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CONNECT
Centre for Future Networks

Digital Twin for Cross-Atlantic Open Access Testbeds

Marco Ruffini et al.
Trinity College Dublin

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It’s a Team Effort!

OpenIreland

COSMOS

NGIAtlantic: experimentation

Mininet Optical

NGIAtlantic: experimentation

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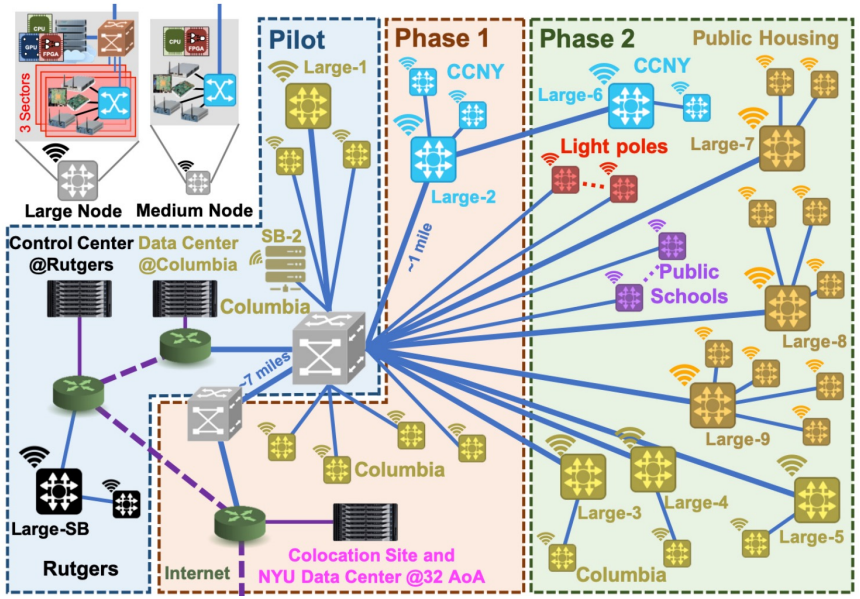
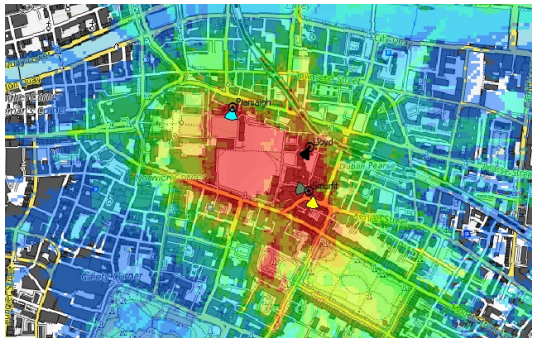
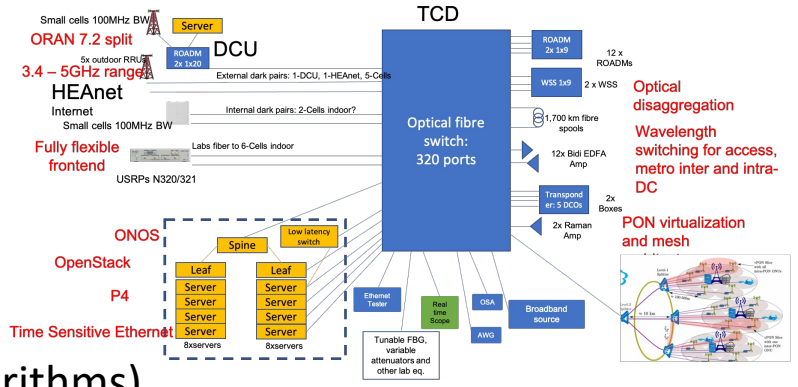
Building a digital twin for Open Access testbeds

