Fully meshed dynamically switched QKD Metro network

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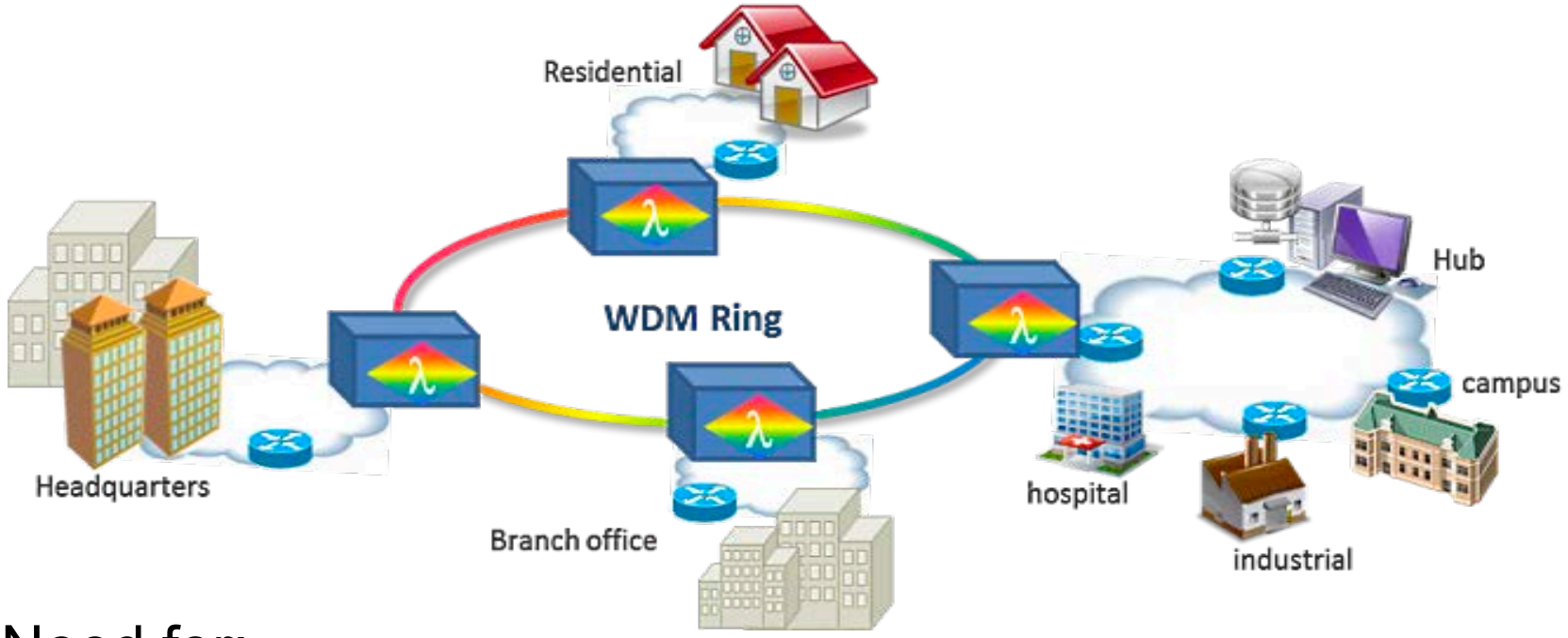
Dynamic Optical Networking for the Metro/Edge



Need for:

- High Bandwidth
- Low Latency
- Very Dynamic

Dynamic Optical Networking for metro/edge

Security?

Dynamic QKD networking

- Compatibility with classical optical networks
  Allow co-existence of classical-quantum channels
- Fit dynamic networking scenarios
  Overcome physical transmission and switching limitations

Enablers:

❑ **Shorter Reach (<20km) + Low loss OXC**

- unamplified classical channels (→ no ASE)
- lower power classical channels (→ low crosstalk)
- Reduced insertion losses
- Negligible fiber non-linearities

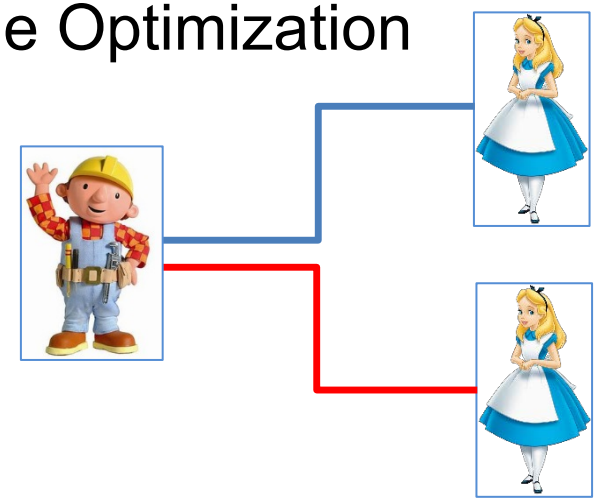
❑ **Advanced Management Schemes**

- SDN to decide and implement routing
- Optimal Path Computation
- Re-arrange wavelengths to minimize non-linearities (FWM)

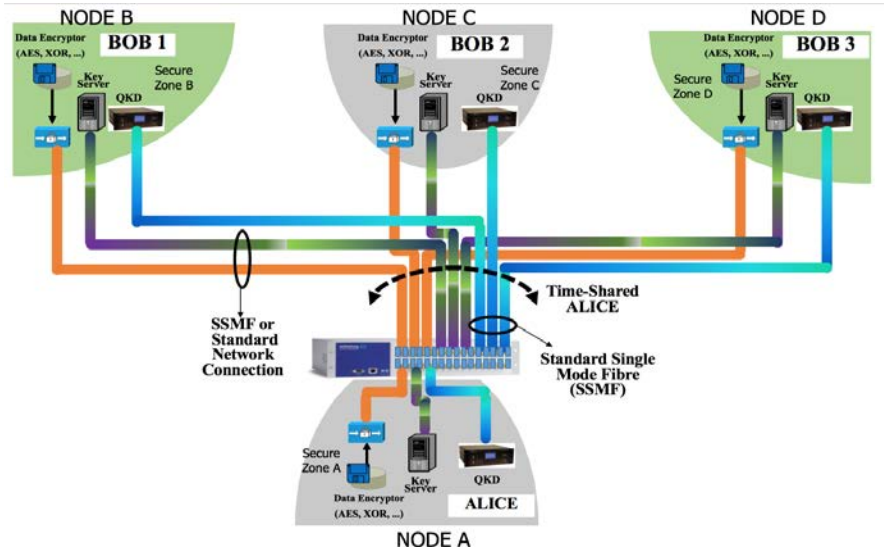
Dynamic QKD networking

Operational Advantages:

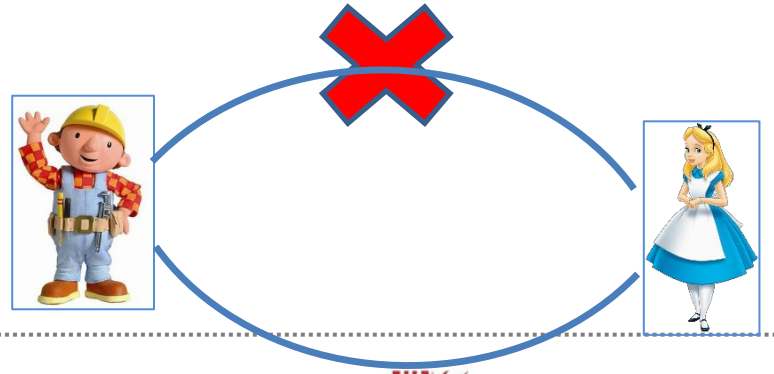
1) Resource Usage Optimization
→ sharing



