SEASON

Self-Managed Sustainable High-Capacity Optical Networks

Deliverable D6.3

Final project report on standardization, communication, and dissemination activities

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DISCLAIMER

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EXECUTIVE SUMMARY

SEASON as a collaborative project involving educational, research, and industrial partners, emphasizes effective communication and dissemination to maximize its impact. The project employs a diverse range of channels, including scientific publications, workshops, demo exhibitions, and engagement in standardization activities.

In this document, we provide an overall assessment of the project activities related to WP6 and summarises the main contributions and how they have impacted industry and academia. The report evaluates the success and highlights strengths and weaknesses. The deliverable also outlines the further plans beyond the life of SEASON.

A summary of the main contributions, take aways of the activities, and metrics reported during the whole lifetime of the project is provided next:

Dissemination

- 40 publications in selected peer-reviewed Journals, some of them joint with other projects.
- 122 presentations and publications at selected scientific conferences/workshops
- Over 10 dissemination talks and presentations at industry conferences, workshops and events.
- 10 datasets, most of the publicly available.

Communication

- Creation of content and regular update of project website, and on social media (LinkedIn, X, and Instagram), which has resulted in over 300 visits per month to the website and a large combined of followers across platforms.
- Communication talks and newsletters for lay and expert stakeholder groups: students, authorities, and the SNS JU community.
- 26 videos and podcasts created and available on our YouTube platform directed at differences audiences.
- 10 project newsletters and 13 press releases

Standardization and Open-Source

- Continuous monitoring and participation in relevant SDOs (e.g., IETF, ETSI, TIP).
- Continuous review and update of the initial standardization roadmap according to the timelines of the SDOs and the project.
- Contributions: 5 to ETSI, 1 to OpenROAM, 2 to IETF, 1 to MOPA.
- Continuous monitoring of relevant open-source projects for networking (e.g., TSF).
- 8 open-source contributions.

TABLE OF CONTENTS

1. INTRODUCTION

The SEASON project is a collaborative endeavour involving a consortium of educational, research, and industrial partners that embarks on a transformative journey at the forefront of technological innovation. This comprehensive report encapsulates the efforts and accomplishments of SEASON focusing on the areas of dissemination, communication, and standardization.

This deliverable reports on the planning and execution of dissemination and communication strategies, illustrating how SEASON has maximized its influence by effectively reaching diverse target audiences. The project's dedication to transparency, collaboration, and knowledge-sharing is evident in its involvement with scientific publications, workshops and demo exhibitions. Moreover, SEASON acknowledges the importance of standardization in ensuring interoperability and fostering a unified ecosystem. The report navigates through the project's active engagement with prominent Specification Developing Organizations (SDOs), outlining its objectives and achievements.

The deliverable is organized as follows:

Section 2 focuses on dissemination activities, including scientific publications in journals and conferences, datasets generated as part of the research activities, organization of events and coordination with other projects.

Section 3 is devoted to communication activities related with the promotion of the project and its results beyond the project's own community. This includes communication of its research in a way that it is understood by non-specialist, e.g., the media and the public.

Section 4 and Section 5 cover monitoring and impact in standardization activities, and contributions to open source.

Each section outlines the further plans beyond the life of SEASON.

Finally, Section 6 summarizes the Strengths, Weaknesses, Opportunities, Threats (SWOT) analysis and the innovation questionnaire carried out as part of exploitation activities.

2. DISSEMINATION

2.1. DISSEMINATION - PLAN AND ACTIVITIES

Scientific publications in peer-reviewed conferences and journals are the primary channel to reach the scientific community and publish SEASON results. In addition, in conferences with technical exhibition forums, it is also possible to reach specific target groups from industry. The overall project dissemination plan is presented in Figure 2-1.

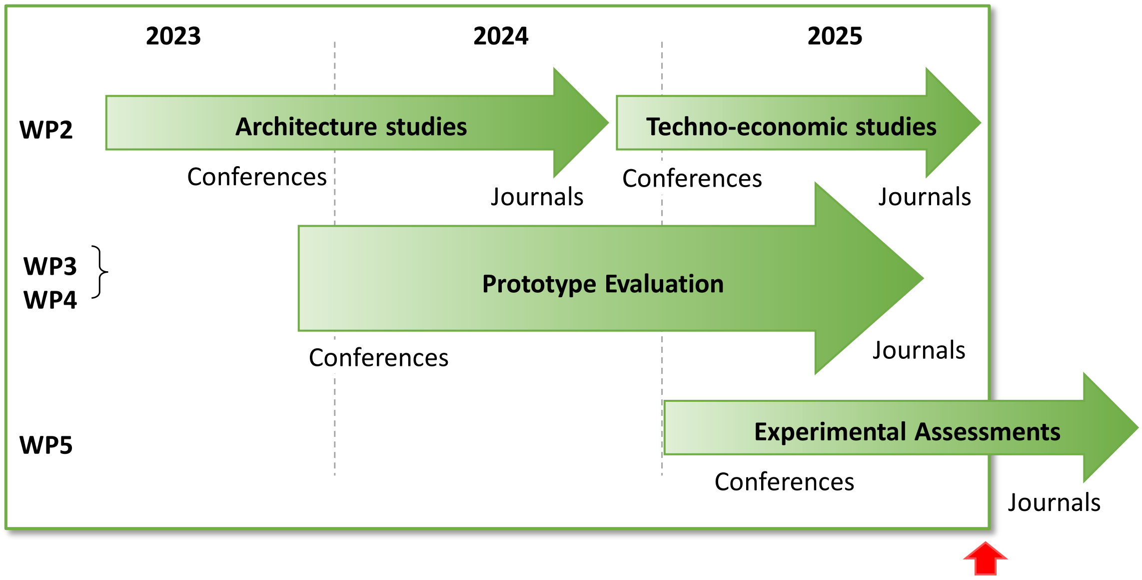

Figure 2-1 SEASON Dissemination Plan

As planned, during the 1st year, dissemination activities were mainly concentrated on demonstrating the SEASON concept, its impact on optical networking, as well as raising the awareness of these target groups about the objectives and expected results of the project.

Starting from the second year onwards, the dissemination activities evolved to publish concrete scientific results, with a special focus on results relating to technological innovation.

Finally, during the last year of the project, publications related to experimental results have been or are in the processed of publication.

Specific results from the key experimental demonstrations have been successfully accepted for publication in the prestigious OFC 2026 Conference.

Major Targeted Conferences: OSA Conference on Optical Fiber Communication (OFC), European Conference on Optical Communication (ECOC), IEEE International Conference on Transparent Optical Networks (ICTON), IEEE International Conference on Optical Network Design and Modelling (ONDM), IEEE International Conference on Communications (ICC), Global Communications Conference (GLOBECOM), and European Conference on Networks and Communications (EuCNC).

Major Targeted Journals: IEEE J. on Selected Areas of Communications, IEEE/OSA J. of Optical Communications and Networking; IEEE/OSA J. of Lightwave Technology; IEEE Trans. on Signal and Inf. Processing over Networks; IEEE Comm. Magazine.

Major target is to publish over 25 journals, articles, magazines, whitepapers, specifications, and standards.

Table 1: Dissemination activities and KPI

Dissemination Activity and Verification Plan	KPI	Achieved
Publication in selected peer-reviewed Journals	25	**40**
Presentation and publication at selected scientific conferences/workshops	40	**122**
Participation at industry conference/workshops/events	3	**>10**
Datasets	-	**10**

Table 2: Journal publications vs Project's Objectives

Objective	#Journals*
O1: Sustainable network architecture	5
O2: Scalable, ultra-high capacity, and power efficient MBoSDM network	5
O3: Novel optical systems and subsystems for MBoSDM	3
O4: Access and front/mid-haul transport solution	7
O5: Monitoring infrastructure for secure and truly self-managed networking	3
O6: Smart edge nodes for packet/optical integration with computing resources	4
O7: Control plane, Monitoring and streaming telemetry	6
O8: AI/ML Service Orchestration and Self-Management and Secure AI	7
TOTAL	**40**

(*) Assigned to the main objective

2.2. Scientific Publications

The following papers were published, presented, or received acceptance for publication. Because of the long list of publications and their large lifecycle from the time they are submitted, accepted, presented/published, publications are consolidated into one single list, so the references listed in this section contain the last available data, e.g., after the final publication.

Open access

SEASON uses Zenodo to deposit accepted scientific publications to comply with the Open Access policy for publications. To that end, the HORIZON SNS SEASON community has been created (https://zenodo.org/communities/horizon_sns_season/).

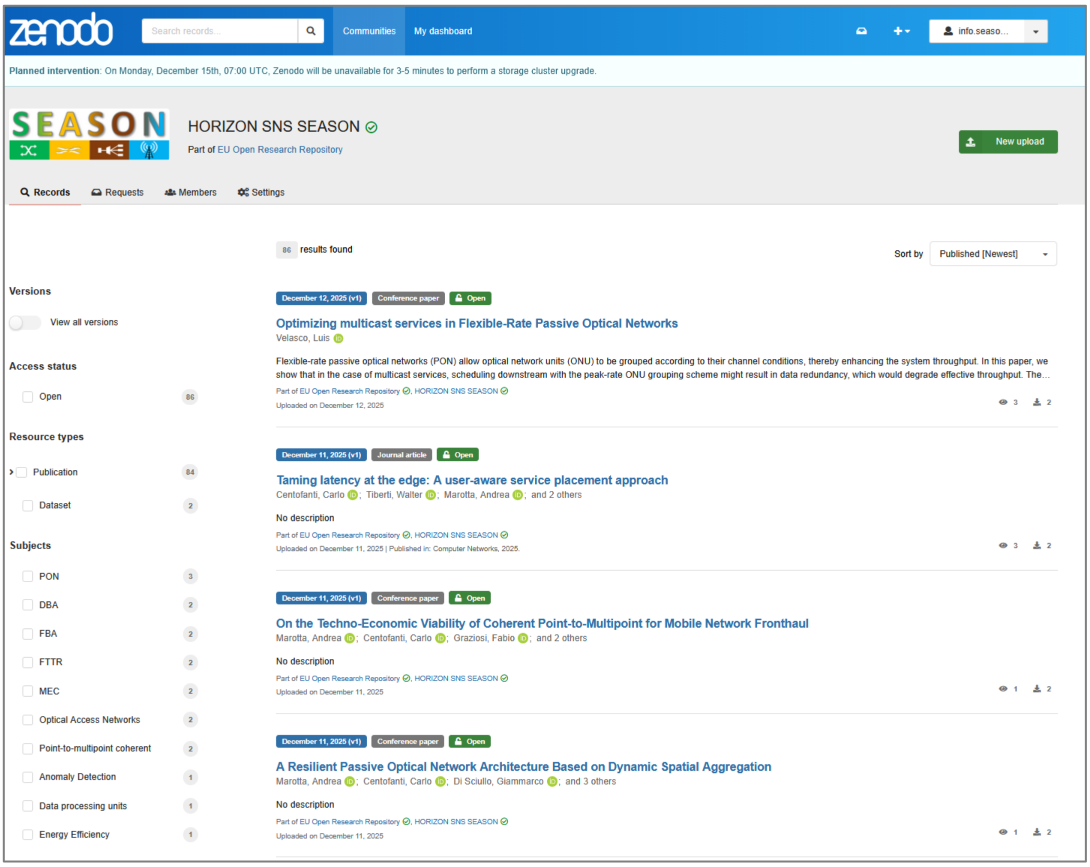

Figure 2-2: SEASON community in Zenodo

2.2.1. Publications in Journals

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14. L. Khan, "Towards Low-Complexity Neural Networks for Failure Management in Optical Networks", Journal of Optical Communications and Networking, vol. 17, 2025
15. Carlos Castro et al., "Power consumption considerations of coherent transceivers in filterless point-to-multipoint metro-aggregation networks with digital subcarrier multiplexing", Journal of Optical Communications and Networking, vol. 17, 2025.

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3. L. Velasco, M. Devigili, and M. Ruiz, "Applications of Digital Twin for Autonomous Zero-Touch Optical Networking [Invited]," in International Conference on Optical Network Design and Modeling (ONDM), 2023.
4. S. Barzegar, M. Richart, S. Wang, A. Castro, M. Ruiz, and Luis Velasco, "Coordination of Radio Access and Optical Transport," in International Conference on Optical Network Design and Modeling (ONDM), 2023.
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2.3. Datasets

2.3.1. Dataset: Synthetic Measurements of Single Carrier and Digital Subcarrier Multiplexing Optical Signals

Available at: https://doi.org/10.34810/data1407
Pub date: 04/2024

MATLAB based Optical Coherent System Simulator

Figure 2-3 depicts the setup of the numerical simulations. A MATLAB-based simulator of a digital coherent system is employed to reproduce both SC and DSCM signal transmissions. In both cases, we consider a dual polarization Nyquist-shaped single-λ channel with a roll-off factor of 0.06, operating at 64 GBd symbol rate. The DSCM signal is composed of 16 DSCs all operating at 4 GBd spaced with a guard-band of 100 MHz.

The pulse propagation along the fiber is modelled by solving the Manakov equation using the split-step Fourier method with a propagation step-size of 1 km including effects such as fiber

loss, arbitrary fiber birefringence, group velocity dispersion, polarization mode dispersion (PMD) and self-phase modulation. Each link consisted of 80-km SSMF spans characterized by fiber loss 0.21 dB/km, dispersion 16.8 ps/nm/km, PMD value 0.04 ps/km$^{1/2}$ and nonlinear coefficient 1.14 W^{-1}km^{-1}.
The EDFAs' noise figure is 5 dB whereas its gain is set to compensate for the span loss and to restore the power to the launch one which is near-optimal (1 dBm for both SC and DSCM signals). Note that each subcarrier has a launch power of -12.2 dBm and that at the transmitter side we assume the same background noise both for SC and DSCM signals leading to a normalized OSNR ratio 49 dB.
In this analysis, we consider three *m*-quaternary modulation formats with index *m* equal to 4, 16 and 64. Moreover, we considered two types of network nodes: wavelength selective (WS-nodes), also known as ROADMs and filterless nodes (FL-nodes).
In particular we consider Route-and-Select (R&S) ROADMs containing two filters: one 1xN *route* wavelength selective switch (WSS) steering the incoming wavelength to the drop port or to another degree and one Nx1 *select* WSS that can block unused wavelengths and add new ones. Differently the F-nodes have the so-called Drop & Waste design: an optical splitter broadcast copies of every channel to every network degree and to the drop port whereas an optical combiner inject all the channels in the fiber. Note that this architecture is not able to erase channels in order to reuse a wavelength. Finally, we assume that both the ROADMs and the FL-Nodes insert similar losses (~ 8 dB). To emulate the WSS, we consider filter shapes that were obtained by characterizing four 1x4 WSSs. These latter have a –3 dB optical bandwidth of approximately 71 GHz and were concatenated with a random pattern in the simulator to mimic an optical lightpath having similar but not coincident filter shapes in each WSSs.
For each configuration, we generate 20 samples and for each sample we store the in-phase (I) and quadrature (Q) optical constellations of the X polarization composed by 218,450 IQ symbols and optical spectra with 150 MHz resolution. Finally, the BER and the Q factor were evaluated over 1,747,600 symbols for 16 QAM and 64QAM (i.e., over 6,990,400 bits and 10,485,600 bits, respectively) and over 3,495,200 symbols for QPSK (6,990,400 bits).
At the receiver side, we considered digital signal processors (DSP) performing ideal chromatic dispersion compensation, ideal carrier phase recovery and equipped with a MIMO equalizer based on Least mean squares (LMS) algorithm with optimized parameters.

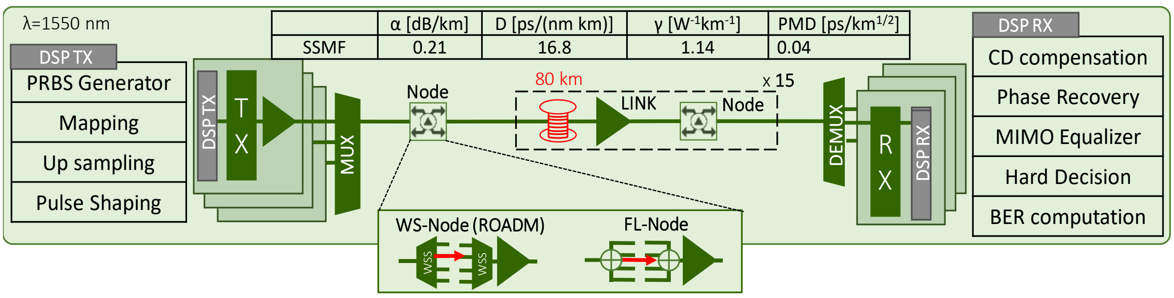

Figure 2-3 MATLAB Simulator

Considered Configurations
We provide data having the following five configurations:

a) Considering WS-Nodes for DSCM and SC signals having 16QAM as MF
b) Considering WS-Nodes for DSCM and SC signals having 64QAM as MF.
c) Considering WS-Nodes for DSCM and SC signals having QPSK as MF.
d) Considering FL-Nodes for DSCM and SC signals having 16QAM as MF.
e) Considering FL-Nodes for DSCM and SC signals having 64QAM as MF.

In particular, Figure 2-4 shows the Q factor in dB collected at the node output as function of the number of crossed network nodes for all these configurations. For each of these configurations we collected 600 IQ Optical Constellations. Namely we collected 20 IQ constellation samples both at the input and at the output of 15 cascaded Network Nodes.

Moreover, Figure 2-5 shows for illustrative purposes the density diagrams of three IQ constellation samples collected from the X polarization of signals having different modulation formats (i.e., QPSK, 16QAM and 64QAM).

