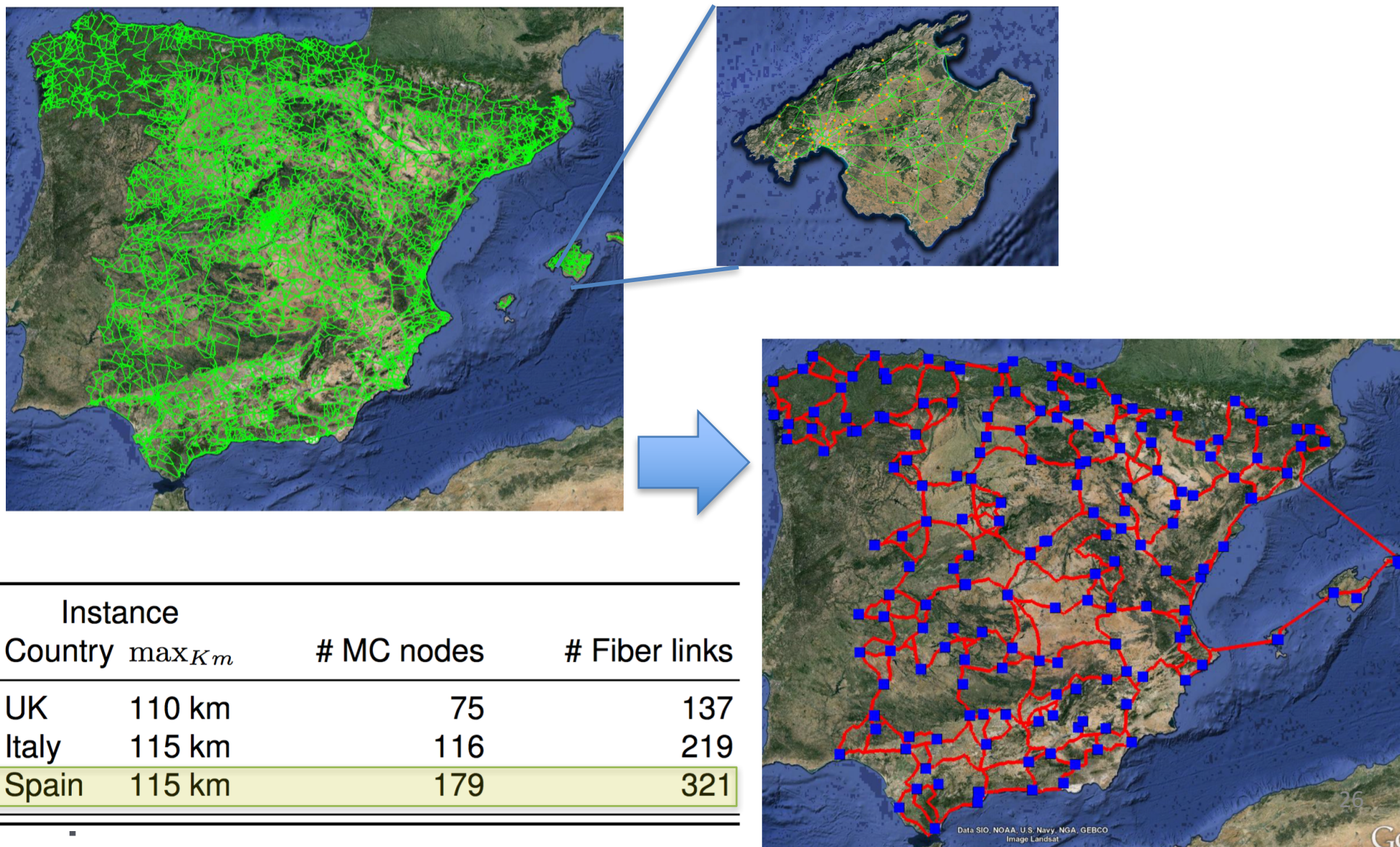
Architectural results

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

- Lower cost compared to other optical access technologies

Comparison of DISCUS power/user with BAU and original estimate

Legend: DISCUS metro-node + ONU, BAU Watts, LR-PON + flat core (orginal)

Cash Flow

Legend: DISCUS LR-PON, FTTCab (VDSL), XR-GPON, Std GPON, Pt-Pt Fibre access

Summary of requirements

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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
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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
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Requirements enabled by consolidation

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Access/Metro Convergence

Space domain

Consolidation

Multi Service

Service domain

Heteregeneous Infrastructure

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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
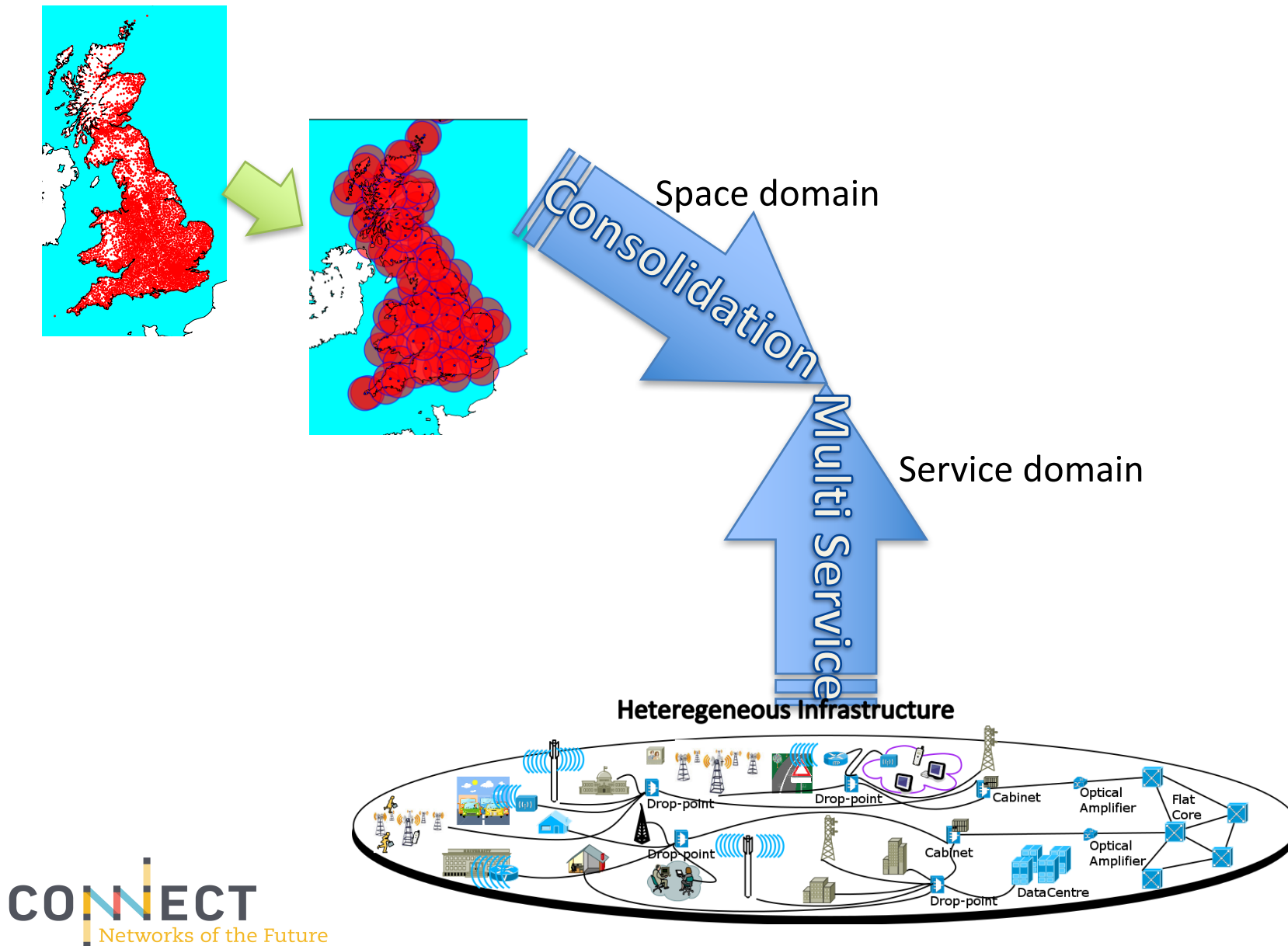
Fixed-mobile convergence

