D5.1 FINAL TEST-BED DESIGN AND DEVELOPMENT PLAN

Implementation, integration and demonstration plans

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EXECUTIVE SUMMARY

This report details the implementation, integration and demonstration plans of the project.

At first a management procedure to choose, design and execute technical demonstrations, which can maximize the visibility and impact of the project is identified. It exploits a "living" spreadsheet that can be filled in by the involved partners.

WP5 in fact is working in close collaboration with other WPs to identify, design and disseminate a set of demonstrators representing the key steps of the project. These demos are related with specific WPs and include subsystems demonstration and integration activities.

The final demo activities will on the other hand be focused in three testbeds located in CTTC, TUE and NICT laboratories and will take advantage of the previous demos in order to integrate the obtained results and demonstrate the project outcomes. In particular in CTTC all the PASSION innovative solutions, according to their availability and portability, will be implemented, integrated, tested and validated within the ADRENALINE testbed®, providing a networking environment for the solution assessment.

It is worth highlighting that depending on the project evolution in the next months, the planned demos may vary in terms of contents and time schedule, in order to capture and valorise all the project results and manage possible issues on the delivery time. For this reason, starting from the initial delivery of this document, it is envisaged that periodic updates of this document may be performed as required.

1 INTRODUCTION

1.1 BACKGROUND AND MOTIVATION

PASSION project aims at developing the basic photonic technology for the next generation of optical networks. Furthermore, additional activities are planned to address the management aspects of all the innovations introduced by the project (e.g. huge bandwidth, fast configurability, flexibility, etc.). This in line with the introduction of new network paradigms such as SDN/NFV, disaggregation and edge computing.

In order to give evidence of the main achievements along the project execution WP5 will work in close collaboration with other WPs to identify, design and disseminate a set of demonstrators representing the key steps of the project.

1.2 METHODOLOGY

In order to maximize the impact of PASSION, a suitable process to identify, design and execute technical demonstrations is important.

Figure 1 shows the proposed process, starting from elementary building blocks until the final demonstrator, potentially integrating all the project achievements.

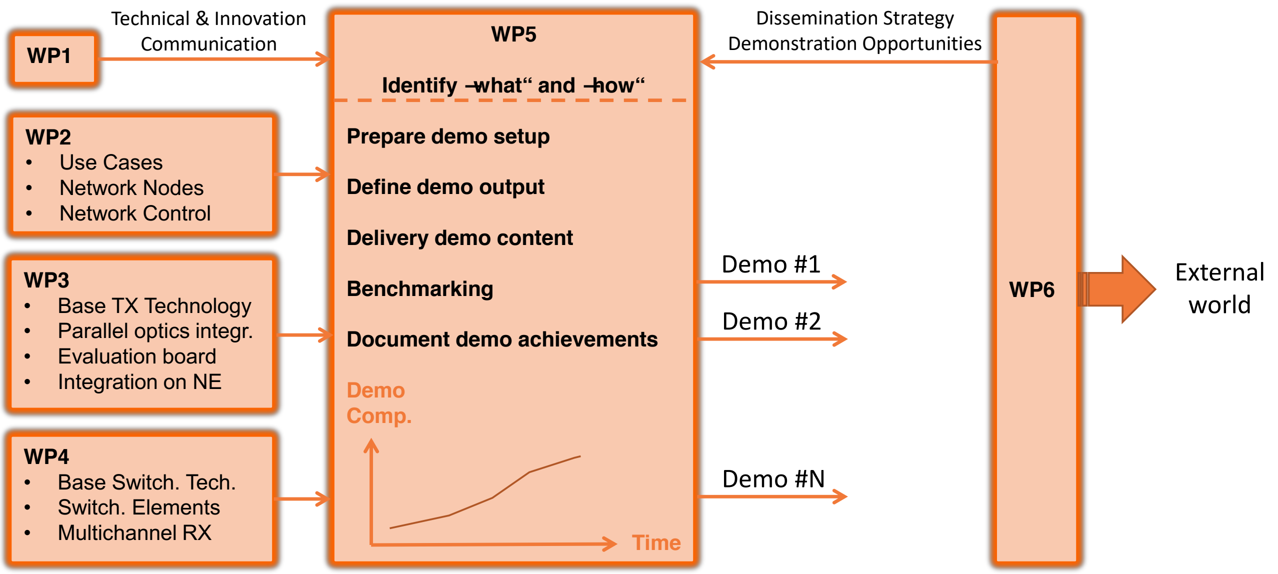


Figure 1. Task 5.1 Methodology

To help the project dissemination effectiveness we designed a spreadsheet outlining planned steps of the demo process, Figure 2.

Demo			Demo Execution			
Proposer	Demo Title	Short Description	Set-up definition	Expected output	Planned Availability	Portability Level
WP3	Basic Transmission Subsystem	A simple test environment is used to demonstrate the capability of transmission subsystem based on VERT VCSEL and the selected IDT drivers	*System under Test (SUT):* Driver evaluation board, integrating VCSEL component from VERT *Instruments:* Arbitrary Waveform Generator (AWG), Fiber Optics, Optical Power Meter, Optical spectrum analyser (OSA), Optical Power Meter, Photodiode+digital storage oscilloscope (DSO)	Report: Performance characteristics	M6, linked to D3.2	medium

Demo dissemination									
Estimated value for the project image/reputation	Candidate events #1	Dealine to decide	Decision Yes/No	Candidate events #2	Dealine to decide	Decision Yes/No	Candidate events #3	Dealine to decide	Decision Yes/No
medium	OFC	tbd	tbd						

Figure 2. Example of Demo Management

2 Relationship with WPs

WP1, in his role of Technical and Innovation Manager WP1 is the privileged interlocutor for the initial selection activity to identify the key demos of the project, in order to capture the most relevant achievement.

WP2 is providing to the project a view of some future use cases that can directly benefit from the PASSION technology. Those use cases cannot be fully implemented at the end of the third year; however, they should inspire the most complex demos of the project

WP3 is developing the key transmission technology and it should be considered one of the most innovative parts of the project. The VCSEL component with the associated driver element is the fundamental building block of the entire PASSION Project.

WP4, similarly to WP3, it develops receiver and switching technology that, together with the transmission part can realize the entire optical transmission path.

WP6, in his responsibility of the project dissemination activity has the goal to use the demonstration setups to maximize the project visibility and impact.

3 Planned demonstrations

According to the current visibility, we are envisaging a certain number of demos that could be arranged during the second phase of the Project (i.e. from M18 until M36).

3.1 WP2 Related Demos

3.1.1 Transmission SubSystem for simulation validation, multi-channel

Demo Leader: ***PoliMI***
Location: ***PoliMI PoliCom DEIB Lab.***
Demo availability: ***M18***

A suitable test environment is used to evaluate the transmission performance based on directly-modulated VCSELs (with discrete multitone (DMT) modulation in case of SSB and DSB) and to compare the experimental results with the simulations achieved by a simulation tool, specifically developed for the project in the framework of WP2 (results have been presented in [MS6]).
The test bed is constituted by a multi-span EDFA-amplified transmission link (up to hundreds of kms long) exploiting coherent detection. WSS filtering is emulated by the employment of programmable optical filters (Finisar Waveshaper, availability 1pcs), as reported in Figure 3. Single- and dual-polarization transmission can be considered, also in case of multi-channel propagation.
First measurement results, submitted to ECOC 2019, have been obtained with a single 14-GHz bandwidth VCSEL on chip provided by VERT, driven through a 40-GHz probe (optical bench for active chip coupling with lensed fibres available in the laboratory). The DMT signal is generated by 100-GS/s digital-to-analog converters (DACs) (Micram 100 GS/s dual channel Digital to Analog Converter System) and is composed by 256 sub-carriers in 20 GHz range for signal to noise ratio (SNR) evaluation (Chow's algorithm, is employed for bit- and power-loading with a target BER of 3.6 10^{-3} as for standard 7% overhead FEC), while a cyclic prefix (CP) of about 2.1% of the symbol length is added. The coherent detection is realized by a Tektronix 33-GHz bandwidth receiver including local oscillator (LO) (this instrument was on-loan, the laboratory is usually equipped by a 25 GHz Finisar coherent receiver CPRV1B22A and a 100-kHz ECL tunable laser as LO). The received signal is sampled by a Tektronix real-time oscilloscope (DPO 73304DX) with 8 bits vertical resolution, 50-100 GS/s (2/4 channels) and 33-GHz electrical bandwidth. After A/D conversion operated by the DPO the off-line processing provides digital symbol synchronization, CP removal, sub-carriers phase recovery, demodulation and BER count. Multi-channel propagation is analysed by adding two dummy-channels, 100-GHz spaced and DMT externally modulated. Standard single-mode fibre spans are used to target up to 200 km. The Waveshaper is programmed in order to emulate the filtering effect of multiple wavelength selective switches (WSSs) in the link. SSB modulation is obtained by a 8-GHz filter detuning. 100-GHz flat top AWGs are available for channel demultiplexing. OSA, ESA and other laboratory test and measurement instruments can be used to perform multichannel performance test evaluations.

