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Mininet-Optical: an SDN optical network emulator for disaggregated optical systems

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Summary

- Optical layer disaggregation
  - The optical margin problem
  - Machine learning to the rescue

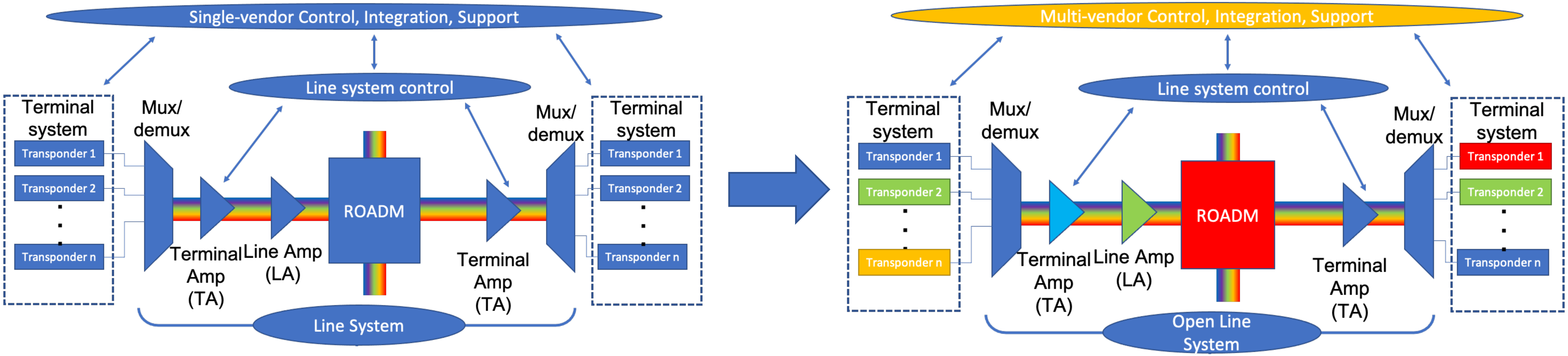
- Optical control plane development and testing
  - Experimental testbed
  - Mininet-Optical Emulation: what is it and how it works
  - Sample Use Cases
  - Synergy of emulation and testbed experimentation

- Conclusions

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

Open Roadmap

- Stage 1: Open Line System
  - The line system is closed but should operate with any transponders
  - The transponders should operate over any line system

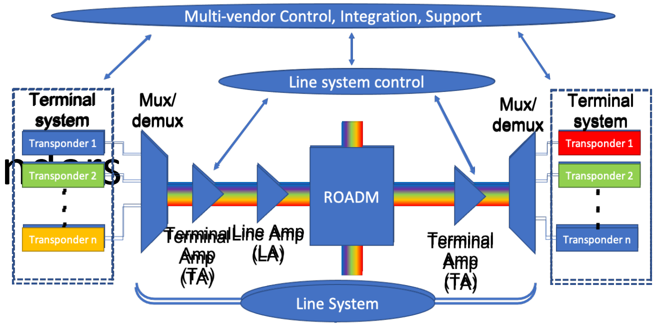
- Stage 2: Open APIs and SDN control
  - Open to external controllers and orchestrators
  - OpenROADM and ODTN (ONF) working on this

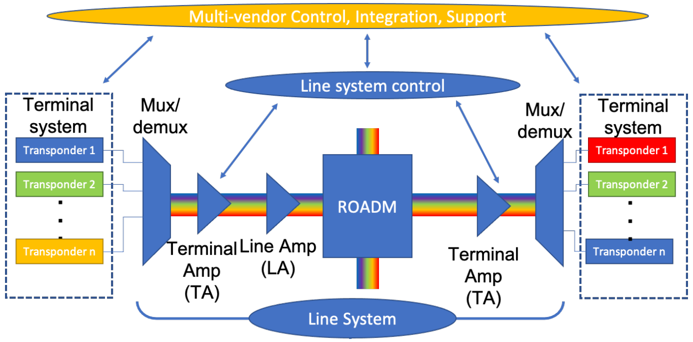
- Stage 3: Disaggregate the OLS
  - Have also in-line amplifiers and ROADMS from different vendors
  - OpenROADM working on this, planned in ODTN

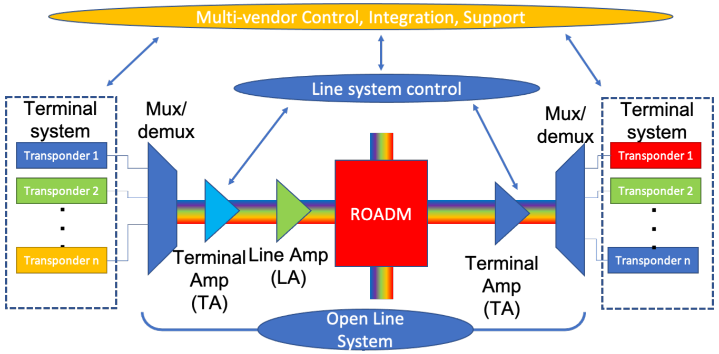
- Stage 4: Full end-to-end integration of the open system
  - The optical system is full disaggregated and open to external control

- Question is who provides the end-to-end integration: one of the components vendors, the orchestration vendor or the operator itself…?

  … or the network becomes so intelligent and does it by itself..?







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Source: Geoff Bennett, Open Line Systems and Open ROADM: How Open Is Your Line System? https://tnc18.geant.org/getfile/4520

Pros and challenges

- Fast evolution: in 5 years went from being unacceptable … to hot topic
- Pros:
  - Open market of components from multiple vendors brings cost down
  - No vendor lock-in, faster network upgrades
  - Possibility of full integration with other control layers to achieve dynamic, fast, end-to-end optical re-configurability ➔ previous mobile, optical, cloud use case
- Challenges:
  - Working on analog system with physical parameters and impairments…

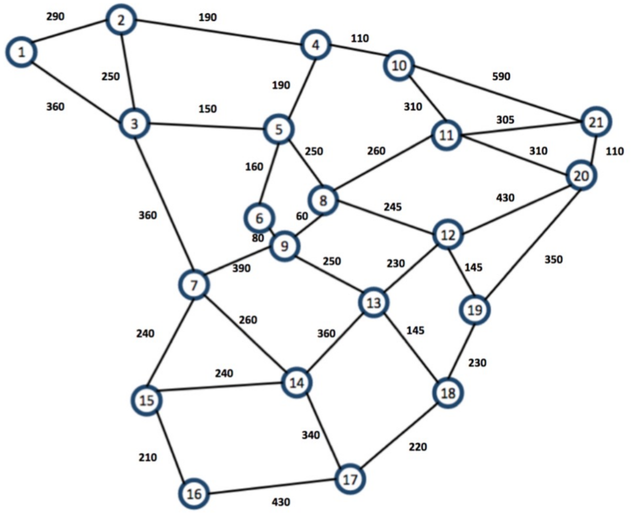
    …notice that a digital system is also built upon a physical analogue layer, but there we have a better abstraction built over 50 years of evolution in computing systems
  - A system engineered by a one vendor producing is more predictable and requires lower optical margins ➔ higher efficiency/lower cost
  - Business-oriented:
    - Who provides system integration?