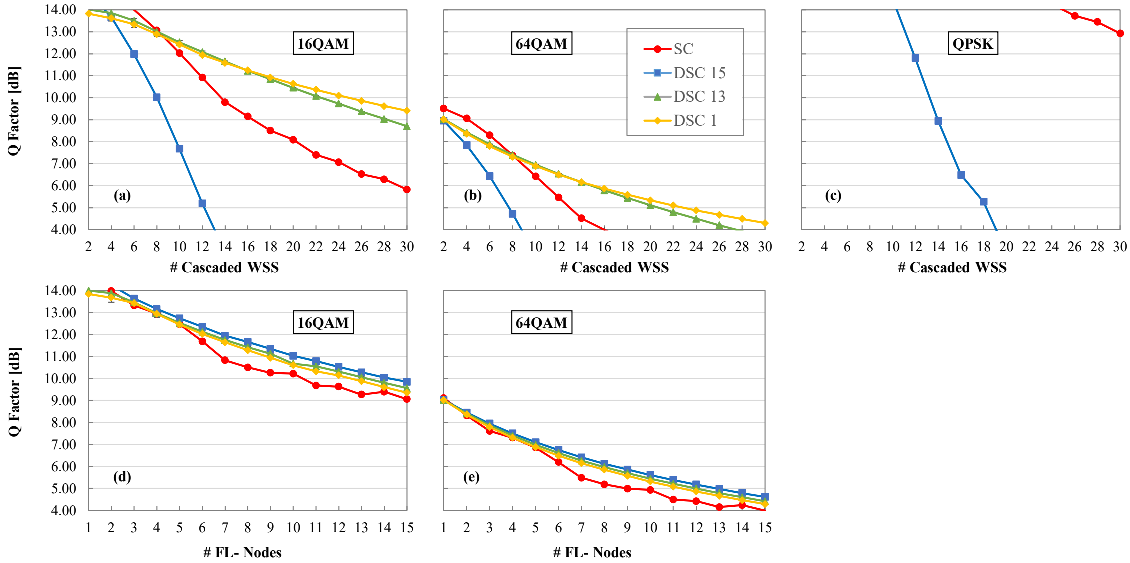

Figure 2-4 Q factor as function of the number of network node crossed

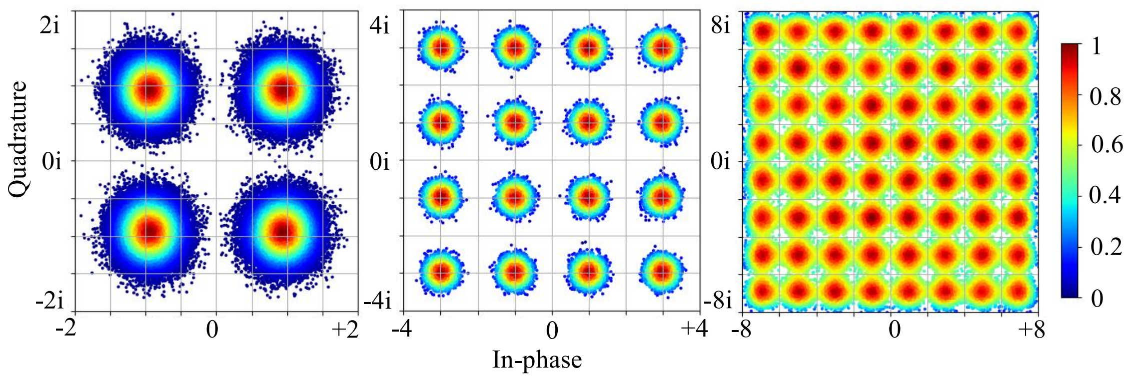

Figure 2-5 IQ Constellations Samples of QPSK, 16QAM and 64QAM Signals

Data Format

The data files are contained in a .zip called 'data.zip'. This latter contains .zip files that follows the format '[a]_[b]-Node_[c]_[d]Sample.zip', where [a] is the signal format (i.e., SC signal or DSCM signal), [b] indicates the node type (i.e., wavelength selective - WS or filterless - FL), [c] indicates the modulation format (i.e., QPSK, 16QAM or 64QAM) and finally [d] corresponds to the sample identifier.

Each .zip file contains five .csv files:

- 'constellations_Xpol_in.csv', 'constellations_Xpol_out.csv': contains the constellation symbols of the X polarization at the ROADM input and at the ROADM output, respectively. Every constellation sample (rows) has 218,450 symbol samples (columns). Every cell contains a complex number, with the position in the real (I) and imaginary (Q) axis.
- spectra_out.csv': contains the spectra of the optical signal before the ROADMs and at the ROADM output. The file has 537 columns that correspond to the relative frequency in GHz around the central frequency (193.41 THz) considering a spectral resolution of 150 MHz.
- 'metadata_in.csv', 'metadata_out.csv': contain metadata at the ROADM input and at the ROADM output, respectively, one sample per row. Specifically, 9 columns are defined:
    - 'Sample': the optical constellation sample identifier (in total there are 20 samples).
    - '#ROADM': the number of ROADM traversed by the optical signal.
    - 'subcarrier_position': digital subcarrier position (counting from the left to the right).
    - ' DSC ': digital subcarrier identifier.
    - 'Subcarriers': the total number of digital subcarriers.
    - 'MF': the m-quaternatary modulation index *m*
    - 'Launch Power [dBm]': optical launch power in dBm.
    - 'D [Km]': length of an optical link in km.
    - 'Gamma [1/(W Km)' : the fiber nonlinear coefficient.
    - 'Spans': the spans contained in every link.
    - 'Links': the total number of links.
    - 'D span [km]': length of a single span in km.
    - 'BER': the bit error rate (BER) measured at the ROADM input or at the ROADM output.
    - 'BER X': the bit error rate (BER) of the X polarization measured at the ROADM input or at the ROADM output.
    - 'BER Y': the bit error rate (BER) of the Y polarization measured at the ROADM input or at the ROADM output.
    - 'Errors X': the number of bits containing errors of the X polarization.
    - 'Errors Y': the number of bits containing errors of the Y polarization.
    - 'Q': the Q factor in dB measured at the ROADM input or at the ROADM output.
    - 'Q X': the Q factor in dB of the X polarization measured at the ROADM input or at the ROADM output.
    - 'Q Y': the Q factor in dB of the Y polarization measured at the ROADM input or at the ROADM output.

At December 2025, this dataset got 4477 Views and 3416 Downloads.

2.3.2. Dataset: Optical Span QoT Data

Dataset name: "Optical Span QoT Data,"
URL: https://github.com/gonz-mart/OpticalFiberSpan_MLmodeling
Pub date: originally 2022 and updated during in the project lifetime.

The OpticalFiberSpan_MLmodeling dataset provides simulated span-level Quality of Transmission (QoT) measurements for Elastic Optical Networks (EONs), tailored to support machine-learning-based performance estimation within the SEASON project on multiband optical transmission. It focuses on predicting the span Generalized Signal-to-Noise Ratio (GSNR) in dB under diverse symbol-rate and loading configurations, enabling data-driven design and control of next-generation, impairment-aware optical transport networks.
In this context of SEASON, accurate QoT estimation at the span level is a key enabler for autonomous control, impairment-aware routing and dynamic spectrum assignment in flexible-grid EONs. The OpticalFiberSpan_MLmodeling dataset contributes with a benchmark for training and validating such ML-based QoT prediction models, complementing SEASON's efforts on multi-band transmission modeling and techno-economic assessment.
The dataset is generated numerically using an incoherent Gaussian Noise (GN) model, which is widely adopted to approximate nonlinear interference in coherent optical systems while keeping computational complexity manageable. GN-based modeling allows systematic exploration of span configurations—varying symbol rate, span length, launch power and channel loading—without the cost of extensive experimental campaigns, while still reflecting realistic transmission characteristics. The resulting data therefore strikes a balance between physical fidelity and breadth of coverage, making it suitable for training supervised learning models that generalize across operating regimes
OpticalFiberSpan_MLmodeling is organized into three CSV datasets, each comprising 10,000 samples that emphasize different operational scenarios for EONs. DS1 fixes the symbol rate at 64 GBaud while sweeping the channel loading factor from 25% to 100%, capturing the impact of spectral congestion on GSNR. DS2 introduces random symbol rates of 32, 64 and 96 GBaud with varying occupancy, thereby emulating elastic transponders and mixed-rate superchannels typical of flexible-grid multiband networks. DS3 again uses a 64-GBaud symbol rate but maintains a fixed 25% loading factor, providing a controlled baseline dataset that isolates the effect of other parameters such as span length and launch power.
Each sample encodes a span configuration via core physical-layer inputs: symbol rate (GBaud), span length (km), launch power (dBm), Channel Under Test (CUT) position within the WDM grid, and aggregate channel loading factor in percent. To better capture local spectral context, several derived features are included, such as CUT deviation from the spectral center (left and right), left/right loading factors, counts of empty adjacent channels, and noise-related quantities like nonlinear interference (NLI) noise and amplified spontaneous emission (ASE) noise. The prediction target is the span GSNR in dB, and all fields are stored in openly available CSV tables with the header "SymbolRate", "SpanLength", "LaunchPower", "CUTPosition", "CLF", "CUTDevLeft", "CUTDevRight", "CLFLeft", "CLFRight", "EmptyAdjLeft", "EmptyAdjRight", "NLINoise", "ASENoise", "GSNR" to facilitate straightforward ingestion into common ML frameworks.

The dataset is explicitly designed for developing, benchmarking and comparing machine learning models for span-level QoT estimation, such as regression trees, kernel methods, and neural networks. By providing multiple datasets with distinct symbol-rate and loading distributions, it supports rigorous studies on generalization, domain shift and training-set selection, as demonstrated in the related JOCN 2025 work "Evaluating QoT-aware hybrid grooming schemes. In dynamic C + L-band optical networks." Within SEASON, such models can feed higher-layer controllers to enable adaptive routing, spectrum and band assignment in multiband networks, ultimately improving energy efficiency and resource utilization in elastic optical infrastructures.

2.3.3. Dataset: Reference Metro-Regional Network Topology Data

Restricted Access.
(Available at: SEASON_Metro-Regional_Reference_Network_Italy.xlsx – internal use only)
Pub date: 09/2024
The entire topology of a metro-regional network (metro core mesh plus all horseshoe structures) inspired by a real TIM deployment is included in an excel file and made available within the consortium for network studies.
The topology is organized in two tiers, a core tier made of 23 metro-core nodes and 29 metro-core links, and 156 aggregation nodes divided in 11 basins, each of them forming a separate horseshoe ended on two metro-core nodes (for a total of 169 metro aggregation links). For confidentiality reason the data are appropriately anonymized. In addition to link lengths some characterization parameters are provided for each node, i.e., the number of households covered, the number of mobile radio site hosting macro cells and the number of mobile radio sites that, in future, could potentially host a small cell mobile radio site.

2.3.4. Dataset: Reference Backbone Network Topology Data

Restricted access
(Available at: SEASON_Backbone_Reference_Network_Italy.xlsx – internal use only)
Pub date: 09/2024
A backbone network inspired by TIM's national photonics network was made available to project partners for network studies.
The field network is constantly evolving, and the number of nodes and links increases over time. The version provided, appropriately anonymized, consists of a meshed network with 44 nodes and 71 links. In addition to the network graph, the role of each node (national, regional, transit) was provided, as well as the overall length of the links, the fiber type, and, for long links (typically over 90-100 km), the number of intermediate amplifications required. For confidentiality reasons, the data has been anonymized and subjected to small changes in value.

2.3.5. Dataset: Packet Trace Data

Available at: https://github.com/josetilos/FlowTraceSimulator
Pub date: 06/2024

This R script simulates network flow traces based on given link capacity, load, and packet/flow characteristics. It generates a trace file that can be used for network analysis and research purposes. The script then outputs the trace data to a CSV file. As input parameters, the simulator takes into account:

- LinkCapacity: The capacity of the link in bits per second (bps); by default, 100 Gbps.
- Link Load: The load on the link as a fraction of the total capacity, by default 0.4 (or 40% load).
- Packet Size Distribution: A vector specifying the sizes of packets in bytes. The script uses a trimodal distribution with packet sizes of 64, 596, and 1500 bytes. Each packet size is characterised by the weights, in this case 4/12, 2/12, and 6/12.
- Flow Characteristics, including the total number of flows (10,000 flows) and the alpha parameter for determining the Zipf structure of the flow size distribution, which determines the number and weight of heavy hitters (alpha initially set to 1.1).
- Trace duration: by default, the time window specified is 100 ms. The script produces a CSV file named Trace100G.csv, which contains the simulated trace data. The columns in the CSV file are:
    - ArrivalTime: The arrival time of the packet.
    - FlowID: The flow ID to which the packet belongs.
    - PacketSize: The size of the packet in bytes. The following is an example of the first rows of the CSV:

```
"ArrivalTime","FlowID","PacketSize"
0.00000123,5,64
0.00000234,7,1500
0.00000345,3,596
...
```

2.3.6. Dataset: Modified detection areas of constellation points of 16QAM signals for nonlinear impairment mitigation

Available at: https://doi.org/10.34810/data1878
Pub date: 04/2024

One way to deal with nonlinear impairments causing signal degradation in quality of transmission (QoT) is to modify the detection areas of each constellation points (CPs). Received optical in-phase and quadrature (IQ) constellations reveal invaluable information of the impairments affecting the optical signal using *m*-QAM modulation format. In our recently published paper [1], we investigated the method to modify the detection areas for different CPs based on the received IQ constellation symbols. Here in this dataset we published the detection area for different configurations of established lightpath.

Simulation environment

To generate the received symbols, we considered a multiband C+L+S scenario with full spectrum usage, with 337 channels considering 50 GHz channel spacing. Ranges of channels for the S, C, and L bands are [1, 128], [129, 215], and [216, 337], respectively. The MATLAB-based simulator of a coherent WDM system was used to generate IQ constellations for 16QAM@32GBd signal shaped by root-raised cosine filter with a 0.06 roll-off-factor. Pseudorandom binary sequences of length 214 are used as input of every channel. The signal is propagated through standard

single mode fiber, with a launch power of 0 dBm and collected at the Rx side after a number of 80-km fiber spans. Spans are modeled by solving the nonlinear Schrödinger equation, whereas ideal inline OAs are modelled as erbium-doped fiber amplifier (EDFA) for the C and L bands and thulium-doped fiber amplifier (TDFA) for the S band. An adaptive step size algorithm is included to further reduce the computation time required. Finally, at the Rx, a
Digital Signal Processing (DSP) block performs ideal chromatic dispersion compensation and phase recovery [1]. According to this simulation environment, we generated constellation after specific number of spans rangingg up to 13, for a set of selected reference channels (RCh) in S band (RCh 1, RCh 20, RCh 97), C band (RCh 154) and L band (RCh 225, RCh 304, RCh 337).

Generated data

To find the modified detection area for each CP, as we explained in [1], we divide the coordination plane of a 16QAM constellation into small grids. In particular, we considered the coordinate plane as a square with top-left corner equals to [-5, 5] and bottom-right corner equals to [5, -5] and divided the plane into k=10000=100×100; thus, the width and height of each grid equals to δ=0.1. The algorithm computes the probability that each grid cells belonging to each CP and then assign the grid to the CP with highest probability. Set of all grids with the same related CP i are considered as the detection area for CP i. Please refer to [1] for additional algorithm details. Figure 2-6 shows an example of the definition of grids and assigned detection area to CP=[-3, 3].

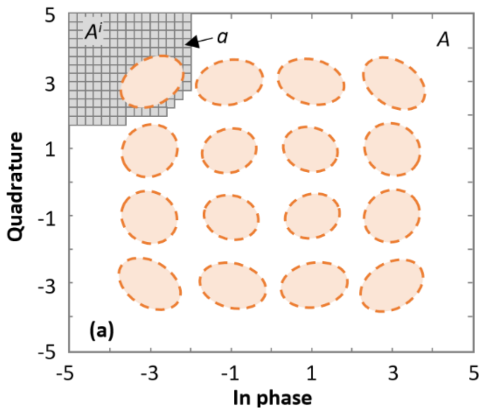

Figure 2-6 Definition grid for 16-QAM signal constellations

Figure 2-7 shows the optimized detection areas for a lightpath with 5 spans using channels in different bands. It is worth noting that we observe the different shapes of the detection areas for the different channels in different bands.

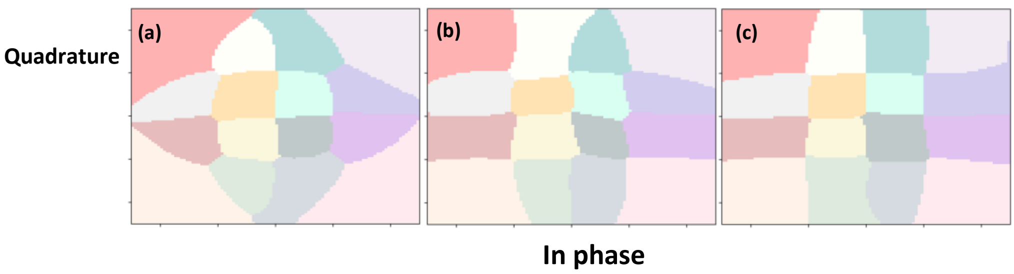

Figure 2-7 Example of optimal detection areas for 5 spans for channel in S band (a), C band (b), and L band (c).

Data structure and processing instructions

The data files are in a .zip file called ‘data.zip’. In the ‘data.zip’ file, there are folders that follow the format ‘Span_[a]’ where [a] indicates the number of spans that the lightpath crosses. In each ‘Span_[a]’ folder, there are 7 folders that follow the format ‘RCh_[b]’ where [b] represents the index of RCh where within each folder there is a .csv file called ‘grids.csv’ which is actually a 100×100 matrix to represent all the grids in the coordination plane and their related CPs.

Within each grid (i.e., a cell in the ‘grids.csv’ file) there is related CP which follows the format ‘[x, y]’ where x and y are the coordination of the centroid of the related CP. To compute the cell in proper ‘grids.csv’ file for the received symbol s=[sI, sQ], we compute the column index and index in the .csv file as below,

$$Colidx = \left\lfloor \frac{s_I}{\delta} \right\rfloor + \frac{\sqrt{k}}{2} \quad (1)$$

$$Rowidx = \left\lfloor \frac{-s_Q}{\delta} \right\rfloor + \frac{\sqrt{k}}{2} \quad (2)$$

where ⌊.⌋ indicates the floor function and *k* is the total number of grid cells (10000).

At December 2025, this dataset got 1788 Views and 855 Downloads.

2.3.7. Dataset: IQ Constellation Samples from Simulation of 16-QAM Multi-Band Optical Transmission System

Available at: https://doi.org/10.34810/data1969

The dataset contains collected symbols for different channels after traversing specific number of spans and the description file introduces a multiband optical simulation environment and the structure of the dataset, enabling the study of signal behaviour across channels and spans to optimize next-generation communication networks.

A multiband C+L+S optical communication system with 337 channels and 50 GHz spacing was simulated using a MATLAB-based WDM system. Signals were 16QAM@32GBd with pseudorandom binary input, shaped by a root-raised cosine filter, and propagated through single-mode fibre using the nonlinear Schrödinger equation solved via the split-step Fourier method. Inline amplifiers (EDFAs and TDFAs) compensated span losses, while DSP performed chromatic dispersion compensation and phase recovery. Constellations were generated for up to 13 spans to analyse signal behaviour across bands and distances, considering inter-channel effects like stimulated Raman scattering.

The collected symbols reflect the behaviour of signal after propagation in multiband optical transmission system. The effect of fibre nonlinearities and stimulated Raman scattering effect can be observed in collected symbols.

The data files are in a .zip file called ‘Data.zip’. In the ‘data.zip’ file, there are folders that follow the format ‘Span_[a]’ where [a] indicates the number of spans that the lightpath crosses. In each ‘Span_[a]’ folder, there are 337 folders that follow the format ‘Channel[b]’ where [b] represents the index of channel under test where within each folder there are 8 folders in format ‘Rep_[c]’ where [c] represents the index of repetitions, and then finally in each folder, there is a file called ‘data.csv’ which is a .csv file contains received symbols for channel under test after specific number of traversed spans. This file is column vector with 16384 rows in complex format ‘[r]+[i]j’ where [r] represents real value of the received symbol (which is translated into 'I' axis in IQ representation) and [i] shows imaginary part of the received symbol (which is translated into 'Q' axis in IQ representation).

2.3.8. Dataset: Simulation and experimental data of frequency domain and time domain optical signal measurements for optical network digital twins

Available at: https://doi.org/10.34810/data1143
Pub date: 04/2024

MATLAB based Optical Coherent System Simulator

A simulator of a digital coherent system has been implemented in MATLAB and employed to model the optical layer. We consider an 11 channels wavelength division multiplexed (WDM) system, where each channel is modulated with 16-QAM and operates at 64 GBd. The channels are mapped into a 75-GHz spectrum grid. The optical signal (constellation sample) is produced by generating $2^{20} - 1$ long pseudorandom binary sequences (PRBS), Nyquist-shaped with a roll-off factor of 0.06. The considered optical lightpaths (LP) configurations are composed of a transmitter and a receiver connected by a number of optical nodes (*N*) and *N*-1 optical links composed by a number of spans of equal length, resulting in a total distance *D*. In each optical node is present a reconfigurable optical add-drop multiplexer (ROADM) composed by two wavelength selective filters (WSS) and by two Erbium-doped fibre amplifiers (EDFA). The optical filters transfer function was obtained from the experimental measurement of a 1x4 WSS.