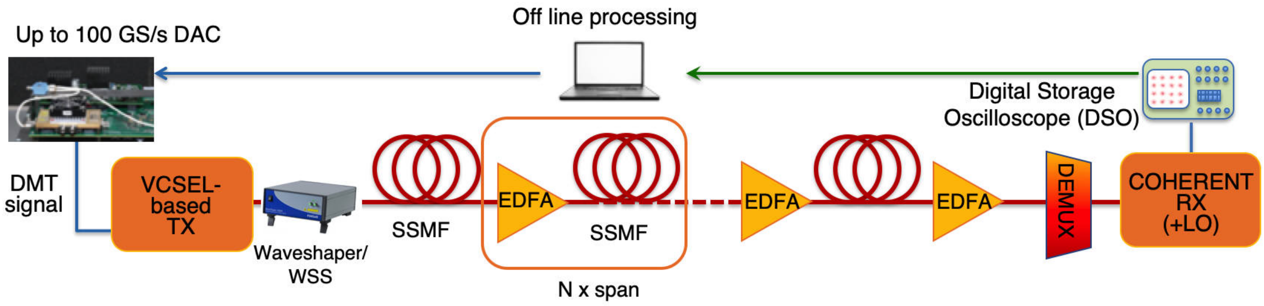


Figure 3. Experimental test bed for multi-span EDFA-amplified transmission performance evaluation, with VCSEL direct modulation (DMT) and coherent detection.

The transmission subsystem could be eventually evaluated/assessed within the ADRENALINE testbed as preliminary initial phase targeted within the final demo (described in Sec. 3.4.1), also considering the requirements and envisioned use cases defined in WP2.

3.2 WP3 Related Demos

3.2.1 Basic transmitter SubSystem, 1 channel

Demo Leader: ***PoliMI***
Location: ***PoliMI PoliCom DEIB Lab.***
Demo availability: ***M8***

A test environment is used to demonstrate the capability of the transmitter subsystem based on VERT VCSEL and the selected IDT driver. The demo set-up is shown in Figure 4. The VCSEL under test is bonded with the selected HXT14100 driver on its proper evaluation board and it is optically coupled with a lensed fibre (optical bench for active chip coupling with lensed fibres available in the laboratory, with XYZ high-precision positioners, microscope, various RF bandwidth and GS configuration probes, AR lensed fibres). The RF driving signal directly modulates the VCSEL and is generated by a Tektronix 50 GS/s arbitrary-waveform-generator (AWG 70001A) with 14-GHz electrical bandwidth for DMT modulations. At the receiver side we exploit a 14-GHz or a 20-GHz PIN photo diode (PD) connected to a Tektronix real-time oscilloscope (DPO 73304DX) with 8 bits vertical resolution, 50 GS/s and 33-GHz electrical bandwidth; alternatively a Tektronix digital sampling oscilloscope (DSO) is used with a 30-GHz optical probe to display the eye diagrams; the received power is kept at 5 dBm and 0 dBm for PIN exploitation respectively and around 5 dBm for the optical probe use. In particular the DMT signal is calculated by Matlab® and is composed by 256 sub-carriers in 16 GHz range for signal to noise ratio (SNR) evaluation and in 10 GHz range for capacity performance evaluation (Chow's algorithm, is employed for bit- and power-loading [REF] with a target BER of 3.6 10-3 as for standard 7% overhead FEC), while a cyclic prefix (CP) of about 2.1% of the symbol length is added. After A/D conversion operated by the DPO the off-line processing provides digital symbol synchronization, CP removal, sub-carriers phase recovery, demodulation and BER count. SSB can be obtained by the employment of a programmable optical filter.

Preliminary experimentation reported in D3.2 demonstrated a single-channel single-polarization DSB DMT capacity of 48.7 Gb/s (50.2 Gb/s with driver chip equalization) by employing the selected IDT HXT14100 driver.

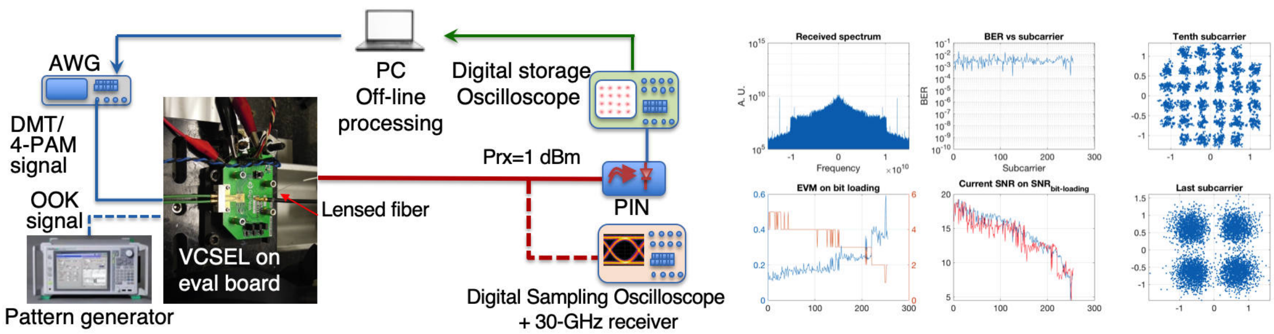


Figure 4. Demo test environment setup (left) and preliminary experimental results with DSB DMT (right)

3.2.2 Basic Transmission SubSystem, 40 channels - 2Tb/s

Demo Leader: ***SMO***
Location: ***SMO R&D Labs, PoliMI DEIB Lab.***
Demo availability: ***M27***

In order to test the Basic Transmission SubSystem, which integrates the 2Tb/s Si-PIC developed by VTT (D3.3) in an electronic board designed by SMO for modulating and controlling the 40 VCSELs, the set-up shown in Figure 5 will be used.

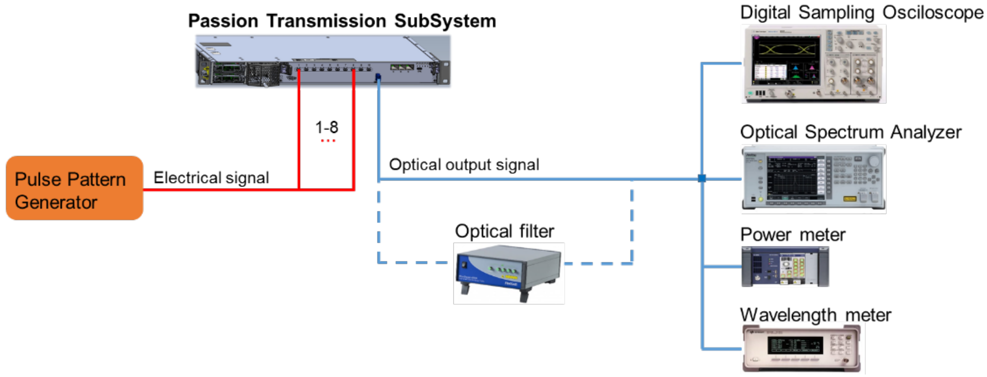


Figure 5. Experimental set-up for Basic Transmission SubSystem validation, characterization and performance evaluation. At SMO R&D Labs VCSELs will be directly modulated by 28 Gb/s NRZ signals while at PoliMI DEIB Lab. they will be modulated by 50 Gb/s DMT signals.

An initial demo will take place at SMO R&D Labs considering the first prototype of the SMO board to check RF signal integrity and to characterize the optical output signal in different configurations (i.e. 100-50-25 GHz grid spacing) and at different temperatures.
Due to the limited number of Pulse Pattern Generators (PPG) with electrical bandwidth larger than 10 GHz available at SMO R&D labs, it will not be possible to modulate all the 40 VCSELs at the same time. Instead, up to 8 VCSELs will be directly modulated by NRZ differential signals at 24-28 Gb/s by using two gearboxes (pocketBERT pB100A4) connected to the IDT HXT14100 drivers on the SMO board.
Initially, a single VCSEL will be considered and modulated at 28 Gb/s in order to employ a RF NRZ signal with the same electrical bandwidth (14 GHz) as the DMT signal at 50 Gb/s (see Paragraph. 3.2.1). The output optical signal will be measured by a digital sampling oscilloscope (Keysight DCA-X-86100D) with a 30-GHz optical probe to display the eye diagrams and check the board signal integrity. In addition, optical characterization of this channel will be performed by means of a wide band Optical Spectrum Analyser (Anritsu MS9740A), optical power meter and wavelength meter. The values obtained for the single channel alone (i.e. no multiplexing) will be compared with those of individual channels when n VCSELs are modulated and multiplexed together to evaluate an eventual signal degradation due to cross-talk. An estimation of cross-talk can be performed by considering degradation of OSNR for the channel under test for the 100, 50 and 25 GHz spectral spacing configurations, with respect to the OSNR measured for the single channel alone. Moreover, the same parameters will be tested at different temperatures to check the control algorithm for ensuring laser stability and alignment to the select grid, in particular for the 25 GHz spectral spacing.

While, at this moment, there are no optical communications based on DMT electrical signals and by consequence it lacks a standardization about them, the characterization performed by modulating with NRZ signals provides values that can be easily compared with those indicated by international standards for similar applications, e.g. IEEE 802.3bm – 100GBASE SR4 and ITU-T Rec. G.698.1 and 2. This comparison can thus serve to evaluate the performances of the Basic Transmission SubSystem and, at the same time, to put the basis for the contributions to standardization activity of WP6.

Once that the first demo at SMO R&D Labs will be concluded, a test on the final board, packaged in an "industrial" chassis as those employed for SMO products, will be performed at PoliMI DEIB Lab. by modulating the VCSELs with DMT electrical signals.

Finally, thanks to the presence of a microprocessor platform inside the board, it will be also possible to test the SDN controller designed in WP2 and developed within this WP5 for the Transmission SubSystem.