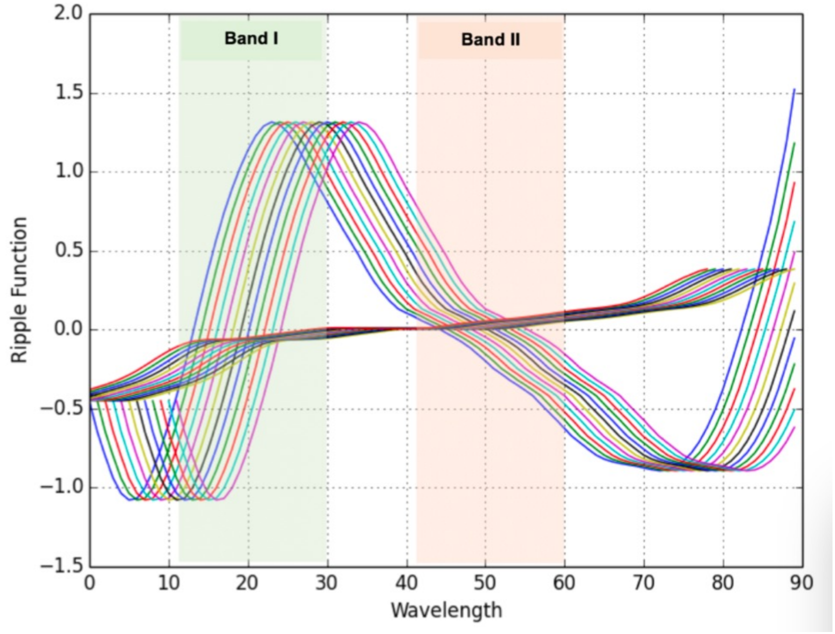
Sample study

ARIZONA

- Spain network topology
  - Physical layer includes OSNR, non-ideal EDFA gain flatness, SRS, …
  - Amplifier behavior not fully known: gain flatness varies depending on
    - Amplifier model
    - Individual device
    - External conditions
    - …

- Use of same margin across all channels is typical
  ➔ $OSNR_{est}$ + Margin > $OSNR_{th}$ (QPSK, 8QAM, 16QAM)





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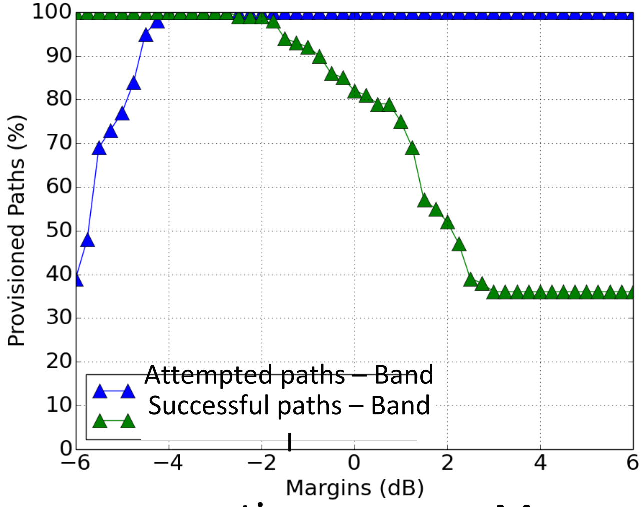
Studying the margins



