SDN control of Spatial Division Multiplexing (SDM) for 5G fronthaul/backhaul networks

Raul Muñoz, R. Vilalta, R. Casellas[1], R. Martínez

(1) Centre Tecnològic de Telecomunicacions de Catalunya (CTTC/CERCA), Castelldefels, Spain.

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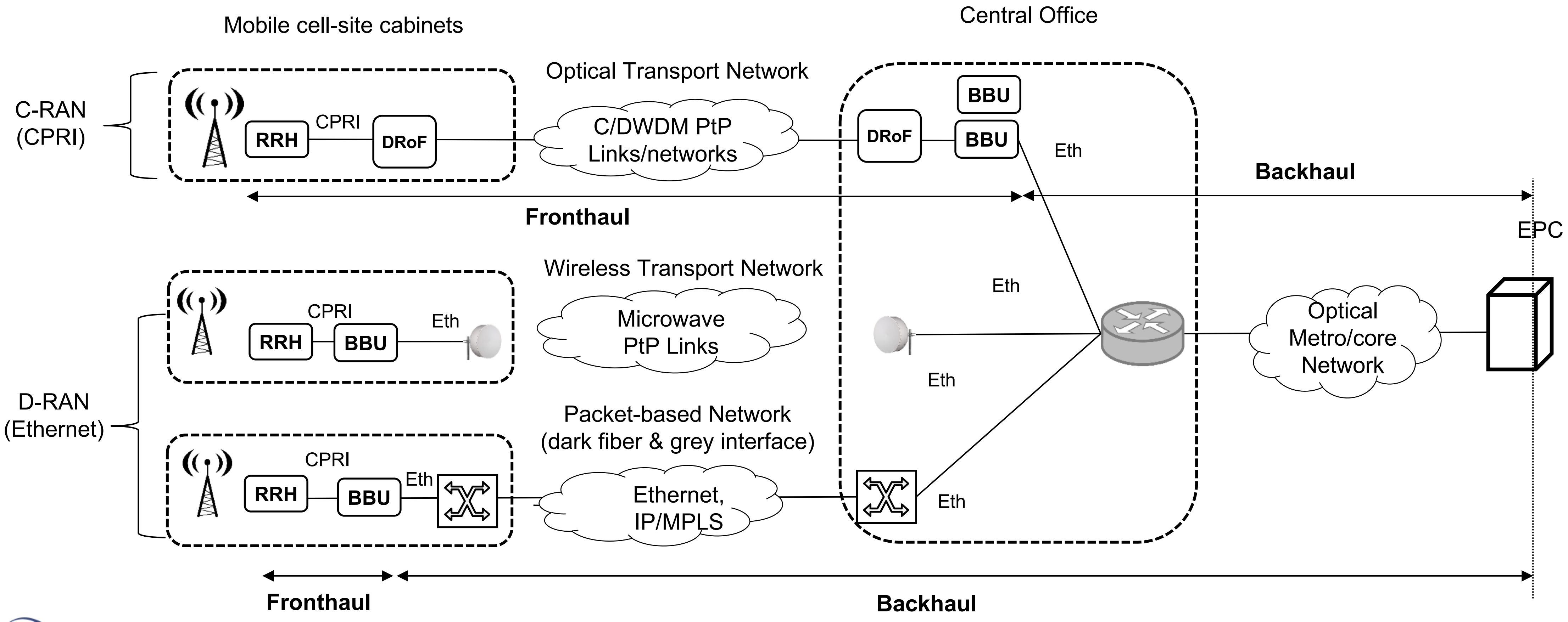
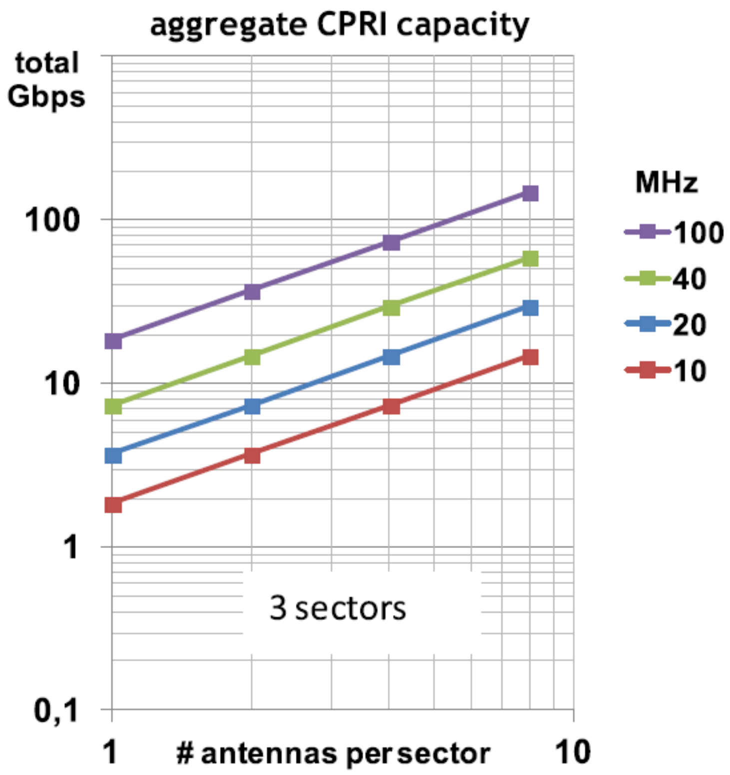
4G mobile transport networks

- Mobile transport networks can be traditionally sorted out as backhaul and fronthaul solutions



Digitalized fronthaul (CPRI) does not scale

- The main drawback that CPRI does not scale for the massive MIMO antenna deployments foreseen in 5G in terms of bandwidth requirements.