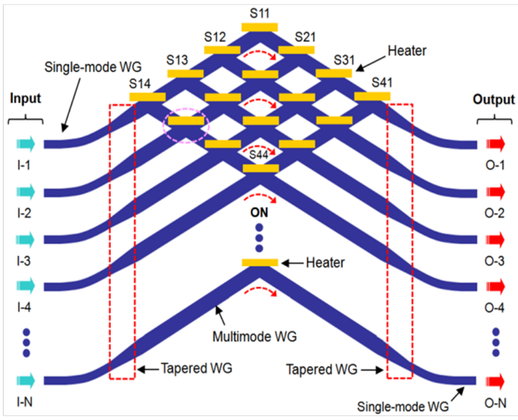
3.3 WP4 Related Demos

In order to fully exploit the PASSION transmission hierarchy, a complex switching infrastructure has to be provided. The basic components are the spatial photonic switch and the so called "agile WSS". In addition, WP4 is also in charge of developing the receiving device, i.e. the multichannel coherent receiver.

3.3.1 Switching Sub-Systems: Photonic Switch

Demo Leader: ***ETRI***
Location: ***ETRI Lab.***
Demo availability: ***M22***

After packaging the fabricated optical device (16x16 polymer-based photonic matrix switch), the characterization of the device will be conducted to check whether the target specifications are satisfied well, Figure 6. Among the specifications, insertion loss (IL), loss uniformity, polarization dependent loss (PDL) and switching time are mainly measured by the following setup, shown in Figure 7.



	Unit	Goal
Operational band	-	C & L
Insertion loss (max)	dB	< 6.5
Loss uniformity	dB	< 1
PDL	dB	< 0.5
Extinction ratio (min)	dB	> 45
Switching time	ms	< 3
Port number	-	16x16

< Target specifications >

Figure 6. NxN optical matrix switch configuration and (b) target specifications

For the PDL/IL measurement, the linearly polarized CW optical signal from the tunable laser (Keysight 81640B) is depolarized by the polarization scrambler (Fibrepro, PL2000). This depolarized CW signal is injected into DUT (16x16 optical matrix switch) via an arrayed waveguide grating coupler. Therefore, by tuning the wavelength of the CW optical signal, the input port corresponding to a certain wavelength is selected, and then the performance of the dedicated channel, the combination of the input and output ports, will be tested. The output signals from the switch are coupled via 1x20 optical switch (JDSU) to the PDL meter (Fibrepro, PL200) and optical power meter (Keysight 81635a).

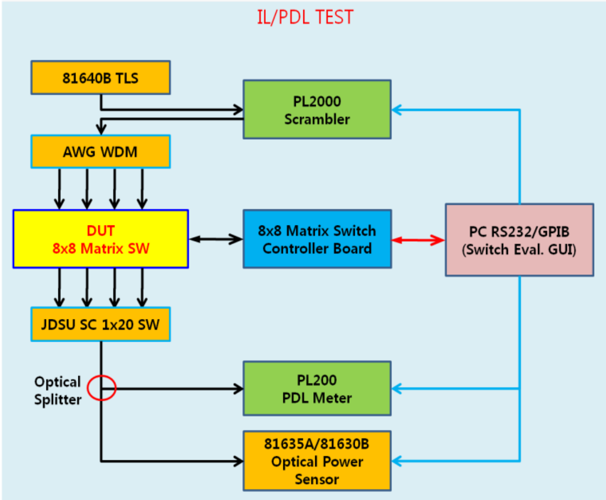


Figure 7. Measurement setup for IL/PDL

Generally, a packaged optical device is attached on an evaluation board to feed bias current/voltage, apply control signals e.g. electrical trigger, and monitor the status of an optical device. One can measure the switching time of the DUT by applying an electrical pulse train signal to one of the switch elements and monitor the gated optical output power as shown in Figure 8.

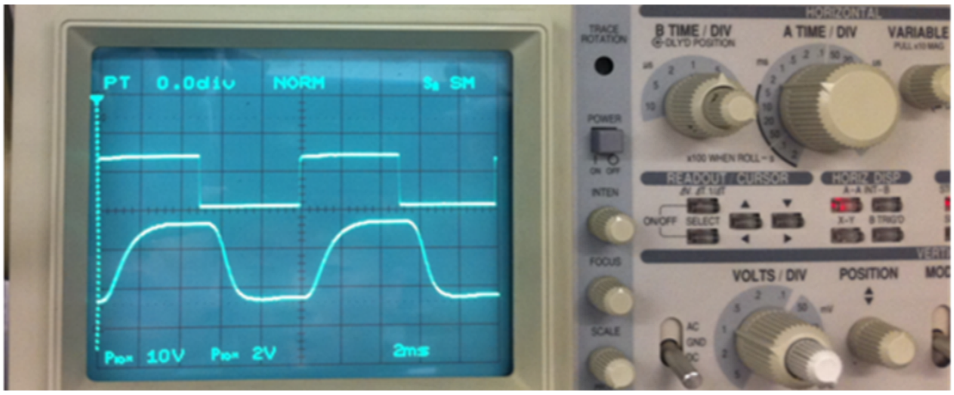


Figure 8. Switching time measurement

3.3.2 Switching Sub-Systems: agile WSS

Demo Leader: ***Tu/e, Contributor:*** *Opsys*
Location: ***Tu/e Lab.***
Demo availability: ***M25***

The subsystem demo setup for agile WSS involves the use of SiP passive chip for the de-multiplexing, and multiplexing functionality and SOA arrays as gate switches. The SOA array are found both as discrete units and on-chip devices. The generic representation of the agile WSS demonstrator setup is shown in Fig. 9. The demonstrator setup given in Fig. 9(a) involves the use of on chip SiP passives and discrete SOA arrays to implement a wavelength blocker (WBL). A WBL is the fundamental unit of a WSS. The passive components have 8 channel wavelength channels which are spaced by 100 GHz. The SiP passives is currently being optically packaged with fibre-pigtails at VTT and will be assembled with discrete SOAs in the premise of Tu/e laboratory. The purpose of this demonstrator to verify the agile WSS concept based on a low-loss SiP passives based on Arrayed waveguide gratings and Echelle gratings. The on-chip SiP passives serves as a de-multiplexer. The output of the de-multiplexer will be interfaced with discrete SOA arrays to produce wavelength blocking functionality. The SOA outputs will be multiplexed with a commercial multiplexer.

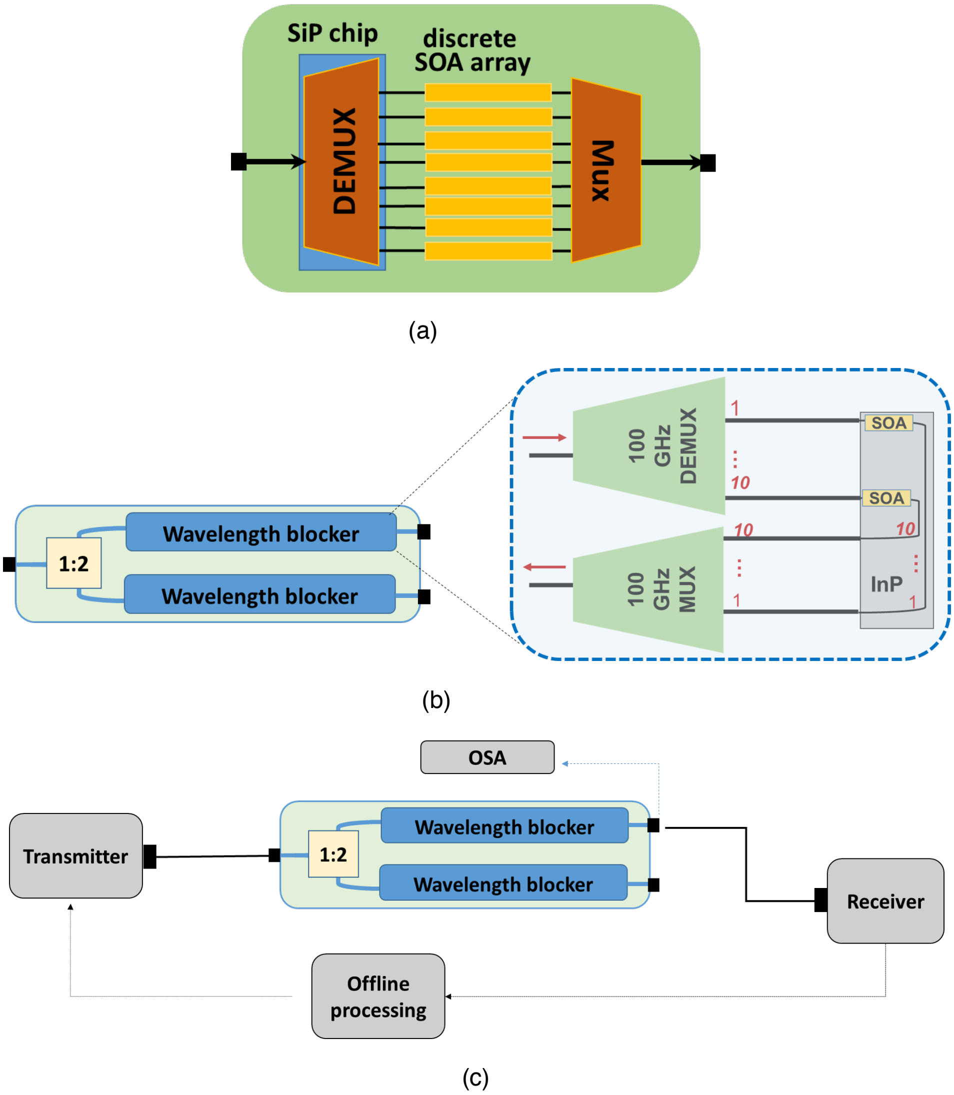


Figure 9 Demo setup for (a) wavelength blocker (WBL) with discrete SOA arrays and SiP deMux chip (b)1x2 agile WSS functionality via a hybrid integration of SiP passives and with InP SOA array (c) experimental setup of hybrid integrated 1x2 WSS

The demonstrator setup presented in Fig. 9(b) enables a 1x2 agile WSS functionality. On chip SiP passives and InP SOA arrays will be packaged via hybrid integration which is currently ongoing collaboration activity between Tu/e and VTT. This demonstrator will be an advanced subsystem setup to what is presented in Fig. 9(a) in that it uses two hybrid integrated chips to implement a 1x2 WSS. The SiP passives are based on 10 channels AWG with 100 GHz channels which are packaged to 10 SOA array chip to produce low-loss wavelength blocker chip. Two of these hybrid packaged chips will be connected to a 1x2 fibre splitter to produce 1x2 WSS functionality.

