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CONNECT
Centre for Future Networks

Improving Optical Control Plane Research and Development through Synergetic Testbed Experimentation and Emulation

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CONNECT research centre, Trinity College Dublin

IPIC BRINGING PHOTONICS TO LIFE

UCC University College Cork, Ireland
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NGI ATLANTIC.EU

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POLITECNICO MILANO 1863

It’s a Team Effort!

OpenIreland | COSMOS

NGIAtlantic: experimentation

Mininet Optical

NGIAtlantic: experimentation

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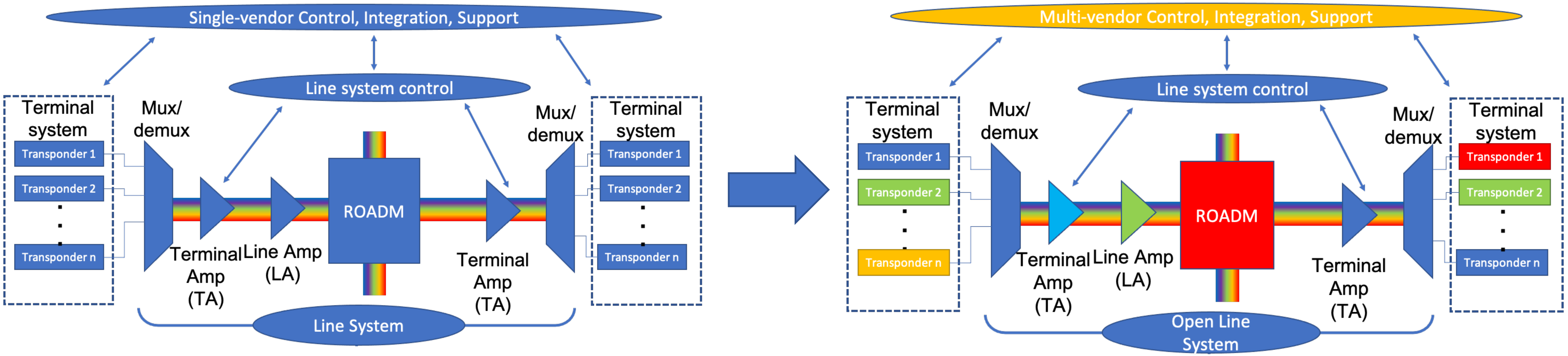
Summary

- Optical layer disaggregation
  - Uncertainty on optical margins
  - Recent work on embedding ML into control plane algorithms
- Control plane design: simulation or experimentation?
  - Open testbeds: COSMOS, OpenIreland
  - Open emulation tools: Mininet-Optical
- Merging simulation with experimentation
  - Use case1: Metro front-haul provisioning
  - Use case2: Building a QoT estimation algorithm

Optical layer disaggregation

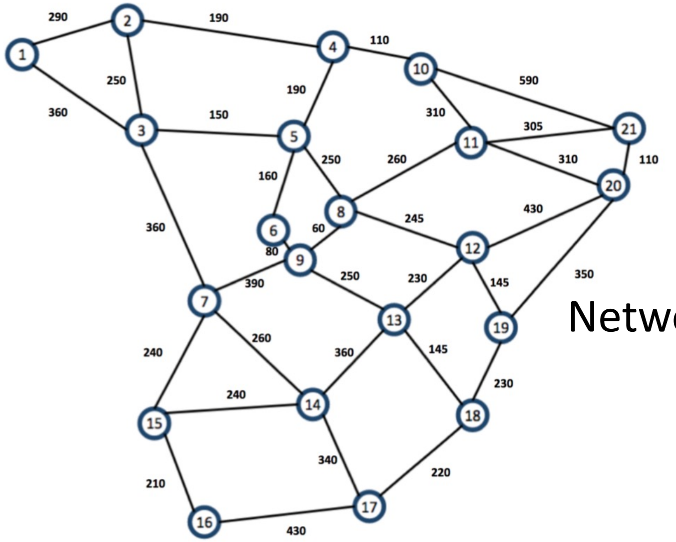
- The open networking movement has permeated across all aspects of networking: OpenRAN, cloud Central Office (SEBA), disaggregated optical networks.

- This show the optical layer disaggregation process:

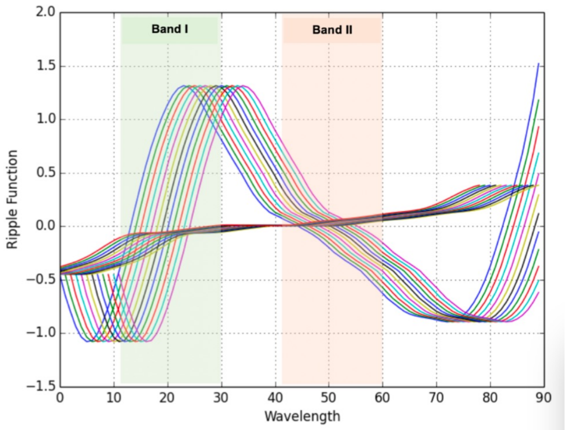


- What it means:
  - Mix and match transponders, amplifiers, ROADMs, control loops, optical control plane

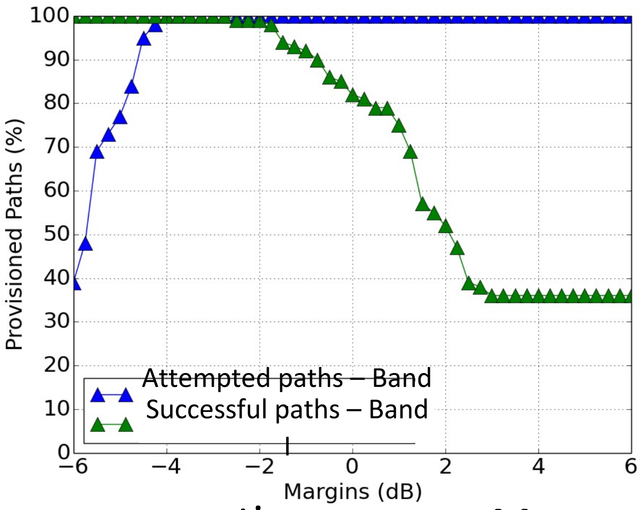
Studying the margins



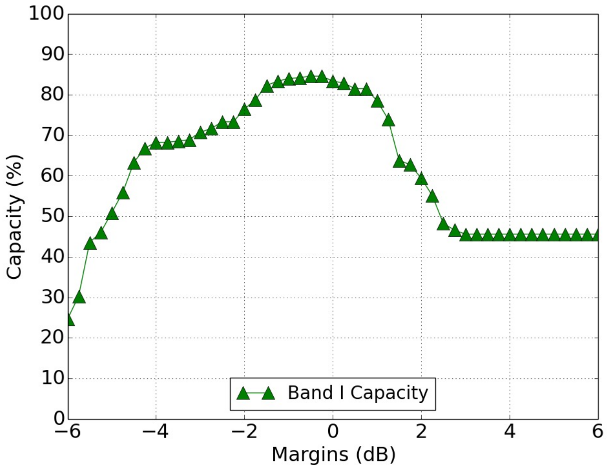
Network topology



Statistically distributed EDFA gain models



Estimation assumes flat amplifier gain



More conservative

More aggressive

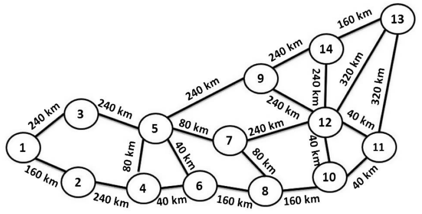
$OSNR_{est}$ + Margin > $OSNR_{th}$

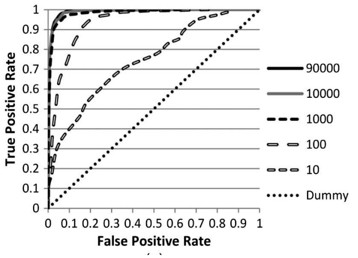
X axis: how conservative are the margins

Use of Machine Learning algorithms for QoT estimation, etc.

