ROADM and Optical Layer

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SDN: Google Map Routing for Networks?  
Packets = Driving, Optics = Flying
Key Questions/Issues

• Better performance: tighten margins or eliminate margins
• Better software control: reduced complexity, improve reliability of software controls
• Reduce testing cycles, repair time
• Disaggregation: more reliable performance from disaggregated hardware
• Enable more dynamic/faster switching/DBA operation

• Can we use test or field data in order to ‘learn’ better methods to address the above issues?
• Which data is useful and where?
Long Term Question

• Can we make optical systems fully open and simple to operate?
  • Buy components from any vendor and put them together however I want without worry
  • Configure, customize, operate as you like
Scope

- **Line system components:**
  - WSSs, space switches, amplifiers, fiber plant, VOAs, OPM/telemetry/OTDR, multiplexers, ASE noise loading

- **Line system controls:**
  - RSA/RWA/PCE, steady state controls (e.g. power leveling, OA gain settings), channel provisioning (e.g. switch settings, power tuning, synchronization)

- **Test, Development, Fault Management:**
  - Engineering rule validation testing, interoperability testing, in-service testing, fault identification/localization, fault prediction, electrical power cycling, in-service maintenance
## Signal Provisioning

<table>
<thead>
<tr>
<th>Stages</th>
<th>Steps</th>
<th>Goal/Issue</th>
<th>AI solution</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Before traffic request</strong></td>
<td>Physical layer characterization</td>
<td>Lack of accurate optical amplifier model</td>
<td>DNN</td>
</tr>
<tr>
<td></td>
<td>Traffic prediction</td>
<td>Optimize resource allocation</td>
<td>LSTM, DCRNN</td>
</tr>
<tr>
<td><strong>Before channel setup</strong></td>
<td>Wavelength selection</td>
<td>Minimize impact to existing channels</td>
<td>DNN</td>
</tr>
<tr>
<td></td>
<td>QoT estimation</td>
<td>Predict signal quality (e.g. OSNR)</td>
<td>GP, GN, TL</td>
</tr>
<tr>
<td><strong>During channel setup</strong></td>
<td>Power tuning</td>
<td>Speed, avoid impact</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Element synchronization</td>
<td>Speed, stability</td>
<td>None</td>
</tr>
<tr>
<td><strong>After channel setup</strong></td>
<td>Adaptive control for transmission</td>
<td>Fluctuation of signal quality reconfiguration</td>
<td>Feedback Control</td>
</tr>
<tr>
<td></td>
<td>Failure detection and recovery</td>
<td>Predict link failure, recover optical link</td>
<td>ML+SDN, tSDX</td>
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</tbody>
</table>
Variations in the Field

• Production system measurements (Microsoft)
• Performance varies by wavelength & route over time
• Mostly transceiver focused: what about network!

Ghobadi, et. al. OFC 2016
Example: OA Models

\[ P_i = R G_M P_{\text{ini}} + G_M \sum_{j \neq i} (R - f g_j) P_{\text{inj}} + G_M (R - f g_I) N_I - f G_M g_R N_R \]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Vector</td>
<td>([P_{\text{ch1}}, P_{\text{ch2}}, P_{\text{ch3}}, \ldots, P_{\text{ch90}}])</td>
</tr>
<tr>
<td>Output Vector</td>
<td>([P_{\text{ch}_i}]) for (i) in ([1, 90])  # (i) is index of the 90 NNs</td>
</tr>
<tr>
<td>Transfer Func.</td>
<td>([\text{ReLU, Linear, ReLU, Linear, ReLU}])</td>
</tr>
<tr>
<td>Training Target</td>
<td>(\text{Min{MSE}})</td>
</tr>
<tr>
<td>Training Method</td>
<td>Stochastic Gradient Descent (SGD)</td>
</tr>
<tr>
<td>Batch Size ((m))</td>
<td>(m = 60)</td>
</tr>
<tr>
<td>Learning Rate ((\alpha))</td>
<td>(\alpha = 0.00025)</td>
</tr>
<tr>
<td>Training Time</td>
<td>(&gt; 15000) iterations</td>
</tr>
</tbody>
</table>
Use Transfer Learning from Test Lab to Field

Y-K. Huang, E. Ip NEC & UA
W. Mo., et. al. OFC 2018

• Improve Quality of Transmission (QoT) estimation and wavelength assignment
• Transfer learning for real time prediction

Q-Factor Prediction

Transfer Learning

Best student paper runner-up for OFC 2018!
Dynamic Domain Power Control Algorithm

- Power drifts over time and new channels are provisioned: need periodic power control to stay within margins
- Adjust nodes in parallel within ‘optically’ isolated domains
  - Node ordering based on channel routes

\[ [1,2,3,4] \]
\[ [i,j,k] = \text{channels adjusting upstream} \]
\[ [1,4] \]
\[ [3] \]
\[ [2] \]
\[ [4] \]
\[ [3] \]
\[ [1] \]

Wait for Chn 1

Ready to Adjust

Kilper & White OFC 2007
The Network Today: Long Haul/Regional

- No point to point trans-continental links
- Large, continental scale transparent network
  - Add and drop traffic many times along route from NY to LA
The Network Today: Metro/Wireless/Access

Manhattan
Crown Castle
(Wireless) Fiber
COSMOS: Multi-Layer Wireless Optical Testbed
New York City Deployment Area

Deployment:
- **Large node**: rooftop deployments with number of antennas and edge cloud
- **Medium node**: street-level devices dual use with wireless/wired backhaul
- **Control Center**: CRAN, control, management and operations center

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COSMOS: Optical Networking
COSMOS: Optical Platform for Data Collection

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