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Secured autonomic traffic management for a Tera of SDN flows

D6.4: Final report on Dissemination, Communication, Collaboration, and Standardisation

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Work package	WP6

Abstract

This deliverable provides a report of the dissemination, communication, collaboration, standardisation and exploitation activities performed during the last 18 months of the project, including an assessment of the impact achieved. It includes also the work performed in T2.3 about evolution of the TFS ecosystem.

[End of abstract]

Revision History

Revision	Date	Responsible	Comment
0.1	24.02.2023	Editor	Initial structure of document
0.2	01.06.2023	Editor, all partners	Inclusion of partners' contributions
0.3	15.06.2023	Editor	General sections
0.4	20.06.2023	Daniel King	Peer Review
0.5	26.06.2023	Adrian Farrel, Daniel King, Ricard Vilalta	Quality Review
1.0	30.06.2023	Ricard Vilalta	Submission
1.1	15.10.2023	Editor	After EC approval

Disclaimer

Acknowledgment

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[1] http://creativecommons.org/licenses/by-nc-nd/3.0/deed.en_US

Executive Summary

The TeraFlow Project has been a research and development initiative focused on advancing communication network technologies, to enhance the efficiency and scalability of network infrastructures in the context of B5G and 6G networks. Throughout its execution, the project has achieved significant advancements and notable outcomes in key areas like network architectures, high-capacity optical networks implementation and detection and mitigation of cyber-attacks in SDN networks, and development of an advanced SDN controller for a more efficient, secure, and adaptable network infrastructure.

TeraFlow has made significant contributions to various standards in multiple organizations related to blockchain, network automation, optical and microwave transport, network slicing, model-based services, and future Internet architectures (ETSI ISG PDL, ETSI ISG ZSM, ETSI ISG mWT, ETSI ISG MEC, TIP, ONF, IETF, OpenConfig). These contributions promote the adoption of open standards and facilitate the development of interoperable and high-performance solutions across diverse network domains.

The creation of the TeraFlow Software (TFS) group under the ETSI umbrella has been a major milestone for the project, as it ensures the long-term sustainability and development of the technologies and standards developed by TeraFlow. In addition, it fosters collaboration and industry adoption of these technologies, driving innovation in communication networks globally for the whole TFS ecosystem. This ecosystem created around TFS has been carefully analysed, applying a complex adaptive systems approach that uses system dynamics modelling. Key variables and causal relationships within the TFS business model were identified, with network effects and switching costs highlighted as important factors. The evolution of the TFS ecosystem is expected to give rise to new business models, such as specialized system integrators, software-centric hardware providers, and specialized application providers. The partners have discussed their alignment with the defined business models, exploitation packages and roadmaps and have explored potential updates based on the evolving business models and ecosystem. The TeraFlow IP Registry was created to clarify ownership and facilitate exploitation by project partners and third parties. The partners have also discussed their commitment to the maintenance and evolution of the components and identified potential missing roles for business development around TFS exploitation packages. Challenges for implementing the exploitation roadmaps include attracting system integrators, engaging telco operators, and convincing hardware vendors to implement open SBIs.

In parallel with technical and business activities, the TeraFlow project has greatly emphasised communication and dissemination of the results obtained. Through its website, social media profiles and the publication of scientific articles, the project has shared its progress with the scientific community and the general public. In addition, events and demonstrations have been held to showcase the achievements and encourage collaboration with other actors in the sector (SIGCOMM 2022, NextworkX 2022, Layer123 2022, OFC 2023, EuCNC & 6G Summit 2022 and 2023 or NetSoft 2023, to name just a few). Marketing materials such as posters, roll-ups, leaflets, and biannual newsletters have also been made available to disseminate project updates, research findings, and other relevant information to the target audience.

Ultimately, TeraFlow represents a significant step forward for the future of telecommunications. It enables deploying advanced services and applications to enhance connectivity and improve the user experience, avoiding vendor lock-in and enabling operators to select the most suitable and cost-effective options for their network infrastructure. However, more work must be done to understand

the costs and challenges of integrating TeraFlow into existing network infrastructures. For this reason, the Consortium recognizes the need for a new project that investigates integration costs. This project would allow us to explore the potential challenges and expenses involved in incorporating TeraFlow's solutions into current networks, while fostering ongoing research and innovation in the field.

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Abbreviations

5G	Fifth Generation
6G	Sixth Generation
3GPP	3rd Generation Partnership Project
5G PPP	5G Public Private Partnership
API	Application Programming Interface
B5G	Beyond 5G
DB	Database
EC	European Commission
EU	European Union
E2E	End-to-End
GSM	Global System for Mobiles
HTTP	Hypertext Transfer Protocol
IETF	Internet Engineering Task Force
IT	Information Technology
ICT	Information and Communications Technology
IoT	Internet of Things
IP	Intellectual Property
KER	Key Exploitable Result
KPI	Key Performance Indicator
L1	Layer 1
L2	Layer 2
L3	Layer 3
L3NM	Layer 3 Network YANG Model
MEC	Multi-access Edge Computing
ML	Machine Learning
MW	Microwave
MWC	Mobile World Congress
NF	Network Function
NFV	Network Functions Virtualization
NBI	North-Bound Interface
ONF	Open Networking Foundation
ONOS	Open Network Operating System
OPEX	Operational Expenditure
OS	Operating System
OSS/BSS	Operation Support System/Business Support System
P4	Programming Protocol-independent Packet Processors
PoC	Proof of Concept
QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio Access Network
SBI	South-Bound Interface
SDN	Software-Defined Networking
SDO	Standards Development Organization
SLA	Service-Level Agreement
TAPI	Transport API
TE	Traffic Engineering

VLAN	Virtual Local Area Network
VPN	Virtual Private Network
WG	Working Group
WP	Work Package

1. Introduction

1.1. Purpose

Work Package 6 in the TeraFlow project has been devoted to defining strategies and executing plans for impact creation. This document is the last deliverable from WP6, and its purpose is to offer a complete and detailed overview of all activities carried out by the Consortium from January 2022 to June 2023 towards following these strategies and plans. The deliverable includes reporting communication and dissemination activities, contributions to standards and open-source projects, an update on exploitation activities reported in D6.3, and collaborations with other related research projects and initiatives. Additionally, to close the work carried out in WP6, this document also provides an analysis of the overall impact achieved by the project, explaining how, thanks to the results achieved, together with effective planning and consecution of WP6 activities, the future of TFS today looks very promising.

1.2. Relation with other deliverables

D6.4 has dependencies with the rest of WP6 deliverables. Indeed, this deliverable is directly related to D6.1 [1], reporting on the activities conducted as per the plans this one described. It is linked with D6.2 [2] in the sense that D6.4 complements and finalises the reporting initiated in D6.2 and with D6.3 [3], that describes the general exploitation strategy, updating it with the latest findings.

It is also very clear that impact activities included in D6.4 depend absolutely on the work conducted in the technical packages. The technical work, and the results obtained, serve as inspiration for the communication messages and are the content itself of dissemination and contribution activities. We can therefore conclude that D6.4 is also related to the corresponding technical deliverables.

1.3. Structure

The remainder of this deliverable is organized as follows:

- Section 2 is about dissemination and communication activities conducted by the Consortium in the second and last period of the project.
- Section 3 reports on the standardisation activities and open-source contributions stemming from the work carried out in this period.
- Section 4 briefs on the exploitation activities of the project, taking into consideration the analysis of the evolution of the TFS ecosystem, that is also included in this section.
- Section 5 explains how the collaboration with other 5G PPP projects and related activities has progressed in the last months of the project.
- Section 6 includes an analysis of the overall impact achieved by the project, analysing how the results have effectively reached targeted stakeholders thanks to the activities carried out around them.
- Finally, section 7 offers conclusions and the next steps.

2. Dissemination and Communication Activities

This section describes the activities related to the website, social media, YouTube channel and communication material produced during the reporting period. It also includes project publications and participation in events. The section also contains an overview of the most impactful events where the project was present, as well as a summary of the dissemination and communication KPIs defined for the project and the final numbers achieved.

2.1. TeraFlow Website

2.1.1 Website updates in this period

The website has been conveniently updated throughout the whole reporting period. Events, scientific papers, news, videos, and blog posts by Consortium experts have been regularly produced and uploaded to their sections. The events also include links to their related presentations, papers or open access proceedings, and pictures of the event when available. Marketing materials like posters, roll-ups, leaflets, and biannual newsletters have also been uploaded to the website. In this project's last phase, the scenarios' definition and implementation has been further developed so the texts on the website have been updated accordingly. Besides, a new section called TeraFlowSDN[2] has been created, connected to the TeraFlowSDN community in ETSI.

The TeraFlow project website will be online at least two years after the project finishes.

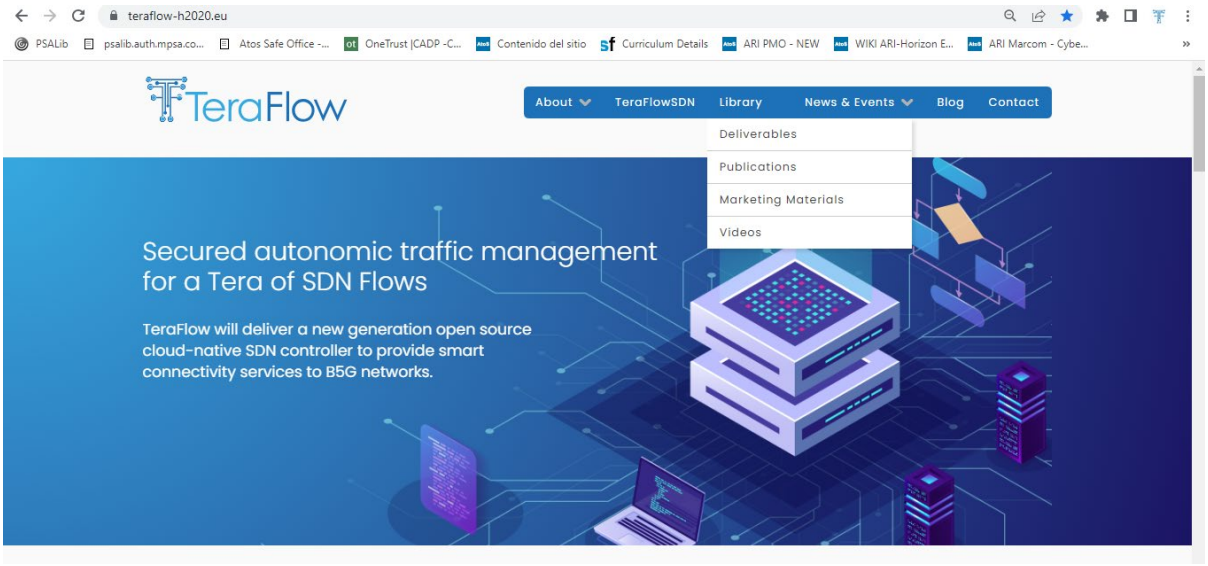

Figure 1: TeraFlow Project Website and dropdown menu

[2] https://teraflow-h2020.eu/teraflowsdn

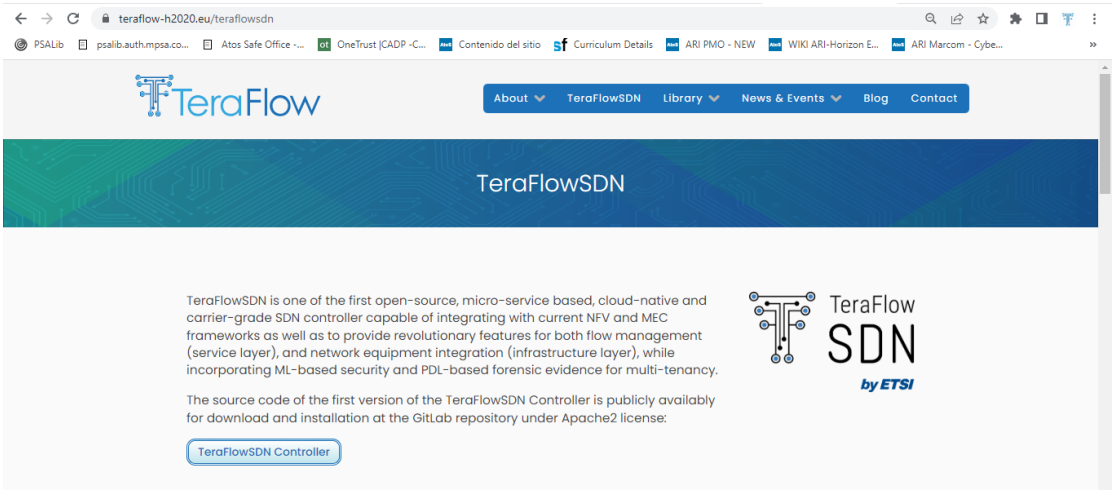

Figure 2: TeraFlowSDN section in TeraFlow Project Website

2.1.2 Metrics

The TeraFlow website has experienced a substantial increase in the total number of unique visitors, as depicted in the table below. Notably, during year 3, which encompassed only six project months, the website attracted more unique visitors than in year 2, which spanned twelve active months. This remarkable achievement can be attributed to the numerous dissemination events, where practical results and documents were shared via the website. Furthermore, it is worth noting that the initial estimate of 5000 unique visitors was surpassed by more than fourfold.

Table 1: TeraFlow's website metrics

Period	Unique Visitors
Year 1 (M1-M12)	2927
Year 2 (M13-M24)	9002
Year 3 (M25-M30)	9301
Total	21230

2.2. Social Media

Social media has become the primary channel for delivering news and information to stakeholders and the public. Updates and relevant news were regularly posted to get further engagement with the targeted audience.

TeraFlow project created accounts on Twitter (@TeraFlow_h2020) and LinkedIn (TeraFlow H2020). The TeraFlowSDN group also set their own Twitter (@TeraFlowSDN) and LinkedIn (TeraFlowSDN) accounts managed by the ETSI communication team. The audiences are slightly different, but all the accounts are interrelated.

From March 2022, the dissemination team implemented a targeted post strategy, specifically tagging relevant profiles like partner chairs, cochairs and speakers in events and other interested parties. Tagging relevant people, projects, or organisations has significatively increased the number of

followers and audience engagement. It became an effective way to gain exposure and benefit from extra exposure when they reciprocally tag the project, widening the reach of posts.

2.2.1 Twitter

TeraFlow's Twitter account has been running since the beginning of the project. All partners went on contributing relevant content that could be shared and retweeted. The figure below shows the look of the project account as well as a tweet posted on June 14th, 2023.

Figure 3: TeraFlow Twitter account and an example of our tweets

Despite Twitter's overall difficulties in maintaining accounts with the change of ownership[3], the graphic below shows that the number of followers – 354 by 15th June, exceeding by 100 our initial objective - has been regularly increasing during this reporting period, with no significant variation along time.

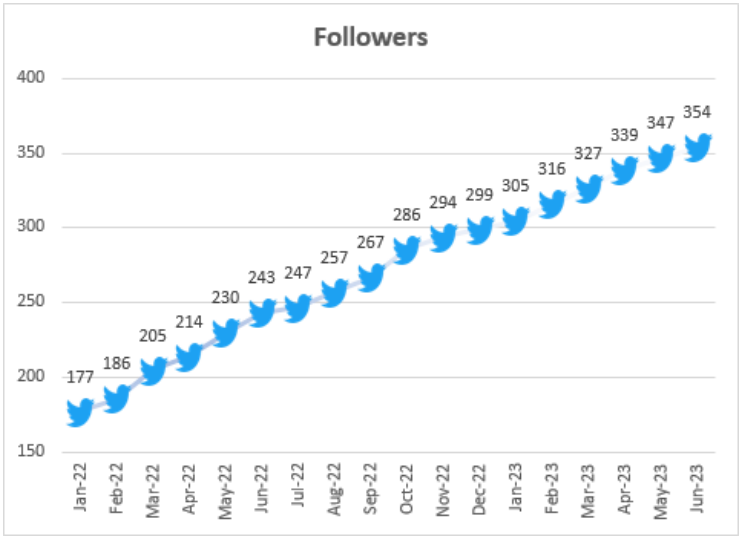

Figure 4: Twitter followers from 1st January 2022 to 15th June 2023

The frequency of the tweets varied from 6 to 30 posts per month through 2022 to fewer but more focused posts in 2023.

[3] https://www.theguardian.com/technology/2022/dec/13/twitter-lose-users-elon-musk-takeover-hate-speech

Regarding the correspondence between tweets and impressions, from the graphic below, we can see that we reached a maximum of impressions with fewer tweets in February 2022. Europe was still under travel restrictions because of the COVID-19 pandemic, and virtual events greatly influenced social network traffic. TeraFlow participated in the virtual ICT-52 Workshop on 6G (February 3rd and 4th, 2022). Peaks in the number of tweets when travel restrictions decreased and people started to attend more face-to-face events could not help to reach higher impressions.

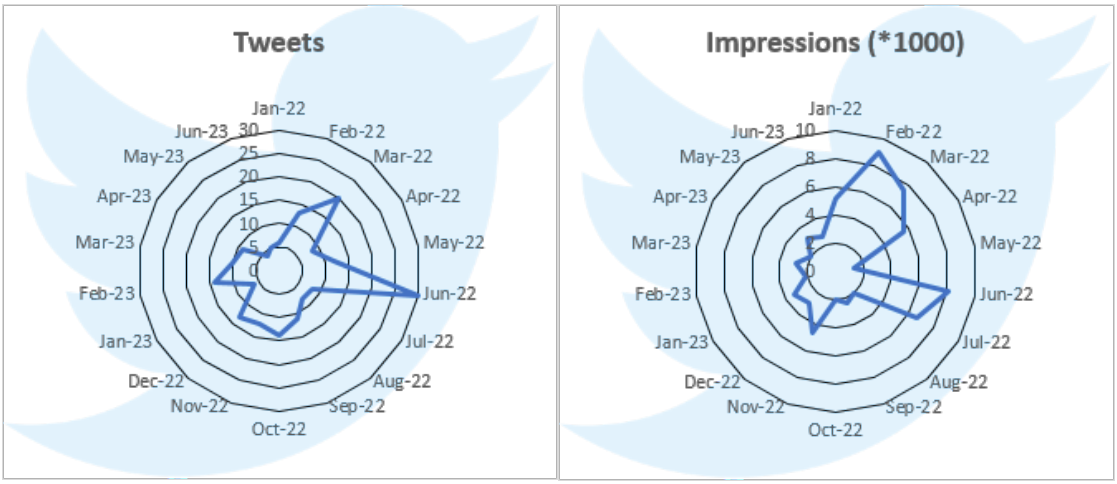

Figure 5: Number of tweets per month vs impressions per month in TeraFlow project account (M19-M30)

The next figure, however, shows an average user engagement with an upward graph slope. Our followers have not only increased, but it looks like they are more actively involved with our content. This effect is particularly interesting in the last months (February - May 2023; notice that data from June reflects only data of half a month).

