SDN control of optical networks: from network automation to quantum communications

NetSoft 2022, PVE-SDN workshop

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CONNECT research centres
Summary of the talk

- Open & Disaggregated Networking trends: CORD, OpenRAN, Open optical

- Optical disaggregation
  - Pros, challenges and the GSNR margin issue
  - Use of Machine learning

- Digital twin
  - Early work: consortia, architectures and control plane
  - Our approach
    - Mininet-optical
    - City testbed (Open Ireland & COSMOS)

- Next generation: quantum
The Network Virtualisation and Open Networking Trend

- Open networking in central office:

This has now evolved into the SDN-Enabled Broadband (SEBA)
And more recently into a converged MEC/Cloud - AETHER
**Open networking in mobile base stations**

**OpenRAN**

The Network Virtualisation and Open Networking Trend II

- Option 1
- Option 2
- Option 3
- Option 4
- Option 5
- Option 6
- Option 7
- Option 8

**RRC**

**PDCP**

**High-RLC**

**Low-RLC**

**High-MAC**

**Low-MAC**

**High-PHY**

**Low-PHY**

**RF**

Option 7.2 (with 7.3 coming)
Opening the optical layer

- This is a difficult one!
- Optical transmission is analogue, meaning that different devices have different behavior (unlike digital)
- Nonetheless now there are SDN-controlled "whitebox" devices, like ROADMs, amplifiers and transponders.
Pros vs challenges

Pros:
- Open market of component 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 and programmability

Challenges:
- Building an end-to-end analog system
- How to do end-to-end system optimization with components whose behavior is not well known?
- Use of margins:
  - More conservative
  - More aggressive

X axis: how conservative are the margins
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.

Deep Learning Shown Effective for Predicting Optical Signal Powers


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

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### ONIS OPERATION TIMINGS

<table>
<thead>
<tr>
<th></th>
<th>OSA-based OSNR computation</th>
<th>ROADM-based OSNR computation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Algorithm initialization</td>
<td>3.15 s</td>
<td></td>
</tr>
<tr>
<td>Single step</td>
<td></td>
<td></td>
</tr>
<tr>
<td>channel opening + OSNR + reward</td>
<td>1.31 s</td>
<td></td>
</tr>
<tr>
<td>Episode (full spectrum filled)</td>
<td>2400 s (40 mins)</td>
<td>182.2 s (3 mins)</td>
</tr>
<tr>
<td>OSNR computation</td>
<td>25.84 s</td>
<td>1.18 s</td>
</tr>
</tbody>
</table>
Has machine learning solved the problem?

• All of this helps, but it still a highly manual process of appropriate measurements, data collection, model building, model validation...

... and then a black box neural network could still provide unexpected outliers

Machine Learning is part of the solution, but still far from “Zero Touch” fully automated system

➡ Concept of digital twin

www.digitaltwinconsortium.org
Next steps towards digital twinning

• What is a digital twin is a good topic of discussion:
  • Emulation of specific aspects of its twin network (i.e., doesn't need to replicate all layers)
• Live interaction between emulated and real network:
  • Use real input/output data from network to improve models across an increasing number of states/scenarios
  • Predict network states that can lead to anomaly (malfunctions or simple SLA breach): Decide when to monitor what
  • Ultimate goal is that of autonomous decision making and trusting the twin to fully manage the networks

• A testbed is essential to enable this type of research
• An open testbed enables research and collaboration on these topics across academic and industrial partners
Early work

- Real digital twin contribution are very early stage
  - Some conceptual architectures
    

- Some early control plane work
  

- A reference physical network is essential
  - Aim is zero margin, not even for component ageing... the twin ages with the network
Our approach to the digital twin

Hardware network on testbed

Virtual network in Mininet-Optical
The emulation side: 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,

```python
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)
```


Now open source: https://mininet-optical.org
Example of operation: 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 be up to 3 dB.
- Adding monitoring every 7 amplifiers can reset the estimation error, keeping it below 1 dB for most of the path.

Example of operation: 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 of channels
- ONOS operating failure recovery through traffic rerouting

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

### Optical transmission, analog RoF, mmWave-THz

### Open Ireland: Ireland’s Open Networking Testbed

*www.openireland.eu*

Based in Trinity College campus

**O-RAN 7.2 split**

**CONNECT research centre building**

**SDR**

**Open-Optical**

- Optical disaggregation
- Wavelength switching for access, metro, inter and intra-DC
- PON virtualization
- Cloud (Edge/central)
- Virtual PON