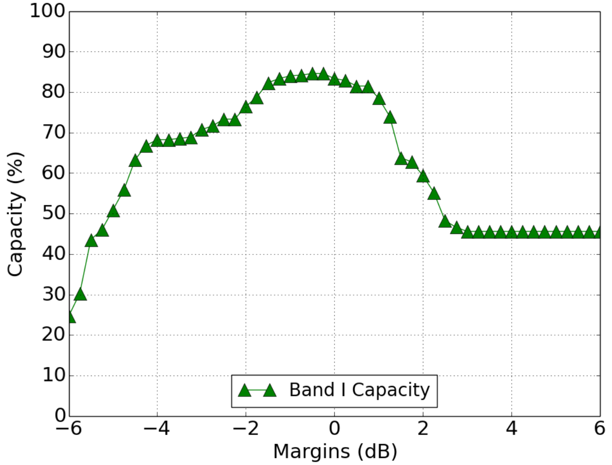
Estimation assumes flat amplifier gain

More conservative

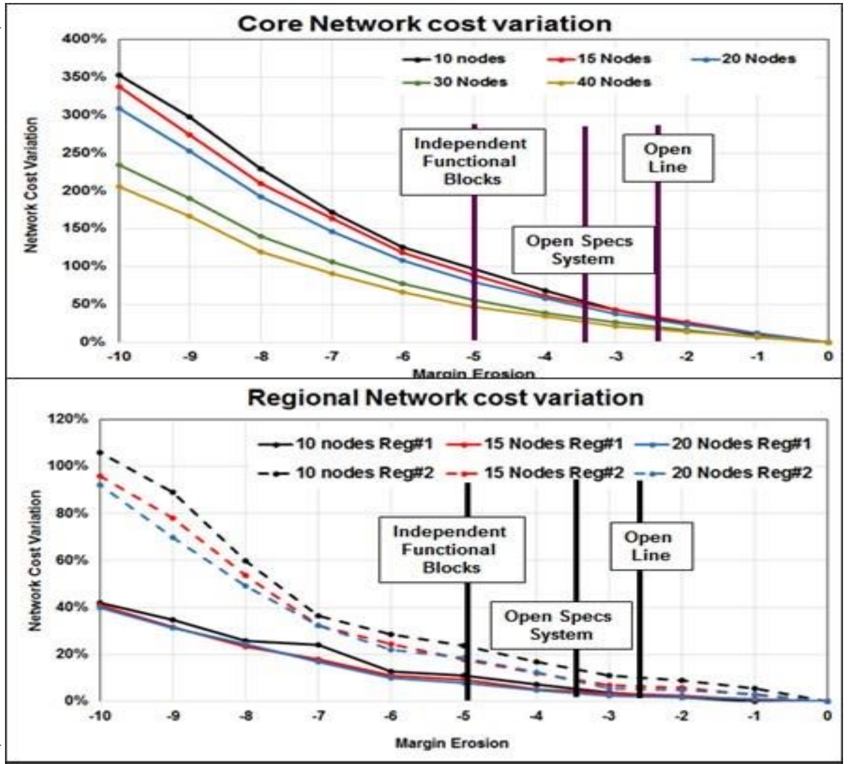
More aggressive

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

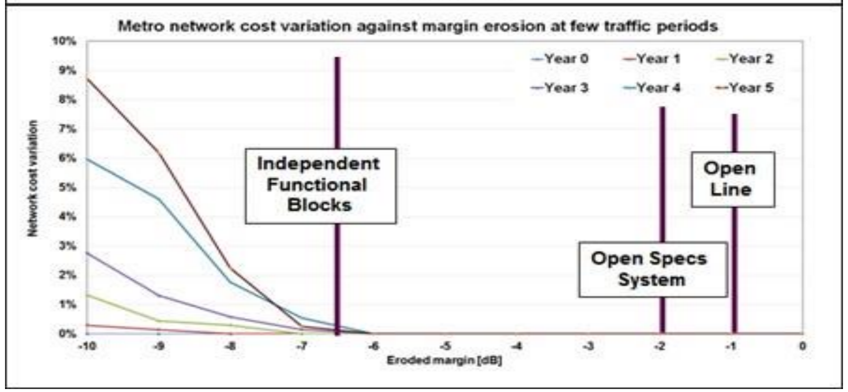
X axis: how conservative are the margins



Effect on cost of core and regional network shown to be substantial due to low available margins



Effect on metro though is negligible, as the metro has larger margins



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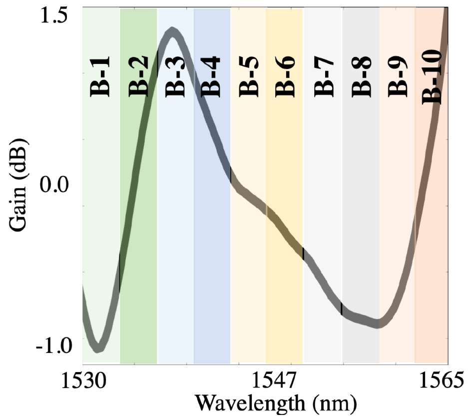
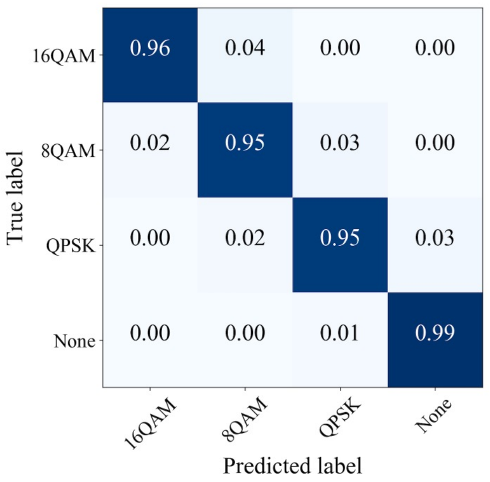
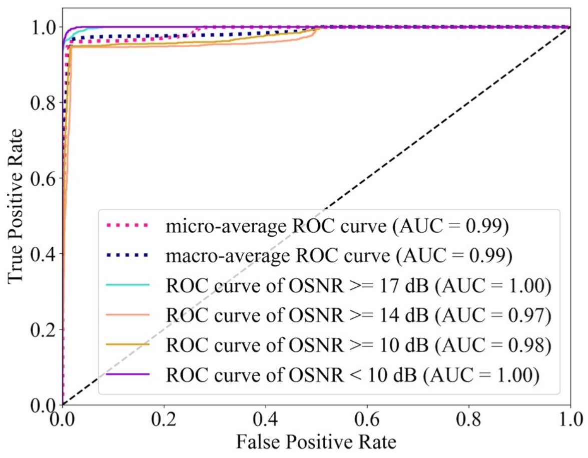
Source: M. Bleanger, M, O'Sullivan and P, Littlewood. Margin requirement of disaggregating the DWDM transport system and its consequence on application economics. M1E.2, OFC '18

Use of Machine learning for quality of transmission estimation in optical transport networks

- Dynamic wavelength allocation suffers from impairments in optical amplifiers:
  - Amplifier gain is not perfectly flat across wavelengths and this function is not known and depends on amplifier, working point…
  - ➔ Adding a wavelength channel can increase/decrease the power and OSNR of all other channel
- Quality of Transmission estimation is an important research area, and ML techniques have been used to provide such estimation
- Build multi-class SVM classifier to decide what modulation is possible (e.g., related to OSNR) with features: number of nodes, fibre length, launch power, EDFA gain, plus the number of wavelength channels already loaded in each of the 10 bins below.







A. A. Dıaz-Montiel, S. Aladin, C. Tremblay and M. Ruffini. Active Wavelength Load as a Feature for QoTEstimation Based on Support Vector Machine. IEEE International Conference on Communications, May 2019