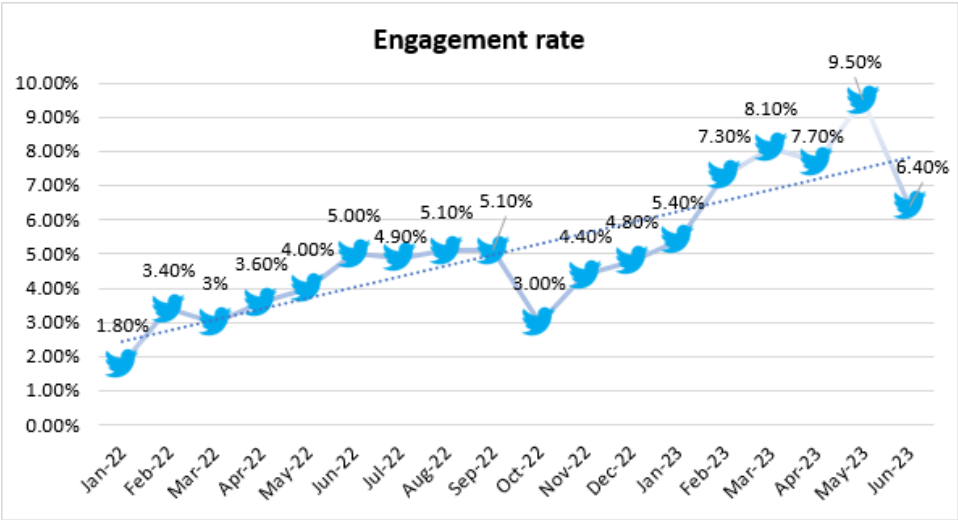

Figure 6: Engagement rate per month in TeraFlow project Twitter account (M19-M30)

During these months, we have launched a special campaign in social networks called “TeraFlowSDN World Tour” (#TFSWorldTour), producing tweet cards of great visual impact and reporting about the last face-to-face events that would take place at the end of the project, offering links to information, demos, videos, presentations, white papers, a book chapter, and open access papers related to TeraFlow.

Figure 7: One of the tweet cards generated for the TeraFlowSDN World Tour campaign.

2.2.2 LinkedIn

TeraFlow's LinkedIn account has also been running from the beginning of the project and received contributions from all the partners. The figure below shows the look of the project account.

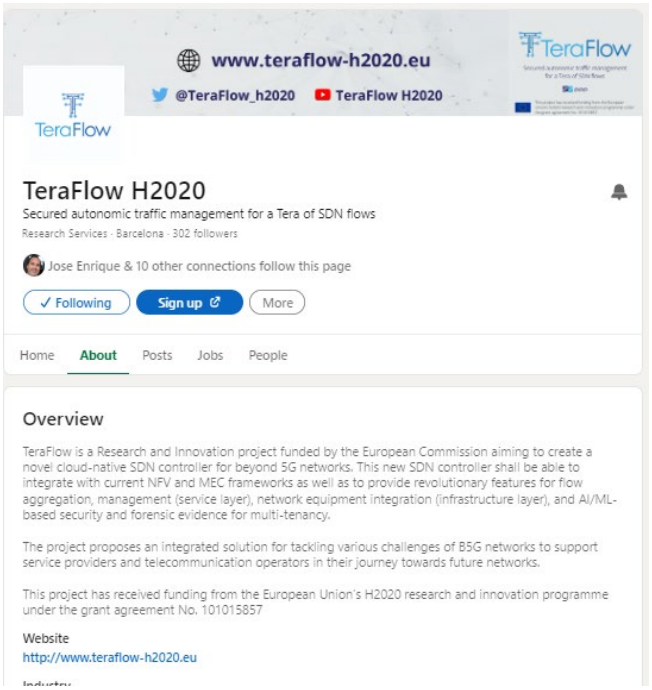

Figure 8: TeraFlow LinkedIn account

The following figure shows an example of a LinkedIn post on May 12th, 2023, and its organic statistics.

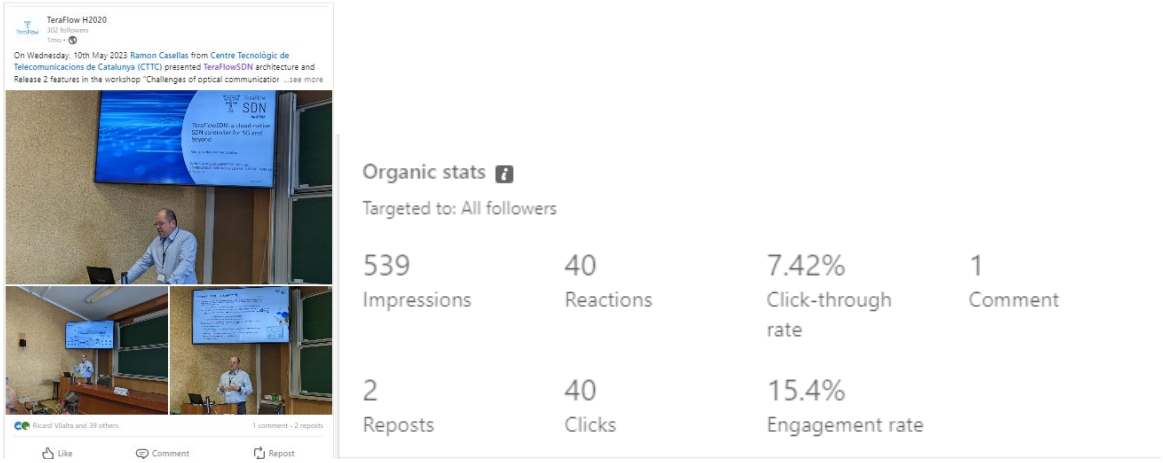

Figure 9: Example of a TeraFlow LinkedIn post on May 12th, 2023, and its organic stats.

As in the case of Twitter, the number of followers on LinkedIn– 302 by 15th June - has been regularly increasing during this reporting period. Remarkably, we have triple the number of followers from our initial objective.

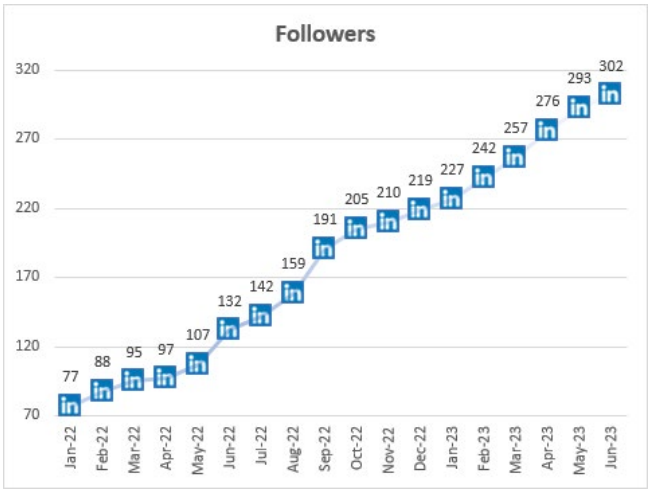

Figure 10: LinkedIn followers from 1st January 2022 to 15th June 2023

The frequency of the LinkedIn posts, contrary to the Twitter case, remained almost constant - from 6 to 9 original posts per month in the reported period.

Regarding the correspondence between tweets and impressions, from the graphic below, we can see that we reached maximum impressions during summertime 2022 (users were less active but saw our posts). Notice that in this case, the months with travel restrictions because of the COVID-19 pandemic had few impressions on LinkedIn. There were big post-impression peaks during the summer months, matching the first important face-to-face events. From November 2022, the impressions have stabilised (1000-2000 post impressions per month).

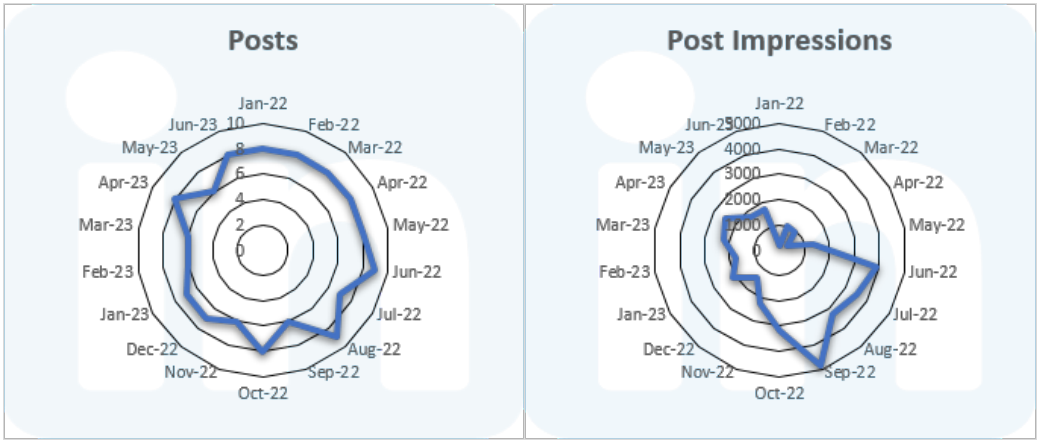

Figure 11: Number of LinkedIn posts per month vs impressions per month in TeraFlow project account (M19-M30)

The next figure shows variations in LinkedIn user engagement with an upward slope in the final months of the graph, and with less activity during the summer and season holidays. Our followers have increased, and are more actively involved with our content in the last few months. Data from June 2023 reflects only data of half a month.

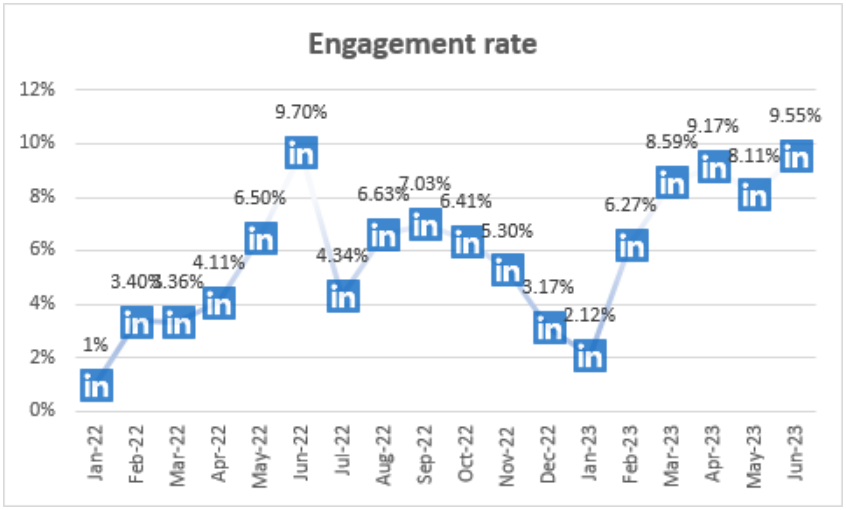

Figure 12: Engagement rate per month in TeraFlow project LinkedIn account (M19-M30)

2.2.3 YouTube

Online events have been recorded. All the recordings have been uploaded to our YouTube channel. All the videos are also linked to our website.

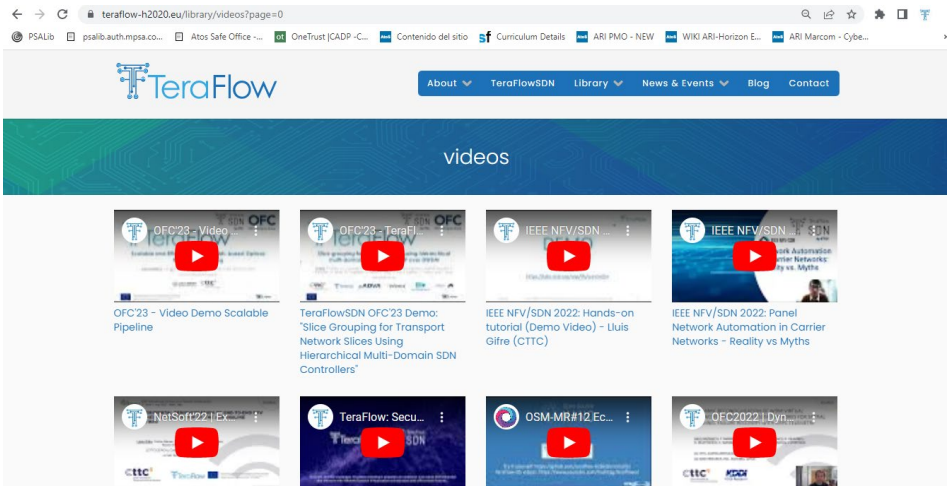

Figure 13: Video section in TeraFlow project website.

Twenty-six videos are available from our website, including one general-purpose video created to promote the project - with a total of more than 1300 views. Twelve of them have been produced during this reporting period.

2.3. Communication material

2.3.1 Logo and graphic elements

A new logo for the TeraFlowSDN community was created in collaboration with the ETSI graphic design team. Both logos have the icon in common and were used in presentations and events during this reporting period. The objective was to adapt the new logo to ETSI requirements for communities under its umbrella and to ensure that our initial audience gradually started associating both logos with our identity.

Figure 14: TeraFlow project logo vs TeraFlowSDN by ETSI new logo

New diagrams have been created for the architecture and the use cases. Release 2 required some adjustments, and some graphic iterations for the diagrams were created. Also, logos with copyright were changed by text.

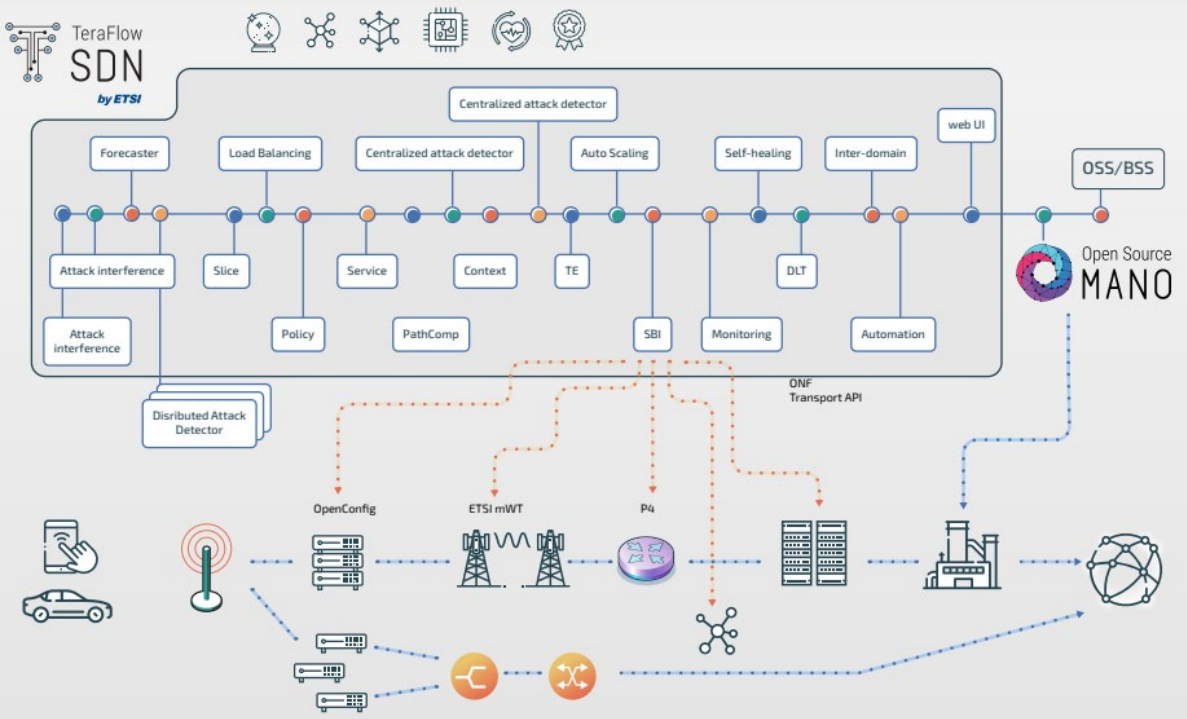

Figure 15: New design for the TeraFlow architecture diagram

2.3.2 Press releases

In the previous reporting period, Atos produced the first press release for the project launch. During this reporting period, four press releases related to TeraFlowSDN were produced and distributed by ETSI.

- 31st May 2022 - ETSI launches a new open-source group: TeraFlowSDN[4].
- 7th December 2022 – ETSI TeraFlowSDN winner of the Layer123 Network Transformation 'Upstart of the Year' Award[5].
- 2nd February 2023 - ETSI launches second release of TeraFlowSDN, its open source Cloud-Native SDN Orchestrator and Controller for transport networks[6].
- 22nd February 2023 - ETSI TeraFlowSDN to serve as reference implementation for TIP[7].

[4] https://www.etsi.org/newsroom/press-releases/2076-2022-05-etsi-launches-a-new-open-source-group-teraflowsdn

[5] https://www.etsi.org/newsroom/news/2157-etsi-teraflowsdn-winner-of-the-layer123-network-transformation-upstart-of-the-year-award

[6] https://www.etsi.org/newsroom/news/2186-etsi-launches-second-release-of-teraflowsdn-its-open-source-cloud-native-sdn-orchestrator-and-controller-for-transport-networks

[7] https://www.etsi.org/newsroom/press-releases/2195-etsi-teraflowsdn-to-serve-as-reference-implementation

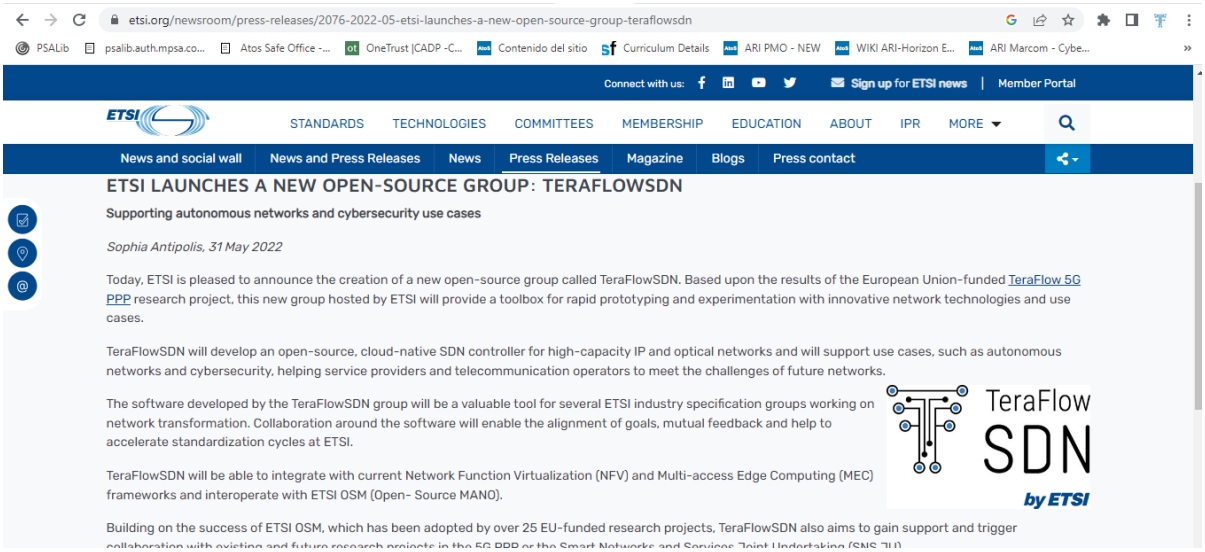

Figure 16: Example of TeraFlow press release in ETSI

Links to press releases are also available from the website[8].