QoT prediction using random forest ML algorithm

Dependency on training set size

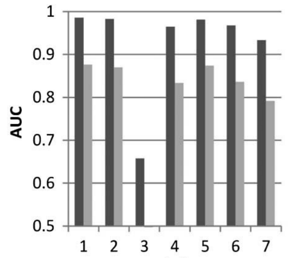




Relevance of different features

CONSIDERED FEATURE SUBSETS

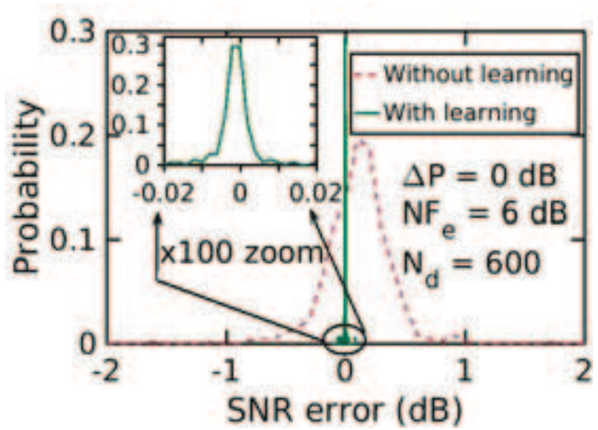
	S1	S2	S3	S4	S5	S6	S7
Number of links	✓	✓	✓	✓			
Lightpath length	✓	✓	✓	✓	✓	✓	
Length of longest link	✓	✓	✓	✓			
Traffic volume	✓	✓	✓		✓		✓
Modulation format	✓	✓		✓	✓	✓	✓
Guardband, modulation format, and traffic volume of nearest left and right neighbor	✓						



(a)

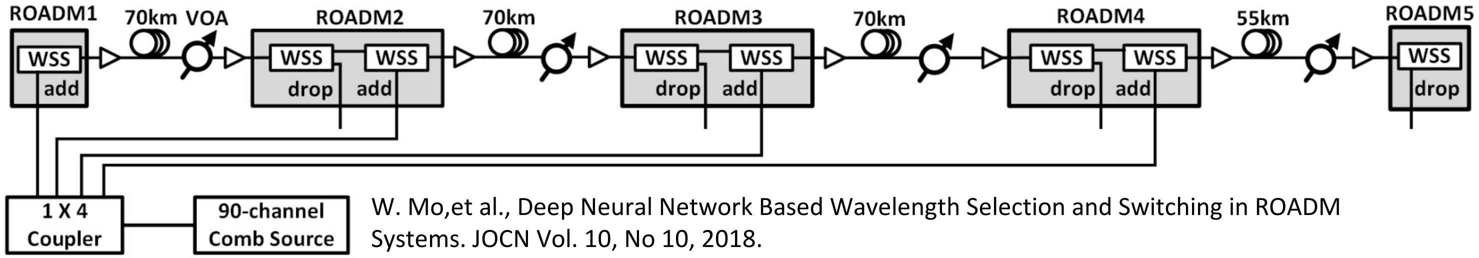
Source: C. Rottondi, et al. Machine-learning method for quality of transmission prediction of unestablished lightpaths. JOCN Vol. 10, No. 2, Feb. 2018

Using gradient descent on input parameters of QoT tool to reduce uncertainty on margins.

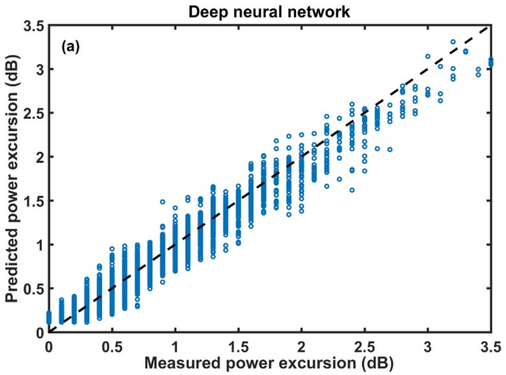


Source: E. Seve, J. Pesic, C. Delezoide, and Y. Pointurier. Learning process for reducing uncertainties on network parameters and design margins. OFC 2017.

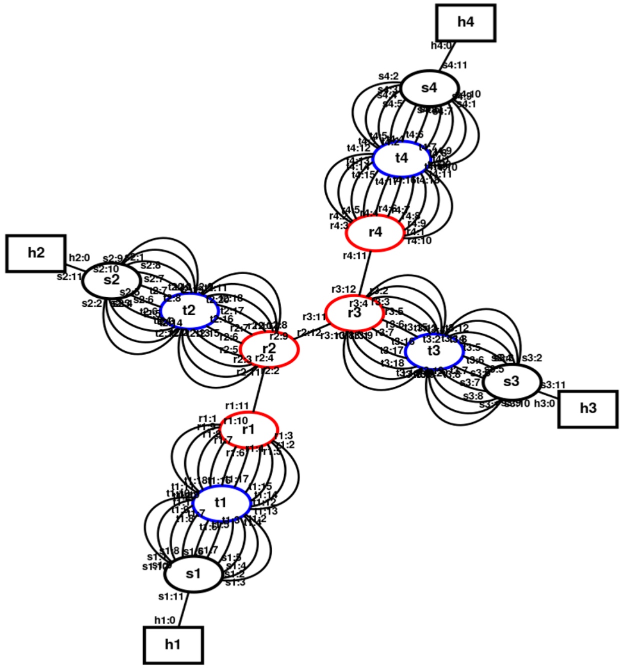
Deep learning (left) shown to accurately predict optical signal power which is main determinant of signal quality, based on the channel configuration alone.



W. Mo,et al., Deep Neural Network Based Wavelength Selection and Switching in ROADM Systems. JOCN Vol. 10, No 10, 2018.



Control plane design, experimentation or simulation?



Network infrastructure experimentation good for:

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

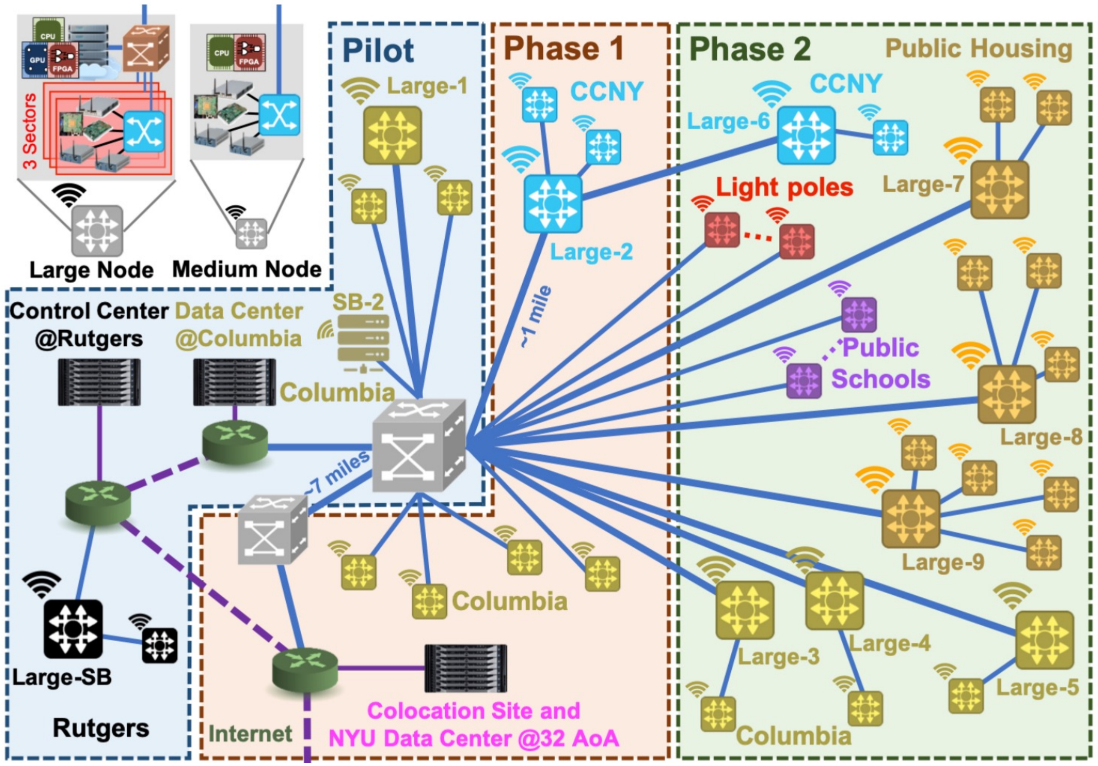
Network simulation good for:

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

a) Experimentation through open testbed

Open testbeds can be accessed by industry and academy researchers who cannot build their own testbed infrastructure:

US-based COSMOS

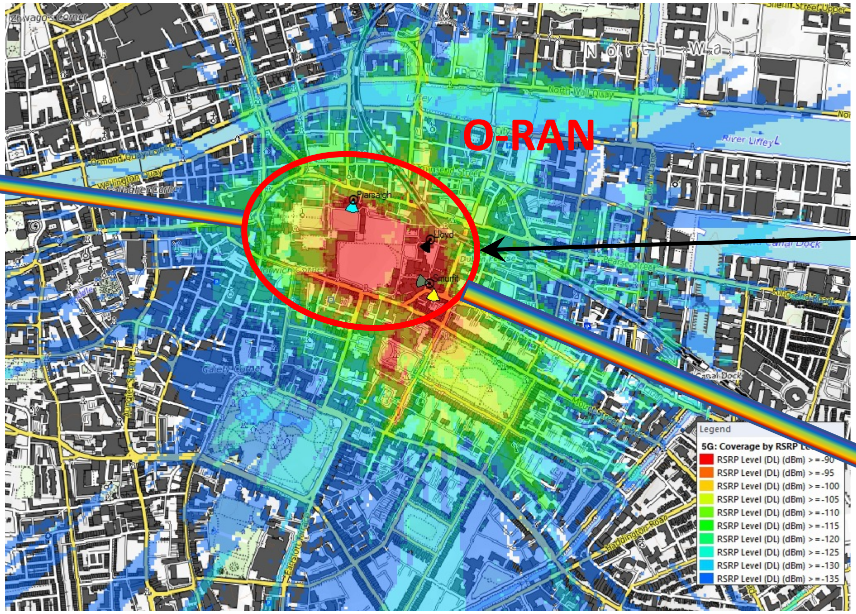


More at: https://wiki.cosmos-lab.org/wiki

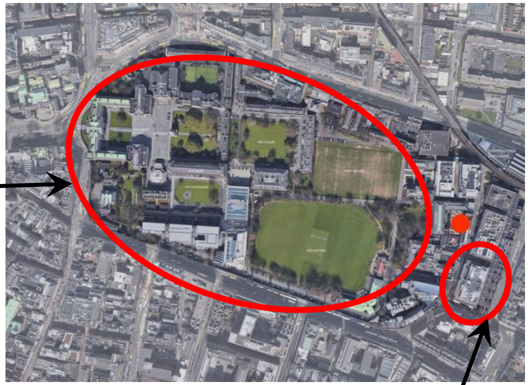
a) Experimentation through open testbed: OpenIreland

www.openireland.eu

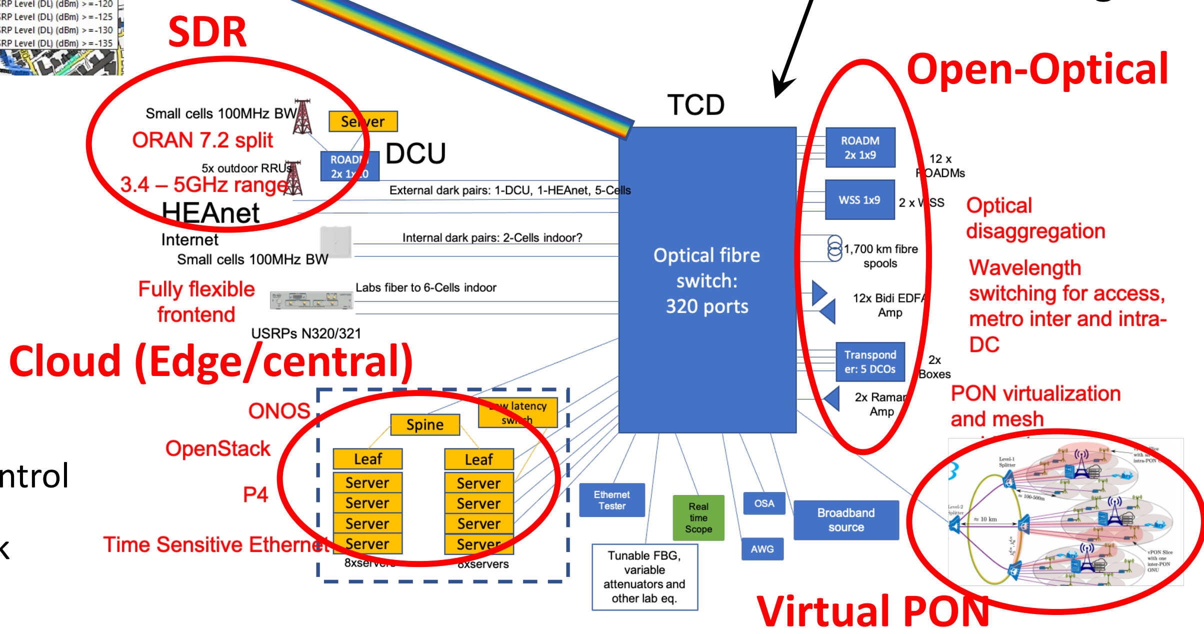
Radio and Optical Communications Laboratory