COSMOS

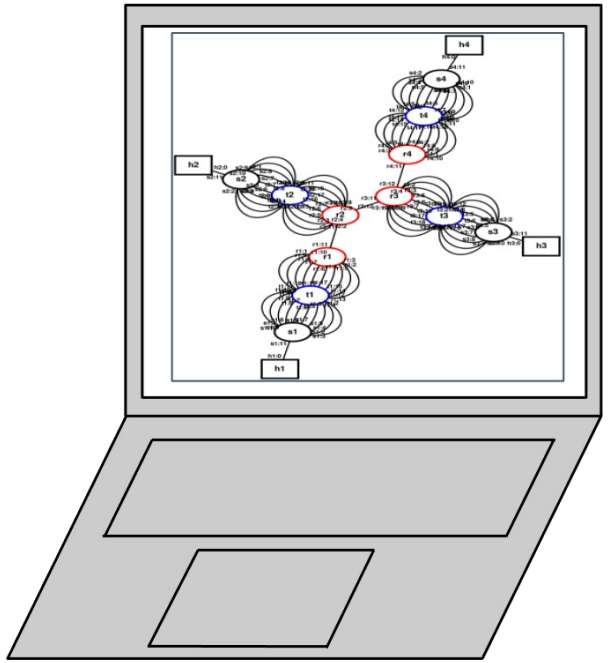


OpenIreland





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

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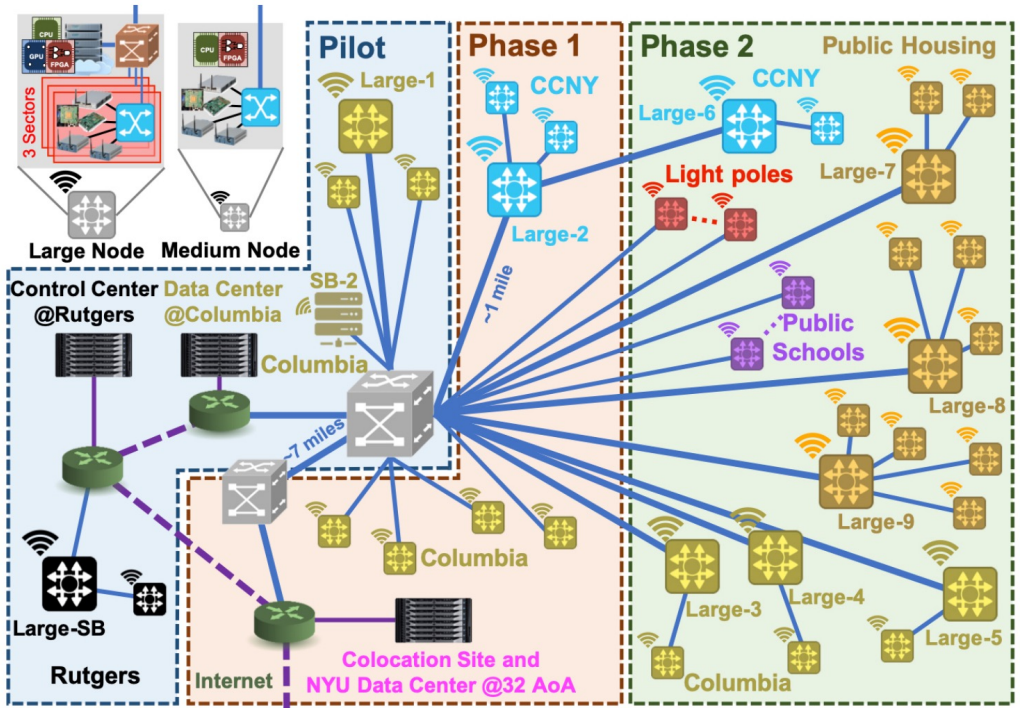
Experimentation through open testbed: COSMOS

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

US-based COSMOS

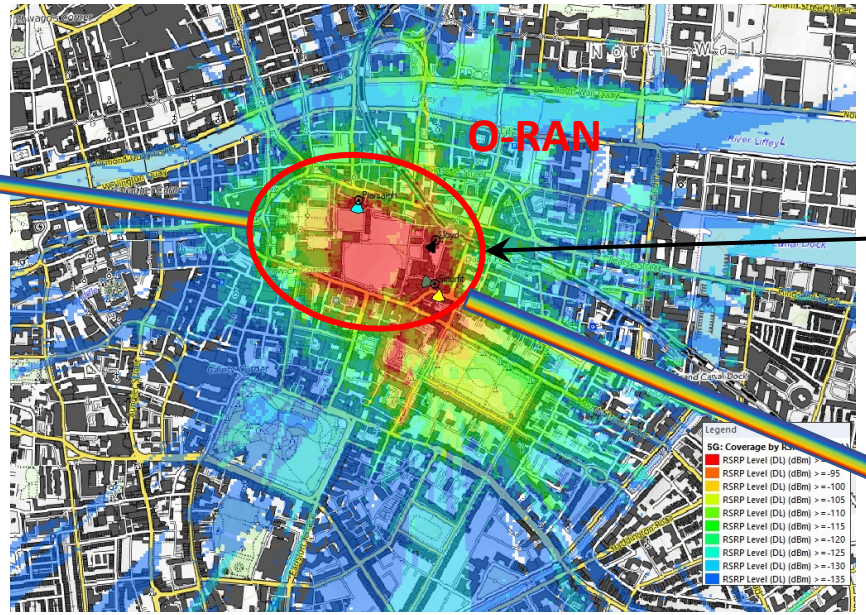


More at: https://wiki.cosmos-lab.org/wiki

Experimentation through open testbed: OpenIreland

www.openireland.eu

Radio and Optical Communications Laboratory

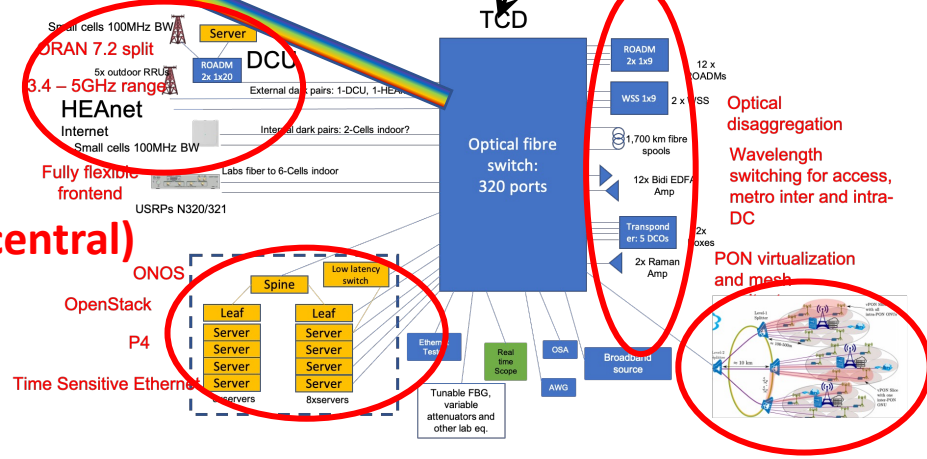


Based in Trinity College campus

CONNECT research centre building

SDR

Open-Optical



Reconfigurable and Lego-like topology reconfiguration with following blocks:

- 1,700km 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..)
- Load your SDN control plane and run experiment (execute commands, read network parameters, train ML algorithm, etc.)

