SDN-enabled Flexible Optical Node Designs and Transceivers for Sustainable Metro-Access Networks Convergence

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ABSTRACT

The Internet data traffic constant growth caused by the popularization of cloud services, mobile and social networks, is being stressed by the advent of 5G technologies. Hence, architectural changes are required at the underlying networks to support the expected traffic volume growth, whereas providing a highly dynamic connectivity. Cost-effective and energy efficient solutions for flexible network subsystems are required in order to provide future sustainable networks. In this paper, we present flexible optical node designs (ROADM and OXC) and transceivers, remotely managed by a Software Defined Networking (SDN) controller, able to satisfy the requirements of future metro-access networks in support of 5G services. In particular, the overall architecture including both the novel data plane devices and the SDN control plane is discussed.

Keywords: ROADM, OXC, ONU, MZM, DFB, VCSEL, RSOA, SDN-Controller

1. INTRODUCTION

The ICT eco-system has been rapidly and dramatically changing in the last years. New multimedia and cloud services, the deployment of the Internet of Things (IoT) and the convergence between optical and wireless communications at the 5G paradigm [1] are requiring changes to the networks in order to enable scalable growth in traffic volume, while supporting a high level of dynamic connectivity, full flexibility and more energy-efficiency. These features can be achieved by considering the cooperation between the network control and data planes. On the one hand, the management and control of the network are evolving towards a SDN-architecture where the network intelligence and state are centralized (see Fig. 1). On the other hand, metro networks are converging with access networks, as depicted in Fig. 1, and evolving towards all-optical solutions [2, 3]. In this context, flexible ultra-Dense Wavelength Multiplexing (u-DWDM) metro-access networks are a promising alternative to Time Division Multiplexing (TDM) solutions due to their high spectral efficiency [4].

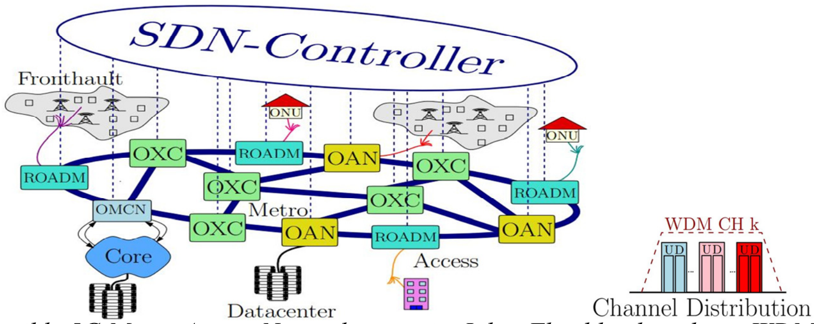

Figure 1. Flexible 5G Metro-Access Network scenario. Inlet: Flexible ultra-dense WDM full-duplex frequency slot division.

In this paper, we present the design of flexible optical nodes and transceivers, remotely managed by a SDN controller, as essential building blocks of metro-access network architectures supporting 5G services. In particular, the overall architecture including both the novel data plane devices and the SDN control plane is discussed.

2. NETWORK SUBSYSTEMS

Flexibility is provided by the network subsystems. As shown in Fig. 1, the Network Subsystems are OMCN (Optical Metro-Core Node), OAN (Optical Aggregation Node), ROADM (Reconfigurable Optical Add-Drop Multiplexer Node), OXC (Optical Cross-Connect) and ONU (Optical Network Unit). In the following, we propose a modelling of each of the above-mentioned network subsystems. The SDN-Controller uses this modelling information to know the subsystem functionalities and all their attributes for an efficient management of optical network resources.

The OMCN, OAN and ONU are the subsystems that allow the transfer of information between the Metro and Core Network, the Metro Network and a Datacentre, or a 5G-Fronthault and the access network and a user, respectively. Due to the different transmission techniques used in each network segment, it is necessary to conduct an optoelectrical conversion within these subsystems. Therefore, these subsystems must be able to add/remove specific channels to/from the networks to which they are connected without affecting the other channels, aggregate and de-aggregate traffic tributaries, conversion of modulation formats, etc.