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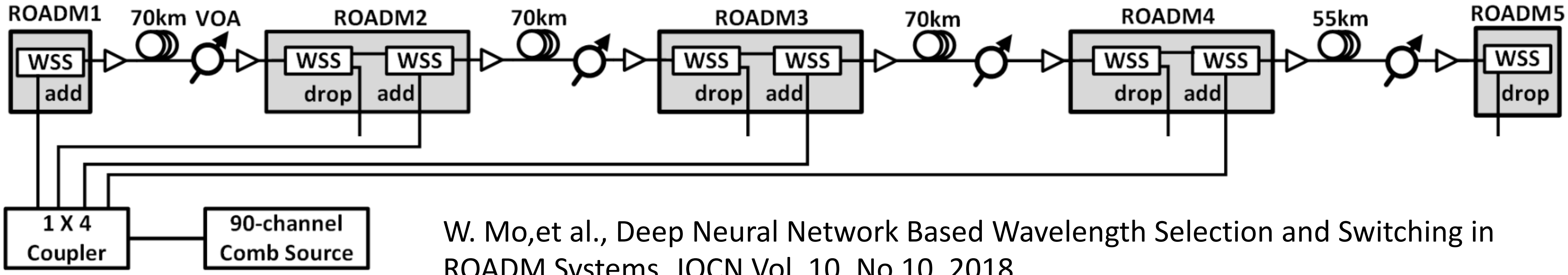
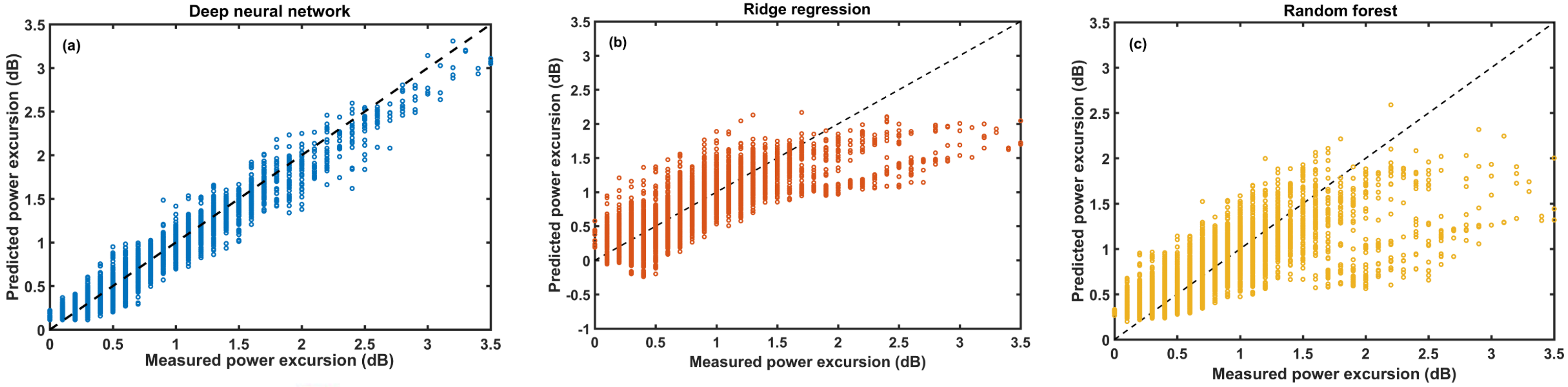
Deep Learning Shown Effective for Predicting Optical Signal Powers



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

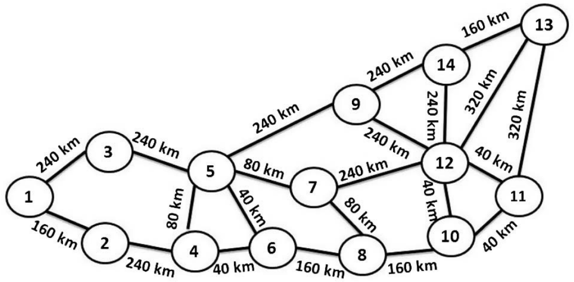


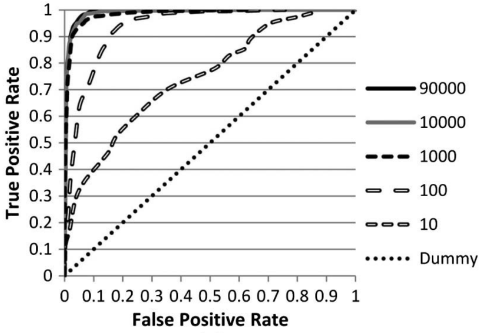
Deep learning (left) shown to accurately predict optical signal power which is main determinant of signal quality, based on the channel configuration alone.

More ML

QoT prediction using random forest ML algorithm

Dependency on training set size

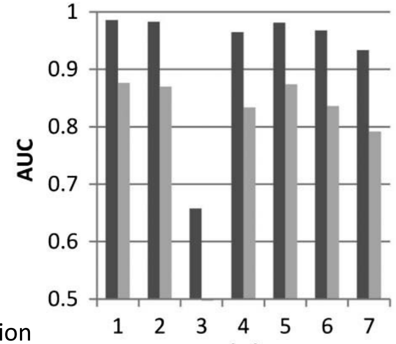




Relevance of different features

CONSIDERED FEATURE SUBSETS

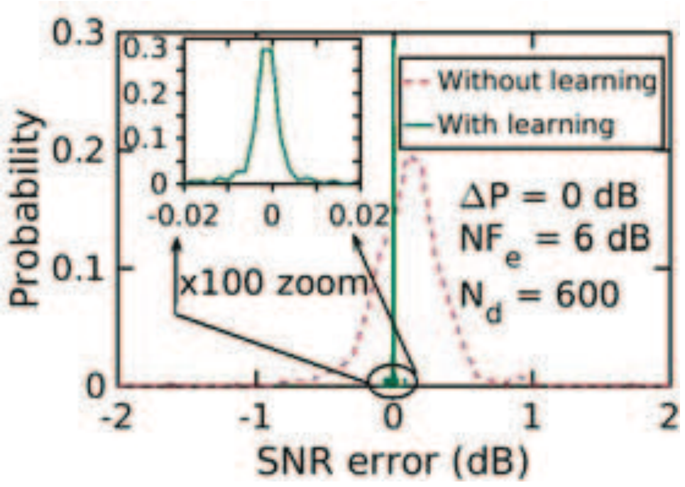
	S1	S2	S3	S4	S5	S6	S7
Number of links	✓	✓	✓	✓			
Lightpath length	✓	✓	✓	✓	✓	✓	
Length of longest link	✓	✓	✓	✓			
Traffic volume	✓	✓	✓		✓		✓
Modulation format	✓	✓		✓	✓	✓	✓
Guardband, modulation format, and traffic volume of nearest left and right neighbor	✓						



(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.