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)**

  ➔ $\dfrac{1000}{2 \cdot 3} = 167$

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
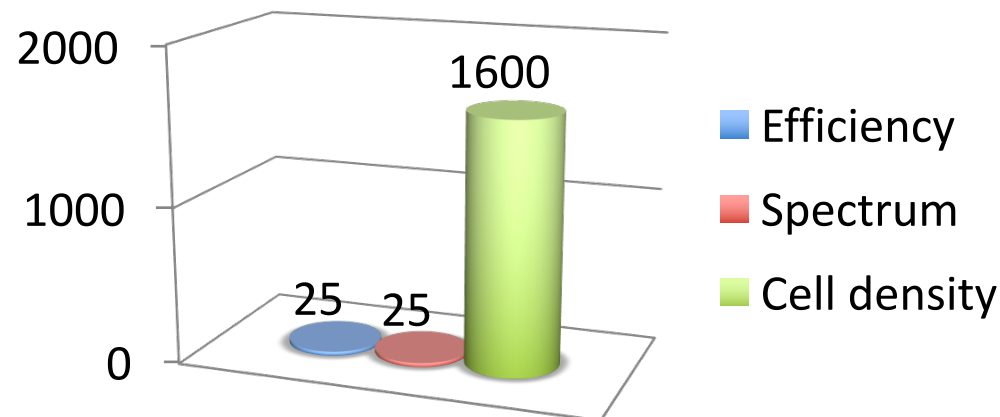
Higher Cell Density
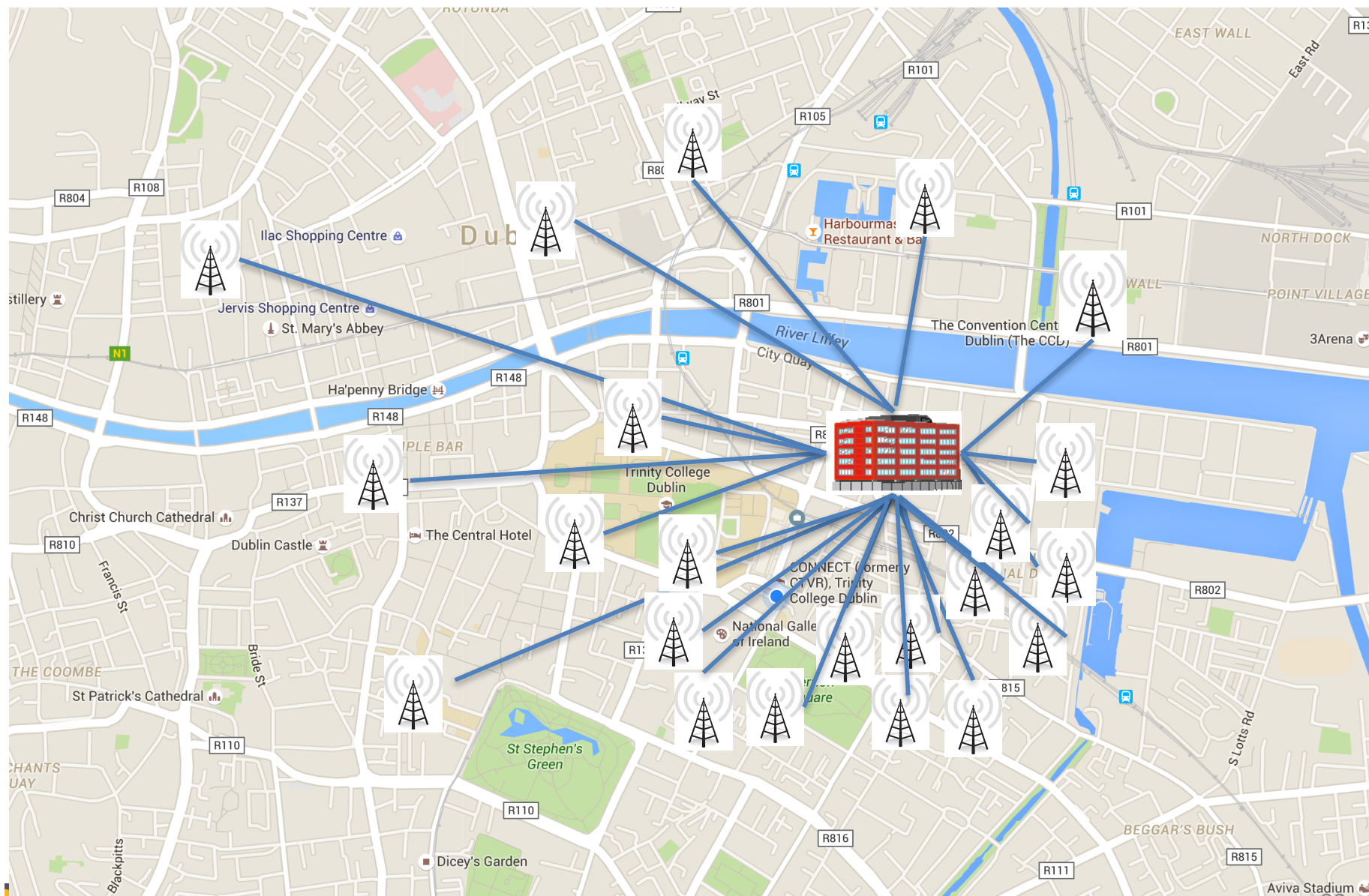
Shared PON for mobile backhauling
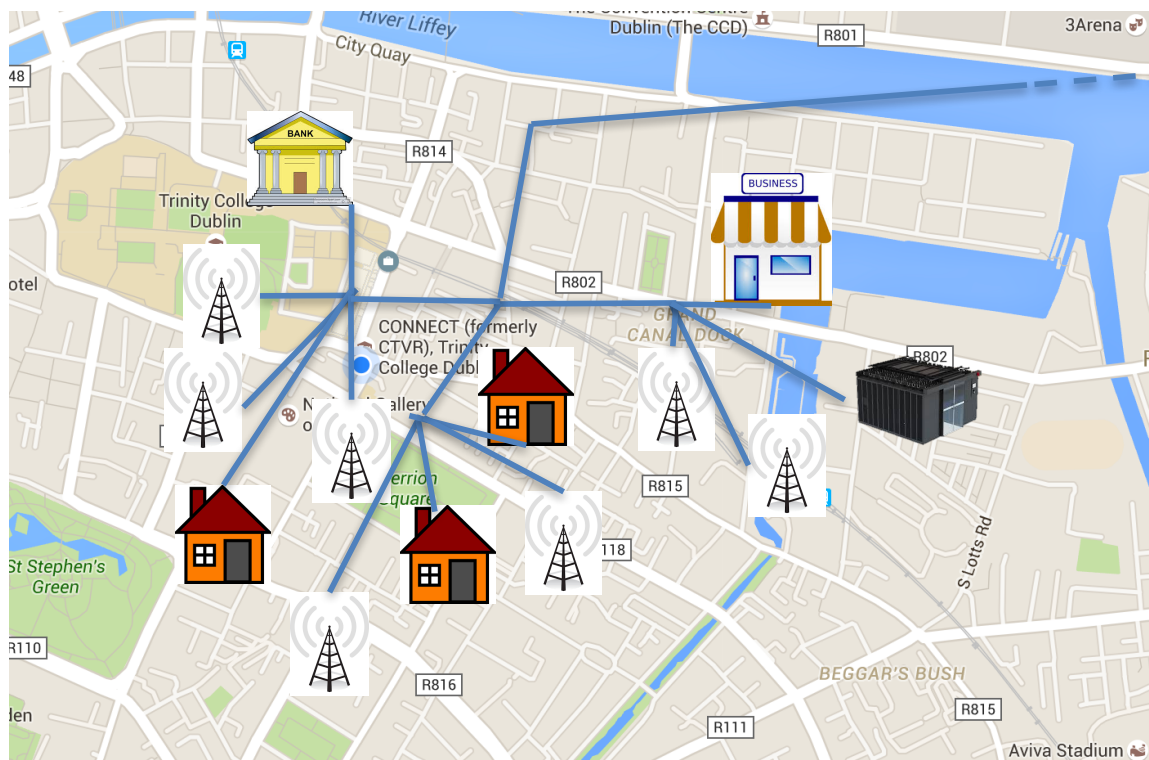
An existing FTTH infrastructure can be used to serve mobile cells, but also other businesses

