A World Leading SFI Research Centre

Trinity College Dubli
Coláiste na Tríonóide, Baile Átha Clia
The University of Dublin

CONNECT
Centre for Future Networks

Edge cloud networking in support for Smart City applications: Open Ireland experimental approach

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CONNECT and IPIC research centres

Trinity College Dublin
The University of Dublin

Ireland's European Structural and Investment Funds Programmes 2014-2020
Co-funded by the Irish Government and the European Union

European Union
European Regional Development Fund

Science Foundation Ireland sfi For what's next

IPIC
BRINGING PHOTONICS TO LIFE

The Research group

OpenRAN Intelligent control

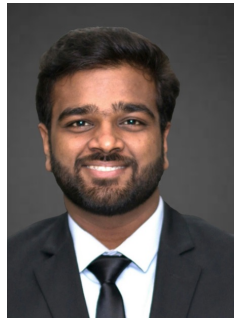
SDN control of quantum networks

Open Networking testbed

Heterogeneous access-metro networks

Free space
optics backhaul

Mininet-Optical
Optical network digital twin



PON
virtualization

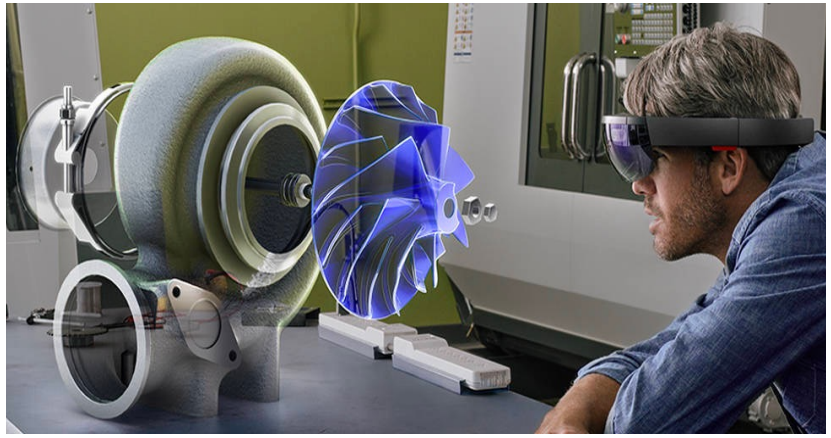
Mesh PON access

Edge-cloud
optimisation

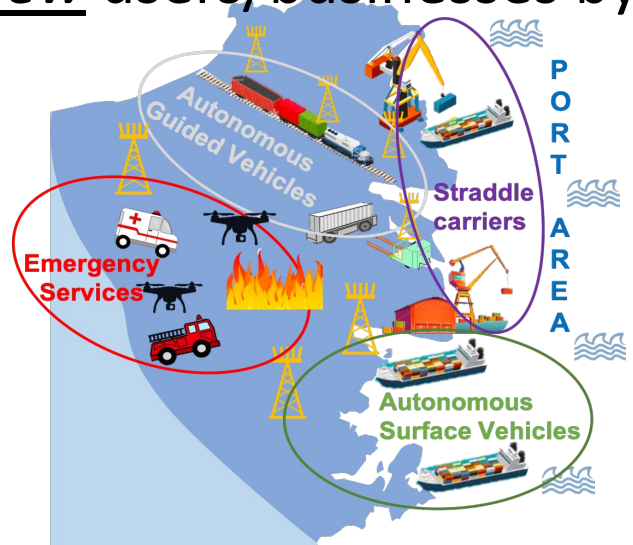
Multi-RAT
optimisation

The value is in new applications: how to attract them?

- Private networks will likely play a leading role in this area
- Driving innovation in end user devices (e.g., AR/VR goggles, etc.)



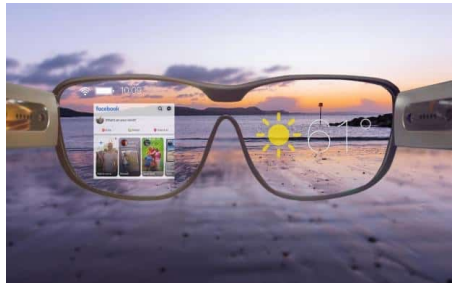
- Attract *new* users/businesses by providing new *unprecedented* features:

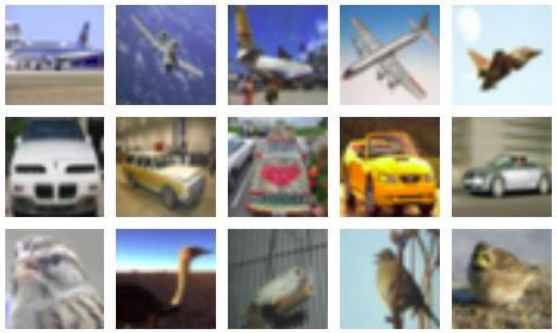


- Till the day we'll be fully immersed in the digital world…

High performance VR today

Object recognition

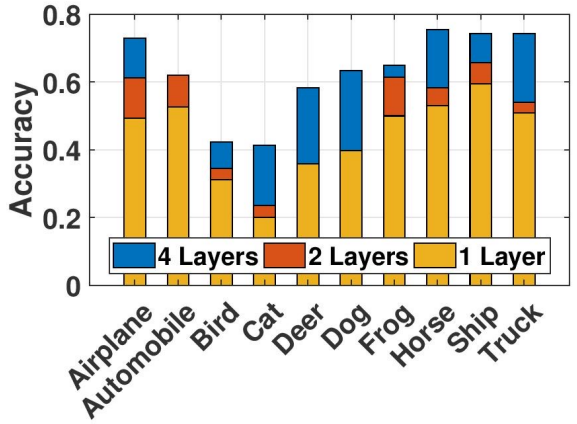




VS

laptop

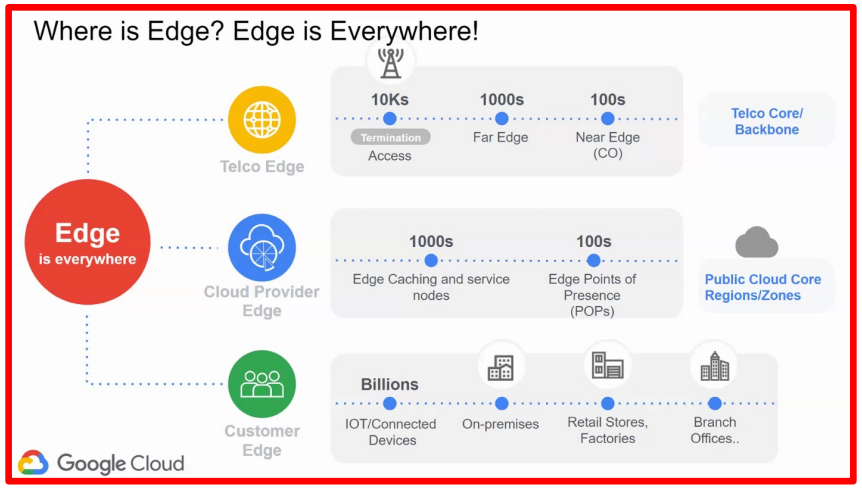
Average time: 2.537 s vs. 0.191

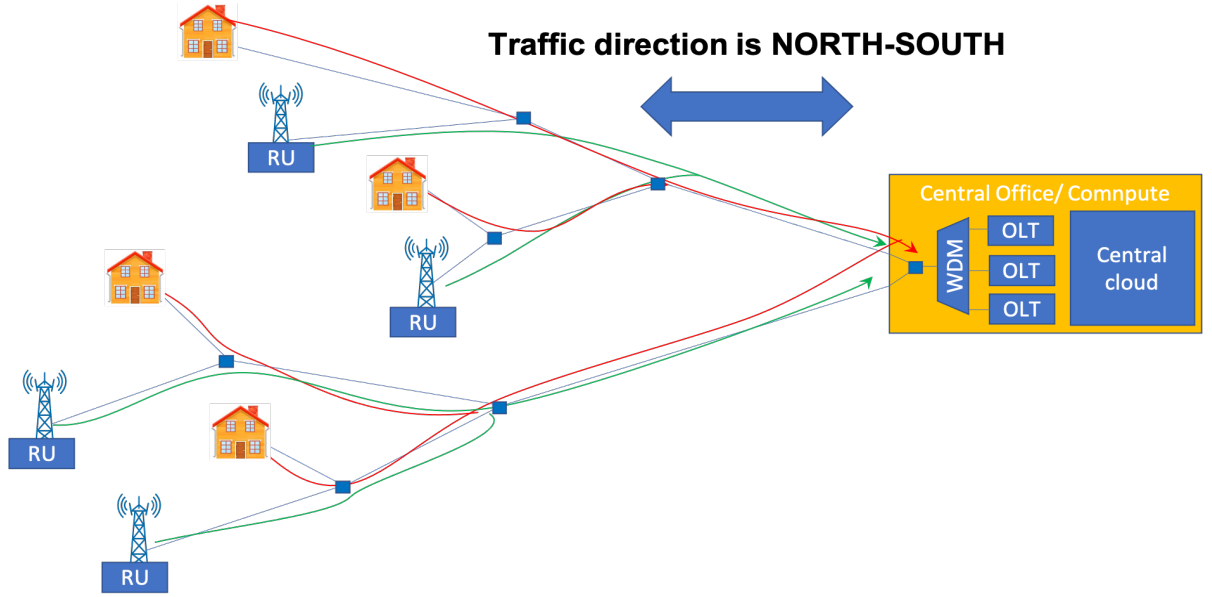


A. Galanopoulos, et al. Improving IoT Analytics through Selective Edge Execution, in proc. of IEEE ICC, 2020

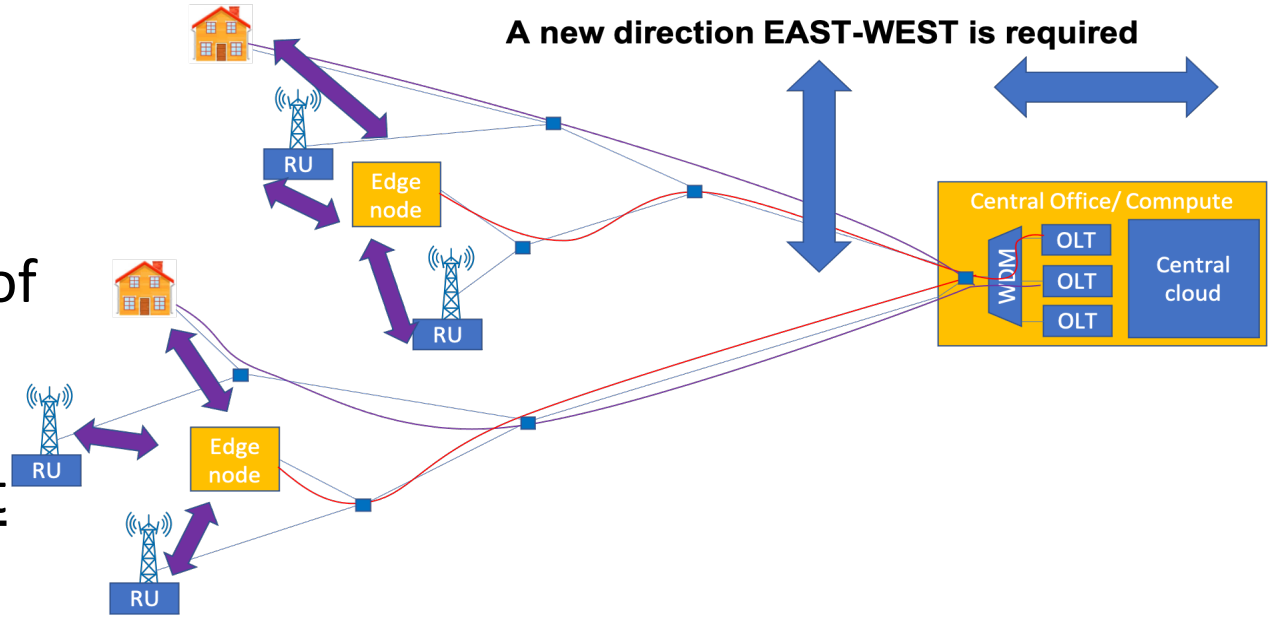
The edge connectivity problem

- PONs can carry the info back to the central office and can work for many applications

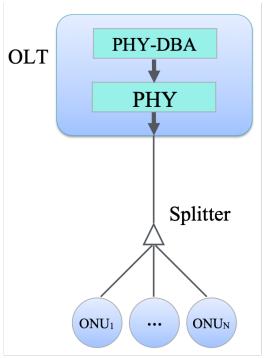




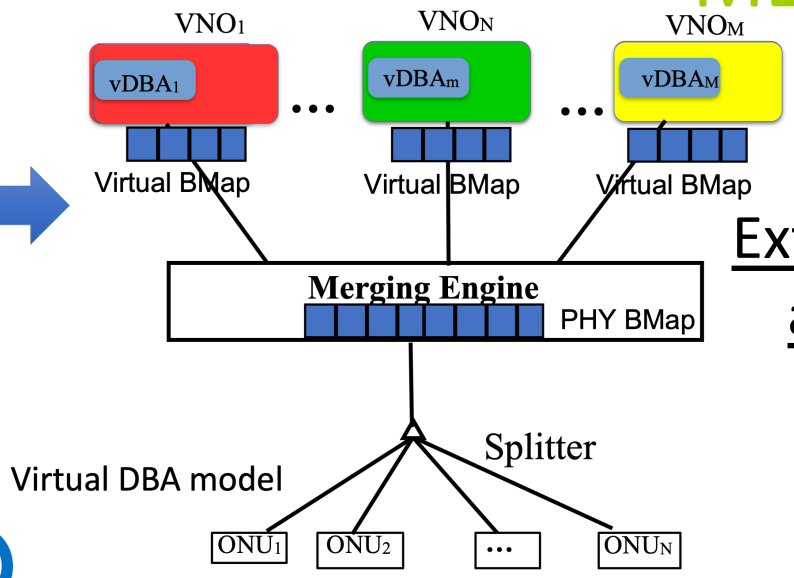
- For lower latency there are MEC nodes… that's why they were invented
- But traffic to edge nodes requires handling of direct end points communications (EAST-WEST)
- <u>This is also crucial for mobile functional split</u>