Figure. 9(c) shows the test bed for these planned demonstrator set-ups. The setup will be used to do device characterization such as measurement of insertion loss, OSNR degradation, and extinction ratio. Afterwards, data transmission through the device will be conducted to further evaluate the device performance. The presented demonstrator setup for agile WSS is expected to be ready on Dec 2019. Table I presents the details of the demonstrator and planed tests.

Table. I Planned tests on agile WSS subsystem

Planned tests	Details
Test-1	-Characterization of agile WSS: OSNR degradation, extinction ratio, cross-talk of Agile WSS
Test-2	-Data transmission of multi-level modulation format for each wavelength
Test-3	-Dynamic switching of wavelength channels following a traffic pattern orchestrated by a central SDN controller

3.3.3 Basic Coherent Receiver

Demo Leader: ***EPF***
Location: ***EPF Lab.***
Demo availability: ***M25 (first stage)***

As with the previously described demos, the coherent receiver will be conducted in stages on a step-by-step basis.

In the *first stage*, a characterisation setup will be used for functional testing and characterization of a first integrated coherent receiver (ICR) prototype. The first ICR prototype was designed to have the possibility to operate with an external laser as local oscillator (LO). The employment of an external LO reduces the bias complexity of the ICR making it possible to focus on its core figures of merit. Yet, the LO has its own figures of merit that also need to be assessed. Hence, in the first phase of the coherent receiver development, a stand-alone demonstrator for the LO is planned on one side, and on the other, a demonstrator for the ICR using an external LO. In short, following this approach permits the characterization of the basic functionalities of both LO and coherent receiver while minimizing the control complexity for an easier and faster debugging, and the collection of feedback for the next development phase. It is envisaged that both LO and ICR exploit the rapid prototyping package used within EFP. The prototyping package allows separate analysis of E/O performance without committing to electronics; the principle of the prototyping approach is shown in Figure 10.

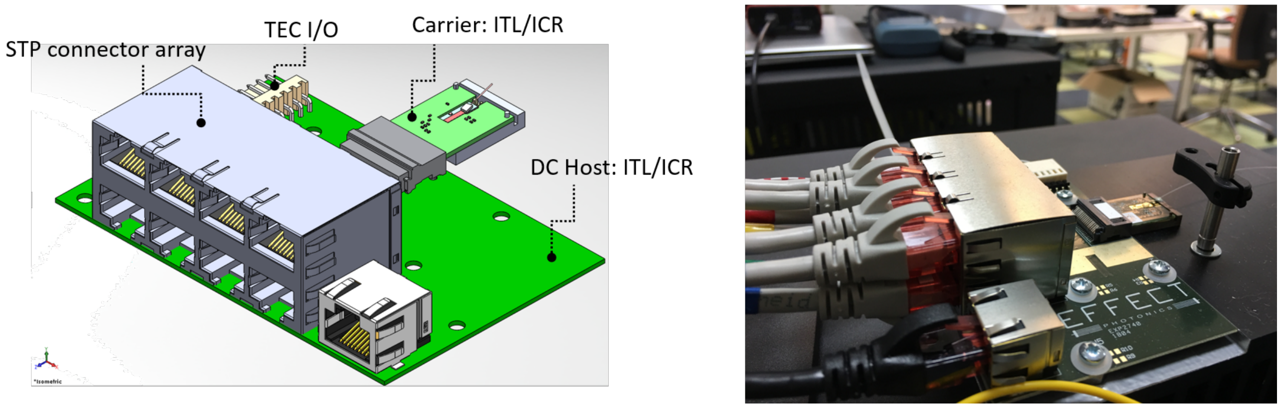


Figure 10. Left: Prototyping approach for integrated tuneable laser (ITL) and integrated coherent receiver (ICR). Right: first realized prototype for ITL.

A test setup allows to connect to these prototype packages (see Figure 11) and enables the basic characterization of the DUT (e.g. ITL or ICR). Figure 11 shows the schematic (left) and the lab setup (right) for the ITL where the laser's main figures of merit can be characterized (e.g. linewidth, power, SMSR, spectra). A setup following the same principles is planned for the ICR so that the subsystem performance can be assessed.

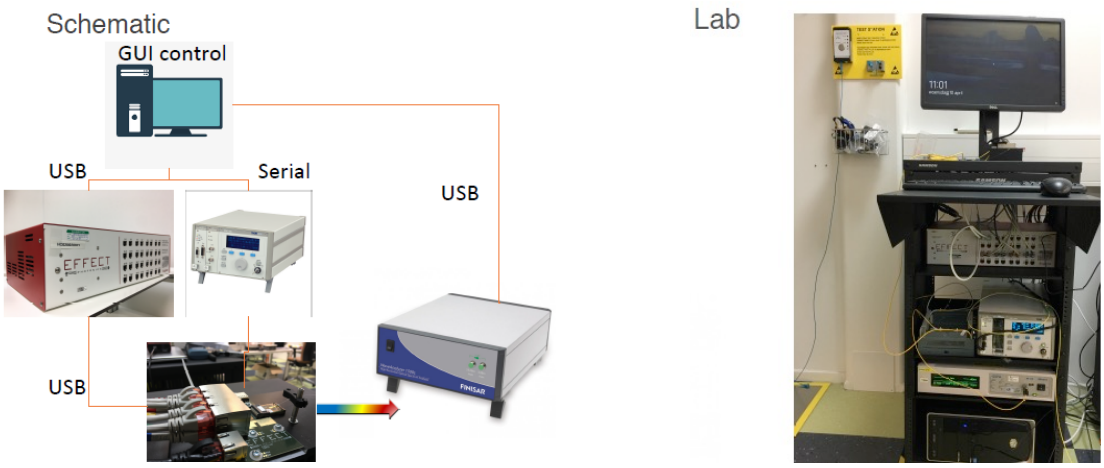


Figure 11. Demo test environment setup for first prototype: schematic (left) and laboratory (right). The lab setup corresponds to that of the ITL; a similar setup is envisaged for the ICR.

A second step is aimed for a more integrated version of the coherent receiver using dedicated driver electronics. The resulting envisaged setup, shown in Figure 12, is expected to be easily integrated with other PASSION subsystems to support in the final demo.

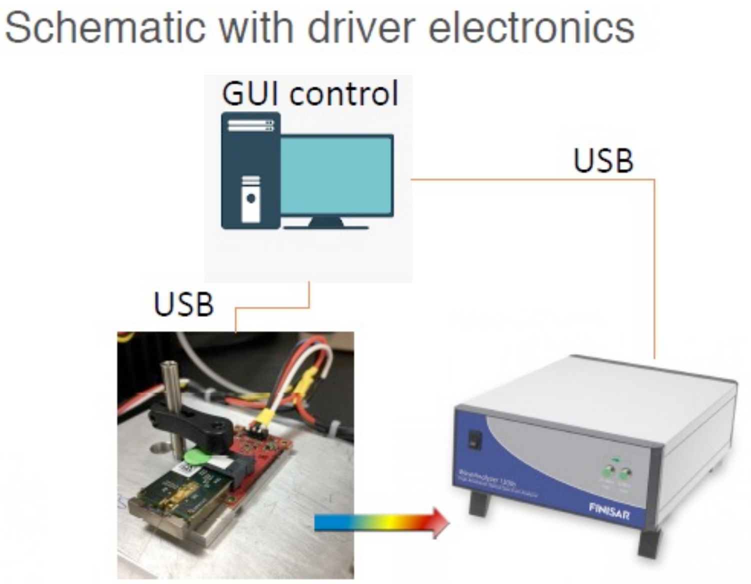


Figure 12. Schematic of PASSION coherent receiver for final demo

3.4 WP5 Related Demos

3.4.1 SDN Controller

Demo Leader: ***CTTC***
Location: ***CTTC Lab.***
Demo availability: ***M30***

In PASSION MS4 [MS4] it is reported the basics and principles that will be adopted by the SDN controller to automatically program all the network elements and devices constituting the PASSION infrastructure (i.e., VCSEL-based and Coherent Receivers S-BVTs and optical switches) when establishing / terminating optical connections. In the context of WP5, one of the goals is to experimentally validate and evaluate these defined SDN controller principles through a planned set of demonstrations and proof-of-concepts (Figure 13). The key SDN controller functions and capabilities to be experimentally validated are:

- The defined information and data models (using YANG) abstracting the capabilities and features of each network element and device
- The encoding and APIs (control protocol interfaces) between the SDN controller and the set of agents (also referred to as in [MS4] as Hardware Abstraction Layer, HAL) handling every network element and device. For the sake of completeness those interfaces are based on REST API relying on JSON encoding.
- The API (based on TAPI 2.0 [T-API]) enabling the communication between a high layer application (also referred to as On-demand Bandwidth Application) and the SDN controller. The goal of this API is to request the establishment and termination of optical connections to

be computed and set up by the SDN controller interacting with the underlying optical transport infrastructure.