We assume a flat launch power profile at the fibre input of -1 dBm for the normal operation. The pulse propagation along the fibre is modelled using the split-step Fourier method with a propagation step-size of 100 m. The impact of fibre loss, group velocity dispersion, and nonlinearities, namely cross- and self-phase modulation, are considered in the simulation. The use of standard single mode fibre (SSMF), modelled as indicated in Figure *2-8* is assumed in the numerical simulations. The EDFAs' noise figure is 5 dB whereas its gain is set to ideally compensate for the span loss. Finally, DSP blocks capable of performing ideal chromatic dispersion (CD) compensation and carrier phase recovery are considered in the receiver. For all the considered configurations, the channel under test was the central one, from which 2^{18} symbols per polarization were collected and stored.

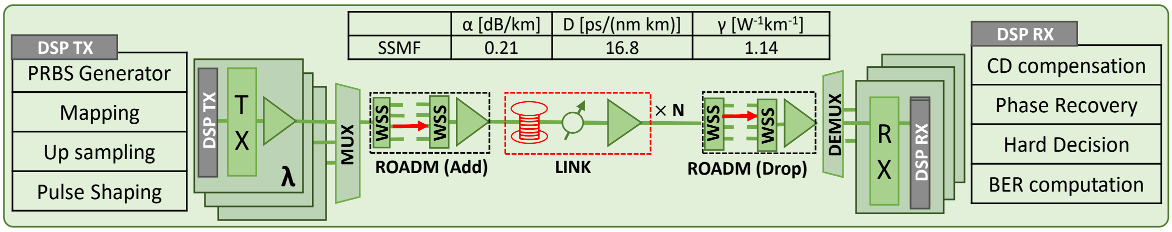

Figure 2-8 MATLAB Simulator

Considered Configurations

"Failure-Free Data"

There are 12 zip files containing lightpaths having different span lengths, number of spans per link and total number of links as detailed in the next table. Thus, in total 62 lightpath configurations were considered (5 x 8 + 6 x 6 + 8 x 5 + 9 x 4 + 8 x 4 + 9 x 3 + 2 x 9 + 3 x 8 + 5 x 5 + 7 x 3 + 8 x 3 + 9 x 2). 20 optical constellation samples (corresponding to 20 uniquely seeded PRBSs) were collected for every LP configuration.

span length[km]	50				60				80			
# of spans per link	5	6	8	9	8	9	2	3	5	7	8	9
# of links	8	6	5	4	4	3	9	8	5	3	3	2

“Failure Data”

As for failure management, we generated a specific DB to investigate the impact of soft-failures on a LP. Figure *2-9* illustrates several possible failures: a) corresponds to the regular network operation, i.e., when the lightpath is not affected by any failure or misconfiguration; b) illustrates a soft-failure in the transmitter, e.g., an extra gain in its booster amplifier leading to an extra transmission power (eTxP); c) illustrates the impact of an EDFA in the first ROADM with an increased noise figure (iNF); Finally, d) corresponds to a failure in a WSS in the first ROADM that produces filter shift (FS) or filter tightening (FT) on the optical signal. In this analysis we considered a lightapth composed by six links of 240 km (4 spans of 60 km). For each soft-failure, optical constellation samples are available with different failure magnitude. Note that five failure magnitudes (FM) where provided for each soft- failure. Moreover, ten samples are provided for the case of correct operation (that has FM equal to zero).

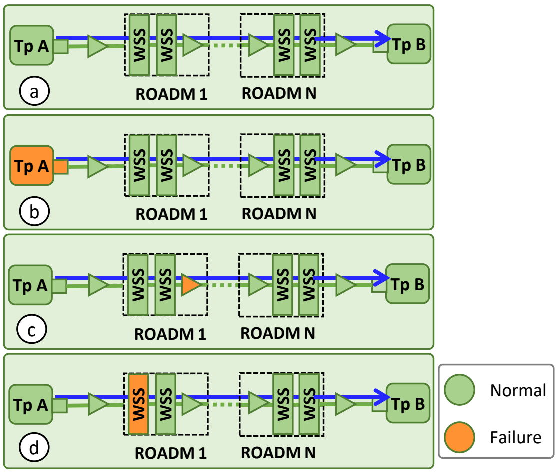

Figure 2-9 Considered use cases for failure management: normal operation (a), eTxP soft-failure (b), iNF soft-failure (c), FS and FT soft-failure (d).

Data Format

The data files are contained in a .zip called “data.zip” in which are contained in turn other two .zip files:
“failure-free_data.zip” and “failure_data.zip”.

“Failure-Free Data”

The data files are contained in a .zip called “Failure-free_data.zip”. This latter contains .zip files that follows the format “[x]Spans_[y]km-long_[z]Links.zip”, where [x] is the number of spans, [y] is the maximum number of links and [z] is the span length in Km. Each .zip file contains three

.csv files

- 'constellations_Xpol_in.csv', ' constellations_Xpol_out.csv': contains the constellation symbols of the X polarization at the ROADM input and at the ROADM output, respectively. Every constellation sample (rows) has 262,144 symbol samples (columns). Every cell contains a complex number, with the position in the real (I) and imaginary (Q) axis
- 'metadata.csv': contains metadata, one sample per row. Specifically, 9 columns are defined:
    - 'Id': row identifier
    - 'Sample': the optical constellation sample identifier (in total there are 20 samples).
    - 'Gamma [1/(W Km)': the fibre nonlinear coefficient in 1/(W Km).
    - 'LP Spans': lightpath number of spans per link.
    - 'LP Links': lightpath number of links.
    - 'Link Length [Km]': length of an optical link in Km.
    - '#Node': number of ROADM.
    - 'Distance [km]': The distance crossed by the optical signal in Km.
    - 'BER': the bit error rate (BER) measured at the receiver.

"Failure Data"

The data files are contained in a .zip called "Failure_data.zip". This latter contains .zip files that follows the format "[a]UC_[b]FM.zip", where [a] is the use case (0: normal operation, 1: ETxP, 2: iNF, 3: FS, 4: FT) and [b] is the total number of samples per use case.

The .zip files contain eight .csv files:

- constellations_Xpol_in.csv', ' constellations_Ypol_in.csv', 'constellations_Xpol_out.csv', 'constellations_Ypol_out_Y.csv': They contains the constellation symbols at the ROADM input and at the ROADM output for both polarizations, respectively. Same format that failure free database constellation files.
- PRBS_Xpol.csv', PRBS_Ypol.csv': contain the PRBSs transmitted over the two polarizations in decimal number.
- spectra_out.csv': this file contains the relative frequency in GHz in the first row (spectral resolution 1GHz) and the measured power spectral density in the second row.
- 'metadata.csv': contains metadata, one sample per row. Specifically, 12 columns are defined
    - 'Id': row identifier.
    - 'UC': use case identifier (0: normal operation, 1: ETxP, 2: iNF, 3: FS, 4: FT).
    - 'FM_id': failure magnitude identifier.
    - 'FM': failure magnitude (in dB for ETxP and iNF, in Hz for FS and FT).
    - 'Sample': use case sample identifier.
    - 'Gamma [1/(W Km)': the fibre nonlinear coefficient in 1/(W Km).
    - 'LP Spans': lightpath number of spans per link.
    - 'LP Links': maximum lightpath number of links.
    - 'Link Length [Km]': length of an optical link in Km.
    - '#Node': number of ROADM.
    - 'Distance [km]': The distance crossed by the optical signal in Km.

- 'BER': the bit error rate (BER) measured at the receiver.

Experimental Setup

Figure 2-10 depicts the experimental setup. At the transmitter (Tx) side, 21 DP-16QAM signals, with symbol rates of 28 GBd and 32 GBd and channel spacing of 50 GHz, were generated using an optical multi-format Tx (OMFT). The modulation losses are compensated by an EDFA (labeled 19 in Figure 2-10. Afterwards, the resulting WDM signal is launched into a reconfigurable optical add/drop multiplexer (ROADM) composed of a WSS, an attenuator and an EDFA. The WDM signal is launched into the optical fiber with optimal launch power of −1 dBm and is then propagated through up to three spans, each composed of two spools of 40 km. For different distances, the setup connects the span EDFAs directly to the coherent receiver using the optical switch (OS). After crossing EDFA 11, the signal is filtered by an optical tunable filter (OTF) with measured bandwidth of 37.34 GHz and is pre-amplified by EDFA 130.

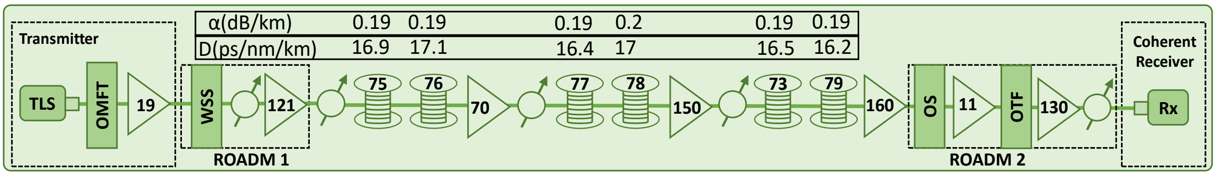

Figure 2-10 Experimental Setup

Considered Configurations

For all the considered configurations, the channel under test was the central channel, from which 216,144 symbols were collected. Eight different configurations were investigated in this analysis, considering two SRs and four distances (0,80,160,240 km).

For further information, please visit https://hhi.fraunhofer.de/networkdata.

Data Format

Data files are contained in ‘data.zip’ file, that contains two different csv files:

- ‘constellations_Xpol_out.csv’: contains the constellation symbols, one sample per row. Every constellation sample has 216,144 symbol samples (columns). Every cell contains a complex number, with the position in the real (I) and imaginary (Q) axis.
- ‘metadata.csv’, contains metadata, one sample per row. Specifically, 7 columns are defined:
  - 'Id': row identifier
  - 'Pol': polarization
  - 'SR [GBd] ': Symbol Rate in GBd
  - 'Distance [km] ': The distance crossed by the optical signal in Km
  - 'Pch [dBm] ': The channel power at the fibre input in dBm
  - 'OSNR [dB] ': the optical signal-to-noise ratio (OSNR) in DB measured at the receiver.
  - 'BER': the bit error rate (BER) measured at the receiver.

2.3.9. Dataset: SEASON Access-Metro Reference Network Topology

“SEASON Access-Metro Reference Network Topology,” Zenodo, 2025, https://zenodo.org/records/16737162

Published: August 22, 2025

This dataset presents a metro-regional network topology inspired by real topologies designed by the Telefónica group and four realistic access network topology geotypes prepared by Telecom Italia within the SEASON project. Mapping access geotypes to metro-regional nodes will help researchers gain a comprehensive understanding of the metro-access segments, which could be a valuable tool for networking studies and technoeconomic analyses.

2.3.10. Dataset: TAPI Streaming over MQTT

This dataset ("TAPI Streaming over MQTT," Zenodo, 2025, https://zenodo.org/records/17189453) corresponds to the traces generated by an optical controller following a Linux Foundation TR-548 TAPI Streaming approach. In this case, the protocol transport used in MQTT. A MQTT Broker (Mosquitto, Open Source) is responsible for collecting traces generated by the optical SDN Controller and forwarding them to subscribed clients depending on specific topics. In this case, the topic is "tapi/streaming"

The SDN Controller is connected to the MQTT broker (localhost, 1883) at startup. A first sync dump is realized upon connection. Subscribers are connected to the same MQTT broker. A TAPI client requests and deletes media channel services using a TAPI North Bound Interface (NBI). Based on specific events on the network streaming log records are generated.

The considered topology corresponds to the Telefonica Network. There are 65 ROADMs (Nodes) and 270 links. Links are flexi-grid with C, L and S bands. Each node has 10 transceivers, so there is a total of 650 Service Interface Points.

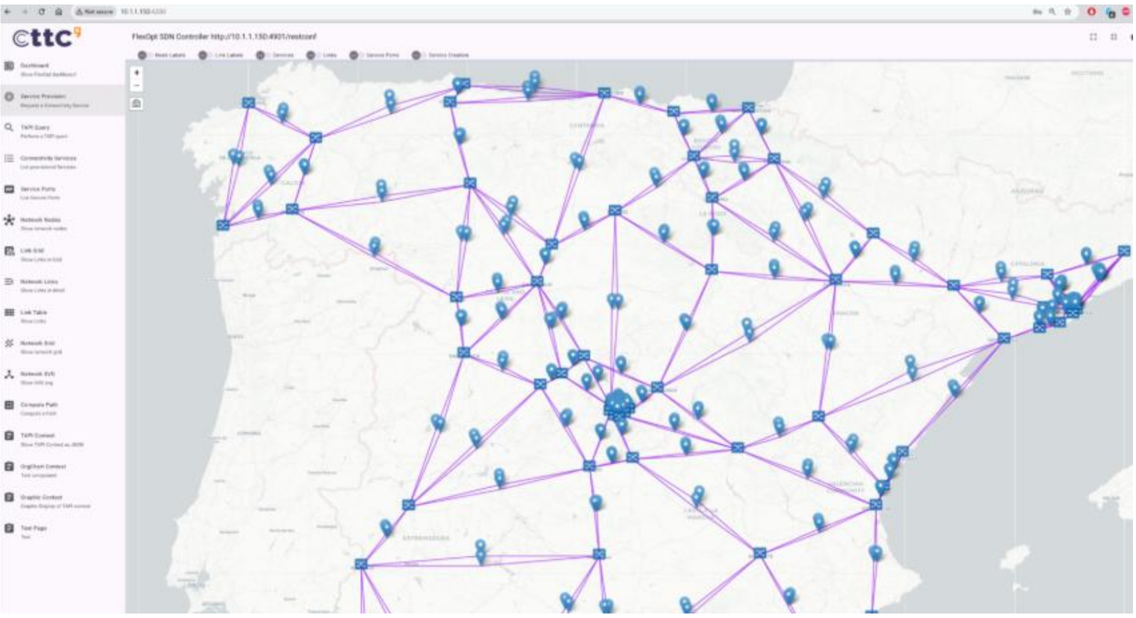

Figure 2-11 Telefonica Network

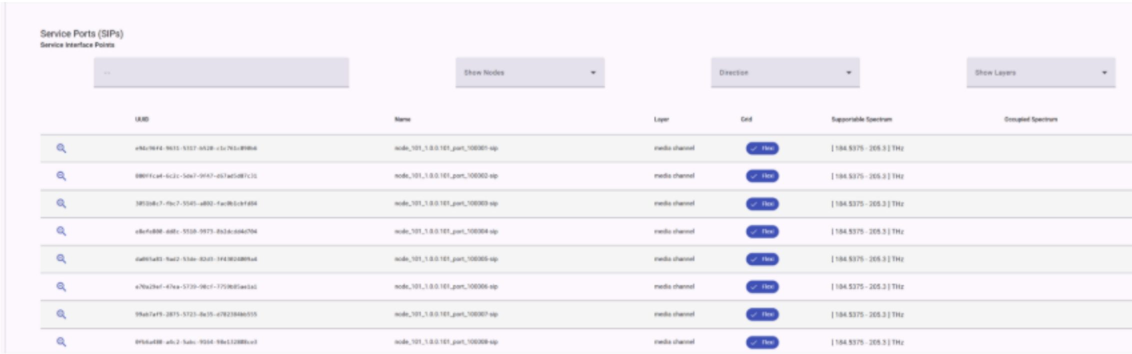

Figure 2-12 Service Points

The full TAPI Context is provided in context.json. Requests are generated randomly, with the following parameters. Number of connections: 1000 (N) Holding Time: 5 “time units” and Interarrival Time: 1 “time units”. The services (file services.log) includes N lines of the format

<timestamp> LSP: # (<name>) - <sip-uuid-src> <sip-uuid-dst> S: <arrival-time> R: departure

```
2025-09-22 18:02:08,204 LSP: 0 (SERVICE-0) - 1e7ad3f6-1b37-5f98-9a31-de5392233a17 to 98c93ee0-e1e1-5d77-8544-5e85c8f4b8f0 S: 0.06901986161910273 s. R: 0.6332621871205555 s.

2025-09-22 18:02:08,204 LSP: 1 (SERVICE-1) - ac1c1264-0989-5197-9f9c-df248cd46e6d to e8d90252-65cc-5572-96b2-a89de38d6ce3 S: 0.753480363939603 s. R: 1.3990739232324951 s.

2025-09-22 18:02:08,228 LSP: 999 (SERVICE-999) - 68e3e9ec-c9d8-5c3a-969f-c4c74984c7b4 to d90e3337-8320-5d28-b01d-3a4dc5d35abf S: 1003.3061257867311 s. R: 1010.0878947148954 s.
```

…

The events are also stored:

```
2025-09-22 18:02:08,275 events: 1999

2025-09-22 18:02:08,275 SETUP LPS: SERVICE-0 1e7ad3f6-1b37-5f98-9a31-de5392233a17 to 98c93ee0-e1e1-5d77-8544-5e85c8f4b8f0 (100 GHz) [5dfb444e-20ec-41ad-9918-6f1eafe21397]

2025-09-22 18:02:08,275 Starting new HTTP connection (1): localhost:4901

2025-09-22 18:02:08,289 http://localhost:4901 "POST /restconf/data/tapi-common:context/tapi-connectivity:connectivity-context HTTP/1.1" 201 0

…

2025-09-22 18:02:13,009 events: 1990

2025-09-22 18:02:13,009 RELSE LSP: SERVICE-5 [54682c87-26cb-412a-8a69-2412ae241a50]

2025-09-22 18:02:13,010 Starting new HTTP connection (1): localhost:4901

2025-09-22 18:02:13,012 http://localhost:4901 "DELETE /restconf/data/tapi-common:context/tapi-connectivity:connectivity-context/connectivity-service=54682c87-26cb-412a-8a69-2412ae241a50 HTTP/1.1" 204 0
```

The file mqtt_messages.log includes the MQTT messages with the format [<timestamp>] Topic: <topic>, Message: JSON message

Example:

[2025-09-22 18:02:01.310927104] Topic: tapi/streaming, Message: {"metadata":{"measurement":"EventTelemetry","index":"cttc-index"},"data":{"tapi-streaming:log-record":{"log-record-header":{"tapi-context":"02a8bff0-dd1e-55f1-b31f-80a02491e44b","token":"0","log-append-time-stamp":"2025-09-22 16:02:01.310221693 UTC","entity-key":"f92aef68-2fef-54e9-b6fe-a4b684354474","record-type":"RECORD_TYPE_CREATE_UPDATE"},"log-

```
record-body":{"event-time-stamp":{"primary-time-stamp":"2025-09-22 16:02:01.310256269
UTC"},"node":{
<snip>
```


2.3.11. Dataset: Synthetic Metrics for AI/ML-enabled Self-Healing Orchestration in Converged Optical-Compute Networks

The dataset ("Synthetic Metrics for AI/ML-enabled Self-Healing Orchestration in Converged Optical-Compute Networks," Zenodo, 2025, https://zenodo.org/records/17985575) contains time-series telemetry and service performance metrics collected from a synthetically modeled execution of the SEASON HHI self-healing dual-protection scenario. The description file introduces the converged optical-compute simulation environment and the structure of the dataset, enabling the study of orchestration efficiency, service resilience, and techno-economic impact under dynamic failure and recovery conditions. A converged optical-compute network environment was simulated using a discrete-time synthetic generator aligned with the SEASON demo architecture (Service Orchestrator, Network Orchestrator, Optical/IP controllers). The scenario models a high-bandwidth video streaming service scaling from 2 to 30 concurrent streamers, subjected to a sequence of critical network faults. The workflow implements a dual-protection strategy: an initial failure on the primary path triggers an automated reroute, followed by a second failure triggering a protection switch to a backup path, and finally a rollback to the primary path. The workload profile models 64 Mbps per stream with non-linear power consumption curves to reflect realistic CPU and optical transceiver energy dynamics.