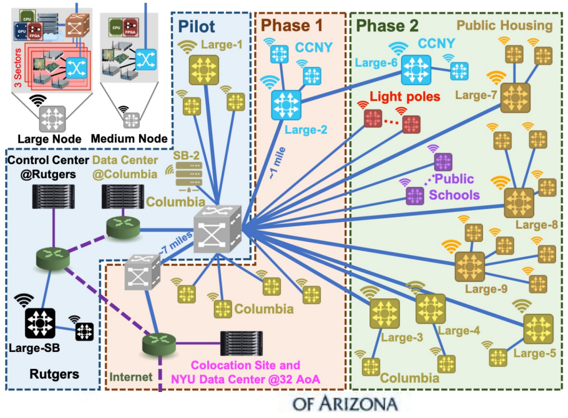
- There are still issues:
  - Scalability for large network systems need to be addressed, black box ML not a good option
  - Data collection, storage and sharing is still the main problem

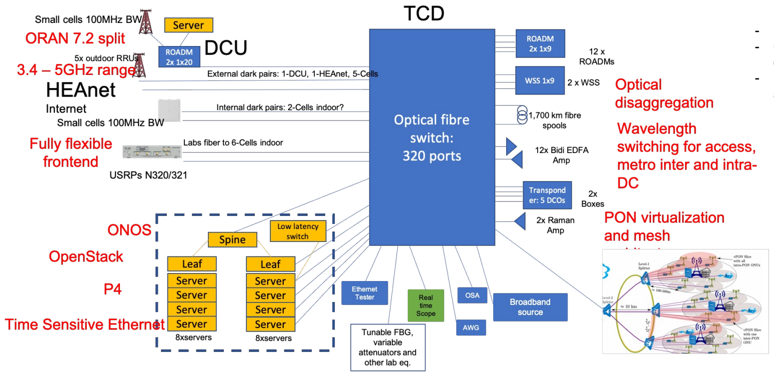
How do I test my control plane / algorithms?

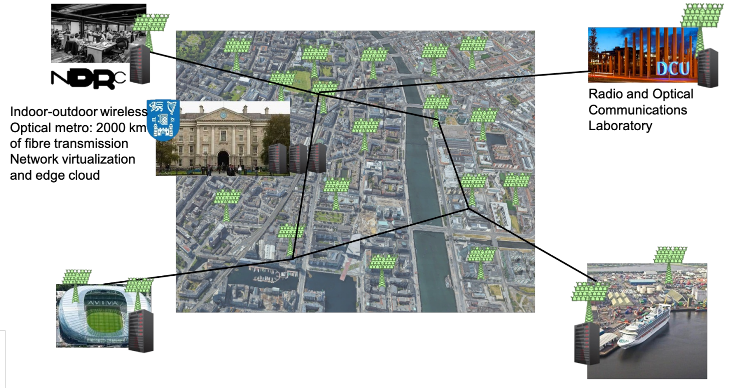
Real network infrastructure is best!... but

1) operator (or large vendor/ service provider) and I own infrastructure
   - Private network, only usable by owner
   - If large scale, then part of production network, so very limited research
   - If standalone just for experiment then it's typically of limited size

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







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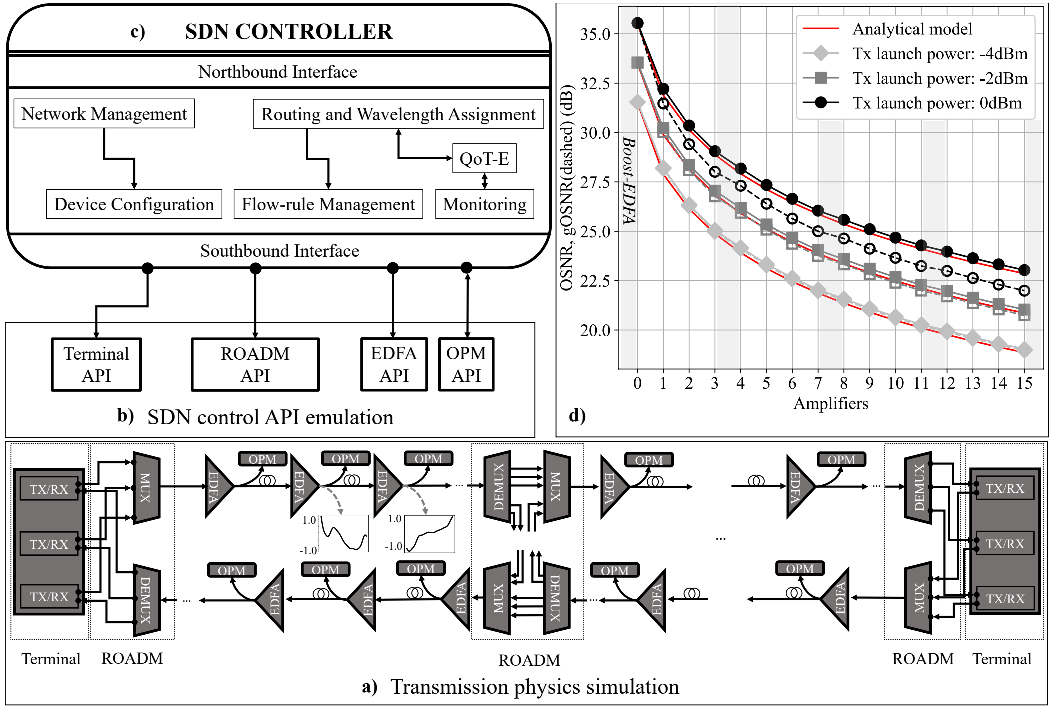
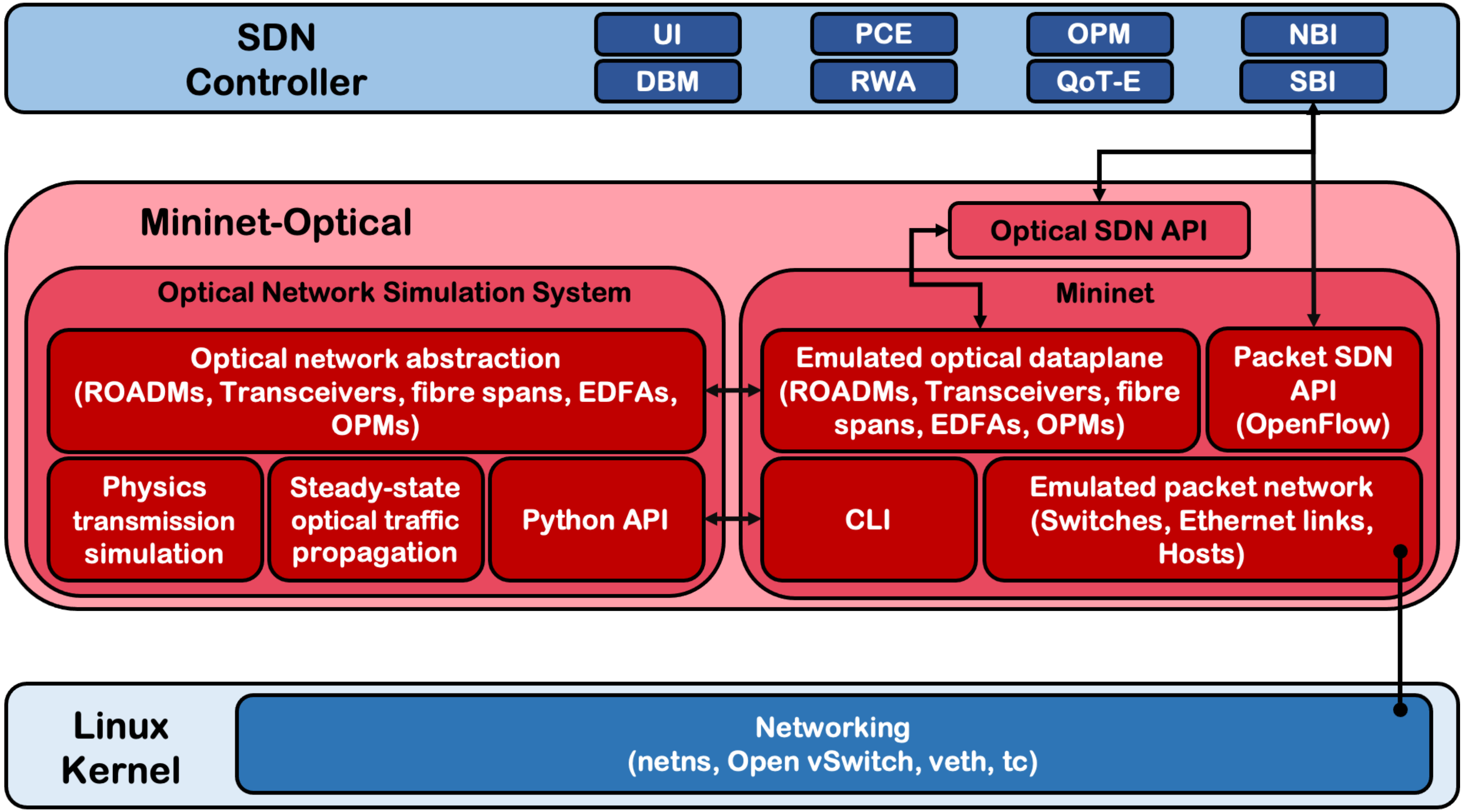
Mininet becomes Optical!

