Adaptation and Monitoring for Elastic Alien Wavelengths

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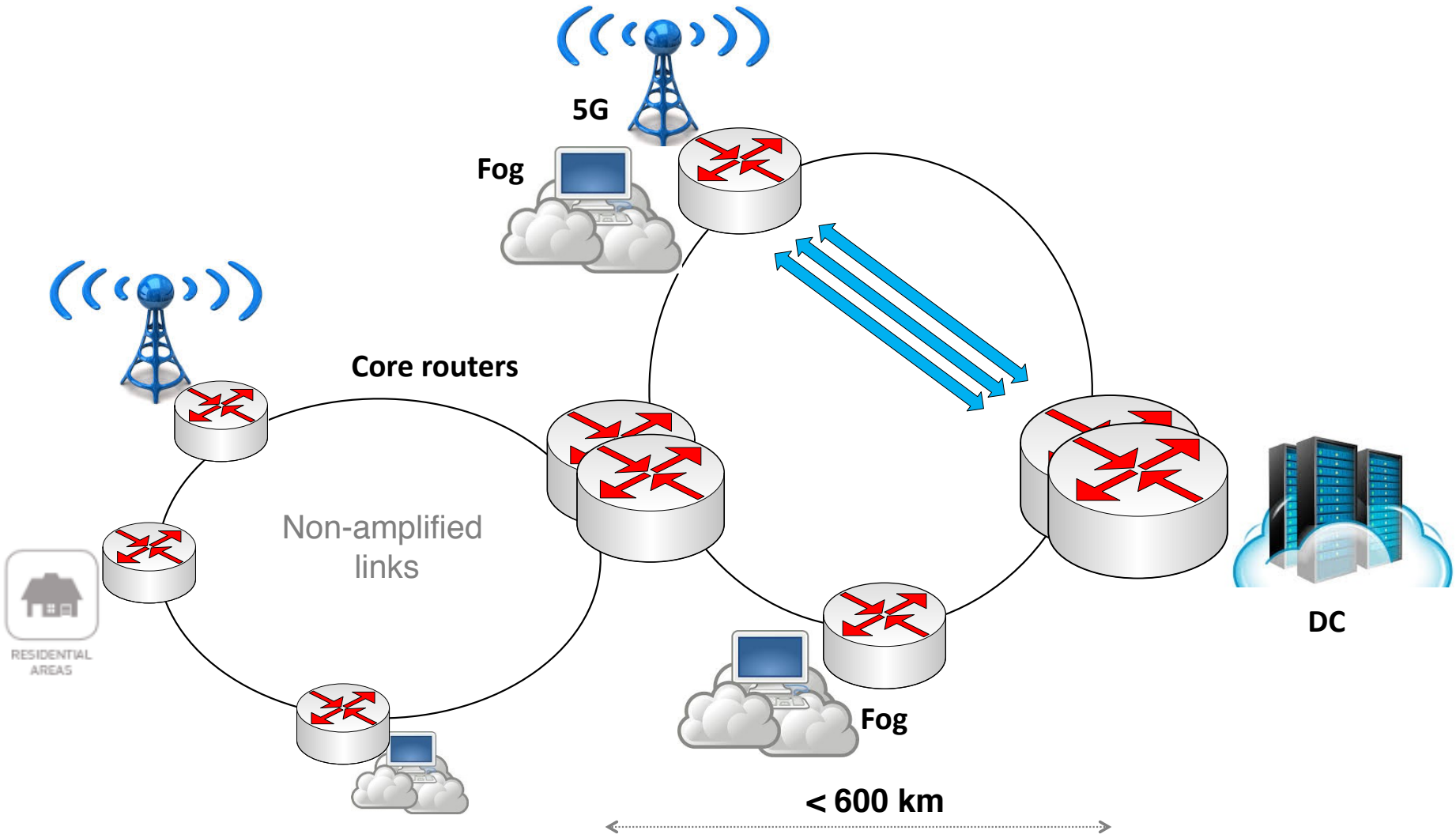
NOC 2016

Introduction

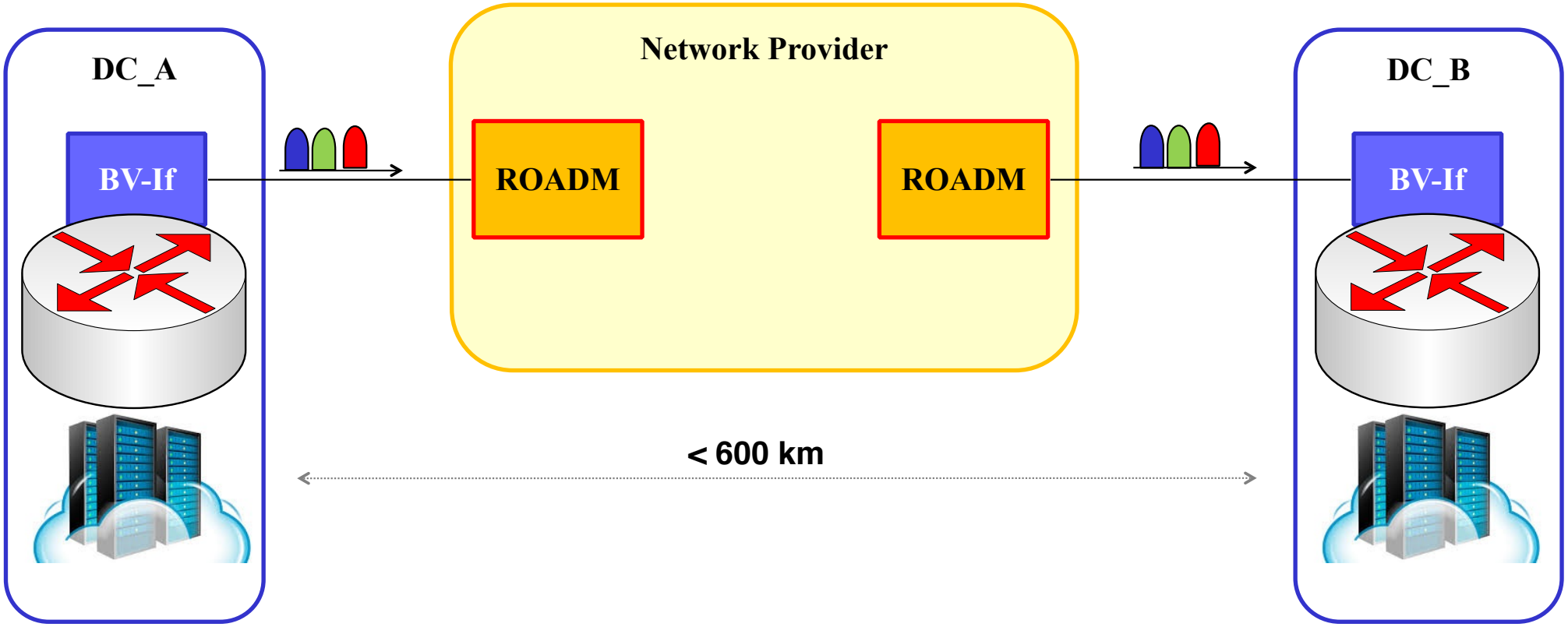
- Data traffic can increase between 10 and 25 times by 2025
- Traffic from/to **Data Center** is going to dominate (relative little impact of peer-to-peer)

- New traffic distribution:
  a. **Edge-to-DC**: edge routers and Fog nodes connected to core routers which go to the DCs
  b. **DC-to-DC**: direct connections for DC backup

Edge-to-DC


5G
Fog
Core routers
Non-amplified
links
RESIDENTIAL
AREAS
Fog
DC
< 600 km

DC-to-DC



New network design

a. Router interfaces (less ROADM transponders)

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b. Distances < 600km (less long-haul)