PON virtualization and Mesh PON architectures for low-latency MEC support

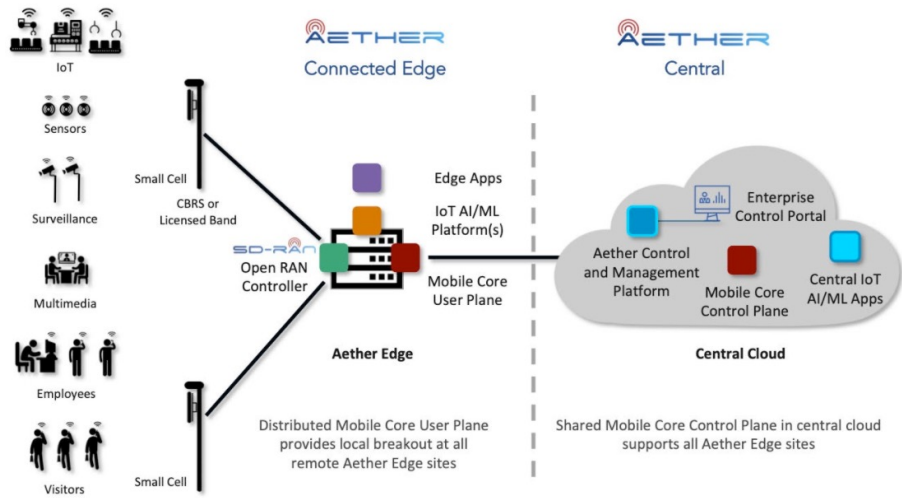


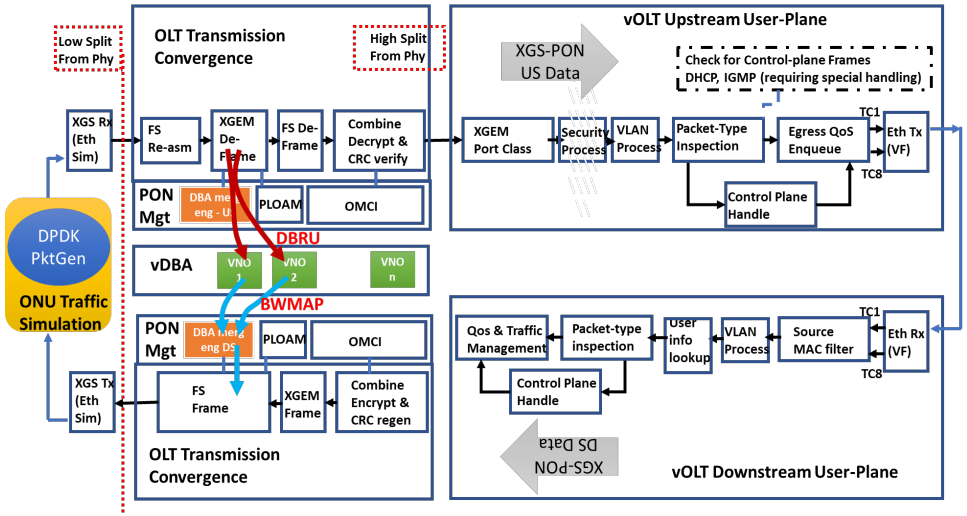
Current physical DBA model



Virtual DBA model

Extend PON physical and virtual layer

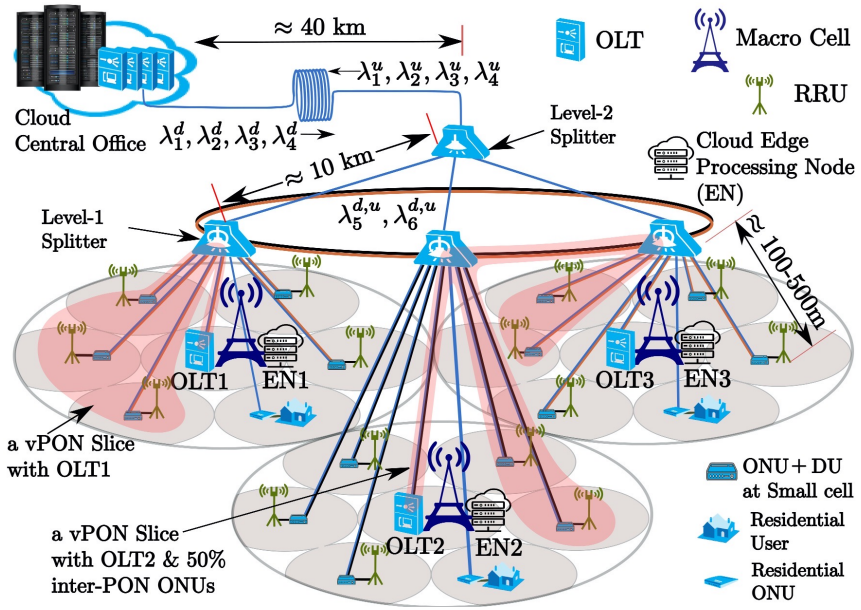




Prototyped PON scheduling virtualization

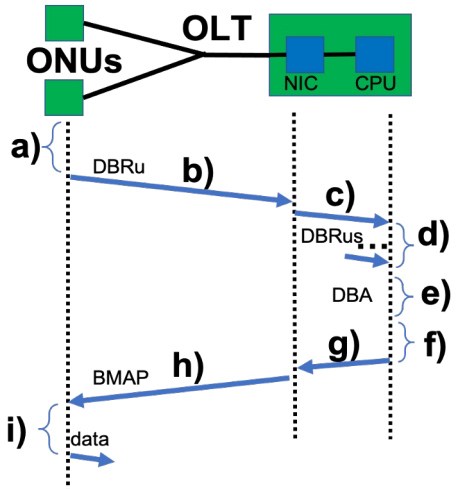
Support high-capacity, low latency communications in a mesh access topology

Extensively published,, standardised at BroadBand Forum (T-402, TR-370i2, WT-477)

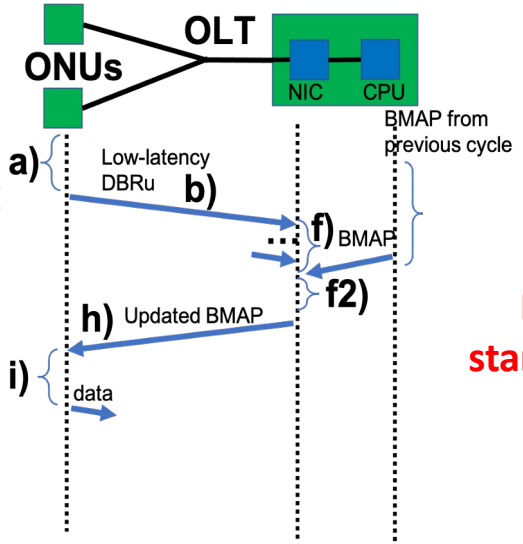


Moving the OLT to the cloud while keeping latency low

Standard DBA process



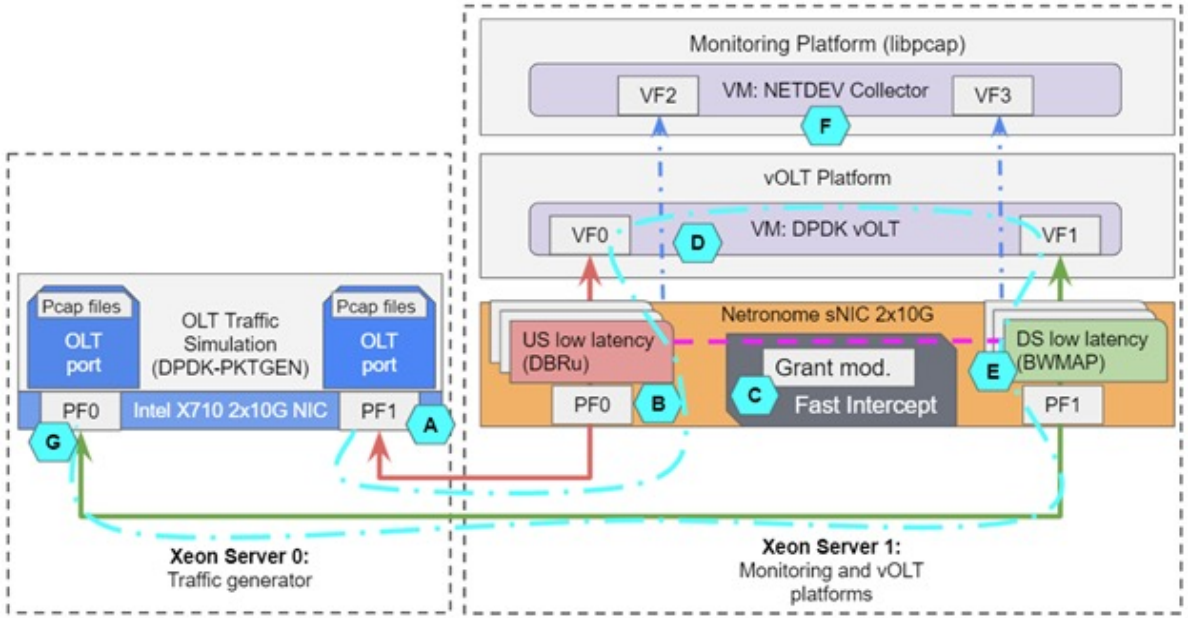
Fast intercept process



BroadBand Forum WT-477 standard is all about moving the OLT to the cloud

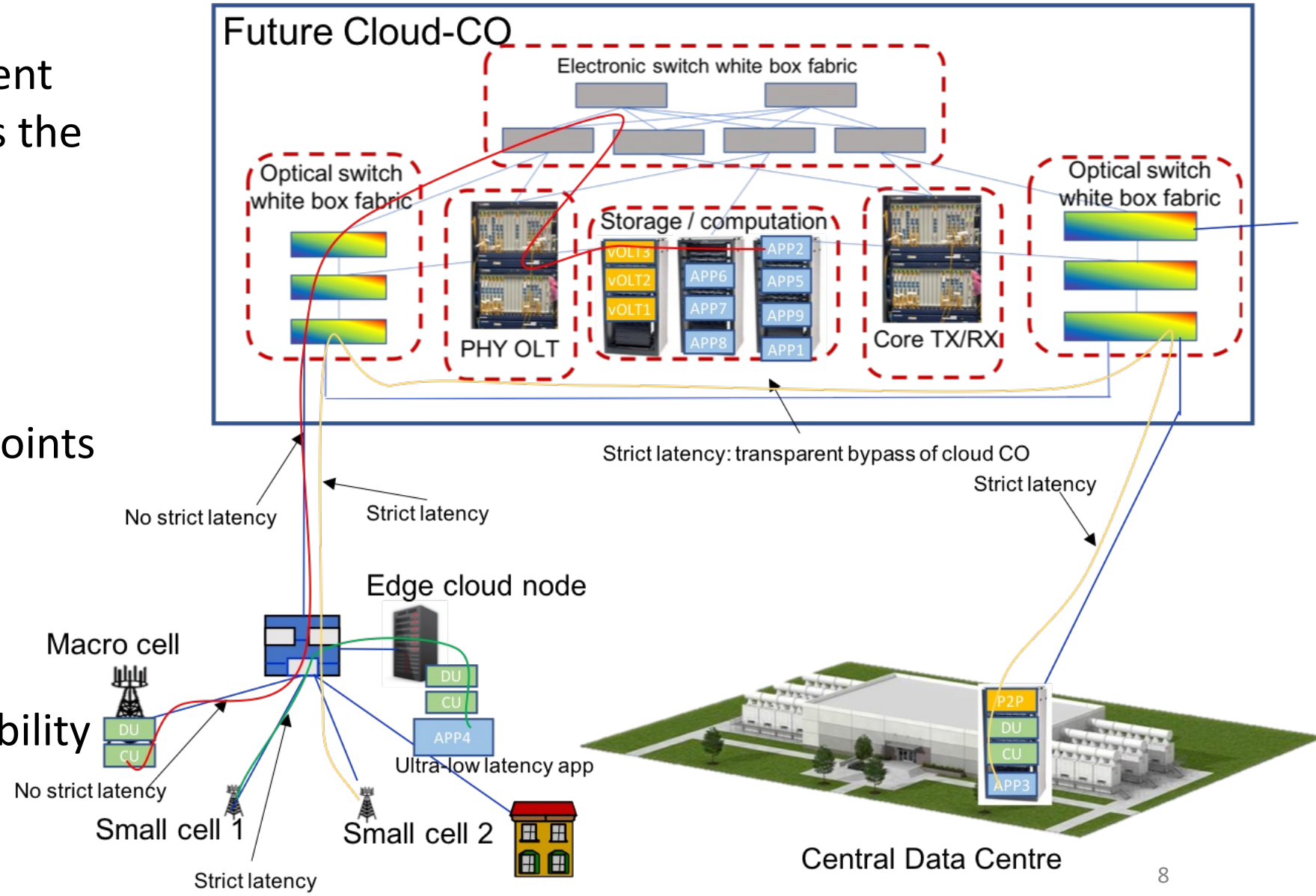
a. ONU waits for the opportunity for the DBRu
b. DBRu propagates through the fibre.
c. Information from phy to virtual process.
d. DBA process waits a time window to receive DBRus.
e. OLT runs the DBA algorithm.
f. BWMAP added to the next downstream frame.
g. BWMAP travels from virtual process to phy.
h. BWMAP propagates through the fibre.
i. ONU transmit the data at its allocated time.