Based in Trinity College campus



CONNECT research centre building



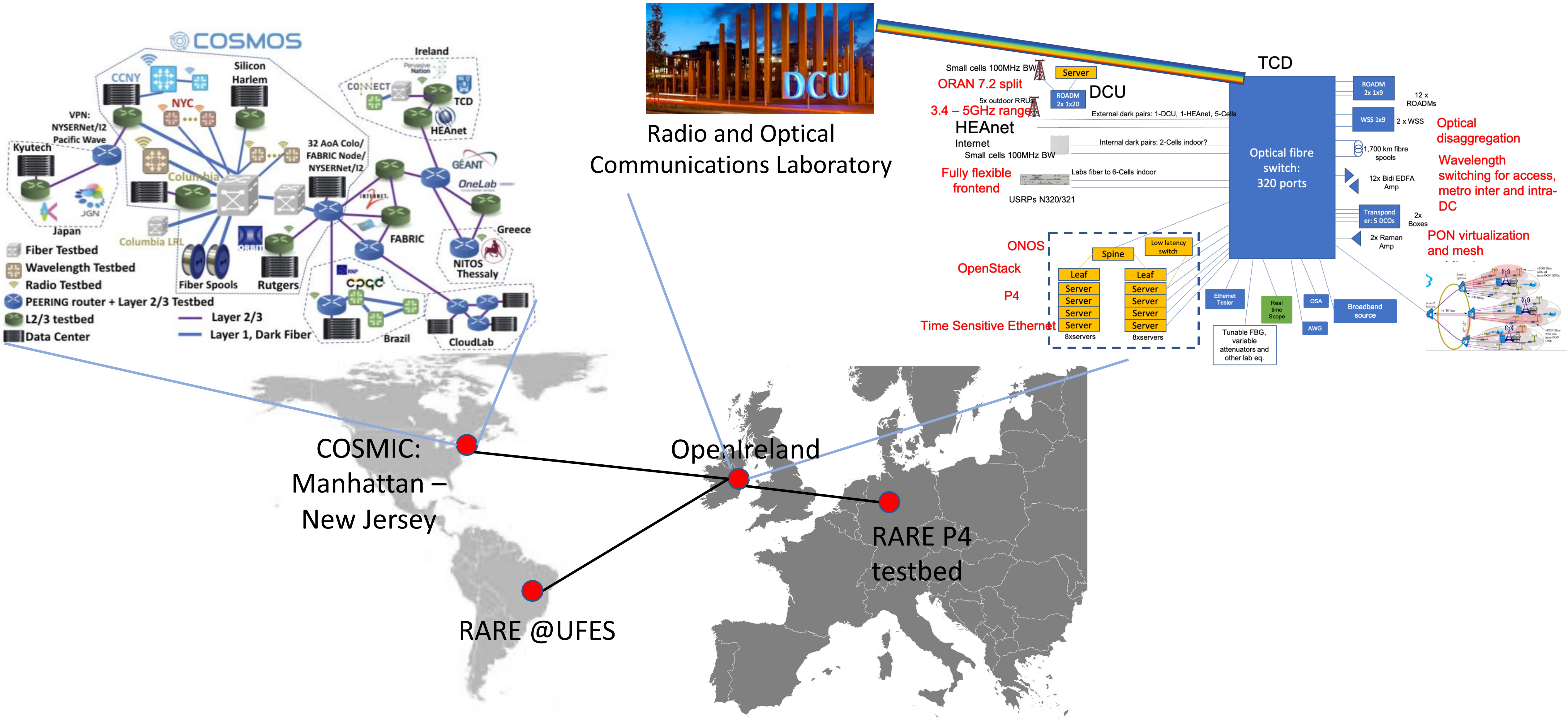
Reconfigurable and Lego-like topology reconfiguration with following blocks:

- 2,000km fibre, power splitters, etc.
- SDN ROADMs (Lumenutm), in line amplifiers and coherent Tx (Cassini)
- Virtual PON prototype (including EAST-WEST ODN – reflective filters)
- 5G O-RAN (outdoor and indoor); USRP SDR running 5G OAI (and soon SRS)
- Server virtualisation
- Laboratory measurements: OSA, power meters, etc.

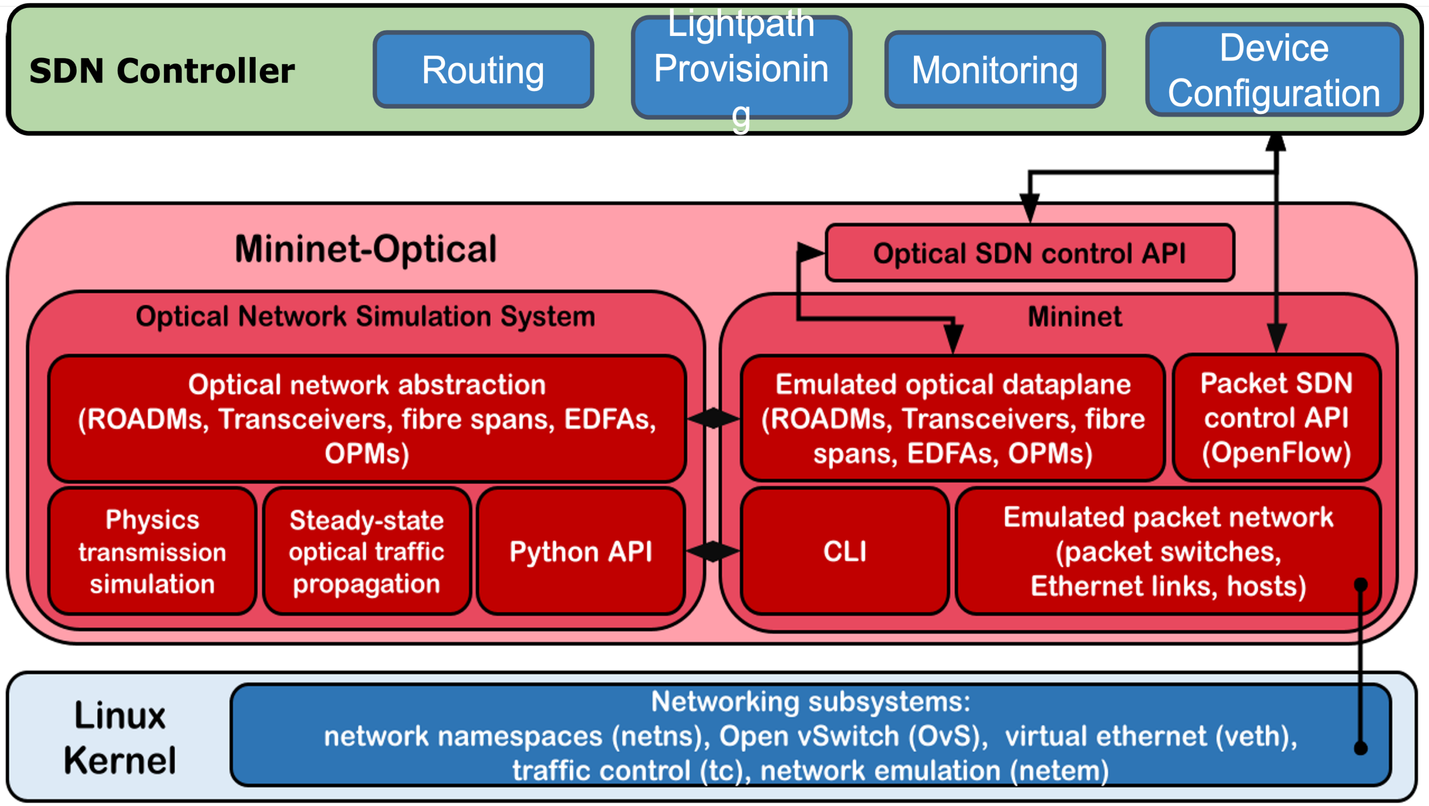
Run an experiment:

- Use optical fibre switch to put together a suitable physical topology of such blocks
- Load your image into servers for data plane (5G-SDR, Virtual PON, etc..) and SDN control plane
- Load your SDN control plane and run experiment (execute commands, read network parameters, train ML algorithm, etc.)

