The Open Ireland research infrastructure: from open networking to digital twins

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The Research group

OpenRAN Intelligent control

Open Networking testbed

Mininet-Optical
Optical network digital twin

Mesh PON access

Free space optics backhaul

PON virtualization

Edge-cloud optimisation

SDN control of quantum networks

Heterogeneous access-metro networks

Multi-RAT optimisation
Expertise and track record

Our research work moves from theory to lab experimentation and prototyping

- Invented, patented and prototyped PON scheduling virtualization, brought to standard at BroadBand Forum (TR-402, TR-370i2, WT-477)

- SDN and network virtualisation:
  - convergence of optical and wireless access systems (coordinated scheduling)
  - optical disaggregated systems (machine learning for quality of transmission estimation) – mininet optical emulator
  - low-latency access
  - network multi-tenancy and multi-service operation
  - OpenRAN and RAN Intelligent Controller
Full disaggregation of the OLT with virtual DBA

- Work on DBA virtualization to enable fine-grained control to different tenants.
- Also other use cases: e.g., for service differentiation, for mobile front haul (more on this later)
- Also included in BBF TR-402 “PON Abstraction Interface for Time-critical Applications” and recently in TR-370i2 “Fixed Access Network Sharing (FANS) and WT-477 in progress (implementation work flow)
Low latency for unpredictable traffic

Standard DBA process

a. ONU waits for the opportunity for the DBRu
b. DBRu propagates through the fibre.
c. Information from phy to virtual process.
d. DBA process waits a time window to receive DBRus.
e. OLT runs the DBA algorithm.
f. BWMAP added to the next downstream frame.
g. BWMAP travels from virtual process to phy.
h. BWMAP propagates through the fibre.
i. ONU transmit the data at its allocated time.

➢ Standard DBA best latency =\textasciitilde 418.5\mu s (virtual implementation)

➢ Fast intercept avg latency =\textasciitilde 237 \mu s (\sim 43\% faster)

Fast intercept process

a) Low-latency DBRu
b) ... f) BMAP from previous cycle
h) Updated BMAP
i) ONU transmit the data at its allocated time.
Extend PON physical and virtual layer

Support high-capacity, low latency communications in a mesh access topology

Overall > 35 publications, including:
- Journal of optical Communications and Networking (JOCN)
- Journal of Lightwave Technology (JLT)
- IEEE Communications Magazine
- IEEE Communications Survey and Tutorials
- Optical Fibre Conference (OFC)
- European Conference on optical Communications (ECOC)
- Globecom
- Optical Network Design and Modeling (ONDM)
The incentive issue

Why would competing VNOs not claim usage of their full capacity, every frame? …thus killing PON bandwidth sharing advantage? *(VNOs are in charge now)*

Market properties:
- Multiple traders (sellers, buyers) on both sides
- Multiple frame units to trade
- Roles changing on each frame

VNOs with excess capacity can sell it in the market

VNO with excess demand can buy it from the market

Disruptive Technology Innovation Fund (DTIF) on Free space optics

Objectives:

- Identify the optimum number of splitter / FSO tower locations
- Identify the connection technology to be used to connect the BS to the splitter/FSO tower.

Assumptions:

- Base stations are already placed (randomly) in a geographical area.

Tradeoff is cost vs reliability
Currently investigating scenario with tracking and routing (informed by technology – Mbryonics SME)

- The towers have steerable transceivers.
- There is temporal traffic variation.
- The weather changes between clear and light fog.
- Number of transceivers per FSO tower is limited.

**Temporal Traffic Variation**

**Reliability during Clear Weather**

**Reliability during Light Fog**
Optical layer disaggregation and application of machine learning

- With CORD, etc. the NFV paradigm was pushed down to the MAC layer of optical technologies (e.g., in PON with the VOLTHA).
- ..and for wireless technologies down to the physical layer (software radio implementation of LTE)
- The optical layer has also started the disaggregation process:
  - What it means:
    - Mix and match transponders, amplifiers, ROADMs, control loops, optical control plane ...

![Diagram](image-url)
Holistic view of integrating edge, central office and large DC computing requires highly dynamic optical transport.

Here it’s all about Control!

We developed Mininet for the optical layer (Mininet-Optical)

→ Test your optical control plane (routing algorithms, ML-based) in large scale emulated networks

Disaggregated optical control plane and Mininet-Optical
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.