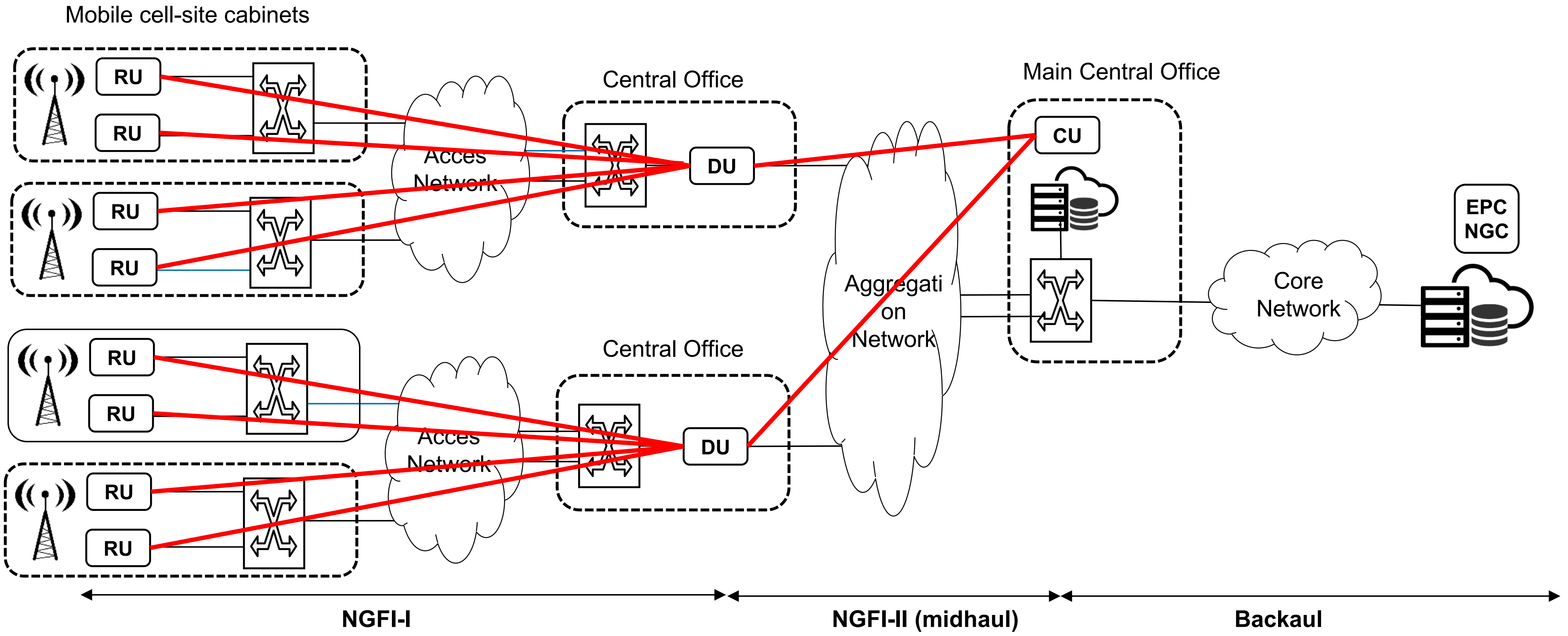


- small cell → 2.5 Gbit/s
  1 sector, 2x2 MIMO, 20 MHz
- macro cell for 2 MNOs, each with → 29.5 Gbit/s
  3 sectors, 2x2 MIMO, (20 + 20) MHz
- tower with different configurations → 56.6 Gbit/s
  3 x (4x4 MIMO) x (20 + 20) MHz,
  3 x (2x2 MIMO) x 20 MHz,
  1 x (8x8 MIMO) x (20 + 20) MHz
- requirement for 1 Gbit/s on downlink → 148 Gbit/s
  3 sectors, 8x8 MIMO, (5 x 20) MHz

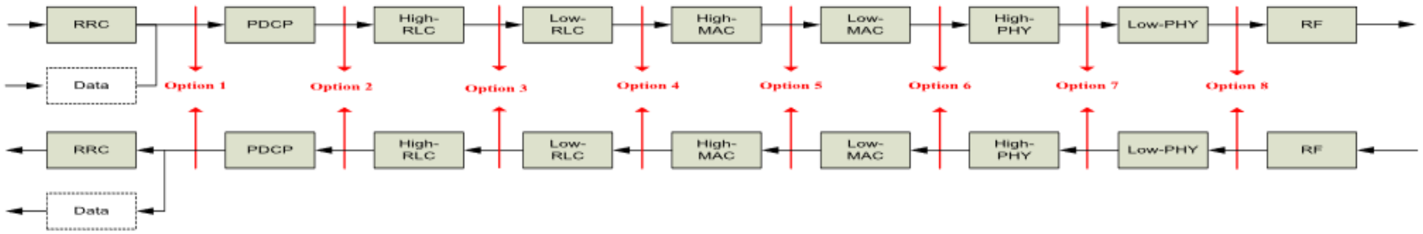
Thomas Pfeiffer, Next Generation Mobile Fronthaul and Midhaul Architectures [Invited] . J. OPT. COMMUN. NETW./VOL. 7, NO. 11/NOVEMBER 2015

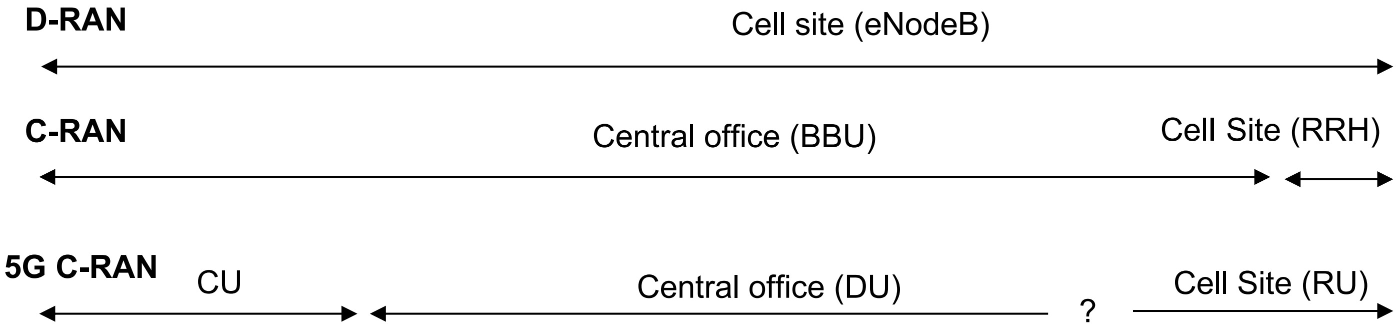
5G C-RAN defined by 3GPP

- BBU functions are split into remote unit (RU), distributed unit (DU) and the centralized unit (CU).
- It brings the introduction of the next generation fronthaul interface (NGFI) that is packetized to provide more efficient network utilization in ultra-dense scenarios (statistical multiplexing)



Function split of the baseband processing





Chih-Lin I, Han Li, Jouni Korhonen, Jinri Huang, Jinri Huang, RAN Revolution with NGFI (xhaul) for 5G, Journal of Lightwave Technology, v:36, n:2, Jan 2018.

TABLE I
SUMMARIZED REQUIREMENTS ON THE UNDERLYING TRANSPORT NETWORK DUE TO A CERTAIN FUNCTIONAL SPLIT, AS A CONSEQUENCE TO SUPPORT A CERTAIN FEATURE/USE CASE (THE ASSUMPTIONS INCLUDE: 100 MHZ BANDWIDTH, 256 QAM, 8 MIMO LAYERS AND 32 ANTENNA PORTS) [14]