a) Experimentation through open testbed: global interconnectivity



b) Experimentation through open software: Mininet-Optical



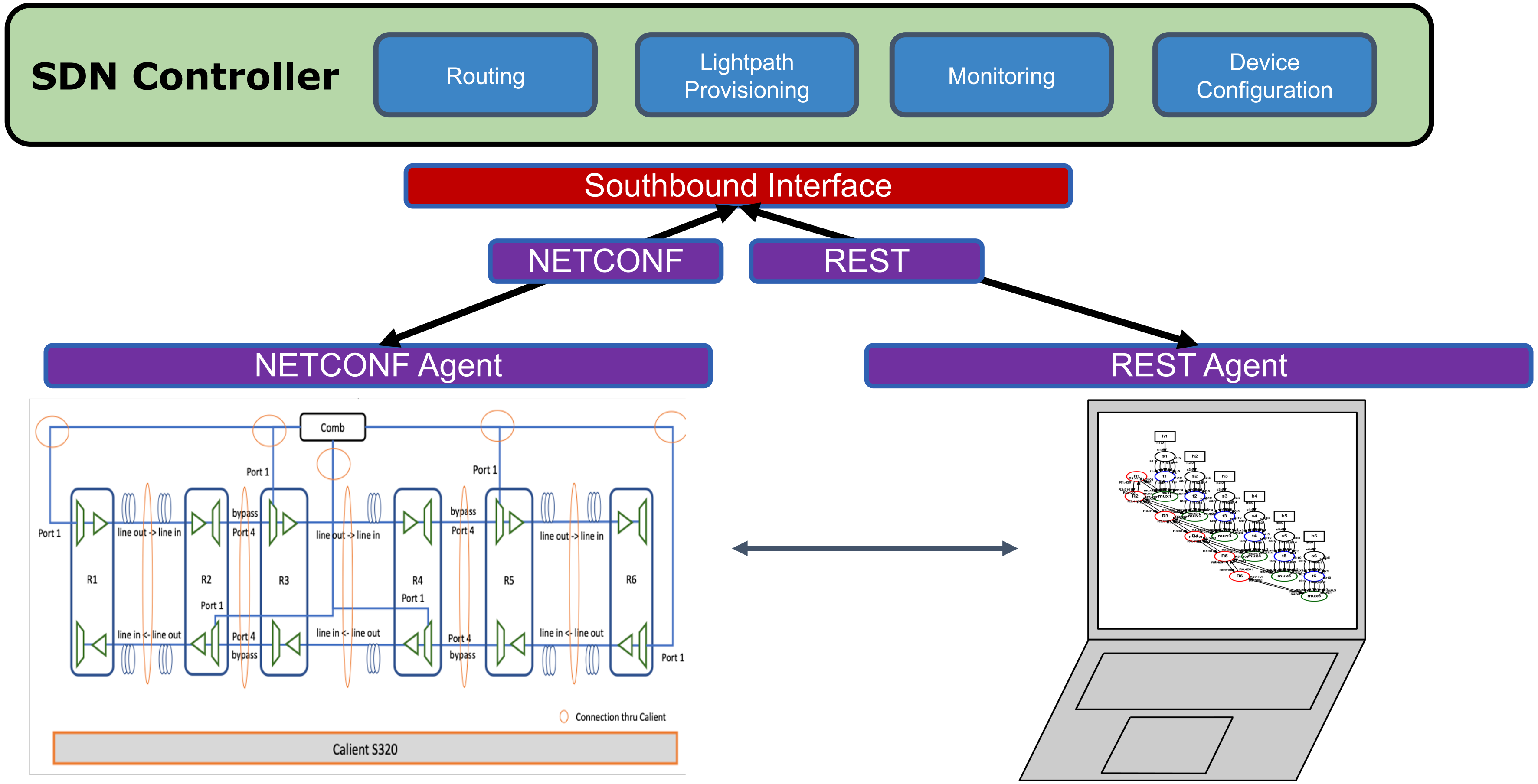
Node types:

- Transponders: modulation, baud rate, power, wavelength, BER from gOSNR
- ROADMs: insertion loss, variable attenuation, wavelength routing, booster/preamp
- EDFA: linear gain, wavelength dependent gain, ASE, automatic gain control mode
- Fibre length: attenuation, dispersion, SRS, nonlinear impairments through the GN model
- Performance monitors to emulate different types: power, OSNR, gOSNR,…

```
def build( self, txCount=4 ):
        "Build our network topo"
        h1, h2 = self.addHost('h1'), self.addHost('h2')
        transceivers = [('t%d' %t, 0*dBm, 'C')
                        for t in range(1, txCount+1) ]
        t1, t2 = [ self.addSwitch( name, cls=Terminal,
                                   transceivers=transceivers )
                   for name in ('t1', 't2') ]
        self.ethLink( h1, t1 )
        self.ethLink( h2, t2 )
        boost = ( 'boost', dict(target_gain=1.0) )
        spans = [ 50.0, ( 'amp1', dict(target_gain=50*.22) ),
                  50.0, ( 'amp2', dict(target_gain=50*.22) ) ]
        self.wdmLink( t1, t2, boost=boost, spans=spans)
```


- A. Diaz-Montiel, B. Lantz, J. Yu, D. Kilper and M. Ruffini. Real-Time QoT Estimation through SDN Control Plane Monitoring Evaluated in Mininet-Optical. IEEE Photonics Technology Letters, April 2021.
- A. Diaz-Montiel, A. Bhardwaj, B. Lantz, J. Yu, A.N. Quraishy, D. Kilper and M. Ruffini. Real-Time Control Plane Operations for gOSNR QoT Estimation through OSNR Monitoring. OSA Optical Fiber Communications Conference (OFC), June 2021
- B. Lantz, A. Diaz-Montiel, J. Yu, C. Rios, M. Ruffini and D. Kilper. Demonstration of Software-Defined Packet-Optical Network Emulation with Mininet-Optical and ONOS. OSA Optical Fiber Communications Conference (OFC), March 2020

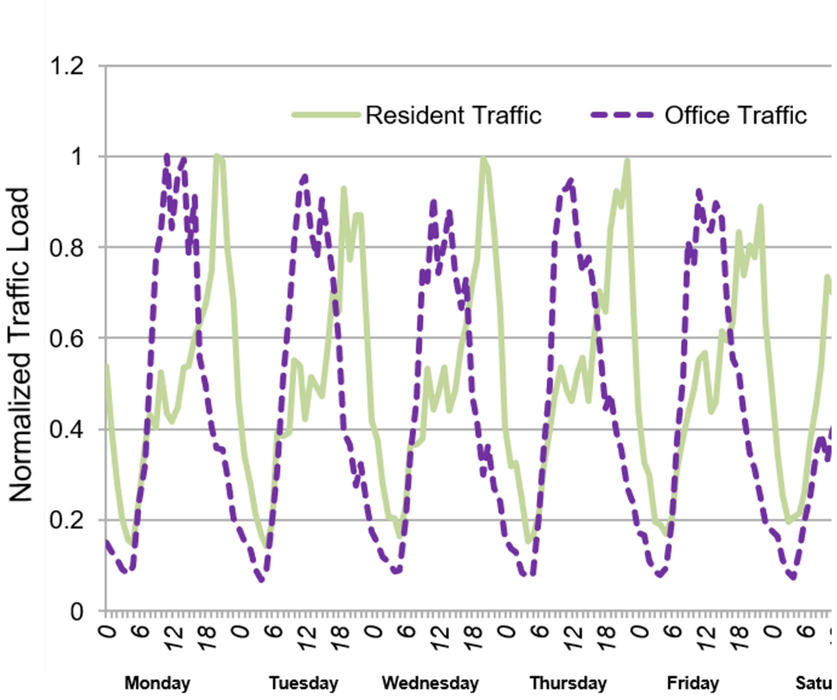
Control plane development through synergetic simulation and testbed experimentation