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)

CPRI

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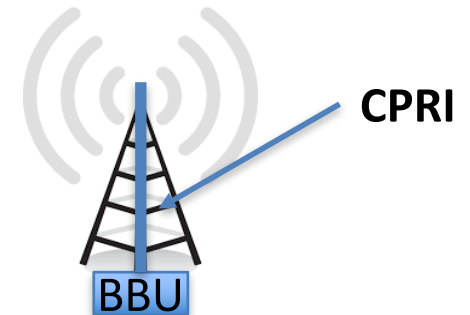
This gave the idea to move the BBU further out giving raise to the Cloud RAN concept

Examples of Fronthaul architectures

One virtual BBU to many RRU

BBU BBU BBU

BBU   BBU

BBU hoteling

BBU pooling

BBU cloud
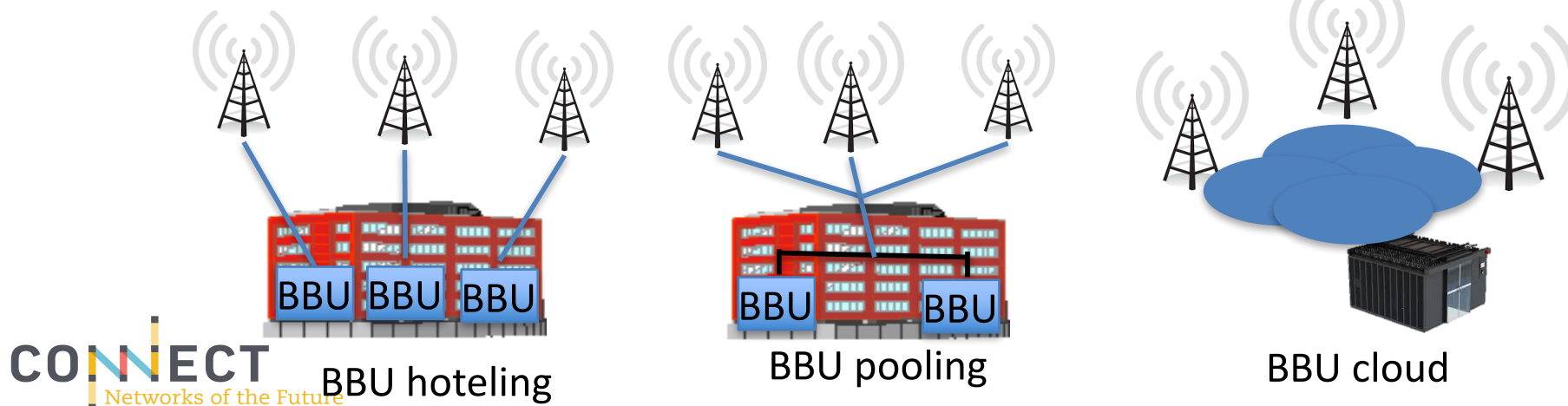
Fronthaul

Problems:

1. High capacity:

$$B = R_s \times N_q \times N_a \times N_b \times R_c \times R_l$$

Quantization bits — N_q
Frequency bands — N_b
Line coding ratio — R_l
Sampling rate — R_s
Antennas — N_a
Word control ratio — R_c