- Standard DBA best latency =~ **418.5µs** (virtual implementation)
- Fast intercept avg latency =~ **237 µs** (~ 43% faster)



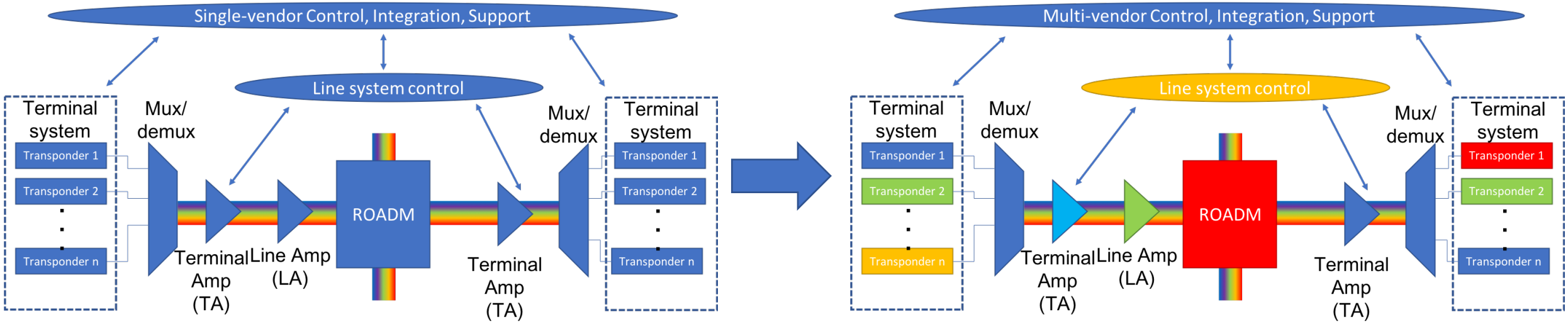
Extension to metro network

- Orchestration of transparent optical connections across the access and metro
- Flexibility in orchestrating computing (edge, CO and central)
- Flexibility in serving end points (cells and fixed users)
- Need for open optical networks for full programmability and flexibility



Optical layer impairments: the margins and network disaggregation issues

- The optical layer is analog: strong interaction between channels but expectation is ultra-high reliability (> 99.999%) ➔ leads to semi-static cautious approach
- … and use of safety margins, that make the network operate at fraction of possible throughput
- To make things worst, disaggregation has also reached the optical layer:



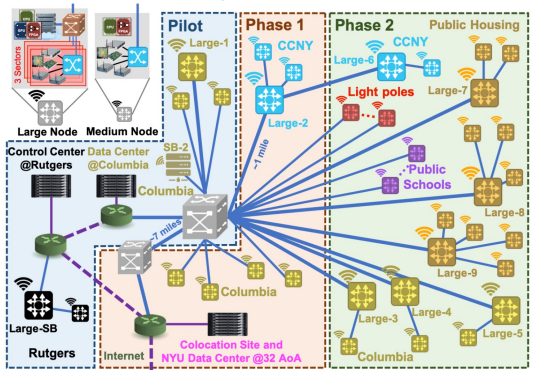
- What it means:
  - Mix and match transponders, amplifiers, ROADMs, control loops, optical control plane

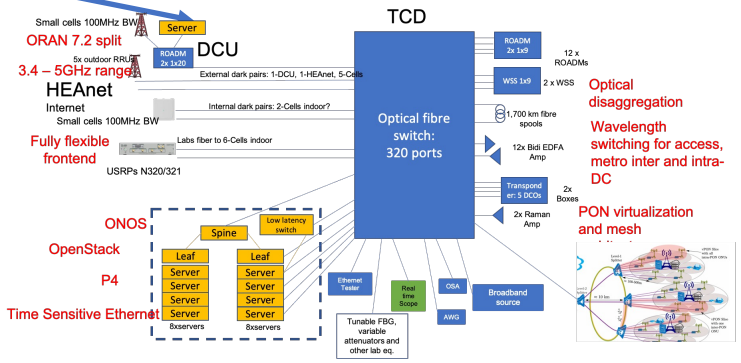
How do I test my control plane / algorithms?

Real network infrastructure is best!... but

1) Only available to operators (or large vendor/ service provider)
   - ➢Private network, only usable by owner
   - ➢If large scale, then part of production network, so very limited research/test
   - ➢If dedicated just for experiments then it's typically of limited size

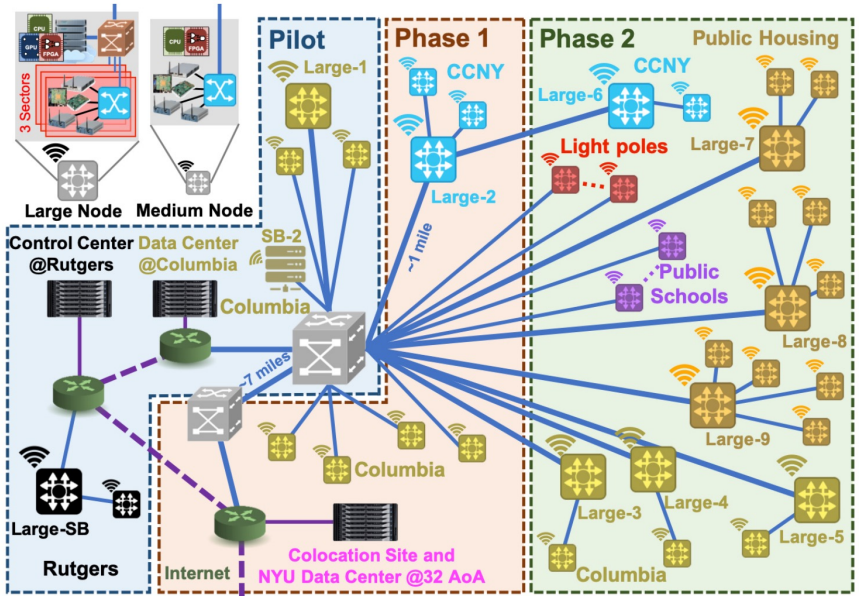
2) I can use public (academic) experimental academic infrastructure
   - i.e., **COSMOS (NY-US), OpenIreland (Dublin)**
   - Limited to a couple of thousand km and around 10 ROADMs



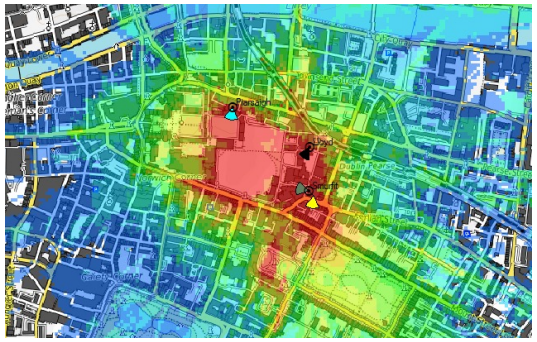


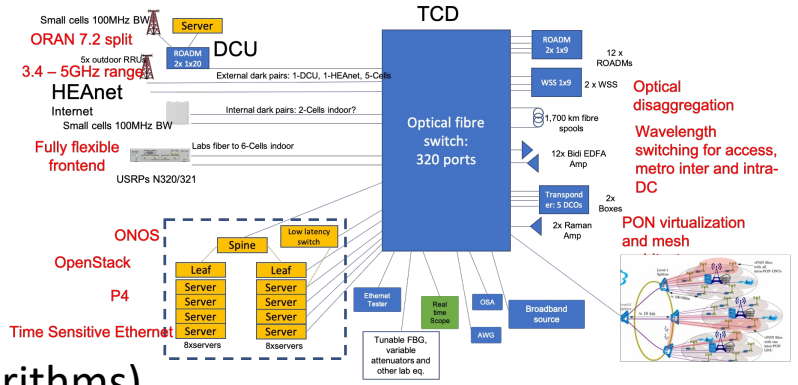
Digital twin for optical communication

COSMOS

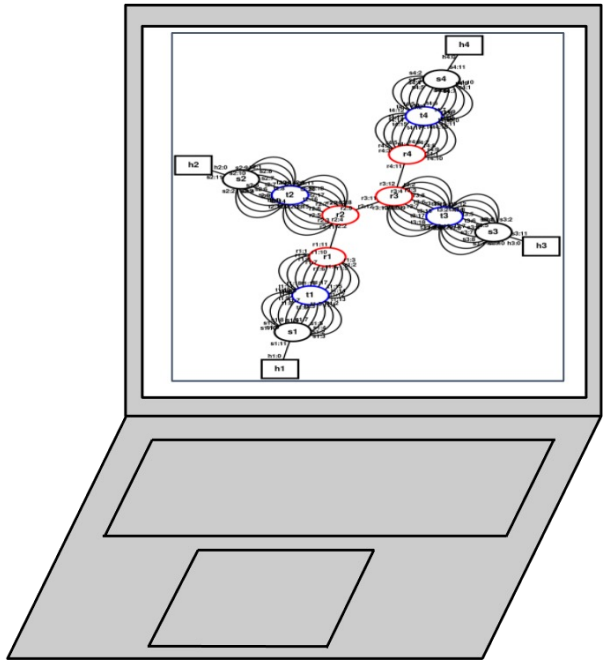


OpenIreland





Mininet-Optical



Network infrastructure experimentation for:

- Data collection (especially training of ML algorithms)
- Compatibility test with hardware interfaces
- Understand constraints (features, timing) from hardware devices
- Ultimate test on operability

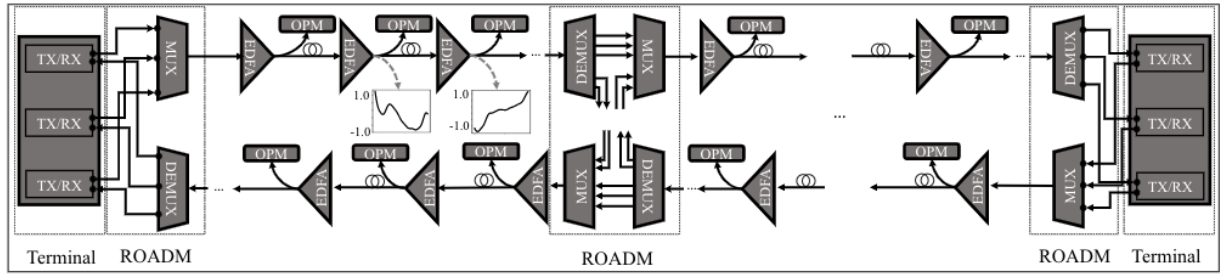
Network emulation for:

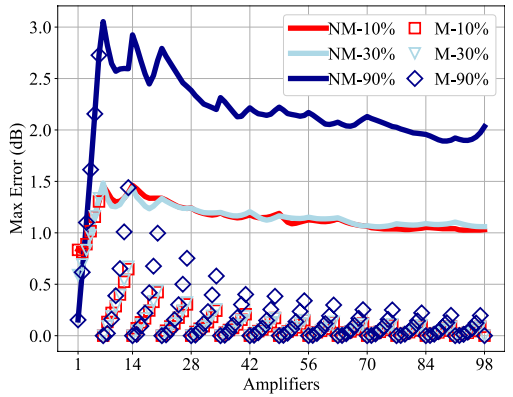
- Fast and ubiquitous experiment setup and testing
- Testing and debugging of conceptual ideas
- Scalability to thousands of nodes
- Accessible to all

Mininet becomes Optical!

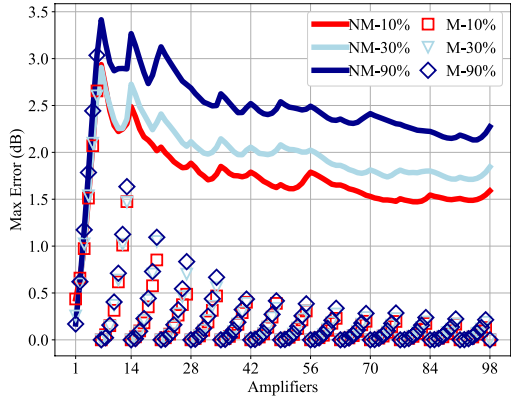
- We have created **Mininet-Optical**: an SDN emulator based on Mininet to emulate optical devices (ROADMs, amplifiers, transceivers, fibre propagation, etc.)

Example 1: analyse effect of taking periodice measurements to improve accuracy of estimation algorithm





Sequential channel loading



Random channel loading

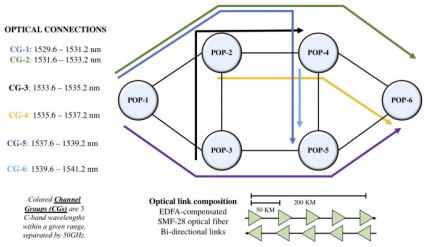
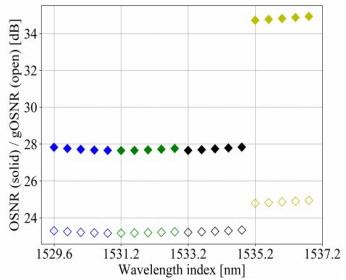


Fig. 3: Controller monitors OSNR (solid) and gOSNR (open) of all channels entering POP-4 (via POP-2) during the initial transmission



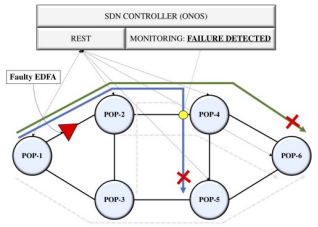
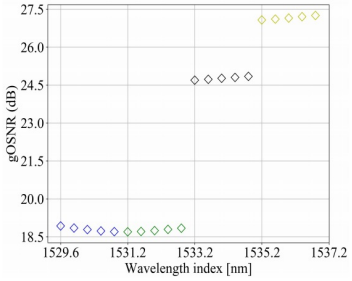


Fig. 4: Faulty EDFA degrades CG-1 and CG-2; controller observes low monitored gOSNR for signals entering POP-4 (via POP-2)



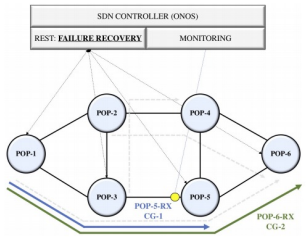
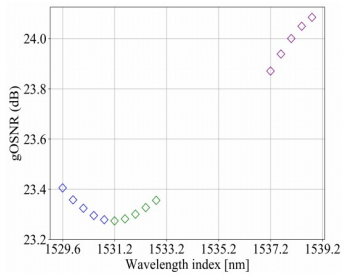


Fig. 5: Controller re-routes CG-1 and CG-2, resulting in high monitored gOSNR for signals entering POP-5 (via POP-3)



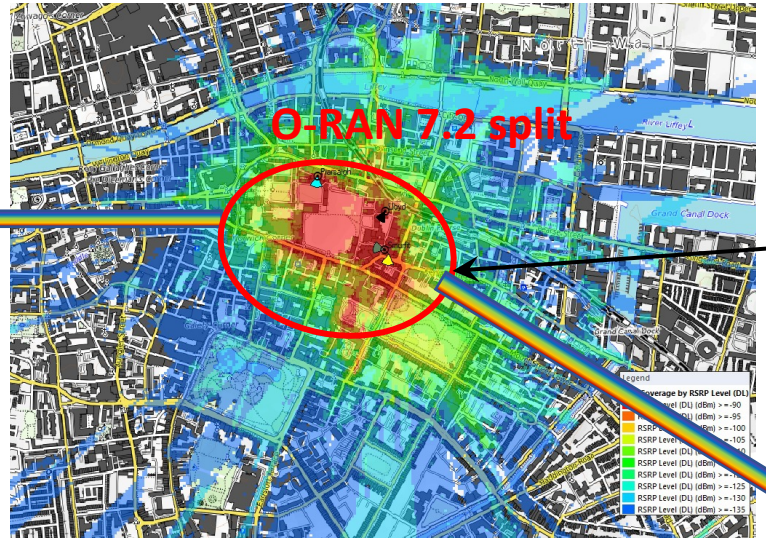
Example 2: simulating EDFA failure with sudden reduction of OSNR across group pf channels

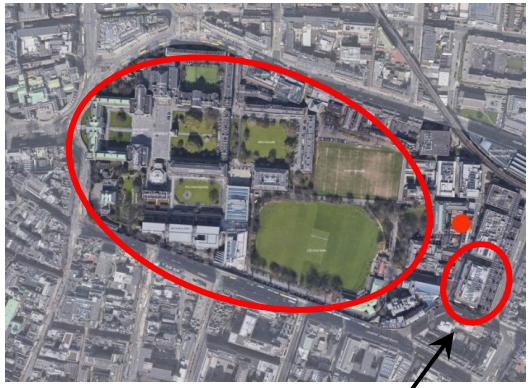
Open Ireland: Ireland's Open Networking Testbed

www.openireland.eu

Based in Trinity College campus

Optical transmission, analog RoF, mmWave-THz



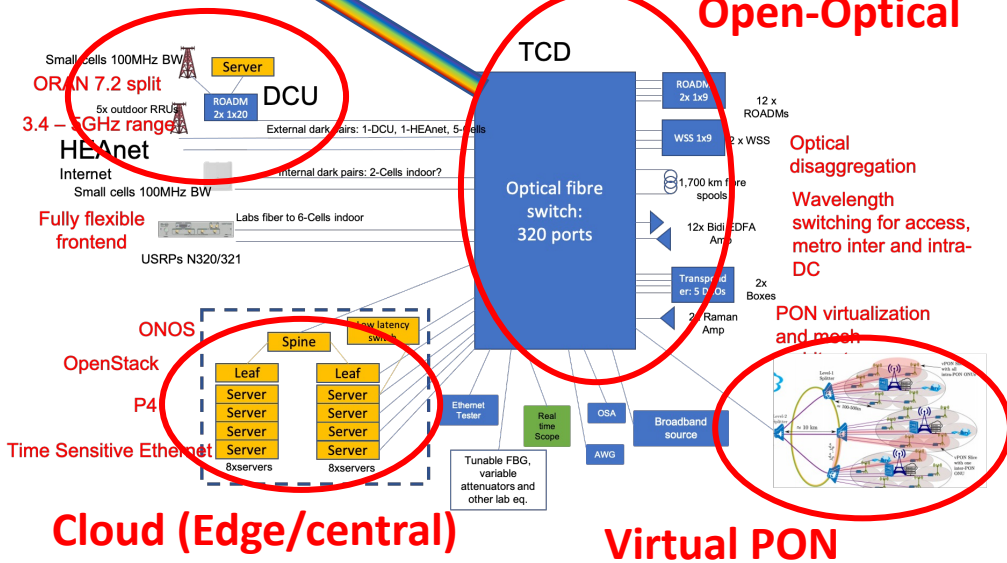


CONNECT research centre building

O-RAN

SDR

Open-Optical



Reconfigurable and **Lego-like** topology reconfiguration with following blocks:

- 1,700km fibre, **SDN ROADMs**, **amplifiers and coherent Tx** (Cassini), virtual PON, OSA, etc.
- **5G O-RAN** (outdoor and indoor); **OpenSource 5G** (OAI and SRS)
- **Edge cloud**, L2 switching, P4 programmability

ComReg 100MHz spectrum license

Existing 3.6 GHz for 5G | **Upper 4 GHz band for 5G**

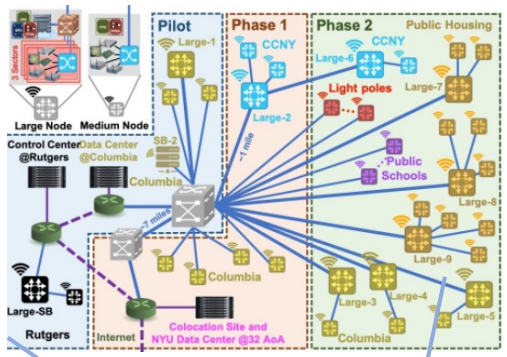
Region		A-Lot		3560 - 3620 B-Lots			
Borders Midlands & West South West East South East Dublin City and Suburbs Cork City and Suburbs Galway City and Suburbs Limerick City and Suburbs Waterford City and Suburbs	Guard Band	Airspan	State Services	Vodafone / Imagine / Airspan		Meteor	Three	CONNECT
Frequency Range (MHz)		3410 - 3435	3410 - 3475	3475 - 3580	3580 - 3615	3615 - 3700	3700 - 3800	3850 - 3950

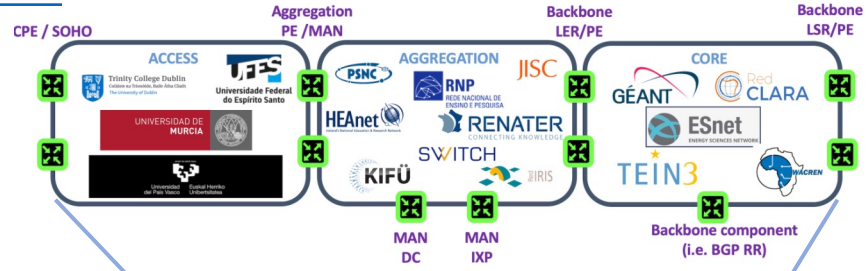
Upper N77 band: 3.8 – 4.2 GHZ

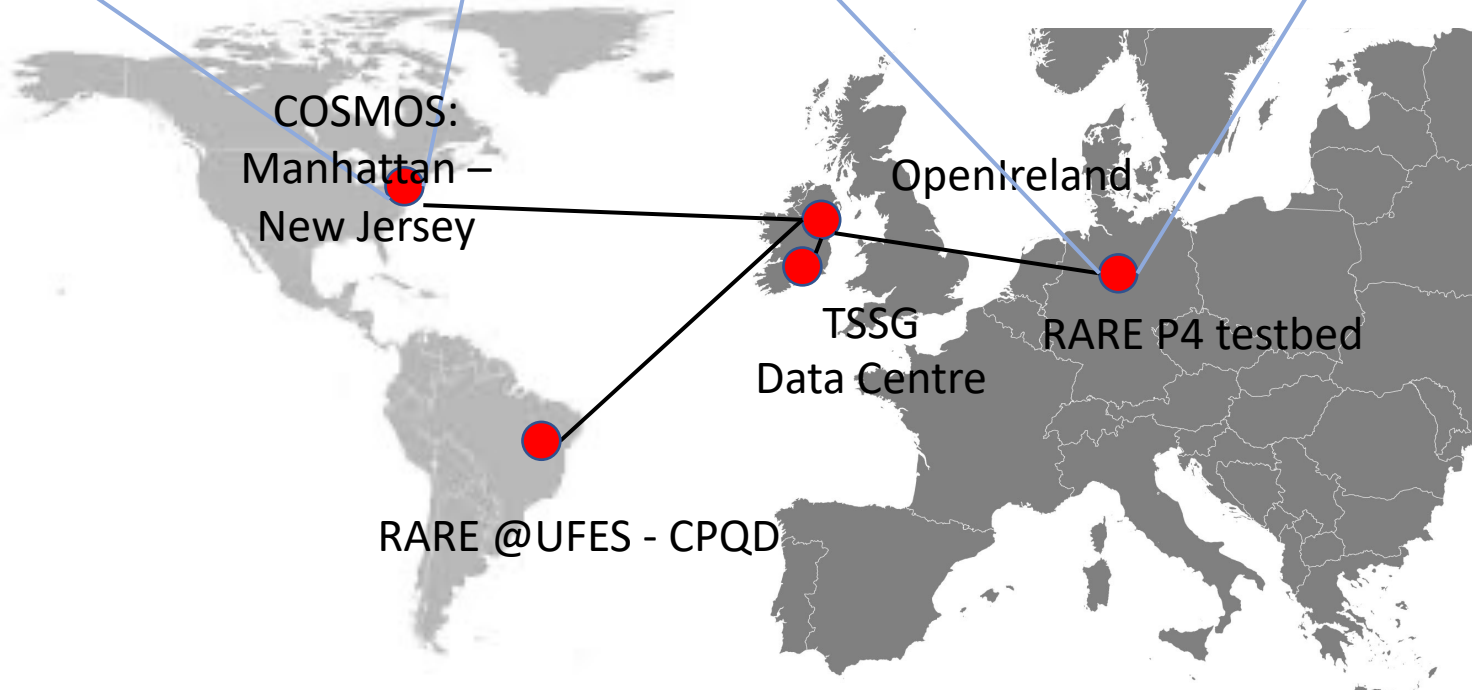
- 5G spectrum enables experimentation with commercial devices (smartphones and future AR, smart cities, etc)
- Use AI to solve complex network interference optimization problems based on real data
- Put together interesting 5G demos, such as smart intersection…

Worldwide reach… and further plans

https://wiki.cosmos-lab.org/wiki



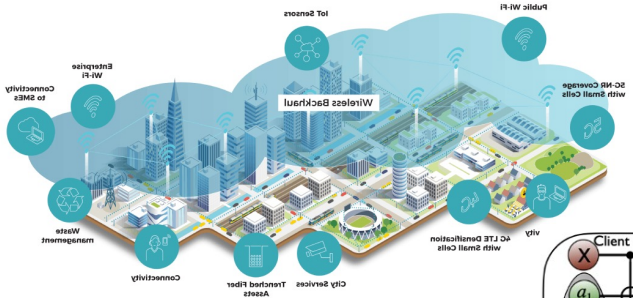




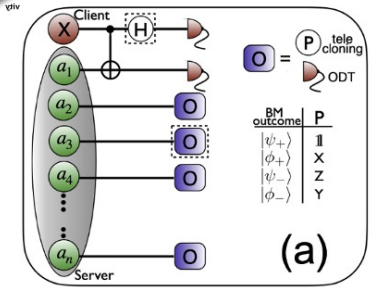
Foundation testbed in CONNECT2
Starting point for further exploration:

⇒ ***mmWave and THz experimentation***

⇒ ***Connected City Infrastructure***



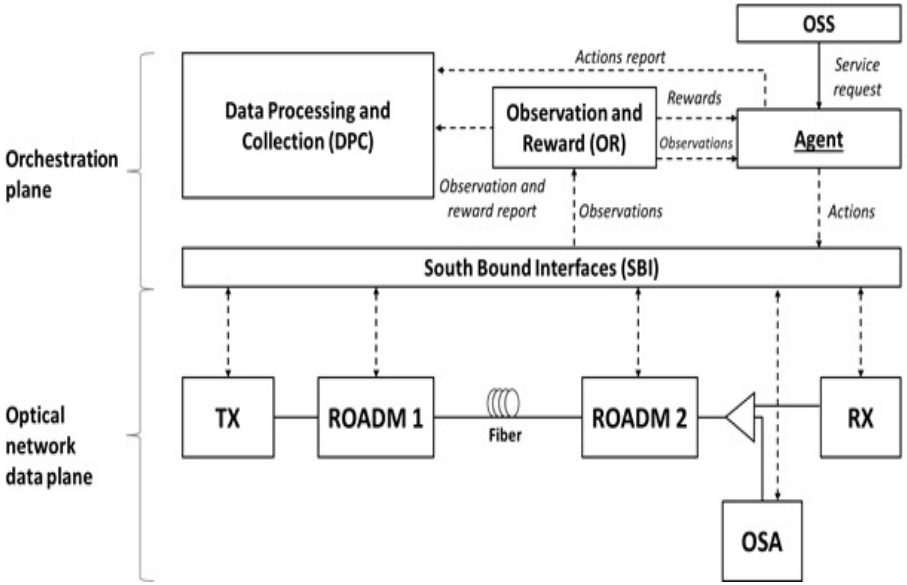
⇒ ***Quantum Internet***

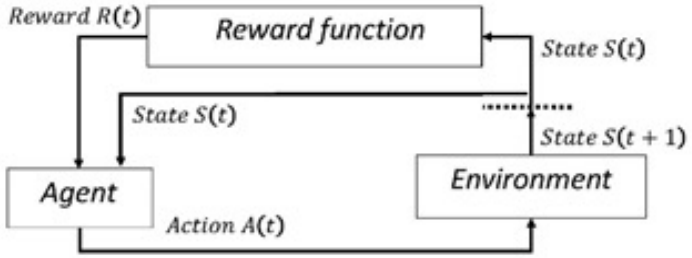


Sample use case: Building a QoT estimation algorithm

Control plane algorithm development and test based on simulation:

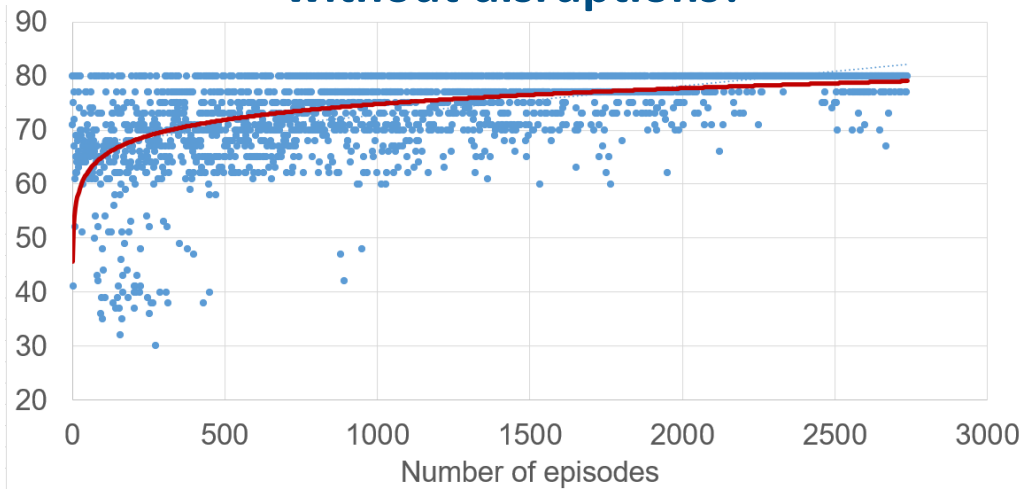
- Online learning through agent that loads the optical spectrum with optical channel and measures OSRN variation
- Through multiple iterations the agent improves strategy for channel selection





Work carried out with Politecnico di Milano optical group

How many channels are allocated without disruptions?

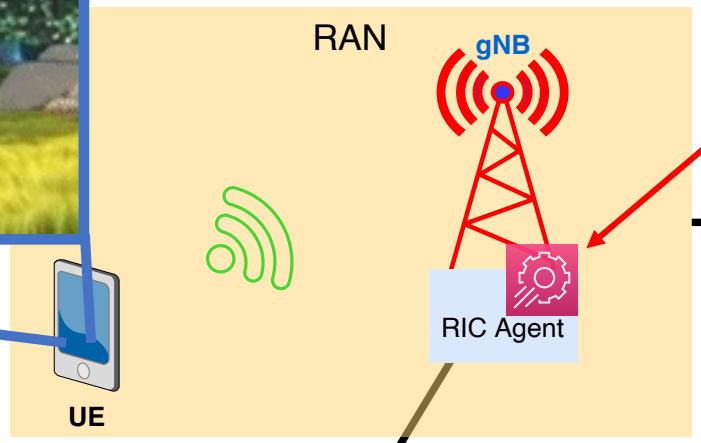


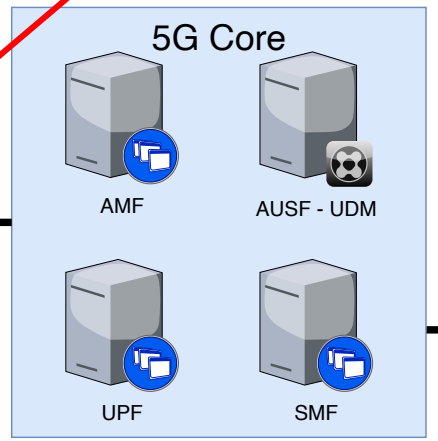
Use of simulated data plane

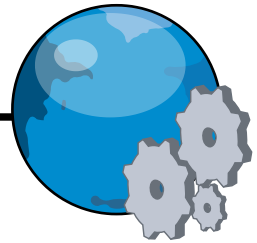
ORAN and RAN Intelligent Controller: video streaming use case

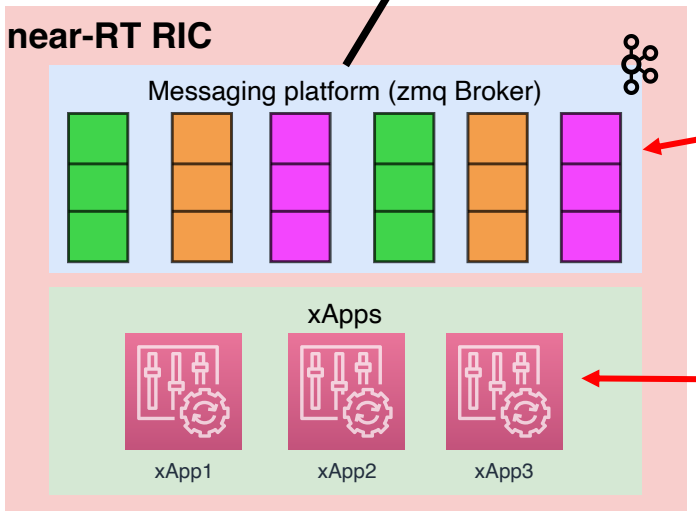
Buffering due to variable bitrate

RIC Agent communicates with the xApps through the messaging platform and applies the RAN reconfigurations