NGFI-II

eCPRI

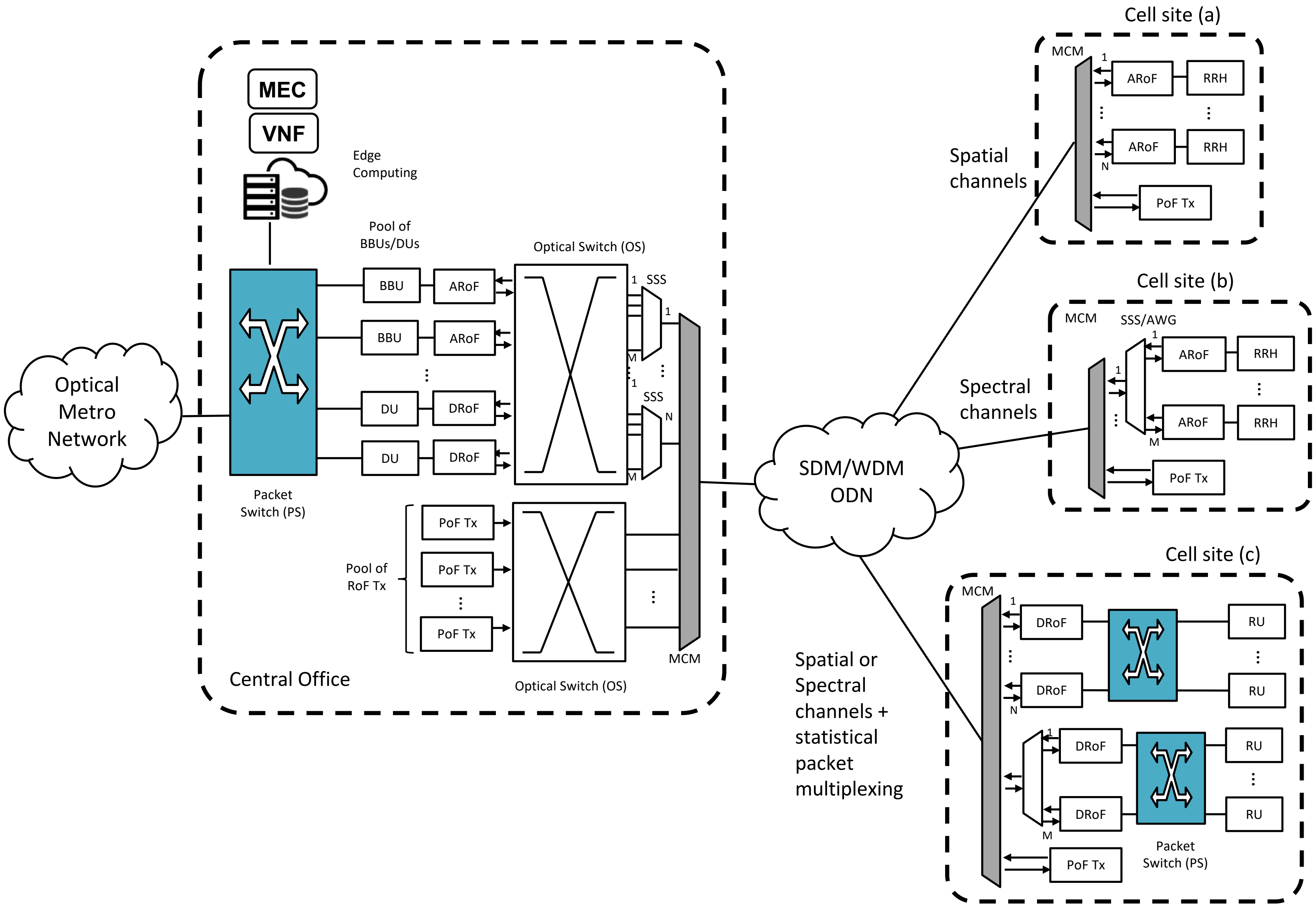
CPRI

Protocol Split option 1	Required bandwidth	Max. allowed one way latency [ms]
Option 1	*[DL: 4Gb/s]* *[UL: 3Gb/s]*	*[10ms]*
Option 2	*[DL: 4016Mb/s]* *[UL:3024 Mb/s]*	*[1.5~10ms]*
Option 3	*[lower than option 2 for UL/DL]*	*[1.5~10ms]*
Option 4	*[DL:4000Mb/s]* *[UL:3000Mb/s]*	*[approximate 100us]*
Option 5	*[DL: 4000Mb/s]* *[UL: 3000 Mb/s]*	*[hundreds of microseconds]*
Option 6	*[DL: 4133Mb/s]*	*[250us]*
	[UL:5640 Mb/s]	
Option 7a	*[DL:10.1~22.2Gb/s]* *[UL:16.6~21.6Gb/s]*	*[250us]*
Option 7b	*[DL:37.8~86.1Gb/s]* *[UL:53.8~86.1 Gb/s]*	*[250us]*
Option 7c	*[DL:10.1~22.2Gb/s]* *[UL:53.8~86.1Gb/s]*	*[250us]*
Option 8	*[DL:157.3Gb/s]* *[UL: 157.3Gb/s]*	*[250us]*

The BlueSPACE Project approach

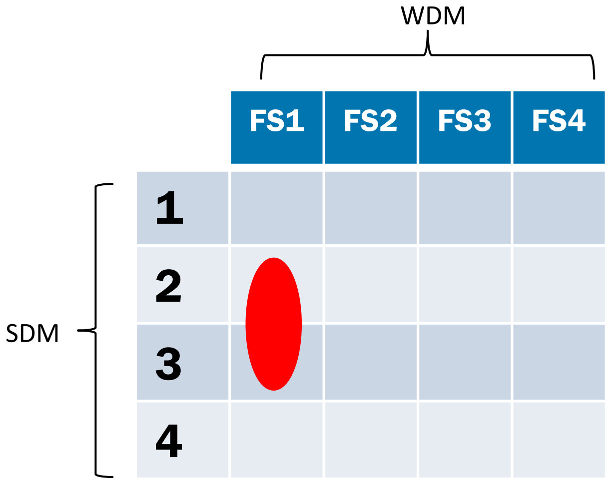
- A complementary solution under investigation in the BlueSPACE project to reduce the bandwidth requirements is to use analog radio over fibre (ARoF) transceivers:
  - The radio waveforms are directly modulated onto light for connecting BBUs and RRHs.
  - It can be used in combination with digital RoF solutions for the 5G NGFI
- Additionally, the BlueSPACE project also considers to include spatial division multiplexing (SDM) for further increasing the network capacity in the fronthaul:
  - It can be deployed with bundles of single mode fibers or multicore optical fiber.
  - SDM can also be used to power the cell sites using Power of Fiber (PoF) devices.
- The BlueSPACE network architecture also deploys edge computing in the central office for NFV and MEC applications (e.g. video analytics, data caching).