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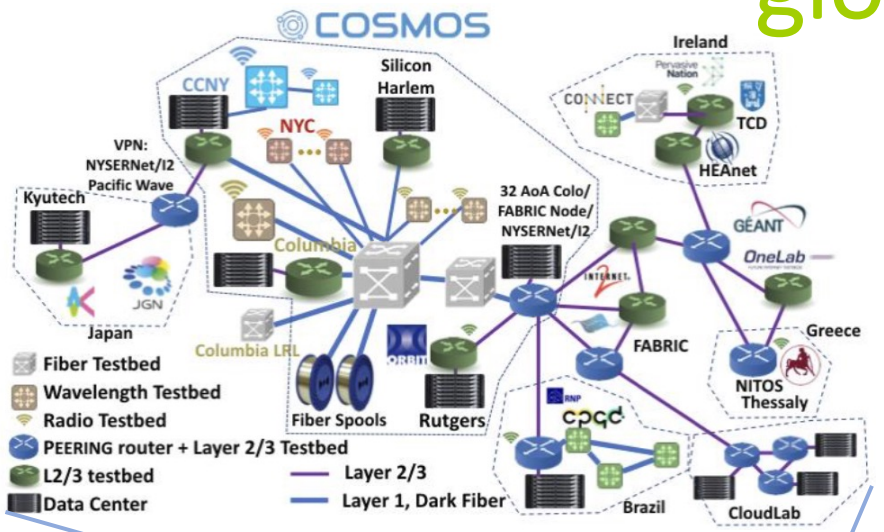
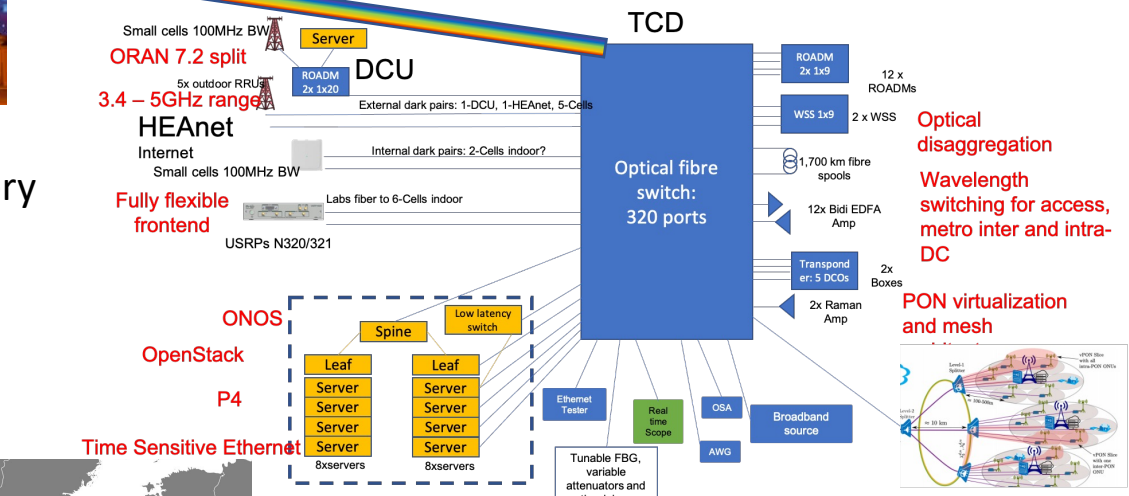
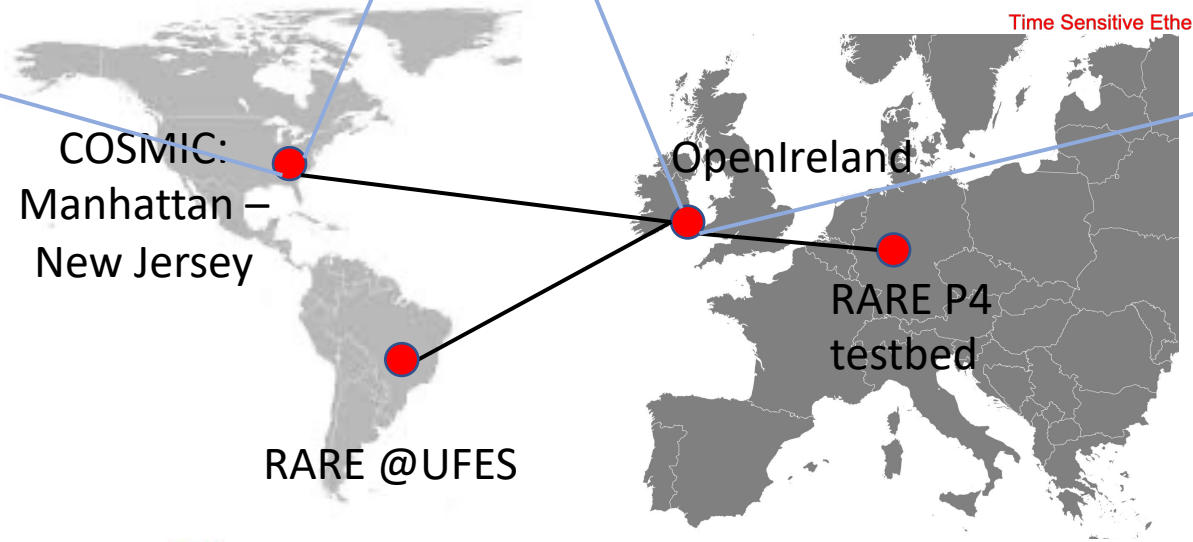
Experimentation through open testbed: global interconnectivity