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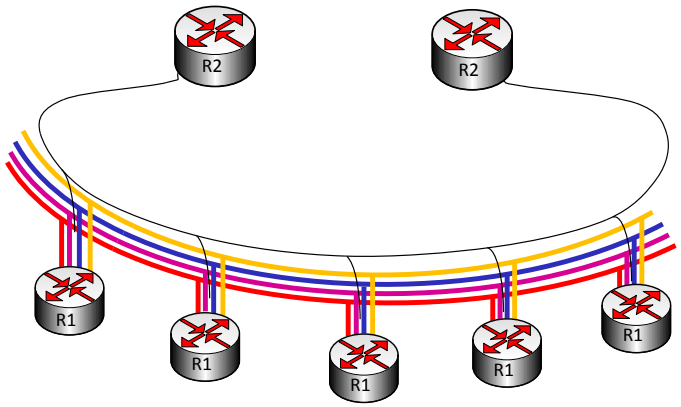
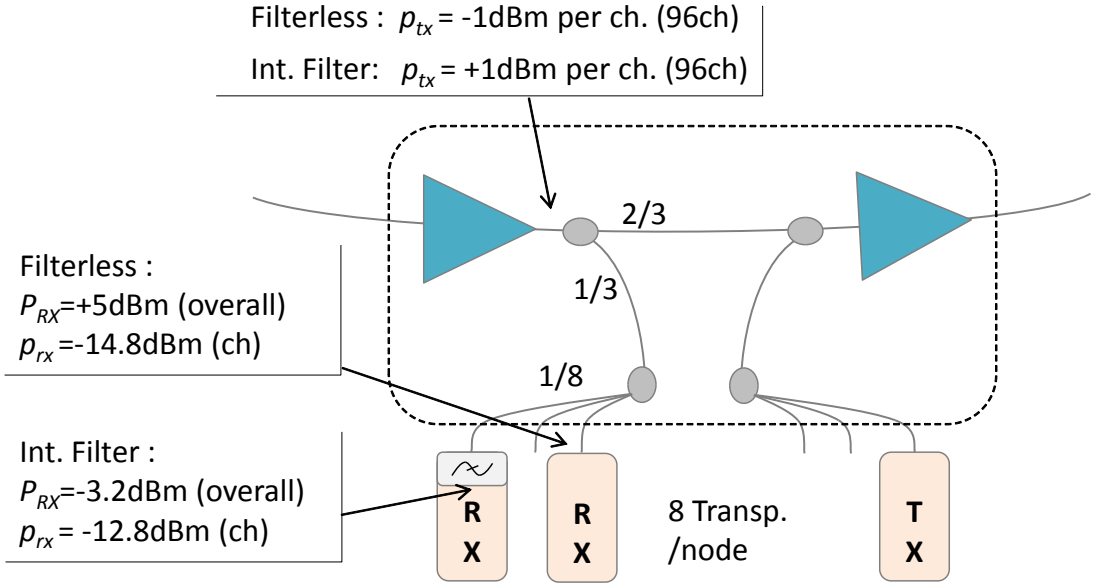
b. Distances < 600km (less long-haul)
c. Multiple lambdas between node pairs
d. Equal Cost Multi Path communication
e. Innovative Layer3 and transmission solutions:
   - Segment routing
   - filterless / semi-filterless
   - alien wavelengths

Filterless / Semi-filterless

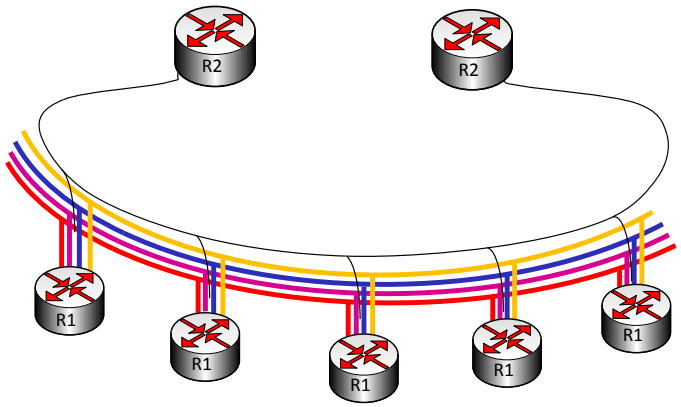


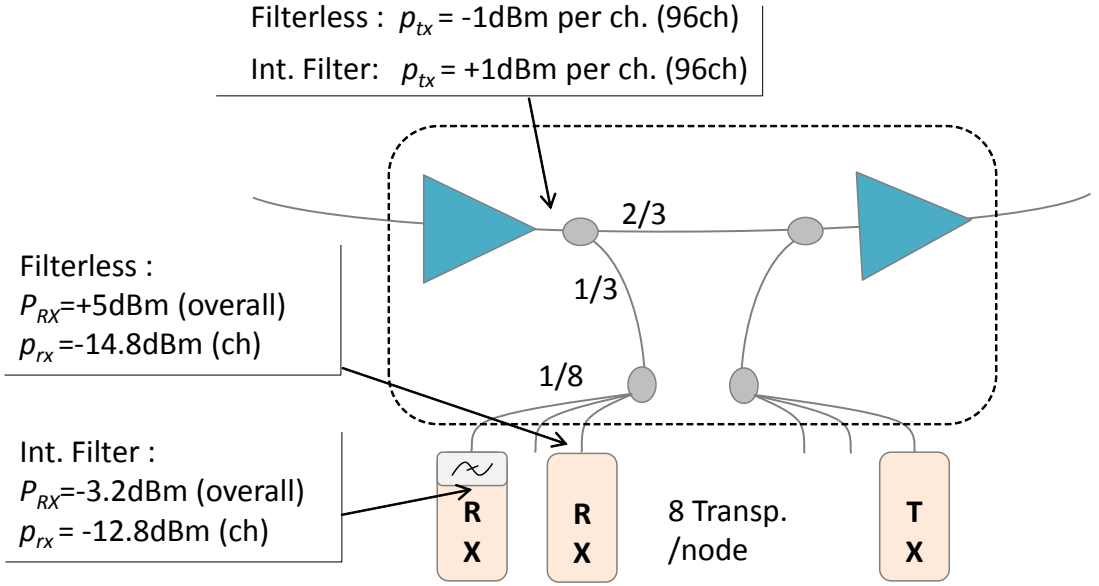


Design issue:

- In filterless networks, excessive power may enter the RX (all DWDM channels)

Filterless / Semi-filterless





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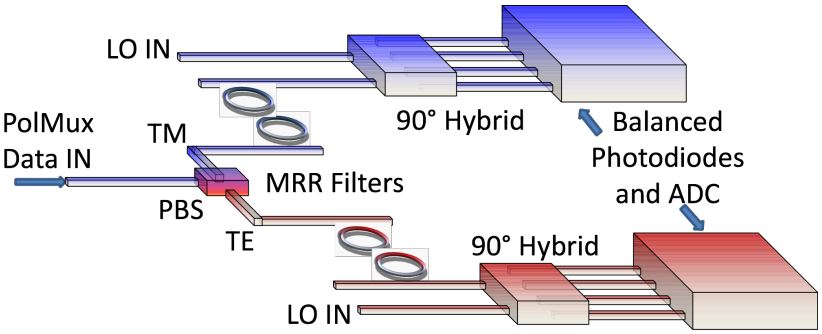
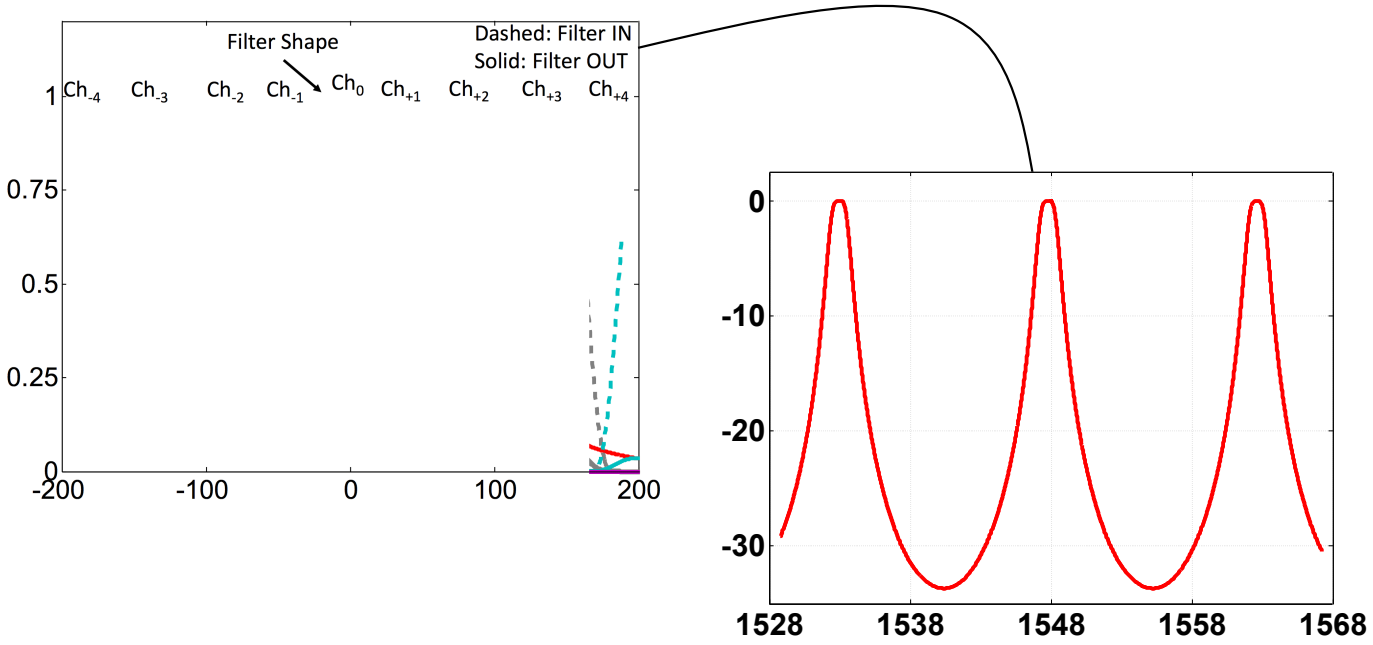
Proposal:

- Encompass a low-cost tunable filtering technology within the RX interface
- The network remains filterless (i.e. only EDFA and splitter/couplers)
- Interface tunability operates on both laser and filter



Filterless / Semi-filterless

- micro-ring resonators
- silicon-on-insulator (SOI) technology



[Ref] F. Cugini et al., “Receiver Architecture with Filter for Power-Efficient Drop&Waste Networks”, OFC 2016

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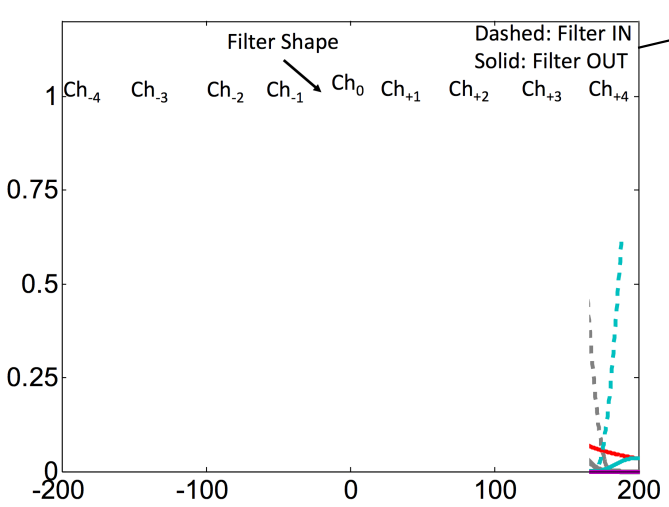
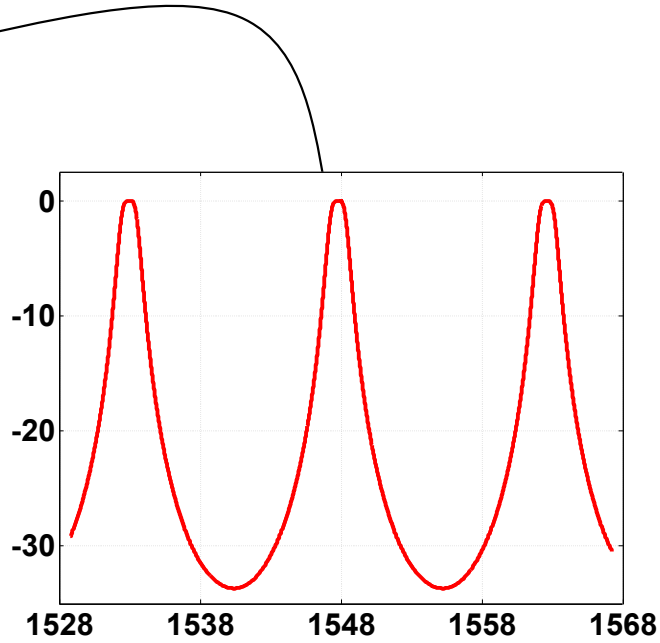
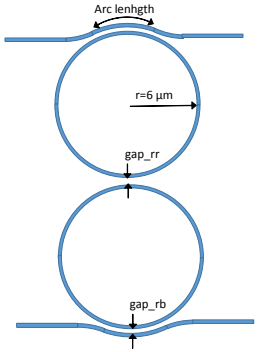
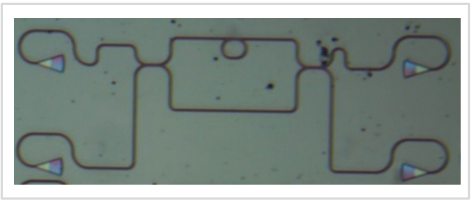






2nd-order Buttherworth design



MZM-loaded 2nd-order Chebyshev design and implementation

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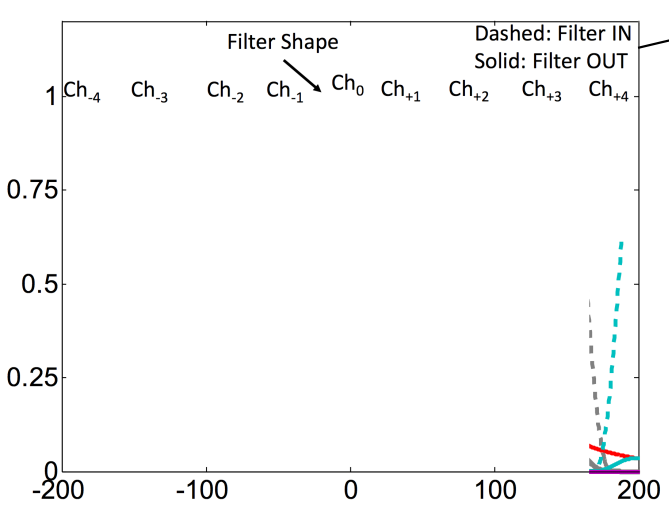
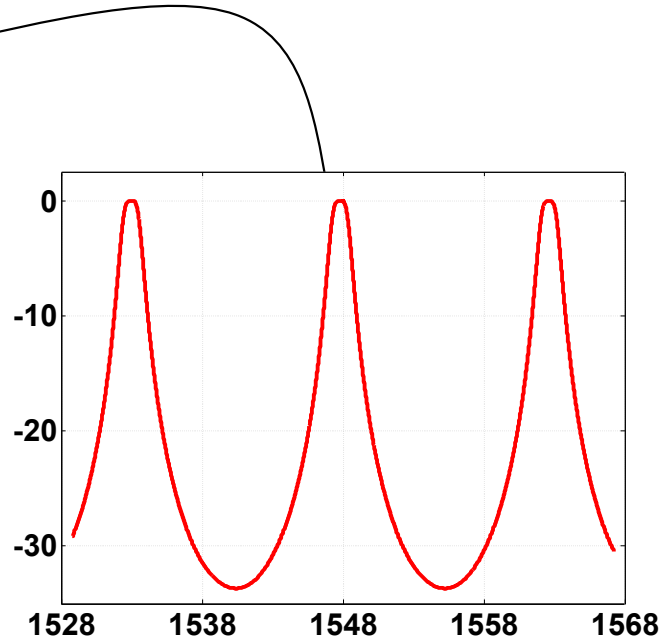
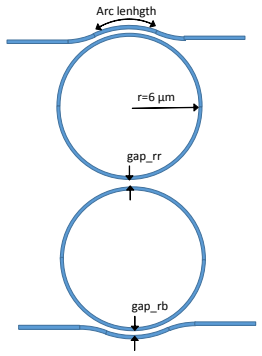
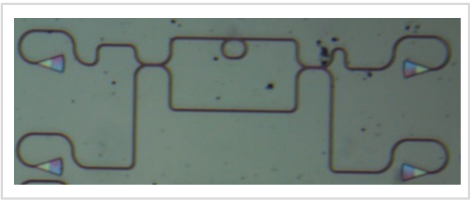