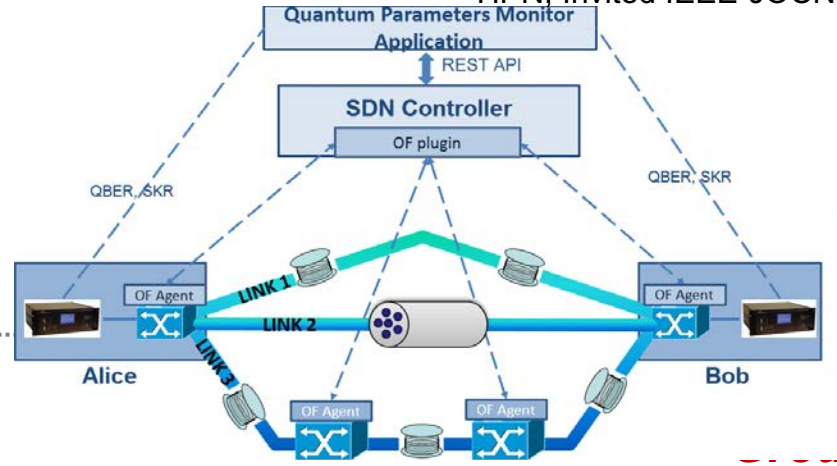
* HPN, IEEE JLT December, 2017



2) Path optimization and DOS Attack mitigation
→ rerouting



*HPN, Invited IEEE-JOCN, 2019



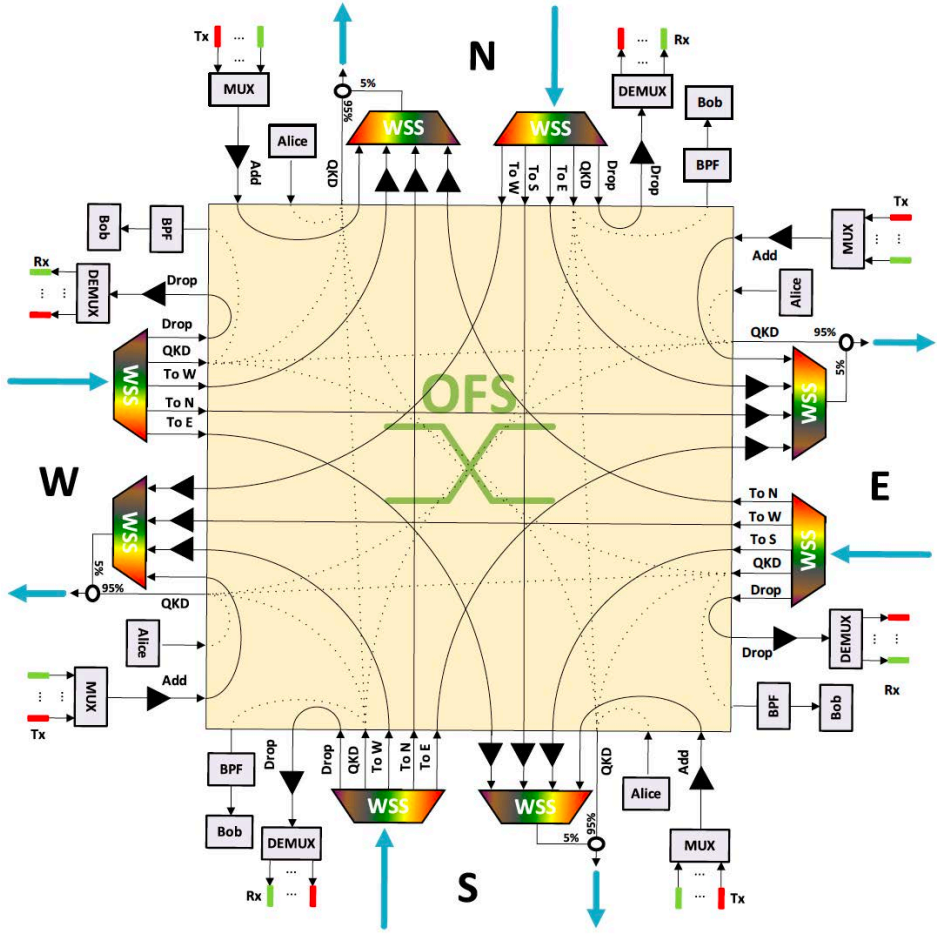
The Q-ROADM

Challenge:

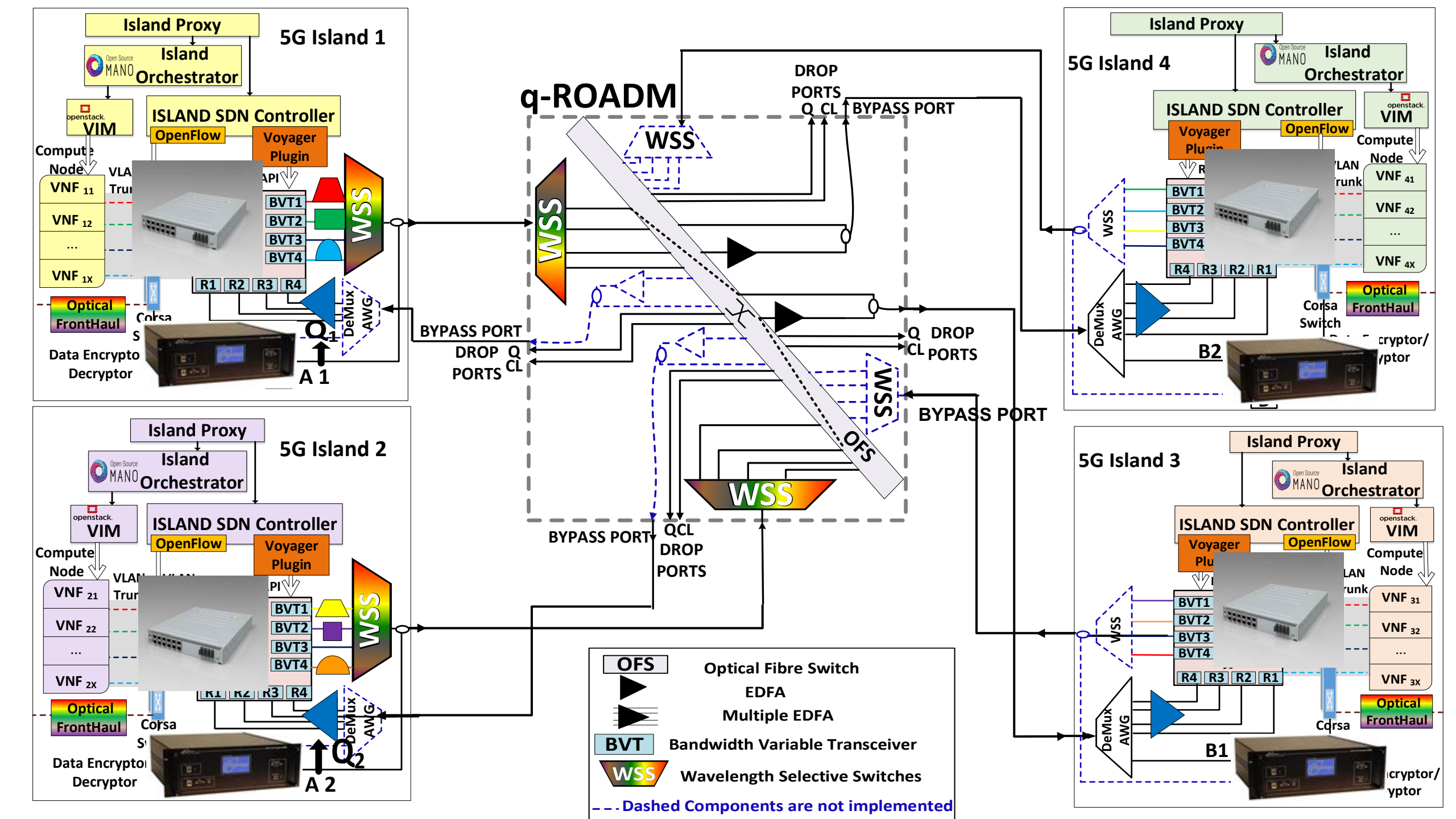
dynamic, flexible, simultaneous quantum and classical resource allocation

Our contribution:

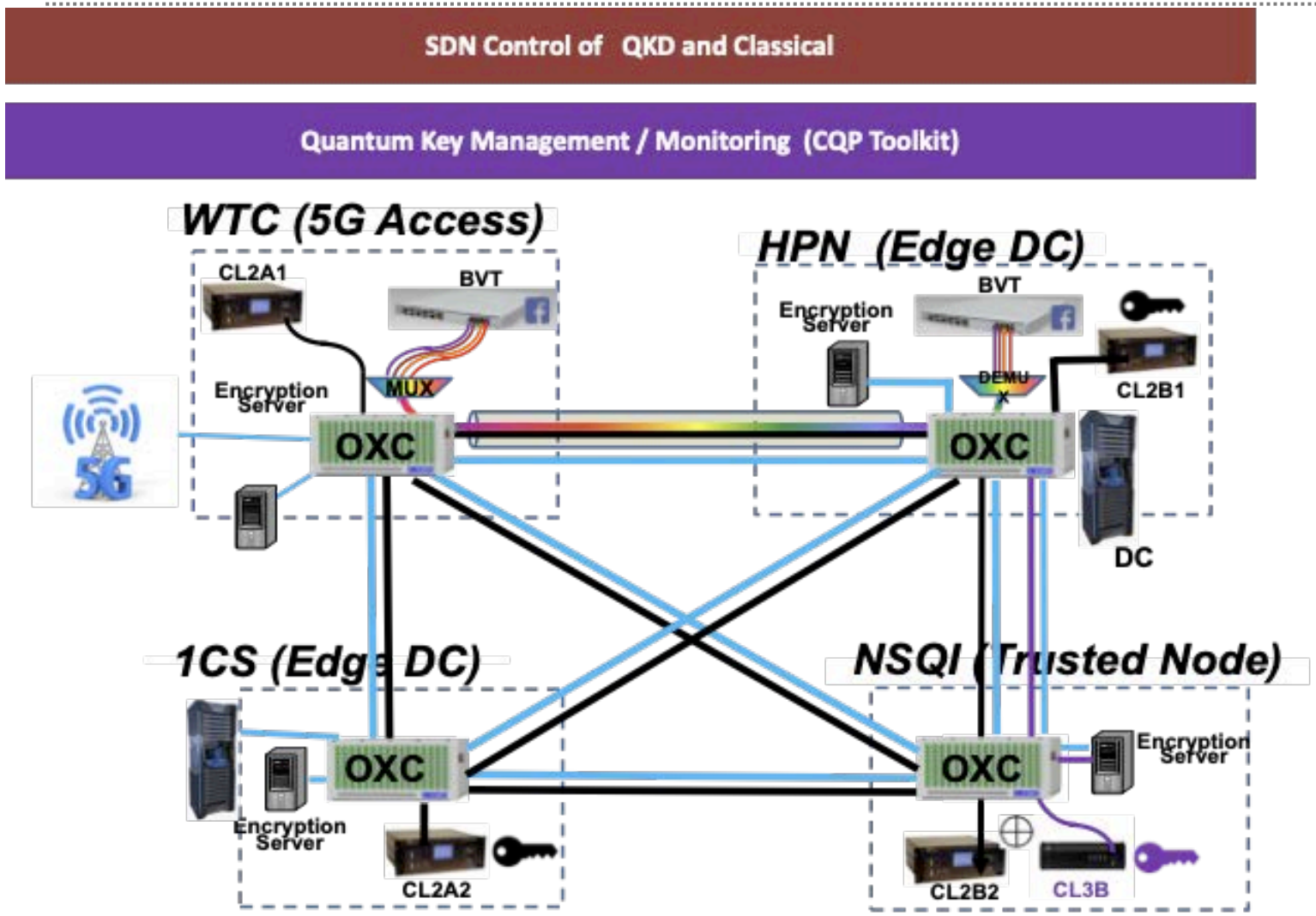
- Four-degree quantum- reconfigurable add/drop multiplexer (ROADM)
- Low loss ROADM design (< 5.3dB loss for QKD channel)
- Flexigrid classical channels routing
- Any combination of classical and quantum channels on the same port
- Dynamically reconfigurable routing of quantum channels

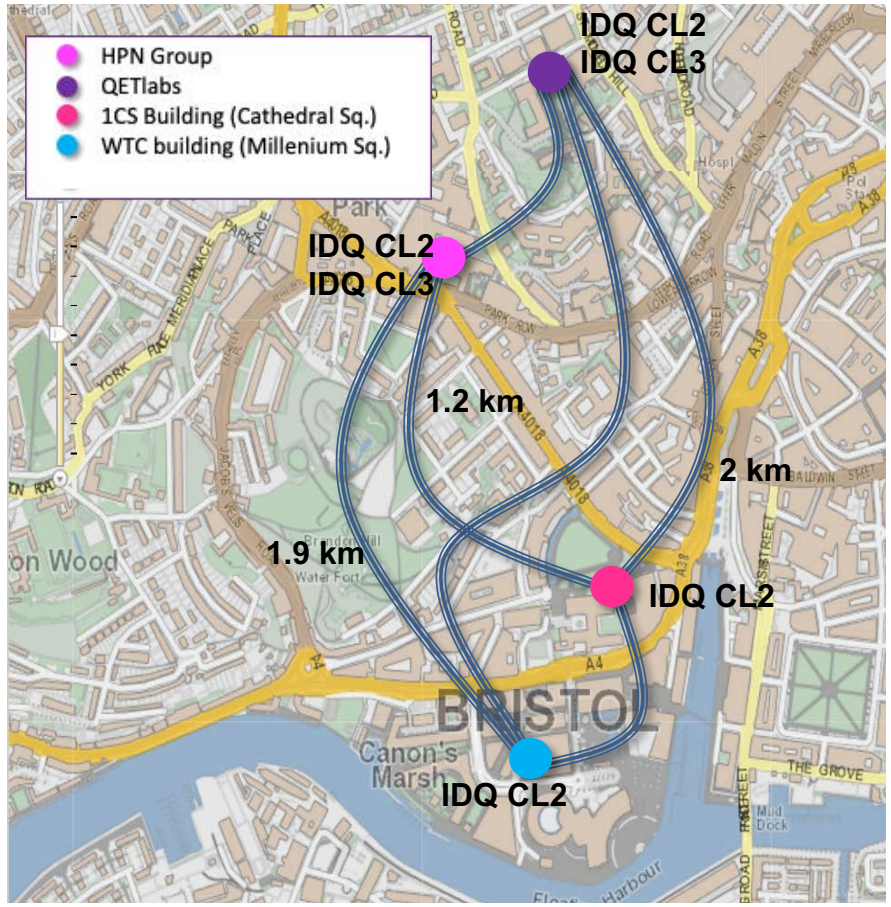


- HPN, invited IEEE JLT, July 2019


5G Island 1
Island Proxy
Island Orchestrator
ISLAND SDN Controller
OpenFlow
Voyager Plugin
VIM
Compute Node
VNF 11
VNF 12
...
VNF 1X
BVT1
BVT2
BVT3
BVT4
R1
R2
R3
R4
WSS
DeMux AWG
Optical FrontHaul
Data Encrypto
Decryptor
Q1
A 1
q-ROADM
DROP PORTS
Q CL
BYPASS PORT
OFS
BYPASS PORT
DROP Q PORTS
CL
Q DROP PORTS
CL
BYPASS PORT
QCL DROP PORTS
5G Island 2
VNF 21
VNF 22
VNF 2X
Q2
A 2
5G Island 4
VNF 41
VNF 42
VNF 4X
Corsa Switch
B2
5G Island 3
VNF 31
VNF 32
VNF 3X
B1
OFS
Optical Fibre Switch
EDFA
Multiple EDFA
BVT
Bandwidth Variable Transceiver
WSS
Wavelength Selective Switches
Dashed Components are not implemented

Demo2: Fully meshed dynamically switched QKD Metro network





Demo2: Fully meshed dynamically switched QKD Metro network

GOALS:

1. Demonstrate Classical-Quantum Channel **Co-Existence** over Mesh Network
   - 4x100G (QPSK) Unamplified Optical Channels
   - 1x Quantum Ch. (IDQ CL.2)
   - 2x optical switches