The collected metrics reflect the behaviour of the service and infrastructure throughout the orchestration lifecycle. The effect of network impairments can be observed in the throughput and RTT measurements, while the efficacy of the self-healing logic is visible in the recovery of QoE metrics and the stabilization of control-plane state after rerouting. More details can be found in D5.3.

2.4. ORGANIZATION OF EVENTS: WORKSHOPS, TUTORIALS, SUMMER SCHOOLS AND DEMOS

SEASON also organizes various events to complement the project's dissemination activities. Yearly workshops have been organized either co-located at well-known conference venues (e.g., ECOC, OFC, EuCNC) or organized as separate events. Tutorials and summer schools were organized to reach out to early-stage researchers as well as the scientific community.

Table 3: Planning of events

Planned organizational events	Month	Goal of the event
Publication in selected peer-reviewed Journals	M10, M22, M32	Communicating SEASON's concepts, goals, and ambitions
Presentation and publication at selected scientific conferences/workshops	M12, M24, M36	Educating the scientific community with technological development within SEASON.

Participation at industry conference/workshops/events	M28, M36	Real-time demonstration of SEASON's technology.

2.4.1. Year 1

During the project's initial year, the following events were organized.

- Workshop on Women in Telecommunications (WeInTel), collocated with the IEEE International Conference on Transparent Optical Networks (ICTON) 2023.
- Workshop on Beyond-5G Network Operation (B5GNeO) collocated with the IEEE International Conference on Transparent Optical Networks (ICTON) 2023
- Co-organization of EUCNC Special Session, "Novel technologies in disaggregated packet-optical networks to support 6G", Gothenburg June 2023

Figure 2-13: WeInTel Workshop 2023 in Bucharest

2.4.2. Year 2

During the project's second year, the following events were organized.

- Workshop on Women in Telecommunications (WeInTel), collocated with the IEEE International Conference on Transparent Optical Networks (ICTON) 2024.
- Luis Velasco, Ramon Casellas, Francesco Paolucci. (ICTON Demo Zone) July 2024, https://icton2024.fbk.eu/icton-demo-zone
- Luis Velasco, Workshop on 6G Network Operation (6GNeO) collocated with the IEEE International Conference on Transparent Optical Networks (ICTON) 2024

- Luis Velasco, “Security in Classical Optical Communications and Quantum technologies”, ONDM, 2024, https://ondm2024.uc3m.es/program/workshops
- Lecture at Summer School “ARTIST - Pervasive ARTIficial Intelligence for Next-G Softwarized neTworks”, F. Cugini (CNIT) on Disaggregated Optical Networks, 2024
- Summer School, “ARTIST - Pervasive ARTIficial Intelligence for Next-G Softwarized neTworks”, Scuola Superiore Sant’Anna, Pisa, Italy, June 9th-13th 2025, Co-organized by SEASON Project (A. Sgambelluri and F. Cugini also part of the key teaching staff) https://www.santannapisa.it/en/seasonalschool/artist-edizione-23-24
- Ramon Casellas, Ricardo Martinez, Ricard Vilalta, Raul Muñoz, “SDN Control of Multi-band over SDM Optical Networks with physical impairments” TUTORIAL at OFC’24 in San Diego, 2024
- Behnam Shariati, “What Can Digital Twins Fueled with Generative AI Offer to Optical Networks.” WS5 at ECOC 2024
- Luis Velasco, “Self MAnaged Sustainable High Capacity Optical Networks”, Symposium on Optical-Wireless Convergence: Beyond Xhaul, Enabling the Communications-Computing Continuum, IEEE Future Networks World Forum, 2024.

Figure 2-14: WeInTel Workshop 2024 in Bari

2.4.3. Year 3

During the project's last year, the following events were organized.

- Workshop on Women in Telecommunications (WeInTel), collocated with the IEEE

International Conference on Transparent Optical Networks (ICTON) 2025.

- ComSoc Women in Communications Engineering (WICE): “Ensuring a Diverse Future Advancing Women in Telecommunication” collocated with IEEE ICMLCN, 2025.
- Luis Velasco, “Optical Network Digital Twin”, in Workshop 3: Integrating Network Digital Twinning into Future AI-based 6G Systems, EuCNC 2025
- Luis Velasco, “Self MAnaged Sustainable High-Capacity Optical Networks”, in Workshop 13: Optics and Photonics Innovations, EuCNC 2025
- Pol González, Ramon Casellas, Francesco Paolucci. (ICTON Demo Zone) July 2025, https://icton2024.fbk.eu/icton-demo-zone
- Luis Velasco and Marc Ruiz, Workshop on 6G Network Operation (6GNeO) collocated with the IEEE International Conference on Transparent Optical Networks (ICTON) 2025
- Behnam Shariati, “Optical networks and AI: do we need a brand-new infrastructure for AI, and can Ai help run it?” WS14 at ECOC 2025.

Figure 2-15: WeInTel Workshop 2025 in Barcelona

Dissemination Level	PU

Figure 2-16: WICE Workshop 2025 in Barcelona

- Summer School, "ARTIST - Pervasive ARTIficial Intelligence for Next-G Softwarized neTworks", Scuola Superiore Sant'Anna, Pisa, Italy, June 9th-13th 2025, Co-organized by SEASON Project (A. Sgambelluri as coordinator, F. Cugini part of the key teaching staff) https://www.santannapisa.it/en/artist-pervasive-artificial-intelligence-next-g-softwarized-networks-24-25
- Summer School on Optical Communication, Heinrich-Hertz-Institut, Berlin, 2025 (https://www.hhi.fraunhofer.de/en/summerschool2025.html). During the summer school, young researchers were introduced to important open questions in view of the operation of optical networks and challenging problem areas in the fields of capacity scaling in optical networks. During the school, several SEASON partners gave several lectures regarding various aspects, such as the potential of multi-band transmission, space division multiplexing and improved monitoring for increasing network availability as well as flexible use of resources. Market and societal requirements were also taken into account. After the presentation, the young researchers had the opportunity to ask questions about the talk and optical networks in general, thereby benefiting from the many years of experience of researchers who have been involved in the development of optical networks for decades.
- Participation in the 2025 open-for-all summer school on *Next generation ultra-high-capacity access/metro optical networks* organized by the NESTOR Marie Skłodowska-Curie Doctoral Network (https://nestor-network.net/mini-symposium-by-upc/). Luis Velasco and Marc Ruiz introduced the main challenges that operators' networks need to face with the introduction of 6G in terms of flexibility, dynamicity, resilience, sustainability, real-time performance, etc. All these motivates the need of developing Network Digital Twinning (NDT) solutions.

2.4.4. Coordination with other projects

SEASON participates actively in the following SNS JU Coordination WGs:

- Steering Board (SB)
- Technical Board (TB)
- Communication Task Force

Active participation in the following SNS JU WGs:

- Pre-Standardization
- Women in Telecommunications and Research (WiTaR)
- Hardware Technologies WG
- SME
- Vision and Societal Challenges
- 6G Architecture
- Test, Measurement and KPIs
- Participation in the Open SNS WG
- Sustainability
- Software Network

Specific activities:

- Phase 1 Projects questionnaire
- AI/ML questionnaire
- Sustainability questionnaire
- Vertical Engagement Tracker

Figure 2-17: SEASON in JU 6GSNS

2.4.4.1. Year 1

- Joint meeting between SEASON and FLEX-SCALE projects, 2hours, Pisa, June 2023
- ALLEGRO: Co-organization of Women In telecommunication (WInTel) workshop during ICTON 2023

2.4.4.2. Year 2

- DESIRE-6G: Common experimental for RAN and Transport
- ALLEGRO: Comparison of OCATA and GNPy Optical layer Digital Twins
- ALLEGRO: Co-organization of Women In telecommunication (WInTel) workshop during ICTON 2024
- B5G-OPEN: Joint experiment and publication of a ECOC paper with the results: 'Monitoring of Chromatic Dispersion in Multiband Access and Metro Converged Optical Network', ECOC; Frankfurt, Germany, 2024.

2.4.4.3. Year 3

- IOWN, OpenROADM, ECO-eNET, "Technical session on open source and standardization activities for IPoWDM" – Co-located with ONDM 2025, Pisa, May 9 2025
- SEASON – FLEXSCALE cooperation on the development of the ETSI TeraFlow SDN Controller. In particular, FLEXSCALE focused on multi-granular SDM scenario, SEASON on IPoWDM infrastructures. The cooperation led to a joint demo which will take place during OFC 2026. The demo is detailed in the following paper: Andrea Sgambelluri, Michael Enrico, Lluis Gifre, Pablo Robles, Waleed Akbar, Raul Muñoz, Oscar De Dios, Nicola Sambo, Filippo Cugini, "Exploiting ETSI TeraFlowSDN to Control Innovative Optical Networks", OFC Demo Zone, OFC 2026
- SEASON – OpenROADM Cooperation: The OpenROADM team led by Prof. Fumagalli (University of Texas at Dallas) has traditionally relied on a combination of proprietary software solutions and OpenDaylight-based implementations for the control of OpenROADM-compliant networks. Thanks to the work carried out within the SEASON project, the ETSI TeraFlowSDN (TFS) controller has now reached a significant level of maturity and includes functionalities not yet supported by OpenDaylight (e.g., TAPI support), making it a potentially more attractive solution for OpenROADM-based network control. As a result, a collaboration between the SEASON project and the OpenROADM team has been initiated. A virtualized test environment has been established for validation purposes, and joint experimental activities have been successfully conducted.
- ALLEGRO: Co-organization of Women In telecommunication (WInTel) workshop during ICTON 2025
- SEASON – PROTEUS-6G cooperation: We developed on a new SDN-Controlled open RAN X-Haul with Point-to-Multipoint transceivers on horseshoe networks. In this context, PROTEUS-6G advanced the OpenConfig terminal-device YANG data model. This work proposed an augmentation to control DSCM-based coherent P2MP transceivers. An

experimental demonstration in an integrated data and control plane testbed showed the successful automatic control of DSCM for a P2MP connection. Concurrently, SEASON supported the 5G automation platform. This led to the implementation and experimental validation of an innovative automation platform for next generation beyond 5G mobile networks. This platform activates 5G DUs according to cell traffic conditions for energy-saving purposes. It leverages a novel xApp by triggering the concurrent activation of the P2MP leaf transceiver on the IPoWDM node serving the corresponding DU.

- SEASON-UNICO 6G OPTRAN cooperation: The 6G-OPTRAN 6G OPTRAN STEROID (TSI-063000-2021-115) and 6G OPTRAN CONTELEM (TSI-063000-2021-22) national projects, funded by ”Ministerio de Asuntos Económicos y Transformación Digital” and the European Union-NextGenerationEU in the frameworks of the ”Plan de Recuperación, Transformación y Resiliencia” and of the ”Mecanismo de Recuperación y Resiliencia”, have leveraged on SEASON data and control plane solutions, in particular to enable SDN-enabled MB operation. The joint activities aim to implement and monitor programmable MB(oSDM) transmission across different network scenarios, using high-resolution optical spectrum S+C+L analyzer prototypes developed in STEROID. Joint publications have been produced such as the invited ONDM paper ‘Addressing Capacity Scaling and Programmability in Future Optical Networks’, presented in PISA in 2025.
- SEASON - UC3M's 6G-INTEGRATION-3 cooperation: The 6G-INTEGRATION-3 national research project, funded by the Ministry of Economic Affairs and Digital Transformation of Spain, has leveraged on the SEASON's terrestrial architecture for the design and validation of converged transport solutions for beyond-5G/6G services, aligning advanced optical IPoWDM infrastructures toward 6G with non-terrestrial network integration. The joint activities enable end-to-end experimentation of integrated terrestrial–non-terrestrial transport, paving the way for future demonstrations where SEASON’s high-capacity optical network and 6G-INTEGRATION-3’s NTN edge solutions are validated in common scenarios supporting innovative 6G services.
- SEASON - UC3M's FUN4DATE cooperation: The FUN4DATE national research project, funded by the Ministry of Economic Affairs and Digital Transformation of Spain, has used both the architecture, use-cases, traffic models and cost-model for developing and validating techno-economic studies on the impact of AI and LLM massive deployment and use at present and in the short-term. The joint activities enable end-to-end trials where SEASON’s optical network platform is combined with FUN4DATE’s data-driven automation components, paving the way for innovative demonstrations of efficient, reliable, and sustainable 6G-ready connectivity.
- The SEASON project actively participated in the SNS JU Sustainability Task Force and contributed to its activities. In particular, the SEASON consortium supported the Task Force by taking part in the data collection process and by providing technical and quantitative inputs on the sustainability aspects of the solutions developed within the project. These contributions were delivered through the completion of the official

questionnaire prepared by the Task Force, and the provided data were integrated into the analysis underpinning the findings and recommendations of the report.

2.5. DISSEMINATION AMBITIONS AFTER PROJECT COMPLETION

This section reports on the ambitions and plans for dissemination after the completion of the project. The purpose of a dissemination plan is to guarantee that all concepts and technologies developed in a project are disseminated adequately to relevant entities, including standards development organizations.

During 2026, once SEASON has officially finished, we plan to continue carrying out dissemination and collaboration activities (primarily within the SNS JU) to help promote the project concept and main outcomes to the large European and more International R&D community, facilitating the adoption of some concepts by other running and emerging projects.

During 2026 we ambition to exploit the availability of the final experimental and validation results to be disseminated mainly through scientific publications and demonstrations.

Another dissemination channel worth mentioning is the defence of academic works (e.g., PhD and MsC thesis) that include project-related results, as there are several that are planned for 2026-2029.

SEASON leverages the services provided by the Open Access Infrastructure for Research in Europe (OpenAIRE), which is an active service provider of the European Open Science Cloud. We aim to continue managing open data and access to research results during 2026. Note that this will be done on a voluntary basis, as partners cannot be contractually bounded to this once the project has finished.

3. COMMUNICATION

Communication activities in SEASON were initiated early in the project in order to promote the project findings to relevant audiences. Based on the impact of the communication activities, the partners regularly update their strategy as appropriate.

Table 4: Planning of communication activities

Activity	Results
Project website https://www.season-project.eu/	Published. Project website is populated with the basic information of SEASON project such as its concept, technical objectives, communication leaflets, public deliverables and consortium info.
Project Portfolio	MS TEAMS repository, project logo and templates for deliverables and milestones have been created. Quality management procedures have been defined (see Milestone MS1.1, Task 1.3)
Social media	Project accounts on X and Instagram were initially created (see Milestone MS1.1, Task 1.3). However, during the course of the project, we realized that these platforms were not well suited to the project's objectives, as they did not effectively reach the intended target audience or support the type of content required. Consequently, dissemination efforts were refocused exclusively on LinkedIn, which proved to be a more appropriate and effective channel for professional outreach and stakeholder engagement.

Table 5: Communication KPIs

Communication Activity	KPIs	Achieved
Project website	>10,000 unique visitors, ~2 minutes average duration of visit, >20,000-page views.	>11000 unique visitors, >2 min. Average duration of visit, >60000-page views.
Socials	>1000 accumulative followers, >250 interactions, >1000 accumulative posts, >10 videos, >6 news.	>500 accumulative followers, >3500 interactions, >300 accumulative posts, 26 videos 8 newsletters and 10 press releases.

3.1. Project logo

Figure 3-1 shows the SEASON Project logo.

Figure 3-1: SEASON logo

3.2. Project website and social media

Figure 3-2, below, shows the SEASON Project website. Figure 3-3 (page views) and Figure 3-4 (new visits) show the SEASON website statistics.