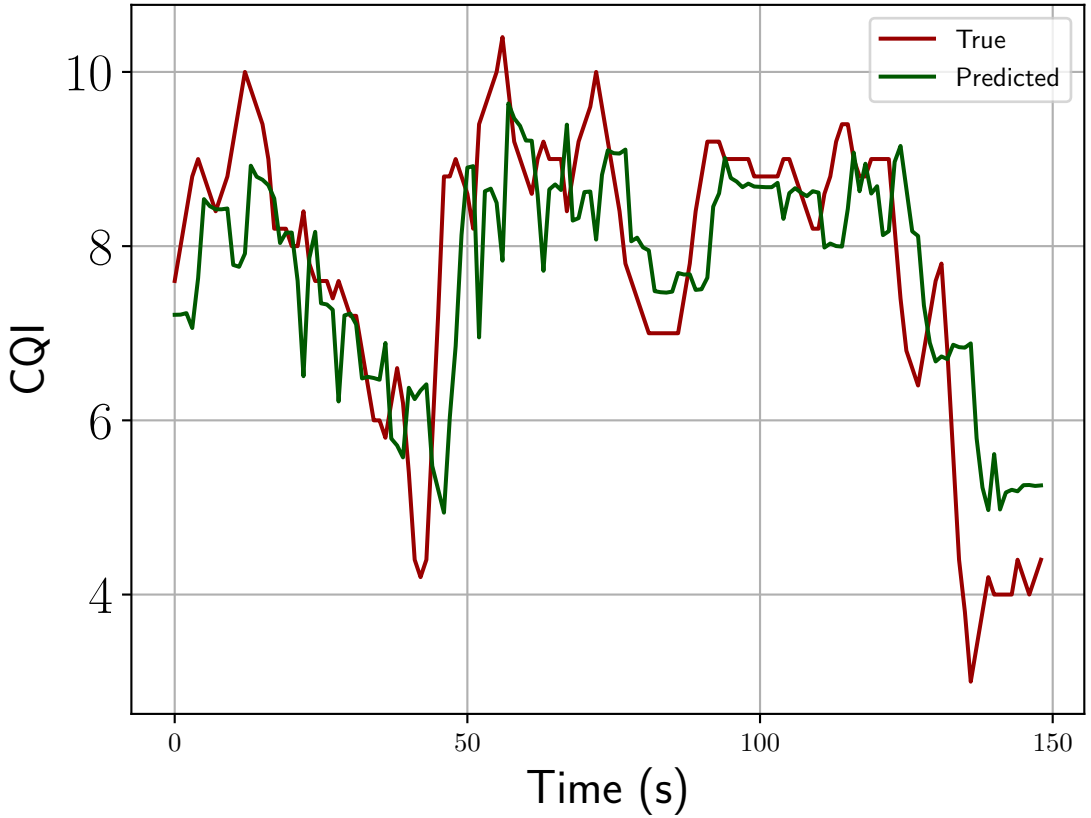


Near-RT RIC implementation done by our team in CONNECT

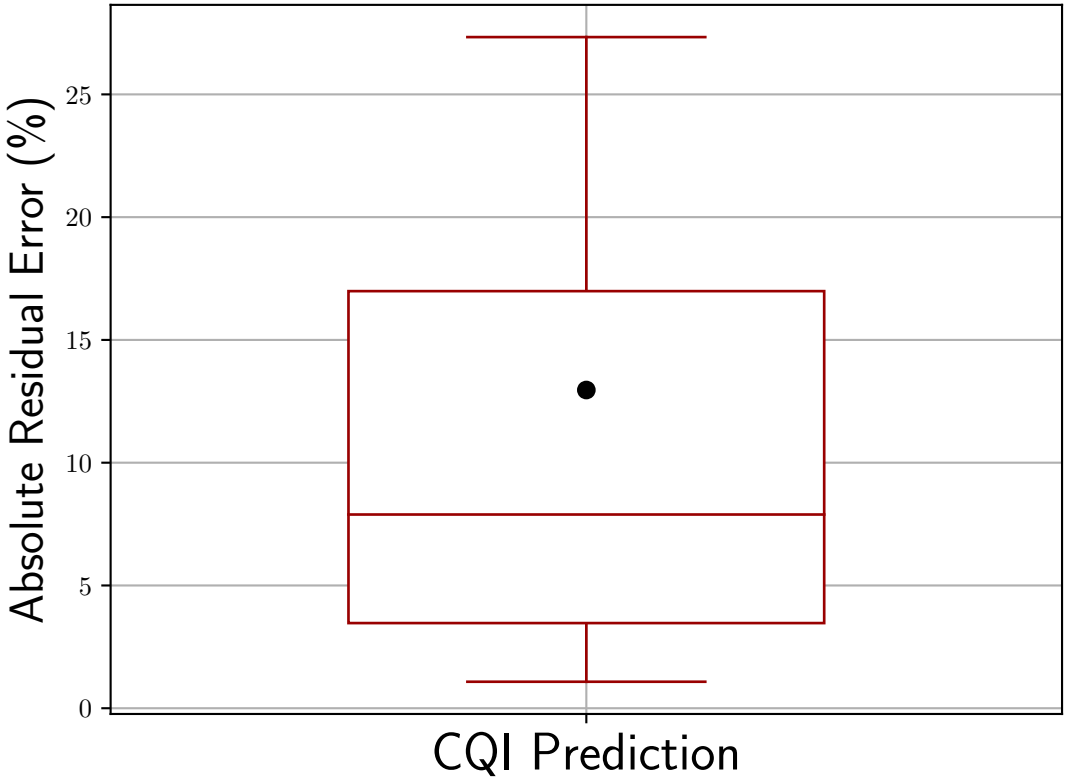
Messaging platform

xApps collecting measurements from the RAN and sending control messages to the gNBs

Preliminary results



Difference between the true CQI values measured in the network and the values predicted by the xApp (LSTM model).

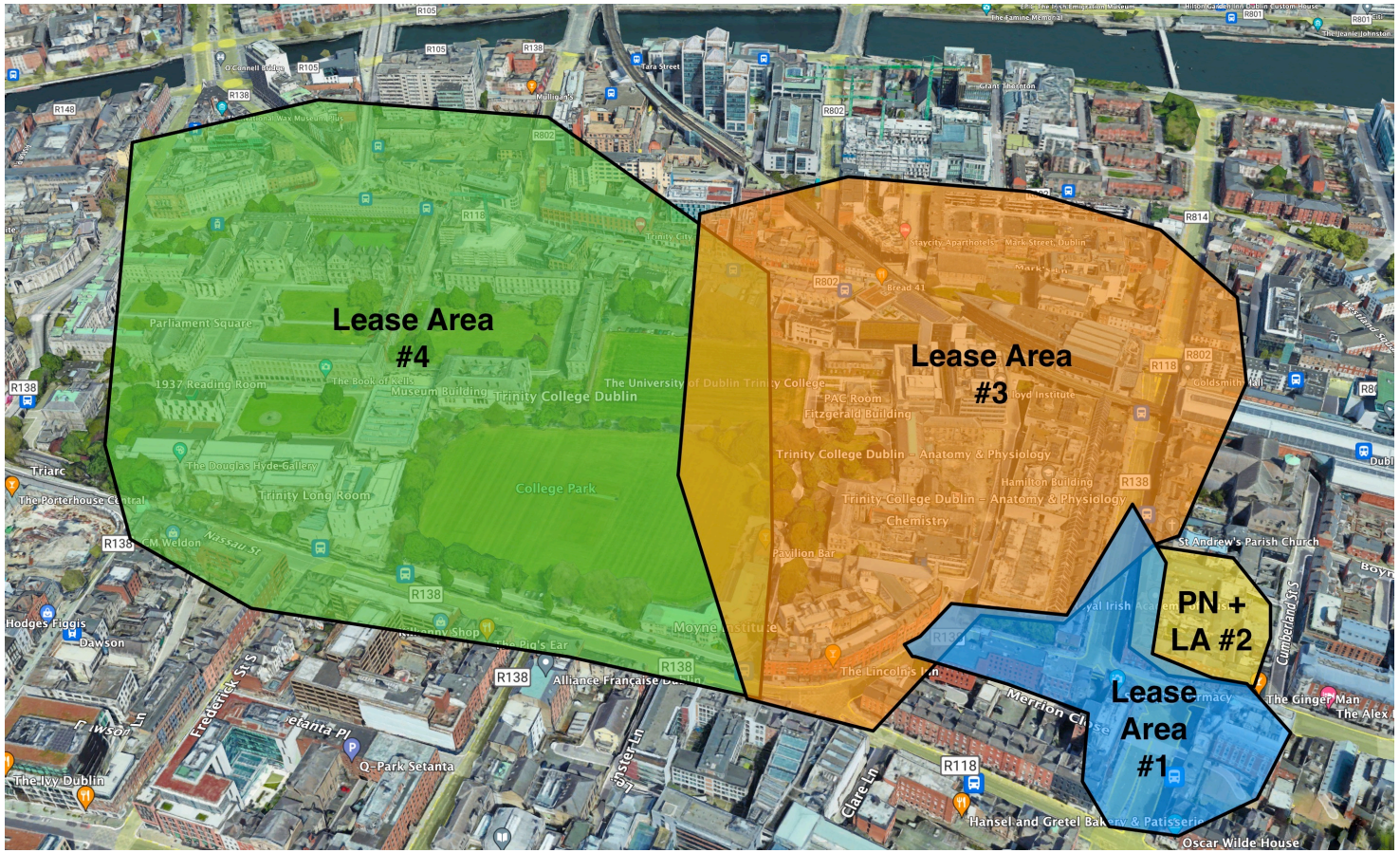


In 50% of the cases the error is below 8%, in 90% of the cases the error is below 26%.

Rivada Networks Demonstration at OpenIreland

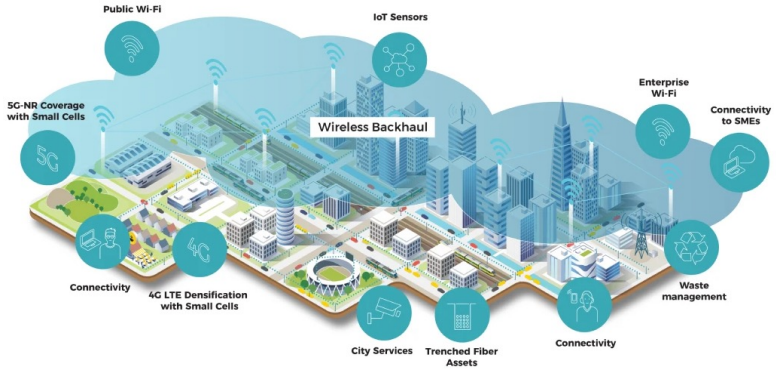
3 outdoor Lease Areas, 1 indoor Leas Area and 1 Private Network

- Network sharing demonstration:
  - Based on capacity lease across networks from different operators
    - The lease can move in and out of lease areas and are distinct, even within the same cell service area.
    - Spectrum sharing opportunities for organizations that require sporadic use of spectrum, but also require ruthless availability, such as public safety communications



Takeaway message

- Ubiquitous fibre connectivity with flexible topology will be instrumental for the growth of 5G and beyond
  - PON can provide low-cost access, but more work required for low latency, mesh topology, etc.
  - … and more study required for seamless integration into city/metro environment



TIP - Connected City Infrastructure, chaired by CONNECT and Dublin City Council

- The importance of city network research infrastructure has become very clear
  - Laboratory testbed experimentation is not able to fully capture the problems that often becomes showstoppers
  - This is critical for 5G and beyond where focus is on successful application rather than network performance

Thank you

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