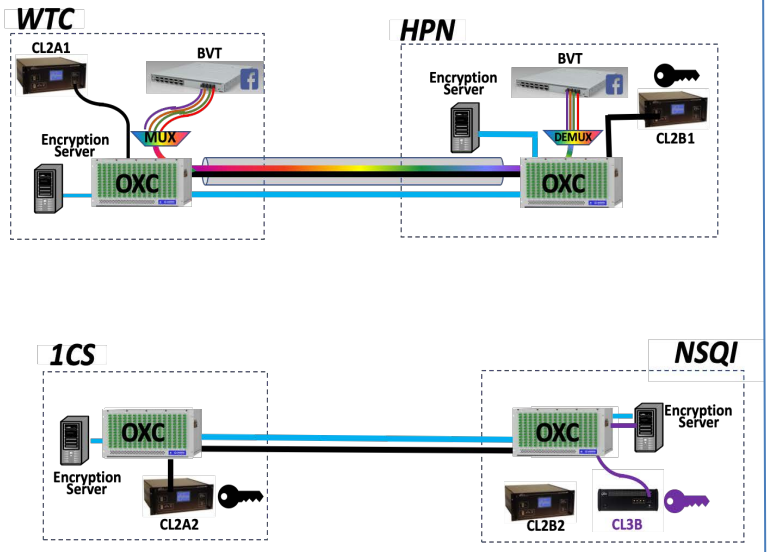
2. Demonstrate Q-Ch. **Denial of Service Mitigation** over Mesh Network
   - Quantum Channel Rerouted over Mesh Network
   - 3x optical switches

3. Demonstrate **QKD Resource Usage Optimization** using dynamic QKD switching
   - 2x QKD pairs → 4x QKD links

4. Software Defined Control plane:
   - Monitor the q-channel
   - rerouting

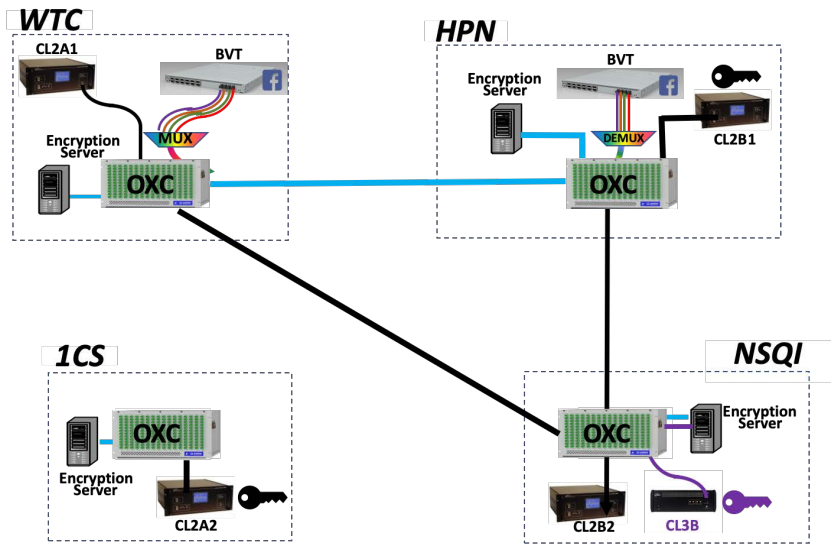
Demo 2 Scenario

Step 0



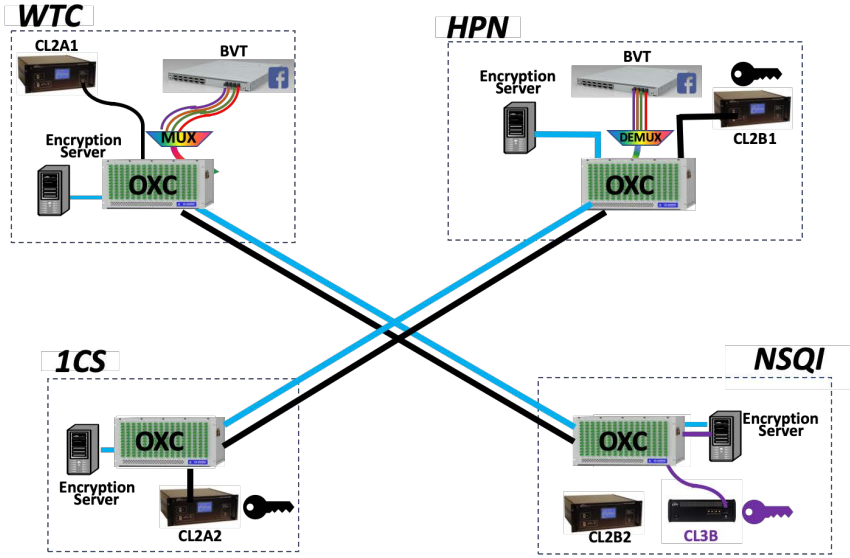
- 2 Secure Links established
- WTC-HPN
- 1CS-NSQI
- Co-existence in WTC-HPN

Step 1



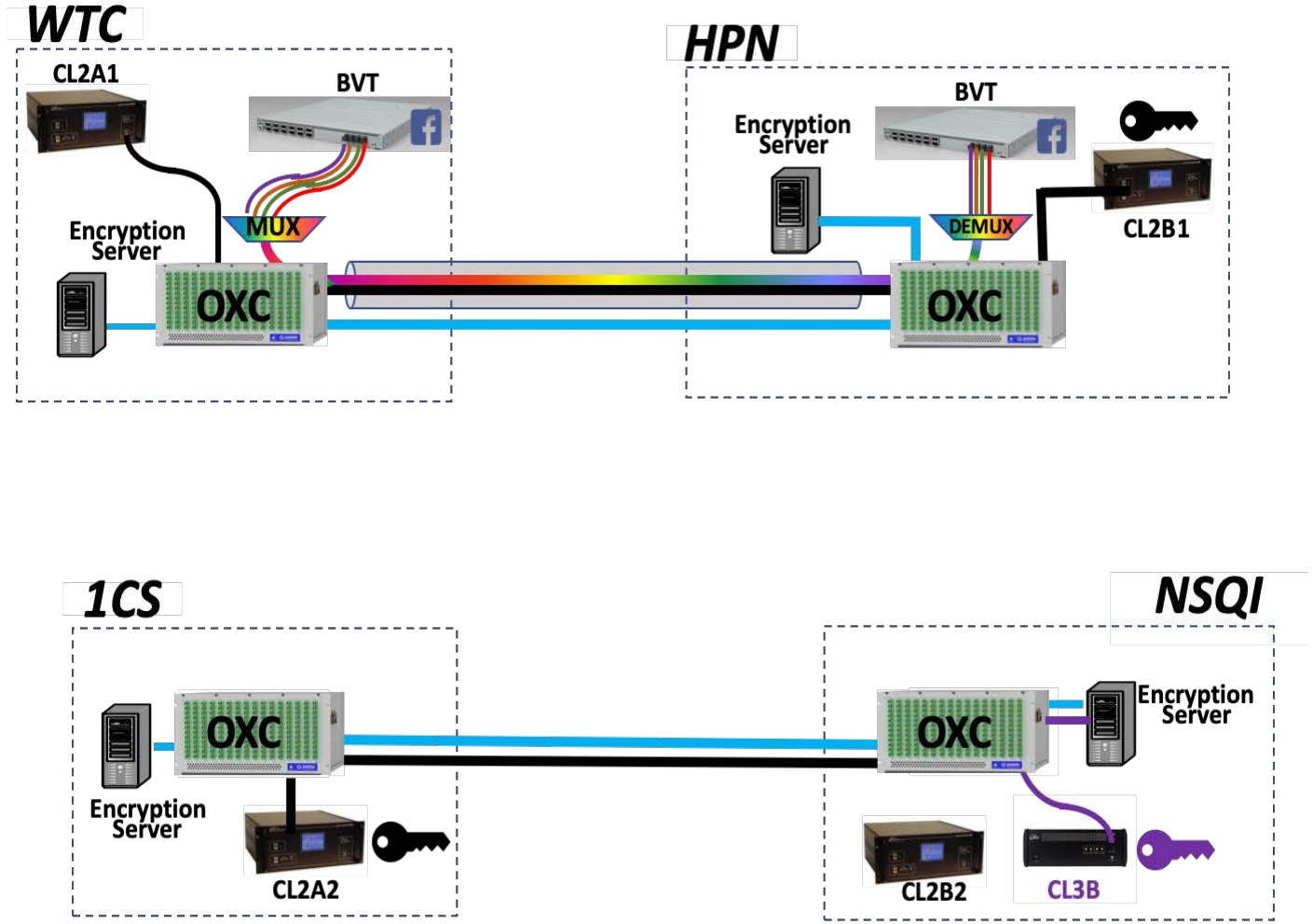
- DOS Attack and mitigation
- WTC-HPN link co-existing channels violate Q-Ch
- SDN controller reroutes Q-ch
- Q-ch new path through 3 switches