2nd-order Buttherworth design



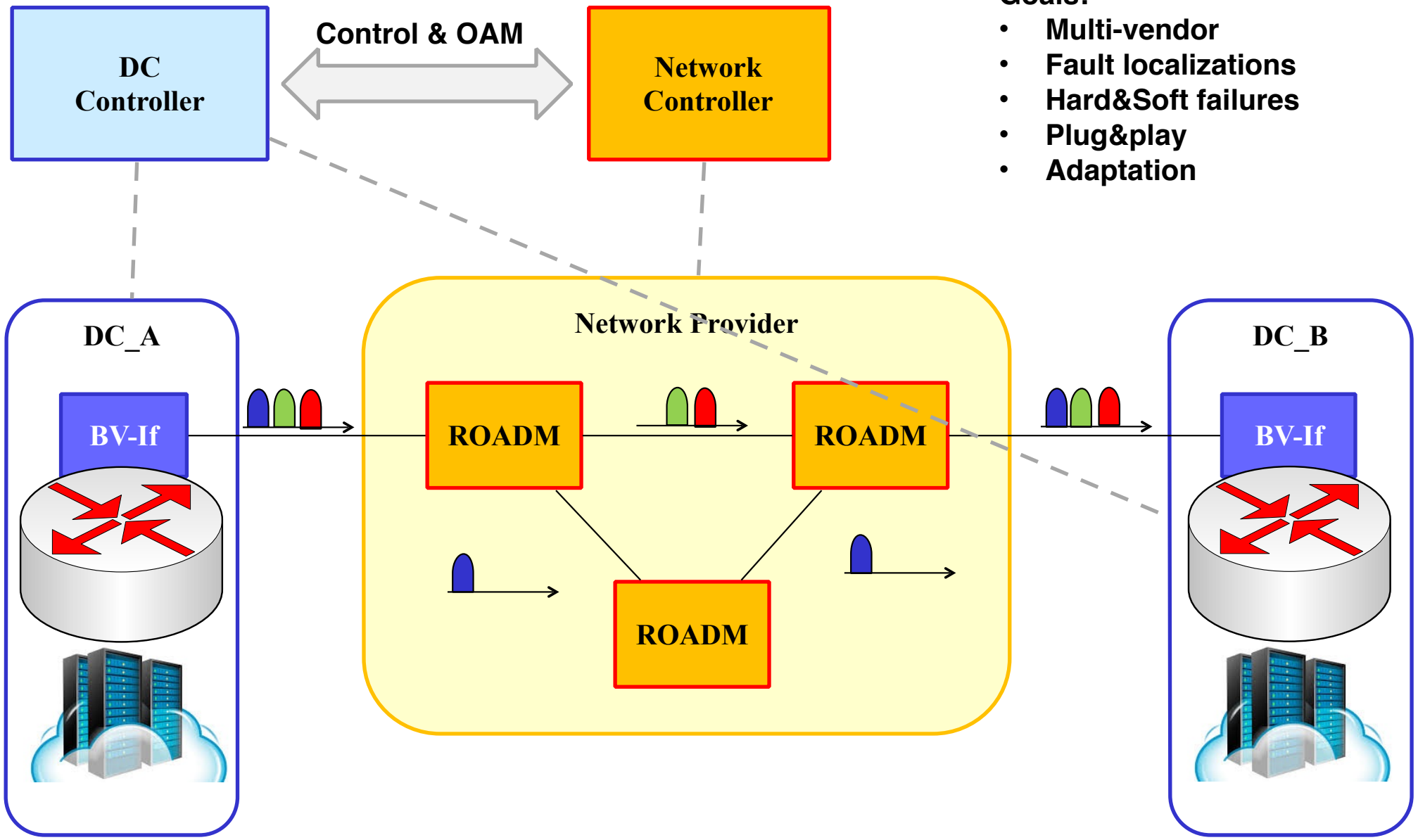
MZM-loaded 2nd-order Chebyshev design and implementation

- In a 96ch system, the number of equivalent channels (ECN) that enter the photodiode is successfully reduced from **96** to **11.35**

→ no more design issues

[Ref] F. Cugini et al., "Receiver Architecture with Filter for Power-Efficient Drop&Waste Networks", OFC 2016

Objective: Alien λ for DC-to-DC



Plug & play Interfaces with adaptation capabilities

- In a single Vendor/Domain scenario, the PCE, included within the SDN Controller, performs impairment-aware path computation
- Given a candidate path, the first set of EON parameters is identified, in the following order:
    1. Modulation format
    2. FEC/Coding
    3. Sub-Channel Spacing
    4. Frequency slot

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    1. Modulation format
    2. FEC/Coding
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    4. Frequency slot
- To guarantee reliable transmission, this first set is typically computed in a conservative way
    - possible impairment estimation inaccuracy
    - nominal value deviations
    - margins

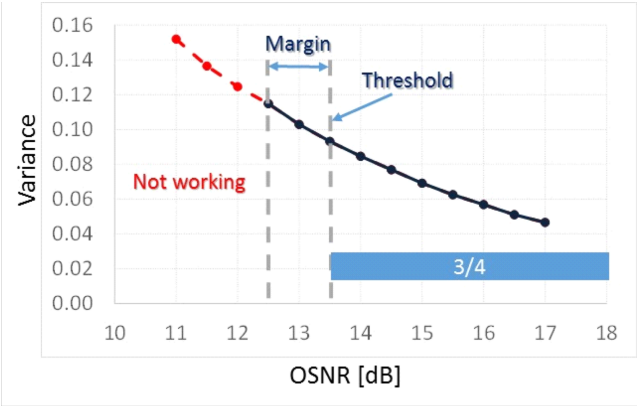
Self adaptation procedure Format & FEC/Coding

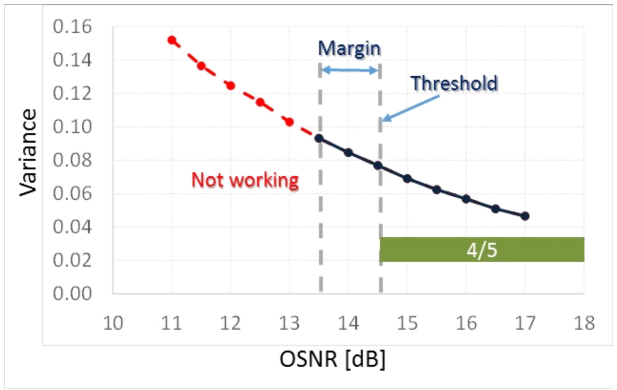
Self adaptation procedure Format & FEC/Coding

- **Step 0**: The optical connection is first established considering the conservative (sub-optimal) computed EON parameters
- Then, adaptation for self-optimization starts.

- **Step 1**: modulation format adaptation

- **Step 2**: FEC/Coding is optimized, considering adequate safe margins



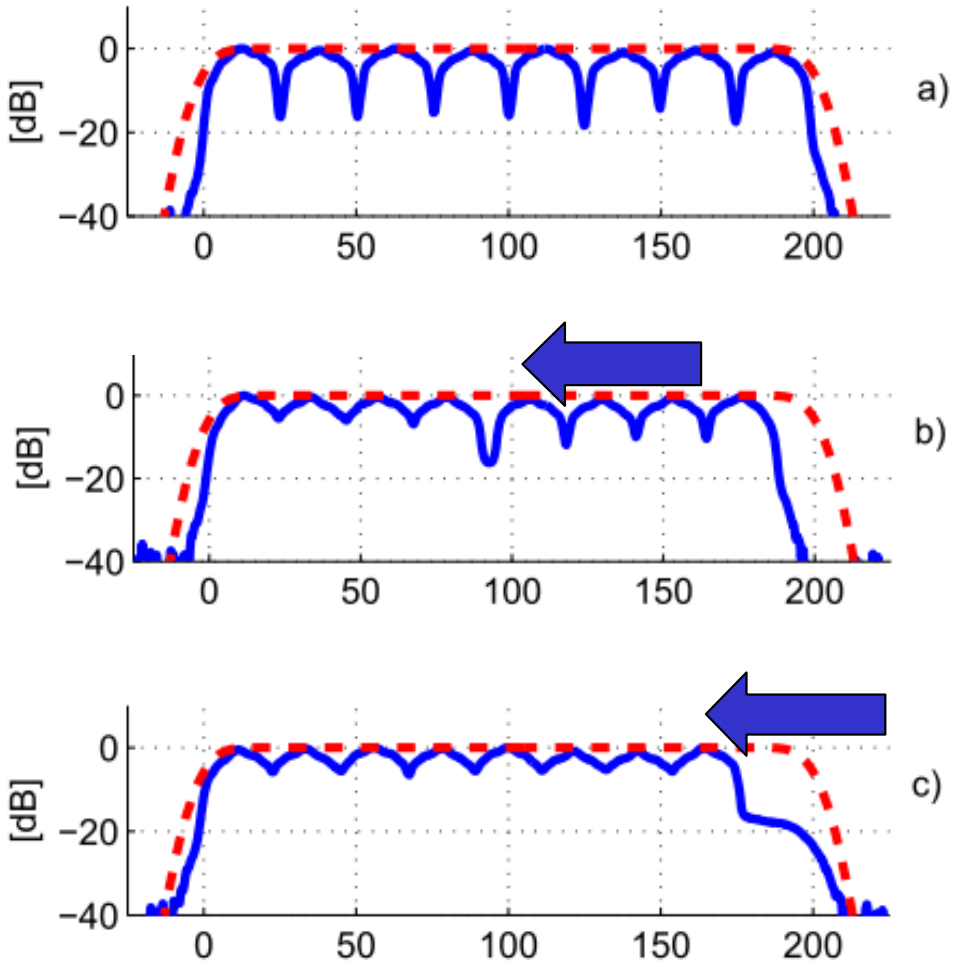


Self adaptation procedure Carrier spacing

- After modulation format and FEC/Coding:
- **Step 2**: sub-carrier spacing is then optimized