- The set of devised algorithms based on Routing and Spectrum Assignment (RSA) mechanisms. Such algorithms should satisfy: i) the requirements imposed by the incoming connection requests (e.g., data rate between a pair of source and destination endpoints); ii) the technological constraints derived by the underlying transport technologies and devices (e.g., maximum distance reach, spectrum continuity and contiguity restrictions, etc.); iii) targeting selected performance objective functions such as attaining efficient use of all the network resources (e.g., minimizing spectrum fragmentation in the links).
- The pool of control operations enabling the automation in the SDN controller: i) retrieval and storing of the topology and network resource status (e.g., state of the VCSELs and coherent receivers at each S-BVT, optical spectrum availability on every network link, etc.); ii) RSA computation; iii) configuration of the computed and selected resources using the defined APIs to effectively accommodate the received connection request.

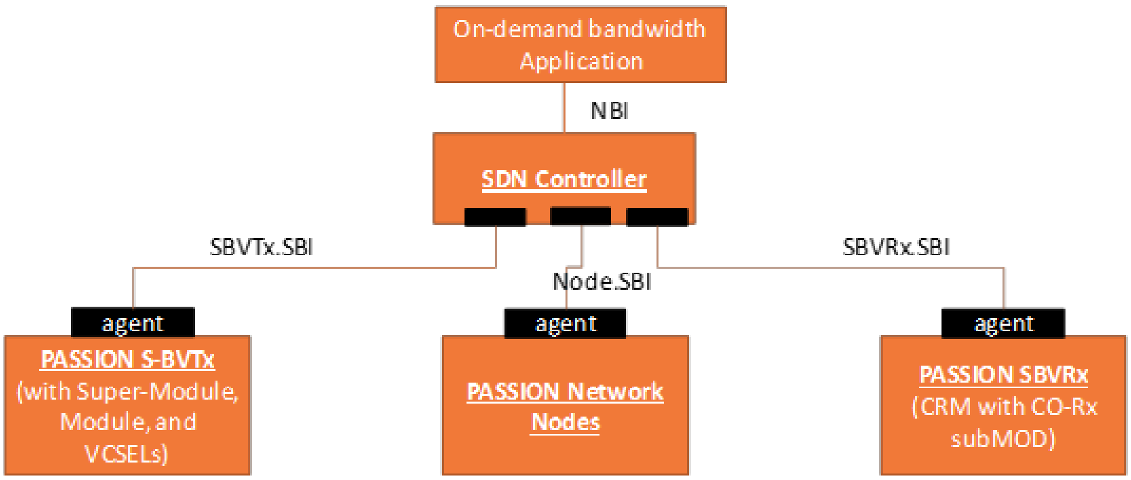


Figure 13 SDN Controller interactions adopted in PASSION (described in MS4 [MS4])

Preliminary proof-of-concept demonstration of the SDN controller functionalities have been conducted and disseminated in [Mar19]. In a nutshell, it was experimentally demonstrated the first version of the designed data model for both the S-BVT transmitter formed by a pool of VCSELs and the S-BVT Rx using Coherent Receivers according to the PASSION architecture. It is worth mentioning that this data model adopted in the aforementioned validation is subjected to be enhanced or modified as the different activities and tasks within the project progress. Nevertheless, focusing on such a first mentioned experimental proof-of-concept, the goal was to validate the coordination of the SDN controller to automatically establish an optical flexi-grid connection entailing (see Figure 14): i) processing the connection request, retrieval of the network topology and resource status; iii) triggering a RSA algorithm and iv) configuring the selected resources within the computed path interacting (via the defined APIs) with the corresponding S-BVT Tx, S-BVT Rx, and optical switches agents.

The above constitutes the main framework to continue designing, deploying and finally demonstrating the automatic control and programmability of the network elements and devices within PASSION project. To this end, the specific outcomes from the activities performed in both tasks T2.2 and T2.3 feed T5.2 which covers the SDN control platform development.

Focusing exclusively on the validation of the SDN control operations (i.e., retrieval of the device and network elements status and information, computation and de-/allocation of S-BVT and optical switch resources), interfaces along with the associated information model and data model, Figure 15 shows a generic representation of the targeted control setup. We note that in such a control setup the optical infrastructure is not present (indeed it is assumed to be emulated) since the purpose is just to validate the aforementioned SDN control operations and APIs communicating the SDN controller and the devices and network elements agents. Without loss of generality, the final demonstration, i.e. with the deployed PASSION optical infrastructure actually in-place, will follow a similar setup from the control perspective. As shown, the data communication network among the SDN controller and the respective agents will be provided by a layer 2 (Ethernet) network infrastructure where each of the control elements has its own IPv4 address in order to be reachable. The intermediate validation and demonstration of the PASSION related control operations and functions will be carried out within the activities covered by T5.2.

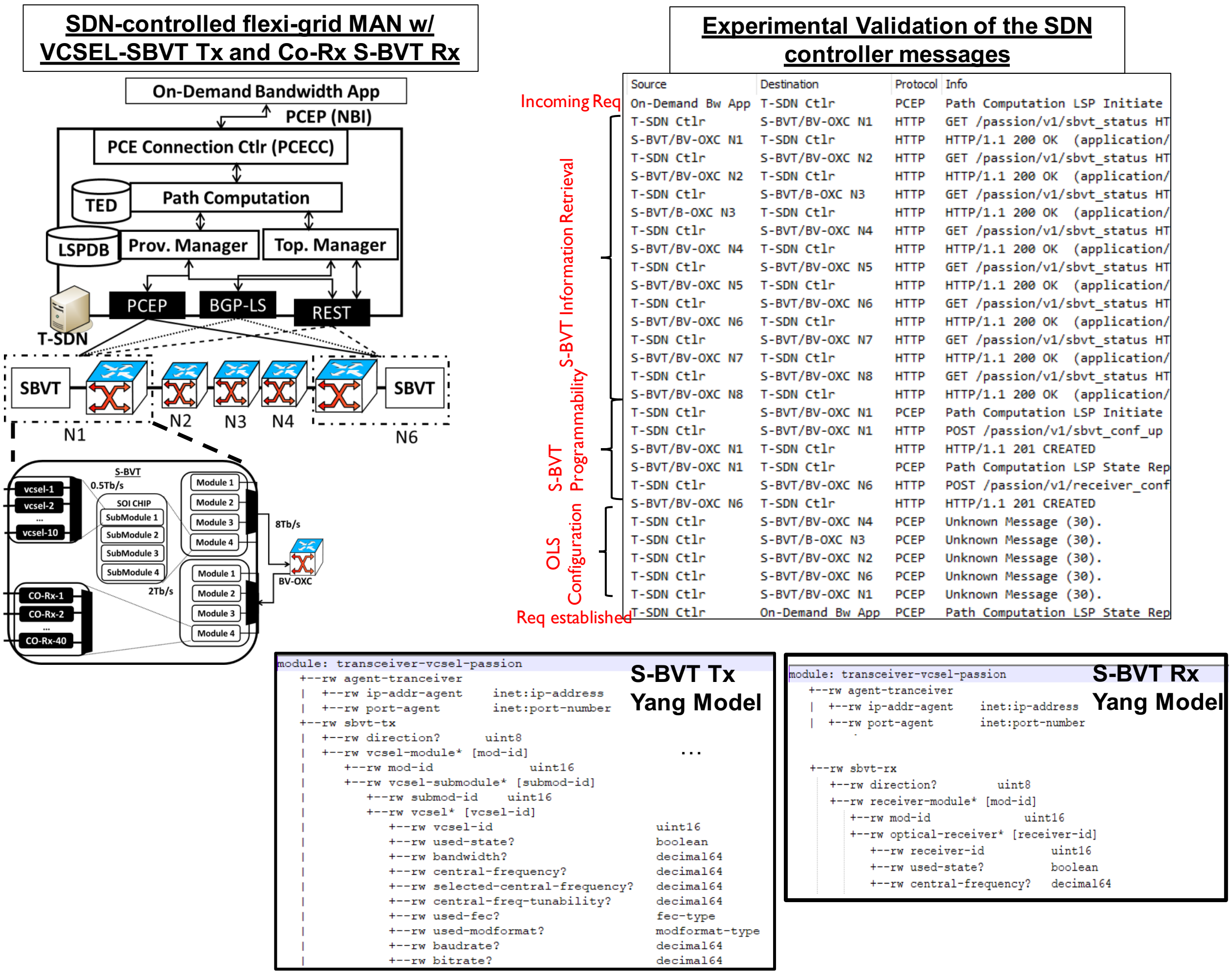


Figure 14 Preliminary validation of the SDN controller functions and data models tailored to the PASSION architecture when automatically setting up an end-to-end optical connection