Hardware network on testbed

Virtual network in Mininet-Optical

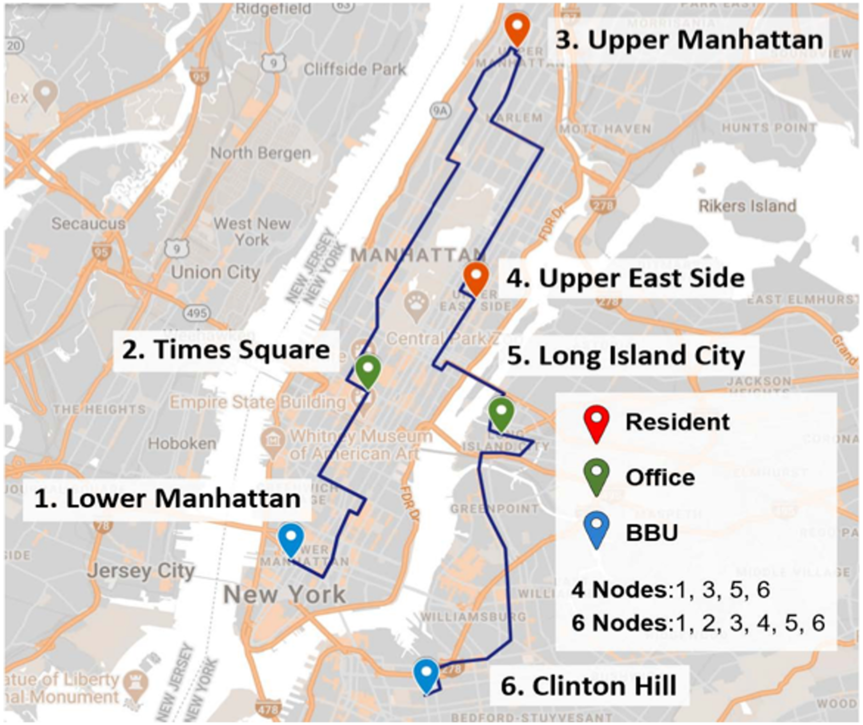
Use case 1: Metro Front-haul Provisioning



Diurnal traffic variation of Residential vs. Office traffic

This changes the traffic pattern over the transport network

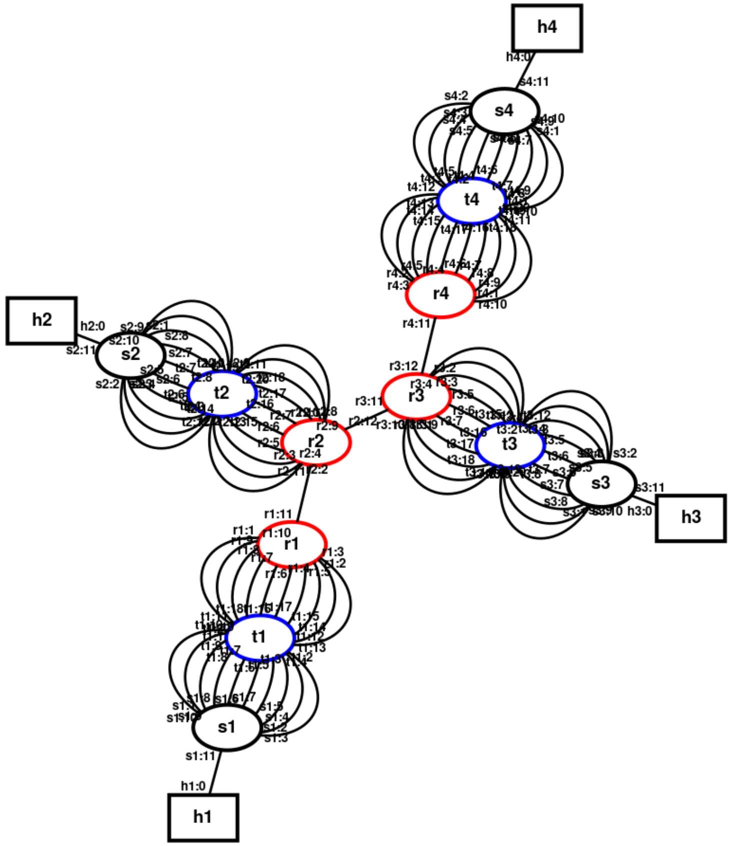
The controller allocates RUs to BBU locations, depending on demand and available network and computing resources



The controller also monitors OSNR. If this goes below given thresholds, it reduces modulation from 16-QAM (200 Gb/s) to QPSK (100 Gb/s) or BPSK (50 Gb/s). Rerouting and re-provisioning is also possible.

B. Lantz, J. Yu, A. Bhardwaj, A. Diaz-Montiel, A. Quraishy, S. Santaniello, T. Chen, R. Fujieda, A. Mukhopadhyay, G. Zussman, M. Ruffini and D. Kilper. SDN-controlled Dynamic Front-haul Provisioning, Emulated on Hardware and Virtual COSMOS Optical x-Haul Testbeds. OSA Optical Fiber Communications Conference (OFC), June 2021

Use case 1: Metro Front-haul Provisioning – Mininet-Optical



Four ROADMs:

(r1,r4): 1-degree

(r2,r3): 2-degree

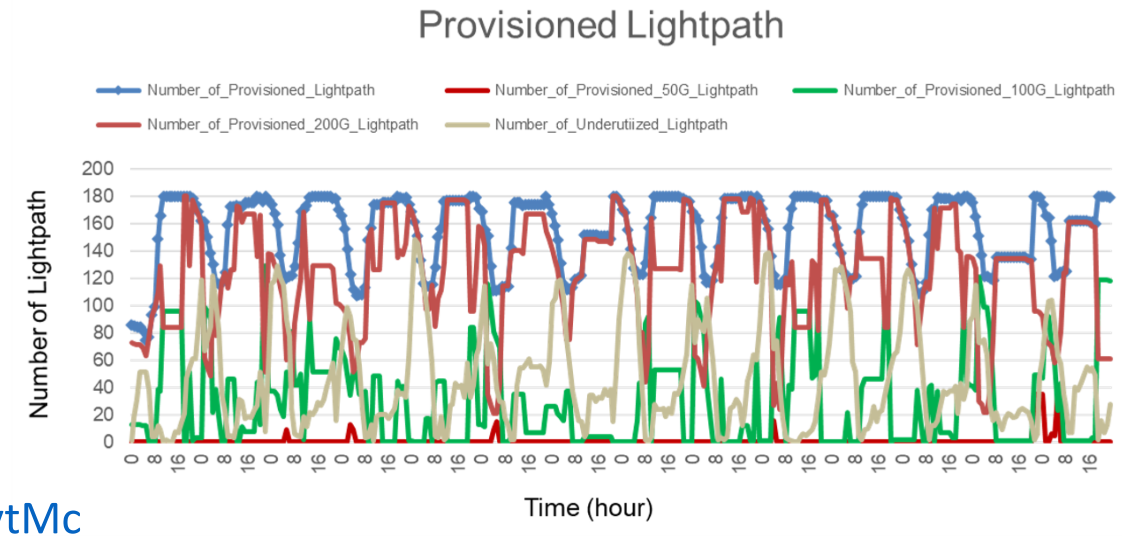
Links are fiber pairs (i.e. both directions)

Endpoints: Data Centers (h1, h4); RU aggregation (h2, h3)