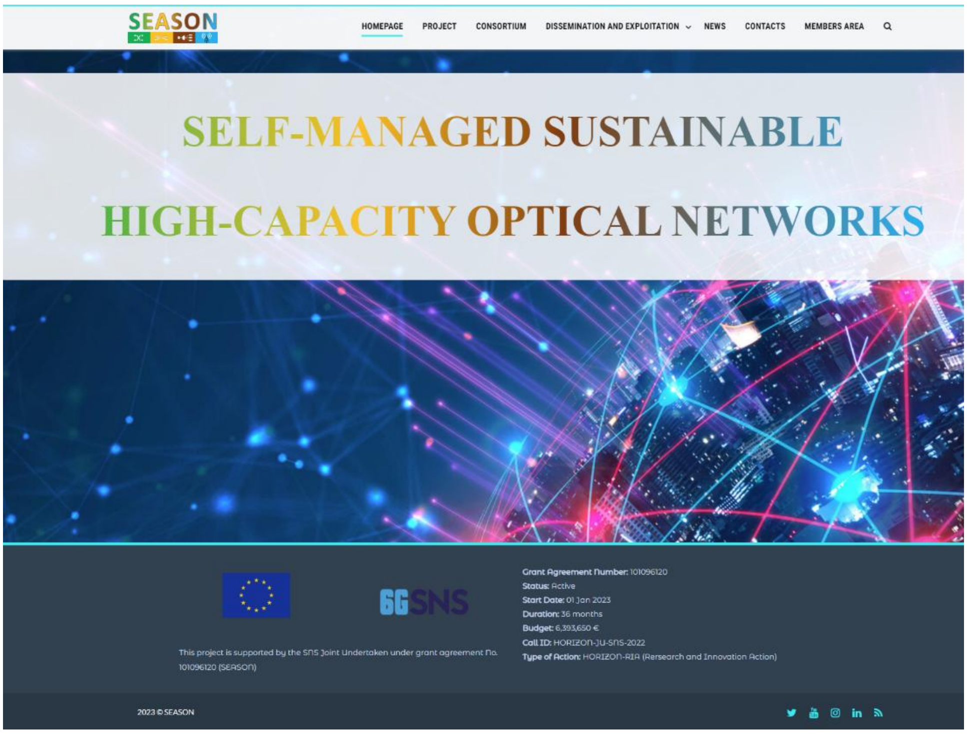

Figure 3-2: Home page of the SEASON website https://www.season-project.eu/

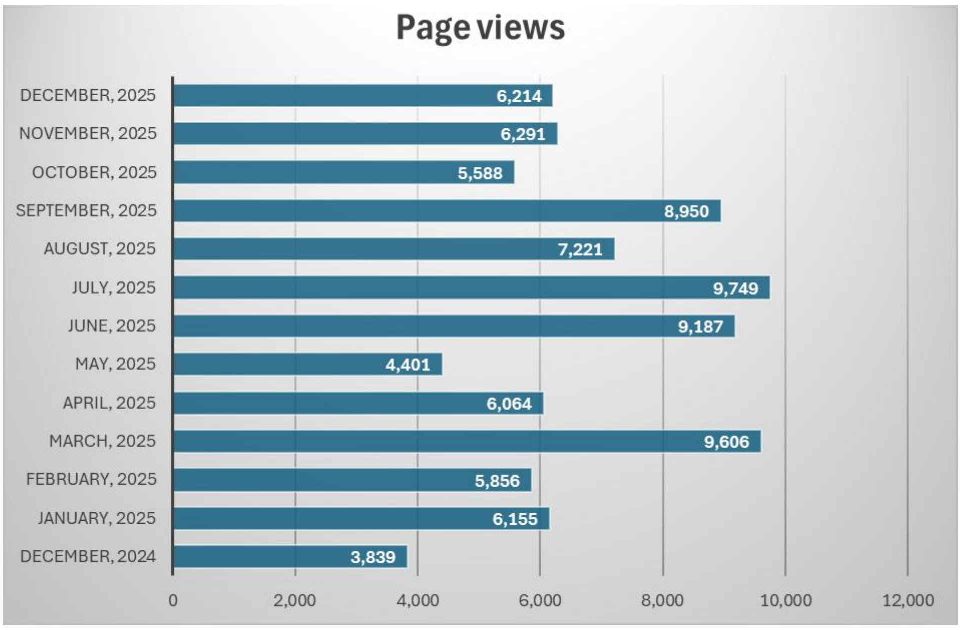

Figure 3-3: SEASON website statistics (page views)

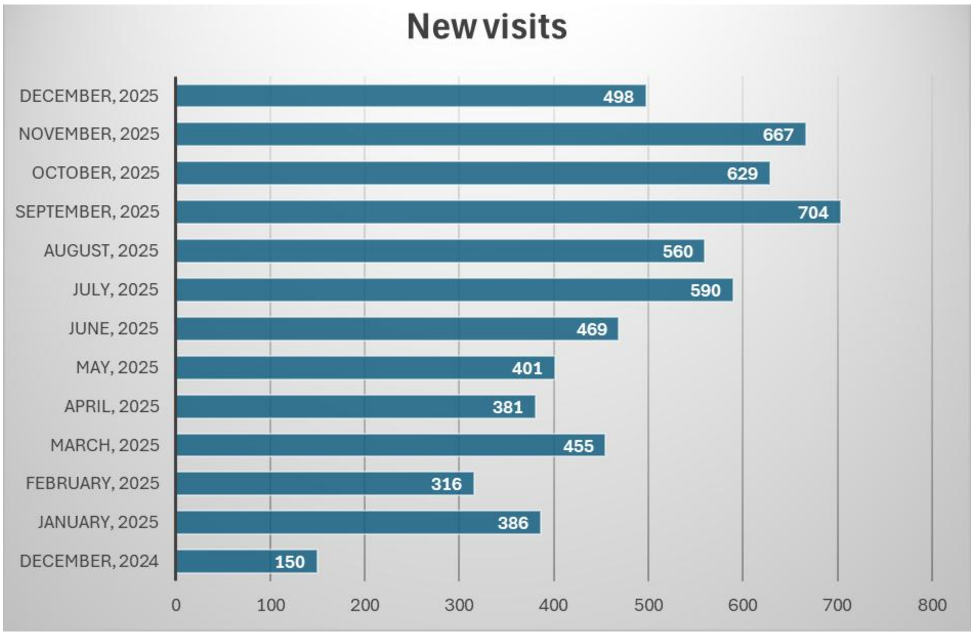

Figure 3-4: SEASON website statistics (new visits).

The project has created its own account in the major social media portals:

- LinkedIn: horizon-sns-season (https://www.linkedin.com/company/horizon-sns-season/)
- X: @HorizonSeason (https://x.com/HorizonSeason)
- Instagram: @horizonsnsseason (https://www.instagram.com/horizonsnsseason/)
- YouTube: @Horizon SNS Season (https://www.youtube.com/@SNS_Season/videos)

3.2.1. Newsletters

Project newsletters have been published in LinkedIn https://www.linkedin.com/newsletters/season-project-newsletter-7412062926720712705/ (Figure 3-5) and two more in partners' websites. The list is as follows:

1) Bridging the Gap in Optical-Mobile Convergence. https://www.linkedin.com/pulse/season-project-newsletter-bridging-gap-optical-mobile-2h3wf/
2) Innovations in Optical Networking. https://www.linkedin.com/pulse/season-project-newsletter-innovations-optical-networking-o60sf/
3) The Intelligent Control Plane. https://www.linkedin.com/pulse/season-project-newsletter-intelligent-control-plane-f5t2f/
4) Scaling capacity beyond C-band. https://www.linkedin.com/pulse/season-project-newsletter-scaling-capacity-beyond-c-band-dmskf/
5) The Digital Twin Advantage. https://www.linkedin.com/pulse/season-project-newsletter-digital-twin-advantage-horizon-sns-season-8xy5f/
6) Innovation in the Optical Data Plane. https://www.linkedin.com/pulse/season-project-newsletter-innovation-optical-data-plane-wptif/
7) Innovation in Energy efficiency. https://www.linkedin.com/pulse/season-project-newsletter-innovation-energy-efficiency-evqxf/
8) Breaking Network Cost Barriers. https://www.linkedin.com/pulse/season-project-newsletter-breaking-network-cost-barriers-kdgtf/?trackingId=YHNMMJepRfeH0Z%2B8AIajZA%3D%3D
9) The SEASON solutions for data plane infrastructure https://www.linkedin.com/pulse/season-solutions-data-plane-infrastructure-horizon-sns-season-neo4e/
10) Final SEASON control plane infrastructure https://www.linkedin.com/pulse/final-season-control-plane-infrastructure-horizon-sns-season-mbvqe/

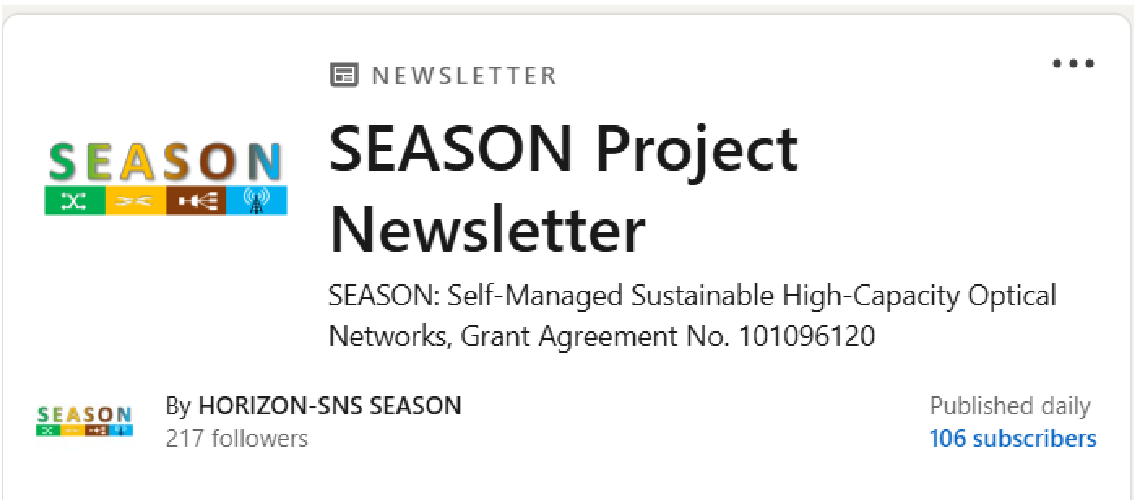

Figure 3-5: SEASON Newsletters.

3.2.2. Press Releases

Partners have published press releases announcing the advances in SEASON in their own corporate websites and/or in likedIn.

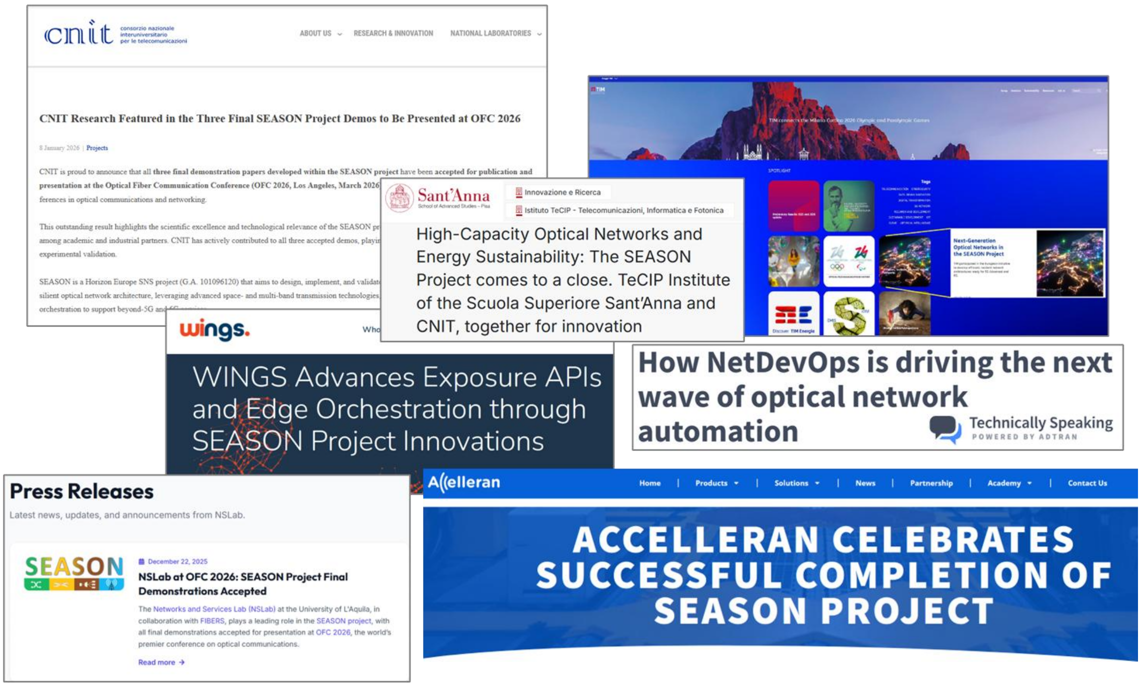

Figure 3-6: Examples of Press releases

1) CNIT: https://www.cnit.it/en/2026/01/08/cnit-research-featured-in-the-three-final-season-project-demos-to-be-presented-at-ofc-2026/
2) FiberCop: https://www.key4biz.it/fibercop-oltre-la-connettivita-edge-cloud-digital-twin-ai-e-6g-per-le-reti-del-futuro/555505/
3) WEST Aquila: https://www.westaquila.com/portfolio/season/
4) UC3M: https://www.it.uc3m.es/jahgutie/SEASON_press.html
5) UPC: https://www.linkedin.com/posts/ccaba_horizon-sns-season-linkedin-activity-7419350488225107968-KqRs?utm_source=share&utm_medium=member_desktop&rcm=ACoAAAZoNS4BDkA6xC10djOzLmbiHNedezln380
6) Wings ICT solutions: https://www.wings-ict-solutions.eu/wings-advances-exposure-apis-and-edge-orchestration-through-season-project-innovations/
7) University of L'Aquila: https://networksandserviceslab.it/press
8) CTTC: https://www.linkedin.com/posts/cttc_ofc2026-cttc-ofc2026-activity-7419350699815161856-7HAn?utm_source=share&utm_medium=member_desktop&rcm=ACoAAAUrGmcBXUJdNe_BmRsNuAPmx0Id0JHS1Ds
9) ACCELLERAN: https://accelleran.com/accelleran-celebrates-successful-completion-of-season-project/

10) HHI: https://www.hhi.fraunhofer.de/en/press/news/demonstration-of-autonomous-network-restoration-fraunhofer-hhi-presents-season-results-at-ofc-2026.html
11) ADTRAN: https://www.blog.adtran.com/en/how-netdevops-is-driving-the-next-wave-of-optical-network-automation
12) TIM: https://www.gruppotim.it/en/innovation/innovation-news/SEASON-Project.html
13) SSSA: https://www.santannapisa.it/en/news/high-capacity-optical-networks-and-energy-sustainability-season-project-comes-close-tecip

3.2.3. YouTube Videos

The project has produced a total of 26 videos that have been published in the SEASON YouTube Channel (Figure 3-7). This channel has been used for the partners to explain their activities in the project, as well as for showcasing key project demonstrations.

The list of videos is as follows:

1) Conversation with Filippo Cugini, the SEASON project coordinator, at the OFC2023 conference. https://www.youtube.com/watch?v=-299qEjuv74&t=138s
2) Prof. Luis Velasco (UPC) explains their role in the SEASON project. https://www.youtube.com/watch?v=wXS2JciaZM8&t=12s
3) Dr. Filippo Cugini (CNIT) explains their role in the SEASON project https://www.youtube.com/watch?v=vx7zby36RI4
4) Dr. Marc Ruiz (UPC) explains the task force that they are involved in WP2. https://www.youtube.com/watch?v=vBZ2FL_QZ-I
5) Dr. Filippo Cugini (CNIT) explains why it is important for CNIT to be in the SEASON project. https://www.youtube.com/watch?v=qeSqyH0NMpQ
6) Prof. Luis Velasco (UPC) interviews Ramon Casellas (CTTC), the technical manager of the SEASON project https://www.youtube.com/watch?v=oVo83iyMjhg
7) Dr. João Pedro Senior Principal Engineer - leader of optical architecture group at Infinera Portugal https://www.youtube.com/watch?v=lA3yhvuaEFk
8) Summary of presentation of Marc Ruiz Ramirez- Assistant professor at UPC- at #OFC2024. https://www.youtube.com/watch?v=QBnHa9jYPgY
9) Dr. Ramon Casellas (CTTC), the technical manager of SEASON project at #OFC2024 https://www.youtube.com/watch?v=EALJxo4Z5Hg&t=2s
10) Simon Pryor R&I Project Strategy Director at Accelleran https://www.youtube.com/watch?v=mrHnydbaxMU
11) Prof. Jose Alberto Hernandez (Associate Professor at UC3M) https://www.youtube.com/watch?v=S2me_Cirl6U&t=2s
12) Prof. Andrea Marotta, Assistant Professor at University of L'Aquila, Italy https://www.youtube.com/watch?v=xnPg6H2Su9k
13) Dr. Nicola Sambo Assistant professor at Scuola Superiore Sant'Anna https://www.youtube.com/watch?v=Z-yW3HqfQsE&t=3s
14) Sokratis Barmpounakis, Senior Solutions Architect & Project Manager at WINGS https://www.youtube.com/watch?v=NmSI6OU-Az4

15) Dr. Stefano Tennina, Co-founder of the SME Company from WEST Aquila, Italy https://www.youtube.com/watch?v=TNVGDF9iLmI
16) Dr. Oscar Gonzalez de Dios, Expert in technology and planning of Transport and IP networks at Telefónica https://www.youtube.com/watch?v=V673bhJWuLw
17) Dr. Behnam Shariati, Deputy Head of Digital Signal Processing Group at HHI. https://www.youtube.com/watch?v=EHgrAnzx_fU
18) Dr. Mohammad Hosseini, Infinera explains why and how SEASON project use the optical fiber technology. https://www.youtube.com/watch?v=rYzsxhWopdk
19) Telefonica, Nokia & CTTC: 400G Optical p2MP Demo at OFC 2025. https://www.youtube.com/watch?v=rbjGV4mpGHU
20) Demonstration of a Programmable Node Prototype for Spatial Lane Switching and Band Switching-OFC2025 https://www.youtube.com/watch?v=3dpKFm7UPvA&t=5s
21) Real time Optical Subcarrier Management in P2MP Networks. https://www.youtube.com/watch?v=WjMDX2WXSy0&t=9s
22) Super Channel Spectrum Optimization in Elastic Optical Networks. https://www.youtube.com/watch?v=zDBFMeNt6pQ
23) Multiband Spatial Division Multiplexing for 6G Optical Networks. https://www.youtube.com/watch?v=rO7mvY-w6_Q&t=18s
24) Networking Benefits of Coherent Pluggable Optics https://www.youtube.com/watch?v=KXEIrEisV3M&t=614s
25) Demo OCATA NDT ICTON2025. https://www.youtube.com/watch?v=Ae3-upKLKrY&t=6s
26) Demo CTTC MBoSDM. https://www.youtube.com/watch?v=HESTt92ULmU&t=2s

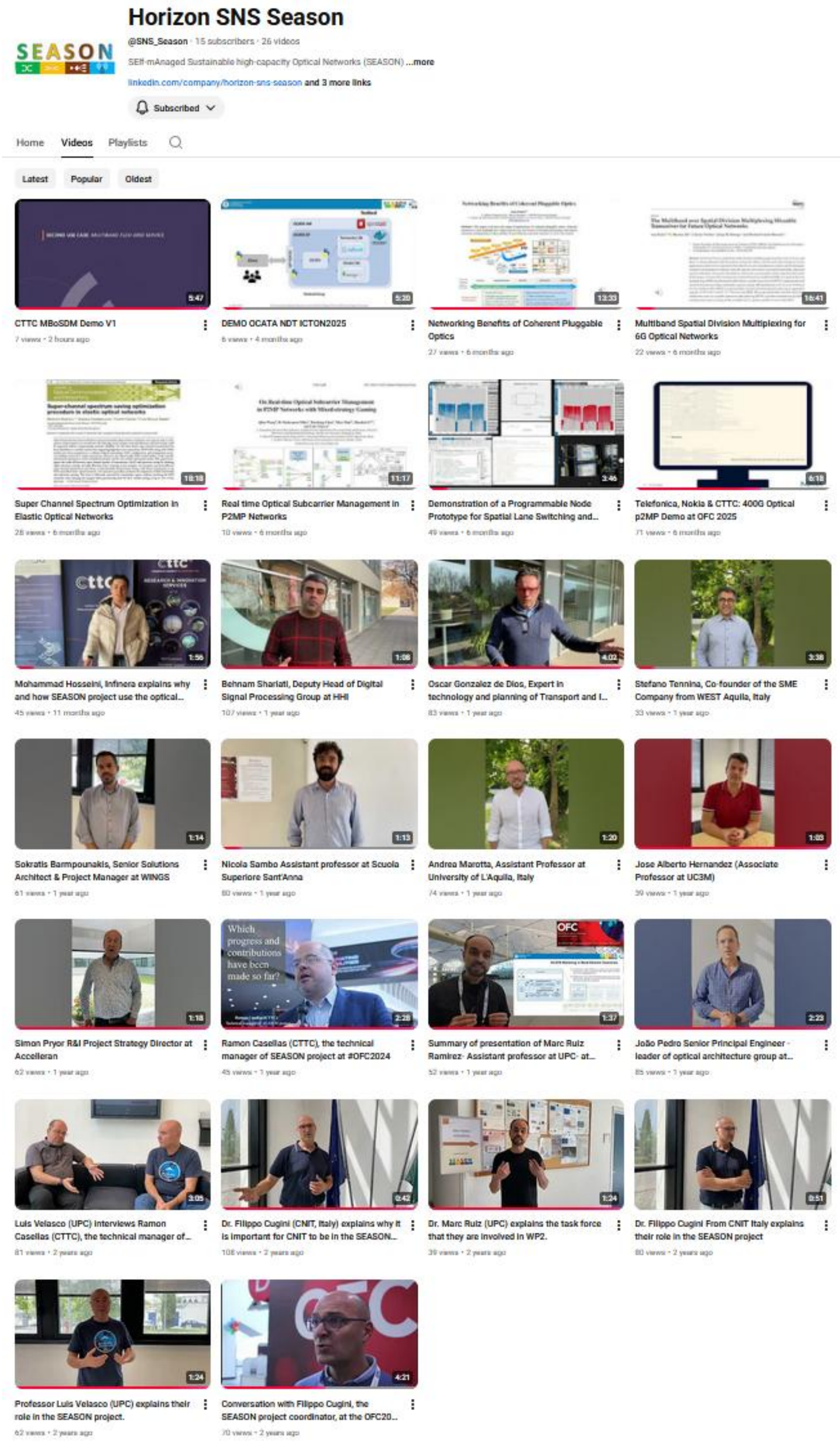

Figure 3-7: SEASON YouTube channel.