Radio and Optical Communications Laboratory





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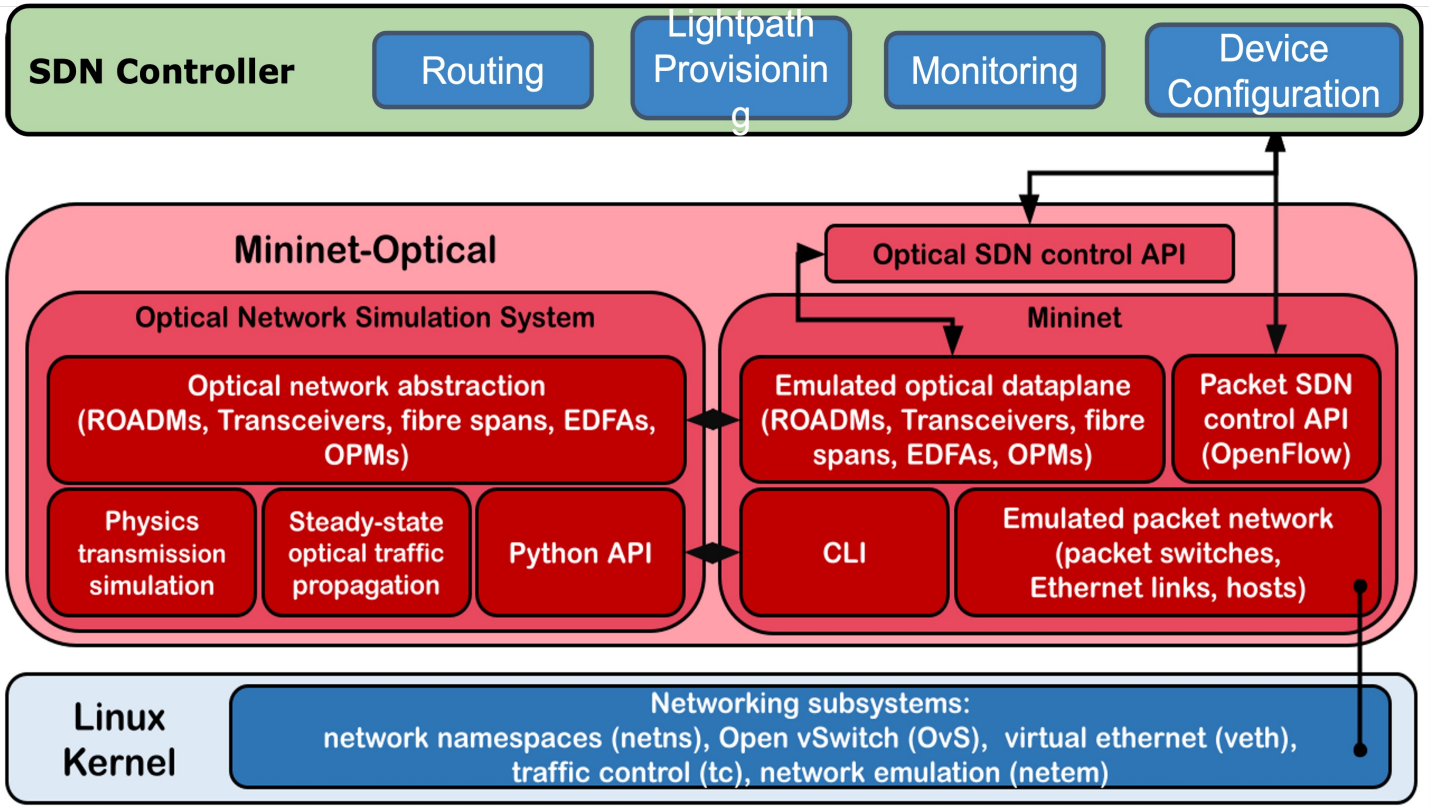
Experimentation through open source software for a Digital Twin: Mininet-Optical