90 transceivers/channels per endpoint

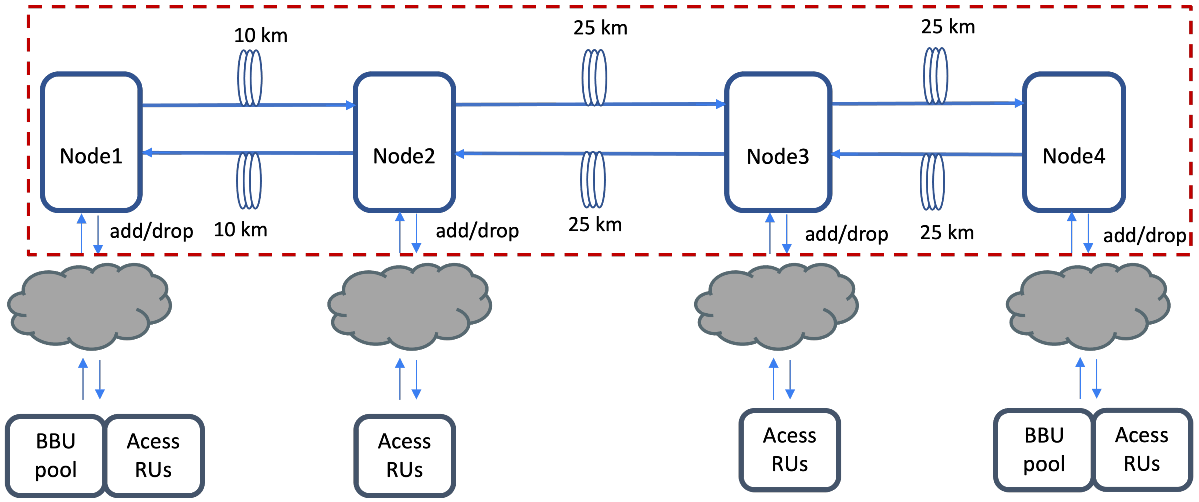
End-to-end model with Optical (ROADM rN, Terminal tN) as well as packet (Host hN, Router sN) elements

- The emulation shows an example of how the lightpaths are reprovisioned over time.

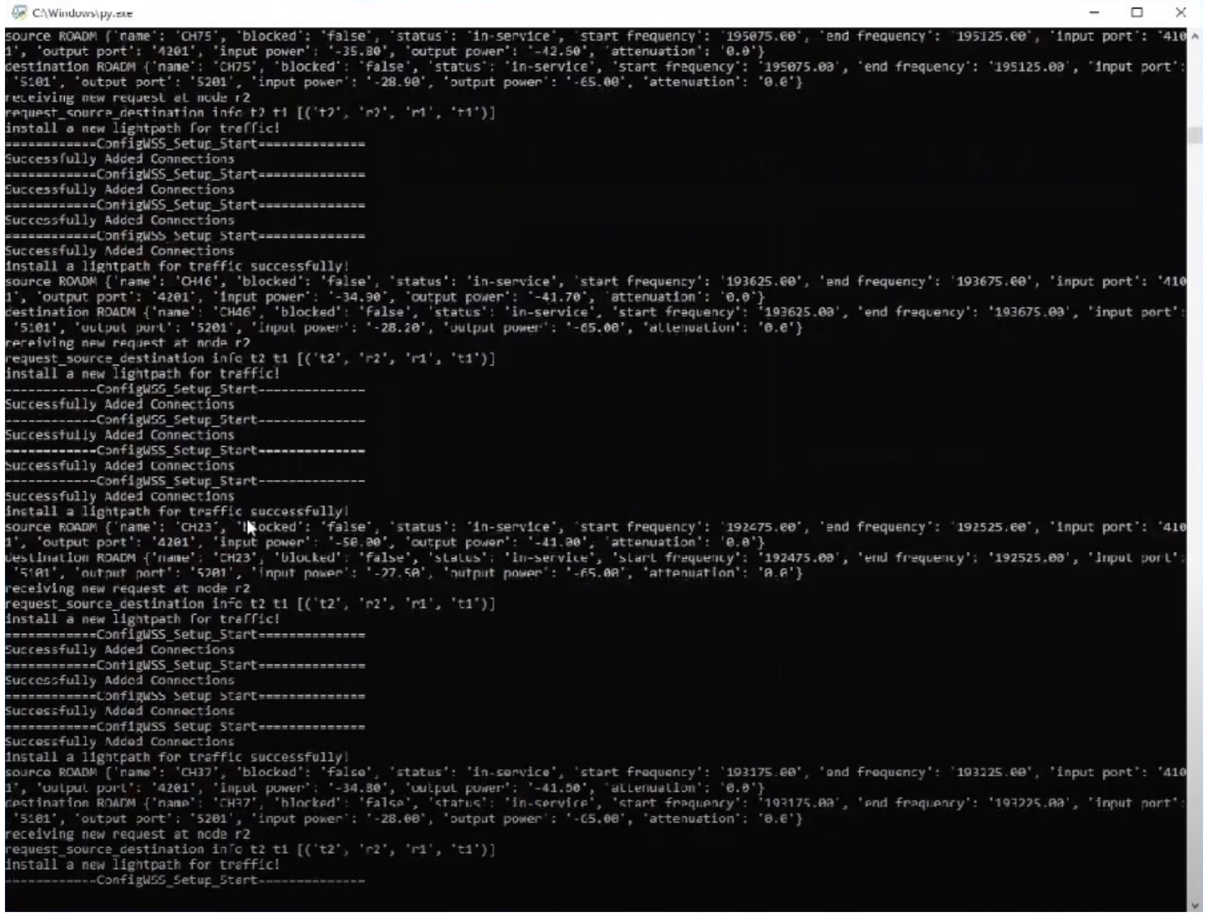


Watch the video at: https://www.youtube.com/watch?v=Bi2E-sGytMc

Use case 1: Metro Front-haul Provisioning – COSMOS



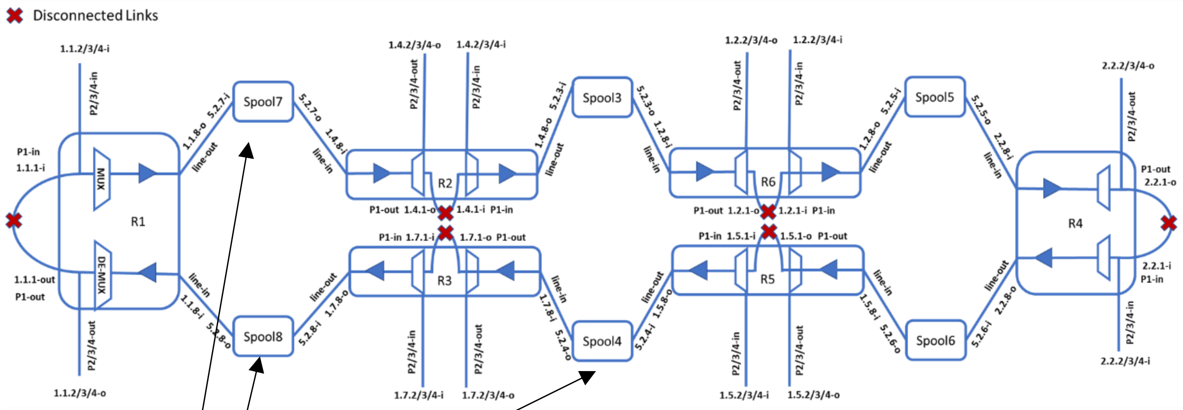
Control plane



Run same controller used for Mininet-Optical for setting up and tearing down of lightpaths:

- Configuration across multiple ROADMs
- Configuration of transceiver
- Measurement of power levels