3.3. PODCASTS GENERATED WITH AI

NotebookLM from Google (http://notebooklm.google.com) can now read PDF files and generate Podcast interviews about their contents. We have used this technology to generate summaries of published works to complement project communication. The podcasts have been published as videos in Youtube.

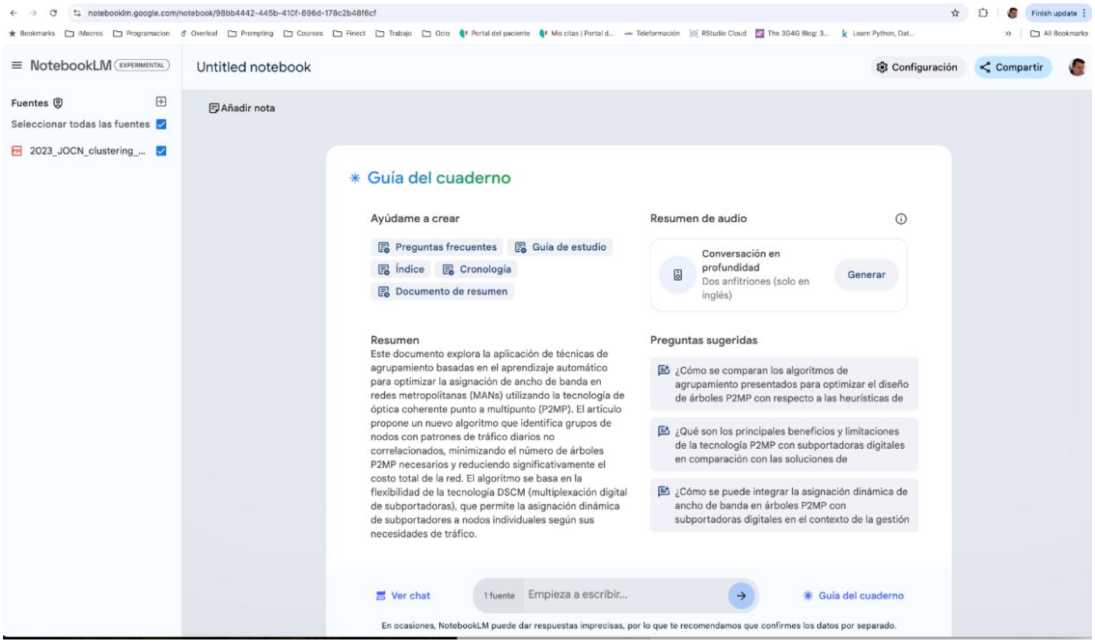

Figure 3-8: Example of Podcast generated using NotebookLM

Dissemination Level	PU

Figure 3-9: Example of generated Podcast published in Youtube

3.4. OTHER COMMUNICATION ACTIVITIES

Besides the communication activities presented above, the project has carried out additional activities that are listed next:

- CNIT presented the SEASON project at the "Internet festival" in both Oct 2024 and Oct 2025, an annual event held in Pisa, Italy, focusing on the digital world and its impact on society. The event brings together experts, enthusiasts, and the general public to explore topics such as technology, innovation, and digital culture.
- Given its role of Technical Manager, during the first year of the project, CTTC communication and dissemination activities focused primarily on raising project awareness in events and workshops. This included, for example, presenting SEASON in the ETSI standards conference, ONDM, as well as the continuous participation in the Technical Board meetings of the SNS program. CTTC contributed to social media commenting in SEASON related posts, sharing posts and insight and contributing to the overall optical networking ecosystem.

  CTTC contributed to the Special Session proposal that was submitted to EuCNC. From the point of view of scientific and technical publications, CTTC submitted conference and journal papers covering the topics of multiband S-BVT, multi-granular optical node, SDN control plane and AI/ML in support of network operation. Accepted and submitted conference and journal papers are listed in this document.

  In order to both complement the work on scientific and research papers, and serve as technical manager of SEASON, CTTC presented the SEASON project in the SNS JU Technical Board, including participating in questionnaires, the SNS journal and contributing with

SEASON concepts to the SNS software Networks working group white paper. SEASON has also been presented in invited talks and workshops as well as internal CTTC seminars.

- TIM carried out internal dissemination and discussing solutions under development with colleagues from the engineering departments in order to understand their applicability in the evolution TIM network. TIM's main dissemination activities have been focused on participating jointly with other partners (in particular INF-G, INF-P, CNIT, CTTC, UC3M and TID) in the drafting and submission of papers to conferences and journals. In June 2024 TIM delivered a seminar at the University of Pavia entitled " Wavelength Switching Technologies and Coherent Systems Design in Photonic Networks". This was partially supported by the SEASON project and with contents related in part to activities ongoing in the SEASON project. Internally, TIM has disseminated the project results at internal meetings attended by colleagues from the Network Engineering Department, that were looking for solutions to address capacity expansion and networking efficiency in deployed networks.
- The objective and scope of the project for ADVA has been communicated in Advanced Photonic Congress 2023 in the “Special Programs” Event at the “AI and Digital Twin” workshop session, presented on the topic “Digital Twins in Optical Transport Network”. The scope and ongoing contributions in the project were also disseminated to internal research teams, during the regular meetings, to discuss on the optimal solutions to improve the work further. The publications associated with the project are updated in social media posts to increase the project visibility. ADVA/ADTRAN have given presentations about SEASON at the ECOC Conference, at the FONDAC 2024 workshop organized by the Universität der Bundeswehr in Munich and the summer school 2025 organized by HHI. Additionally, papers on demonstrations were presented to ECOC 2024, CNSM 2024 and OFC 2025 conferences.
- During the "Jornadas de Puertas Abiertas 2025" at Universidad Carlos III de Madrid (UC3M), the SEASON SNS project was presented to prospective students, researchers, and industry visitors as part of the university’s commitment to innovation in next-generation communication networks. The presentation highlighted SEASON’s vision to develop sustainable, autonomic optical infrastructures that will support 6G and future network paradigms. It also introduced the project’s main objectives, key technological advances, and its role within the Smart Networks and Services (SNS) initiative, underscoring UC3M’s active contribution to European research in future networks and telecommunications.
- Infinera (INF-P and INF-G) focused on the internal communication of the project guiding principles and on potential architectures, aiming to (i) collect useful feedback on the scope of applications of SEASON solutions; and (ii) further refining some of the concepts being investigated in the project. INF-P and INF-G engaged in cooperation with multiple project partners that led to publications in major conferences and journals in the field. Moreover, INF-P and INF-G continued to make more extensive use of social media (e.g., LinkedIn) to disseminate the project findings to a larger audience. Dr. Antonio Napoli presented the results of the work carried out with Ericsson at the event organized by SNS JU entitled “top 10 key-achievements”. Posts on LinkedIn have been prepared as well. The event, including the whole streamed session, can be watched here: https://smart-networks.europa.eu/sns-ju-unveils-its-2025-top-10-key-achievements-leading-europes-6g-innovation/ .
- Ericsson has presented SEASON in several editions of the Ericsson Innovation Days. In Genoa, professionals, experts and industry leaders gathered the 14th and 15th of November

2023 to discuss the future of mobile networks during the 12th edition of the Ericsson R&D Italy Innovation Days.

ERICSSON

R&D Innovation Days in numbers

- Total number of visitor
  - 280 in person
  - 385 online
- 19 different demos
- 10 speakers
- 4 technical seminars
- 9 Companies and Institutions present

Figure 3-10: Ericsson R&D Italy Innovation Days

The program of the two-days event included panels and presentations with the participation of Ericsson customers, technology experts and companies driving the evolutions of 5G mobile networks.

The plenary sessions were interleaved with live demonstrations of innovative prototypes developed by Ericsson researchers, within the three major R&D centres of excellence in Italy: Genoa, Pisa and Pagani. (See: Post | LinkedIn)

Figure 3-11: Live demonstrations of innovative prototypes during Ericsson R&D Italy Innovation Days

A dedicated space, in the main live demos area, was set-up to highlight the commitment of Ericsson in EU funded projects as part of the innovation program. A set of selected dissemination slides, continuously running on a monitor, highlighted the vision, goals and challenges of the SEASON Project. Dedicated presentations were given to visitors during the demo sessions.
On November 14th and 15th, 2024, during the 13th edition of the Ericsson R&D Italy Innovation Days, Genoa hosted a gathering of professionals, experts, and industry leaders

to delve into the future of mobile networks. The event spanned two days and featured an array of panels and presentations, including contributions from Ericsson's customers, technology innovators, and companies at the forefront of 5G mobile network development. Plenary sessions were enriched with live demonstrations of state-of-the-art prototypes created by Ericsson from the company's three principal R&D centres of excellence in Italy: Genoa, Pisa, and Pagani. In the main area dedicated to live demos, a special space was established to highlight Ericsson's dedication to EU-funded projects as a facet of its innovation program. A continuous loop of selected slides showcased the vision, objectives, and challenges of the SEASON Project, and visitors were provided with tailored presentations during the demonstration sessions.

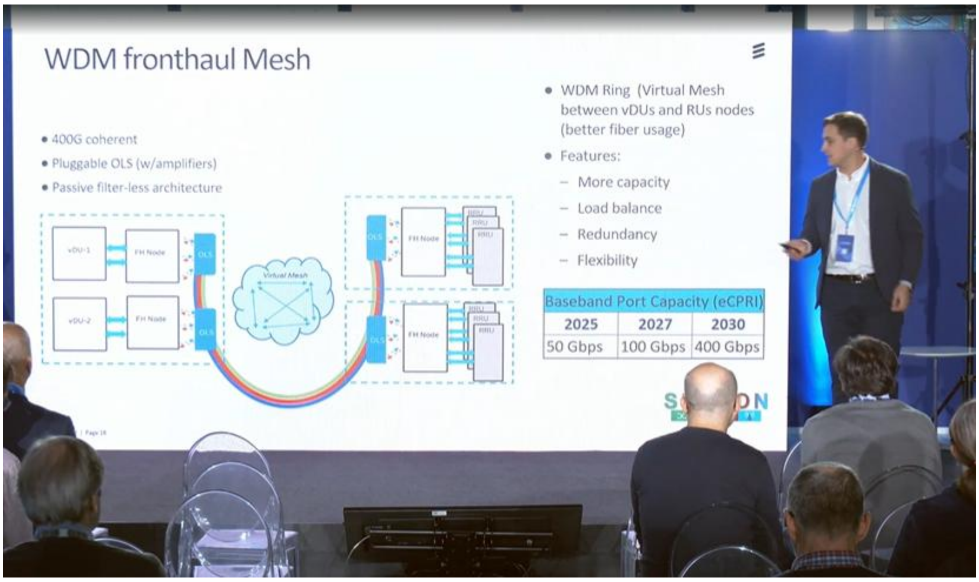

Figure 3-12: Ericsson Innovation Days

- FiberCop main dissemination activities have been focused on participating jointly with other partners (in particular INF-G, INF-P, CNIT, CTTC, UnivAq and TID) in the drafting and submission of papers to conferences and journals. At OFC 2025 FiberCop discussed SEASON architectural innovations within the OPEX XR FORUM panel at the show floor of the conference. Internally, FiberCop has disseminated the project results at internal meetings attended by colleagues from the Innovation and Engineering Department, with the target to exploit the best solutions to address infrastructure expansion and networking efficiency.

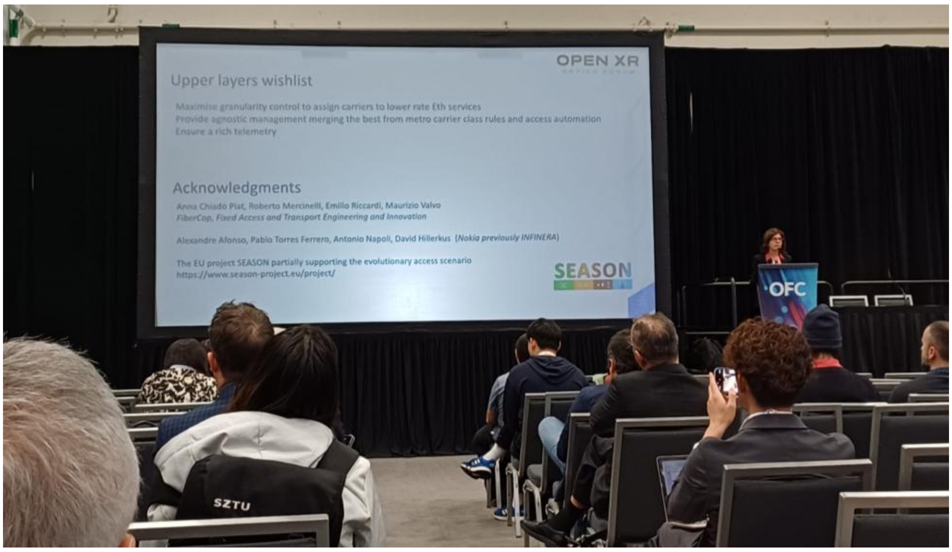

Figure 3-13: OFC 2025 OPEN XR FORUM panel

- Accelleran promoted and credited SEASON at available speaking slots, specifically at the 'IMEC Wireless Community' event on 5/10/2023 (https://www.wirelesscommunity.be/work-meetings/softwarization-and-virtualisation-for-intelligent-wireless-networks/), a Belgian technical forum facilitated by IMEC, where Simon Pryor presented a talk on 'Going green and saving OPEX with 5G Open RAN', where the SEASON next-gen transport networks, with WP4 multi-domain Open RAN RIC intelligence, was discussed and elaborated, within an energy saving context.
  The goal of Accelleran is to further promote and disseminate SEASON at future events and conferences (like EuCNC but also industry events and fora relevant to Open RAN, mindful, at the same time, of Accelleran being an industrial rather than an academic partner). There is growing industry-wide interest in this specific topic of cross-domain integration (of RAN, transport network & core) in the control-plane towards 6G, especially within an Open RAN context, leveraging the RIC, and ACC considers this an ideal vehicle to promote and position the ACC brand and thought leadership, resulting from the excellent SEASON research to date.
- During the phases of demo preparation, as per the project proposal, WEST (*i*) participated in EU Researcher's Night in L'Aquila (2023-2025), with a target 300-400 audience of school students, engaging students in a research environment and familiarizing them with EU-funded actions and SEASON activities as well as (*ii*) presenting preliminary demo results from working testbeds in industry attended events or events organized by the EC. The main project's social media channels informed the general public regarding the project's events, activities, and advances.
- WINGS presented the SEASON project during the keynote presentation of Mobihoc 2024's AIoT workshop. WINGS also presented SEASON WP4/WP5 related activities in the SNS JU TMV WG activities, as well as at internal WINGS seminars.
- TID engaged in comprehensive dissemination activities, collaborating with partners such as UC3M, CTTC, and CNIT to draft and submit papers to prestigious conferences and journals.

Furthermore, TID actively participated in standardization efforts, contributing to TIP MANTRA, OpenConfig, and TeraflowSDN initiatives alongside partners like CTTC and CNIT. These collaborative endeavours aimed to advance industry standards and promote innovation in telecommunications and network technologies.

- HHI co-organized a well-attended workshop at ECOC 2024 entitled "WORKSHOP 5: What Can Digital Twins Fuelled with Generative AI Offer to Optical Networks?". Several other SEASON partners, including CTTC and ADTRAN also presented their work at the workshop. HHI also presented the activities of the project within ETSI ISG F5G group. In addition, HHI organized the Summer School on optical networking focused on communicating SEASON project activities.
- In order to better communicate the SEASON project activities to future Engineers, at UPC PhD students presented key research topics and provided details on how to become a researcher during master courses. In particular, Sadegh Ghasrizadeh presented the hot topic of network digital twins applied to optical communications in a course on Mathematical Models. To illustrate digital twin applications, Sadegh presented some ideas that SEASON has implemented and requested the students to envision new ones. In addition, Pol González focused his presentation on a different hot topic related to pervasive telemetry data collection and processing in a course on Network Security. Advanced methods for providing robust and secure data and models exchange in distributed environments were discussed with the students. Finally, for undergraduate students, Prof. Marc Ruiz gave a talk in a course on Cybersecurity Management. He highlighted SEASON research as an example enhancing protection of AI-based systems in 6G network environments.

Figure 3-14: UPC Outreach Activities

UPC participated in the research café 2025 to attract students to research. The presentation was entitled: "Digital twins for secure and intelligent operation of next generation networks" https://upcommons.upc.edu/handle/2117/426767.

3.5. Communication ambitions after project completion

This section reports on the ambitions and plans for communication and project reach after the completion of the project.

Table 6 updates the Communication Plan and includes the targeted audience, the related activities, the timing, and the metrics of the communication activities, including quantified goals.

Table 6: Communication activities after project completion

Activity	Timing
Project website. SEASON shares its concepts, results and achievements through the project website. The website is the primary tool of communication and promotion of the project.	Minor updates with relevant achievements during 2026
Public Communication. SEASON project is regularly being promoted through participation and organization of events for society at large and distribution through social media. We plan to make use of EC communication tools and magazines after the completion of the project.	Event-driven only (during 2026)
Videos. SEASON will post on its networks (mainly the YouTube channel) videos related to demos and events where project results are shown during 2026.	Event-driven only (during 2026)
Lecture materials related with SEASON will be introduced in academic courses taught by partners for the course 2025-2026.	At least during the 2025-2026 academic year

In order to provide visibility and guidance on what the main contributions and results are, we ambition to continue presenting the achievements of SEASON, leveraging the fact that many of the project partners will be involved in projects starting in 2026. We will foster proper acknowledgement of the reuse of SEASON concepts, results and lessons learned, as a basic instrument to prove the value of the SNS JU (and in general of the Horizon Europe) program.

4. STANDARDIZATION

4.1. TARGETS FOR STANDARDIZATION

Standardization is a key target for the SEASON project, and many aspects of SEASON developments are subject to active standardization. The list of targeted standardization activities is compiled below.