2.3.3 Newsletters

The TeraFlow communication plan included the production of 5 biannual newsletters during the project's lifetime. At the moment of this report's production, four newsletters have been published and there is one more in preparation.

The newsletter includes a summary of the work progress for each work package, highlights and relevant events of the period and the section “Meet our partners”.

Figure 17: examples of pages of one of TeraFlow Newsletters

All newsletters have been promoted through our social networks and can be downloaded from a special section of our website[9].

[8] https://teraflow-h2020.eu/news
[9] https://teraflow-h2020.eu/news-events/newsletters

2.3.4 Blog posts

Blog posts are updates about the evolution of our project, interesting aspects of particular events and in-depth analyses by TeraFlow experts. Until 30th July 2023, 20 blog posts, including a final blog post by our coordinator, have been produced, all them during the second reporting period.

The blog posts are available in a special section of our website[10] and have been promoted through our social networks.

Figure 18: Blog post section in TeraFlow website

2.3.5 Brochure

During this period, the project brochure has been conveniently updated. A short run was printed for some particular events (i.e., IEEE ICC 2023 in Rome).

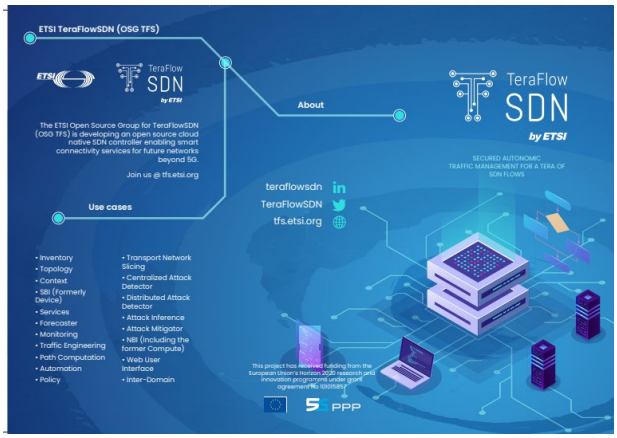

Figure 19: TeraFlow Brochure version 2023

[10] https://teraflow-h2020.eu/blog

The brochure is available on our website[11].

2.3.6 Posters and rollups

During this period, several posters were generated. Each partner generated scientific posters when requested to explain some particular project aspects. A 200 x 85 cm rollup and DINA1 posters have been produced for exhibitions. Our dissemination team also produced a fascia and a front desk design for the booth at IEEE ICC 2023.

Figure 20: TeraFlow Architecture rollup and Use Cases posters

Posters and roll up are available on our website[12]

2.4. Journal Publications and Scientific Papers

A total of 30 papers have been produced during this period. Machine-readable electronic copies of the published versions or final peer-reviewed manuscripts accepted for publication have been uploaded to Zenodo, Arxiv, or institution repositories for scientific publications by our partners when possible, except in those cases of Gold Open Access, in which the original link to the publication is provided.

At the moment of the composition of this deliverable, the Consortium has produced a total of 51 publications, with 44 publications in open access (34 conferences and 10 journals).

The distribution by reported period is as follows:

- 2021 (M1-M12): 21 in open access (19 conferences and 2 Journals)
- 2022-2023 (M13-M30): 23 in open access (15 conferences and 8 Journals); 7 not in open access yet, some of them under review (6 conferences and 1 journal)

[11] https://teraflow-h2020.eu/library/marketing-materials
[12] https://teraflow-h2020.eu/library/marketing-materials

The next table lists all publications in this reporting period. They have also been included in the European Commission Continuous Reporting tool and are available through our website with links to persistent repositories[13].

Table 2: TeraFlow Publications from M13 to M30

Type	Title	Authors	Conference or Journal	Link
Conference	Dynamic Reconfiguration of WDM Virtual Network Topology over SDM Networks for Spatial Channel Failure Recovery with gRPC Telemetry	Raúl Muñoz, Carlos Manso, Filippos Balasis, Ramón Casellas, Ricard Vilalta, Ricardo Martínez, Cen Wang, Noboru Yoshikane, Takehiro Tsuritani, Itsuro Morita	2022 Optical Fiber Communications Conference and Exhibition (OFC)	https://zenodo.org/record/7260228#.ZFpZynZBzcc
Conference	Microservice-Based Unsupervised Anomaly Detection Loop for Optical Networks	Carlos Natalino, Carlos Manso, Lluis Gifre, Raul Muñoz, Ricard Vilalta, Marija Furdek, Paolo Monti	2022 Optical Fiber Communications Conference and Exhibition (OFC)	https://zenodo.org/record/7348062#.Y4dJ6xTMLcd
Conference	Architecture to Deploy and Operate a Digital Twin Optical Network	R. Vilalta, R. Casellas, Ll. Gifre, R. Muñoz, R. Martínez, A. Pastor, D. Lopez, J.P. Fernández-Palacios	2022 Optical Fiber Communications Conference and Exhibition (OFC)	https://zenodo.org/record/7461914#.ZFpXunZBzcc
Conference	Demo: Demonstration of Zero-touch Device and L3-VPN Service Management using the TeraFlow Cloud-native SDN Controller	Ll. Gifre, C. Natalino, S. González-Diaz, F. Soldatos, S. Barguil, C. Aslanoglou, F. J. Moreno-Muro, A. N. Quispe Cornelio, L.	2022 Optical Fiber Communications Conference and Exhibition (OFC)	https://zenodo.org/record/7260852#.ZFpa_3ZBzcc

[13] https://www.teraflow-h2020.eu/publications

Type	Title	Authors	Conference or Journal	Link
		Cepeda, R. Martinez, C. Manso, V. Apostolopoulos, S. Petteri Valiviita, Ó. González de Dios, J. Rodríguez, R. Casellas, P. Monti, G. P. Katsikas, R. Muñoz, and R. Vilalta		
Journal	Evaluation of the abstraction of optical topology models in Blockchain-based data center interconnection	Pol Alemany, Ricard Vilalta, Raúl Muñoz, Ramón Casellas and Ricardo Martínez	Vol. 14, No. 4 / April 2022 / Journal of Optical Communications and Networking	https://zenodo.org/record/7313073#.ZFozlHZBzcc
Conference	Demo Track Paper: Demonstrating QoE-aware 5G Network Slicing Emulated with HTB in OMNeT++	Marija Gajic, Marcin Bosk, Susanna Schwarzmann, Stanislav Lange, Thomas Zinner	IEEE INFOCOM 2022 - IEEE Conference on Computer Communications Workshops	https://zenodo.org/record/7383009
Conference	QoS-Aware Inter-Domain Connectivity: Control Plane Design and Operational Considerations	Stanislav Lange, Jane Frances Pajo, Thomas Zinner, Hakon Lønsethagen, Min Xie	NOMS 2022-2022 IEEE/IFIP Network Operations and Management Symposium	https://zenodo.org/record/7383031
Conference	Experimental Demonstration of End-to-end NFV Orchestration on Top of the ADRENALINE Testbed	Lluis Gifre, Carlos Manso, Ramón Casellas, Ricardo Martínez, Ricard Vilalta, Raul Muñoz	IEEE International Conference on Network Softwarization (NetSoft2022)	https://zenodo.org/record/7273745#.ZFozAHZBzcc

Type	Title	Authors	Conference or Journal	Link
Journal	Synthetic flow-based cryptomining attack generation through Generative Adversarial Networks	Alberto Mozo, Ángel González-Prieto, Antonio Pastor, Sandra Gómez-Canaval and Edgar Talavera	Scientific Reports volume 12, Article number: 2091 (February 2022)	https://zenodo.org/record/7401818#.Y45B6lLMLUI
Conference	End-to-end Interdomain Transport Network Slice Management Using Cloud-based SDN Controllers	Ricard Vilalta, Lluis Gifre, Min Xie, Jane Frances Pajo, Håkon Lønsethagen, Stanislav Lange, Harald Øverby, Thomas Zinner, Raul Muñoz, Ramón Casellas, Ricardo Martínez	27th OptoElectronics and Communications Conference/International Conference on Photonics in Switching and Computing 2022	https://zenodo.org/record/7273494#.ZFo3O3ZBzcc
Journal	B5GEMINI: AI-driven Network Digital Twin	Alberto Mozo, Amit Karamchandani, Sandra Gómez-Canaval, Mario Sanz, José Ignacio Moreno and Antonio Pastor	Sensors 2022, 22	https://www.mdpi.com/1424-8220/22/11/4106/pdf?version=1653727238
Journal	Improving the quality of generative models through Smirnov transformation	Ángel González-Prieto, Alberto Mozo, Sandra Gómez-Canaval, Edgar Talavera	Information Sciences journal, arXiv e-prints	https://zenodo.org/record/7053057#.Y3tmj3bMLcc

Type	Title	Authors	Conference or Journal	Link
Conference	Experimental Demonstration of Transport Network Slicing with SLA Using the TeraFlowSDN Controller	Lluis Gifre, Daniel King, Adrian Farrel, Ramón Casellas, Ricardo Martínez, Juan-Pedro Fernández-Palacios, Óscar González de Dios, José Juan Pedreño-Manresa, Achim Autenrieth, Raul Muñoz, Ricard Vilalta	ECOC2022	https://zenodo.org/record/8084794
Conference	Dynamic Upgrade/Downgrade of WDM Link Capacity in SDN-enabled WDM VNTs over SDM Networks	R. Muñoz, C. Manso, F. Balasis, C. Wang, R. Vilalta, R. Casellas, R. Martínez, N. Yoshikane, T. Tsuritani.	ECOC2022	https://zenodo.org/record/8084804
Conference	MITOSIS: Practically Scaling Permissioned Blockchains	Giorgia Azzura Marson, Sebastien Andreina, Konstantin Munichev, Ghassan Karame	Proceedings of the Annual Computer Security Applications Conference (ACSAC), 2021	https://arxiv.org/pdf/2109.10302.pdf
Conference	On the Storage Overhead of Proof-of-Work Blockchains	Alessandro Sforzin, Matteo Maso, Claudio Soriente, Ghassan Karame	Proceedings of the IEEE Blockchain Conference 2022	https://arxiv.org/pdf/2205.04108.pdf
Journal	Practical Mitigation of Smart Contract Bugs	Jens-Rene Giesen, Sebastien Andreina, Michael Rodler,	ArXiv - Computer Sciences (published March 2022)	https://arxiv.org/pdf/2203.00364.pdf

Type	Title	Authors	Conference or Journal	Link
		Ghassan Karame, Lucas Davi		
Conference	Providing More Than 'Just' Reachability Through Semantic Networking (Keynote Paper)	Dirk Trossen; Adrian Farrel; Daniel King; Mohamed Boucadair; Luis Miguel Contreras Murillo	FIRA '22: ACM SIGCOMM Workshop on Future of Internet Routing & Addressing	http://www.olddog.co.uk/fira2022-final13.pdf
Conference	Towards Assessing Effects of Isolation on Determinism in Multi-Application Scenarios	Stanislav Lange, Marija Gajić, Thomas Zinner, Jane Frances Pajo, Håkon Lønsethagen, Min Xie and Ricard Vilalta.	FIRA '22: ACM SIGCOMM Workshop on Future of Internet Routing & Addressing	https://zenodo.org/record/7341181
Conference	Intent-Driven Management for Multi-Vertical End-to-End Network Slicing Services	Min Xie, Pedro Henrique Gomes, Jorg Niemoller, Jens Patrick Waldemar	IEEE GLOBECOM-WS01-3rd Workshop- Network management 6G communication systems NETMAN6G	https://zenodo.org/record/8084990
Conference	P4-based Telemetry Processing for Fast Soft Failure Recovery in Packet-Optical Networks	Filippo Cugini, Carlos Natalino, Davide Scano, Francesco Paolucci and Paolo Monti	2023 Optical Fiber Communications Conference and Exhibition (OFC)	https://research.chalmers.se/publication/534687/file/534687_Fulltext.pdf
Conference	Dynamic bypass of wavelength switching in SDN-enabled WDM VNTs over SDM Networks with high bit-rate optical channels	R. Muñoz, C. Manso, F. Balasis, D. Soma, S. Beppu, R. Casellas, Ll. Gifre, R. Vilalta, R. Martínez, N.	2023 Optical Fiber Communications Conference and Exhibition (OFC)	https://zenodo.org/record/8084742

Type	Title	Authors	Conference or Journal	Link
		Yoshikane, T. Tsuritani		
Conference	End-to-End Inter-domain Transport Network Slice Management Using DLT-enabled Cloud-based SDN Controllers (invited paper)	R. Vilalta, P. Alemany, Ll. Gifre, R. Martínez, R. Casellas, R. Muñoz	2023 Optical Fiber Communications Conference and Exhibition (OFC)	https://zenodo.org/record/8084736
Conference	Slice Grouping for Transport Network Slices Using Hierarchical Multi-domain SDN Controllers	Ll. Gifre, R. Vilalta, J.C. Caja-Díaz, Ó. Gonzalez de Dios, J.P. Fernández-Palacios, J.J. Pedreño-Manresa, A. Autenrieth, M. Silvola, N. Carapellese, M. Milano, A. Farrel, D. King, R. Martinez, R. Casellas and R. Muñoz	2023 Optical Fiber Communications Conference and Exhibition (OFC)	https://zenodo.org/record/8084731
Conference	Demonstration of a Scalable and Efficient Pipeline for ML-based Optical Monitoring	Carlos Natalino, Lluis Gifre, Raul Muñoz, Ricard Vilalta, Marija Furdek, Paolo Monti	2023 Optical Fiber Communications Conference and Exhibition (OFC)	https://research.chalmers.se/en/publication/534910
Conference	P5: Event-driven Policy Framework for P4-based Traffic Engineering	Panagiotis Famelis, Georgios P. Katsikas, Vasilios Katopodis, Carlos Natalino, Lluis Gifre, Ricardo Martinez, Ricard Vilalta, Dimitrios Klonidis, Paolo	IEEE HPSR 2023 conference	https://zenodo.org/record/8032190

Type	Title	Authors	Conference or Journal	Link
		Monti, Daniel King, Adrian Farrel		
Journal	ETSI TeraFlowSDN: the SDN Controller for the Beyond 5G/6G Era	Ll. Gifre, G. P. Katsikas, Ó. González de Dios, C. Natalino, A. Autenrieth, M. Milano, M. Xie, P. Armingol Robles, R. Martínez, R. Muñoz, J.P. Fernández-Palacios, H. Lønsethagen and R. Vilalta	IEEE Communications Standards Magazine	Under review
Journal	Scalability analysis of machine learning QoT estimators for a cloud-native SDN controller on a WDM over SDM network	Carlos Manso, Ricard Vilalta, Raul Muñoz, N. Yoshikane, Ramón Casellas, Ricardo Martínez, C. Wang, F. Balasis, T. Tsuritani, I. Morita	Journal of Optics Communications and Network - 14	https://zenodo.org/record/7330598#.ZFo0fnZBzcc
Journal	A Machine-Learning-Based Cyberattack Detector for a Cloud-Based SDN Controller	Alberto Mozo, Amit Karamchandani, Luis de la Cal, Sandra Gómez-Canaval, Antonio Pastor, Lluis Gifre	Applied Sciences	https://zenodo.org/record/8017098
Journal	Flexible and scalable ML-based diagnosis module for optical networks: a security use case	Carlos Natalino, Lluis Gifre, Francisco-Javier Moreno-Muro, Sergio Gonzalez-Diaz,	Journal of Optical Communications and Networking Vol. 15, Issue 8 (2023)	https://opg.optica.org/jocn/fulltext.cfm?uri=jocn-15-8-

Type	Title	Authors	Conference or Journal	Link
		Ricard Vilalta, Raul Muñoz, Paolo Monti, and Marija Furdek		C155&id=532131

2.5. Events, workshops and demos

TeraFlow has been presented in a total of 61 events. During this reporting period, TeraFlow was presented in 40 events with 5 booths. After the pandemic, 2022 and 2023 have been very active years, with increasing attendance to face-to-face events.