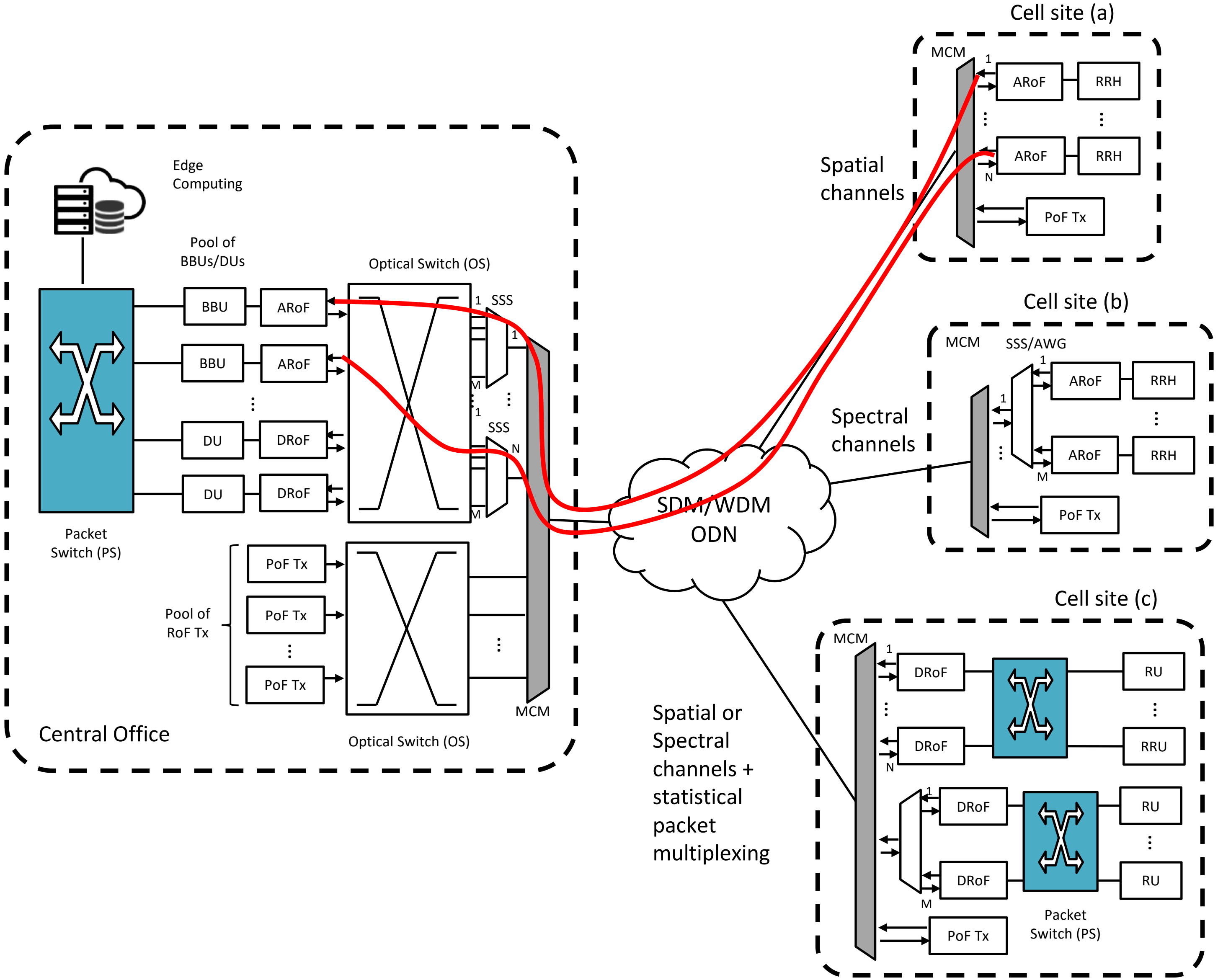
BlueSPACE's network architecture



Spatial channels

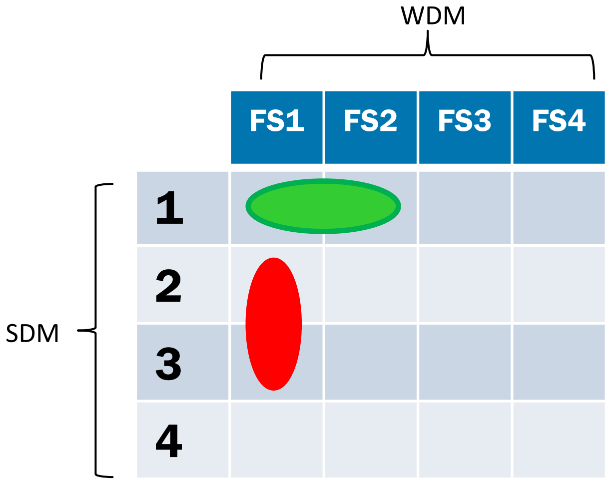
- An array of NxRRH is connected to an array of NxBBU using the same wavelength in different cores/ fibers.

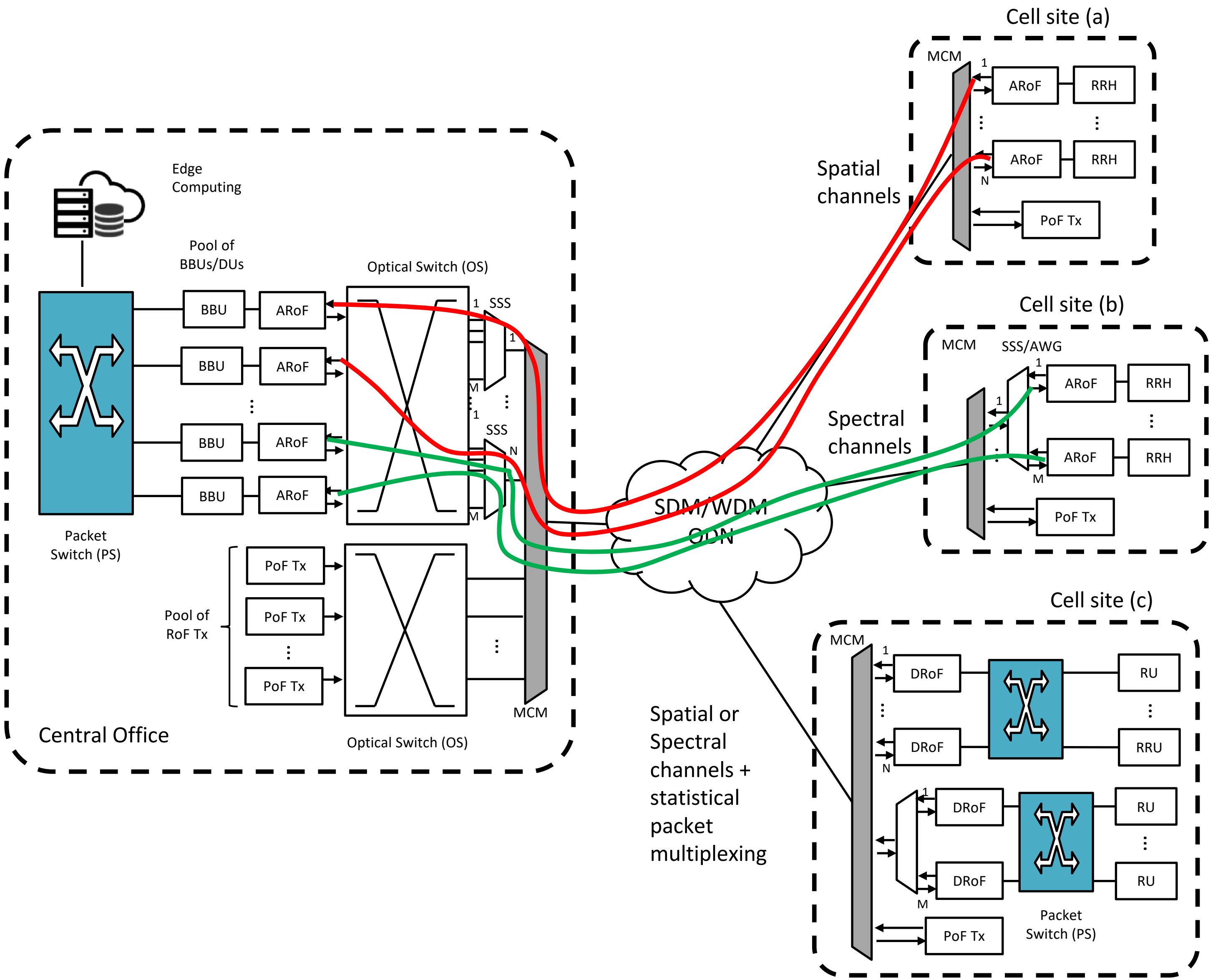




Spectral channels

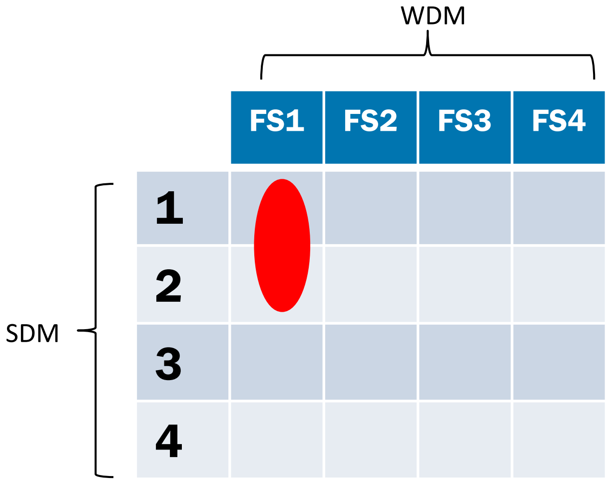
- An array of NxRRH is connected to an array of NxBBU using the same fiber/core and different wavelengths.