Table 7: List of target standardization activities

SDO / Open-Source Project	Target direction for standardization	Partners
ETSI OSM	Integration of ETSI OSM with transport SDN with the development of OSM plugins to interwork with the TAPI North Bound Interface of Transport SDN controllers, to dynamically provision end to end connectivity services.	CTTC, TID
ETSI ISG F5G	Align with the ETSI Industry Specification Group on 5th generation fixed network, to support three main features: full-fibre connection (FFC), enhanced fixed broadband (eFBB) and guaranteed reliable experience (GRE). CTTC, HHI and TID are members of the ETSI ISG	CTTC, HHI, TID
ETSI ZSM / ENI	Provision of information regarding the orientation of the project, architecture elements, results from PoC	WINGS
IETF/IRTF	Interaction with research groups working on network management and related algorithms and operations WG (e.g., OPSAWG).	WINGS, TID
ITU-T	Contribute to ITU-T Focus Group on "Environmental Efficiency for Artificial Intelligence and other Emerging Technologies" (FG-AI4EE) with SEASON innovation on energy efficiency SDM Optical Access. Contribute to ITU-T SG15 Q2 "Optical systems for fibre access networks"	WEST, TIM, FIB
5G-PPP TMV WG	Contributions related to Test, Measurement, and KPIs Validation for validating technology performance.	WINGS
OIF	Contribution to PLL WG MANAGEMENT TRACK for pluggable interface management using CMIS interface and Network Operator (NetOp) WG	TID
ONF ODTN/ ONOS	ONOS SDN Controller and open data models to control (1) disaggregated Multi-band over SDM infrastructure, (2) innovative computing nodes and DPU/smartNICs equipped with coherent pluggables for edge-to-cloud power-efficient interconnections.	CNIT. CTTC, ADVA
ONF OTCC	Development of TAPI NBI. Improvement of the photonic media layer, with focus on the modelling of physical layer impairments, provisioning of services B100G, new cases related to Path Computation, Alarm Management and OAM,	CTTC, TID, ADVA

	based on successive refinements over the TAPI 2.3 version. Develop transport SDN use cases to be fed to for a, such as TIP.	
Open Config	Development of data modes and Manifest files in support of Optical Transport devices such as transponders.	TID
OpenROADM	Optical and YANG data models interoperability specifications of ROADM switch as well as transponders and pluggable optics.	TIM, INF-G/P, FIB
OpenXR Optics Forum	Contribute with scientific works and standard proposals towards enabling the deployment of P2P & P2MP smart transceivers.	TID, TIM, INF-G/P FIB
ORAN	Submission of results of integration of optical transport SDN controllers with SMO and Near-RT RIC for potential O-RAN standard evolution (WG1, WG3, WG4, WG9	ACC
TIP MANTRA	Development of PoC and demonstrations in the TIP Metaverse ready Architectures for Open Transport (MANTRA) subgroup, to demonstrate unified SDN control and management of the disaggregated, multi-vendor components within an open optical network: Open Line System (OLS), Open Terminals (OTs) and Optical Planning tools, in view of the Multi-vendor integration and service operations were achieved through open standard models and APIs supported by the Optical SDN Controller, including OpenConfig, Transport-API (TAPI) and Open REST	TID
TIP MUST	Development of Transport SDN Use Cases in sub-group within the Open Optical & Packet Transport project group, called MUST (Mandatory Use Case Requirements for SDN for Transport). The main objective is to accelerate and drive the adoption of SDN standards for IP/MPLS, Optical and Microwave transport technologies	TID, CTTC, TIM

4.2. Strategy

The standardization activities carried out within the SEASON project have been defined and executed following a coherent and well-structured strategy, fully aligned with the project's technical objectives, architecture, and expected impact. Rather than isolated or opportunistic contributions, SEASON's engagement in standardization has been driven by a clear roadmap that maps project innovations to the most relevant Standards Development Organizations (SDOs) and open-source communities.

The selected standardization targets collectively cover the full SEASON technology stack, including control and management architectures (ETSI ZSM, ENI, TFS, ONF TAPI), optical transport and access technologies (ITU-T SG15, OpenROADM, OpenConfig, open XR optics forum, MOPA), SDN and orchestration frameworks (ETSI OSM, TIP MANTRA, TIP MUST), and cross-domain integration with mobile and cloud ecosystems (O-RAN, IETF ACTN). This ensures consistency between architectural choices, software implementations, and standardization outputs.

A strong emphasis has been placed on avoiding fragmentation and duplication of effort by converging contributions towards a limited number of well-established platforms, most notably ETSI TeraflowSDN (TFS), which has been selected as the primary SDN controller platform for SEASON. This strategic choice led to a focused and sustained contribution effort, replacing earlier plans involving alternative platforms (e.g., ONOS) once it became clear that TFS offered better alignment with project requirements and broader ecosystem adoption.

The involvement of partners holding key roles within SDOs and open-source communities (e.g., Oscar Gonzales De Dios chair of the TIP Open Optical & Packet Transport Project Group) has further ensured that SEASON contributions are timely, technically relevant, and effectively integrated into ongoing standardization processes. In addition, many activities are supported by concrete proofs of concept, demonstrations, and open-source code contributions, strengthening the credibility and impact of the proposed specifications. A concrete example of this coordinated and sustained approach is the acceptance of a live demonstration at a major international venue. The demo *"Exploiting ETSI TeraFlowSDN to Control Innovative Optical Networks"* (A. Sgambelluri et al.) has been accepted in the OFC 2026 Demo Zone. The demonstration showcases the evolution and practical use of ETSI TeraflowSDN developed jointly within SEASON and the related FLEXSCALE project, highlighting cross-project synergies and reinforcing the role of TFS as a reference SDN controller platform aligned with ongoing ETSI standardization efforts.

Furthermore, the collaboration between Nokia and Ericsson, somewhat related to the awarded top 10 key-achievements by the SNS JU, was part of the white paper of the MOPA (https://mopa-alliance.org/wp-content/uploads/MOPA_Technical_Paper-v3.3-Final.pdf),which draft the solution proposed in SEASON as one of the possible candidates for next generation mobile transport support beyond 5G and 6G. In this document, Sec. 13.13, entitled "Single-laser (wavelength) DSCM-based coherent communication for Adaptive and Flexible Bi-directional (Bi-Di) transmission over single fiber", describes the benefits of digital subcarrier-based transceiver in enabling single fiber single laser single wavelength transmission.

Overall, the SEASON standardization strategy demonstrates a high level of internal coherence, with contributions planned along the project lifecycle and consistently aligned with both technical developments and external standardization timelines. This approach maximizes the potential for long-term adoption of SEASON results beyond the project duration and reinforces its contribution to the evolution of open, interoperable, and energy-efficient network infrastructures.

4.3. Activities

TeraflowSDN

- CTTC is leading the effort on ETSI TFS and managing the overall community. TFS is being used by several projects in the SNS umbrella, such as SEASON, FLEXSCALE, PROTEUS-6G and ACROSS. SEASON is contributing to the TeraflowSDN ecosystem in aspects such as network orchestration and IP control.

- TID and ADTRAN are members of the Technical Committee.
- TID and CNIT are actively contributing to the TeraflowSDN ecosystem in aspects such as network orchestration, IP control and Coherent Pluggable Control (see above)

Table 8: Contributions to TFS

Contribution	Link to contribution
Create IP link with supporting coherent pluggable	https://labs.etsi.org/rep/tfs/controller/-/merge_requests/239
Multi-vendor Openconfig driver	https://labs.etsi.org/rep/tfs/controller/-/merge_requests/104
Enhancement of Openconfig driver	https://labs.etsi.org/rep/tfs/controller/-/merge_requests/162
Expose Device inventory via NBI	https://labs.etsi.org/rep/tfs/controller/-/merge_requests/237
ZR + Pluggable control	https://labs.etsi.org/rep/tfs/controller/-/tree/cnit_related_activity?ref_type=heads

ETSI F5G.

- CTTC has been contributing to the F5G ETSI ISG in several ways. CTTC has been participating in the technical meetings and standardization meetings, characterizing the evolution of F5G advanced.
- CTTC has organized and contributed to F5G workshops and talks, such as NGON / NetworkX talk on "ETSI: Evolving Towards F5G-Advanced for Green 10Gbps Everywhere", by Dr. Raul Muñoz.

ETSI OSM

- Given the relative maturity of ETSI Open-Source Mano (OSM), the contributions to OSM are targeted, and these include making sure that the OSM releases can be integrated with the TFS SDN controller and minor changes to the underlying framework. CTTC contributes to hackfests and coordinated events in support of Open Source.

SDN Controller

- CNIT was initially planning to use and improve the ONOS SDN Controller to control disaggregated Multi-band over SDM infrastructure as well as innovative computing nodes and DPU/smartNICs equipped with coherent pluggables for edge-to-cloud power-efficient interconnections. However, during the early phase of the project, the SEASON Consortium agreed that ONOS is not the ideal open-source SDN platform to perform the required technical activities. Instead, the ETSI TeraFlow (TFS) SDN Controller has been identified as the preferred SEASON Platform to be used as SDN Controller. During the project execution, multiple enhancements to TFS have been introduced.

- Similarly, CTTC is not contributing to the ONOS SDN Controller after recent changes in organization. Priorities have been shifted to either contribute to TeraflowSDN or, in the specific case of optical control, rely in its own proprietary software.

TIP MANTRA (Metaverse ready Architectures for Open Transport).

- Development of PoC and demonstrations in the TIP MANTRA subgroup. SEASON IPoWDM control was candidate to be used in MATRA PoC for 2025

TIP MUST (Mandatory Use Case Requirements for SDN for Transport).

- Telefonica (with contributions and collaboration from CTTC) has been contributing to TIP MUST, mostly in topics related to the adoption of Transport SDN from the perspective of network operators, consolidating use cases and raising awareness of TeraflowSDN as a reference platform.
- The main objective is to accelerate and drive the adoption of SDN standards for IP/MPLS, Optical and Microwave transport technologies

OpenROADM.

- TIM held the role of chairperson of the consortium from October 2022 until September 2023; during this period, YANG models releases 12.1, 13.0 and 13.1 14.0 have been published.

  Within the SEASON Project an OpenROADM agent developed by TIM complied to R12.1, has been updated for the management of external pluggable transceivers.

OpenROADM.

- Development of data modes and Manifest files in support of Optical Transport devices such as transponders. TID attends to weekly calls reviewing and contributing.

Table 9: Contributions to OpenROADM

Contribution	Link to contribution
Update openconfig transport types	https://github.com/openconfig/public/pull/1011

Linux Foundations ONMI (former ONF)

- CTTC, as a member of the Technical Steering Team (TST), had contributed in the first reporting period to the TAPI releases 2.4 and 2.5 having served as editor of the TR-547 on Reference Implementation Agreement. During the second reporting period, we have further contributed to the refinement of TAPI RIA use cases, addressed errata in previous versions, worked on a set of TAPI 2.5 examples for operators, published extensions related to RESTCONF pagination and published TAPI version 2.6. Work is now progressing to TAPI 2.7 with new features.

- Consolidations of the improvements of the photonic media layer, with focus on the modelling of physical layer impairments, provisioning of services B100G, new cases related to Path Computation, Alarm Management and OAM, based on successive refinements over the TAPI 2.3 version.
- Attending meetings, reviewing implementation agreements and refinements.
- Contributions by CTTC, ADVA, TID

O-RAN.

- Submission of results of integration of optical transport SDN controllers with SMO and Near-RT RIC for potential O-RAN standard evolution (WG1, WG3, WG4, WG9. ACCELERAN is closely following the standard to ensure SEASON is aligned in terms of RAN-Optical transport integration.

IETF.

- Standardization of use case and architecture for the control of IP – optical network with coherent pluggables.
- Presentation of multiple drafts in IETF meeting
- Currently, the SEASON ACKed draft is candidate for working group adoption

Table 10: Contributions to IETF

Contribution	Link to contribution
Applicability of Abstraction and Control	https://datatracker.ietf.org/doc/html/draft-poidt-ccamp-actn-poi-pluggable
Use cases, Network Scenarios and gap analysis for Packet Optical Integration (POI) with coherent pluggables under ACTN Framework	https://datatracke.ietf.org/doc/draft-poidt-ccamp-actn-poi-pluggable-usecases-gaps/

OpenXR.

Telefónica and CTTC regularly present at the OpenXR Optics Forum meetings, including the studies carried out within the demos. In case of Telefonica, a joint demo with CTTC was also streamed at OFC 2025 at the Nokia booth and uploaded on the YouTube channel.

FiberCop has participated in technical discussions at plenary meetings since July 2024 and has hosted POC experimental activities assessing XR technology in metro-access scenarios and interoperability with different vendors equipment. In November 2025 FiberCop gave a presentation describing the execution and the results of SEASON demo 2 extension 2 (Figure 4-1), during an OpenXR plenary meeting, participated by most of the vendors and telecom operators of the Forum.

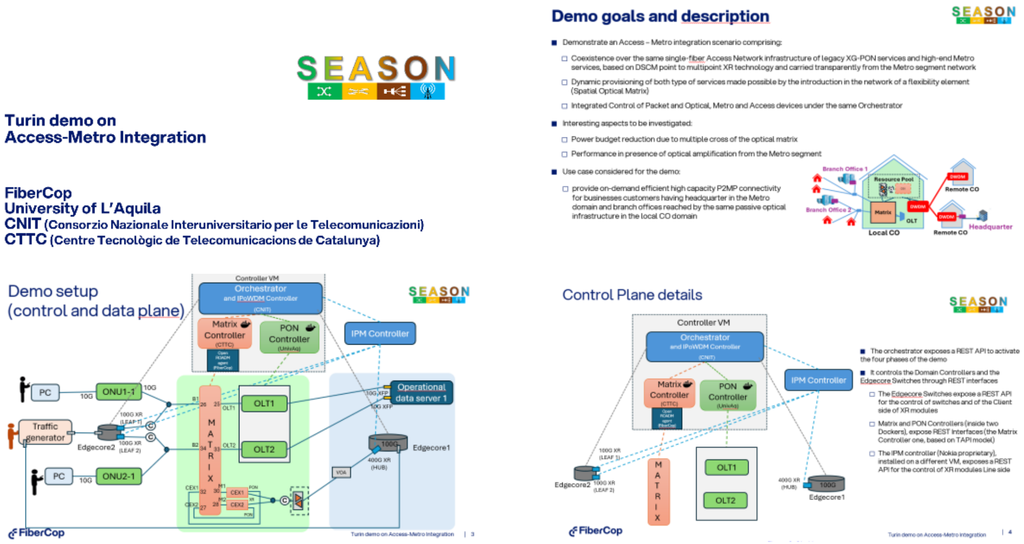

Figure 4-1 Demo2 extension 2 presentation at OpenXR plenary in November 2025

Nokia has been continuously supporting FiberCop/TIM and Telefonica both in terms of contributions to the forum, and also by providing hardware, software and technical support – all free of charge – to carry out the experiments at their laboratories in Madrid and Torino.

MOPA.

Nokia and Ericsson contributed to the technical white paper, which can be freely downloaded on this link: https://mopa-alliance.org/wp-content/uploads/MOPA_Technical_Paper-v3.3-Final.pdf. This article, among other topics, also gives an overview of possible solutions for next-generation mobile transport, and proposes the solution investigated in the ECOC 2025 SEASON article as one of the strong solutions to realize single fibre single laser single wavelength transmission to support B5G and 6G.

4.4. STANDARDIZATION AMBITIONS AFTER PROJECT COMPLETION

From its inception, SEASON has had a clear goal of contributing to both standardization and open-source activities. During the project execution lifetime, this purpose has been perceived as a bidirectional interaction between the project and external communities. This meant that any progress in the standardization and open-source arenas could influence the development of SEASON architecture and innovations, and vice versa.

Once the project finishes, our ambition is:

- maintain (if required) those project-related contributions that are still "alive" (e.g., adopted, but not yet published, or not-adopted but with good chances to be adopted).
- evaluate whether new contributions are needed mapping to the latest developments of the project.

- Some results might become features of the solution provided SEASON members.

5. Open-Source

5.1. Open-Source Licenses

The SEASON project has not enforced a particular license on the software developed by partners and contributed to the community as Open Source. The contributions to SEASON have used the following licences:

- Apache 2 License
- MIT 1.0 License
- Creative Commons 1.0 https://creativecommons.org/publicdomain/zero/1.0/

5.2. Overview of OPEN-SOURCE Frameworks

The software developed in SEASON has relied on well-known Open-Source Frameworks for some components. This section describes the main frameworks used.

5.2.1. TeraFlowSDN (TFS)

TeraFlowSDN (TFS) is an open-source, cloud-native SDN (Software-Defined Networking) controller developed under the ETSI (European Telecommunications Standards Institute) Software Development Group. Designed to enable next-generation automation, orchestration, and management across complex transport and optical networks, TFS stands out for its microservices-based architecture and strong alignment with international standards, making it particularly well-suited for research, prototyping, and integration within modern telecom and enterprise environments.

The most recent release, TeraFlowSDN Release 6, delivers important advances for network automation and optimization. A key new feature is the seamless integration of an IETF Network Slice Controller (NSC), enabling robust end-to-end orchestration of network slices, a critical capability for 5G and beyond, where differentiated services and rapid provisioning are required. The release also introduced support for SmartNICs, enhancing programmability and detailed hardware management by exposing information such as vendor, model, and component details. Telemetry functions have been enhanced to enable more granular real-time monitoring, faster troubleshooting, and lower latency for critical applications. The update further expands OpenFlow compatibility for broader network integration and introduces zero-touch provisioning, enabling dynamic and automated onboarding of white box hardware with minimal manual intervention.

For project teams or enterprises, TeraFlowSDN provides a robust platform for deploying programmable, standards-compliant network automation solutions. Participation is open not only to ETSI members but also to non-member organizations and individual contributors, reflecting a commitment to collaborative open-source development.

More specifically, the SEASON project contributed to ETSI TeraFlowSDN by extending its southbound and control-plane functionalities to support optical transport networks through standardized models and programmable interfaces. In particular, SEASON implemented OpenROADM-based southbound drivers, leveraging YANG models and NETCONF/gRPC mechanisms to enable configuration, monitoring, and control of ROADM devices within the TeraFlowSDN controller framework. The project introduced automatic discovery and lifecycle management of optical endpoints and pluggable transceivers, integrating device inventory updates into the TFS context and topology services. These capabilities were exposed through RESTful northbound APIs and integrated into the TeraFlowSDN WebUI, enabling operator-level visibility and control of optical resources. SEASON also enhanced TeraFlowSDN with external telemetry ingestion pipelines, allowing performance metrics and operational data from optical devices and third-party monitoring systems to be collected and correlated in real time. This telemetry data was integrated with TFS monitoring and analytics components to support closed-loop control and data-driven service management. Furthermore, SEASON extended optical service provisioning workflows by enabling fine-grained configuration of transceivers and optical channels, improving end-to-end service orchestration across the transport layer.

A screenshot is presented in Figure 5-1 and shows the SEASON contributions to TFS.