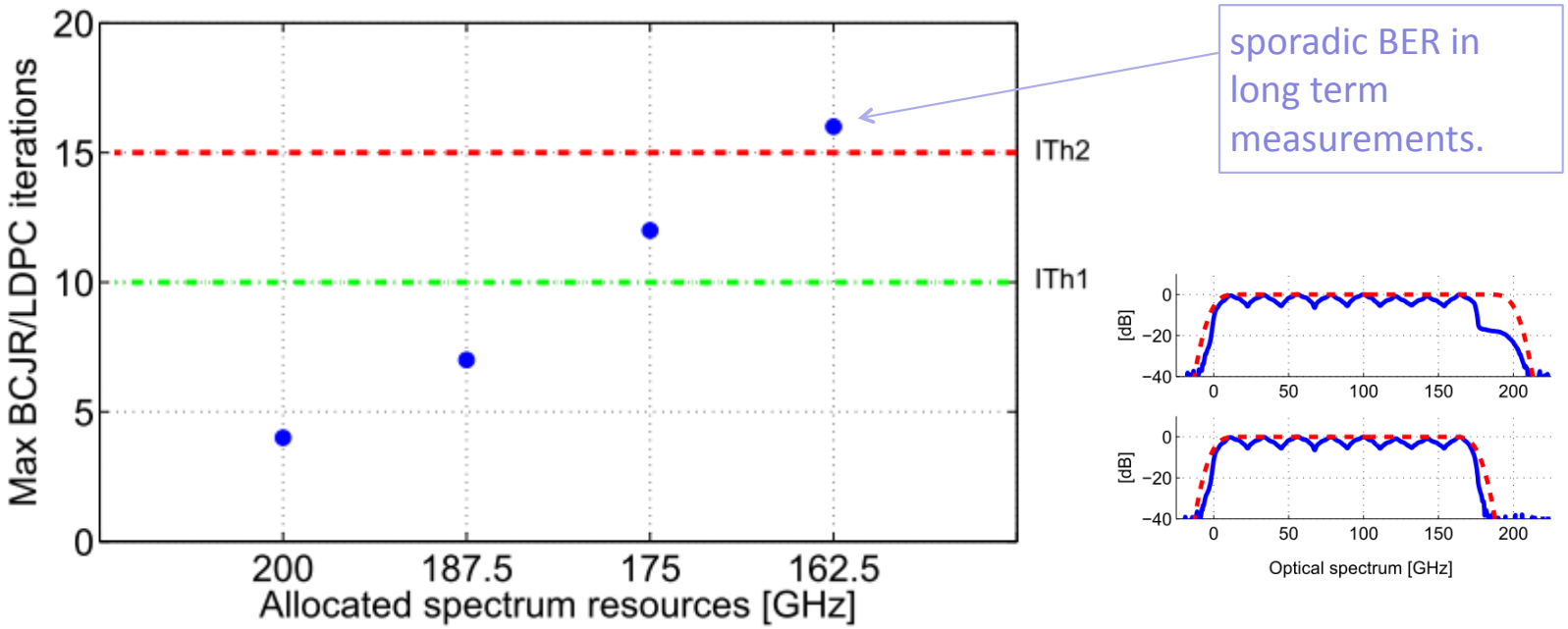
- If Iterations<TH1:

  hitless shift (push-pull) of each subcarrier, targeting 12.5GHz of spectrum saving for the whole super-channel



Monitoring during self-optimization

- **Validated in 1Tb/s field trial**
- 1300km link between Milan (Italy), Finkenstein (Austria) and back to Milan, traversing two BV-WSS and 21 amplifiers.
- 8 sub-carriers baud rate 36GB/s, net information rate at 1Tb/s.
- PM-QPSK, LDPC code rate 8/9, channel spacing successfully adapted from 200GHz to 175GHz, with no traffic disruption



Control plane

No.	Time	Source	Destination	Protocol	Info
13	5.095113	10.0.0.1	10.0.0.49	OFP	SSON Lightpath_In (AM) (84B)
15	5.096714	10.0.0.49	10.0.0.1	OFP	SSON Flow Mod (CSM) (72B)
16	5.096770	10.0.0.49	10.0.0.2	OFP	SSON Flow Mod (CSM) (72B)
19	6.658010	10.0.0.2	10.0.0.49	OFP	SSON Flow Ack (CSM) (28B)
21	6.679884	10.0.0.1	10.0.0.49	OFP	SSON Flow Ack (CSM) (28B)
22	6.681103	10.0.0.49	10.0.0.1	OFP	SSON Lightpath_Out (CSM) (80B)
35	88.279817	10.0.0.1	10.0.0.49	OFP	Unknown Type 33 (24B) → OFPT_REQ_FLOW_MOD
36	88.281044	10.0.0.49	10.0.0.1	OFP	SSON Flow Mod (CSM) (72B)
37	88.281084	10.0.0.49	10.0.0.2	OFP	SSON Flow Mod (CSM) (72B)
40	89.842359	10.0.0.2	10.0.0.49	OFP	SSON Flow Ack (CSM) (28B)
42	89.869436	10.0.0.1	10.0.0.49	OFP	SSON Flow Ack (CSM) (28B)

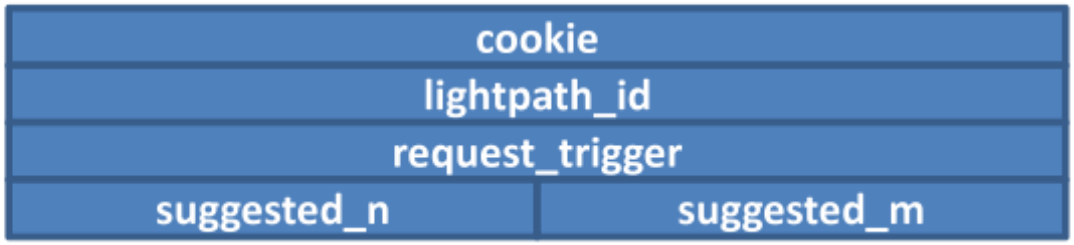
Setup @200GHz

Self adaptation @175GHz

```
0000  bc 30 5b e1 22 2a 00 01  c0 06 47 89 08 00 45 00   .0[."*.. ..G...E.
0010  00 4c 0a 02 40 00 40 06  1c 79 0a 00 00 01 0a 00   .L..@.@. .y......
0020  00 31 19 e9 32 2b 15 1f  da 00 3d 3f f5 c8 80 18   .1..2+.. ..=?....
0030  00 5b 3e 80 00 00 01 01  08 0a 17 16 26 a4 24 23   .[>..... ....&.$#
0040  51 fe 01 21 00 18 00 00  00 01 00 00 00 01 00 00   Q..!.... ........
0050  00 01 00 00 00 01 00 2e  00 0e                     ........ ..
```

OFPT_REQ_FLOW_MOD
(OFPT header type = 33)

- request_trigger = OSC (1)
- suggested_n = 46
(f_c = 193.3875 THz)
- suggested_m = 14
(width = 175 GHz)



F. Cugini et al., “Towards Plug-and-Play Software-defined EONs: Field Trial of Self-Adaptation Carrier Spacing”, ECOC 2015

YANG for alien λ

Goals, for alien wavelengths:

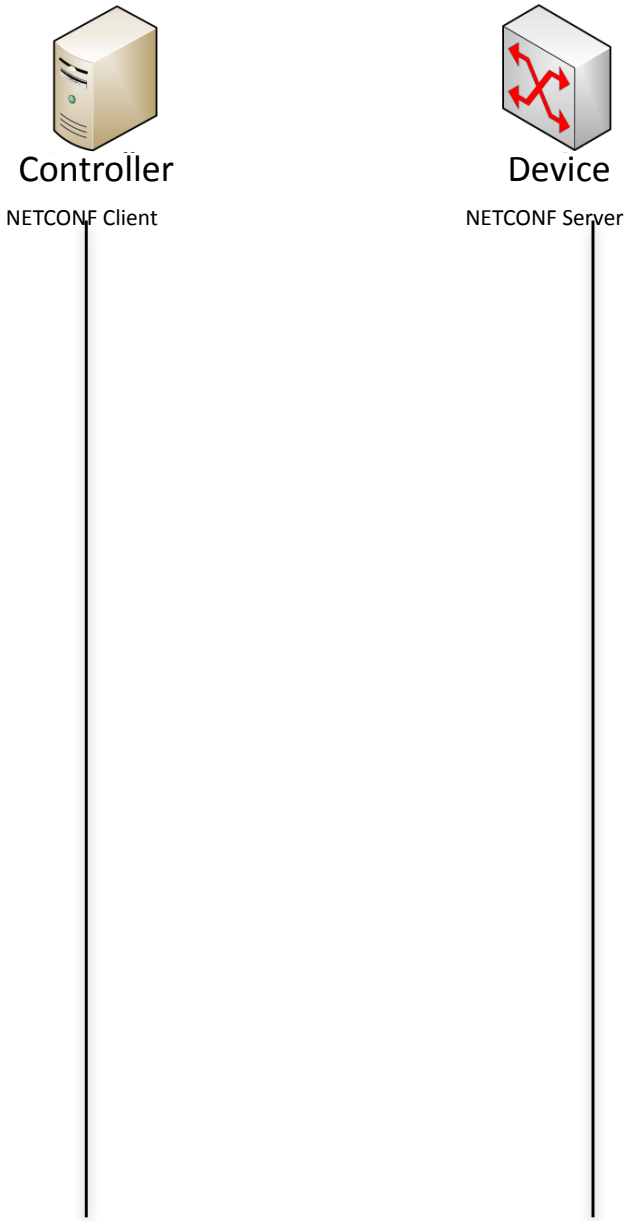
- Provisioning: multi-vendor and plug&play adaptation
- Monitoring & management: fault localizations, hard&soft failures..