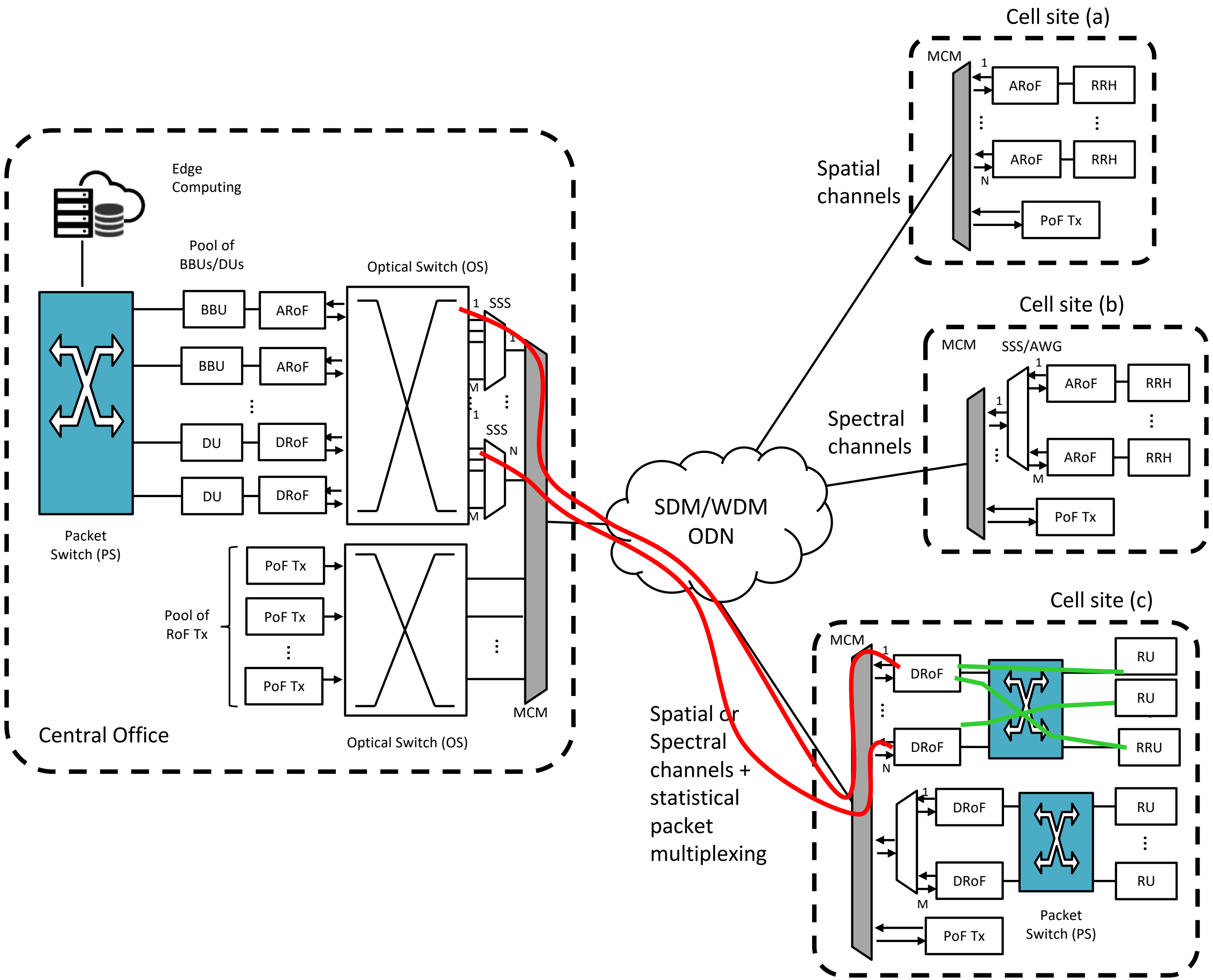




Spatial or Spectral channels + statistical multiplexing

- An array of MxRU is connected to an array of NxDU using spatial or spectral channels.
- M >= N





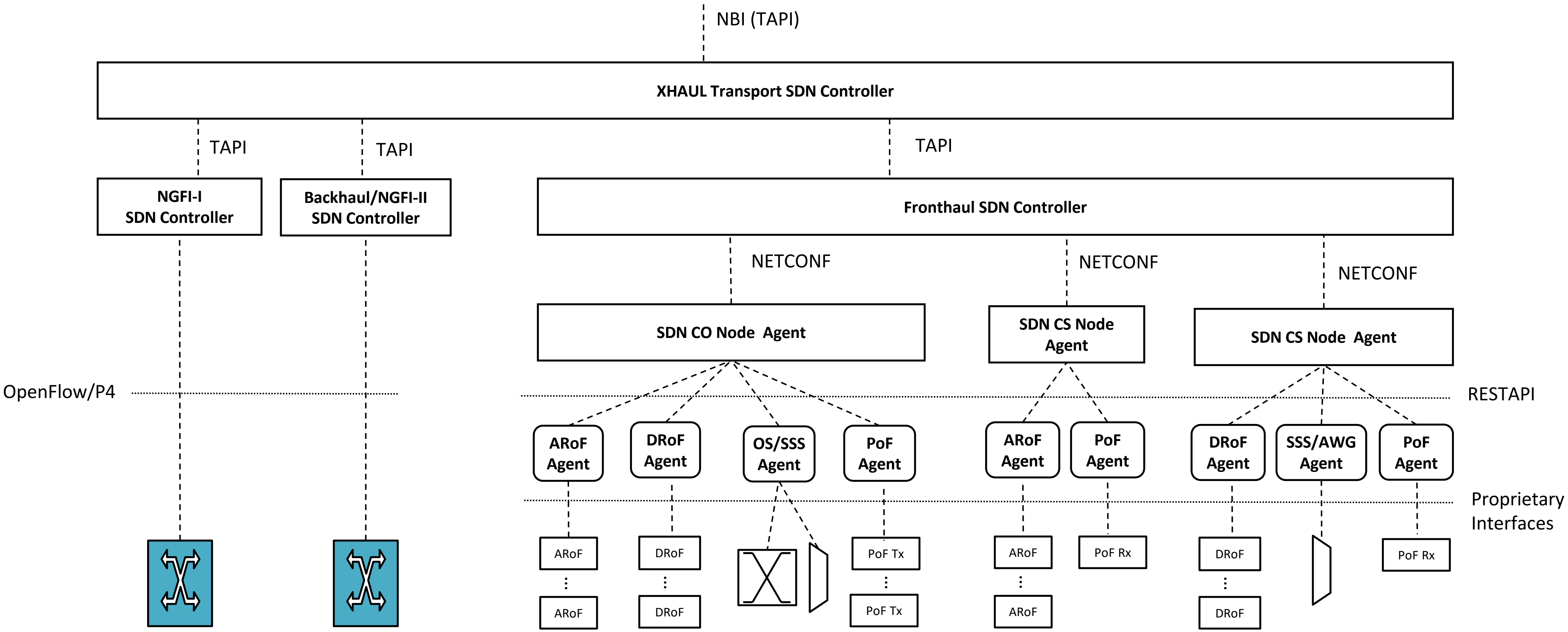
BlueSPACE's SDN control requirements

- To develop a hierarchical transport SDN solution to control the SDM/WDM-enabled fronthaul network and packet-based network segments:
  - A single SDN controller comprising the multiple and diverse technologies of the SDM/WDM-based fronthaul and packet-based backhaul is not realistic.
  - Traditionally, network operators fragment their networks into multiple administrative domains for scalability, modularity, and security purposes
- To integrate the developed Transport SDN control solution with the NFV MANO framework to provide NFV network services:
  - Current NFV MANO framework considers the network as a commodity that provides packet pipes with QoS. It can be dynamically provisioned between the specified end-points.
  - Currently, the interface with the Transport SDN defined by the ETSI NFV MANO framework is still lacking of maturity.