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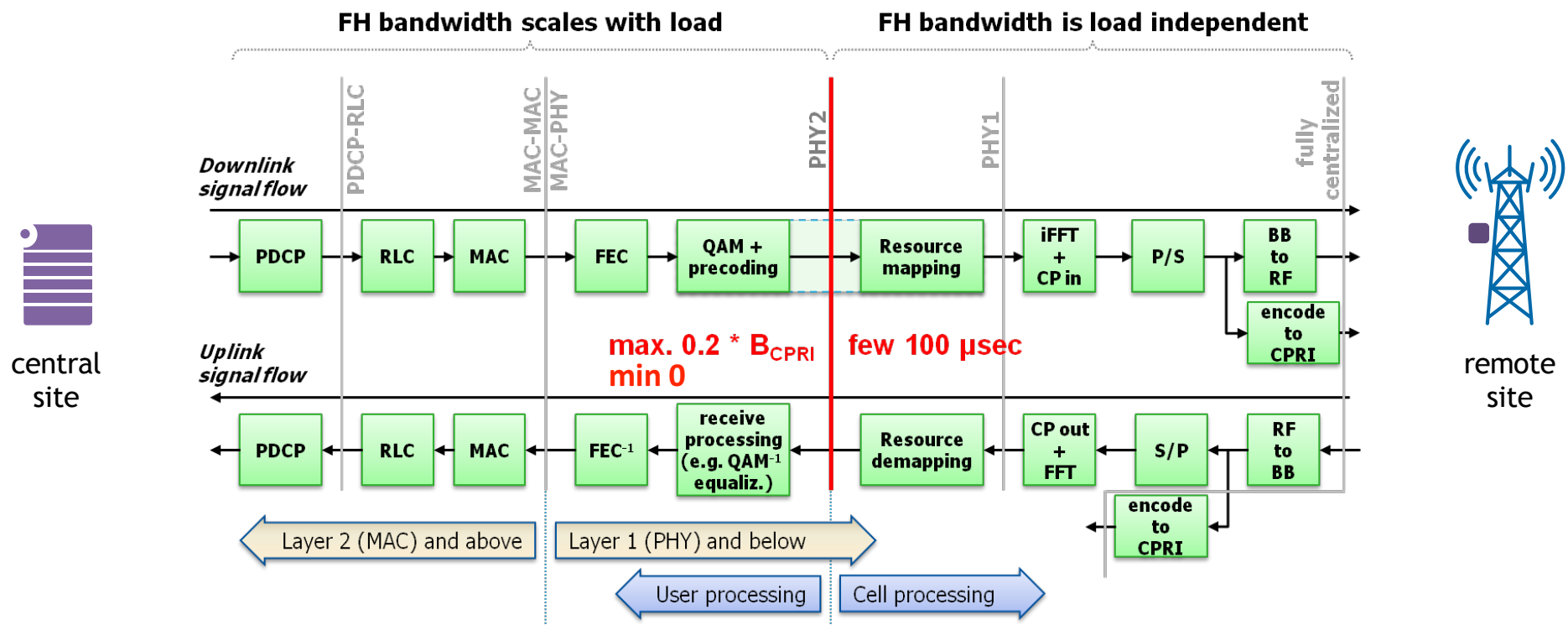
Source: Thomas Pfeiffer, Next Generation Mobile Fronthaul and Midhaul Architectures. IEEE/OSA JOCN 7(11), Nov 2015.
Original work from: U. Dotsch, et al., Quantitative Analysis of Split Base Station Processing and Determination of Advantageous Architectures for LTE

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).

Total fibre length to >100km
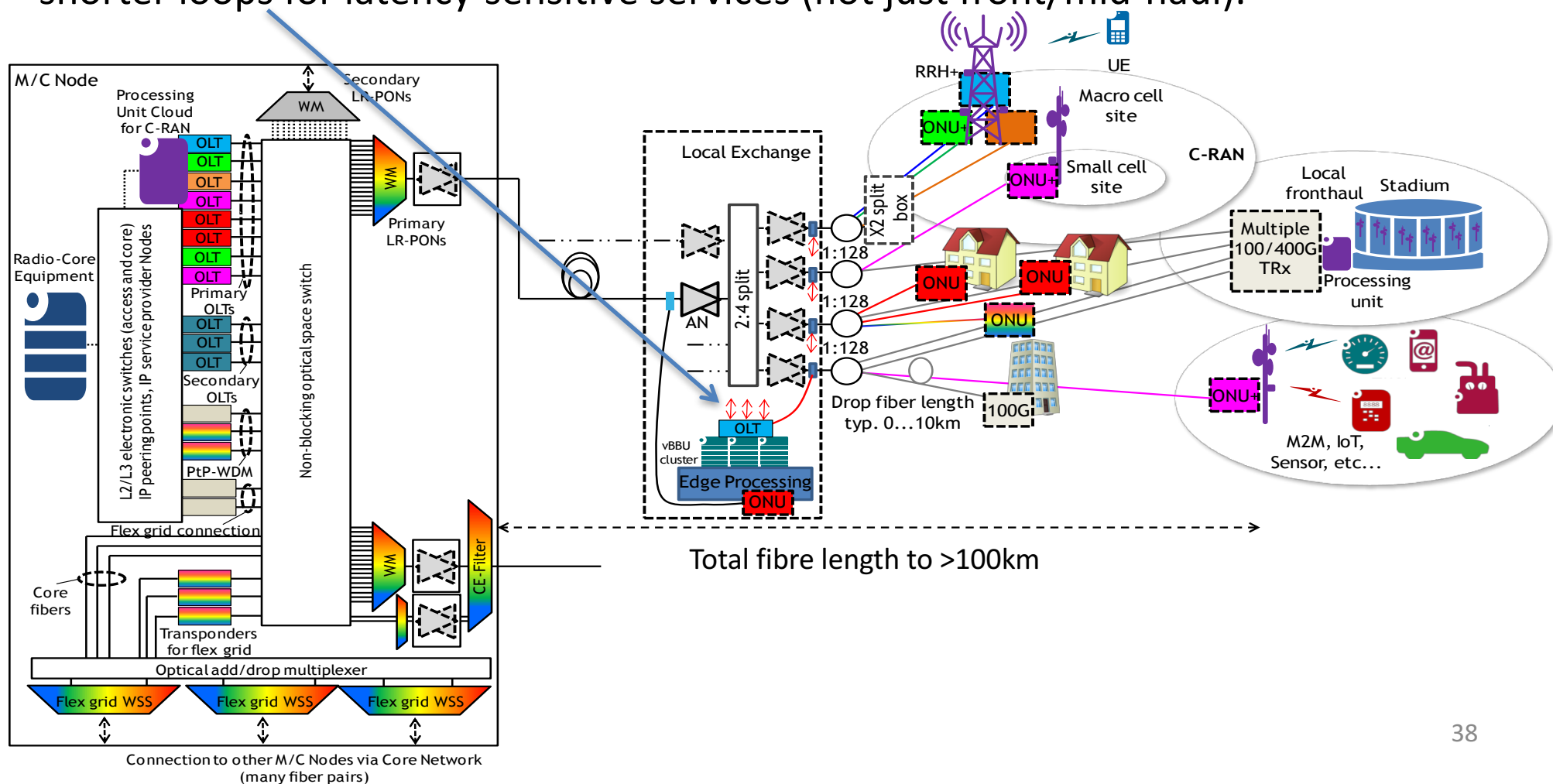
Data centre integration

