Experimental demonstration of fully disaggregated white box including different types of transponders and monitors, controlled by NETCONF and YANG

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Abstract: We experimentally demonstrated a fully disaggregated white box composed of two different types of transponders, monitors (including filtering effect parameters), add-drop multiplexers, and switches. NETCONF and YANG control the hardware. © 2018 The Author(s)

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1. Introduction

White boxes are attracting increasing interest from service providers and network operators [1], as they provide disaggregation of software from hardware (including separation of control, management and forwarding planes) and can be assembled with modules from different vendors that inter-operate. They are expected to penetrate the wide area networks market in the following years, as a way for network operators to better optimize transmission, digital signal processing (DSP), and monitoring systems, while reducing costs. To support control and management of white boxes, standardized data models are required. YANG [2] is a widely agreed language among operators and service providers for enabling interfaces with the control and the management system. YANG is supported by the emerging NETCONF protocol standardized by IETF [3].

In this paper, we experimentally demonstrate a fully disaggregated white box composed of the following cooperating modules, provided by different partners: two types of transponders, monitors (including a filtering effect monitor), switches, add-drop multiplexers, and an agent for interfacing with the control and management plane. We demonstrate the configuration of the white box through NETCONF and YANG, as well as its dynamic reconfiguration (baud rate adaptation, filter reconfiguration, and signal frequency shifting) upon physical layer degradations (e.g., filtering effects).

2. White box architecture and specifications

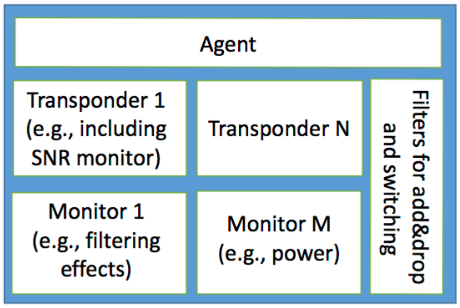
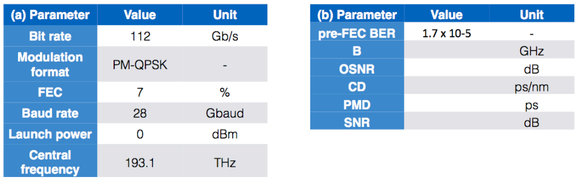


Fig. 1 White box architecture



(a) Parameter	Value	Unit
Bit rate	112	Gb/s
Modulation format	PM-QPSK	-
FEC	7	%
Baud rate	28	Gbaud
Launch power	0	dBm
Central frequency	193.1	THz

(b) Parameter	Value	Unit
pre-FEC BER	1.7 x 10-5	-
B		GHz
OSNR		dB
CD		ps/nm
PMD		ps
SNR		dB

Fig. 2 Part of databases recording: (a) configuration parameters, (b) monitored parameters

The white box architecture is shown in Fig. 1. Its hardware (separated from the control and management software) consists of modules provided by different partners: two different types of transponders that include end-to-end performance (signal to noise ratio – SNR) monitors, filtering effect monitor, power monitor, and filters for add and drop multiplexing and switching based on flexible grid. Finally, the white box provides an agent interfacing with software-based control and management plane.

Transponder 1 supports PM-16QAM, PM-8QAM, and PM-QPSK modulation formats in a single carrier scheme, with 200, 150, and 100 Gb/s respective net rates, 12% and 28% code rate, 28 and 32 Gbaud, end-to-end monitor of SNR, optical SNR (OSNR), chromatic dispersion (CD), polarization mode dispersion (PMD), and bit error rate (BER). ***Transponder 2*** supports two carriers, each supporting PM-16QAM and PM-QPSK modulation formats, with 200 and 100 Gb/s respective net rates, 7% code rate, 28 Gbaud, and end-to-end monitor of CD, PMD, and BER. ***Monitor 1*** monitors filter effects through the measurement of the 10dB-bandwidth (B) of the signal before DSP. ***Monitor 2*** consists of a commercial power monitor. ***Add and drop and switching*** are based on commercial Bandwidth Variable Wavelength Selective Switches (BV-WSSs) supporting the ITU-T flex-grid. An amplifier stage is also included (booster in the add and pre-amp in the drop).