- We have created **<u>Mininet-Optical</u>**: an SDN emulator that uses Mininet and additional physical layer optical simulation to emulate optical devices, such as ROADMs, amplifiers, transceivers, fibre propagation (including nonlinearities), etc.
  - Now you can test an SDN control plane also on optical devices (i.e., ONOS-ODTN) on large scale networks



- 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
- Alan A. Díaz-Montiel, J. Yu, W. Mo, Y. Li, D.C. Kilper and M. Ruffini. Performance Analysis of QoT Estimator in SDN-Controlled ROADM Networks. Proc. of Optical Network Design and Modeling conference (ONDM), May 2018

The architectural diagram



DBM: Database Manager

UI: User Interface

PCE: Path Computing Element

RWA: Routing and Wavelength Assignment

OPM: Optical Power Monitoring

QoT-E: Quality of Transmission Estimation

NBI: North-Bound Interface

SBI: South-Bound Interface

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How does it work?

- Node types:
  - Transponders: modulation, baud rate, power, wavelength, BER from gOSNR
  - WSS: insertion loss, variable attenuation, wavelength routing
  - EDFA: linear gain, <u>wavelength dependent gain</u>, ASE, automatic gain control mode
  - Fibre length: attenuation, dispersion, SRS, self-channel and cross-channel interference through the GN model
  - Performance monitors to emulate different types: power, OSNR, gOSNR,…

- Operation mode:
  - Simulation: configure topology and devices in advance and run the simulation (for quick testing of features or transmission model results).
  - Emulation: control plane dynamically interact with network nodes; also links with electronic nodes (i.e., original mininet nodes)

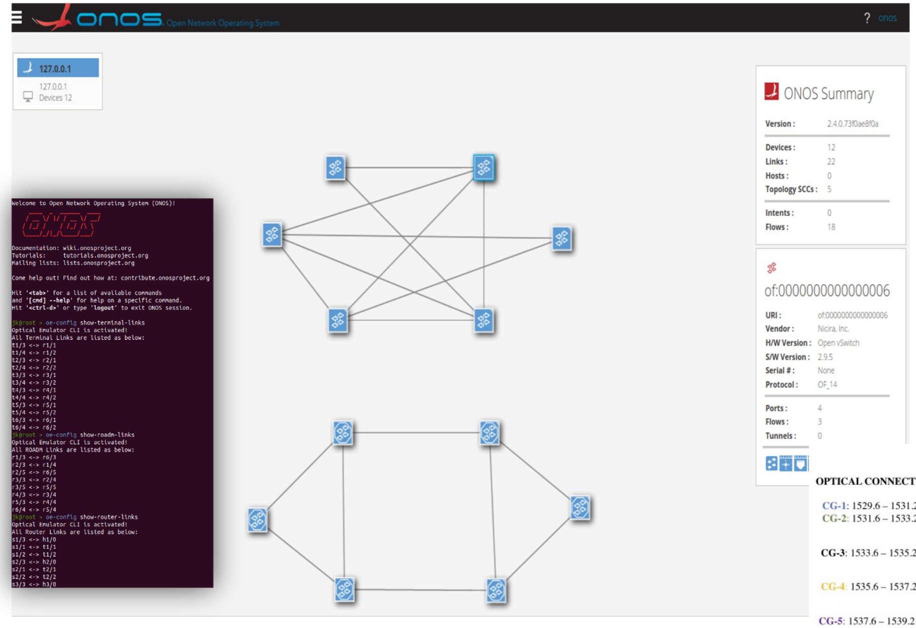
How does it work?