- 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

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Summary of requirements

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to deliver real value**
- Reliable applications (reliable capacity, latency, survivability,…)
- Application availability anytime anywhere (really ubiquitous network access)

**5G requirements:
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- Multiple technologies working seamlessly together
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Improve network business case
- Reduction of network operating cost
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Requirements enabled by consolidation, service multiplexing

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Access/Metro Convergence

Space domain

Consolidation

Multi Tenancy

Ownership domain

Multi Service

Service domain

Heteregeneous Infrastructure

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??

Open access

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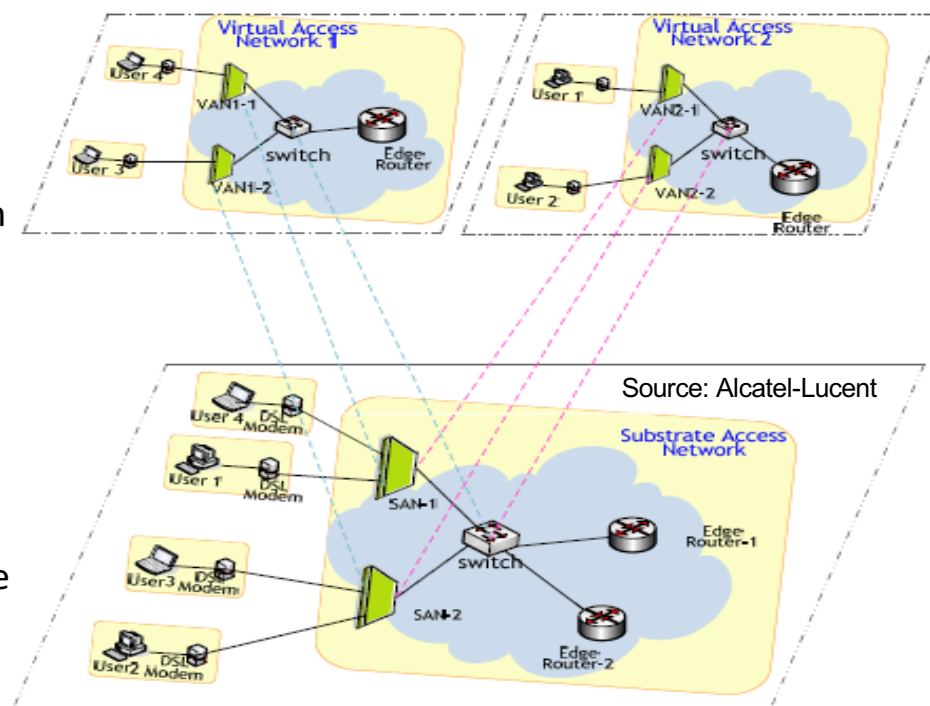
Source: Bruno Cornaglia (Vodafone) 2014 Broadband Forum presentation: "Fixed Access Network Virtualization"

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

www.oshare.ie

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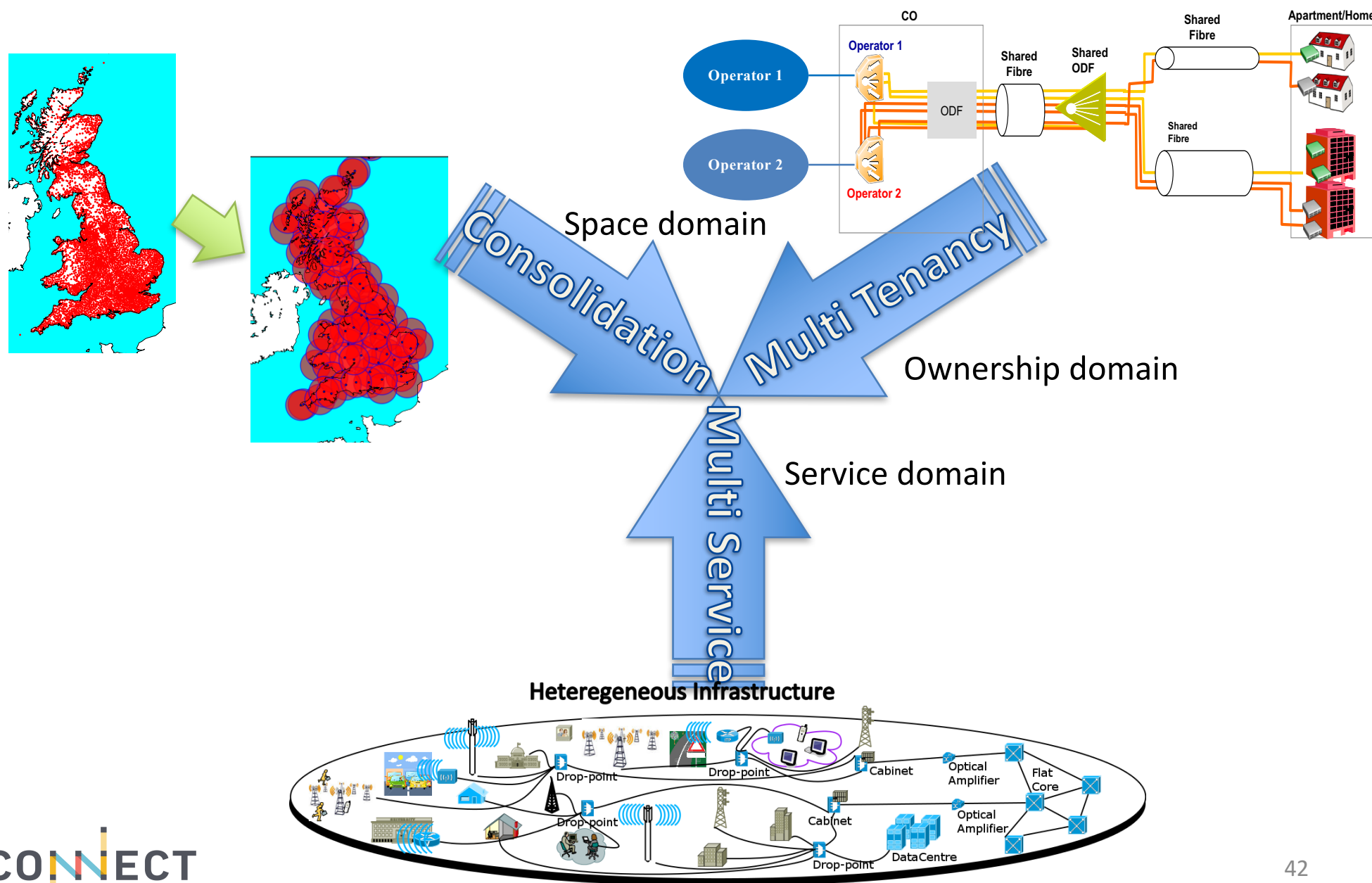- Application availability anytime anywhere (really ubiquitous network access)