Hierarchical Transport SDN controller

- We rely on a hierarchical Transport SDN control approach with different levels of hierarchy (parent/child architecture):
  - Three SDN controllers (child WIMs) for the fronthaul, backhaul and NGFI-I segments.
  - Another SDN controller on top (parent WIM) acting as the Xhaul transport network controller.
- The child WIM for the packet network segment is based on a regular SDN controller using OpenFlow or P4 protocols as SBI to configure the packet switches.
- On the fronthaul segment side, the proposed solution is to deploy SDN agents at the cell sites and another at the CO.
- The SDN agent's purpose is to map high-level operations coming from the child SDN controller into low-level, hardware-dependent operations.

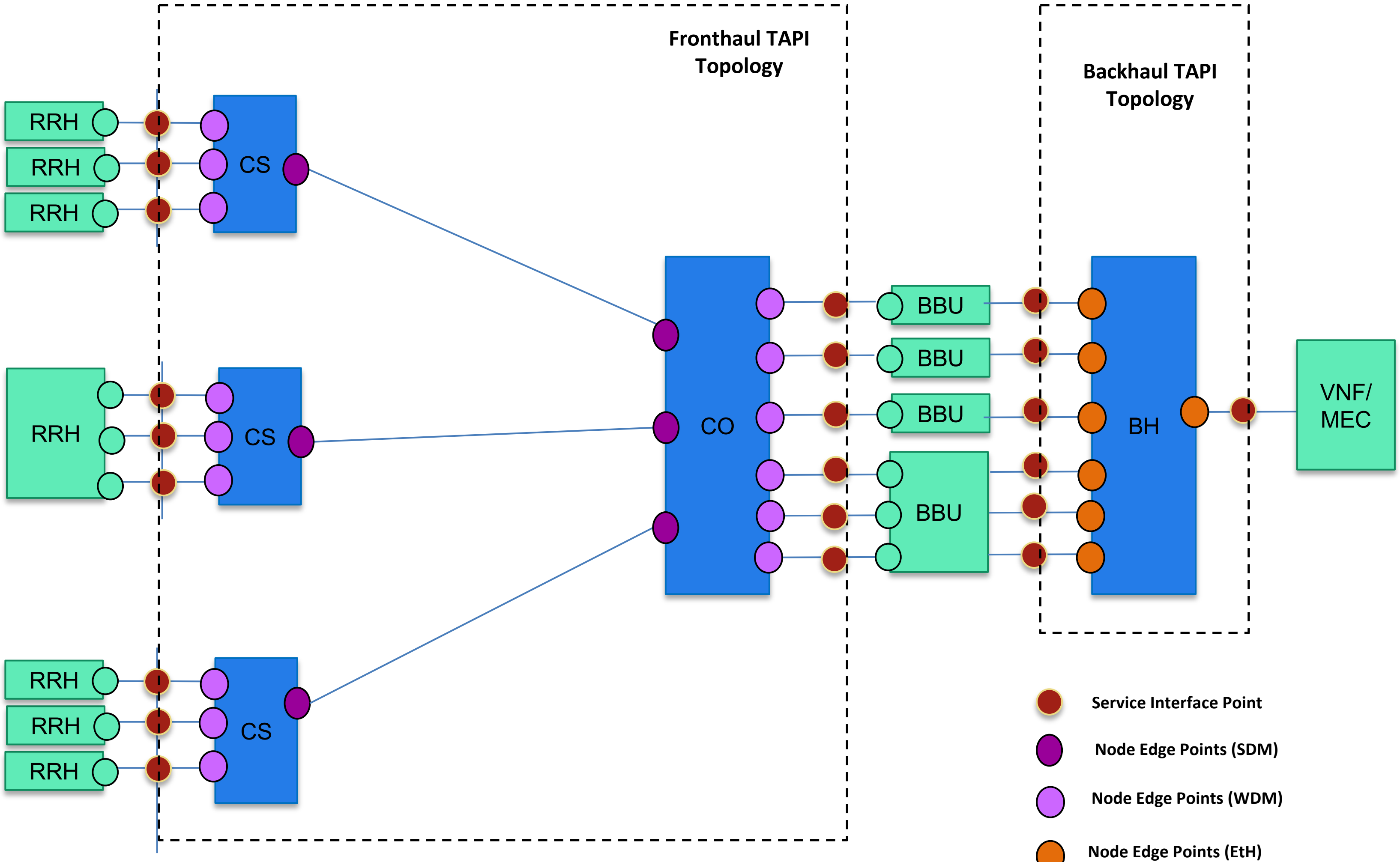
Hierarchical Transport SDN controller



Transport API (TAPI)

- It enables to abstract a set of common SDN control plane functions (e.g., path computation, topology and connection provisioning) and defines a common data model and protocol based on YANG/RESTconf.
- TAPI has a flexible modularity and it allows extension of all its data models. In fact, extensions for OTSi, ODU, and Ethernet are included in official release.
- We have followed the same procedure in order to define a novel hybrid SDM/OTSi data model (tapi-sdm.yang):
  - node edge point data model has been extended by introducing an sdm-pool container, which includes a list of available cores and available transceiver information.
- Regarding connectivity service extensions, connection end points are augmented with information regarding the termination core id, as well as a list of selected frequency slots.

BlueSPACE scenario using TAPI topology and connectivity service data models



NETCONF for the fronthaul segment

- We consider YANG data model and NETCONF protocol between the SDN agents and the child SDN controllers.
- The CO and the cell sites can be modelled as nodes with ports connected to A/DRoF transceivers (WDM ports) or to the ODN (SDM ports).
- We have developed YANG data models for:
  - Configuring and monitoring of sliceable SDM/WDM transceiver (sliceable-transceiver-sdm.yang).
  - Retrieving the topology of the CO and cell sites nodes (node-topology.yang).
  - Provisioning a spatial/spectral connection between ports (node-connectivity.yang)
- The defined YANG models are on a public repository in:
  - https://github.com/CTTC-ONS/SDM

YANG data models for node topology and connectivity

```
module: node-topology
  +--ro node-id
  +--ro port [port-id]
     +--ro layer-protocol-name
     +--ro available-core* [core-id]
     | +--ro core-id
     | +--ro available-frequency-slot* [slot-id]
     | | +--ro slot-id
     | | +--ro nominal-central-frequency
     | | | +--ro grid-type?
     | | | +--ro adjustment-granularity
     | | | +--ro channel-number
     | | +--ro slot-width-number
     | +--ro occupied-frequency-slot* [slot-id]
     |   +--ro slot-id
     |   +--ro nominal-central-frequency
     |   | +--ro grid-type
     |   | +--ro adjustment-granularity
     |   | +--ro channel-number
     |   +--ro slot-width-number
     +-- ro available-transceiver
        +-- ro transceiver-id
        +-- ro transceiver-type
        +-- ro supported-modulation-format [modulation-id]
        |  +-- ro modulation-id
        |  +-- ro mod-type
        +-- ro supported-center-frequency-range
        |  +-- ro max-cf
        |  +-- ro min-cf
        +-- supported-bandwidth
        |  +-- ro max-bw
        |  +-- ro min-bw
        +-- ro supported-FEC
        +-- ro supported-equalization
        +-- ro supported-monitoring
```