Finally, the white box contains an **agent** interfacing with NETCONF protocol. It includes two databases (shown in Fig. 2) storing the values of *configuration* parameters (e.g., transponder bit rate and modulation format) and *state* (or monitored) parameters (including values such as B and BER). Configuration data is decided by the control plane, it is carried by NETCONF and it is written in the database to configure the white box accordingly. Monitoring data is sent via NETCONF to the management system.

3. Control and management of white box

The control and management plane is based on the IETF ABNO [4] architecture, and it includes a stateful ABNO controller, appropriate databases (e.g., traffic engineering database – TED), the Provisioning Manager, and the OAM Handler. NETCONF is used for configuration and for carrying monitoring information. The ABNO controller is extended to take decisions, closing the observe-decide-act control loop envisioned in the ORCHESTRA project [5]. Within this framework, actions (e.g., code adaptation, rerouting, spectrum shifting) are taken based on (re)optimization decisions triggered by the observation of the monitored parameters (e.g., SNR, filtering effects). *Opendaylight* tool is used as Provisioning Manager after being extended for NETCONF.

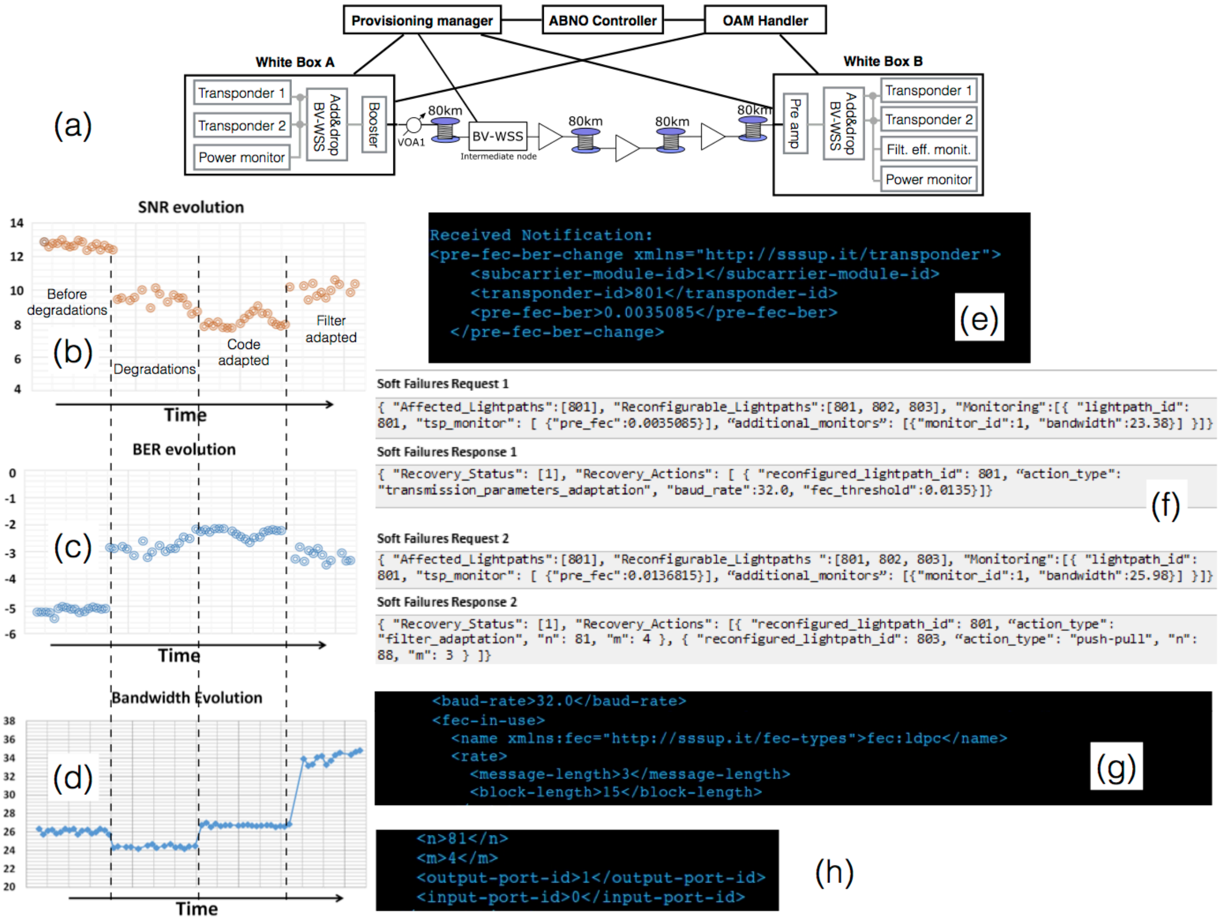
The ***ABNO-controller*** uses the DEPLOY optimization engine [5] as Path Computation Element using related databases, such as TED. Given a request for a connection between two nodes at a specific rate, DEPLOY decides the transponder configuration parameters (gross rate, baud rate, code rate, and modulation format), and the routing and spectrum assignment. Then, the ABNO controller triggers the ***Provisioning Manager*** to configure the data plane using NETCONF: this includes configuring the selected transponder at the proper configuration parameters' values, and the BV-WSS for the add-drop and switching functions. In case of problems such as faults or physical layer degradations (e.g., due to increased attenuation or unexpected filtering effects), the ABNO controller reconfigures the white box or performs re-routing of the entire connection.