Table 3: TeraFlow events from M13 to M30

Event Name	Venue	Date	Type of participation	Description	Attendees	Link
ICT-52 Workshop on 6G	Virtual	3-4/02/2022	Workshop	Presentation "TeraFlow: TeraFlow use cases for a novel cloud-native SDN controller for beyond 5G networks" within session: 6G use cases and societal values – including aspects of sustainability, security and spectrum	200	https://www.teraflow-h2020.eu/events/ict-52-workshop-6g
MWC2022	Barcelona	28/02-03/03/2022	Booth	TeraFlow is presented at CTTC's booth	50	https://www.teraflow-h2020.eu/events/mwc-2022
OFC Conference 2022	Hybrid	6-10/03/2022	Presentations	Oral presentation: Dynamic Reconfiguration of WDM Virtual Network Topology over SDM Networks for Spatial Channel Failure Recovery with gRPC Telemetry Paper presentations: Microservice-Based Unsupervised Anomaly Detection Loop for Optical Networks + Architecture to Deploy and Operate aDigital Twin Optical Network	200	https://www.teraflow-h2020.eu/events/optical-networking-and-communication-conference-exhibition-ofc2022

Event Name	Venue	Date	Type of participation	Description	Attendees	Link
				Demo: Demonstration of Zero-touch Device andL3-VPN Service Management using the TeraFlow Cloud-native SDN Controller		
OSM Ecosystem Day	Virtual	9/3/2022	Presentation	15:05 - 15:30: CET Demonstration of Zero-touch Device and L3-VPN Service Management using the TeraFlow Cloud-native SDN Controller - Lluis Gifre and Ricard Vilalta, CTTC	100	https://teraflow-h2020.eu/events/osm-ecosystem-day-0
Layer123 Reunion Congress	Madrid, Spain	26-28/04/2022	Presentations	TeraFlow SDN: smart open-source connectivity form research to industry PoCs and standards Speakers: -Ricard Vilalta, CTTC -Oscar González de Dios, Telefónica - Sergio González, Atos Track Two: AI (27/04/2022 - 14:35 - 15:25) Presentation: "TeraFlow: Secured autonomic traffic management for a Tera of SDN flows" - Track Two: Cybersecurity - Ricard Vilalta (28/04/2022 - 15:15-15:35) WINNER - Layer123 Network Transformation 'Upstart of the Year' Award	50	https://www.teraflow-h2020.eu/events/layer123-reunion-intelligent-network-automation-congress
2nd IFIP/IEEE (FlexNGIA 2022)	Virtual	27-29/04/2022	Panel	International workshop on Fully-Flexible Internet Architectures and Protocols for the Next-Generation Tactile Internet (FlexNGIA 2022) collocated with IEEE/IFIP Network Operations and Management Symposium (NOMS2022) Paper presentation of joint work of Telenor and NTNU carried out within TeraFlow ("QoS-Aware Inter-Domain Connectivity: Control Plane Design and Operational Considerations", Stanislav Lange (NTNU), Jane Frances Pajo (Telenor), Thomas Zinner (NTNU),	100	https://teraflow-h2020.eu/events/teraflow-2nd-ifipieee-international-workshop

Event Name	Venue	Date	Type of participation	Description	Attendees	Link
				Hakon Lonsethagen (Telenor), Min Xie (Telenor)). Additionally there was a Special Panel on Research Projects on the design, management and security of Future Internet , 5G and beyond, with Ricard as speaker.		
IEEE International Conference on Computer Communications - IEEE INFOCOM 2022	Virtual	2-5/05/2022	Demo	Demo Track Paper: Demonstrating QoE-aware 5G Network Slicing Emulated with HTB in OMNeT++	50	https://www.teraflow-h2020.eu/events/ieee-international-conference-computer-communications-2022
EuCNC 2022	Grenoble, France	07-10/06/2022	Workshop, special session and booth	Special Joint Session: Redesigning Transport Networks for 6G: From the cell site to the core - B5GOPEN Workshops: HEXA-X AI (1) confirmed - Smart5Grid NetApps. Upload to the website the info of the tweets Booth dedicated - Exhibition/Demo confirmed	50	https://teraflow-h2020.eu/events/teraflow-2022-eucnc-6g-summit
OSM (Open Source Mano)13 Ecosystem Day	Virtual+f2f	15-Jun-22	Presentation	4:30 - 4:50 pm CEST Launching a new ETSI Open Source Group for TeraFlowSDN (OSG TFS) by CTTC Speakers: Ricard Vilalta (TFS Convenor) - CTTC This talk described the project scope, relation with OpenSourceMANO and other ETSI groups, governance, how to join, etc..	50	https://teraflow-h2020.eu/events/teraflow-oms13-ecosystem-day
ETSI TeraFlowSDN KoM	Virtual	20-Jun-22	Presentation	OSG TFS#1 kick off Meeting and Press release	100	https://teraflow-h2020.eu/events/etsi-teraflowsdn-kick-meeting

Event Name	Venue	Date	Type of participation	Description	Attendees	Link
NGON-DCI (Next Generation Optical Networking)	Barcelona, Spain	21-23 June 2022	Workshop	TeraFlow SDN session with several presentations	100	https://teraflow-h2020.eu/events/teraflow-ngon-dci-next-generation-optical-networking-world-2022
IEEE International Conference on Network Softwarization (NetSoft2022)	Milan, Italy	27 June–1 July 2022	Demo paper	Experimental Demonstration of End-to-end NFV Orchestration on Top of the ADRENALINE Testbed - Author(s): Lluis Gifre (CTTC) Renom, Carlos Manso, Ramon Casellas, Ricardo Martinez, Ricard Vilalta (CTTC) and Raul Muñoz	50	https://teraflow-h2020.eu/events/8th-ieee-international-conference-network-softwarization-netsoft2022
OECC/PSC 2022	Toyama, Japan	5-Jul-22	Presentation	3:45 PM - 5:15 PM Room F (Room 204, Toyama International Conference Center) Oral Sessions. O1. Core/Access/Data Center Networks and Subsystem. [TuF3] Optical Network Slicing. Presentation & paper: "End-to-end Interdomain Transport Network Slice Management Using Cloud-based SDN Controllers" Ricard Vilalta & others	50	https://teraflow-h2020.eu/events/teraflow-oeccpsc-2022
CSNDSP 2022, 13th International Symposium on Communication Systems, Networks, and Digital Signal Processing.	Porto, Portugal - António Cupertino de Miranda Centro de Congressos - Auditorium II	20-21 July 2022	Presentation	Plenary Talk 02 Start: 14:00 End: 15:00 Location: Auditorium II Session Chairs: Monica Figueiredo, Polytechnic Institute of Leiria and Stanislav Zvanovec, Czech Technical University in Prague P - "Optical Transport Networks in the 5G Era", Paolo Monti (CHAL)	50	https://teraflow-h2020.eu/events/teraflow-csndsp-2022

Event Name	Venue	Date	Type of participation	Description	Attendees	Link
SIGCOMM 2022 - FIRA Workshop	Amsterdam, The Netherlands	22 - 26 August 2022	Workshop and presentations	2 Papers submitted and accepted, one workshop (FIRA22) organised by TeraFlow members. Submitted article about WP4 for co-located FIRA Workshop: "Towards Assessing Effects of Isolation on Determinism in Multi-Application Scenarios"	50	https://teraflow-h2020.eu/events/teraflow-acm-sigcomm-2022
ECOC2022 European Conference on Optical Communication	Basel, Switzerland	18-22 September 2022	Presentations	1. Experimental Demonstration of Transport Network Slicing with SLA Using the TeraFlowSDN Controller 2. Dynamic Upgrade/Downgrade of WDM Link Capacity in SDN-enabled WDM VNTs over SDM Networks	100	https://teraflow-h2020.eu/events/teraflow-will-be-48th-edition-ecoc2022-european-conference-optical-communication
5GPPP Workshop on 6G KPIs and how to measure them	online	28-Sep-22	Presentation	9:00 - 12:00 CEST: Participation of TeraFlow in KPI measures, white paper composition of 5GPPP	200	https://teraflow-h2020.eu/events/5gppp-workshop-6g-kpis
6G O-RAN evolution workshop	Madrid, Spain	20-Oct-22	Presentations	Raúl Muñoz, CTTC: "ETSI OSG TeraFlowSDN: an open-source SDN controller for 6G xHaul transport networks" 14:10-14:30(CEST) (Marriott Auditorium Hotel & Conference Center)	100	https://teraflow-h2020.eu/events/teraflow-invited-6g-o-ran-evolution-workshop
HackFest, Network X, 1er Hackathon TeraFlowSDN - (collocated with OSM Hackathon 18-19 Oct)	RAI Amsterdam, Netherlands	20-Oct-22	Hackathon	Hackathon in the form of a tutorial featuring TeraFlow Release 1 allowing participant to get hands on experience with TeraFlowSDN.	50	https://teraflow-h2020.eu/events/teraflow-sdn-etsi-hackfest-networkx
IETF - 115	London, UK	5-11 November 2022	Presentations	Adrian Farrel and Daniel King from Old Dog Consulting presented 3 TeraFlow drafts at the TEAS (Traffic Engineering Signalling and		https://www.teraflow-h2020.eu/events/115th-meeting-ietf

Event Name	Venue	Date	Type of participation	Description	Attendees	Link
				Architecture) working group meetings. A further TeraFlow Internet-Draft, "Extensions to the Access Control Lists (ACLs) YANG Model", was presented in the Netmod working group. An unofficial side meeting was organised as a follow-up to the successful Future Internet Routing and Addressing (FIRA) workshop at SIGCOMM .This side meeting also helped to promote two TeraFlow drafts.		
IEEE NFV-SDN 2022 - The 8th IEEE Conference on Network Functions Virtualization and Software-Defined Networking	Chandler (Arizona), USA	14-16 November 2022	Demo and panel	Demo (Hands-on tutorial) and panel session	50	https://teraflow-h2020.eu/events/teraflow-ieee-nfv-sdn-2022
IEEE GLOBECOM -Global Communications Conference	Rio de Janeiro, Brazil	4-8 December 2022	Presentation	Intent-Driven Management for Multi-Vertical End-to-End Network Slicing Services	100	https://teraflow-h2020.eu/events/teraflow-will-be-ieee-globecom-netman6g
Layer 123 World Congress	London, UK	5-7 December 2022	Presentation	Closing Keynotes presentation: "Fostering innovation in Transport Networks with ETSI TeraFlowSDN controller" Ricard Vilata, Juan Pedro Fernández Palacios, Hakon Lonsethagen, Silvia Almaglia 7 Dec 2022 16:30-17:30 GMT. In addition to this, TeraflowSDN received the 2022 Network Transformation Awards in the category of Product & Services-Emerging Product.	100	https://teraflow-h2020.eu/events/teraflow-layer123-world-congress-2022

Event Name	Venue	Date	Type of participation	Description	Attendees	Link
Workshop on 6G by Hexa-X and ICT-52	online	18-19 January 2023	Presentation	On 18 January 2023, 9-12 CET Ricard Vilalta (CTTC) presented "TeraFlow: Do we need yet another SDN controller? Use cases for a novel cloud-native SDN controller for beyond 5G networks" in a Workshop on 6G organized by the Hexa-X project and ICT-52 cluster.	200	https://teraflow-h2020.eu/events/teraflow-hexa-x-workshop
ETSI Research Conference: Maximizing the Impact of European 6G Research through Standardization	ETSI Headquarters, Sophia Antipolis, France	8-Feb-23	Presentation	TeraFlow presentation scheduled in SESSION 9: Research into Standards - Lessons Learned, Overcoming Challenges: how you can help and what contribution you could make. 14:45 Overview of TERAFLOW H2020 Project - the journey from an EU Research Project to Standards Activity Ricard Vilalta, ETSI Open Source Group TeraFlowSDN Chair (ETSI OSG TFS)	200	https://teraflow-h2020.eu/events/teraflow-etsi-research-conference
TFS r2.0 ETSI Webinar	Virtual	13-Feb-23	Webinar	14h-15h During the webinar, some of the main TFS participants introduced the highlights of the new TFS release 2 along with some demonstrations of the new capabilities and use cases that the TFS community has been working on during this cycle	100	https://teraflow-h2020.eu/events-news/etsi-presentation-webinar-teraflowsdn-release
NetBCN meeting	Barcelona, Spain	21-Feb-23	Presentation	18:30 TeraFlow SDN - ETSI open source group: a SDN controller for smart connectivity in B5G (Spanish)	50	https://teraflow-h2020.eu/events/teraflow-netbcn-meeting
MWC (Mobile World Congress)	Barcelona, Spain	27 February - 3 March 2023	Presence in a booth	Gran Via venue of Fira Barcelona. Centre Tecnològic de Telecomunicacions de Catalunya (CTTC) booth: Congress Square, Catalonia Pavillion, Hall 210, Booth 19. Ricard Vilalta from CTTC took this opportunity to disseminate the fact that the TeraFlowSDN group	100	https://teraflow-h2020.eu/events/teraflowsdn-mobile-world-congress-mwc2023

Event Name	Venue	Date	Type of participation	Description	Attendees	Link
				at ETSI (European Telecommunications Standard Institute) chaired by CTTC has completed this year the second release and actively participated in international standardization fora. He also could establish new alliances and enhance contributions		
OFC 2023	San Diego, California, USA	5-9 March 2023	Presentations and demos	5 papers accepted., 2 different demos, 3 presentations	200	https://teraflow-h2020.eu/events/five-teraflow-papers-accepted-ofc-2023
BCN LATAM SUMMIT 2023	Virtual	13-14 March 2023	Presentation	Project presentation (Spanish)	100	https://teraflow-h2020.eu/events/teraflow-bcn-latam-summit
Hackathon in the IETF-116 March 27-31	Yokohama, Japan	25-31 March	Hackathon	On the Saturday and Sunday before (25th and 26th), there was a hackathon for people working on projects (usually open source) related to IETF specifications.	50	https://teraflow-h2020.eu/events/teraflow-will-participate-ietf-116-hackaton
MPLS SD & AI Net World Congress	Paris, France	18-20 April 2023	Presentation	Diego R. Lopez (Telefónica) coordinated and Silvia Almaglia (ETSI) participated in the session "Recent Advances in the Network Transformation Path" on 18th April	50	https://teraflow-h2020.eu/events/teraflow-mpls-sd-ai-net-world-2023
The 27th International Conference on Optical Network Design and Modelling (ONDM 2023)	Coimbra, Portugal	8-11 May 2023	Presentation, paper	Presentation in the workshop "Challenges of optical communications in the 6G era: a view from EU projects"	50	https://teraflow-h2020.eu/events/teraflow-will-be-ondm-2023
AI-NET Annual Event (EUREKA	Massy, France	25-May-23	Presentation	TeraFlowSDN in AI-NET PROTECT demonstrator	50	https://teraflow-h2020.eu/events/teraflow-ai-net-annual-event-2023

Event Name	Venue	Date	Type of participation	Description	Attendees	Link
CELTIC-NEXT CLUSTER)						
IEEE International Conference on Communications (IEEE ICC 2023) -	Rome, Italy	28 May – 01 June 2023	Workshop, booth	Booth and participation in a Workshop on “AI/ML-driven Autonomous 6G networks” organised by the 6G Smart Networks and Services Industry Association (6G-IA) that will take place on Monday May 29th, 2023, from 16.15 to 18.00 in the framework of the IEEE ICC’23 conference in Rome.	100	https://teraflow-h2020.eu/events/teraflow-ieee-icc
NGON & 5G Transport 2023	Cote d'Azur, France	30 May - 1 June 2023	Workshop, Roundtable, Presentation	On 31st May 2023 - 16:10 CEST, Daniel King, Old Dog Consulting chaired the roundtable: "Is it the End Nigh for Layered IP Over DWDM: Smart Pluggable Coherent Optics”: Also workshop on 1st June 2023 - 11:40 CEST: “Role of Standards in Automating Intelligent Optical Networks”. Presentation “Operator requirements and use cases for automated networking” by Juan Pedro Fernandez-Palacios (Telefonica)	100	https://teraflow-h2020.eu/events/teraflow-ngon-5g-transport-2023
IEEE HPSR 2023 International Conference on High Performance Switching and Routing	Albuquerque, NM, USA	5–7 June 2023	Presentation	"P5: Event-driven Policy Framework for P4-based Traffic Engineering" Paper by Panagiotis Famelis, Georgios P. Katsikas (UBI). Poster and paper.	100	https://teraflow-h2020.eu/events/teraflowsdn-ieee-hpsr-2023
EuCNC 2023	Gothenburg, Sweden	6-9 June 2023	Booth, Special Session, Presentation, Chapter in book, White	Organisation of a Special Session 7, “Novel technologies in disaggregated packet-optical networks to support 6G” (Thursday, 8 June 2023, 16:00-17:30, Room G1) chaired by Ricard Vilalta and Ramón Casellas from CTTC which includes a TeraFlow presentation by Pablo Armengol,	100	https://teraflow-h2020.eu/events/teraflow-2023-eucnc-6g-summit

Event Name	Venue	Date	Type of participation	Description	Attendees	Link
			paper collaboration	Telefónica - Presentation 6G KPIs Whitepaper 5GPPP (contributor Daniel King) - TeraFlow chapter in book "Towards Sustainable and Trustworthy 6G: Challenges, Enablers, and Architectural Design" - Booth		
OSM#15 Hackfest	Barcelona, Spain	12-16 June 2023	Presentation	Lluis Gifre, Ricard Vilalta (CTTC): "ETSI OSM-TFS Integration: New WIM-related features and future OSM+TFS integration plans"	50	https://teraflow-h2020.eu/events/teraflow-open-source-mano-ecosystem-day-osm15
NetSoft 2023	Madrid, Spain	19-23 June 2023	Hackathon, workshop, Keynote speaker	ETSI TFS Hackathon, Madrid, Spain – 20 and 21/6/2023 10h – 17h, Additionally, TeraFlow organized here a Workshop DataSlice 2023. Also participation in Distinguished Experts Panel -Keynote Speaker (Aurora Ramos, Atos) - Collaboration in other workshops	20	https://teraflow-h2020.eu/events/teraflow-will-organise-hackfest-and-netdata-23-workshop-netsoft23

2.6. Events Highlights of the period

The list of dissemination activities is extensive; we have created a summary of the most important events and highlights of the period.

OFC 2022

06 – 10 March 2022, San Diego Convention Center (California, USA), hybrid event.

The Optical Fiber Communication Conference and Exhibition (OFC) is the premier international event for the latest advances in optical communications and networking.

The 2022 edition featured a comprehensive programme from research to the marketplace, spanning the entire ecosystem. The event got a global audience of executives, technical experts, academia, media and analysts connected through OFC's hybrid format with a five-day technical programme and featured peer-reviewed presentations with more than 120 invited speakers. Additional technical programming throughout the week included symposia, in-depth tutorials, workshops, panels, round tables and discussion sessions – the perfect melting pot of experts in pandemic times to present TeraFlow.

In OFC 2022, **Lluis Gifre from CTTC performed the first virtual demo of Release 1**. TeraFlow Technical Manager Óscar González de Dios was our ambassador at the face-to-face event. A record of the session is available on the website[14], and a summary of the sessions in which TeraFlow participated[15].

Figure 21:TeraFlow in OFC 2022

OFC2023

05 – 09 March 2023, San Diego Convention Center (California, USA), hybrid event.

[14] https://www.teraflow-h2020.eu/videos/ofc2022-demo-zero-touch-device-and-l3-vpn-service-management-using-teraflow-sdn-controller

[15] https://www.teraflow-h2020.eu/events/optical-networking-and-communication-conference-exhibition-ofc2022

TeraFlow presence in OFC 2022 generated much interest. In the next edition, OFC 2023, TeraFlow had a very intense participation in the event. Ricard Vilalta and Carlos Natalino were invited speakers; Hanne-Stine Hallingby from Telenor was asked to virtually share her thoughts and visions about the mobile operator's expectations to transport networks; five papers about TeraFlow were accepted; two demonstrations related to the project were performed; and for the very first time, Óscar González de Dios, Head of SDN Transport Networks in Telefonica and TFS member announced TeraFlow as a reference implementation for Telecom Infra Project (TIP).

The details, presentations, demos and papers are available on the website[16].

Figure 22: TeraFlow in OFC2023

Layer 123, 2022

05 – 07 December 2023, London (UK).

Layer123 World Congress is one of the leading events in Europe devoted to network transformation and the applications it makes possible. This event brings together network operators and owners, telecommunications industry associations, the analyst community and solution providers.

TeraFlow was in one of the Closing Keynotes of this event. Our project also won the 2022 Network Transformation Awards in the Product & Services-Emerging Product category.

[16] https://teraflow-h2020.eu/events/five-teraflow-papers-accepted-ofc-2023

Figure 23: TeraFlow in Layer123 - 2022

More details can be found on the website[17] and in the ETSI press release[18].

NextworkX 2022

18 – 20 October 2022, RAI, Amsterdam (The Netherlands).

Network X is a sparkling and exciting telecom and mobile industry event, with attractive coverage and an impressive media spectacle; it is defined as "the new home of the long-running 5G World and Broadband World Forum" and covers the full spectrum of the telecoms ecosystem. This innovative event combines 5G, broadband and telco cloud technologies and is a great opportunity to network and get updated about the latest open-source projects and activities. This was the perfect place to organise with ETSI's help, the first TeraFlow Hackfest. Many materials were created for this event (presentations, video sessions, T-shirts…), and there is a record of the interview with our coordinator.

More information and the materials produced can be consulted on the website[19] and in ETSI[20].