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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

Residence/Enterprise | Central Office | Backbone Core | Data Center

ONU

ACCaaS   SUBaaS   CDN   INTaaS

OLT as white-box switch

19" Ethernet Ports   GPON Ports
1-4 5-8 9-12 13-16 17-20 21-24 25-28 29-32 33-36 37-40 41-44 45-48

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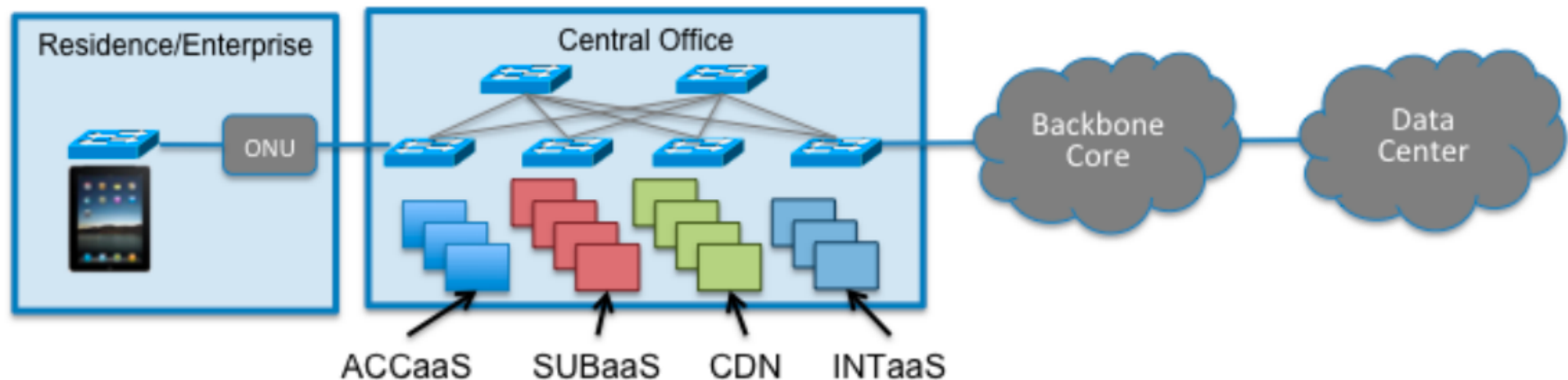
SDN enabling innovation and convergence

- 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
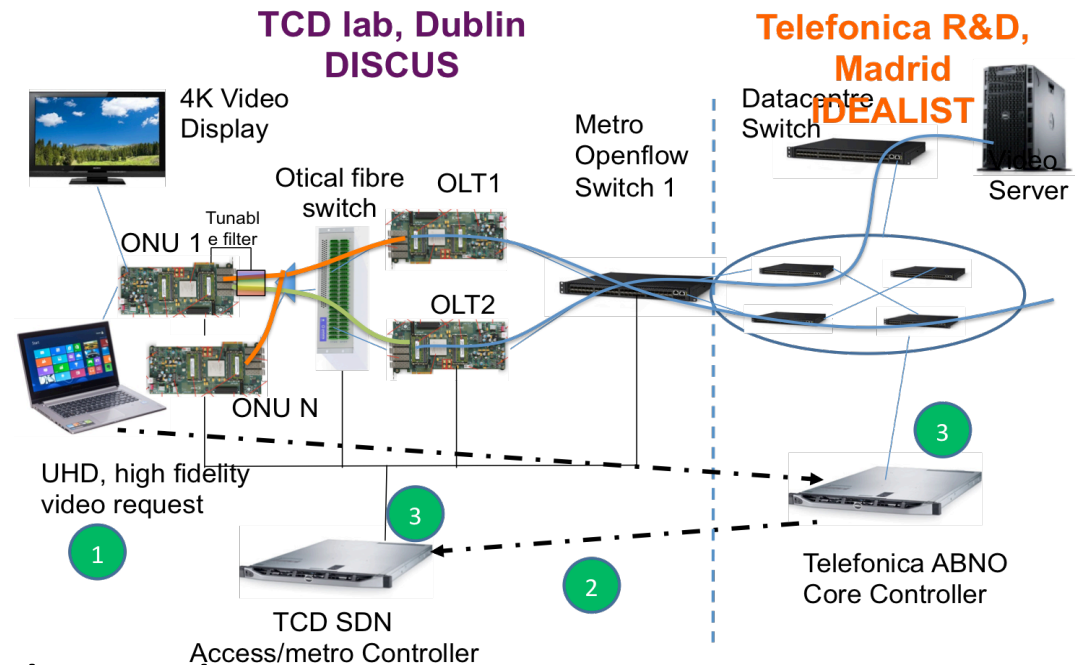
- Access/metro re-architected as a data centre
  - Flat LAyer Two Large-scale Network (FLATLANd)
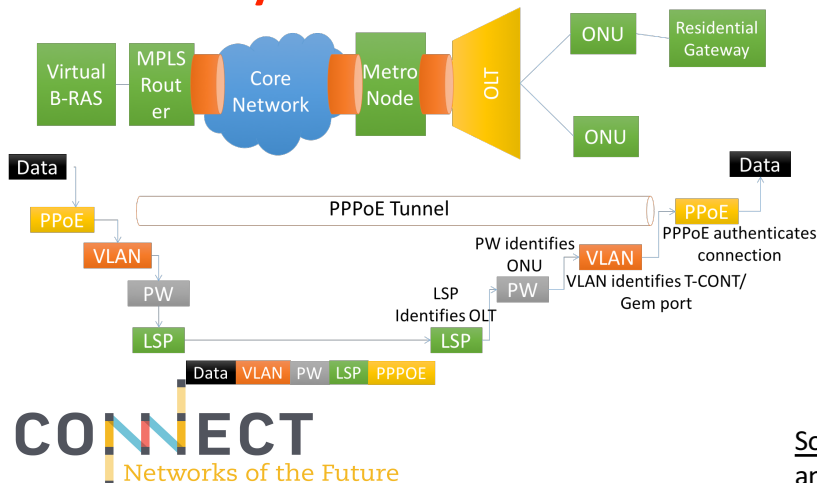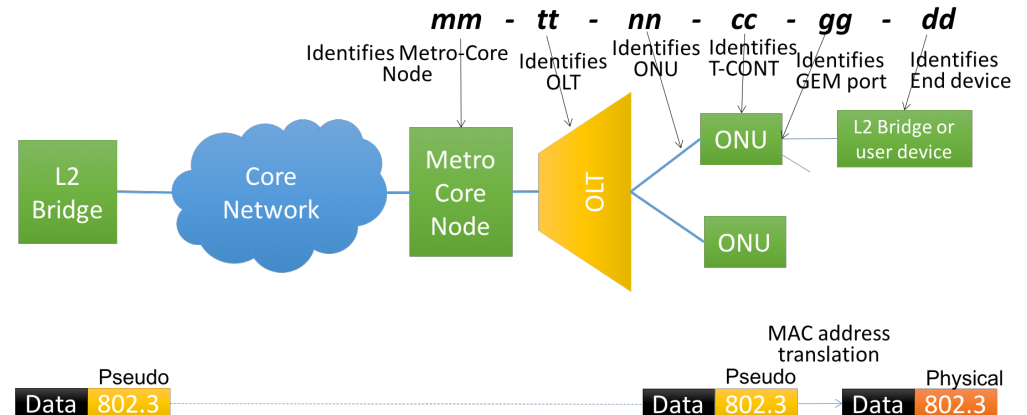
Source: F. Slayne et al., FLATLANd: A Novel SDN-Based Telecoms Network Architecture Enabling NFV and Metro-Access Convergence, to appear in ONDM 2016