Step 2



- Establish 2 new Secure links
- WTC-NSQI
- 1CS-HPN

Demo 2 - Step 0



Step 0 Flowchart:

User defines 2 Secure Links
WTC-HPN (Co-exist)
1CS-NSQI

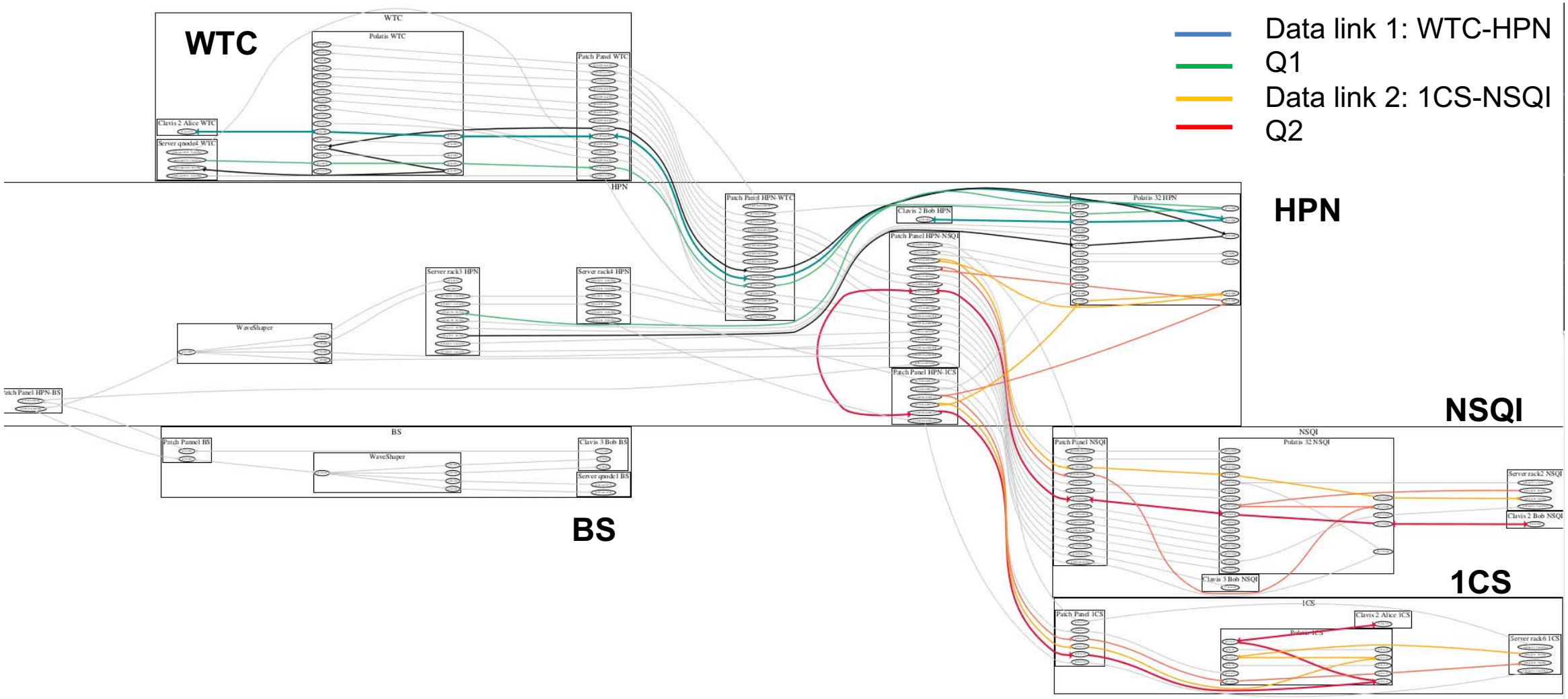
↓

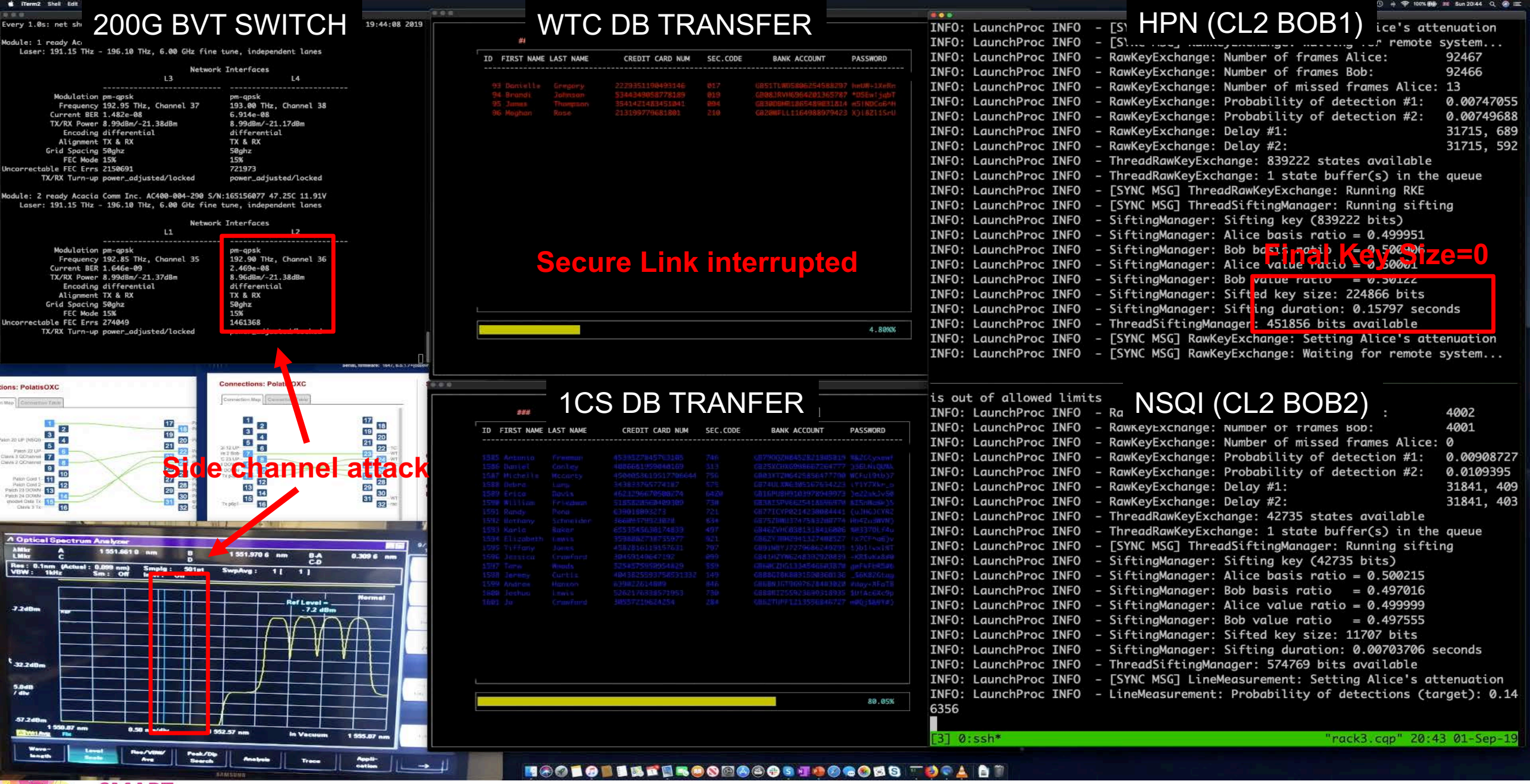
DOS Attack:
Co-exist Cl-Ch. Shifts w/l close to Q-ch