Tables I and II show the most representative attributes of different cost-effective solutions for transmitters (TX) and receivers (RX) respectively, that may be part of each of the mentioned subsystems. The proposed transmitters are based on: i) a Mach-Zehnder Modulator (MZM) plus a tuneable laser potentially covering C and L bands; ii) a Distributed Feedback Laser (DFB), whose emission wavelength can be tuned thermally within a range of 4-5nm; iii) a continuous-emitting Vertical Cavity Surface Emitting Laser (VCSEL) and a phase-modulated Reflective Semiconductor Optical Amplifier (RSOA) with a range of use of 5nm; and iv) a VCSEL where an amplitude modulation is implemented and can be employed within a range of 5nm. For each of these transmitters, we indicate the modulation format, the baud rate and the transmission power that can be implemented or obtained. A set of transmitters are proposed as a selection of the most appropriate subsystem for each case. The proposed receivers are based on: i) direct detection, ii) a coherent receiver in which the detected signal is mixed with a local oscillator based on a DFB (Coh. DFB), iii) a coherent receiver in which the local oscillator is a VCSEL (Coh. VCSEL), and iv) a coherent integrated receiver. For all these receptors the receiver sensitivity is calculated as the minimum received power to ensure a BER of $2.2 \cdot 10^{-3}$, as a function of the modulation format and baud rate. Polarisation dependency is also indicated so that for those receivers, where frequency selectivity is possible, double the number of channels could be received.

Table I. Cost-effective TX ONU, OAN, OMCN.

Transmitter based on	Subsystems	Wavelength Range (nm)	Modulation Format	Baud Rate (GBaud)	Tx Power (dBm)	Refs
MZM	OAN & OMCN	(C+L)~120	OOK	1-10	-6 to 0	[5]
			DPSK	1-10		
			QPSK	0.5-5		
			8-PSK	0.25-2.5		
			8-QAM	0.25-2.5		
			16-QAM	0.125-1.25		
			M-QAM	0.125-40		
DFB	ONU, OAN & OMCN	4-5	OOK	1-10	-6 to 0	[5]
			DPSK	1-10		
			QPSK	0.5-2.5		
			8-PSK	0.125-1.25		
			8-QAM	0.125-1.25		
			16-QAM	0.0625-0.625		
VCSEL-RSOA	ONU, OAN & OMCN	5	OOK	1-10	-3	[6]
			DPSK	1-10		
			QPSK	0.5-2.5		
			8-PSK	0.125-1.25		
			8-QAM	0.125-1.25		
			16-QAM	0.0625-0.625		
VCSEL	ONU, OAN & OMCN	5	OOK	1-5	-3 to 0.6	[6] [7]

Table II. Cost-effective RX ONU, OAN, OMCN.

Receiver	Wav. Range (nm)	Modulation Format	Baud Rate (GBaud)	Rx Sens. (dBm)	Pol. Depend.	Wav. Select.	Refs
D. Detection	(C+L)~120	OOK	1-10	-26	NO	NO	[8]
Coh. DFB	4	OOK	1-10	-48.5	YES	YES	[6] [10] [11]
		DPSK	1-10	-52			
		QPSK	0.5-2.5	-48.8			
		8-PSK	0.125-1.25	-43.3			
		8-QAM	0.125-1.25	-43.7			
		16-QAM	0.0625-0.625	-40.9			

Table II. Cost-effective RX ONU, OAN, OMCN. (Cont.)

Receiver	Wav. Range (nm)	Modulation Format	Baud Rate (GBaud)	Rx Sensitivity (dBm)	Pol. Depend.	Wav. Select.	Refs.
Coh. VCSEL	5	OOK	1-10	-45.5	YES	YES	[7] [10] [11]
		DPSK	1-10	-49			
		QPSK	0.5-2.5	-45.8			
		8-PSK	0.125-1.25	-40.3			
		8-QAM	0.125-1.25	-40.7			
		16-QAM	0.0625-0.625	-37.9			
Coh. Integrated	C~40	DPSK	1-10	-39.1 to -34.1	YES	YES	[9] [11]
		QPSK	0.5-2.5	-35.9 to -30.9			
		8-PSK	0.125-1.25	-30.4 to -25.4			
		8-QAM	0.125-1.25	-30.8 to -25.8			
		16-QAM	0.0625-0.625	-28 to -23*			

*: for acceptable OSNR penalty of 1.5dB

All these proposed transmitters and receivers can be adapted to implement transmission techniques based on u-DWDM, in which each WDM channel of 100(200)GHz can be subdivided into smaller channels called frequency slots wherein the up-link and the down-link for each user is established (see Fig. 1). The users are connected to the metro network using a Passive Optical network (PON), as depicted in Fig. 1. Thus, all users of the same PON share the same WDM channel. Recent efforts show that these frequency slots can be of 6.25 GHz [5], generically allowing service to 16(32) users per PON.