→ YANG standardization (IETF & OpenROADM)

YANG model, has emerged as a standard SDN technology enabling both control (e.g., data plane device configuration) and management (e.g., access to monitoring information)

- NETCONF protocol
- Focus on monitoring

NETCONF - Example



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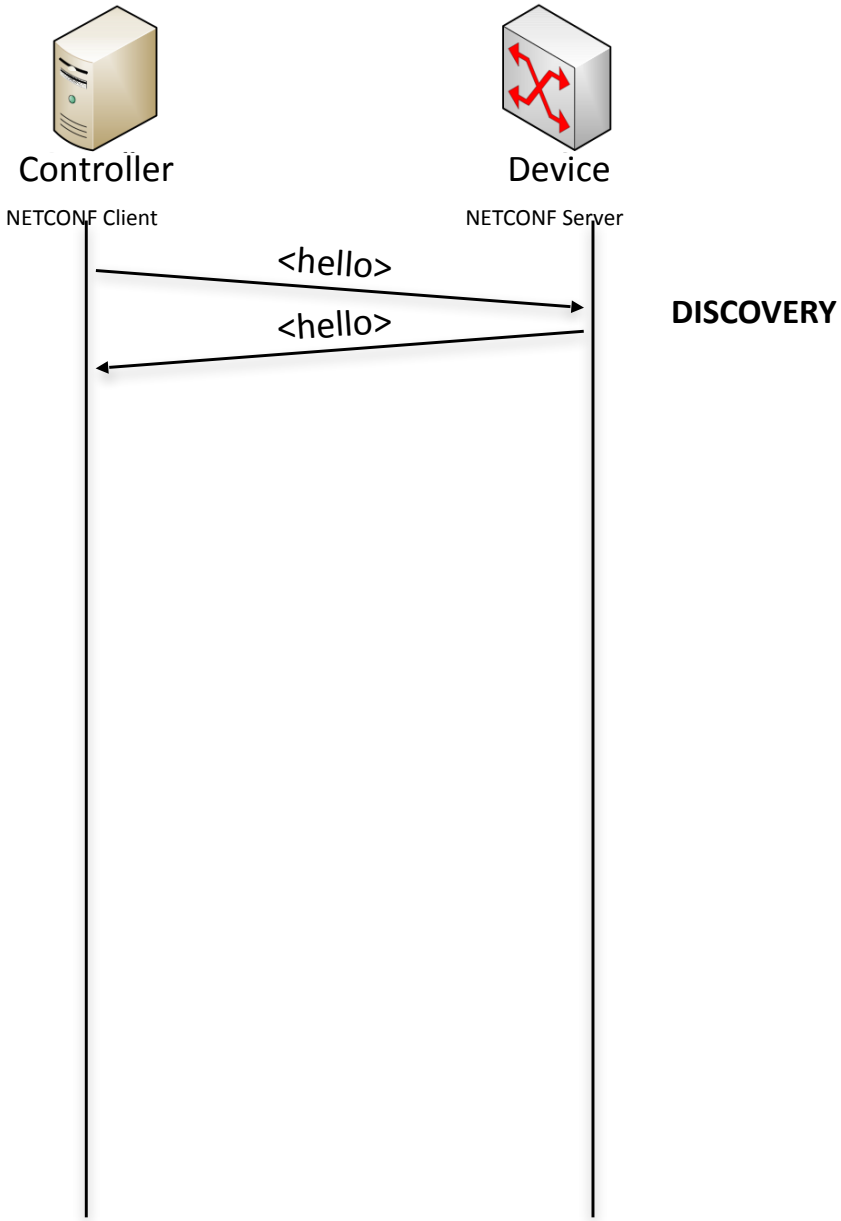

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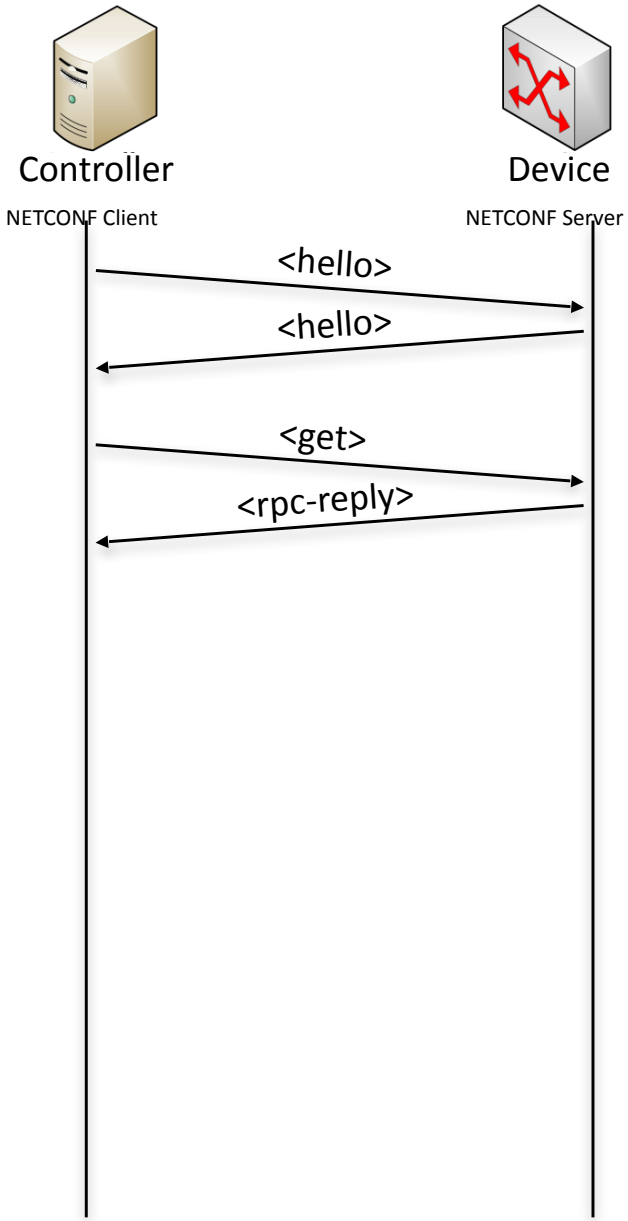
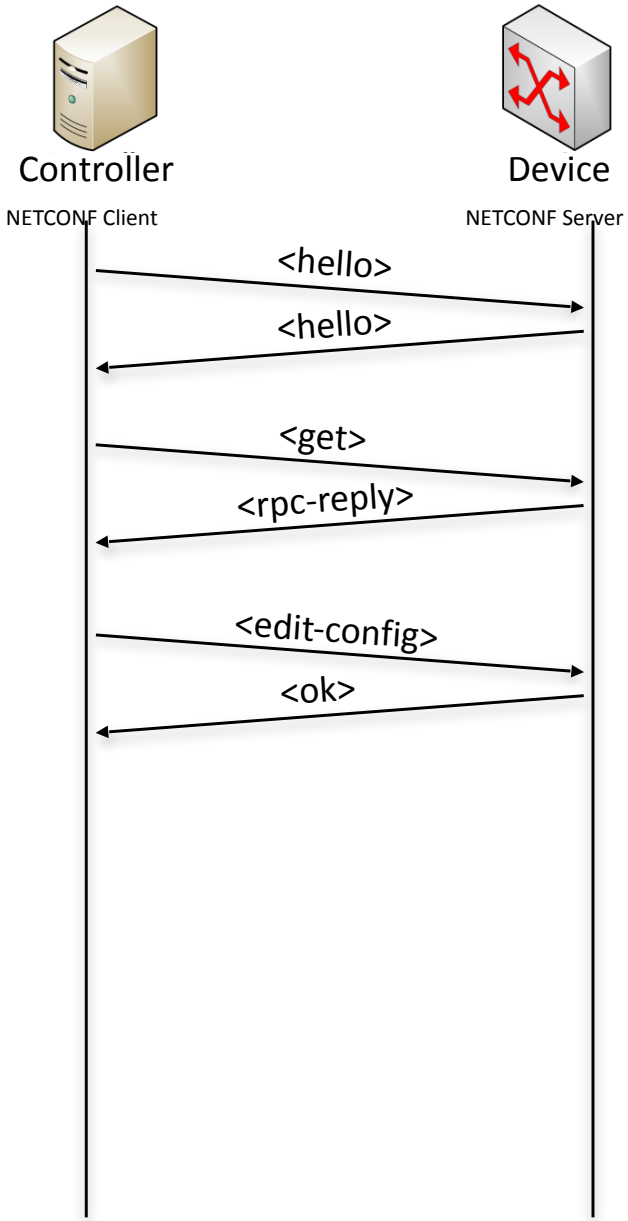


DISCOVERY

WHICH CAPABILITIES ARE SUPPORTED?