The ***OAM Handler*** forms the core of the management system. Its role is to ensure the proper operation of the services, being responsible for polling monitored parameters, receiving and processing alarms, processing the monitored parameters so as to identify and localize problems (e.g., fiber cuts, filtering effect, or signal attenuation), and triggering the ABNO-controller to perform white box reconfiguration or service rerouting for recovery.

NETCONF protocol supports the ***YANG*** model proposed in [6] for controlling the transponders and managing end-to-end performance parameters (e.g., SNR). YANG model has been extended to include the ***signal bandwidth parameter B*** provided by the monitor for filtering effects due to filters concatenation. Then, a YANG model including the configuration of filter central frequency, bandwidth, and in/out ports is adopted to configure the BV-WSSs' add-drop and switching functions. A NETCONF **<*edit-config*>** message is sent by the Provisioning Manager to the white box agent to (re-)configure transponders and BV-WSSs. Configuration values are written in the agent's database and are used to configure the hardware. A NETCONF **<*get*>** message is sent by the OAM Handler to poll monitoring information. The agent receiving this message retrieves the proper monitored values by the database and sends them in a reply message to the OAM Handler. A NETCONF **<*notification*>** message is sent by the agent to the OAM Handler as an alarm if a parameter exceeds a pre-defined threshold (e.g., $BER>2x10^{-3}$).

4. Experimental demonstration

We experimentally demonstrated the white box control and monitoring in the testbed of Fig. 3a, also showing the proper operation of services through reconfiguration in case of physical layer degradations. Indeed, the control and management plane guarantee the proper (below the BER threshold) operation of services by reconfiguring the white box's transmission parameters and filters. We emulated two simultaneous physical layer degradations: (1) a SNR decrease (e.g., due to fiber or amplifier aging) by varying the attenuation of the Variable Optical Attenuator (VOA) and (2) filtering effects (e.g., laser and filter misalignment in a cascade of filters, e.g. due to laser aging, thus distorting the signal) by narrowing the filter in the second BV-WSS. Three connection requests were considered, one at 150Gb/s and two at 200 Gb/s net rate. Transponder 1 is configured at 150 Gb/s, PM-8QAM, 28 Gbaud, and 12% code rate, with central frequency 193.6 THz (i.e., $n=80$ in the ITU-T flex-grid). Transponder 2 is configured supporting two carriers, with central frequencies of 193.5625 THz (n=74) and 193.6375 THz (n=86), respectively, each at 200 Gb/s, PM-16QAM, 28 Gbaud, and 7% code rate. All the signals are switched with 37.5 GHz bandwidth ($m=3$ according to ITU-T flex-grid recommendations). Then, SNR degradation is introduced, as well as filter distortions affecting the signal generated by Transponder 1. Fig. 3b,c,d show the SNR, BER, and signal bandwidth (B) evolution of this signal, as the white box has monitored. Before the failures, SNR is above 12 dB, BER is around 10^{-5}, and B=26 GHz. When the two degradations occur, BER jumps to around 10^{-3}, SNR falls by about 10 dB, and B=24 GHz. Here, a first observe-decide-act control loop is performed. Indeed, the BER increase and SNR decrease cause an alarm (Fig. 3e with the transponder *Id* and the BER value) to be sent to the OAM Handler, which triggers the ABNO controller for decision. Fig. 3f shows the log of the DEPLOY engine reporting, in "Soft Failures Request



```
Received Notification:
<pre-fec-ber-change xmlns="http://sssup.it/transponder">
    <subcarrier-module-id>1</subcarrier-module-id>
    <transponder-id>801</transponder-id>
    <pre-fec-ber>0.0035085</pre-fec-ber>
  </pre-fec-ber-change>
```