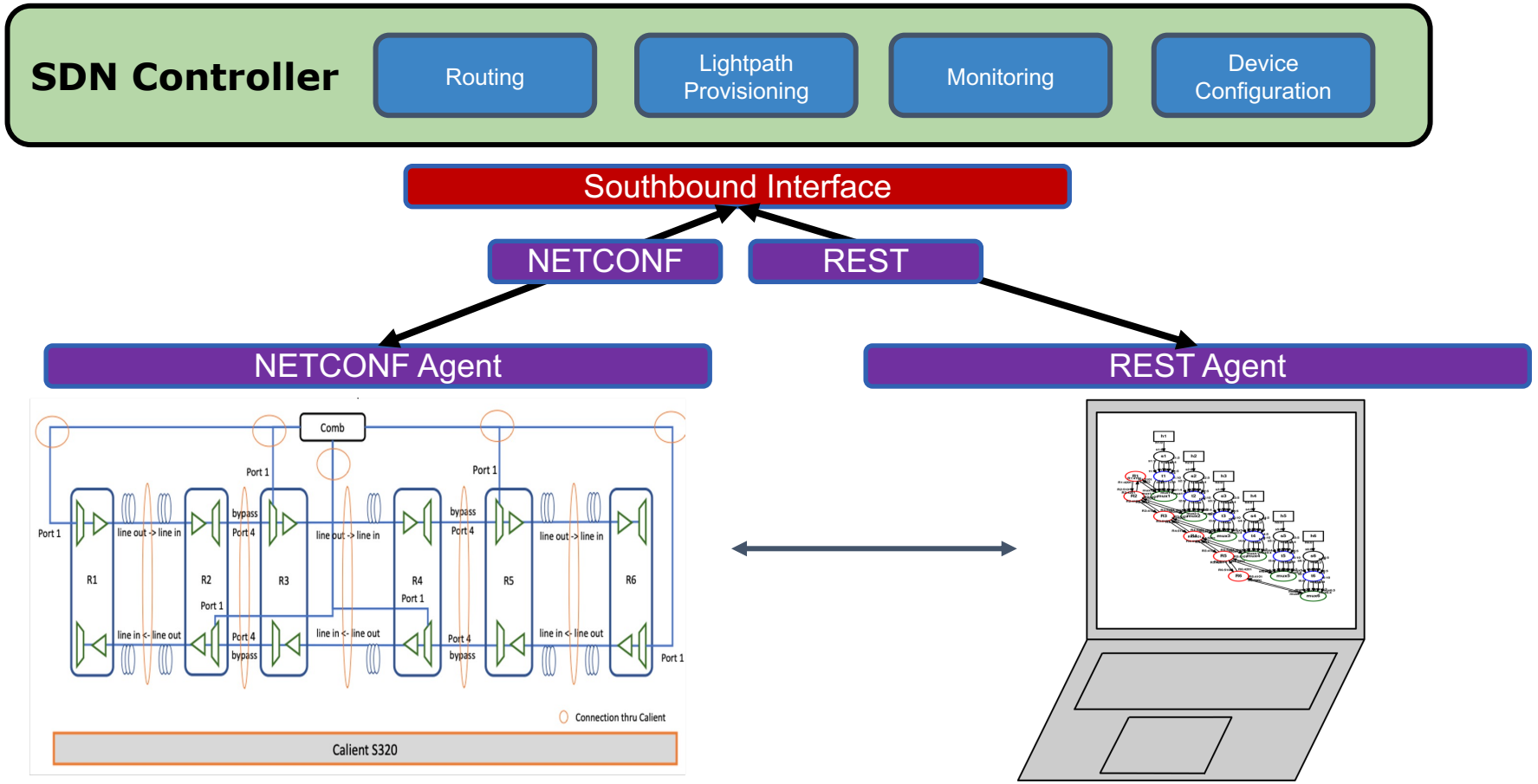
Node types:

- 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 emulation and testbed experimentation



Hardware network on testbed

Virtual network in Mininet-Optical

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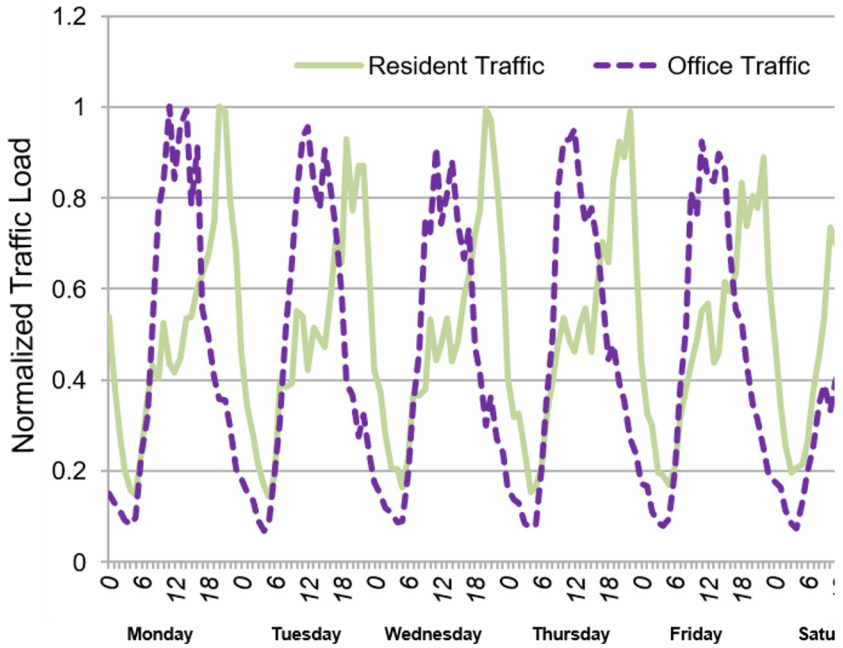
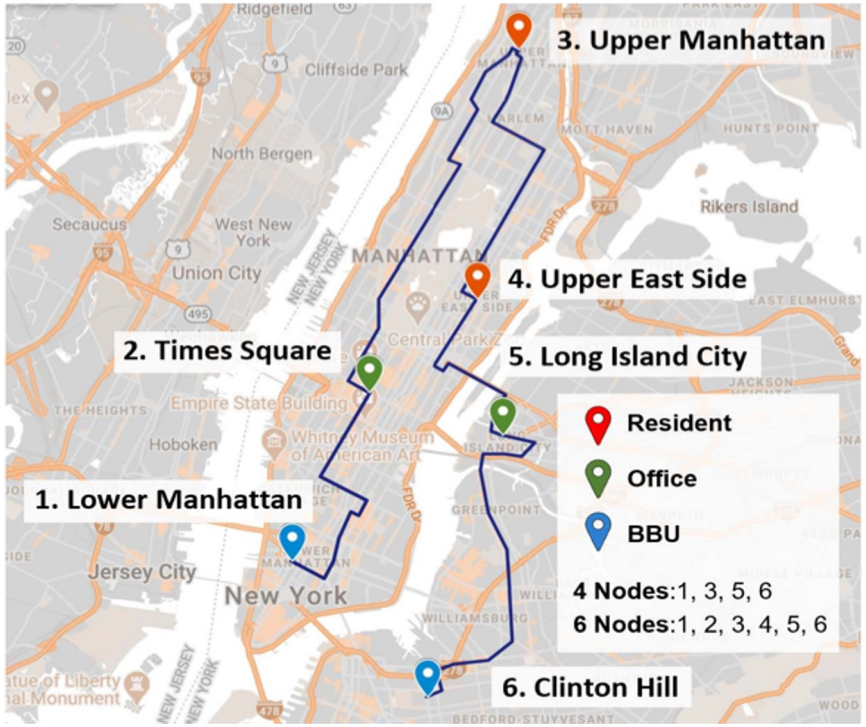
Use case 1: Metro Front-haul Provisioning