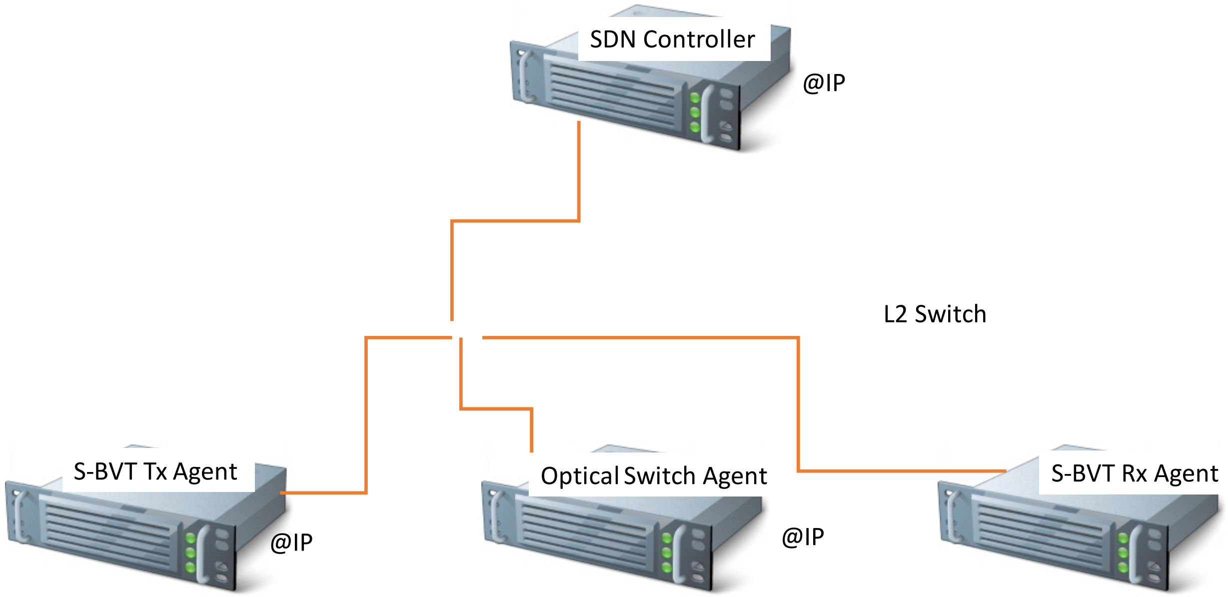


Figure 15 Preliminary validation of the SDN controller functions and data models tailored to the PASSION architecture when automatically setting up an end-to-end optical connection

3.5 PASSION FINAL DEMOS

3.5.1 PASSION Reference demo at CTTC

Demo Leader: ***CTTC***
Location: ***CTTC ADRENALINE Testbed®***
Demo availability: ***M34-M36***

The CTTC ADRENALINE testbed® is an SDN/NFV packet/optical transport network and edge/core cloud platform for end-to-end 5G and IoT services, designed and developed by the CTTC Optical Networks and Systems Department for experimental research on high-performance and large-scale intelligent optical transport networks [Mun17]. It allows researchers, system vendors and operators to experimentally evaluate different data and control plane aspects in a heterogeneous infrastructure featuring, among other capabilities, a DWDM Metro/Core network with four optical nodes. In fact, the ADRENALINE testbed® encompasses multiple interrelated although independent components and prototypes, to offer end-to-end services, interconnecting users and applications across a wide range of heterogeneous network technologies. ADRENALINE includes a multi-technology SDN control and orchestration system handling multi-layer network infrastructure combining packet over optical switching.

Besides the 4 optical switching nodes, the ADRENALINE testbed also integrates a packet transport network providing metro segment capabilities such as traffic aggregation and switching.

The ADRENALINE testbed also includes the EOS platform (Experimental platform for Optical OFDM System), which allows the development and assessment of optical connectivity solutions, based on multicarrier modulation (MCM) technology (either OFDM or DMT), adopting offline processing. This platform is connected to the mentioned 4-node photonic mesh network in order to encompass the different setups, including optical and optoelectronic systems and subsystems, mainly for MCM transmission and reception based on offline digital signal processing (DSP).

Specifically, the 4-node photonic mesh network has five bidirectional DWDM amplified optical links ranging from 35 km up to 150 km (610 km of G.652 and G.655 optical fibre deployed in total); it consists of two OXCs (optical cross-connects) and two ROADMs (reconfigurable optical add-drop multiplexers). As specific nodes of the testbed network are equipped with programmable wavelength selective switch (WSS) modules, a link is available to suitably allocate and support channels and superchannels with flexible grid. Within the EOS platform, different programmable DSP modules are available (and novel adaptive DSP can be implemented to be therein integrated) for adaptive loading, digital mixing, channel signal-to-noise-ratio (SNR) estimation, equalization, self-performance monitoring and impairment compensation. Furthermore, the EOS platform can be configured with a suitable choice of alternative options of optical, electro-optical and electrical devices, available in the lab, required to implement flexible optical transmission systems, based on modular transceiver architecture. Additionally, CTTC has specialized laboratory facilities with the common tools for development and experimental assessment of optical connectivity solutions. The facilities include optical communication test and measurement equipment, optical network test and measurement equipment, hardware design and development, simulation engines, and software design and development.

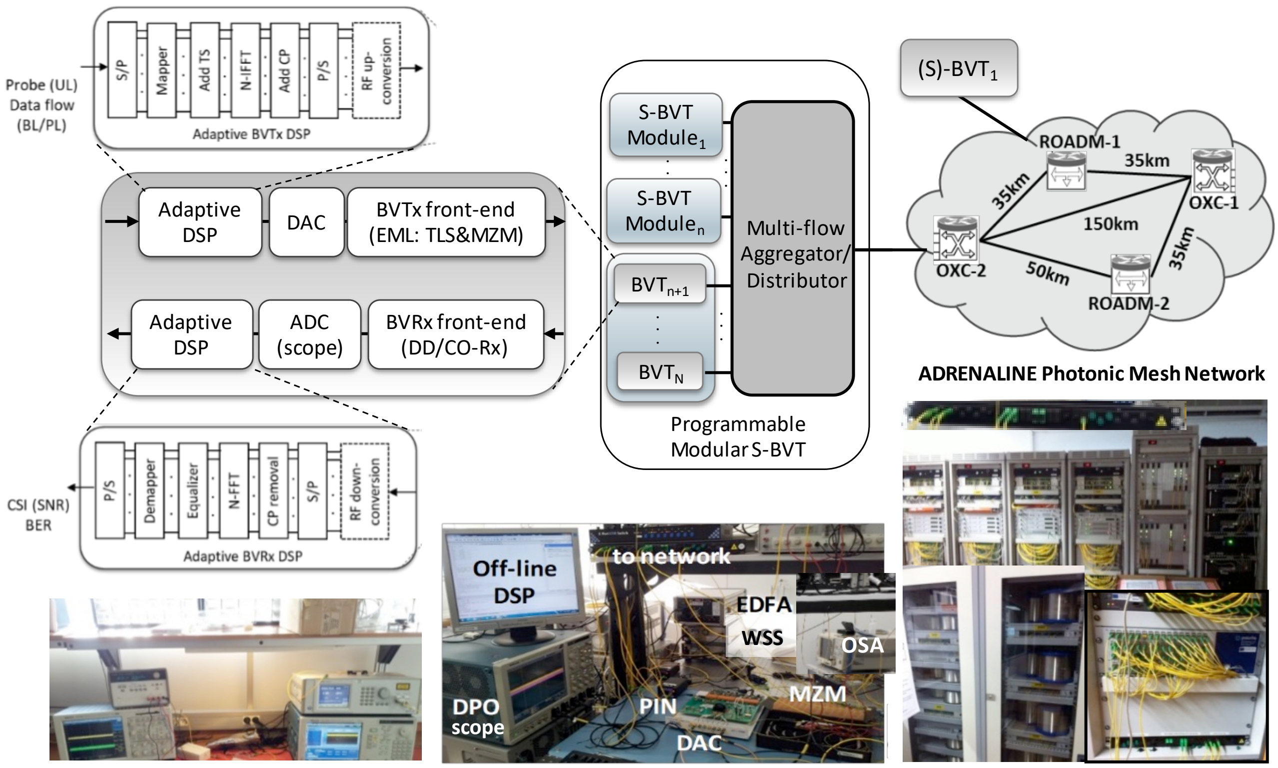


Figure 16 EOS experimental platform (schematic, pictures and examples of DSP and set-ups) and 4-node ADRENALINE testbed network with amplified bidirectional links.

Thus, the innovative solutions, including the modular programmable sliceable bandwidth variable transceiver (S-BVT), designed and developed in PASSION, according to their availability and portability, can be implemented, integrated, tested and validated within the ADRENALINE testbed®, providing a networking environment for the solution assessment.

Particularly, at the transmitter side, either an arbitrary waveform generator (up to 24 GSa/s single channel and 12.5 GSa/s two channels with 9.6 GHz bandwidth) or a high-speed digital to analogue converter (DAC with 4 channels up to 64 GSa/s each and 13 GHz bandwidth), included in the platform, can be used to provide the desired electrical analogue signals. Different optoelectronic transmitter front-end modules based on direct or external modulation can be adopted and suitably integrated within the EOS platform. Accordingly, in the framework of WP5, the VCSELs within the PASSION modular transmitter solution can be directly modulated by the DAC output signals. Additionally, S/C/L-band tuneable laser sources (TLS) with picometer resolution and broadband interferometric modulators (Mach-Zehnder, MZM, up to 40 GHz), based on different technologies (LiNbO3, GaAs) with the corresponding linear drivers are available. The flows aggregation/distribution is performed by using a bandwidth variable (BV) WSSs, based on liquid crystal on silicon technology (LCoS), which can be part of either the transceiver or the network. In particular, the platform includes 1:1 and 1:4 tuneable optical filters, with variable bandwidth from 12.5 GHz to 5 THz. Furthermore, the bandwidth occupation, central optical carrier frequency and power/attenuation per port of the WSSs can be adaptively tuned. These programmable elements can also serve as optical filters suitable to implement single side band (SSB) modulation. Several optical reception options, based on direct or coherent detection, are available within the EOS platform. These modules can be eventually adopted to complement the CO-Rx module (CRM) being developed within PASSION and/or used for the transmission system assessment/benchmarking. In the inset picture of Figure 16, an external modulation (TLS and MZM) with direct detection (DD) (PIN, including TIA) scheme is shown. For analogue-to-digital conversion (ADC), a real-time digital phosphor oscilloscope (up to 4 channels at 50 GSa/s and 2 channels at 100 GSa/s, with 20 GHz bandwidth) is available to recover the transmitted electrical data per flow. Additionally, other optical and electrical devices are available, including C-band EDFAs, optical spectrum analyzer (OSA), variable optical attenuator (VOA), polarization beam combiners/splitters (PBCs/PBSes), CD/PMD emulation and analysis instruments.