- Mininet was extended to use the optical transmission simulator as built-in API
- Nodes (ROADM, transceivers) are OVS switches
- Optical layer information (power, wavelength, noise, etc) is encoded into packet headers

Mininet-Optical API example

```
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)
```

Use case I: SDN controller operating failure recovery



- Creating system of 6 ROADM nodes and in line amplifiers
- ONOS monitoring OSNR at given points (OPMs)
- Simulating EDFA failure: sudden reduction of OSNR across group pf channels
- ONOS operating failure recovery through traffic rerouting

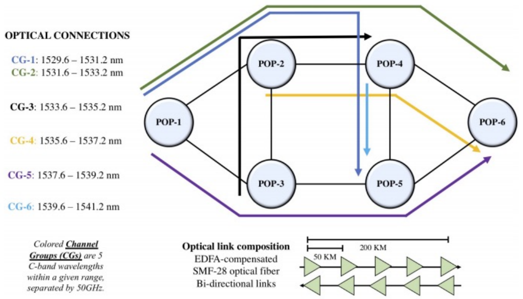
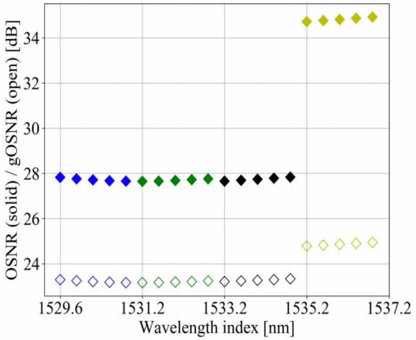


Fig. 3: Controller monitors OSNR (solid) and gOSNR (open) of all channels entering POP-4 (via POP-2) during the initial transmission



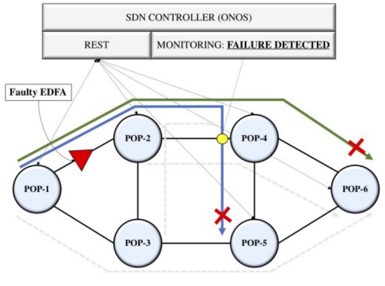
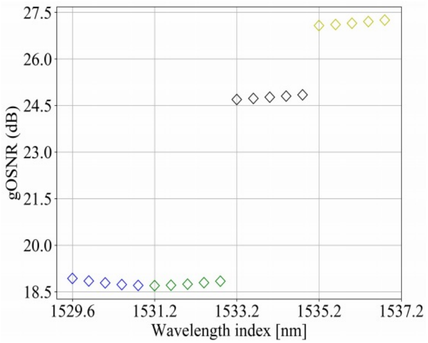


Fig. 4: Faulty EDFA degrades CG-1 and CG-2; controller observes low monitored gOSNR for signals entering POP-4 (via POP-2)



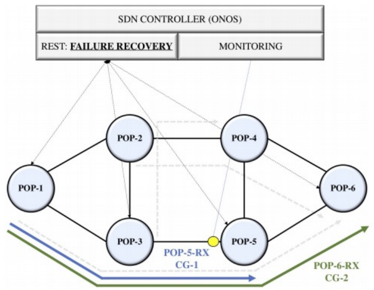
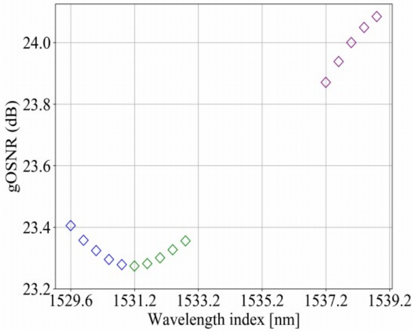


Fig. 5: Controller re-routes CG-1 and CG-2, resulting in high monitored gOSNR for signals entering POP-5 (via POP-3)



Bob Lantz, Alan A. Díaz-Montiel, Jiakai Yu, Christian Rios, Marco Ruffini, Dan Kilper. Demonstration of Software-Defined Packet-Optical Network Emulation with Mininet-Optical and ONOS. OFC 2020.

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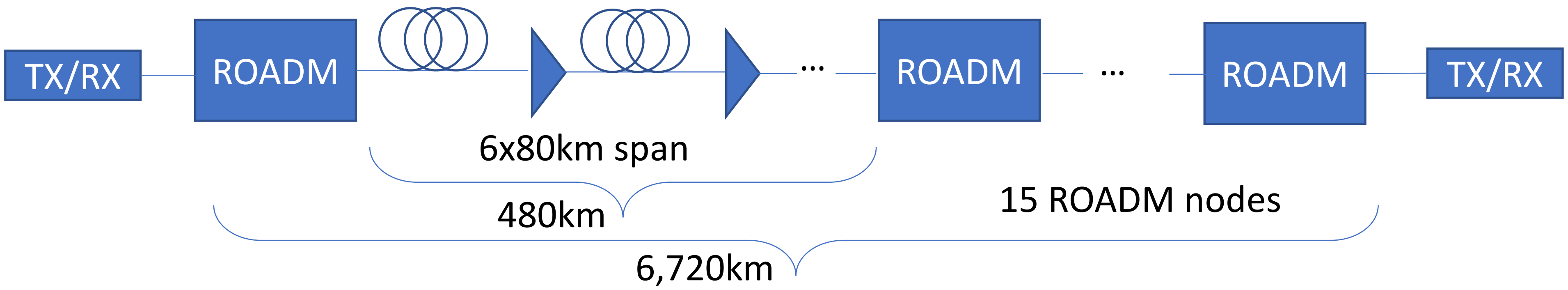
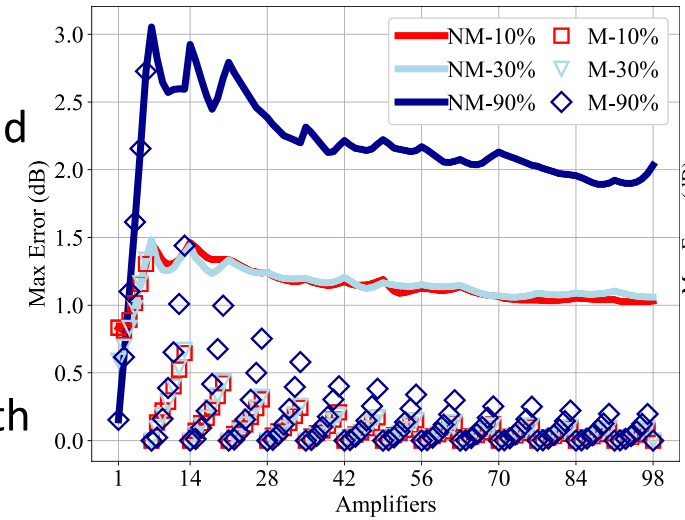
Use case II: Use OPM to improve controller's QoT estimation