Open Ireland: Ireland’s Open Networking Testbed

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
ComReg 100MHz spectrum license

### Existing 3.6 GHz for 5G

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### Upper 4 GHz band for 5G

- **Upper N77 band**: 3.8 – 4.2 GHZ

- **5G spectrum enables experimentation with commercial devices (smartphones and future AR, smart cities, etc)**
- **Use AI to solve complex network interference optimization problems based on real data**
- **Put together interesting 5G demos, such as smart intersection...**
Worldwide reach... and further plans

Foundation testbed in CONNECT2
Starting point for further exploration:

⇒ *mmWave and THz experimentation*

⇒ **Connected City Infrastructure**

⇒ **Quantum Internet**
The TCD lab: optical, wireless and computing
Optical devices

- Large count fibre switch: allows creating any physical fibre topology and interconnect
  - Connect any fibre to any other fibre, measure power
- 1,700 km fibre, power splitters, etc.
- 11 x Inline optical amplifiers
- 11 x ROADM (lumentum graybox): allow switching of optical wavelength channels across
  - Actions: add/drop channel (set filters), set amplification params, variable attenuation, measure power at wavelengths and ports
- 8 x coherent transceivers: allow long distance transmission and software-defined modulation format (DP-QPSK – 100Gb/s, 1,200 km; DP-16QAM – 200Gb/s, 600km)
  - Actions: set wavelength, power, modulation, FEC,... measure power, BER (deduct OSNR), constellation
- 1 x Comb generator: spectrally shape (filter) random photons to emulate data channels of a given spectral width.
  - Generate arbitrary number of channel at given power
Wireless devices

• **USRPs:**
  • 8 x X310, 8 x B210
    • Implement radio part for open source SDR (OAI, SRS), in non-standalone and standalone
      • Currently getting 100Mb/s out of standalone OAI
    • Implement 7.2 split (upcoming) – with functions in USRP FPGA

• **Commercial O-RAN based on 7.2 split**
  • 6 x Indoor/Outdoor units – 100MHz, 4x4 MIMO, 37 dBm per port* (4GHz band restricted to 30 dBm total EIRP)
  • Accelleran (DU) – CU and RIC, but waiting for open source OpenRAN
L2 and above infrastructure

• Servers:
  • 6 x high performance (data plane switching, virtual network functions, SDR, DU/CU/RIC)
  • 3 x Network virtualization services

• Switches:
  • P4-enabled SDN switch (programmable data plane)
  • SDN enabled Low latency L2 switch
  • Management switches

• Virtual PON:
  • Full virtualized Passive Optical Network
  • Standard compliant XGS (10G symmetric) PON
  • Additional TCD IP of virtual DBA (scheduler virtualization)
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.
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 OSRN variation
- Through multiple iterations the agent improves strategy for channel selection

Work carried out by Politecnico di Milano optical group

How many channels are allocated without disruptions?

Use of simulated data plane
ORAN and RAN Intelligent Controller: video streaming use case

Near-RT RIC implementation done by our team in CONNECT

Buffering due to variable bitrate

RIC Agent communicates with the xApps through the messaging platform and applies the RAN reconfigurations

Message platform

xApps collecting measurements from the RAN and sending control messages to the gNBs
Preliminary results

Difference between the true CQI values measured in the network and the values predicted by the xApp (LSTM model).

In 50% of the cases the error is below 8%, in 90% of the cases the error is below 26%.
near-RT RIC

xApps

xApp1 xApp2 xApp3

Messaging platform (zmq Broker)

RIC Agent

gNB

RAN

UE

5G Core

AMF

AUSF - UDM

UPF

SMF

Web services
Digital twin for optical communication

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
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 = [('tx%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)
```
Example of QoT use case

Testbed control plane vs Digital twin control plane

- L2 switch
- Transceivers
- ROADMs

Physical Topology
Configured already

with open('/data_collection/sample_channels_4.txt', 'w') as f:
    f.write('%s
% channels)

channels = utils.generateRandom(94)
agents.runner_parallel_agents('channels, 'close')

for ch in $(seq 1 $numCh); do
    echo "" Configuring ROADDM to forward chSCH from t1 to t2"
    port=$((300 + $ch[chain][ch-1]))
    $curl "$1/1/forward-channels=t1-t2&port=$port&port-$channels=$ch[chain][ch-1]"
    $curl "$1/2/forward-channels=t2-port-$channels=$ch[chain][ch-1]"
    $curl "$1/3/forward-channels=t3-port-$channels=$ch[chain][ch-1]"
    done

for tname in t1 t2; do
    url=$((tname)
    echo "" $tname"
    $curl "$1/monitor?monitor=$tname-monitor"
    echo "" "$>> testResult.txt"
    $curl "$1/monitor?monitor=$tname-monitor" >> testResult.txt
    done

 agents.runner_parallel_agents('l', 'open')

item_a = obs.check_first_signal_level(item_a)
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**: extremely weak quantum signals are very easily impaired by much stronger classical communications signals (order of 100 dB difference in power)

Project scope is 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.**
US-Ireland Project: Investigators

- Emulation of quantum & classical communication systems: Dan Kilper
- Classical and quantum control architectures: Marco Ruffini
- Simulating and emulating hybrid non-Markovian quantum systems in quantum networks (modeling quantum noise): Prineha Narang
- Physical Layer Emulation of Quantum Applications: Mauro Paternostro
- Emulation of quantum covert communications: Boulat Bash
- Emulation of photonic components: Bob Norwood
We recently built an optical layer emulator to extend the Mininet tool to support control plane of optical layer transmission and switching.

- 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