Diurnal traffic variation of Residential vs. Office traffic

This changes the traffic pattern over the transport network

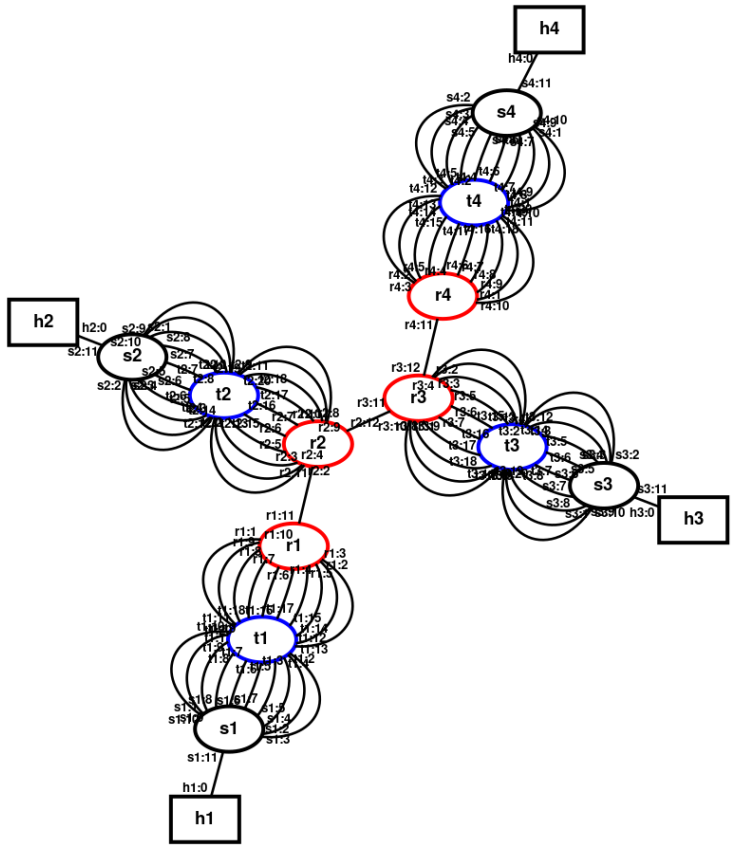
The controller associates RUs to BBU locations, depending on demand and available network and computing resources



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)

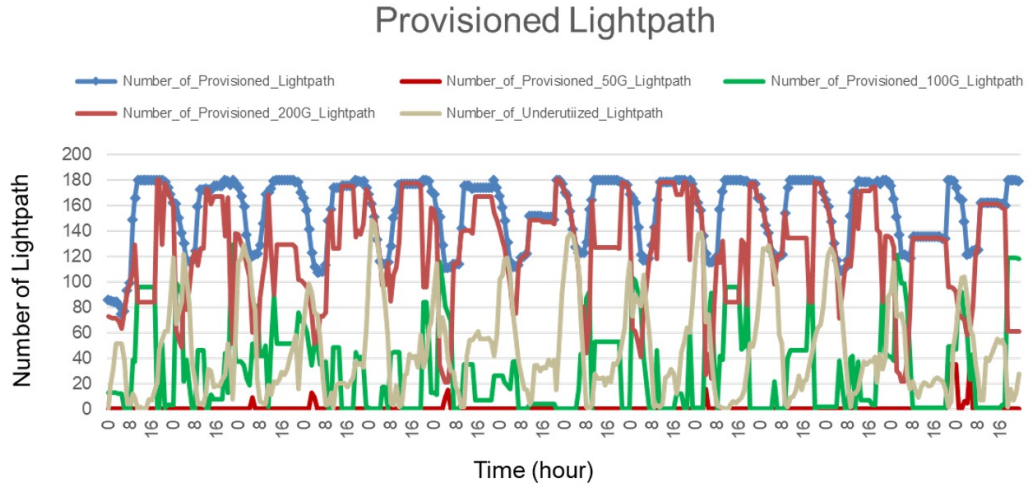
Endpoints: Data Centers (h1, h4); RU aggregation (h2, h3)