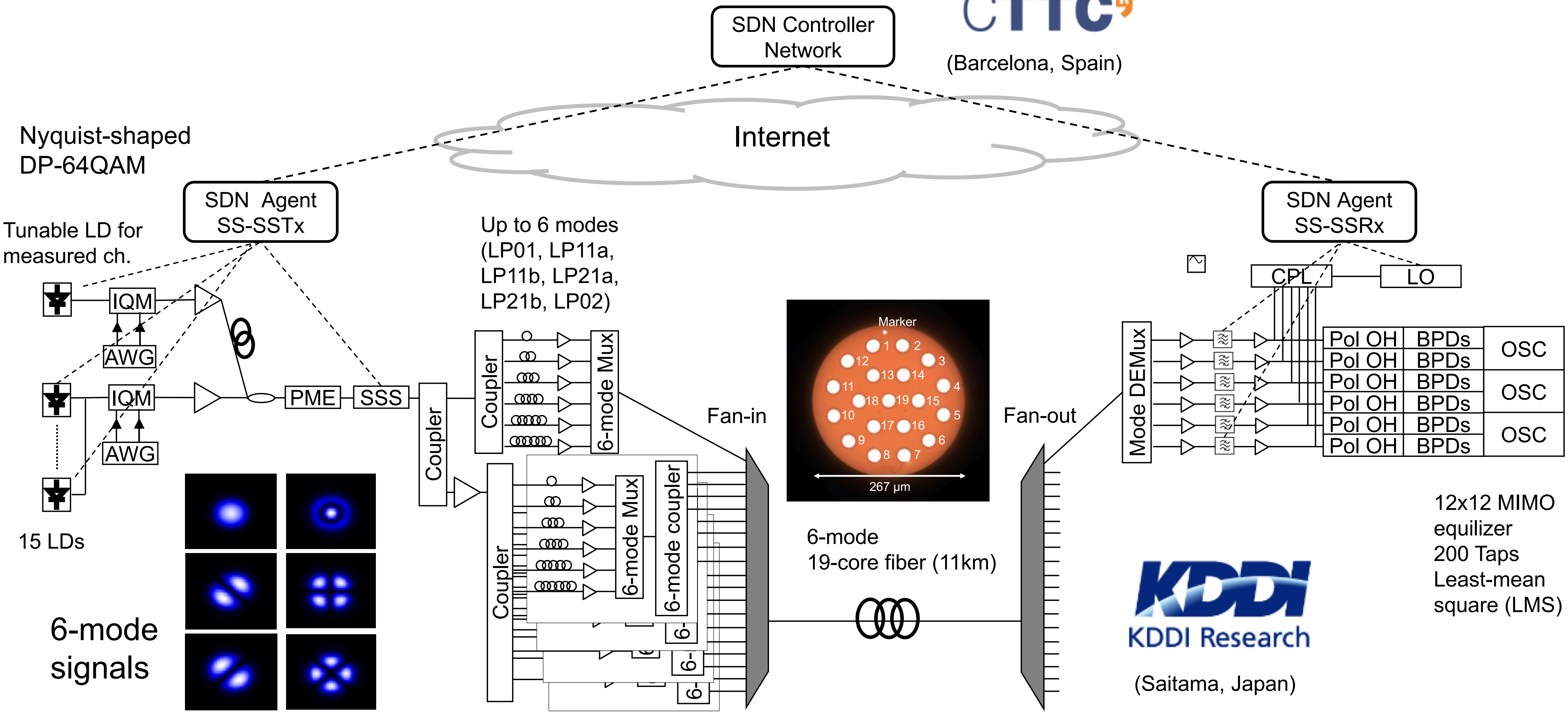
```
module:  node-connectivity
  +--rw connection  [connectionid]
     +--rw connectionid
     +--rw port-in_id
     +--rw port-out_out
     +--rw transceiver[transceiverid]
```

YANG data model for SDM/WDM transceivers

- List of transceivers.
  - Each transceiver is composed of a list of slices.
    - Each slice is composed of a slice ID, a list of:
    - Optical-channels :
      - optical-channel-id,
      - frequency-slot(n,m),
      - mode-id and core-id.
    - optical-signal parameters (associated to the optical-channels).
      - optical-channel-id (for associating the signal parameters to an optical channel),
      - constellation (e.g. Nyquist-shaped DP-16QAM),
      - bandwidth (e.g. 12GHz), FEC (e.g, SD-FEC)
      - equalization: equalizer (e.g., LMS 12x12), MIMO (e.g. True/False), and num-taps (e.g. 500).
      - State data: BER and OSNR in the monitor field.

```
module: sliceable-transceiver-sdm
   +--rw transceiver [transceiverid]
      +--rw transceiverid
      +--rw slice* [sliceid]
      +--rw sliceid
      +--rw optical-channel* [opticalchannelid]
      |  +--rw opticalchannelid
      |  +--rw coreid
      |  +--rw modeid
      |  +--rw frequency-slot
      |     +--rw ncf
      |     +--rw slot-width
      +--rw optical-signal* [opticalchannelid]
         +--rw opticalchannelid
         +--rw constellation
         +--rw bandwidth
         +--rw fec
         +--rw equalization
         |  +--rw equalizationid
         |  +--rw mimo
         |  +--rw num_taps
         +--ro monitor
            +--ro ber
            +--ro osnr
```

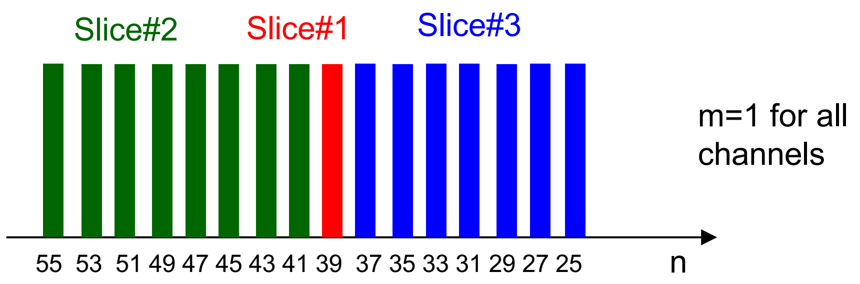
Experimental setup



R. Muñoz, et al., SDN-enabled Sliceable Multi-dimensional (Spectral and Spatial) Transceiver Controlled with YANG/NETCONF, OFC 2018.