**Existing 3.6 GHz for 5G**

<table>
<thead>
<tr>
<th>Frequency (GHz)</th>
<th>Mode</th>
<th>3410 - 3435</th>
<th>3410 - 3475</th>
<th>3475 - 3580</th>
<th>3580 - 3615</th>
<th>3615 - 3700</th>
<th>Upper 4 GHz band for 5G</th>
</tr>
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<tbody>
<tr>
<td>3410 - 3435</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3410 - 3475</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3475 - 3580</td>
<td></td>
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<td></td>
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<tr>
<td>3580 - 3615</td>
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<td></td>
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<tr>
<td>3615 - 3700</td>
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<td></td>
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<tr>
<td>3700 - 3800</td>
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<tr>
<td>3850 - 3950</td>
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</table>

Upper N77 band: 3.8 – 4.2 GHZ
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**

COSMOS: Manhattan – New Jersey

OpenIreland

TSSG Data Centre

RARE P4 testbed

RARE @UFES - CPQD
The power of topological reconfiguration

- **Use case 1:** Compare different O-RAN fronthaul, for meeting basic requirements, effect on performance for advanced RIC-based coordination.

- **Use case 2:** Examine coexistence of different transmission formats analogue, digital RoF for support of 6G dense mmWave, THz.
What’s next?
Arguments against:
- Very early stage of computing – expensive cryogenic devices
- Not many around to build a network
- No quantum memory
- Transmission of quantum states very delicate...

But:
- Recent progress has been fast, strong investments
- Hardware is slow, but there is appetite for development of quantum algorithms and for network control (we like to be ready to go once the hardware is there)

<table>
<thead>
<tr>
<th>Role</th>
<th>MSc(grad)</th>
<th>POST DOC (2 years)</th>
<th>1-3 years (industry)</th>
<th>2-3 years (industry)</th>
<th>3-4 years (industry)</th>
<th>5+ years +</th>
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<tbody>
<tr>
<td>Quantum Algorithm Scientist</td>
<td>$90k +</td>
<td>$115k - $145k</td>
<td>$130k - $150k</td>
<td>$155k - $180k</td>
<td>$190k - $225k</td>
<td>$250k +</td>
</tr>
<tr>
<td>Quantum Hardware Engineer</td>
<td>$80k +</td>
<td>$95k - $125k</td>
<td>$115k - $130k</td>
<td>$125k - $160k</td>
<td>$150k - $180k</td>
<td>$200k +</td>
</tr>
<tr>
<td>Quantum Software Engineer</td>
<td>$90k +</td>
<td>$115k - $145k</td>
<td>$130k - $150k</td>
<td>$155k - $180k</td>
<td>$190k - $225k</td>
<td>$250k +</td>
</tr>
<tr>
<td>Optomechanical Engineer</td>
<td>$85k +</td>
<td>$110k - $125k</td>
<td>$125k - $140k</td>
<td>$145k - $155k</td>
<td>$160k - $180k</td>
<td>$200k +</td>
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<tr>
<td>Superconducting Circuit Designer</td>
<td>$90k +</td>
<td>$110k - $125k</td>
<td>$125k - $140k</td>
<td>$145k - $155k</td>
<td>$160k - $180k</td>
<td>$200k +</td>
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<tr>
<td>Business Development</td>
<td>$75k +</td>
<td>$90k - $110k</td>
<td>$105k - $115k</td>
<td>$120k - $135k</td>
<td>$140k - $155k</td>
<td>$175k +</td>
</tr>
</tbody>
</table>

For more information or to discuss career opportunities contact Connor@quantum-futures.com
Quantum computing will require the ability to distribute quantum information across multiple locations:

- **Scaling quantum computing**: increase the power of quantum computing through distributed quantum computing
- **Ubiquitous access to quantum resources**: end user access to quantum state information from centralized quantum computing nodes
- **Secure communication**: operate Quantum Key Distribution seamlessly across any access node (fixed and mobile)

Optical fibre can provide ubiquitous access, particularly through coexistence between quantum and classical channels:

- Issue is that extremely weak quantum signals are very easily impaired by much stronger classical communications signals (order of 100 dB difference in power)

New US-Ireland project with scope to realize an emulation platform to enable study of quantum network control planes and facilitate coexistence between classical and quantum signals:

- Analyze signals and predict interference; provide suitable routing; cross-optimization of quantum and classical signal generation, detection and routing.
Mininet quantum

- We are working in joint US-Ireland projects on quantum communications
- Centre-to-centre (CQN – CONNECT) project looking at multiple aspects of quantum communication (both hardware and software)

- Plan is to extend the physical layer model of Mininet-Optical to include quantum transmission models and control architectures
- Include quantum devices models (photon generators, photon transmission, quantum memories, other components for quantum optics)
- Design and develop interfaces for the quantum devices
Network virtualisation & open networking has really opened up the possibility to analyse, research and test control planes.

The big question is if will we be able to orchestrate AI algorithm to build a reliable digital twin framework?

- ... and going ahead, a digital twin that builds itself?

The second big question is how long before we need a quantum network...

- ... and an SDN controller?

- SDN controller already being used for QKD...
Thank you

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