Bristol is open

Wireless connectivity: 3G, 4G, LTE & 5G Technologies

ACTIVE NETWORK
- Fibre network
- Core network nodes with accessible rack space
- Network emulator
- High performance computer
- cityOS Software
- Data Dome

WIRELESS NETWORK
- Main hubs
- 'Sub-hubs'

3G, 4G, LTE & 5G Technologies
60GHz & Experimental wireless
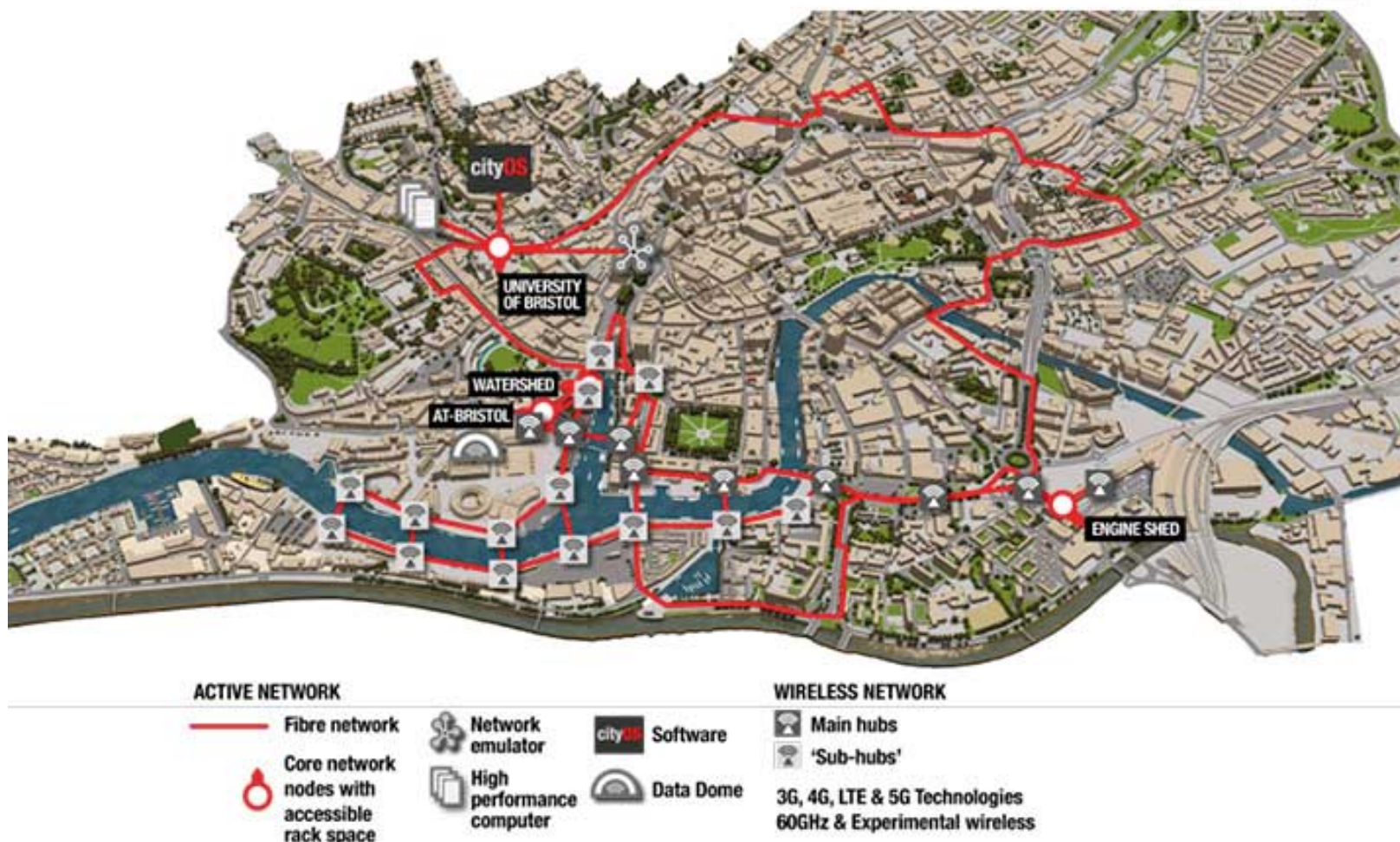
www.bristolisopen.com | @bristolisopen | #bristolisopen