Soft Failures Request 1

```
{ "Affected_Lightpaths":[801], "Reconfigurable_Lightpaths":[801, 802, 803], "Monitoring":[{ "lightpath_id":
801, "tsp_monitor": [ {"pre_fec":0.0035085}], “additional_monitors”: [{"monitor_id":1, "bandwidth":23.38}] }]}
```

Soft Failures Response 1

```
{ "Recovery_Status": [1], "Recovery_Actions": [ { "reconfigured_lightpath_id": 801, “action_type":
"transmission_parameters_adaptation", "baud_rate":32.0, "fec_threshold":0.0135}]}
```

Soft Failures Request 2

```
{ "Affected_Lightpaths":[801], "Reconfigurable_Lightpaths ":[801, 802, 803], "Monitoring":[{ "lightpath_id":
801, "tsp_monitor": [ {"pre_fec":0.0136815}], “additional_monitors”: [{"monitor_id":1, "bandwidth":25.98}] }]}
```

Soft Failures Response 2

```
{ "Recovery_Status": [1], "Recovery_Actions": [{ "reconfigured_lightpath_id": 801, “action_type":
"filter_adaptation", "n": 81, "m": 4 }, { "reconfigured_lightpath_id": 803, “action_type": "push-pull", "n":
88, "m": 3 } ]}
```

```
    <baud-rate>32.0</baud-rate>
    <fec-in-use>
      <name xmlns:fec="http://sssup.it/fec-types">fec:ldpc</name>
      <rate>
        <message-length>3</message-length>
        <block-length>15</block-length>
```

```
    <n>81</n>
    <m>4</m>
    <output-port-id>1</output-port-id>
    <input-port-id>0</input-port-id>
```

Fig. 3 (a) Experimental setup; (b) SNR, (c) BER, and (d) bandwidth evolutions; (e) NETCONF <notification>; (f) DEPLOY log; (g) NETCONF <edit-conf> for transponder reconfiguration; (h) <edit-conf> for filters reconfiguration

1”, the affected lightpath connection (with id 801) among the three connections (801, 802, and 803) and, in “Soft Failures Response 1”, the “transmission_parameters_adaptation” decision. In particular, baudrate is increased to 32 Gbaud to support a more redundant code (28%) and a higher BER threshold of 0.0135. Fig. 3g shows the NETCONF message sent for transponder reconfiguration. The increase of baudrate, however, implies an increase of the signal bandwidth, worsening even more the detrimental filtering effects. Indeed, SNR becomes even worse and BER increases up to 10^{-2}. We can observe only a slight increase of B up to 27 GHz because of the strong filtering effects that cut the signal. Thus, the filtering effect monitor raises a new alarm. In response to it, the DEPLOY engine (bottom part of Fig. 3f) computes an appropriate reconfiguration of the filters. The filter enlargement can only be enabled by shifting the third connection (id 803) from n=86 to n=88. The “push-pull” technique is exploited for signal shift [7]. Fig. 3h shows the NETCONF message for filter reconfiguration, with parameter m=4 (50 GHz) instead of m=3 (37.5 GHz). This operation reports SNR and BER to acceptable values. Reconfiguration time is in the order of few seconds, dominated by laser synthonization and BV-WSS reconfiguration. Bandwidth parameter B in Fig. 3d becomes 34 GHz, approaching the baudrate value of 32.

5. Conclusions

We experimentally demonstrated a fully disaggregated white box, where hardware was separated by the control and management plane, showing the continued proper operation of services even in the presence of Quality of Transmission problems (e.g., due to increased attenuation or unexpected filtering effects). The white box is composed of transponders, performance monitors (including a filtering effect monitor), and add-drop multiplexers provided by different partners, as well an agent for interfacing with the control and management plane. NETCONF protocols and YANG models were used to control and manage the white box.

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6. References

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