↓

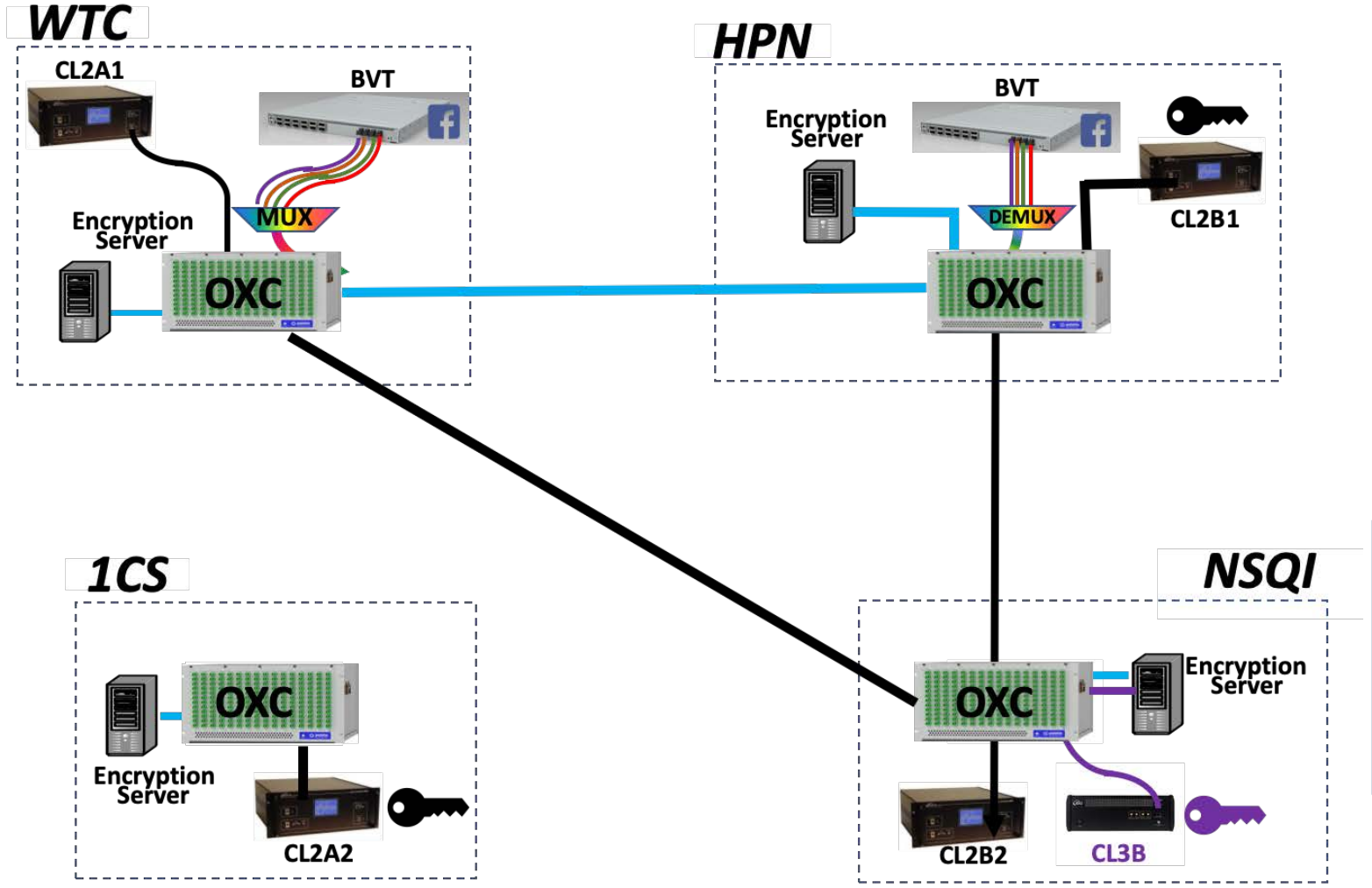
Q-ch error msg:
Final key size=0
Secure Link 1 interrupted

Step 0 Actual Network topology




200G BVT SWITCH
WTC DB TRANSFER
HPN (CL2 BOB1)
Secure Link interrupted
Final KeySize=0
1CS DB TRANFER
NSQI (CL2 BOB2)
Side channel attack

Demo 2 Step 1



Phase 1 Flowchart:

SDN controller detects Attack (msg: Final Key Size=0)

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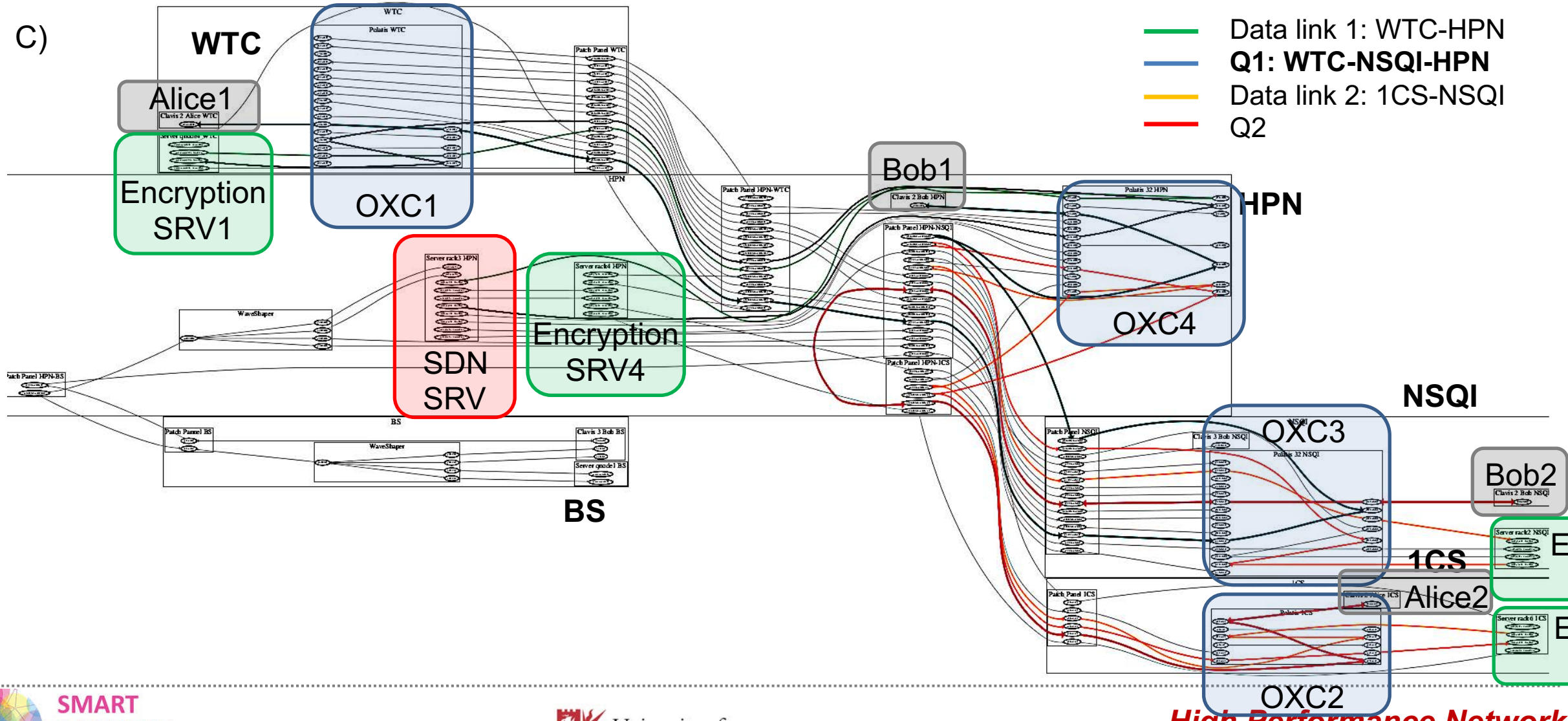
SDN Controller defines Q-ch rerouting through NSQI-HPN
CI-Ch remains unaffetced