OPEN PROGRAMMABLE CITY REGION

~~Conclusions~~ Vision

Content-focused business models

Move from the
current model:
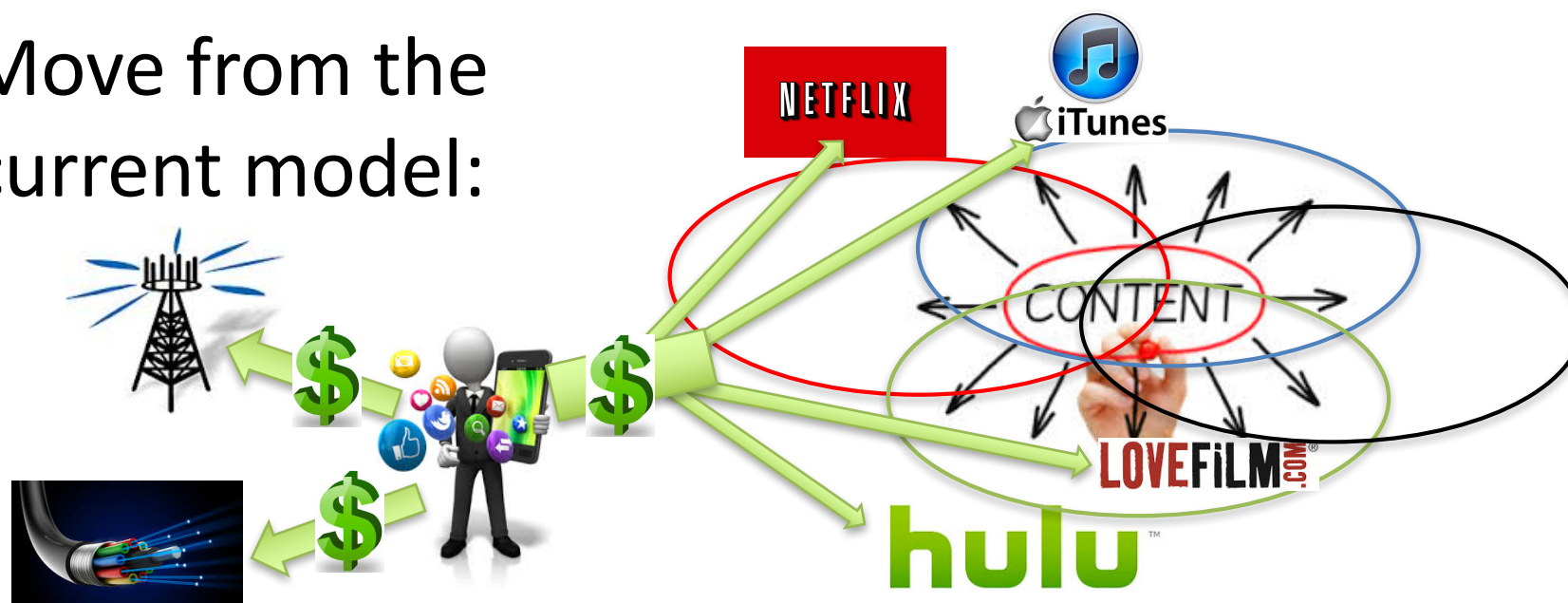
To a service-driven model:

Example: Amazon Kindle 3G

End-to-end ephemeral network

Aggregated services

Request: Services

Response: Aggregated Services

Application-oriented service provisioning

Ephemeral network connection

Virtualized service-oriented network

Virtual on-demand Network

Brokerage of pool of vitualized network resources

SDN orchestration

Heteregeneous Infrastructure

Services Networks
Resources Providers

Drop-point

Drop-point

Drop-point

Cabinet

Cabinet

Optical Amplifier

Optical Amplifier

Flat Core

DataCentre

Long Reach PON ~ 100km

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

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(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?!?

CONNECT
Networks of the Future

Thank you for your attention!

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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

Burst-mode receiver with FEC and differential range

M/C Node

BM-Rx Tx OLT

80 channels US/DS interleaved in C-band with EDFA SOA amplification for other bands

40G Bit interleaved protocol downstream

Coherent 100G point-to-point overlay channel

512- Total Split

Low-cost tunable laser

Low-cost SiP tunable filter

ONU

Tx

Rx   TF

10 Km

LE/CO

4 x 4

P2P

Optical Switch

90 Km

Optional day 1 WDM mux/demux

FPGA prototype of LR-PON OLT

1x16 1x8

1x4

FPGA prototype of LR-PON ONU

TF - Narrowband (Tuneable) Filter

- Circulator

- Connector

- Splice

4x4 Splitter

90 Km

Dual-homed protection

Stand-By: M/C Node

- EDFA

- MUX

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DISCUS Multi-service Metro-Core Node

Network Orchestrator

Core Network Controller

Access Node Controller

In-band

non- blocking single sided optical space switch

ONUs/ONTs

OLT OLT OLT OLT   OLT OLT OLT OLT

MPLS Access switch

Grey clients
Alien lambdas

Flexgrid WSS Line interface

Access

IP/MPLS service node (SP1)

IP/MPLS service node (SPn)

MPLS Core switch

ADD/DROP

Transponders/ regenerators

Duct routes out of Metro node to other nodes

Mux/Demux

IP/MPLS peering points (Internet)

many fibre pairs

IP/MPLS peering points (other NGNs)

Access elements

Core elements

SP elements

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
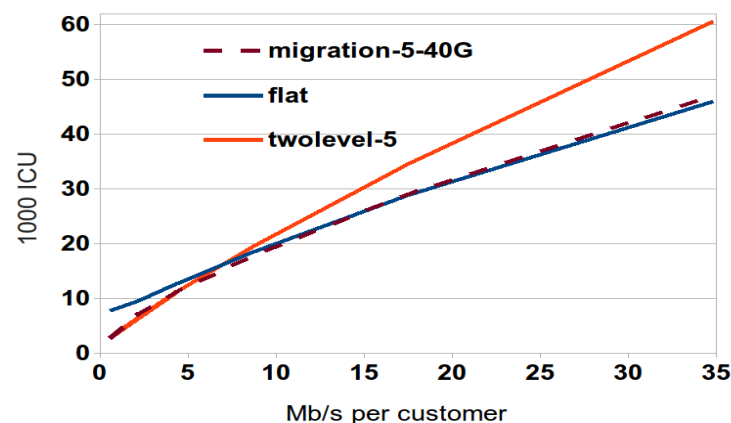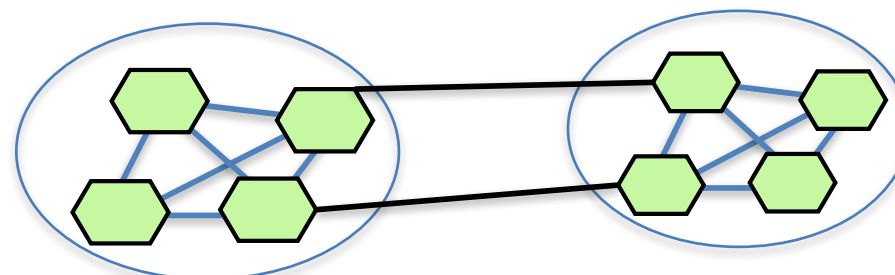
PON wavelength plan

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