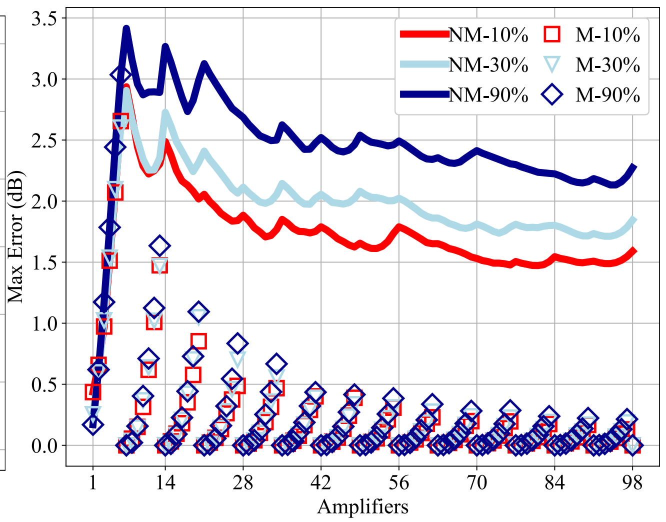


- Loading channels on a 90-wavelength transmission system.
- The unknown EDFA wavelength dependent gain causes errors on the QoT estimation algorithm.
- The controller can use OPM to correct the estimation error

- Controller's QoT estimation considers nonlinear effects and EDFA noise, but not the wavelength-dependent gain
- The estimation error on the worst channel can range between and 3 dB.
- Adding monitoring every 7 amplifiers can reset the estimation error, keeping it below 1 dB for most of the path



Sequential channel loading



Random channel loading

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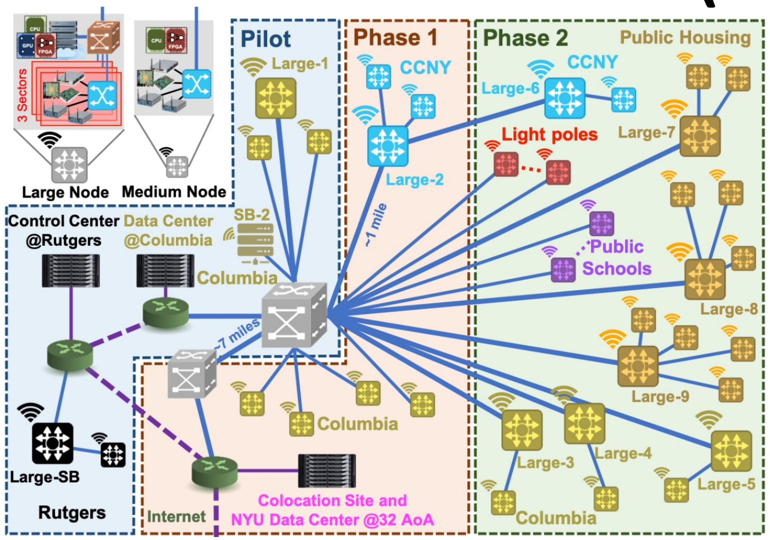
Mininet-optical in support of testbed infrastructure

- Emulation platforms like Mininet-Optical can be fully complementary to testbed experimentation

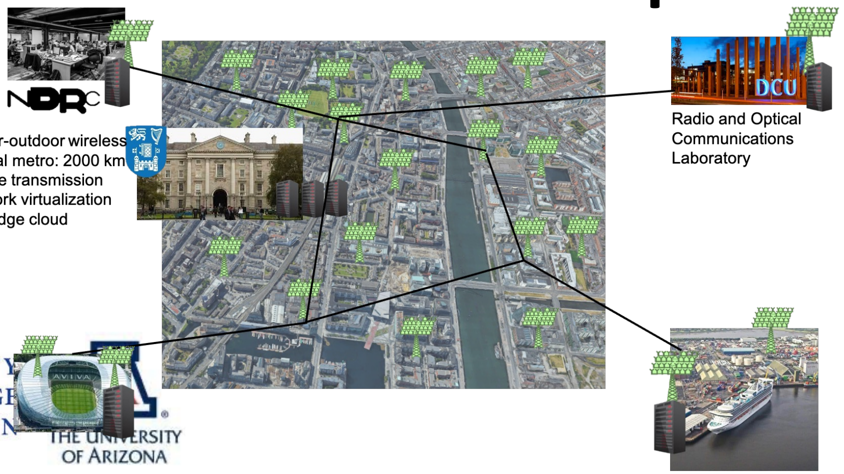
1. Can provide a ”sandbox” environment for testing/debugging control plane application in “home” environment before migrating to testbed
2. Can provide means for testing control planes over much larger topologies than available in testbed
3. ==> Emulation and testbed can be used side-by-side to develop and test both accuracy and scalability of control planes for disaggregated optical networks!

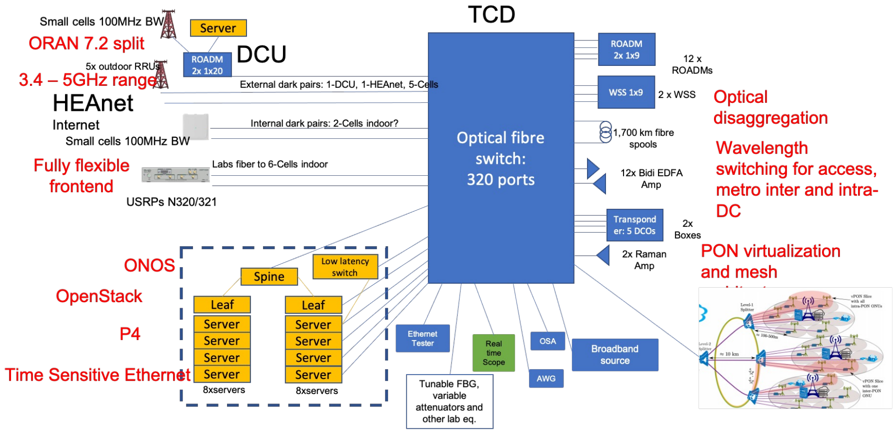
COSMOS (US)



OpenIreland

- Indoor-outdoor wireless
- Optical metro: 2000 km of fibre transmission
- Network virtualization and edge cloud





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Conclusions

- Optical layer disaggregation extend the open systems concept to the optical layer (i.e., following similar trends in Data centres - SDN, Central Office - Cloud-CO and mobile networks - OpenRAN).
- However it requires development of complex and intelligent control plane, especially in order to maintain error margins low

  ➔ <u>Controlling the system is the key challenge</u>

- We developed Mininet-Optical, the Mininet extension for optical SDN control planes, considerably simplifying testing operations and increasing scalability.
- We envisage this emulation tool to be fully complementary with testbed experimentation: <u>enabling both accuracy and scalability!</u>

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