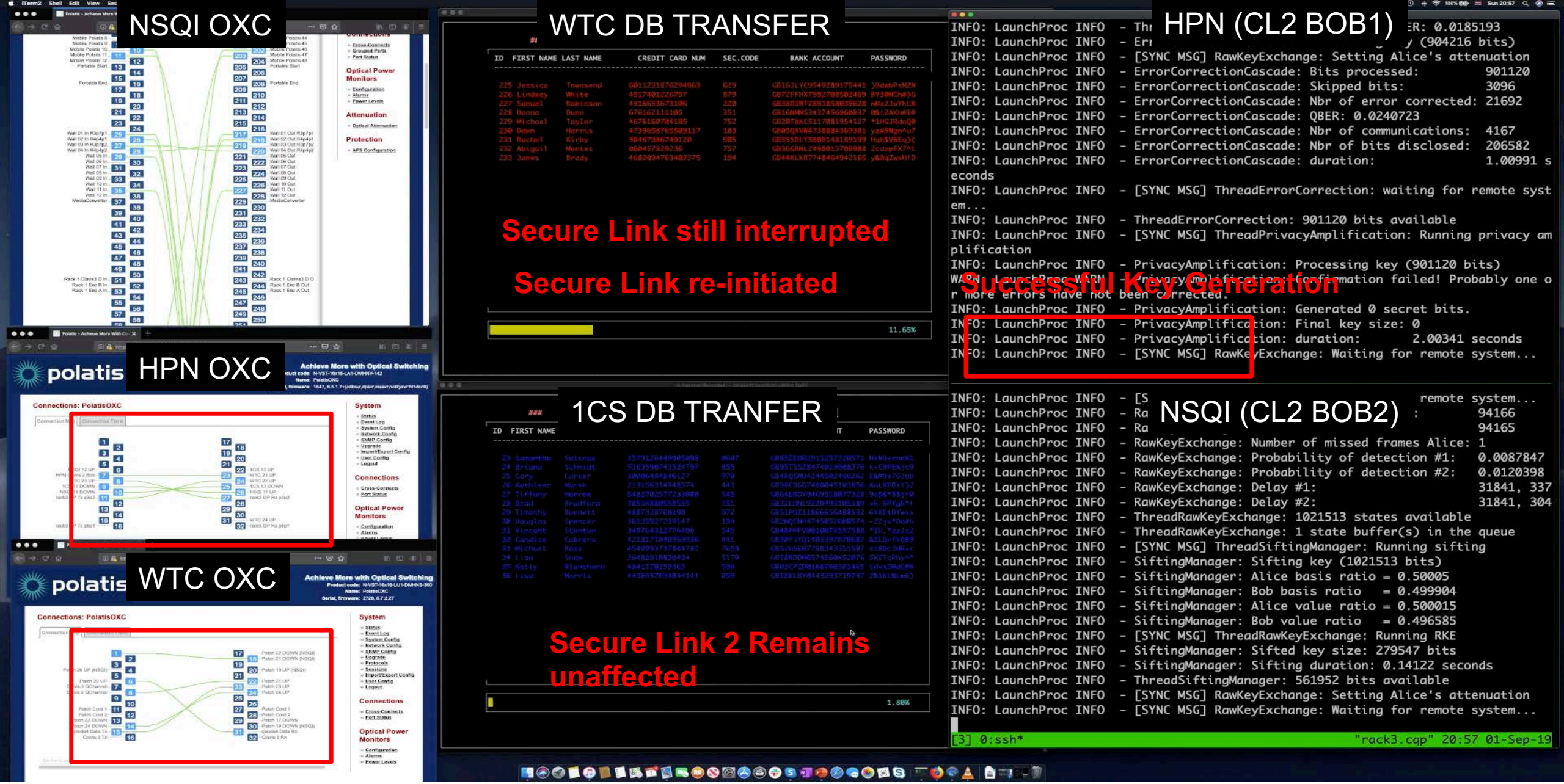
↓

SDN Controller Switches
OXC1/OXC3→ establish WTC-NSQI for Q-ch
OXC3/OXC4 → establish NSQI-HPN for Q-ch

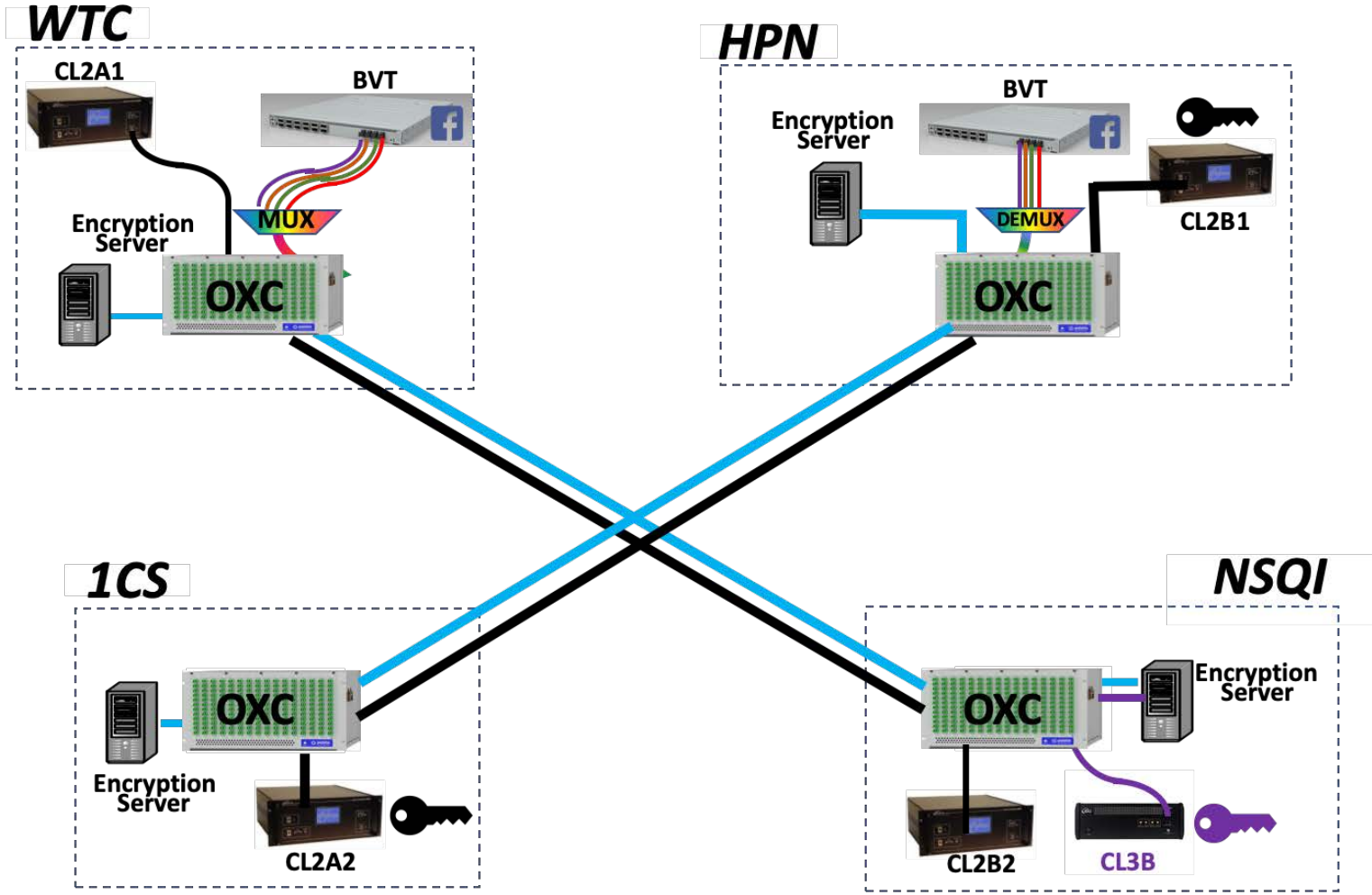
Key Points:
Secure Link 1 re-established