[17] https://teraflow-h2020.eu/events/teraflow-layer123-world-congress-2022
[18] https://www.etsi.org/newsroom/news/2157-etsi-teraflowsdn-winner-of-the-layer123-network-transformation-upstart-of-the-year-award

[19] https://teraflow-h2020.eu/events/teraflow-sdn-etsi-hackfest-networkx

[20] TFS HACKFEST 1 · Wiki · TFS · GitLab (etsi.org)

Figure 24: TeraFlow in NetworkX 2022

IETF-115

05 – 11 November 2022, London (UK).

TeraFlow is making significant contributions to the standardisation work of the IETF. These contributions are better explained in section 3. Participation in the IETF meetings provided significant visibility to our project.

During IETF-115, three TeraFlow drafts were presented at the TEAS working group meetings. The TEAS (Traffic Engineering Signalling and Architecture) working group is where traffic engineering in the IETF is predominantly developed and is specifically responsible for network slicing. A further TeraFlow Internet-Draft was presented in the Netmod working group describing a set of extensions that fix many of the limitations of the ACL YANG model.

Additionally, three papers from the previous Future Internet Routing and Addressing (FIRA) workshop at SigComm23 were informally presented to those IETF-115 participants who could not attend FIRA. More information can be read in the events[21] and blog posts[22] area of our website.

[21] https://www.teraflow-h2020.eu/events/115th-meeting-ietf

[22] https://www.teraflow-h2020.eu/blog/teraflow-ietf-115

Figure 25: TeraFlow in IETF-115

IETF-116

25 – 31 March 2023, Yokohama (Japan).

A 2-day TFS Hackathon session was organized on this event, which allowed us to identify the key capabilities required for future releases of ETSI TFS.

More information can be read in the events[23] and blog posts[24] area of our website.

Figure 26: TeraFlow in IETF-116

[23] https://teraflow-h2020.eu/events/teraflow-will-participate-ietf-116-hackaton

[24] https://www.teraflow-h2020.eu/blog/teraflow-ietf-116

FIRA'22 Workshop at SIGCOMM 2022

22 – 26 August 2023, Amsterdam (The Netherlands).

The ACM SIGCOMM 2022 conference looks for significant research contributions to the field of communication networks and networked systems. Daniel King from Old Dog Consulting chaired the FIRA'22 Workshop on the Future of Internet Routing & Addressing. The workshop was very successful – attendance places were sold out weeks in advance.

More information can be read in the events[25] and blog posts[26] area of our website, and also the workshop program[27] and the proceedings[28].

Figure 27: TeraFlow in FIRA'22 workshop at SIGCOMM 2022

ETSI Research Conference: "Maximizing the Impact of European 6G Research through Standardization"

06 – 08 February 2023, Sofia Antipolis (France).

This face-to-face event provided an exceptional opportunity for the research community to join industry representatives and standardization experts for interesting discussions about future developments.

At the beginning of 2023, the Smart Networks and Services Joint Undertaking (SNS JU) launched the first phase of 5G / 6G research projects funded by the EC. The ETSI Conference provided the perfect opportunity to present the new projects, discuss with experts on their standardization roadmaps and knew on first hand good practices in standardization in European projects. TeraFlow and its sibling project Open Source MANO were presented by Diego R. López from Telefónica. The title of his presentation was "The ETSI ISG NFV Research Agenda" on Tuesday 7th February. Ricard Vilalta also

[25] https://teraflow-h2020.eu/events/teraflow-acm-sigcomm-2022

[26] https://teraflow-h2020.eu/blog/adventures-semantic-networking-and-1st-acm-sigcomm-workshop-future-internet-routing-addressing

[27] ACM SIGCOMM 2022 - ACM SIGCOMM 2022

[28] fira2022_acmproceedings_frontmatter.pdf (teraflow-h2020.eu)

devoted a presentation to our project in his role of ETSI Open Source Group TeraFlowSDN Chair (ETSI OSG TFS).

Figure 28: TeraFlow in ETSI Research Conference

More details on the website[29].

EuCNC & 6G Summit 2023

6 – 9 June 2023, Gotheburg (Sweden).

The 2023 EuCNC & 6G Summit focused on all aspects of telecommunications ranging from 5G deployment and mobile IoT to 6G exploration and future communications systems and networks; last year, more than 1300 delegates and more than 70 exhibitors attended the conference.

TeraFlow was an exhibitor in this event with a dedicated booth. TeraFlow was also in the Special Session 7 “Novel technologies in disaggregated packet-optical networks to support 6G” chaired by Ricard Vilalta and Ramón Casellas from CTTC.

Pablo Armingol-Robles from Telefónica presented TeraFlow in his talk “An operator’s perspective on 6G requirements for Transport Networks”

During the AI-NET event that was c-located with EuCNC 2023, Carlos Natalino from Chalmers also participated in the panel discussion on 6G and Digital Transformation; the AI-NET subproject AI-NET-PROTECT has plans to use TeraFlow for its demonstrator.

Michael Dieudonne (5GPPP TMV Chair) highlighted the new B5G/6G white paper on KPI Measurement. Daniel King from Old Dog Consulting and on behalf of TeraFlow, has been one of the contributors to this white paper that also was developed by other projects (B5G-OPEN, DAEMON, REINDEER, DEDICAT 6G and MARSAL).

[29] https://teraflow-h2020.eu/events/teraflow-etsi-research-conference

The new book "Towards Sustainable and Trustworthy 6G: Challenges, Enablers, and Architectural Design" was also presented during this event. This book includes a complete section about our project.

More information can be found in our website[30].

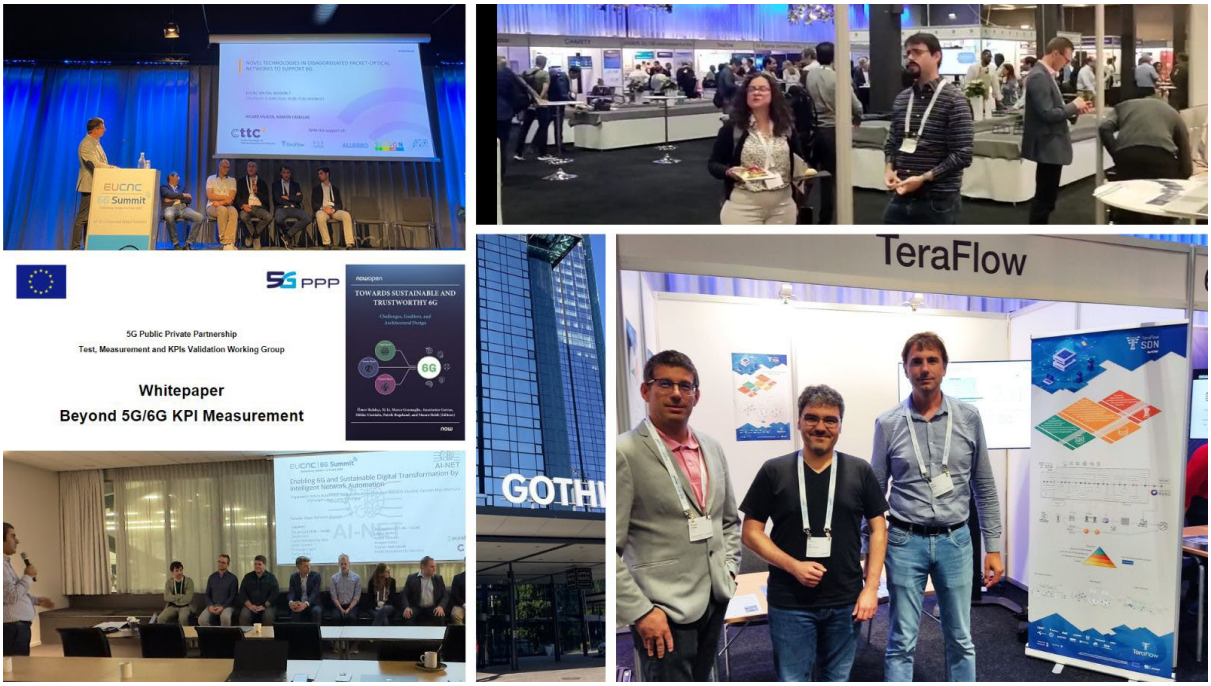

Figure 29: TeraFlow at EuCNC & 6G Summit

IEEE-ICC 2023

28 May – 01 June 2023, Rome (Italy).

Around 2,000 attendees from over 70 countries attend this event which consists of keynotes, technical papers, industry sessions, tutorials and workshops. Each year IEEE ICC brings together audiences from both industry and academia to learn about the latest research and innovations in communications and networking technology, share ideas and best practices. This year IEEE ICC 2023 was focused on "Sustainable Communications for Renaissance".

TeraFlow was an exhibitor in this event with a dedicated booth. Demonstrators, posters, a rollup and a project brochure, were prepared for this event.

Our coordinator Ricard Vilalta (CTTC), presented TeraFlowSDN during the session PR-2: SELF-ORGANIZING, SELF-MANAGING (AI-DRIVEN) AUTONOMOUS 6G NETWORKS, chaired by Alexandros Kaloxylos, Executive Director of the 6G Smart Networks and Services Industry Association (6G-IA). Other European projects were also presented at this event: ARIADNE, B5G-OPEN, 5GASP, DAEMON, Hexa-X. Ricard Vilalta also presented TeraFlow in the Podium Industrial Pitches.

More information on the website[31].

[30] https://www.teraflow-h2020.eu/events/teraflow-2023-eucnc-6g-summit

[31] https://www.teraflow-h2020.eu/events/teraflowsdn-ieee-icc-2023

Figure 30: TeraFlow at IEEE ICC 2023

AI-NET Annual Event 2023

25 May 2023, Massy (France).

As a member of the Celtic-Next AI-NET project, CHAL has been discussing the possibility of taking advantage of the ETSI TeraFlowSDN Controller as the SDN controller to be used in the final demonstration of the AI-NET PROTECT subproject. As a result of this possibility, CHAL was invited to speak at the AI-NET public event[32]. CHAL will continue to participate in the discussions, aiming to serve as a bridge to facilitate collaboration between the two projects.

Figure 31:TeraFlow in AI-NET Annual Event 2023

IEEE NETSOFT 2023

19 – 21 June 2023, Madrid (Spain).

IEEE NetSoft 2023 showcases the latest research in the areas of AI/ML, SDN/NFV, edge/fog networking, management and orchestration, network slicing, energy efficiency, cloud-native deployments, security, Future Internet, open softwarized network environments with full automation

[32] https://www.teraflow-h2020.eu/events/teraflow-ai-net-annual-event-2023

and automaticity, native network slicing, AI-based and dynamic control, management and orchestration.

TeraFlow was NetSoft 2023 Hackfest patron; the 2nd TFS Hackfest organised by ETSI's Centre for Testing and Interoperability and the TeraFlowSDN community was held there on 20-21 June 2023. The event has taken the form of a competition to integrate ETSI TeraFlowSDN Controller Release 2 with the ContainerLab environment.

Besides the Hackfest, TeraFlow organised the workshop DataSlice 2023: From Data Plane Programmability to Slicing Automation for Softwarized Infrastructures towards 6G.

Some other members of the TeraFlow team participated in other event activities: Aurora Ramos from Atos gave Keynote #3 – AI-Based Smart Network Management across. Other members of the TFS team, like Carlos Natalino and Paolo Monti from Chalmers, or Diego López from Telefónica participated in demos or were part of the technical committee in other workshops of this event.

More information can be found on the website[33].

Figure 32: banner announcing workshop at NetSoft and TFS Hackfest

[33] https://teraflow-h2020.eu/events/teraflow-will-organise-hackfest-and-dataslice-23-workshop-netsoft23

2.7. Other communication and dissemination activities

Table 4: TeraFlow publications @media, partners' websites, others

Type	Title	Source	Estimated Audience (Monthly Unique Visitors) [34]	Link
External	TERAFLOW NEWSLETTER #2	5G PPP	24780	https://5g-ppp.eu/teraflow-newsletter-2/
External	EUROPEAN 5G ANNUAL JOURNAL	5G PPP	24780	https://bscw.5g-ppp.eu/pub/bscw.cgi/d424095/5G%20European%20Annual%20Journal%202021.pdf
Partner	TeraFlow project launches the 1st release of a software-defined cloud-native SDN controller	Atos Research and Innovation Website	1860	https://booklet.atosresearch.eu/press-releases/teraflow-project-launches-1st-release-software-defined-cloud-native-sdn-controller
Partner	TeraFlow project launches the 1st release of a software-defined cloud-native SDN controller providing capabilities and deployments of Beyond 5G networks	CTTC Website	24210	http://www.cttc.es/teraflow-project-launches-the-1st-release-of-a-software-defined-cloud-native-sdn-controller-providing-capabilities-and-deployments-of-beyond-5g-networks/
External	TeraFlow press release promoted at 5GPPP LinkedIn Group	5G PPP - LinkedIn	1293	https://www.linkedin.com/feed/update/urn:li:activity:6904459335045627904
External	1ST RELEASE OF THE TERAFLOW OS	5G PPP	24780	https://5g-ppp.eu/1st-release-of-the-teraflow-os/
Partner	Spain-based TeraFlow releases first native cloud-based SDN controller	Telecompaper website	Unknown	https://www.telecompaper.com/news/spain-based-teraflow-releases-first-cloud-native-sdn-controller-for-b5g--1416229
Partner	TeraFlow project launches the 1st release of a software-defined cloud-native SDN controller providing capabilities and deployments of Beyond 5G networks	Paper.li website	Unknown	https://paper.li/YAKBAKIT/1408541986?share_id=4d439da0-94ae-11ec-a254-fa163eed9ef2
Partner	Sergio Diaz presented TeraFlow in Layer 123. ARI internal newsletter	ATOS research newsletter	200	Internal action

[34] The estimated audience reached has been calculated through the free online tool Siteworth Traffic (https://www.siteworthtraffic.com/) which provides data on the number of unique visitors of a website on a daily, monthly and yearly basis. The number presented in the tables for Estimated Audience Reached corresponds to the monthly unique visitors and it calculates all the people accessing the website. For estimating the number of people reading the news or article about TeraFlow we recommend considering only between 5% and 7% of the monthly views.

Type	Title	Source	Estimated Audience (Monthly Unique Visitors) [34]	Link
Partner	Presented to 2022 Innovation Radar Prize	Dealflow.eu	Unknown	Dealflow.eu
External	Presented to Layer123 - Prize - WINNER	Layer 123 - ETSI	Unknown	https://www.etsi.org/newsroom/news/2157-etsi-teraflowsdn-winner-of-the-layer123-network-transformation-upstart-of-the-year-award
Partner	CTTC @CttcTech 13/09/2021 (not reported in previous period) Participem a l'European Corner de la Nit Europea de la Recerca amb diferents projectes europeus. @TeraFlow_h2020	CTTC Website	Unknown	https://twitter.com/CttcTech/status/1437349917069090817
External	Press release CasaDomo TIP + TeraFlow SDN ETSI		Unknown	https://www.casadomo.com/2023/02/27/etsi-integra-requisitos-casos-uso-obligatorios-tip-controlador-sdn-nativo-nube
Partner	Press release: SIAE MICROELETTRONICA being one of the founding Members of ETSI TeraFlowSDN Working Group	SIAE website	Unknown	https://www.siaemic.com/index.php/news-media/news-events/item/122-siae-microelettronica-being-one-of-the-founding-members-of-etsi-teraflowsdn-working-group
External	TeraFlow 2nd release announced in Newsflash 5GPPP	5GPPP	24780	https://5g-ppp.eu/newsflash-march-2023/
Partner	ARI Bytes - Internal Newsletter - TeraFlow, a reference implementation for Telecom Infra Project (TIP)	Atos Internal Newsletter	200	https://atos365.sharepoint.com/sites/600002597/SitePages/NL-MarchApril-23-TeraFlow.aspx
External	Silvia Almagia (ETSI) Podcast	Tech Co Talks		https://www.linkedin.com/posts/techcotalks_techcotalks-iquallnetworks-telecommunications-activity-7059181607319945216-OgFH?utm_source=share&utm_medium=member_desktop

2.8. Summary of dissemination and communication activities

Table 5: TeraFlow Dissemination and Communication KPIs at the end of the project

Type	KPI	Total Target by M30	Achieved
Website	Unique Visitors	5.000	21230
	Average Time	2:00	0:44
	Page Views	10.000	44059
	Blog and News entries	20	20
Twitter	Tweets	360	598
	Retweets	800	824
	Likes	1.500	1802
	Followers	250	353
	Engagement Rate	≥ 1.2%	4.4%
	Impressions	100000	121300
LinkedIn	Page Views	2.000	1046
	Visitors	400	529
	Reactions	≥ 1.2%	5%
	Followers	100	302
Marketing Material	PPT – Scientific/Technical Dissemination Material	3	5
	Brochure	3	2
	Videos	2	1 +25
	Press Releases	3	5
	Newsletters	5	5
Scientific Dissemination	Scientific Publications	25	51
	Articles in specialised magazines/journals	10	11
	Posters	5	5
Events	Workshops organised	2	12
	Attendees to the project workshops	25	820
	Demo events	10	14
	Events and presentations where the project will be presented	20	61
Others	Liaisons and joint activities with other projects, communities, initiatives, etc. (e.g., website links, workshops, newsletters, social media, etc.)	20	24

3. Standardisation Activities and Open-Source Contributions

This section provides a description of the activities that have focused on contributions and collaborations within Standard Defining Organizations (SDO) and Open Source Software (OSS) communities.

3.1. Standards

3.1.1 ETSI ISG PDL

Members: NEC Europe Ltd. (Brigitta Lange), TID (Diego Lopez), ODC (Daniel King).

NEC and Telefónica are a founding members of ETSI ISG PDL (Industry Specification Group Permissioned Distributed Ledger). This group targets the utilization of blockchain technologies for the creation of open and trustworthy ecosystems of industrial digital solutions, and contributes to the group's working items and reports on challenges, concepts, and features related to the operation of permissioned distributed ledgers.

TeraFlow project is already part of the PDL work items PDL 007 Research Landscape and PDL 008 Research and Innovation Landscape, where NEC has been rapporteur.

3.1.2 ETSI ISG ZSM

Members: TID (Diego Lopez), CTTC (Ricard Vilalta), ODC (Daniel King), TNOR (Min Xie).

The ETSI Zero-touch network and Service Management (ZSM) Industry Specification Group (ISG) applies modern principles in its low-touch management framework for 5G end-to-end automation.

We studied the feasibility of running a Proof-of-Concept based on ZSM006-PoC Framework, but it was discarded due to the focus on ETSI TeraFlowSDN community building.

TNOR contributed to ETSI ZSM-011 based on the Inter-domain scenario and inter-domain module. The contribution has been approved and included in ETSI ZSM-011 draft (Section 4.3.1. Automotive use case).

3.1.3 ETSI ISG mWT

Members: SIAE

The group's activities cover several aspects related to the MW transport network and related technologies.

Great focus has been placed on defining use-cases of Software Defined Networking related to MW transmission. That activity led to identifying an appropriate ETSI standard model to be exposed through RestConf API in the north bound of a MW SDN Controller.

Several PlugTests have been done to demonstrate vendor SDN controller's capabilities and functionalities in a multivendor scenario. The last PlugTest took place in Sophia Antipolis 20-24 February 2023.