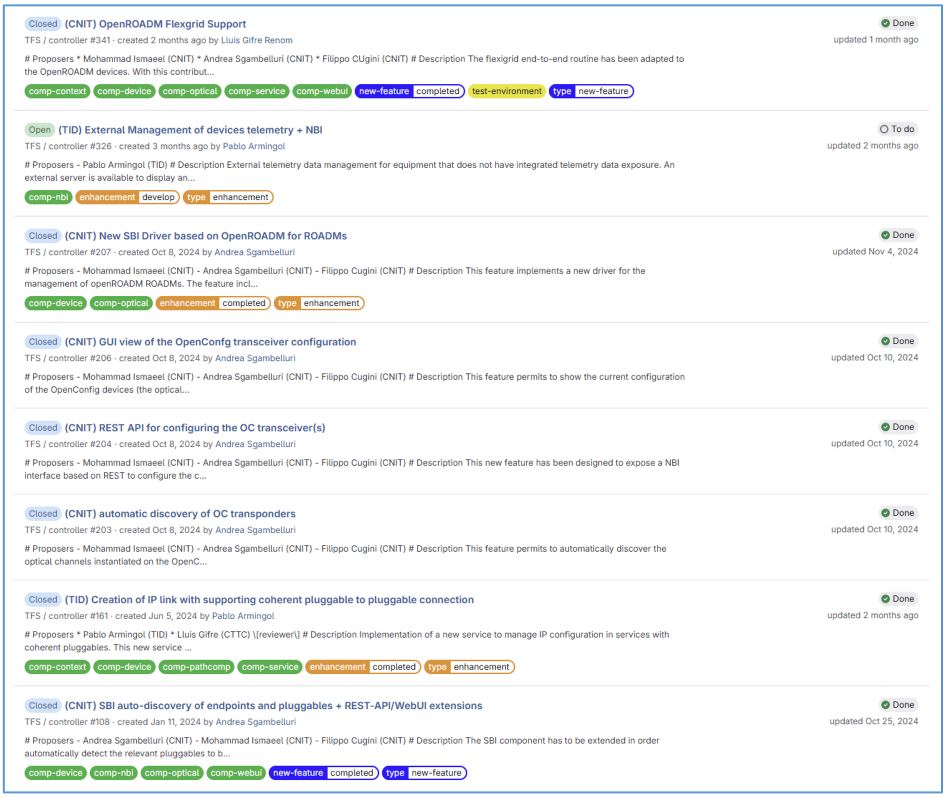

Figure 5-1: SEASON contributions to TFS

5.2.2. SEASON Github Organization

The software contributed by SEASON to open source is publicly available. With the aim of facilitating the access to the sofware, a Github Organization has been created and available at https://github.com/SEASON-Project. The contributions are either forked in the repository or directly uploaded under the SEASON organization.

5.3. Specific Open-Sourced Contributions

5.3.1. Access Controller

As part of its contribution to the SEASON project's open-source efforts, a dedicated REST-based controller for spatial Passive Optical Networks (PONs) has been developed, designed to support dynamic bandwidth allocation and energy-efficient activation/deactivation of optical branches.

The controller is publicly available under an MIT license and has been integrated into the Demo 2 to enable experimental validation of spatial PON concepts envisioned in SEASON.

The REST Controller acts as a lightweight management layer between higher-level orchestrators (e.g., the SEASON Network Service Orchestrator) and the underlying Calix E7-2 OLT, leveraging a hybrid control plane based on both REST and NETCONF protocols. It allows remote provisioning and dynamic reconfiguration of ONU interfaces, VLAN profiles, and policy-maps associated with traffic and power management. The controller also exposes a northbound RESTful API that abstracts low-level operations, enabling seamless integration with SDN controllers or AI/ML agents for traffic-aware control.
The design focuses on modularity, extensibility, and real-world compatibility with commercial OLT hardware. Its primary innovation lies in exposing fine-grained control of transceiver states, enabling the system to power down unused optical branches based on real-time traffic conditions. This functionality is essential for achieving SEASON's energy savings goals and has been used to demonstrate closed-loop control in AR/VR use cases involving dynamic user loads and midhaul aggregation.

The contribution not only provides a valuable tool for the SEASON experimental ecosystem, but also offers a reusable framework for future projects exploring energy-aware control of disaggregated access networks. Its availability as open-source ensures long-term impact and fosters collaboration across research and industry partners beyond the SEASON consortium.

The source code can be found at https://github.com/Mellgood/calix-olt-netconf-rest

5.3.2. Techno-Economic Analysis Tool for Optical Transport Solutions in Next Generation RAN

As part of its contribution to the SEASON project's open-source activities, a techno-economic modelling tool has been developed to evaluate and compare different mobile transport architectures, with a focus on Point-to-Multipoint (P2MP) coherent fronthaul systems based on digital subcarrier multiplexing (DSCM). The tool is publicly available and has been used to validate results available in Deliverable D2.3

The Python-based framework allows users to model realistic deployment scenarios by defining traffic demand, node density, transceiver types, and topology layout. It integrates parametric equipment catalogues, energy models, and cost structures to compute capital and operational expenditures, and to assess the energy footprint of alternative architectures including P2P, WDM, and coherent P2MP.

One of the key innovations of the tool is its ability to simulate the impact of traffic aggregation strategies at the optical level, quantifying how digital subcarrier sharing across multiple remote units affects the overall cost and power consumption. This functionality is crucial for assessing the viability of coherent P2MP solutions, especially in high-density or cost-sensitive deployment contexts.

The contribution provides SEASON with a reproducible, extensible, and transparent methodology for cost-performance benchmarking of advanced optical transport options. It serves as a reference implementation for techno-economic analyses in future 5G and 6G network planning, and its open-source availability ensures its reuse in other projects, standardization efforts, and industrial feasibility studies beyond SEASON.

The source code can be found at https://github.com/andreamarotta/SeasonTechnoEconomic

5.3.3. Edgecore Sonic Driver

The agent has been developed in python based on a sonic driver and it exposes a custom-built REST API on port 3105 to perform the configuration of the sonic-based Edgecore devices. The driver converts the REST requests in cli commands, i.e., to configure an IP address, to activate a pluggable transceiver, to enable a VLAN.

The source code can be found at: https://github.com/asgamb/sonicdriver

5.3.4. Edgecore IPoWDM Netconf/Openconfig agent

The NETCONF OpenConfig agent image has been provided on the format of a docker image that includes all the relevant pre-compiled YANG models and a default datastore image of an IPoWDM device fully equipped with 400G pluugables.

The agent exposes two main NETCONF APIs: on port 2022, exploiting the SSH protocol, and on port 2023, offering an un-encrypted channel (over TCP). The agent communicates via REST with the Edgecore driver to perform the device configuration.

The source code can be found at: https://hub.docker.com/repository/docker/asgamb1/ipowd

5.3.5. Planning Tool: 6DMAN

The 6DMAN planning tool, developed within the SEASON project, is an open-source Python-based toolkit focused on optical network modelling, planning, and performance analysis. This tool enables researchers, engineers, and students to build, analyse, and visualize optical communication networks. The toolkit supports the definition of nodes and links, the incorporation of real or synthetic topologies, and the simulation of multiple wavelength bands such as C-band and L-band. Its modular architecture makes it suitable for both academic research and educational use, helping to bridge the gap between theoretical design and experimental validation in optical network studies.

The tool includes features for traffic routing and wavelength assignment (RWA), optical signal-to-noise ratio (OSNR) calculations, and estimation of required signal margins under different network conditions. These functionalities allow users to evaluate the impact of planning choices on network performance and to assess key performance indicators (KPIs) in multi-band optical systems. 6DMAN also provides visualization tools for interpreting simulation outcomes, making it easier to analyse network topologies and performance metrics through clear graphical representations.

For research projects, 6DMAN provides an adaptable and transparent environment that supports reproducibility and collaboration. It can be extended with custom modules, integrated with other Python-based simulation frameworks, and used in teaching environments to illustrate optical network design principles. Being distributed under the MIT license, it is freely accessible to the research community, encouraging open collaboration and the acceleration of advances in multi-band optical network planning and optimization.

The source code can be found at: https://github.com/UC3M-ONDT/SixDman

5.3.6. Latency AI Agent: percentile estimator

The LatencyEstimation AI Agent is an open-source R-based implementation, developed within the SEASON project, allows to estimate latency percentiles between network nodes in a topology where nodes are equipped with multigigabit coherent pluggable transceivers. It provides a practical application of the latency envelope methodology which models empirical upper bounds for latency guarantees in packet-optical networks. The agent uses M/M/1 queuing models, where real link loads are converted into “envelope loads” to derive upper-bound latency percentiles beyond the 50th percentile, enhancing reliability analyses for complex network scenarios.

This AI agent leverages the ellmer library for constructing and coordinating its internal reasoning system, where large language models (LLMs) such as Google Gemini, OpenAI, or Claude can serve as its cognitive engine. Through natural language interaction, users can request latency percentile calculations across single or multiple network links, enabling intuitive experimentation with theoretical queuing models in practical network topologies. The example implementation showcases the agent’s capability to interpret user commands, apply internal modelling equations, and output latency estimates in real time.

By combining queueing theory with AI-driven reasoning, the tool offers a reproducible and intelligent framework for analysing delay performance in optical and packet-switched networks. Distributed under a CC0-1.0 license, it is available for research, teaching, and extension purposes without restriction. This makes it an ideal reference implementation for projects exploring latency modelling, intelligent network agents, or performance-bound estimation in autonomous networking environments.

The source code can be found at: https://github.com/josetilos/AI_agent_LatencyEstimation

5.3.7. xApp

The xApp is part of the SEASON's Distributed Intelligence Platform that provides streaming telemetry of a selected set of metrics available in the RAN controller (such as traffic load or active users) and it provides a REST API exposing RAN reconfiguration procedures to external entities.

The source code can be found at: https://github.com/SEASON-Project/Infrastructure-Management-xApp

5.3.8. Telemetry Collector

The Telemetry Collector is part of the SEASON's Distributed Intelligence Platform and it is designed not only as a telemetry ingestion and decision-making tool but also as a module for improving the energy efficiency of the network infrastructure. By collecting metrics from the RAN, it applies configurable decision logic. The Telemetry Collector can trigger the right action to the xApp so it can implement energy-saving actions (like activating/deactivating cells).

The source code can be found at: https://github.com/SEASON-Project/Telemetry-Collector

5.4. Open-Source ambitions after project completion

SEASON leverages the services provided by the Open Access Infrastructure for Research in Europe (OpenAIRE), which is an active service provider of the European Open Science Cloud. We aim to continue managing open data and access to research results during 2026. Note that this will be done on a voluntary basis, as partners cannot be contractually bounded to this once the project has finished.

As in the case of standardization, there is a multiplicity of Open-Source communities that are relevant for the project. We ambition to conduct maintenance activities during 2026 regarding our open-source contributions, in case those are needed (and with a best effort/voluntary approach).

6. Exploitation

6.1. Strengths, Weaknesses, Opportunities, Threats

The project has carried out strategic analysis of strengths, weaknesses, opportunities, and threats related to:

- Innovation and Technological Advancement
- Sustainable and Efficient Network Solutions
- Market Impact and Capacity Building

Figure 6-1, Figure 6-2, and Figure 6-3 show the summary of the SWOT analysis.

Strength	• **Advanced Technology and Research**: Leading in the development of cutting-edge technologies such as SmartNIC/DPU solutions, SDN, and AI/ML, which position these entities at the forefront of innovation in the ICT sector. • **Collaborative Ecosystems**: Strong partnerships with academic institutions, industry leaders, and standardization bodies enrich the environment for technological exchange and advancement. • **Resource Availability**: Access to extensive research facilities and technical expertise allows for comprehensive exploration and validation of new technologies.	• **High Complexity and Technical Challenges**: Advanced technological solutions involve increased complexity, requiring specialized expertise and posing integration challenges. • **Long Development Cycles**: The research and development of cutting-edge technologies often require significant time, potentially delaying market entry in a rapidly evolving industry. • **Dependency on External Technologies**: Some solutions rely on advancements in related technologies, which may limit control over development timelines and capabilities.	Weaknesses
Opportunities	• **Emerging Technology Demand**: There is a growing need for advanced ICT solutions across various industries, presenting significant market opportunities for innovative products. • **Standardization Influence**: Active participation in standardization efforts can shape industry norms to favor advanced technologies, potentially creating a competitive edge. • **Market Expansion**: As technologies mature, there is potential for expansion into new geographical and sectoral markets, broadening the impact of innovations.	• **Rapid Technological Evolution** • **Competitive Pressure** • **Integration with Existing Systems**	Threats

Figure 6-1 Innovation and Technological Advancement

Strength	• **Energy Efficiency**: Focus on developing solutions that optimize energy usage, aligning with global sustainability trends and reducing operational costs. • **Advanced Management Technologies**: Utilization of cutting-edge technologies such as SDN and intelligent transceivers to enhance network efficiency and performance. • **Standard Compliance**: Efforts to align with international standards ensure broad adoption and ease integration challenges.	• **Development Costs**: Significant initial investment is required for research, development, and testing of sustainable technologies. • **Integration Complexity**: New technologies can be complex and costly to integrate with existing network infrastructures, potentially deterring adoption. • **Dependency on Technological Adoption**: Effectiveness of solutions may rely on the broader industry adoption of related technologies like SDN.	Weaknesses
Opportunities	• **Regulatory Incentives**: Increasing regulations on energy consumption and emissions create a demand for sustainable solutions, presenting market opportunities. • **Market Leadership**: Innovating in sustainable solutions can position companies as leaders in this niche but growing sector. • **Emerging Market Potential**: Developing regions may prefer to implement the latest sustainable technologies, providing significant market opportunities.	• **Rapid Technological Evolution** • **Competition** • **Economic Constraints**	Threats

Figure 6-2 Sustainable and Efficient Network Solutions

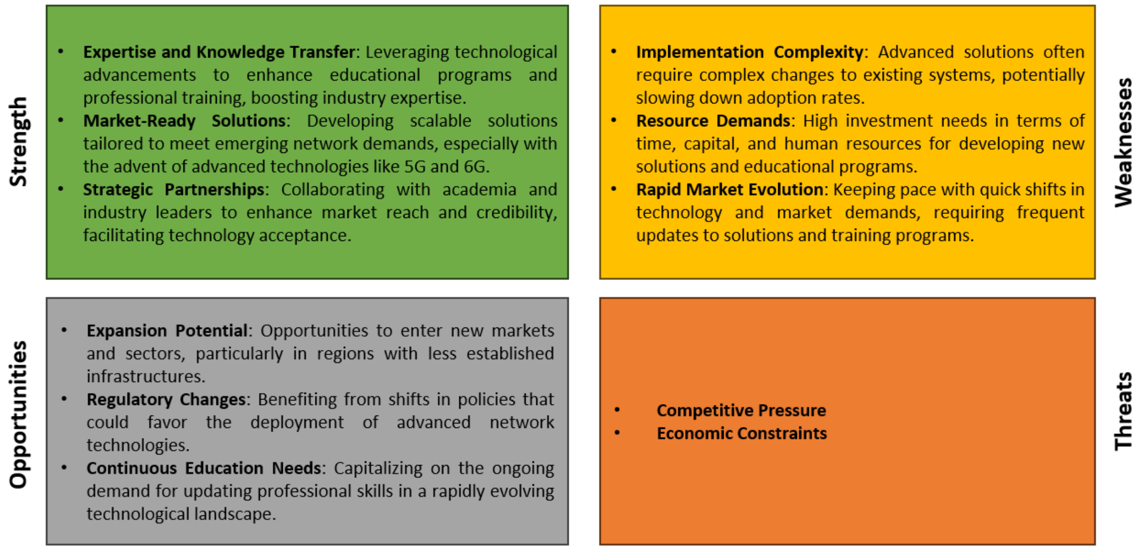

Figure 6-3 Market Impact and Capacity Building

6.2. Innovation Questionnaire

The questionnaire was prepared to show how the innovation is connected with the SEASON project. The questionnaire identified each innovation as follows:

Intellectual property of the innovation:

- Technical Readiness Level (TRL) before
- Asset type
- TRL expected
- Business mode
- Description

Main features

- Intellectual property / License scheme?
- Market segment which your asset is targeting
- Roadmap
- Expected Achievements
- Capability / technology gap addressed
- How does this move beyond state of the art

In this deliverable, we report on the identified innovations and the evolution of the TRL level before and after the conclusion of SEASON (see Table 11).

Table 11: Identified innovations

Innovation aspect	TR level (Current → Expected)
DPUs loaded with pluggable optical transceivers to offer joint network and computational functionalities.	2 → 5
Teraflow SDN Controller for openconfig-based control of IP and optical resources (i.e., coherent transceivers).	3 → 5
ROADM-based control of coherent transceivers	2 → 5
MB(oSDM) sliceable bandwidth/bitrate variable transceiver (S-BVT)	2 → 4
MBoSDM node	2 → 4
Multi-band Optical Power Consumption Models and Energy-Efficient ML-enabled Algorithms to assist SDN control operations	2 → 4
SDN Controller for multi-band flexi-grid over SDM networks	2 → 4
Advanced Sustainable AI/ML solutions for SDN-controller multi-band/SDM transport networks	2 → 4
Telemetry Agent	3 → 4
Optical Network Digital Twin	2 → 3
NetDevOps based telemetry streaming and network management	1 → 3
OCATA Digital Twin	2 → 4
Dynamic bandwidth allocation optimization software based on a point-to-multipoint transmission scheme	2 → 3
Power Optimization on Multi-band Systems Using Multi-Objective Genetic Algorithm	2 → 3
SDM-PON	2 → 4
REST Controller for Optical Access Networks	4 → 5
XR system with computation at the Edge	4 → 5
Single fibre single laser single wavelength transmission	4 → 5
The integration of Near-RT RIC with optical transport SDN controllers.	3 → 4

AI/ML-powered Service/Application-component orchestration	2 → 3/4
E2E 5G lab continuously updated with latest Ericsson Radio, Baseband and RAN Transport Solutions	2 → 4
Industrial collaboration and technology transfer to P2MP technology	3 → 5

6.3. FURTHER STATEMENTS ON EXPLOITATIONS

Vendors participating in the SEASON project have made a significant contribution to the development of new technologies aimed at further increasing transmission capacity in fibre-optic networks.

A key aspect was the development of a potential upgrade scenario that takes into account both multiband technology and space-division multiplexing. The results obtained were used to better align companies' R&D efforts and were presented in bilateral discussions with network operators to ensure early adaptation of transmission networks to newly introduced technologies.

In summary, the work of vendors has prepared the introduction of the two most promising technologies allowing to meet the increased capacity demand coming up in the next five to seven years. Already now, the results have been exploited to plan and prepare this introduction.

7. GLOSSARY

Acronym	Description
B5GNeO	Workshop on 6G Network Operation
DPU	Data Processing Units
ECOC	European Conference on Optical Communication
eFBB	enhanced fixed broadband
EuCNC	European Conference on Networks and Communications
FFC	Full-fibre connection
FG-AI4EE	Focus Group on Environmental Efficiency for Artificial Intelligence and other Emerging Technologies
GLOBECOM	Global Communications Conference
GRE	Guaranteed reliable experience
ICC	IEEE International Conference on Communications
ICT-DM	Information and Communication Technologies for Disaster Management
ICTON	IEEE International Conference on Transparent Optical Networks
IMOC	International Microwave and Optoelectronics Conference
JOCN	Journal of Optical Communications and Networking
MANTRA	Metaverse ready Architectures for Open Transport (
MUST	Mandatory Use Case Requirements for SDN for Transport
NetSoft	International Conference on Network Softwarization
OFC	Conference on Optical Fiber Communication
OLS	Open Line System
ONDM	IEEE International Conference on Optical Network Design and Modelling
OSM	Open-Source MANO
OT	Open Terminal
PSC	Photonics in Switching and Computing
SB	Steering Board
S-BVT	Sliceable bandwidth/bitrate variable transceiver
SDO	Specification Developing Organizations
TAPI	Transport-API
TB	Technical Board
TST	Technical Steering Team
WeInTel	Women in Telecommunications
WiTaR	Women in Telecommunications and Research

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