Use case 1: Metro Front-haul Provisioning – OpenIreland



Modified propagation distances

Control plane

```
fslyne@ol02: ~/optical-network-emulator/ofcdemo
============ConfigWSS_Setup_Start=============
Successfully Added Connections
install a lightpath for traffic successfully!
source ROADM {'name': 'CH28', 'blocked': 'false', 'status': 'in-service', 'start frequency': '192725.00', '
end frequency': '192775.00', 'input port': '4101', 'output port': '4201', 'input power': '-50.00', 'output
power': '-40.70', 'attenuation': '0.0'}
destination ROADM {'name': 'CH28', 'blocked': 'false', 'status': 'in-service', 'start frequency': '192725.0
0', 'end frequency': '192775.00', 'input port': '5101', 'output port': '5201', 'input power': '-17.20', 'ou
tput power': '-20.91', 'attenuation': '0.0'}
downgrading lightpath capacity from 200G to 100G
downgrading lightpath capacity from 200G to 100G
downgrading lightpath capacity from 200G to 100G
downgrading lightpath capacity from 200G to 100G
downgrading lightpath capacity from 200G to 100G
receiving new request at node r2
request_source_destination info t2 t1 [('t2', 'r2', 'r1', 't1')]
install a new lightpath for traffic!
============ConfigWSS_Setup_Start=============
Successfully Added Connections
============ConfigWSS_Setup_Start=============
Successfully Added Connections
============ConfigWSS_Setup_Start=============
Successfully Added Connections
============ConfigWSS_Setup_Start=============
Successfully Added Connections
install a lightpath for traffic successfully!
source ROADM {'name': 'CH33', 'blocked': 'false', 'status': 'in-service', 'start frequency': '192975.00', '
end frequency': '193025.00', 'input port': '4101', 'output port': '4201', 'input power': '-50.00', 'output
power': '-40.70', 'attenuation': '0.0'}
destination ROADM {'name': 'CH33', 'blocked': 'false', 'status': 'in-service', 'start frequency': '192975.0
0', 'end frequency': '193025.00', 'input port': '5101', 'output port': '5201', 'input power': '-17.10', 'ou
tput power': '-20.81', 'attenuation': '0.0'}
downgrading lightpath capacity from 200G to 100G
downgrading lightpath capacity from 200G to 100G
downgrading lightpath capacity from 200G to 100G
downgrading lightpath capacity from 200G to 100G
downgrading lightpath capacity from 200G to 100G
downgrading lightpath capacity from 200G to 100G
receiving new request at node r2
request_source_destination info t2 t1 [('t2', 'r2', 'r1', 't1')]
install a new lightpath for traffic!
============ConfigWSS_Setup_Start=============
Successfully Added Connections
============ConfigWSS_Setup_Start=============
Successfully Added Connections
============ConfigWSS_Setup_Start=============
```

Run same controller used for Mininet-Optical and COSMOS for OpenIreland:

- Configuration across multiple ROADMs
- Configuration of transceiver
- Measurement of power levels, BER

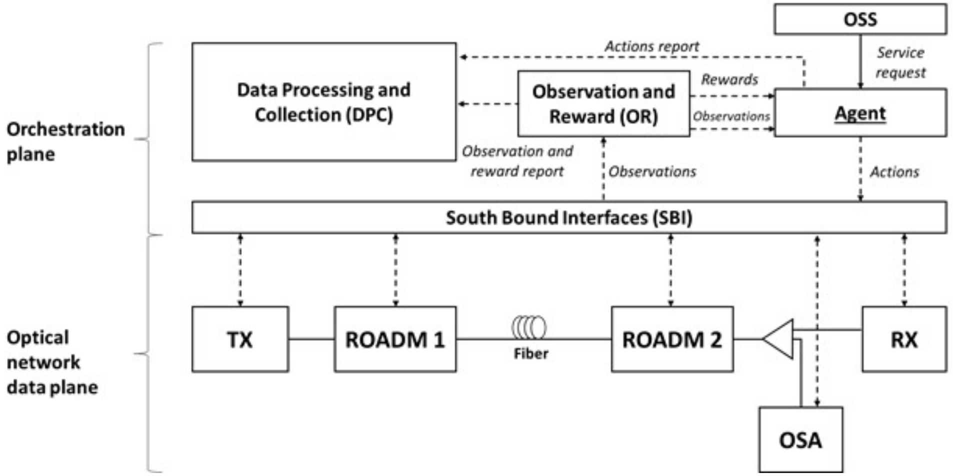
```
stroia@ol02:~/testbed-setup$ sudo python3 actions.py test
Output power:   1.200000e-01
Input power:   4.100000
Current output power:   4.600000e-01
Operation status:   ready
DSP operation status:   ready
Modulation format:   dp-16-qam
Laser frequency:   193900000000000
Post-fec BER:   3.412794e-02
Pre-fec BER:   2.448365e-02
SD-fec BER:   2.447128e-02,2.449601e-02
HD-fec BER:   8.164130e-04,2.049768e-02
```

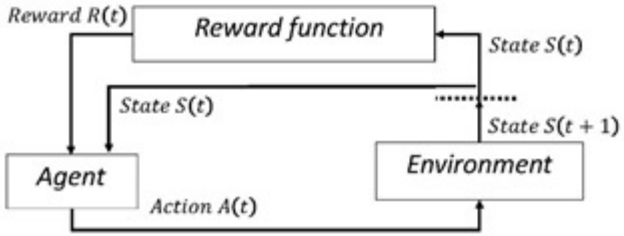
```
stroia@ol02:~/testbed-setup$ sudo python3 test.py
1) get powers; 2) get OSA; -> 2
marker:   193.93398,-17.57DBM
```

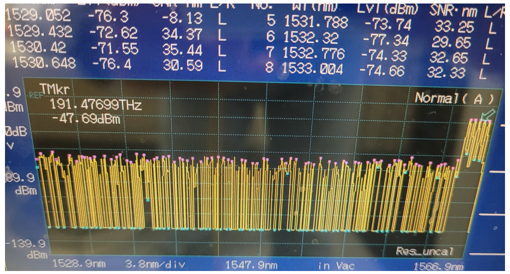
Use case 2: Building a QoT estimation algorithm

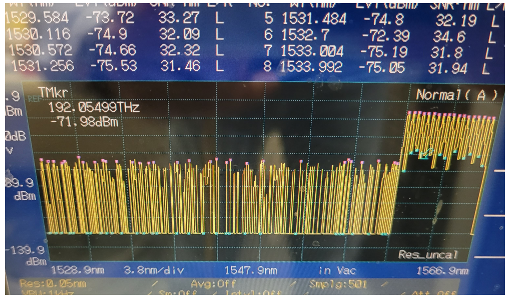
Control plane algorithm development and test based on simulation:

- 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



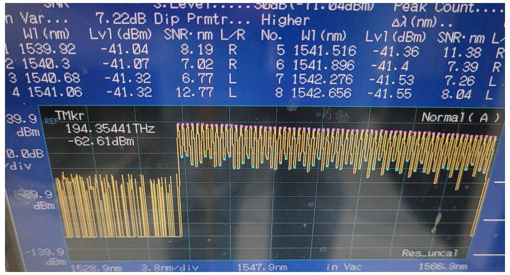


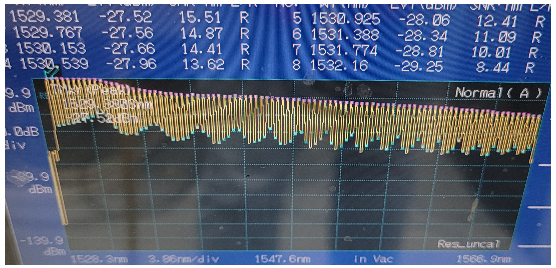




Control plane algorithm test on testbed:

- Agent automatically loading the network topology through a comb generator
- Control plane becomes aware of all devices, their interfaces, their behavior, their response time… and how to read and interpret the results
- … to be continued…





Conclusions

- Optical layer disaggregation extend the open systems concept to the optical layer.
- Machine learning can provide advantages in automatic most decision.
- However, it is critical to develop and test such ideas considering control plane and real hardware limitation.

- Shown examples of open testbeds that can enable testing remotely.
- Shown the (soon to be released as open source) Mininet-Optical, for fast deployment.

- Synergy between simulation and testbed experimentation to use same controller across two platforms.
- Still much work to be done..