Standard model exposed by the RestConf API of SIAE intermediate SDN controller is the base of the integration of the MW portion into the TeraFlow ecosystem with specific focus on network topology retrieval and end2end service configuration.

3.1.4 ETSI ISG MEC

Members: CTTC

An important aspect during TeraFlow has been to align the SDN architecture with ETSI MEC 015 to offer Bandwidth Management (BWM) Services to Multi-access Edge Computing (MEC) applications.

ETSI MEC 015 introduces optional traffic management services to address potential resource conflicts between different MEC applications running on the same MEC host. These services include Bandwidth Management (BWM) and Multi-access Traffic Steering (MTS). The Bandwidth Management (BWM) service enables allocating and adjusting bandwidth resources for MEC applications. It allows applications to specify their specific bandwidth requirements, including bandwidth size and bandwidth priority. This service helps ensure that each application receives the necessary bandwidth to function optimally and prevents one application from dominating the available resources. The BWM service can handle static and dynamic bandwidth allocation, allowing applications to request changes to their bandwidth resources as needed. This flexibility accommodates varying requirements and allows applications to adapt to changing network conditions. By integrating BWM services into the SDN framework, network operators can efficiently allocate and manage bandwidth resources for MEC applications, ensuring optimal performance and quality of service for edge computing deployments.

Several discussions have been taken between TeraFlow representatives and ETSI MEC contributors. The following meetings have served the base to understand each project architectural domains and to propose some extended features to TeraFlowSDN to be performed in the scope of future research projects.

Participation and discussions in:

- ETSI MEC#32 meeting, 29/11-2/12, Sophia Antipolis (France).
- ETSI MEC #33, 13/3/2023, Castelldefels (Spain).
- Joint MEC-TFS call, 4/5/2023, Virtual.

3.1.5 Telecom Infra Project

Members: TID (Oscar González-de-Dios, Victor López, Juan-Pedro Fernández-Palacios)

The Open Optical & Packet Transport group is a project group within the Telecom Infra Project that works on the definition of open technologies, architectures, and interfaces in Optical and IP Networking.

The project is an engineering-focused effort led by major operators, technology vendors and research institutions. It concentrates on different parts of the Transport network architecture, including optical transponders, line systems, IP access devices, open APIs and network simulation and planning tools.

Use cases and technical requirements in TeraFlow are aligned with TIP. In particular, TeraFlow follows both NBI and SBI specifications defined in Mandatory Use Case Requirements For SDN Transport (MUST) group.

IPoDWDM SDN Architecture

https://cdn.brandfolder.io/D8DI15S7/at/n85t9h48bqtkhm9k7tqbs9fv/TIP_OOPT_MANTRA_IP_over_DWDM_Whitepaper_-_Final_Version3.pdf

MW SDN controller

https://cdn.brandfolder.io/D8DI15S7/at/kzt845vb2q9r2twr8jtgqm4/TIP_OOPT_MUST_Use-Cases-and-Technical-Requirements-for-Wireless-Backhaul-SDN-Domain-Controller--Network-Equipment-FINAL-GREEN-ACCESSv20.pdf

Optical SDN controller

https://cdn.brandfolder.io/D8DI15S7/at/sp6tgqcpjp8rgsshf8pvmwpg/TIP_OOPT_MUST-Optical-SDN-Controller-NBI-Technical-Requirements-v11_FINAL_GREEN_ACCESS.pdf

https://cdn.brandfolder.io/D8DI15S7/at/pgnh4kq5fhbj56kwnfwn3r4/TIP_OOPT_MUST-Optical-SDN-Controller-SBI-Technical-Requirements-for-Open-Terminals_V10_FINAL_GREEN_PUBLIC-ACCESS.pdf

IP SDN Controller

https://cdn.brandfolder.io/D8DI15S7/at/5xmjvcr3sgfrfwgmkbrhbwrs/TIP_OOPT_MUST_IP_SDN_Controller_SBI_Routers_Interface_Technical_Requiremenets_Document-FINAL_GREEN_ACCESS_v11.pdf

https://cdn.brandfolder.io/D8DI15S7/at/wq47398bnkjx48fw8pxmkk5/TIP_OOPT_MUST_IP_NBI_Technical_Requirements_Document_v10_FINAL_GREEN_PUBLIC_ACCESS.pdf

Finally, the ETSI TeraFlowSDN community has announced[35] their commitment to implementing TIP's Mandatory Use Case Requirements for SDN for Transport (MUST) Requirements in their innovative cloud-native SDN Controller. This will position TeraFlowSDN as a reference implementation in the Telecom Infra Project Open Optical & Packet Transport group (TIP OOPT). This move will also make it possible to accelerate the adoption of SDN standards for IP/MPLS, Optical and Microwave transport technologies, which is one of the main objectives of MUST.

With TeraFlowSDN as a reference implementation, the networking community will benefit from an open, standards-based solution that will make it easier to develop, test and deploy new functionality, and make it available to the broader communities. This alignment will help to foster the development and adoption of open, standards-based infrastructure solutions that can be easily integrated and deployed in real-world networks, enabling the delivery of new services and applications.

3.1.6 ONF

Members: TID (Oscar González-de-Dios), SIAE (Roberto Servadio, Danilo Pala), CTTC (Ramon Casellas, Ricard Vilalta), ODC (Daniel King).

[35] https://www.etsi.org/newsroom/press-releases/2195-etsi-teraflowsdn-to-serve-as-reference-implementation

The ONF 5G-xHaul project charted under the ONF Open Transport Configuration & Control (OTCC) is responsible for developing a technology-specific interface definition for wireless network functions.

Activities of this group led to the definition of standard models to be implemented over NETCONF protocol for the management of MW equipment by SDN controllers.

The yang models have been tested in a multi-vendor environment in 5 PoCs (Proof of Concepts) where SIAE Microelettronica has always been present.

TR-532 model has been adopted as a reference in the TeraFlow ecosystem to manage the functionalities of MW equipment.

Another of the project work items is the specification of the Transport Application Programming Interfaces (TAPI) data models, publishing open standard interfaces, whose main application domain is the controllers North Bound Interfaces (NBI). Considering the "network layering" that TeraFlow envisions, such standard API (along with the implementation guidelines and sample model usage) becomes a target interface in view of the integration of the transport layers (L0/L1) into the network orchestration functions of the TeraFlow controller (for example, as a controller South Bound Interface, SBI, to consume the services provided by dedicated per-domain optical controllers).

3.1.7 IETF

Members: ODC (Adrian Farrel and Daniel King), TID (Oscar González-de-Dios), CTTC (Ramon Casellas and Ricard Vilalta), TNOR (Håkon Lønsethagen).

The Internet Engineering Task Force (IETF) is at the core of the Internet. A leading non-profit standards body that develops standards needed for technology interoperability. It is an international community of network designers, operators, vendors, and researchers cooperating in various working groups. The work at the IETF, and its engineers, are vital for the smooth operation of Internet innovation. The open standards it publishes underpin the infrastructure and applications to facilitate the Web. TeraFlow project members lead several technical initiatives and have leadership roles.

The projects IETF innovative contributions are spread across three distinct areas:

- Investigating and Updating the IETF Principles for Internet Traffic Engineering;
- Framework to Manage Network Slicing and Applicable Data Models for Slice Instantiation;
- YANG-based Data Models for Service Deployment via the TeraFlowSDN (TFS) Platform.

In addition, the project partners have additional IETF protocol work to support several TeraFlow components.

The following sub-section details the IETF standardisation and activity and the impact it will have beyond the life of TeraFlow.

3.1.7.1. Evolving Internet Traffic Engineering

Internet Traffic Engineering ensures efficient and reliable network operations, optimizing resource utilisation and delivering high-quality services to end-users.

Overview and Principles of Internet Traffic Engineering
https://datatracker.ietf.org/doc/draft-ietf-teas-rfc3272bis

Internet Traffic Engineering ensures efficient and reliable network operations, optimizing resource utilisation, and delivering high-quality services to end-users. This IETF Internet-Draft will help the wider community agree on the requirements and principles of traffic engineering.

3.1.7.2. Network Slicing

Network slicing is a concept that involves partitioning a single physical network infrastructure into multiple virtual networks, called slices. Each network slice operates independently with resources and capabilities tailored to specific requirements and use cases.

Framework for IETF Network Slices
https://datatracker.ietf.org/doc/draft-ietf-teas-ietf-network-slices/

Instantiation of IETF Network Slices in Service Providers Networks
https://datatracker.ietf.org/doc/draft-barguil-teas-network-slices-instantation/

Applicability of Abstraction and Control of Traffic Engineered Networks (ACTN) to Network Slicing
https://datatracker.ietf.org/doc/draft-ietf-teas-applicability-actn-slicing/

A YANG Data Model for Network Resource Partitions
https://datatracker.ietf.org/doc/draft-wdbsp-teas-nrp-yang/

IETF Network Slice Controller and its associated data models
https://datatracker.ietf.org/doc/draft-contreras-teas-slice-controller-models/

IETF Network Slice YANG Data Model"
https://datatracker.ietf.org/doc/draft-liu-teas-transport-network-slice-yang/

Network slicing has several benefits and applications across domains, including 5G and beyond. It enables the coexistence and support of critical services with different requirements on a shared physical infrastructure. Network slicing offers greater flexibility, resource efficiency, and customization, enabling operators to efficiently manage and deliver services that meet the unique requirements of different applications, industries, or user groups.

The several Internet-Drafts we have developed present use cases, architectures, interfaces and data models for deploying and operating network slicing.

3.1.7.3. Model-driven Services

In general, "model-driven services" refer to Internet services or systems designed and implemented based on a model-driven approach. Operators need models to define the structure, behaviour, and characteristics of the services they want to deploy and operate. These models serve as a blueprint or representation of the desired service or system and guide the development, deployment, and management processes.

The following Technology developments in the IETF have helped us develop north-bound interface support for the TFS platform:

A Layer 2/3 VPN Common YANG Model
https://datatracker.ietf.org/doc/RFC9181

3.1.7.4. Future Internet Architecture

Future Internet Architecture seeks to overcome these limitations and enable new capabilities and functionalities to support emerging technologies and applications. Future Internet Architecture aims to create a more advanced and sustainable Internet infrastructure that can support the evolving needs of society, enable innovative applications, and facilitate the efficient exchange of information and services.

A Survey of Semantic Internet Networking Techniques
https://datatracker.ietf.org/doc/draft-king-irtf-semantic-routing-survey/

Challenges for the Internet Routing Infrastructure Introduced by Changes in Address Semantics
https://datatracker.ietf.org/doc/draft-king-rtgwg-challenges-in-routing/

Considerations for the use of SDN in Semantic Routing Networks
https://datatracker.ietf.org/doc/draft-boucadair-rtgwg-sdn-and-semantic-routing

These Internet-Drafts we help in the discussion and development of future Internet architecture.

3.1.7.5. Hackathon

During one of the final IETF sessions we attended (March, 2023), we organised our first TeraFlow Hackathon. These IETF Hackathons help encourage the wider Internet community to collaborate and develop practical implementations of IETF standards.

Our objective for the event included disseminating the TeraFlow project to the wider IETF community and highlighting the ETSI TeraFlow SDN (TFS) controller. The Hackathon's practical aspect was implementing more capabilities described in the IETF service models, which have limited support in release 2.0 of the ETSI TFS platform. These YANG-based models were developed in the IETF to communicate service and network requirements between the service orchestrator and TFS controller via a Northbound Interface API.

Our Hackathon table was well attended, with industry and academics from around the world, visiting us to discuss the TeraFlow project and the ETSI TFS controller. We also used the event to discuss TFS with wider industry partners and show other engineers how the TFS open source SDN controller may be used for integrated IETF network slice management.

The 2-day Hackathon session also allowed us to identify the key capabilities required for future releases of ETSI TFS. We hope to run future IETF Hackathons, and topics for the next sessions include the emerging IETF work on Inventory Management and the current Optical Device Models.

3.1.7.6. Post Project

It will be important to finalise the work that was started in the TeraFlow project but due to the time it takes to standardise; it may not be completed before the end of the project. We expect several drafts

to be completed as ETSI TFS activity continues and project partners continue developing technologies within their organisations.

3.1.8 ITU-T FG-AN

Members: ODC (Daniel King), TID (Oscar González-de-Dios)

ITU-T FG-AN stands for International Telecommunication Union Telecommunication Standardization Sector Focus Group on Artificial Intelligence and Machine Learning for Autonomous Networks (ITU-T FG-AN). The work of ITU-T FG-AN contributes to the advancement of AI and ML technologies in the context of network operations, helping to improve the efficiency, reliability, and intelligence of future networks. It also promotes cooperation among industry stakeholders and fosters global consensus on using these technologies in the telecommunication sector.

Various project partners followed the activities of this project, but ultimately, we could not make any specific contribution or development in the latter stages of the project.

3.1.9 OpenConfig

Members: TID (Oscar González-de-Dios)

TeraFlow's IP/MPLS-based use cases employ OpenConfig YANG data models at the Service-Based Interface (SBI) of the TeraFlow SDN controller, utilizing the device driver. TID, an active member of OpenConfig, has made significant contributions to fill the gaps identified by TeraFlow during their work on supporting these use cases. The contributions provided by TID include the following YANG code:

- OpenConfig EVPN YANG model: This model facilitates Layer 2 connectivity, encompassing the modelling of Ethernet segments. The contribution is thoroughly documented in https://github.com/openconfig/public/blob/master/doc/evpn_use_cases.md. It covers various technologies, such as:
  - BGP MPLS-Based Ethernet VPNs (RFC 7432) with VLAN-based service.
  - Provider Backbone Bridging Combined with Ethernet VPN (PBB-EVPN) (RFC 7263) with VLAN-based service.
  - Network Virtualization Overlay (NVO) EVPN (RFC 8365) with VLAN-based service and symmetric Integrated Routing and Bridging (IRB).
- Ethernet counters: These are Ethernet-related information retrieved from the TeraFlow SDN controller.
- Keychains and authentication of routing protocols: These additions are essential for the TeraFlow network creation use cases, ensuring the necessary security and authentication measures are in place.
- Extensions of the ACL (Access Control List) YANG model: These extensions are being developed to support the Attack Mitigator Component, enhancing its capabilities in managing network security and mitigating potential threats.
- Move ethernet segments to top-level container (EVPN) by oscargdd · Pull Request #768 · openconfig/public (github.com)
- Manage prefix list and extend ACLs to match prefix lists in source/destination by oscargdd · Pull Request #649 · openconfig/public (github.com)

- Add control word support for EVPN by oscargdd · Pull Request #792 · openconfig/public (github.com)

Furthermore, there are ongoing contributions that are currently in progress:

- Move ethernet segments to top-level container (EVPN)[36]
- Configure BFD min interval, multiplier when activated in protocols[37]

3.2. Open-Source Contributions

3.2.1 TeraFlowSDN Controller

Members: ALL

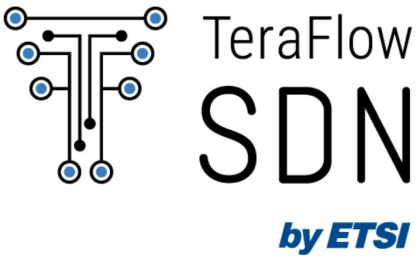

Figure 33 ETSI TeraFlowSDN logo designed by ETSI (inspired by TeraFlow H2020 project)

On May 31st 2022, ETSI announced[38] the creation of a new open-source group called TeraFlowSDN (TFS). Based upon the European Union-funded TeraFlow 5G PPP research project results, this new group hosted by ETSI provides a toolbox for rapid prototyping and experimentation with innovative network technologies and use cases. Figure 33 shows the logo designed by ETSI to promote the open-source group.

TeraFlowSDN follows up the code base from the H2020 TeraFlow project and currently develops an open-source, cloud-native SDN controller for high-capacity IP and optical networks and will support use cases, such as autonomous networks and cybersecurity, helping service providers and telecommunication operators to meet the challenges of future networks.

The software developed by the TeraFlowSDN group is a valuable tool for several ETSI industry specification groups working on network transformation. Collaboration around the software will enable the alignment of goals, and mutual feedback and help to accelerate standardization cycles at ETSI. TeraFlowSDN has been integrated with current Network Function Virtualization (NFV) and Multi-access Edge Computing (MEC) frameworks and interoperates with ETSI OSM (Open-Source MANO).

[36] Move ethernet segments to top-level container (EVPN) by oscargdd · Pull Request #768 · openconfig/public (github.com)

[37] Configure BFD min interval, multipleir when activated in protocols by oscargdd · Pull Request #856 · openconfig/public (github.com)

[38] https://www.etsi.org/newsroom/press-releases/2076-2022-05-etsi-launches-a-new-open-source-group-teraflowsdn

Building on the success of ETSI OSM, which has been adopted by over 25 EU-funded research projects, TeraFlowSDN also aims to gain support and trigger collaboration with existing and future research projects in the 5G PPP or the Smart Networks and Services Joint Undertaking (SNS JU). Several projects have been identified, and a call for presentation for TFS ecosystem day has been published, expecting contributions from 8 SNS projects.

Figure 34 shows the elected ETSI TeraFlowSDN Leadership Group (LG). Its responsibilities include setting and sharing the project vision.

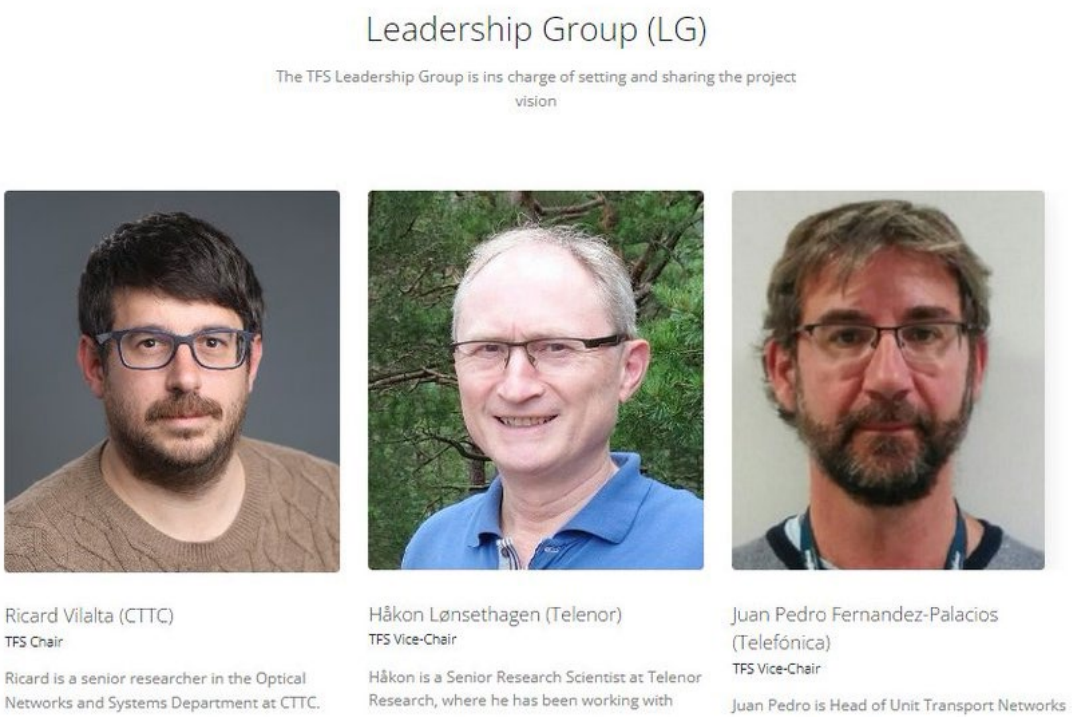

Figure 34: ETSI TFS Leadership Group (LG)

The Events section provides detailed information about ETSI TFS events, but we are eager to highlight TFS Hackathons taking place in Amsterdam (NetworkX), Japan (IETF), and Madrid (NetSoft). These hackathons offer an excellent opportunity to actively engage with the community and contribute to improving TFS open-source software.