Step 1 Actual Network topology




NSQI OXC
WTC DB TRANSFER
HPN (CL2 BOB1)
Secure Link still interrupted
Secure Link re-initiated
Successful Key Generation
HPN OXC
1CS DB TRANFER
NSQI (CL2 BOB2)
WTC OXC
Secure Link 2 Remains unaffected

Demo 2 Step 2



Phase 2 Flowchart:

User defines new Secure Links

↓

SDN Controller Switches
OXC2/OXC4 → 1CS-HPN (Green)

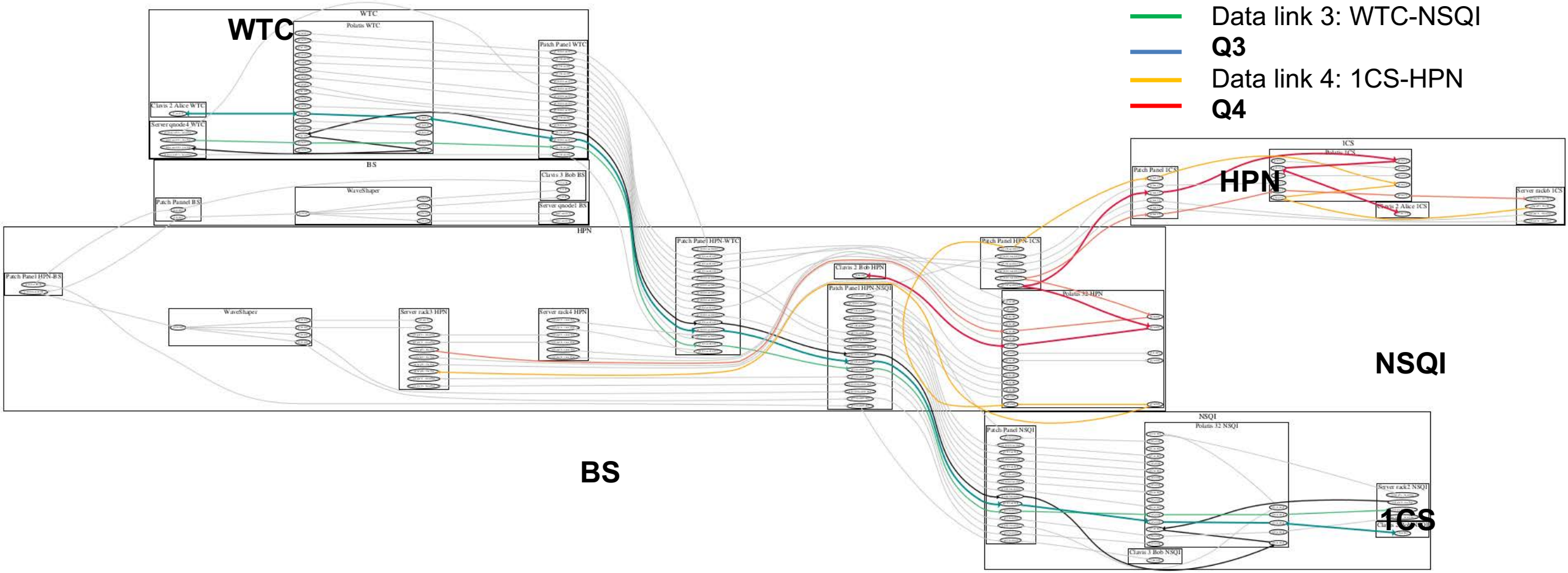
↓

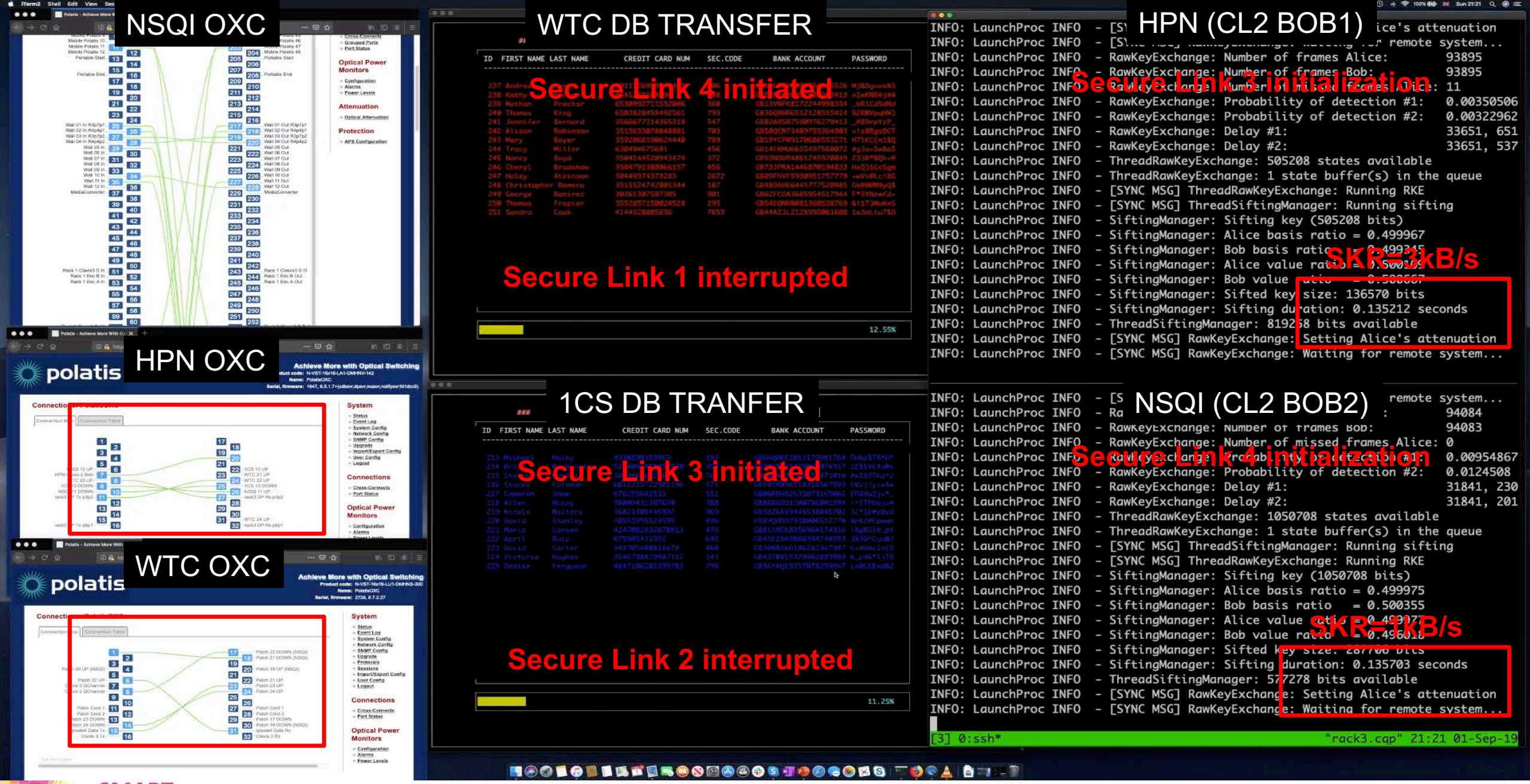
SDN Controller Switches
OXC3 → WTC-NSQI (Yellow)

Key Points:

2 New Secure Links established

Step 2 Actual Network topology




NSQI OXC
WTC DB TRANSFER
HPN (CL2 BOB1)
Secure Link 4 initiated
Secure Link 3 initialization
Secure Link 1 interrupted
SKR=3kB/s
HPN OXC
1CS DB TRANFER
NSQI (CL2 BOB2)
Secure Link 3 initiated
Secure Link 4 initialization
WTC OXC
Secure Link 2 interrupted
SKR=1kB/s

Summary

- First public, field-deployed QKD switched mesh network
- Optical switch in each node
- Co-existence capabilities

Acknowledgements

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