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



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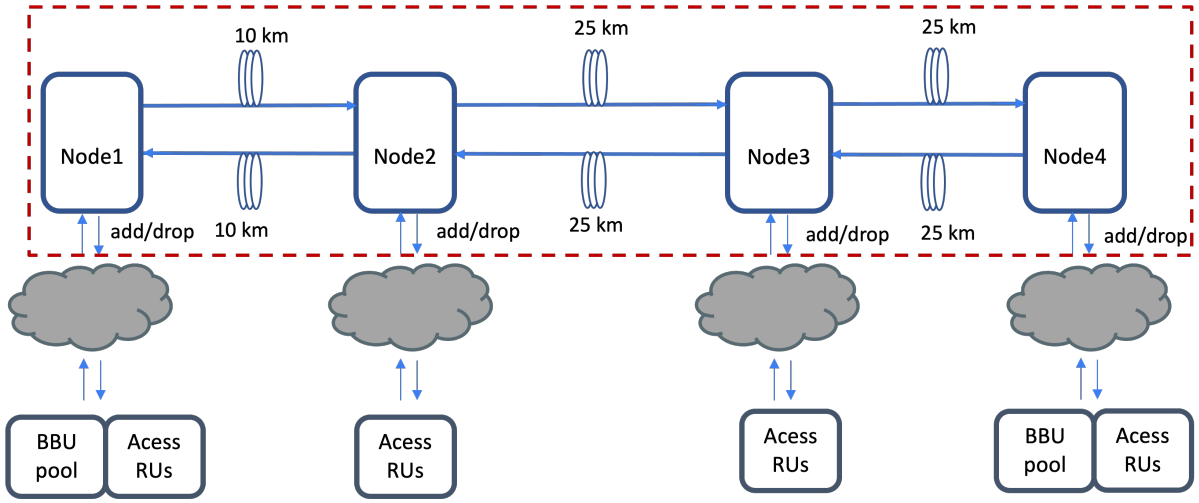
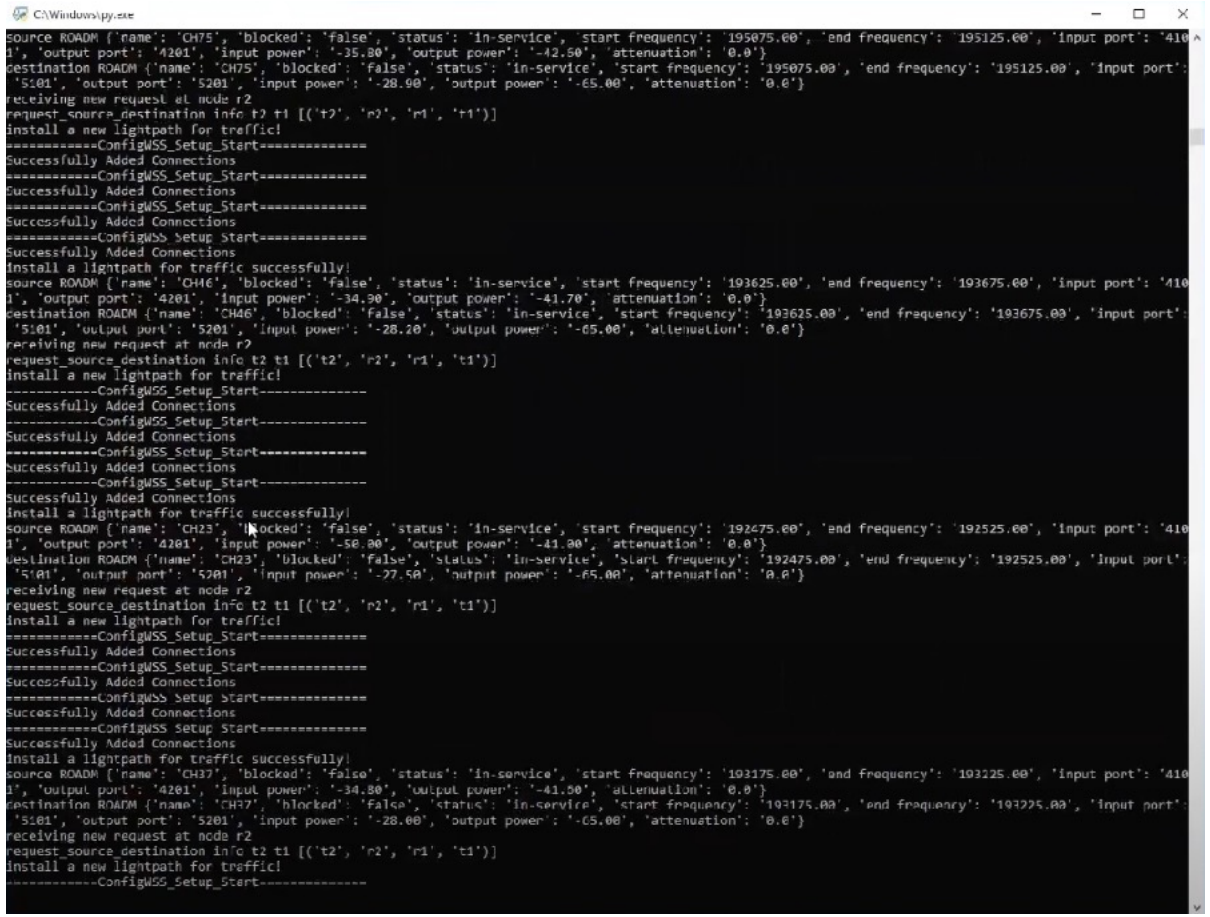
Use case 1: Metro Front-haul Provisioning – COSMOS



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

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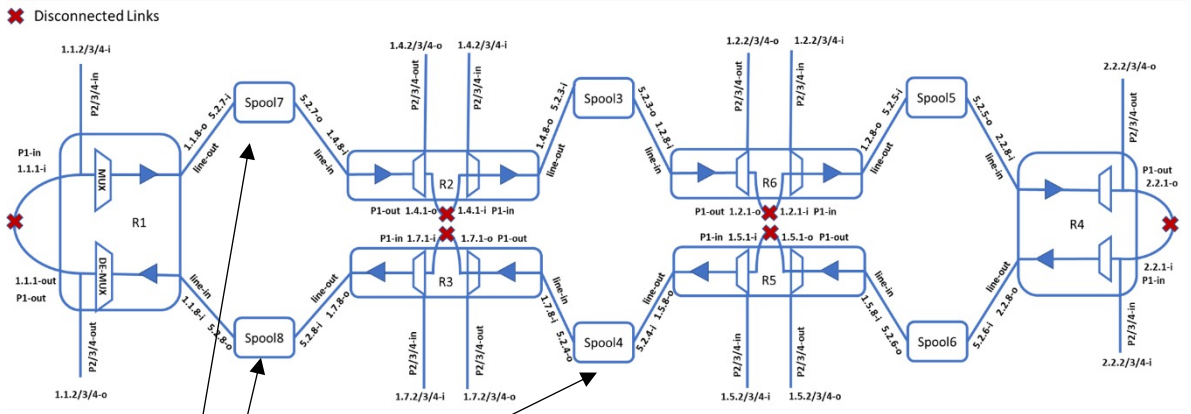
Use case 1: Metro Front-haul Provisioning – OpenIreland