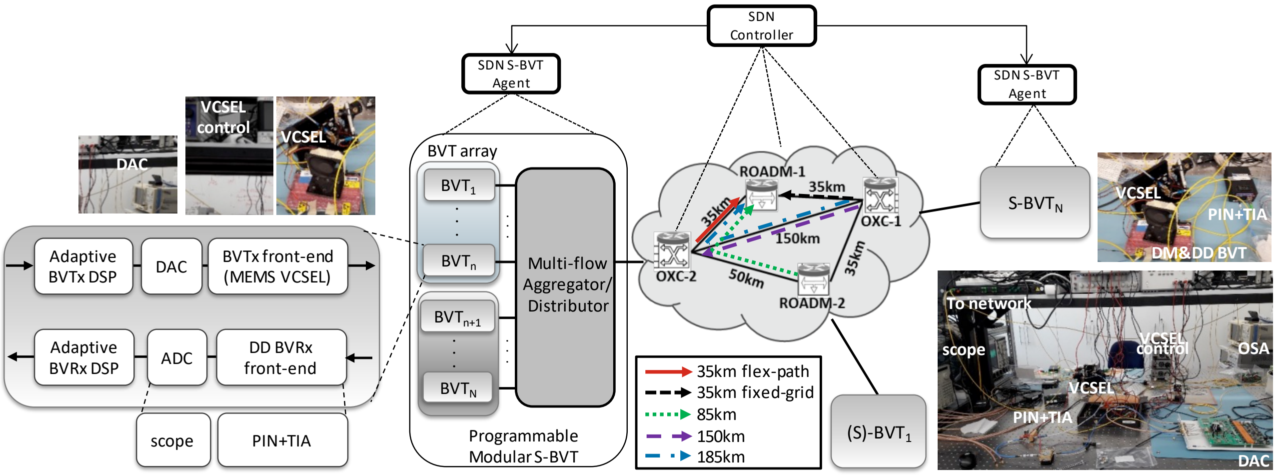


Figure 17 Schematic, set-up and pictures of the SDN-enabled S-BVT adopting MEMS VCSEL at the BVTx front-end. The ADRENALINE network paths considered in the experiment are indicated.

A preliminary assessment of a programmable (SDN-enabled) S-BVT adopting a directly modulated widely tunable MEMS VCSEL and DD has been performed in the ADRENALINE testbed, as presented in [Sva18] and reported in detail in D2.1 [D2.1]. Figure 17 describes the set-up of the EOS platform and the ADRENALINE network paths considered in the experiment.

Similarly, the PASSION modular S-BVT architecture described in MS6 [MS6], based on directly modulated (MCM with adaptive DSP) VCSELs (on SOI chip modules) and CO-Rx modules, are envisioned to be integrated within the EOS platform for proof-of-concept validation. This integration will be implemented in different phases, starting with a single flow assessment generated by a single directly modulated VCSEL and recovered by a single CO-Rx in back-to-back (B2B), to be further analyzed and validated with additional channels/flows and considering different fibre link, spans and lightpaths, including filtering and switching elements. This will be done according to the PASSION node and network architectures, targeting the identified use cases in the framework of WP2, as described in MS6 and to be further defined and optimized in the next envisioned D2.3 on the design of the programmable nodes and modular transceiver architectures, to be delivered on M28.

Multiple flows will be generated by multiple VCSELs (as discrete elements or integrated within the SOI-chip in order to test the PASSION transmitter solution) operating at different wavelengths within the C-band according to the ITU-T grid and eventually aggregated at the WSS. The PASSION CRM solution will be also included and validated as incremental phase of the integration and proof-of-concept. In addition to the single polarization assessment, the possibility of also exploiting the PDM option will be taken into account.

Within the EOS platform various fibre spools, ranging from 1 km to 50 km, of standard single mode fibre (SSMF) are available (Figure18). Particularly in the framework of PASSION project, 4 SSMF fibre spools of equal lengths (50 km) are also available for the performance assessment of the transmission of multiple flows. The most appropriate set of experimental implementations and connectivity scenarios will be set-up, including the testbed network, to suitably prove the PASSION solutions and concepts.

Also, it is envisioned to implement a recirculating loop prototype for eventually testing the reach/capacity performance of the PASSION solution, including the S-BVT and possibly the switching nodes (depending on their availability/portability).

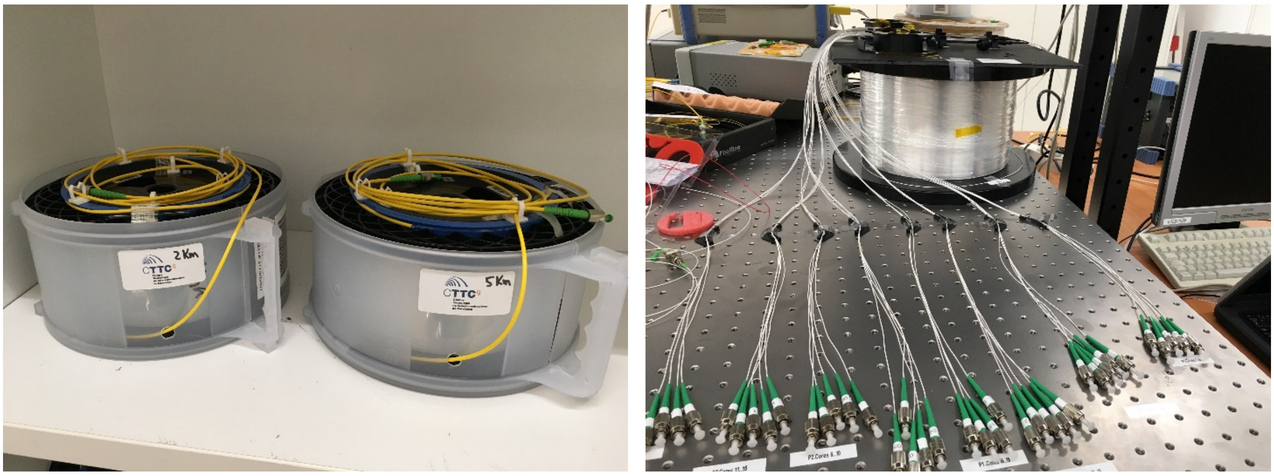


Figure 18 (Left) examples of SMF fibre spools available within the EOS platform. (Right) 19-core fibre of 25 km including fan-in, fan-out elements.

Finally, it is worth mentioning that a 19-core fibre of 25 km, including fan-in, fan-out elements is going to be integrated within the ADRENALINE testbed in order to further prove the SDM concept of the PASSION solution (Figure18), including the exploitation and assessment of the spatial dimension.

The SDN controller will allow the automatic selection and configuration of the underlying network elements, devices and optical resources to dynamically accommodate multiple optical flows with heterogeneous requirements in terms of demanded data rate. This automatic programmability will be validated considering the SDN controller basics (i.e., northbound and southbound APIs, RSA algorithm, control operations) listed above in section 3.2.1.

The SDN agents and the corresponding APIs are being designed for handling the PASSION S-BVT and optical switch node programmability and (re)-configurability. This is driven and coordinated by the SDN controller considering the output of the RSA algorithm at the time of establishing (or updating) a new (or existing) optical connection. So far, different S-BVT programmable elements and reconfigurable parameters have been identified to model the transceivers, as mentioned in previous section 3.2.1 and reported in MS4 [MS4], MS6 [MS6]. The specific elements, parameters, capabilities and restrictions of the PASSION technologies and architecture are subject to be modelled with specific and well-defined information and data models as well as APIs. By doing so, the SDN controller, even operating with an abstraction view of those network elements and devices, will allow the targeted programmability supporting flexible and dynamic multiple capacity/reach and multiple flow transmission. The latter is a key objective to be experimentally validated and demonstrated in the ADRENALINE testbed.

On the other hand, the proof-of-concept including the evaluation and assessment of key advanced features and functionalities can be enabled and tested within the ADRENALINE, to fulfil the dynamic and flexibility requirements as well as the capacity/reach challenges of PASSION targeted metro network. In particular, spectral manipulation/slice-ability and rate/distance adaptability for optimal spectrum/resource usage will be assessed, as the modular transceiver is capable of generating a multi-format/rate/reach data flow thanks to the adaptive DSP. Finally, it will be confirmed the proposed S-BVT architecture scalability, facilitating suitable sizing of the solution according to the metro network or specific node requirements, following a grow/pay-as-you-need approach.

3.5.2 PASSION Reference demo at TUE

Demo Leader: ***TUE***
Location: ***TUE Lab.***
Demo availability: ***M28***

Tu/e demo is envisioned to serve as an intermediate reference PASSION demo prior to the final demo at CTTC premises. The demonstration of the integration tests can be done in to two stages:

- Functionality demonstration of the switching devices: These involves standalone performance verification of the WSS, WBLs and multi-cast switches (MCS). This stage of the demo is used to benchmark the switching devices before building the reference demo. Tests related with insertion loss, cross-talk, noise figure, polarization dependent loss will be done.