Proof-of-concept

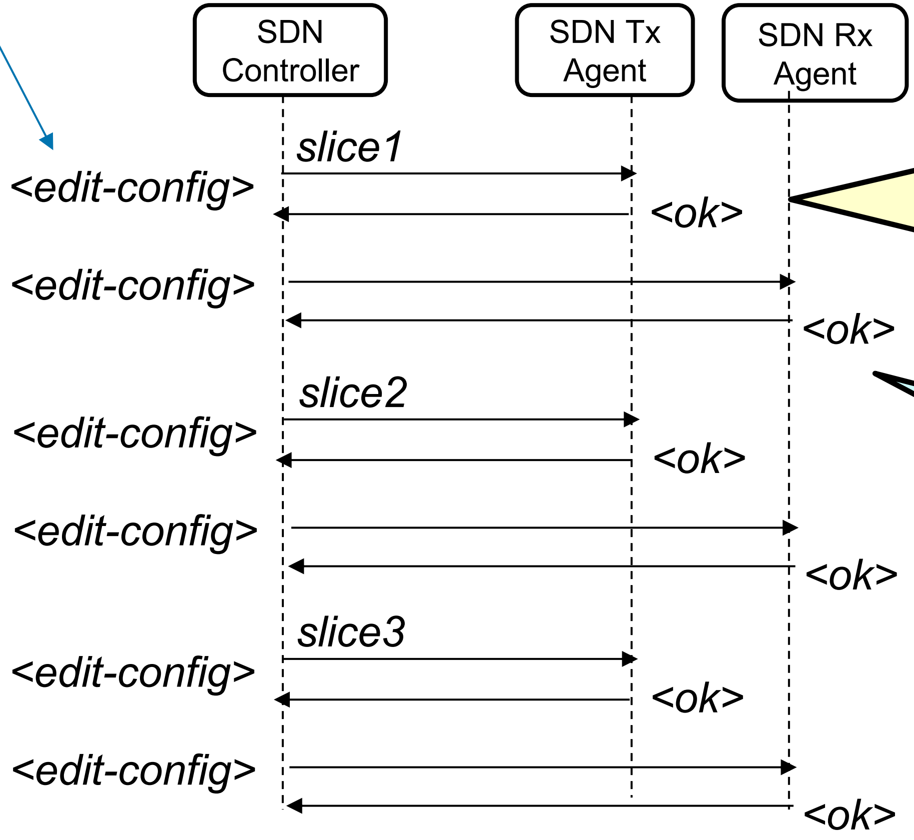
- There are available 16 optical channels (1 measured + 15 dummy) transmitted in the 6 modes and the 19 cores (16x6x19=1824 channels).
- First, we sequentially provision three slices:
  - For slice #1, we transmit 114 channels (measured channel x 6 modes x 19 cores)
  - For slice #2, we transmit 912 channels (8 dummy channels x 6 modes x 19 cores)
  - For slice #3 we transmit 798 channels (7 dummy channels x 6 modes x 19 cores).
- Second, we experimentally measure the BER of the optical channels of slice #1 in all modes in the reference core in order to monitor the impact due to the provisioning of additional slices



Provisioning of slices with YANG/NETCONF

- We sequentially provision the three slices using the NETCONF message exchange between the SDN controller and the SDN Tx and Rx agents.


```
<edit-config><target><running/></target><config><top
xmlns="urn:sliceable-transceiver-sdm">
<transceiver>
  <slice>
    <sliceid>1</sliceid>
      <optical-channel>
        <opticalchannelid>1</opticalchannelid>
        <coreid>Core19</coreid>
        <modeid>LP01</modeid>
        <frequency-slot>
          <ncf>39</ncf>
          <slot-width>1</slot-width>
        </frequency-slot>
      </optical-channel>
      <optical-signal>
        <opticalchannelid>1</opticalchannelid>
        <constellation>64qam</constellation>
        <bandwidth>12000000000</bandwidth>
        <fec>sd-fec</fec>
        <equalization>
          <equalizationid>1</equalizationid>
          <mimo>true</mimo>
          <num_taps>500</num_taps>
        </equalization>
      </optical-signal>
      <opticalchannelid>2</opticalchannelid>
          .....
  </slice>
</transceiver>
</top></config></edit-config>
```

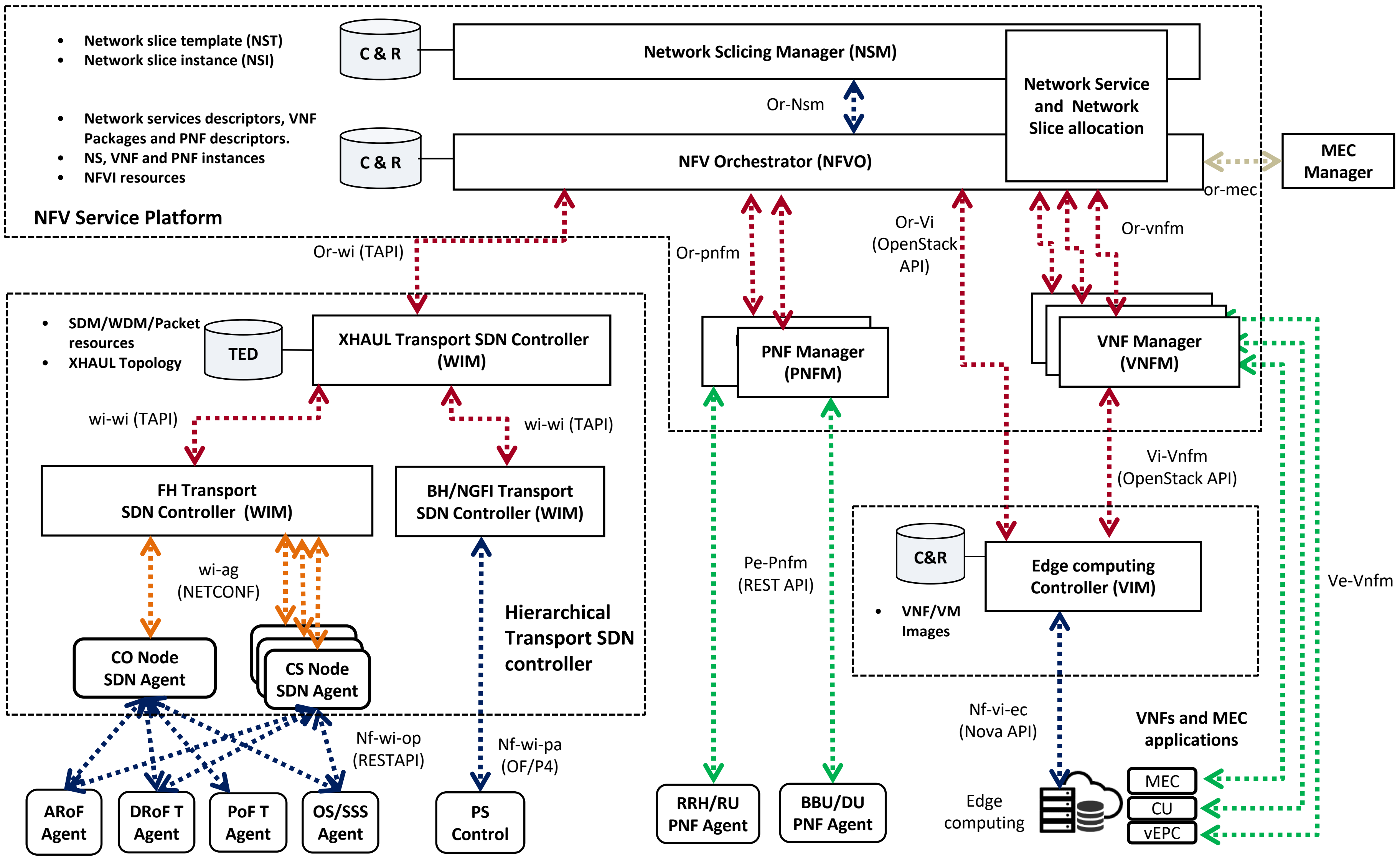



When the agent (TX) completes setting up the transmitter (LDs, and SSS), the agent sends “OK” message to the controller.
* 3-4 minutes

When the agent (RX) completes setting up the receiver (LO, and OSC), the agent sends “OK” message to the controller.
* Approx 3 minutes

overall provisioning time of a slice is between 6-7 minutes

Integration in the BlueSPACE's NFV MANO architecture



Conclusions

- The BlueSPACE project proposes Spatial Division Multiplexing (SDM) as the key technology to overcome the capacity crunch that the conventional optical single-mode fibers (SMFs) are facing to accommodate the increasing bandwidth demands forecasted for 5G mobile communications in the fronthaul network.
- The combination of SDM with flexi-grid DWDM enables to exploit both dimensions (spectral and spatial resources) in combination with analog and digital Radio over Fiber (RoF) techniques.
- This talk has presented the challenges and architectural Transport SDN solutions proposed to enhance the ETSI NFV MANO framework in order to meet the functionalities considered in BlueSPACE.

Thank you! Questions?

Raul Muñoz

Raul.munoz@cttc.es

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