On February 02nd, 2023, ETSI Open Source Group TeraFlowSDN announced[39] the 2nd release of TeraFlowSDN controller, an innovative and robust SDN orchestrator and controller. TeraFlowSDN Release 2 provides extended and validated support for end-to-end transport network slicing over multiple network domains. This release complete SDN orchestration for L2/L3VPN provisioning, microwave networks, Point-to-Multipoint integration of XR optical transceivers, and interaction with optical SDN controllers through the Open Networking Foundation (ONF) Transport API (TAPI).

[39] https://www.etsi.org/newsroom/news/2186-etsi-launches-second-release-of-teraflowsdn-its-open-source-cloud-native-sdn-orchestrator-and-controller-for-transport-networks

A webinar was prepared on February 13th 2023, with more than 75 registered attendants. The webinar is available via the ETSI website[40].

As part of the TeraFlowSDN Leadership Group, we have organized the following calls:

- TFS LG 9 - 15 May 2023
- TFS LG 8 - 17 April 2023
- TFS LG 7 - 20 March 2023
- TFS LG 4 - 12 December 2022
- TFS LG 3 - 19 September 2022

As part of the TeraFlowSDN technical Steering Committee, we have organized the following calls:

- TFS TSC 10 - 24 April 2023
- TFS TSC 9 - 27 March 2023
- TFS TSC 7 - 30 January 2023
- TFS TSC 6 - 19 December 2022
- TFS TSC 5 - 21 November 2022
- TFS TSC 4 - 24 October 2022
- TFS TSC 3 - 29 August 2022
- TFS TSC 1 - 4 July 2022
- TFS TECH 12 - 5 June 2023
- TFS TECH 11 - 8 May 2023
- TFS TECHDAY 2 / TFS TECH 10 - 25 April 2023
- TFS TECH 7 - 16 January 2023
- TFS TECH 6 - 7 November 2022
- TFS TECHDAY 1 / TFS TECH 5 - 11 October 2022
- TFS TECH 4 - 10 October 2022
- TFS TECH 3 - 12 September 2022
- TFS TECH 1 - 18 July 2022

Following TFS procedures, we had elections for TSC in March 2023. Figure 35 shows the elected TSC members for TFS release 3.

[40] https://www.etsi.org/events/2178-webinar-teraflowsdn-release-2-overview.

Figure 35: TFS TSC for release 3

3.2.2 ETSI OpenSource MANO

Members: TID (Diego Lopez), CTTC (Ricard Vilalta), TNOR (Pål Grønsund).

ETSI OpenSource MANO (OSM) is an initiative developing an open-source Management and Orchestration (MANO) stack which is compliant with the information models being defined within the ETSI ISG NFV standardization activities. To this end, the OSM project is being developed in a community fashion targeting the MANO implementation dealing with operators' requirements for delivering commercial and production NFV services. In this regard, the under-deployment TeraFlow OS leverages the current OSM solution to attain a tight integration with OSM acting as a WAN Infrastructure Manager (WIM) (i.e., SDN controller). This enables the OSM platform to request to the TeraFlow OS the deployment of connectivity services between Virtual Network Functions (VNFs) hosted at remoted cloud facilities (NFVI-Pops).

To this end, on June 14th 2023, Lluis Gifre presented in OSM Ecosystem Day a summary of contributions to OSM in order to better integrate with ETSI TeraFlowSDN. Table 7 summarizes the multiple open-source contributions to ETSI OpenSourceMANO from TeraFlow.

Table 6: List of Contributions to OSM from TeraFlow

Change	Subject	Project	Branch
#12683	**Feature 10954 to automatically select WIMs for inter-datacenter networks**	**osm/LCM**	**master**
#13226	**Feature 10937: Transport API (TAPI) WIM connector for RO**	**osm/RO**	**master**

#11712	Fix bug 1886 to hide WIM password properly in command wim-show	osm/osmclient	v10.0
#12511	Fix 2152 to hide WIM password properly in command wim-show	osm/osmclient	v12.0
#12512	Fix 2153 to hide WIM password properly in command wim-show	osm/osmclient	master
#11731	Fix 1899 to select correct WIM connector class and prevent exceptions with missing parameters	osm/RO	v10.0
#12523	Fix 2154 to select correct WIM connector class and prevent exceptions with missing parameters	osm/RO	v12.0
#12525	Fix 2156 to select correct WIM connector class and prevent exceptions with missing parameters	osm/RO	master
#11732	Fix bug 1902 to resolve issues with IETF L2VPN WIM connector	osm/RO	v10.0
#12524	Fix 2155 to resolve issues with IETF L2VPN WIM connector	osm/RO	v12.0
#12526	Fix 2157 to resolve issues with IETF L2VPN WIM connector	osm/RO	master
#11730	Fix 1901 to encrypt correct WIM account password field and check WIM accounts	osm/NBI	v10.0
#12509	Fix 2150 to encrypt correct WIM account password field and check WIM accounts	osm/NBI	v12.0
#12510	Fix 2151 to encrypt correct WIM account password field and check WIM accounts	osm/NBI	master

3.2.3 ONF ONOS and Stratum

Members: UBI (Georgios P. Katsikas)

No contribution was made to ONF Stratum, as its integration with ETSI TFS has been smooth. ONF ONOS has been an inspiration for the P4 activities of ETSI TFS.

3.2.4 HyperLedger

Members: NEC (Ghassan Karame)

Hyperledger is an umbrella project of open source blockchains and related tools of the Linux Foundation. Its most noteworthy project is Hyperledger Fabric, a modular open-source permissioned blockchain initiative originally led by IBM.

However, the current implementation of Fabric does not support Byzantine Fault Tolerance (BFT) algorithms, and only crash-fault tolerance is supported.

NEC led the development of the open-source consensus algorithm MinBFT that was accepted as an hyperledger-lab project[41]. MinBFT was designed to integrate Hyperledger Fabric and can be considered a consensus module for Fabric.

3.2.5 rebar3_docker

Members: STR (Sébastien Merle)

STR's open-source rebar3 plugin[42] provides valuable enhancements to the TeraFlow project, facilitating the creation of Erlang-based microservices. The plugin allows Docker images to be readily generated, streamlining deployment and distribution.

With the Docker image creation automated by STR's rebar3 plugin, manual configuration complexities are notably reduced. This integration frees TeraFlow to fully leverage Erlang's robust capabilities in microservices development without cumbersome setup procedures.

3.2.6 braidnet43

Members: STR (Sébastien Merle)

STR has developed a comprehensive software system utilizing the rebar3_docker plugin, which is crucial for managing an Erlang node cluster. This system deftly handles all aspects of node lifecycle - creation, operation, and termination, as well as managing inter-node connectivity, which enhances system adaptability and efficiency.

Demonstrating a high degree of versatility, the software system by STR is adaptable across various applications. Users can efficiently manage Erlang nodes in various environments, including local servers and cloud platforms. On the service side, STR's software provides robust tools for managing node connectivity, simplifying inter-node communication, particularly in complex systems. All core functionalities related to Erlang node lifecycle management and node connectivity have been fully implemented and integrated.

This software system could contribute significantly to the TeraFlow project, particularly in scaling traffic engineering. Efficiently managing Erlang-based services ensures optimal operation and effective communication within the system.

3.2.7 SONIC

Members: INF (Mika Silvola)

INF used and extended Edgecore Enterprise SONiC funtionality, which is commercialized hardened version from Open Source SONiC from Edgecore. Infinera extended SONiC CMIS 5.1 base functionalities to support XR QSFP-DD optics and it's integration with DCS240/AS9726-32DB hardware to verify compatibilty with OCP designed HW product, see details from https://www.edge-core.com/_upload/images/2022-091-DCS240_AS9726-32DB-DS-R05-20221229.pdf. Infinera is

[41] https://github.com/hyperledger-labs/minbft
[42] https://github.com/stritzinger/rebar3_docker
[43] https://github.com/stritzinger/braid

considering working with SONiC community to back-port XR related CMIS extensions to community SONiC version with community supported HW vendor.

4. Exploitation Activities

In deliverable D6.3, the exploitation activities carried out by the whole Consortium and individual partners until December 2022 were reported, together with an action plan to materialise joint exploitation activities and further use of TFS in the short, mid, and long term.

An important aspect for partners in planning and executing their exploitation plans is to understand the possible business models that can operate between the different actors belonging to the TFS ecosystem, as they are themselves part of this ecosystem. In the last six months of the project, T2.3 has been addressing the potential evolution of TFS ecosystem to help partners anticipate business opportunities around TFS and benefit from a competitive advantage in the SDN market. T2.3 and T6.3 leadership (TNOR, NTNU and ATOS) objective has been to facilitate and convey these insights to the partners, so that they could update their exploitation intentions in this last part of the project and work towards adopting the project results. To do so in the most efficient way, an internal exploitation workshop was planned in two different days. The first session took place on the 21st of April, 2023. The agenda comprised three different blocks in which T2.3 and T6.3 leaders made presentations to refresh the potential business models around TFS, the exploitation packages and roadmaps included in D6.3, and to introduce the methodology for the ecosystem evolution analysis. Each slot was followed by a presentation of the questions for partners to reflect upon until the next session. This second workshop session took place on the 5th of May 2023; it was devoted to an open discussion around the questions presented and gathering feedback to complement the analysis of the ecosystem evolution.

The information that partners give in this deliverable around exploitation activities for boosting TFS ecosystem and materialising business opportunities is the result of the internal exploitation workshop and subsequent interaction with T6.3 leader. As per AMD-101015857-17, the result of the ecosystem evolution analysis is also reported in this deliverable.

4.1. Analysis of the evolution of the TFS ecosystem

Understanding and analysing the behaviour of interconnected and constantly evolving systems, like the TFS ecosystem, requires a powerful framework. Therefore, to gain a deeper understanding of the system's dynamics, identify potential paths, and develop strategies to navigate the complexities and uncertainties of this rapidly evolving technology landscape, we utilized the principles of complex adaptive systems to analyse the evolution of the TFS ecosystem. This approach enables us to recognize and leverage opportunities, mitigate risks, and contribute to shaping the future of the TFS ecosystem in a way that promotes innovation, growth, and long-term success.

System Dynamics Modeling (SDM) and Agent-based Modeling (ABM) are two widely accepted methodologies and modelling techniques to frame, understand, and analyse complex adaptive systems. In this deliverable, we apply system dynamics modelling to analyse the relationships between

different components, feedback loops, and potential paths emerging from the constructed business model presented in Table 1 from D2.2[44] [4].

<table>
<tr>
<td rowspan="2">Key partnerships
Providers of HW and SW which are components of the solutions.

Providers of controllers such as TFS.

Potential neutral test platform where compatibility in the integrated system can be pre-tested (provided by e.g., operators)</td>
<td>Key activities
Identify and capture customer key challenges – transfer to design.

Design systems with sufficient novelty and reliability.

Risk analyses: technological and financial.

Implement and run systems.

Efficient failure support.</td>
<td rowspan="2">Value proposition
Combines transport network components – design and implementation.

Has responsibility and carries the risk for functioning according to predefined levels.

One point of failure-support.

Proven record and large enough customer portfolio – trust position for service quality and endurance.</td>
<td>Customer relationships
Request for Information/Quotation
Long-term relationships.
Dedicated support
Potential high switching costs.</td>
<td rowspan="2">Customer segments
Large contracts:

Network operators.

Data centre operators.

Hyperscalers.</td>
</tr>
<tr>
<td>Key resources
Network architects, implementers, and managers.

Purchasing, contract, and logistics expertise.

Customer and partner/vendor portfolio management.</td>
<td>Channels
Owned digital provisioning

Partner channel</td>
</tr>
<tr>
<td colspan="2">Cost structure
Salaries. Management systems.</td>
<td colspan="3">Revenue streams
Complements: Per hour/project. Fixed yearly price for operation.
Reseller fees (HW and SW).</td>
</tr>
</table>

Figure 36: Business Model Canvas for System Integrator in the Transport Network

As described in D2.2, this business model is affected by the operators' use of system integrators, or "doing-it-yourself" (DIY) approach. The factor of operators using system integrators versus adopting a DIY approach can significantly impact the evolution and potential future stable ecosystems of TeraFlowSDN. A balanced approach that accommodates both system integrators and DIY approaches could offer the greatest flexibility and adaptability, ensuring that operators have the freedom to choose the approach that best suits their needs and capabilities. Figure 37 illustrates the alternative paths and stable ecosystems considering this influencing factor.

[44] In D2.2, there are nine business model canvases each representing a unique approach and value proposition for stakeholders. However, due to resource and time constraints, we made a conscious decision to delve deeper into the system integrators' business model (Table 1). Our choice was driven by several factors. Firstly, system integrators play a critical role in the ecosystem, facilitating the seamless integration of TeraFlowSDN and related services into existing infrastructure. They act as key enablers for organizations seeking to leverage the benefits of TeraFlowSDN, ensuring smooth implementation and optimizing system performance. Secondly, system integrators' business models have a significant impact on the overall adoption, scalability, and success of TeraFlowSDN. Their ability to effectively integrate TeraFlowSDN into diverse environments and provide customized solutions addresses the needs and challenges faced by various stakeholders.

It is important to note that while we focused on the system integrators' business model in this report, we acknowledge the significance of other business models within the TeraFlowSDN ecosystem. The analysis and findings presented here can be complemented by further research and exploration into additional business models, allowing for a more comprehensive understanding of the ecosystem dynamics and evolution.

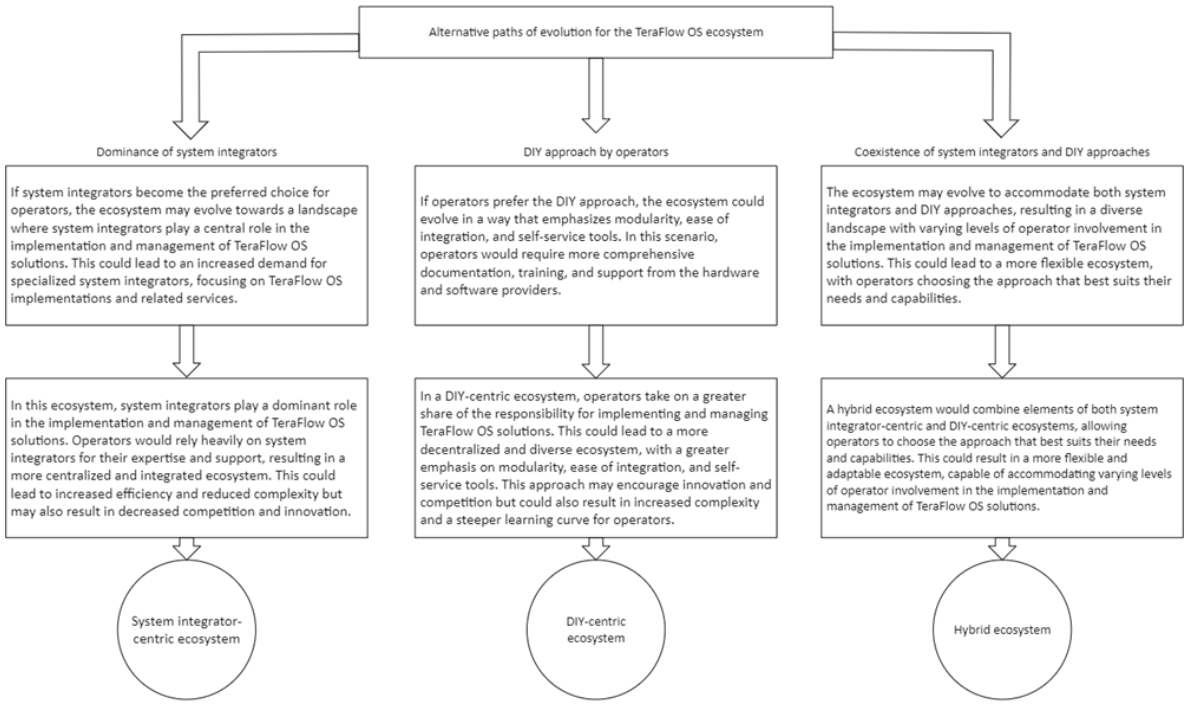

Figure 37: The alternative paths of evolution and end states of business model 1 affected by operators' use of system integrators, or "doing-it-yourself" (DIY) approach

Before we describe the system dynamics model of this business model, we need to highlight that the TeraFlowSDN ecosystem and its potential alternative future stable ecosystems should consider the impact of network effect, switching costs, and lock-in effect to ensure sustainable growth and foster innovation. Below, we outlined the two concepts of network effect and switching costs. By focusing on openness, interoperability, and collaboration, the ecosystem can reduce switching costs, minimize the lock-in effect, and maximize the benefits of the network effect.

Network effect: As the TeraFlowSDN ecosystem grows, the network effect will play a significant role in its development. The network effect occurs when the value of a product or service increases as more people use it. In the context of TeraFlowSDN, as more network operators, hardware and software providers, and NetApp providers adopt and integrate the system, its value will grow. This increased value may attract even more users, thereby reinforcing the network effect. An open or hybrid ecosystem would likely benefit the most from the network effect due to the emphasis on collaboration, interoperability, and the potential for a larger user base.

Switching costs: Switching costs refer to the expenses (financial, time, or effort) that customers incur when changing from one product or service to another. In the TeraFlowSDN ecosystem, switching costs could include the cost of replacing hardware, retraining staff, or reconfiguring systems to work with a different solution. High switching costs may deter customers from adopting alternative solutions, leading to a lock-in effect (i.e., the lock-in effect could be driven by factors such as proprietary hardware or software, long-term contracts, or a lack of viable alternatives). To minimize switching costs and encourage adoption, the TeraFlowSDN ecosystem should prioritize interoperability, modularity, and ease of integration. In a hybrid or open ecosystem, the focus on openness and collaboration could help reduce switching costs, making it easier for customers to adopt and integrate new solutions.