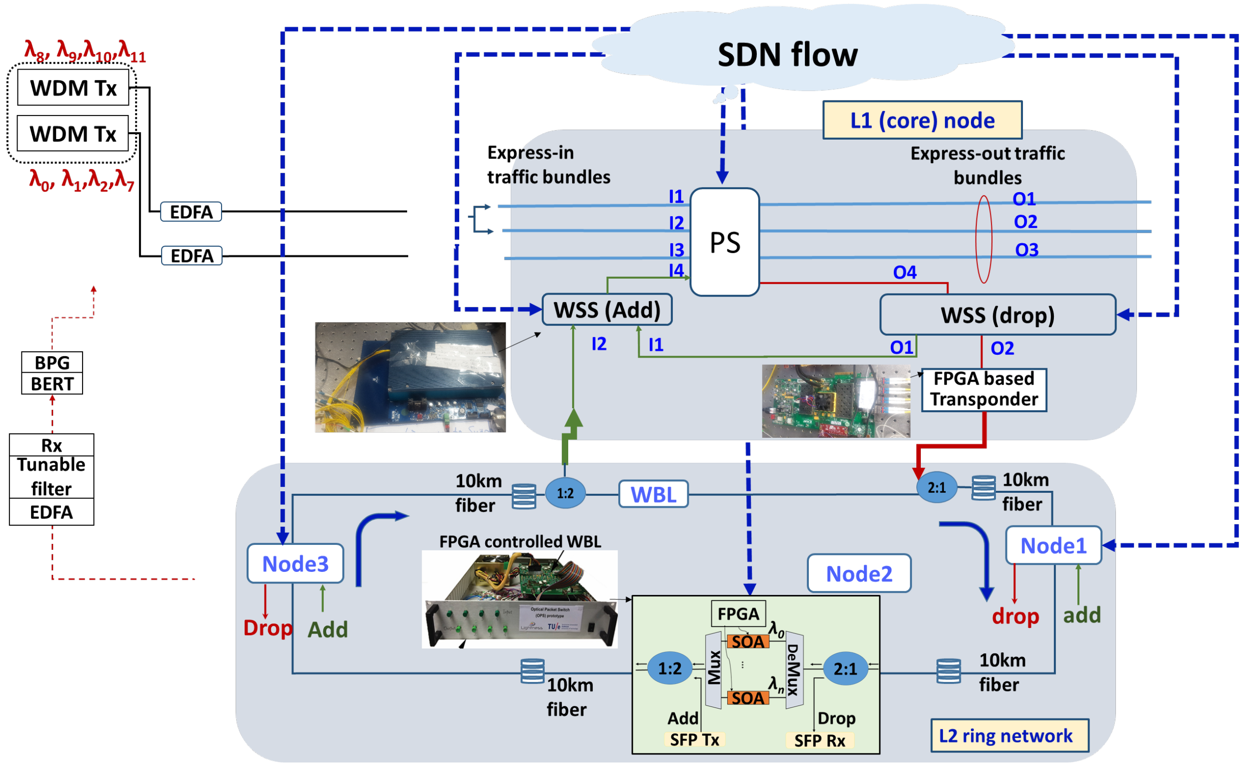


Figure 19. PASSION switching node test bed at TU/e

- Integration tests of the PASSION switching node illustrating the use-case scenario: these involves the demonstration of the whole PASSION switching node functionality at two aggregation levels (HL3 and HL4 network levels) according to the use-case scenarios. The tests will be designed to demonstrate the capacity to scale the network. Currently, at Tu/e, we are building the complete PASSION switching node as seen in Fig. 19, step by step to solve the technical challenges associated with the whole integrated system.
- At the HL3 node, the following devices will be employed :
  - 16x16 space switch: expected to be delivered from ETRI, if it is not available on schedule, this will be replaced by 4x4 ETRI space switch.
  - 1x10 WSS (drop) direction from Opsys, 10x1 WSS (add) direction (which is already available in Tu/e premises).
  - Low loss MCS (low-loss hybrid integration) : designed on InP SOA arrays and will be packaged at VTT
  - Receiver modules from EP : expected to be delivered by EFP
- At the HL4 node, the following devices will be employed :
  - A discrete Wavelength blocker (consisting of a demux AWG, discrete SOAs and mux AWG) at 50 GHz
  - Add/ and drop functionality with a simple 1x2 splitter
- Depending on the availability, the option to include PASSION transmitter modules in the reference demo of Tu/e will be explored. As an alternative approach, directly modulated laser sources will be explored

- On-top of the HL3 and HL4 nodes a central SDN controller (ONOS) connected with NETCONF will be employed. Pre-defined dynamic traffic patterns orchestrated by a central SDN controller will be used to evaluate the performance of the switching node.

All the integrated (on-chip) switching subsystems can be moved from Tu/e to the final PASSION demo location, Barcelona at CTTC premises. Other components would pose transportation challenges.

3.5.3 PASSION Reference demo at NICT

Demo Leader: ***NICT***
Location: ***NICT Lab.***
Demo availability: ***M32***

This demo relay on multicore fibre deployment accessible at NICT premises and will be focused on the demonstration of capacity increase by multicore fibres (MCFs).

At NICT, the aim is to perform experiments using the PASSION transceiver in conjunction with NICT's space-division multiplexing (SDM) transmission test-bed. The aim will be both to demonstrate a multiplication of the achievable data-throughput possible by combining the PASSION technology with multicore fibres (MCFs) and to explore the impact of fibre characteristics on performance of transmission systems utilising PASSION technologies.
The test-bed allows SDM transmission in a range of SDM fibres from 4- to 22 single-mode cores over varying transmission lengths. Individual fibre spans for 7-core fibre, the most likely candidate for a PASSION demonstration up to 53.7 km are available and these fibres may also be combined with a recirculating transmission test-bed capable or recirculating multiple spatial channels in parallel. Furthermore, if required it is also possible to test PASSION transceiver technology over few-mode transmission in various span lengths or loop transmission and in multi-core few-mode fibres with up to 38 cores.

Figure 20 NICT laboratory and SDM transmission test-bed.

To investigate interference between spatial channels, transmitted signals may be copied and amplified in dummy channel circuits with large power range to replicate the impact of spatial channel crosstalk in a range of scenarios. Dummy channels in a range of modulation formats and Baud-rates may also be generated using the available transmitter based on broadband interferometric modulators and arbitrary waveform generators with 15 GHz analogue bandwidth operating at 80 Gs/s. Whilst, it is imagined that the inter-core skew will have little impact on the use of PASSION technologies under MCF transmission, the impact of changing propagation delay can be investigated by conducting experiments with fibres in thermally controlled chamber.

To recover data signals for investigation with offline processing a number of integrated coherent receivers and coherent receives based on bulk components optimised for high-order QAM modulation are available. For analogue-to-digital conversion (ADC), a real-time sampling oscilloscope with up to 12 channels and 35 GHz bandwidth and 80 GSa/s or 8 channels at 65GHz and 160 GSa/s is available to recover the transmitted electrical data. In addition, all other optical components typical in optical research labs will be available for use in PASSION experiments including wavelength-selective switches, optical amplifiers and monitoring and test equipment.

4 CONCLUSIONS

This report summarises the state of the art of the envisaged integration and demonstration activities and the related availability plan.

The adopted strategy foresees a first demonstration activity relative to the elementary building blocks developed by the project, i.e. transmitter, receiver and switching devices, which may be used as standalone solutions. These demos, linked to the actual deliverables of the WPs, in the beginning will be located in the laboratories of the leader partners; however, with the purpose to disseminate and promote PASSION solutions, we will pursue their show in events such as international conference, dedicated workshop, etc.

At the end of the project, the final demo will integrate the entire elementary components in order to build an end-to-end transmission solution, based on PASSION technology. This demo will be hosted by CTTC in Barcelona, taking advantage of the ADRENALINE© platform. In addition, two demos respectively focussed on multicore fibre transmission (NICT) and switching devices (TUE), not jet confirmed, will be considered as an additional opportunity for the Project dissemination.

All the demonstrations include the definition of the test bench and the identification of the measures that will highlight the achievements of PASSION technology.

At the current stage of the project, some of the planned demonstrations are linked to the availability of subsystems developed by the “technological” work-packages, which can incur in possible delays due to process and fab vacancy. For this reason, we can consider this report a living document that will be periodically updated in terms of schedule and contents.

The excel file of Figure 2 (located in the PASSION repository) will be used to monitor and update the status of all demo activities.

5 REFERENCES

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6 Acronyms

ADC	Analog to Digital Converter
BVT	Bandwidth-Variable Transceiver
CWDM	Coarse Wavelength Division Multiplexing
DAC	Digital to Analog Converter
DMT	Discrete multitone
DSP	Digital signal processing
EDFA	Erbium doped fibre amplifier
ESA	Electrical Spectrum Analyzer
ICR	Integrated coherent receiver
IT	Information Technologies
IP	Internet Protocol
LO	Local Oscillator
MCF	Multicore fibre
MCS	Multi-cast switches
ONT	Optical Network Termination
OSA	Optical Spectrum Analyzer
OSNR	Optical signal to noise ratio
OXC	Optical cross-connects
PDM	Polarization-Division Multiplexing
ROADM	Reconfigurable optical add-drop multiplexers
RSA	Routing and Spectrum Assignment
SBVT	Sliceable Bandwidth-Variable Transceiver
SDM	Space-Division Multiplexing
SDN	Software defined network
SNR	Signal to noise ratio

SOA	Semiconductor optical amplifier
SOI	Silicon On Insulator
SSMF	Standard single mode fibre
SWT	Switch
PD	Photodiode
VCSEL	Vertical-Cavity Surface-Emitting Laser
WBL	Wavelength blocker
WDM	Wavelength-Division Multiplexing
WSS	Wavelength selective switch

7 APPENDIX

Excel File summarising demo details. Living Document located in the PASSION repository