The ROADM is the subsystem that connects the metro to the access network. Fig. 2a shows the configuration of a ROADM that can route a group of frequency slots of the same WDM channel. These frequency slots can be routed to the West (W) or East (E) ports in the metro part of the network from the Add/Drop (A/D) port where the access part of the network is connected. The ROADM consists of two fixed filters and two latched switches. The filtered channel may pass through the module or can be added/dropped to/from the Access network depending on the 2x2 switch configuration. The 1x2 switch determines over which port, E or W, the connection is established.

The OXC is responsible for conveying information through the Metro network. Fig. 2b shows the configuration of a grade four full-duplex OXC. This subsystem is based on four fixed filters, similar to those used in the ROADM and two 2x2 latched switches, which depending on the configuration thereof, any WDM channel between one of the ports can leave through any of the other three. Both ROADM and OXM can be scaled to other wavelengths adding similar stages to those shown in Fig. 2a and 2b, respectively. Therefore, they enable coverage of work bands C and L.

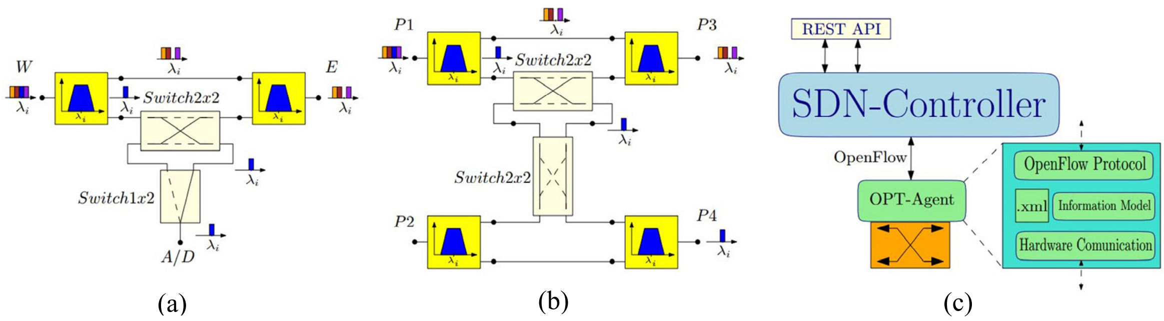

Figure 2: (a) ROADM set-up, (b) OXC set-up, (c) SDN-based Optical-subsystem.

3. SDN CONTROL PLANE

The SDN-based architecture proposed for the control plane is depicted in Fig. 2c. The figure depicts an overall design, which is valid for every type of optical subsystem described in the previous section. The architecture shows a full north-south integration, including the optical subsystem to be controlled, the optical agent that enables the SDN-based configuration of the subsystem, the SDN controller itself, and the REST APIs that communicate the controller with the upper layers (i.e. applications, orchestration, etc.). The modelling of each subsystem becomes crucial to define the requirements for the optical agent running on top of it. In this case, each particular agent contains a set of modules that allow the communication between the optical subsystem and the SDN controller. As shown in Fig. 2c, the Hardware Communication module establishes a connection towards the subsystem, providing control and retrieval of optical features. The Information Model module sets up a local database, where the node state information is stored in XML format. Finally, the OpenFlow Protocol module establishes an OpenFlow (OF) protocol [12] based connection with the controller, exposing the particular subsystem features and capabilities. For our purposes, an extended version of the OF protocol is used, which allows handling optical information.

The SDN controller defines the centralized logic component of this architecture, where the information received from the optical subsystem, through OF protocol messages, is analysed and exposed to upper layers (e.g., applications, orchestration) by means of well-implemented northbound REST APIs [13]. These types of APIs provide access to optical related data managed by the controller.

4. CONCLUSIONS

In this paper, a model for each of the subsystems presented is proposed: OMCN, OAN, ROADM, OXC, ONU. Each model includes the basic functionality of each subsystem and its most representative attributes. The north to south architecture of the network control plane is also proposed. In this, the optical resources can be managed directly from the application level.

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