NETCONF - Example

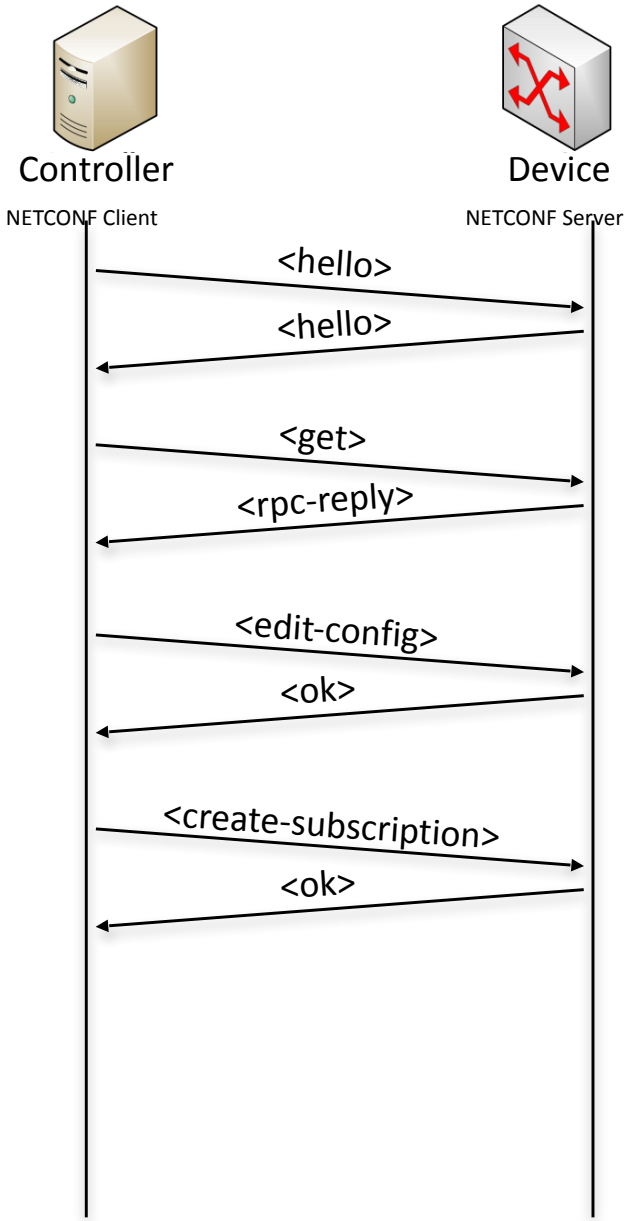


DISCOVERY

WHICH CAPABILITIES ARE SUPPORTED?

DEVICE CONFIGURATION

NETCONF - Example



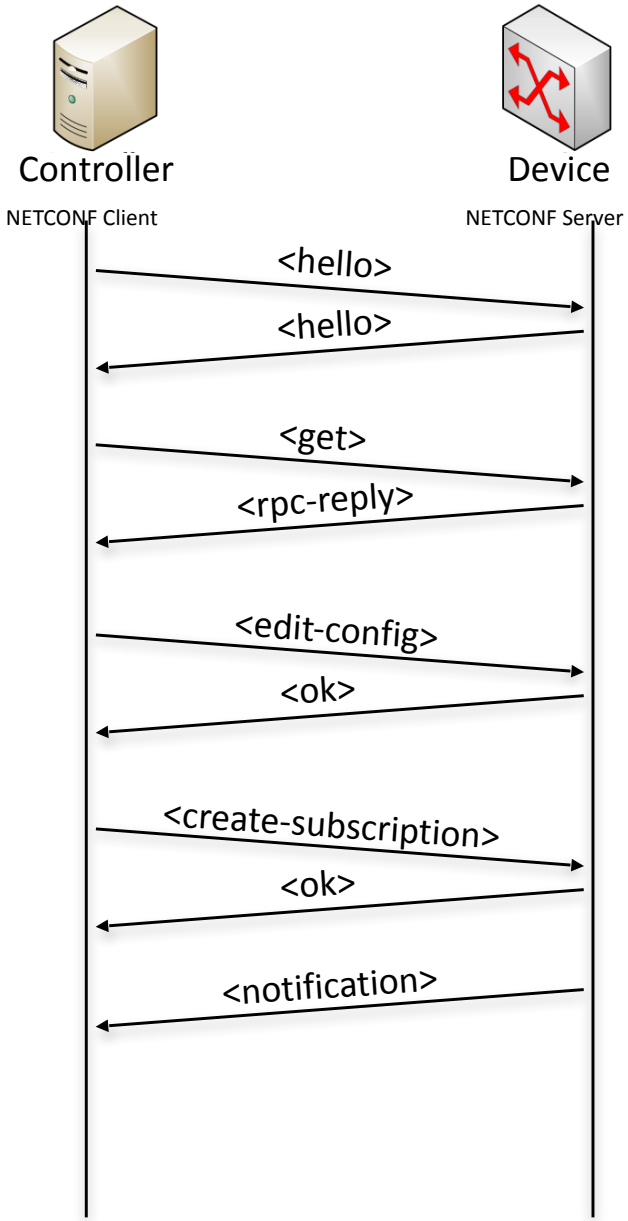
DISCOVERY

WHICH CAPABILITIES ARE SUPPORTED?

DEVICE CONFIGURATION

SUBSCRIPTION TO SPECIFIC NOTIFICATIONS

NETCONF - Example



DISCOVERY

WHICH CAPABILITIES ARE SUPPORTED?

DEVICE CONFIGURATION

SUBSCRIPTION TO SPECIFIC NOTIFICATIONS

NOTIFICATION THAT SUBSCRIBED EVENT OCCURRED

Experimental demonstration: BVT

- The Controller based on PYTHON NETCONF client
- The device runs ConfD, a NETCONF server implementation made by Tail-f
- A 100 Gb/s connection request has been considered:
  - a baudrate of 28 Gbaud PM-QPSK supports 100 Gb/s net rate and 7% FEC
  - 31 Gbaud around 20% FEC
- The controller subscribes to the transponder Notification stream specifying, through a filter, that it is interested on pre-FEC BER exceeding 9×10^{-4} threshold.