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 test.py
1) get powers; 2) get OSA; -> 2
marker:  193.93398,-17.57DBM
```

```
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
```

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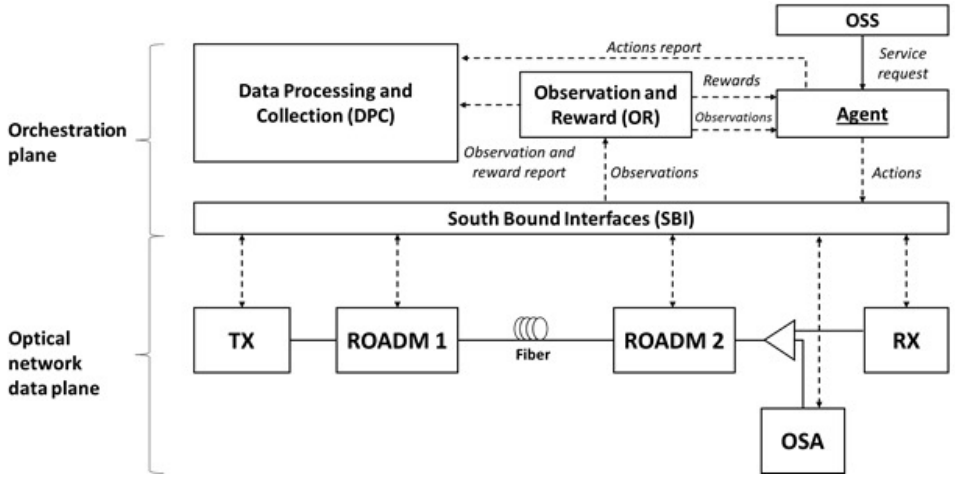
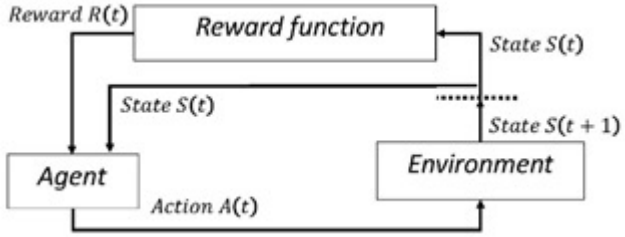
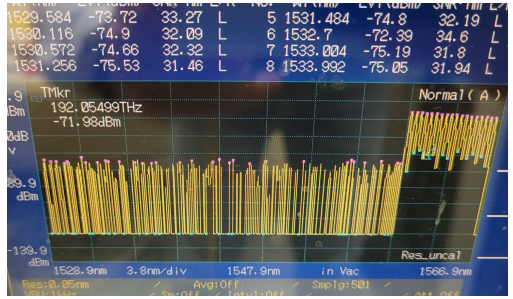
Use case 2: Building a QoT estimation algorithm

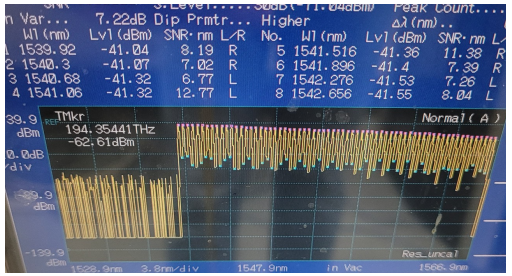
Control plane algorithm development and test based on simulation:

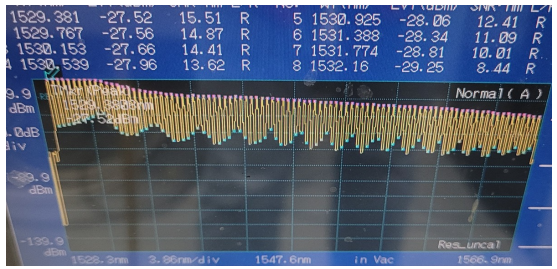
- Online learning through agent that loads the optical spectrum with optical channel and measures OSRN variation
- Through multiple iterations the agent improves strategy for channel selection











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…

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NGI Atlantic support

- Open access testbeds are key for widespread (i.e., all active research community) and accurate development of control plane mechanisms, machine learning algorithms, etc.
  - This is an important contribution to the community: provide access to testbed facilities so researchers can explore activates that are otherwise limited to limited number of industry and academic institutions.

- NGI-Atlantic really facilitated this to come together:
  - Support joint (US-Ireland) development of Mininet-Optical digital twin
  - Support joint testbed development to enable transferring experiments between US and Ireland
  - Support external experimenters:
    - Milan Polytechnic with ML approach
    - Already discussing experiments with other entities

- Testbed still being built, but we will carry out more and more experiments with external researchers – much room for cooperation!

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Thank you for your attention

Marco Ruffini (marco.Ruffini@tcd.ie)

CONNECT research centre, Trinity College Dublin

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