No.	Time	Source	Destination	Protocol	Length	Info
1	0	192.168.56.103	192.168.56.102	TCP	74	53106 > 2023 [SYN] Seq=0 Win=29200 Len=0 MSS=1460 SACK_PERM=1 TSval=253933 TSecr=0 WS=128
2	0.000373	192.168.56.102	192.168.56.103	TCP	74	2023 > 53106 [SYN, ACK] Seq=0 Ack=1 Win=28960 Len=0 MSS=1460 SACK_PERM=1 TSval=203711958 TSecr=253933 WS=128
3	0.000401	192.168.56.103	192.168.56.102	TCP	66	53106 > 2023 [ACK] Seq=1 Ack=1 Win=29312 Len=0 TSval=253933 TSecr=203711958
4	0.000511	192.168.56.103	192.168.56.102	TCP	106	53106 > 2023 [PSH, ACK] Seq=1 Ack=1 Win=29312 Len=40 TSval=253933 TSecr=203711958
5	0.000691	192.168.56.102	192.168.56.103	TCP	66	2023 > 53106 [ACK] Seq=1 Ack=41 Win=29056 Len=0 TSval=203711958 TSecr=253933
6	0.000704	192.168.56.103	192.168.56.102	TCP	337	53106 > 2023 [PSH, ACK] Seq=41 Ack=1 Win=29312 Len=271 TSval=253933 TSecr=203711958
7	0.000925	192.168.56.102	192.168.56.103	TCP	66	2023 > 53106 [ACK] Seq=1 Ack=312 Win=30080 Len=0 TSval=203711958 TSecr=253933
8	0.010643	192.168.56.102	192.168.56.103	TCP	2818	2023 > 53106 [PSH, ACK] Seq=1 Ack=312 Win=30080 Len=2752 TSval=203711960 TSecr=253933
9	0.01074	192.168.56.103	192.168.56.102	TCP	66	53106 > 2023 [ACK] Seq=312 Ack=2753 Win=34816 Len=0 TSval=253936 TSecr=203711960
10	0.013463	192.168.56.103	192.168.56.102	TCP	216	53106 > 2023 [PSH, ACK] Seq=312 Ack=2753 Win=34816 Len=150 TSval=253937 TSecr=203711960
11	0.013594	192.168.56.103	192.168.56.102	TCP	1514	53106 > 2023 [ACK] Seq=462 Ack=2753 Win=34816 Len=1448 TSval=253937 TSecr=203711960
12	0.013909	192.168.56.102	192.168.56.103	TCP	66	2023 > 53106 [ACK] Seq=2753 Ack=1910 Win=34048 Len=0 TSval=203711961 TSecr=253937
13	0.013941	192.168.56.103	192.168.56.102	TCP	290	53106 > 2023 [PSH, ACK] Seq=1910 Ack=2753 Win=34816 Len=224 TSval=253937 TSecr=203711961
14	0.052621	192.168.56.102	192.168.56.103	TCP	66	2023 > 53106 [ACK] Seq=2753 Ack=2134 Win=36992 Len=0 TSval=203711971 TSecr=253937
15	0.05847	192.168.56.102	192.168.56.103	TCP	206	2023 > 53106 [PSH, ACK] Seq=2753 Ack=2134 Win=36992 Len=140 TSval=203711972 TSecr=253937
16	0.059472	192.168.56.103	192.168.56.102	TCP	219	53106 > 2023 [PSH, ACK] Seq=2134 Ack=2893 Win=37632 Len=153 TSval=253948 TSecr=203711972
17	0.05978	192.168.56.102	192.168.56.103	TCP	66	2023 > 53106 [ACK] Seq=2893 Ack=2287 Win=39808 Len=0 TSval=203711972 TSecr=253948
18	0.059795	192.168.56.103	192.168.56.102	TCP	70	53106 > 2023 [PSH, ACK] Seq=2287 Ack=2893 Win=37632 Len=4 TSval=253948 TSecr=203711972
19	0.059936	192.168.56.102	192.168.56.103	TCP	66	2023 > 53106 [ACK] Seq=2893 Ack=2291 Win=39808 Len=0 TSval=203711972 TSecr=253948
20	0.060521	192.168.56.102	192.168.56.103	TCP	206	2023 > 53106 [PSH, ACK] Seq=2893 Ack=2291 Win=39808 Len=140 TSval=203711973 TSecr=253948
21	0.060628	192.168.56.102	192.168.56.103	TCP	66	2023 > 53106 [FIN, ACK] Seq=3033 Ack=2291 Win=39808 Len=0 TSval=203711973 TSecr=253948
22	0.060707	192.168.56.103	192.168.56.102	TCP	66	53106 > 2023 [FIN, ACK] Seq=2291 Ack=3034 Win=40576 Len=0 TSval=253948 TSecr=203711973
23	0.061007	192.168.56.102	192.168.56.103	TCP	66	2023 > 53106 [ACK] Seq=3034 Ack=2292 Win=39808 Len=0 TSval=203711973 TSecr=253948
24	38.3766	192.168.56.103	192.168.56.102	TCP	74	53107 > 2023 [SYN] Seq=0 Win=29200 Len=0 MSS=1460 SACK_PERM=1 TSval=263527 TSecr=0 WS=128
25	38.376944	192.168.56.102	192.168.56.103	TCP	74	2023 > 53107 [SYN, ACK] Seq=0 Ack=1 Win=28960 Len=0 MSS=1460 SACK_PERM=1 TSval=203721553 TSecr=263527 WS=128
26	38.377021	192.168.56.103	192.168.56.102	TCP	66	53107 > 2023 [ACK] Seq=1 Ack=1 Win=29312 Len=0 TSval=263527 TSecr=203721553
27	38.377132	192.168.56.103	192.168.56.102	TCP	106	53107 > 2023 [PSH, ACK] Seq=1 Ack=1 Win=29312 Len=40 TSval=263527 TSecr=203721553
28	38.377425	192.168.56.102	192.168.56.103	TCP	66	2023 > 53107 [ACK] Seq=1 Ack=41 Win=29056 Len=0 TSval=203721553 TSecr=263527
29	38.378372	192.168.56.102	192.168.56.103	TCP	2818	2023 > 53107 [PSH, ACK] Seq=1 Ack=41 Win=29056 Len=2752 TSval=203721553 TSecr=263527
30	38.378419	192.168.56.103	192.168.56.102	TCP	66	53107 > 2023 [ACK] Seq=41 Ack=2753 Win=34816 Len=0 TSval=263528 TSecr=203721553
31	38.383082	192.168.56.103	192.168.56.102	TCP	667	53107 > 2023 [PSH, ACK] Seq=41 Ack=2753 Win=34816 Len=601 TSval=263529 TSecr=203721553
32	38.392732	192.168.56.102	192.168.56.103	TCP	202	2023 > 53107 [PSH, ACK] Seq=2753 Ack=642 Win=30208 Len=136 TSval=203721557 TSecr=263529
33	38.429415	192.168.56.103	192.168.56.102	TCP	66	53107 > 2023 [ACK] Seq=642 Ack=2889 Win=37632 Len=0 TSval=263541 TSecr=203721557
34	70.141241	192.168.56.102	192.168.56.103	TCP	416	2023 > 53107 [PSH, ACK] Seq=2889 Ack=642 Win=30208 Len=350 TSval=203729495 TSecr=263541
35	70.141327	192.168.56.103	192.168.56.102	TCP	66	53107 > 2023 [ACK] Seq=642 Ack=3239 Win=40576 Len=0 TSval=271468 TSecr=203729495

a)

Config

```
<?xml version="1.0" encoding="UTF-8"?>
                <rpc xmlns="urn:ietf:params:xml:ns:netconf:base:1.0"
                     message-id="1">
<edit-config xmlns:nc='urn:ietf:params:xml:ns:netconf:base:1.0'>
<target><running/></target><config>
<transponder xmlns="http://sssup.it/transponder"
             xmlns:nc="urn:ietf:params:xml:ns:netconf:base:1.0">
    <subcarrier-module>
        <subcarrier-id>2</subcarrier-id>
        <config>
            <direction>TX</direction>
            <bit-rate>112</bit-rate>
            <baud-rate>28</baud-rate>
            <modulation xmlns:mf="http://sssup.it/modulation-formats">
                mf:pm-qpsk
            </modulation>
            <fec-in-use>
                <name xmlns:fec="http://sssup.it/fec-types">
                    fec:ldpc
                </name>
                <rate>
                    <message-length>14</message-length>
                    <block-length>15</block-length>
                </rate>
            </fec-in-use>
            <central-frequency>193100</central-frequency>
            <bandwidth>33.6</bandwidth>
            <transmitter>
                <output-power>0</output-power>
            </transmitter>
        </config>
    </subcarrier-module>
    <connections>
        <connection nc:operation="create">
            <connection-id>2</connection-id>
            <config>
                <connection-id>2</connection-id>
                <transmission-scheme>NWDM</transmission-scheme>
                <subcarrier>
                    <subcarrier-id>2</subcarrier-id>
                </subcarrier>
                <frequency-slot>
                    <n>0</n>
                    <m>3</m>
                </frequency-slot>
            </config>
        </connection>
    </connections>
</transponder>
</config></edit-config>
</rpc>
```

b)

Subscription to pre-FEC increase

```
<?xml version="1.0" encoding="UTF-8"?>
<rpc xmlns="urn:ietf:params:xml:ns:netconf:base:1.0" message-id="1">
  <create-subscription xmlns="urn:ietf:params:xml:ns:netconf:notification:1.0">
    <stream>transponder</stream>
    <filter type="xpath" xmlns:tran="http://sssup.it/transponder"
    .select="/tran:pre-fec-ber-change[tran:pre-fec-ber>=0.0009]"/>
  </create-subscription>
</rpc>
]]>]]>
```

c)

Notification of pre-FEC BER increase

```
<?xml version="1.0" encoding="UTF-8"?>
<rpc-reply xmlns="urn:ietf:params:xml:ns:netconf:base:1.0" message-id="1"><ok/></rpc-reply>]]>]]>
<?xml version="1.0" encoding="UTF-8"?>
<notification xmlns="urn:ietf:params:xml:ns:netconf:notification:1.0"><eventTime>2015-10-12T13:11:58.306596+00:00</eventTime>
<pre-fec-ber-change xmlns='http://sssup.it/transponder'>
  <subcarrier-module-id>1</subcarrier-module-id>
  <pre-fec-ber>0.00096</pre-fec-ber>
</pre-fec-ber-change>
</notification>]]>]]>
```

d)

M. Dallaglio et al “YANG Model and NETCONF Protocol for Control and Management of Elastic Optical Networks”, OFC 2016

Conclusions

- Evolutions in network design driven by DC-centric traffic are discussed
- For DC-to-Edge traffic, a semi-filterless solution is presented, based on interfaces equipped with low-cost tunable filters
- For DC-to-DC traffic, work is on-going to enable adaptation of alien wavelengths:
  - Adaptation capabilities
  - YANG
  - NETCONF protocol implementation
  - Monitoring

Thank you

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