Now, we explain the steps of applying system dynamics modelling to analyse the business model presented in Figure 36. We created a system dynamics model to analyse the evolutions and alternative

paths of the TeraFlowSDN ecosystem. This model helps us understand the complex relationships between the various components and factors, allowing us to make more informed decisions about the ecosystem's development. The model's scope covers the TeraFlowSDN ecosystem, focusing on key actors such as network operators, hardware and software providers, NetApp providers, system integrators, and the influence of factors like network effects, switching costs, and lock-in effects. The model will also consider the impact of operators choosing between system integrators and DIY approaches. By employing this model, we aim to:

1. analyse the dynamics of the TeraFlowSDN ecosystem in terms of its evolution, considering the role of system integrators and DIY approaches taken by network operators;
2. understand the impact of network effects, switching costs, and lock-in effects on the adoption and growth of TeraFlowSDN and its ecosystem;
3. identify alternative paths of evolution for the TeraFlowSDN ecosystem and evaluate the potential stability and sustainability of these paths, and;
4. provide insights to stakeholders in the TeraFlowSDN ecosystem, enabling them to make informed decisions about the development and growth of the ecosystem.

We start by identifying and defining the key variables in the business model. Below, we listed the key variables in the ecosystem:

- Number of network operators: The total number of operators that are adopting and implementing TeraFlowSDN in their operations.
- Number of system integrators: The total number of system integrators specializing in TeraFlowSDN implementations and related services.
- Number of DIY operators: The total number of operators who prefer to implement and manage TeraFlowSDN solutions in-house.
- Number of hardware providers: The total number of hardware providers supplying components for TeraFlowSDN solutions.
- Number of software providers: The total number of software providers offering solutions related to TeraFlowSDN, including both embedded software and standalone applications.
- Number of NetApp providers: The total number of NetApp providers that develop and sell applications for use in the operation of transport networks based on TeraFlowSDN.
- TeraFlowSDN adoption rate: The rate at which network operators are adopting and implementing TeraFlowSDN solutions.
- Network effect: The impact of the increasing number of TeraFlowSDN users on the value of the ecosystem for existing and potential adopters.
- Switching costs: The costs associated with operators switching from their current transport network solutions to TeraFlowSDN-based solutions.
- Lock-in effect: The degree to which operators become dependent on TeraFlowSDN and its ecosystem, making it difficult for them to switch to alternative solutions.
- Operator satisfaction: The level of satisfaction of operators with TeraFlowSDN solutions and the ecosystem, which can influence their decision to continue using or expand their adoption of TeraFlowSDN.
- Market growth: The growth of the overall market for transport network solutions, which can impact the potential for TeraFlowSDN ecosystem expansion.

After the identification of the key variables, we determined the causal relationships between the variables. For example, the adoption of TeraFlowSDN by operators may lead to an increase in demand for system integrators or a preference for DIY approaches. Figure 38 shows a causal loop diagram representing the system's structure.

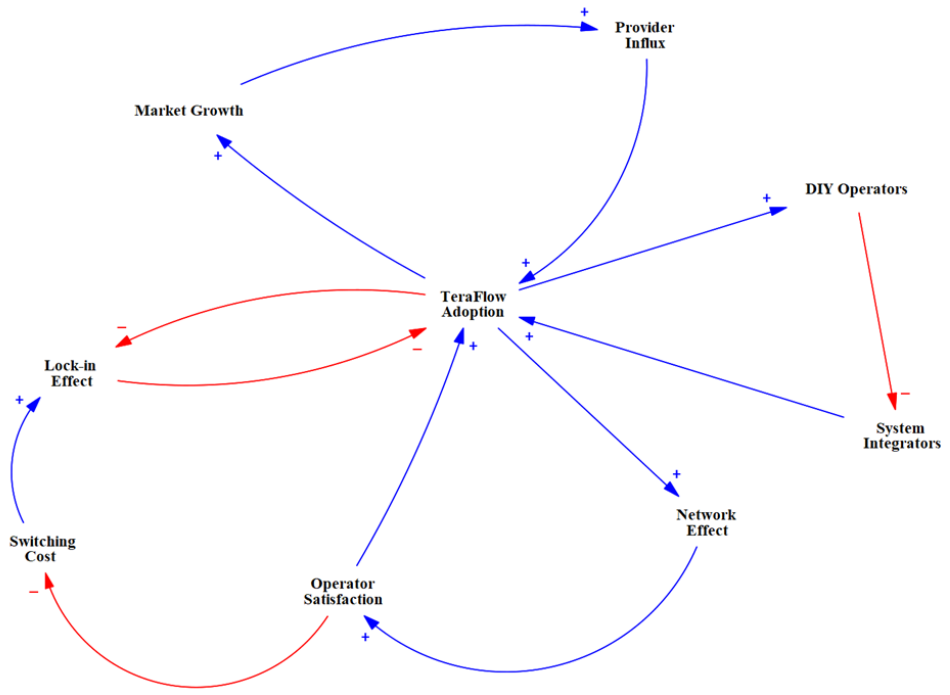

Figure 38: The causal loop diagram to present the relationships between the variables

The following highlights the identified feedback loops in our causal loop diagram. These loops represent the self-reinforcing or self-balancing mechanisms within the system, such as the network effect, switching costs, and lock-in effect.

1. Positive feedback loop - TeraFlowSDN Adoption, Network Effect, and Operator Satisfaction:

- As more network operators adopt TeraFlowSDN, the network effect increases, enhancing the perceived value of TeraFlowSDN.
- The stronger network effect and a growing ecosystem lead to higher operator satisfaction.
- Higher operator satisfaction encourages more operators to adopt TeraFlowSDN, reinforcing the positive feedback loop.

2. Negative feedback loop - Operator Satisfaction, Switching Costs, and Lock-in Effect:

- As operator satisfaction increases, network operators may become more willing to bear the switching costs associated with TeraFlowSDN adoption.
- However, the lock-in effect becomes stronger as operators rely more on TeraFlowSDN and its ecosystem.
- The increased lock-in effect may deter potential new adopters due to the perceived difficulty in switching to alternative solutions, counterbalancing the positive impact of operator satisfaction on TeraFlowSDN adoption.

3. Positive feedback loop - TeraFlowSDN Adoption, Market Growth, and Provider Influx:

- As TeraFlowSDN adoption increases, the market for transport network solutions grows.

- The growing market attracts more hardware, software, and NetApp providers to enter the TeraFlowSDN ecosystem.
- The increased variety and competition among providers can lead to better TeraFlowSDN solutions, resulting in a higher adoption rate and further reinforcing the positive feedback loop.

4. Negative feedback loop - TeraFlowSDN Adoption, DIY Operators, and System Integrators:

- As TeraFlowSDN adoption increases, some network operators may choose the DIY approach, reducing the demand for system integrators.
- The reduced demand for system integrators might prompt them to improve their services and offerings to attract more operators, resulting in an increased adoption rate.
- As the adoption rate increases, the balance between DIY operators and system integrators adjusts, creating a negative feedback loop.

Important. As the adoption of TeraFlowSDN increases, the lock-in effect is reduced because the TeraFlowSDN aims to promote interoperability, open standards, and reduced dependency on proprietary solutions. The negative relationship between the lock-in effect and TeraFlowSDN adoption indicates that when organizations are locked into proprietary solutions, it becomes harder for them to switch to alternative solutions like TeraFlowSDN due to high switching costs, resistance to change, and potential incompatibilities. As a result, a higher lock-in effect would discourage organizations from adopting TeraFlowSDN.

After identifying feedback loops, we presented the diagram to the partners to ask for their expert opinions to refine the loops by adjusting the relationships and variables. In answer to "Are there any feedback loops in the TeraFlowSDN ecosystem that are not captured in the causal loop diagram?", the partners responded that they agree with the proposed causal loop as it accurately represents the key variables and their relationships.

We also asked the partners how they think the TFS ecosystem might evolve in response to changes in the causal loop diagrams. As Figure 39 shows, 75% of the respondents responded that the adoption rate of TeraFlowSDN will be accelerated due to stronger positive feedback loops. They also pointed out the changes in the competitive landscape due to the stakeholder dynamics (e.g., change in their roles) and the emergence of new business models.

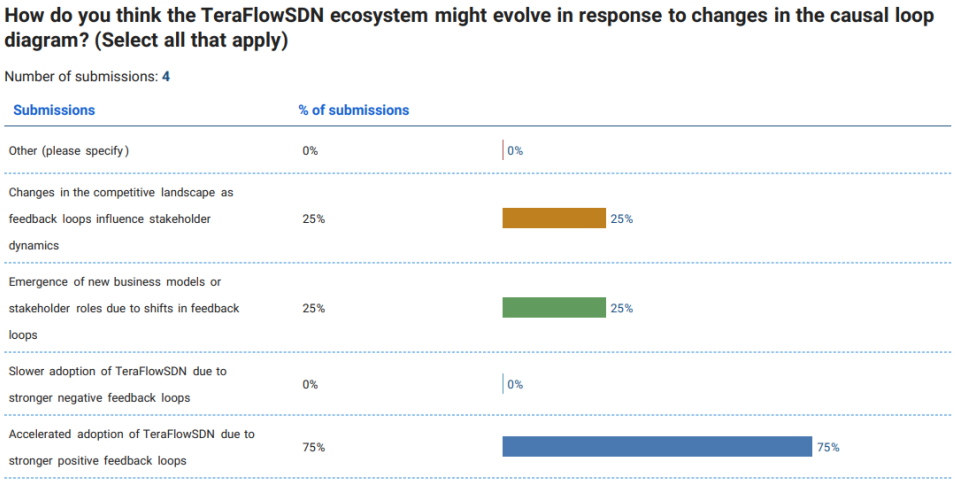

Figure 39: Feedback collected for ecosystem evolution study

Regarding the adoption rate of the TeraFlowSDN, we asked the partners about the key driver for accelerated adoption. As Figure 40 shows, increased demand for innovative services and solutions and strong collaboration among stakeholders are on the top, followed by rapid technological advancements and delivering complex services at a reduced price.

What do you consider the key drivers for accelerated adoption of TeraFlowSDN? (Select all that apply)

Number of submissions: 4

Submissions	% of submissions	
Other (please specify)	25%	25%
Increased demand for innovative services and solutions	100%	100%
Favorable regulatory changes	0%	0%
Strong collaboration among stakeholders	100%	100%
Rapid technological advancements	25%	25%

Please specify other key drivers you consider for accelerated adoption of TeraFlowSDN.

- Increased pressure on operators to deliver complex services at a reduced price in an increasingly competitive market

Figure 40: Feedback collected for drivers for adoption

Regarding the competitive landscape and stakeholders' dynamics, we asked the partners two questions, shown in Figures 41 and 42.

How can TeraFlowSDN maintain or enhance its competitive advantage in the face of emerging alternatives? (Select all that apply)

Number of submissions: 4

Submissions	% of submissions	
Other (please specify)	25%	25%
Enhanced security and resilience	50%	50%
Emphasis on interoperability and open standards	100%	100%
Strategic partnerships	50%	50%
Continuous innovation	75%	75%

Figure 41: Feedback collected for competitive landscape

How do you anticipate stakeholder roles to change as the TeraFlowSDN ecosystem evolves? (Select all that apply)

Number of submissions: 4

Submissions	% of submissions	
Other (please specify)	0%	0%
Increased collaboration among stakeholders	0%	0%
Expansion into new market segments	75%	75%
Focus on specialized services (e.g., system integration, consulting, NetApp development)	75%	75%
Hardware providers transitioning to software providers	75%	75%

Figure 42: Feedback collected for stakeholders dynamics

Based on our analysis of these results, new business models are expected to emerge as the TeraFlowSDN ecosystem evolves, driven by the need for open, flexible, and cost-effective solutions in the transport network industry. Therefore, the following new business models may emerge as a result of the evolution in the TeraFlowSDN ecosystem:

- Specialized System Integrators: Companies focusing on providing integration services for TeraFlowSDN-based solutions. They will combine hardware and software components from multiple providers, reducing complexity and risk for transport network operators. Their value proposition will include seamless integration, customization, and support for TeraFlowSDN-based systems.
- Software-centric Hardware Providers: Traditional hardware providers will shift their focus towards providing software and developing open, interoperable interfaces. They will have to adapt their business models to accommodate software licensing, subscription-based pricing, or other software-focused revenue streams.
- Niche NetApp Providers: With the increased adoption of TeraFlowSDN, new opportunities will arise for smaller NetApp providers to develop specialized applications that address the specific needs of transport network operators. These providers can leverage the open ecosystem and standardized interfaces of TeraFlowSDN to target a larger customer base.
- SDN Consultancies and Solution Integrators: As TeraFlowSDN gains traction, there will be a demand for specialized consultancies and solution integrators that can help organizations design, implement, and manage SDN solutions based on TeraFlowSDN. These businesses will offer services such as system integration, consulting, and development of new TeraFlowSDN features.
- Open-Source Support and Maintenance Services: With the increased adoption of open-source solutions like TeraFlowSDN, there will be a need for companies that specialize in providing support, maintenance, and updates for these systems. These businesses will offer various support packages, ensuring the long-term sustainability of the open-source ecosystem.
- Interoperability and Certification Services: As the TeraFlowSDN ecosystem grows, there will be a need for organizations that focus on certifying interoperability between various hardware, software, and NetApp solutions. These organizations will provide testing and certification services to ensure seamless integration and compatibility within the TeraFlowSDN ecosystem.

We shared our findings with the partners and asked them for their feedback regarding these new business models. We also discussed the potential implications for these new business models. Finally, based on these discussions and the responses to the questionnaire, we suggested a new business model for Specialized System Integrators. Figure 43 represents our refined business model after we received the partners' feedback. The new business model represents an adaptive, forward-looking approach that focuses on embracing emerging technologies, expanding customer segments, and strengthening partnerships. This evolution is characterized by a strategic shift towards increased flexibility, scalability, and innovation to better serve the ever-changing needs of the market.

Key partnerships	**Key activities**	**Value proposition**	**Customer relationships**	**Customer segments**
• Hardware and Software Providers • NetApp Providers • System Integrators	• Identifying customer challenges and designing solutions • Integrating and managing TeraFlowSD	• Seamless integration of TeraFlowSDN-based solutions • Customized solutions tailored to specific customer needs	• Long-term partnerships with network operators and service providers • Providing training and	Network Operators Communication Service Providers (CSPs) Digital Service Providers (DSPs)

<table>
<tr>
<td rowspan="2">

SDN Controller Providers
Test Environment Providers (Certifiers, Testers)
Standard Developing Organizations (SDOs)
Open-Source Communities
Cloud Providers (for virtualized components)
Semiconductor Providers (for open hardware solutions)

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N and related components
Collaborating with partners for solution development and customization
Ensuring interoperability and compliance with standards
Driving adoption through marketing and promotion
Providing support and maintenance services

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Reduced complexity and risk for transport network operators
Ongoing support and maintenance
Delivering "network functions as a service" to the operator

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support services
Active engagement in industry forums and open-source communities

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Key resources

Technical expertise in TeraFlowSDN and related technologies
Hardware and software integration knowledge
Robust partner/vendor networks
Strong relationships with SDOs and open-source communities

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Channels

Direct sales and support
Partner channels (system integrators, hardware/software providers)
Industry events and forums
Open-source community engagement

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<td colspan="3">
Cost structure

Research and development expenses
Salaries for development and network management teams
Marketing and promotional expenses
Support and maintenance costs

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<td colspan="3">
Revenue streams

Seamless integration of TeraFlowSDN-based solutions
Customized solutions tailored to specific customer needs.
Reduced complexity and risk for transport network operators.
Ongoing support and maintenance

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Figure 43: Refined business model

4.2. Update on the exploitation strategy

After reflecting upon the evolution of the TFS ecosystem, in this section, partners review the exploitation packages (EPs) and steps of the exploitation roadmaps described in D6.3. The Consortium believes these steps have been well addressed and elaborated along the different project activities and, more recently, revisited in the internal exploitation workshop. Below are the questions that were used at this internal workshop to stimulate conversation among the partners and give an update of the exploitation strategies.

- How aligned are we with respect of the roadmaps defined?
- In light of the evolution of the business models and ecosystem, can we update these roadmaps?
- What do you think you could do to help one or both roadmaps to materialize?

- What are the challenges you foresee?

The main highlights of these discussions are given in the subsequent sections.

4.2.1 Update of the TeraFlow IP Registry and exploitation strategies

One of the short-term steps of the roadmap is to have a full picture of the TFS components and the baseline of the EPs around which partners are willing to develop a profitable business (see D6.3 [3] section 3.2).

These results have been monitored throughout the project and collected in an Excel file called TeraFlow IP registry. This file's aim has been to clarify ownership and agreements in order to facilitate exploitation by project partners and third parties.

In the table below, we present the status of the TeraFlow IP registry at the end of the project.

Table 7: TeraFlow IP Registry

KER	Component	OWNER1	OWNER2	OWNER3	OWNER4
1	Context Mngt	CTTC	TID		
2	Monitoring	ATOS			
3	SBI	TID	CTTC	INF	UBI
	P4 SBI Plugin	UBI			
	Microwave (MW) Device Driver Plugin	SIAE			
	OpenConfig	TID	CTTC		
	TAPI	CTTC			
	XR Constellation Driver	INF			
4	Service	CTTC	INF	TID	UBI
	P4 L2 Service Handler	UBI			
	L2NM Emulated Service Handler	CTTC	TID		
	L2NM OpenConfig Service Handler	TID	CTTC		
	L2NM IETF L2VPN Service Handler	TID	CTTC		
	L3NM Emulated Service Handler	CTTC	TID		
	L2NM OpenConfig Service Handler	TID	CTTC		
	ONF TR532 Microwave Service Handler	SIAE			
	TAPI Service Handler	CTTC	TID		
	TAPI XR Service Handler	INF			
5	Automation	UBI			
6	Policy Mngt	UBI	ODC		
7	Slice Mngt	CTTC	TNOR	NTNU	ADVA
8	Distributed Ledger	NEC	CTTC		
9	Traffic Engineering	STR	TNOR		
10	NBI	CTTC			
11	Attack inference	CHAL			
12	Centralized attack detector	TID	UPM	CHAL	
13	Distributed Attack Detector	TID	UPM		

14	Attack Mitigator	TID	UPM	CHAL	
15	Web UI	CTTC	CHAL		
16	Inter-domain	TNOR	NTNU	CTTC	
17	Forecaster	CTTC			
18	Path computation	CTTC	TNOR		

Since the results of the project resulted in the creation of ETSI OSG TeraFlowSDN (TFS) back in June 2022, the software, as well as the documentation, installation instructions, and description of the functional tests defined to enable experimentation with TFS Controller are all public and available at ETSI Labs. However, the license assigned (Apache 2.0) does not prevent partners or third parties from taking these results from there and creating a product with a commercial licence attached.

Partners have also discussed another point of the roadmap, their willingness to participate in the maintenance and evolution of their components and the identification of potential missing roles. For example, in the case of EP1 (TFS – E2E), taking into consideration the components needed for this exploitation package, the partners involved would be: CTTC, TNOR, NTNU, CHAL, ADVA, INF, TID, ATOS, NEC, UBI, ODC. In case one or more partners were not interested in joining this exploitation path or could not find financial support to continue, the rest would be able to take over, as there is a generalised expertise of the whole controller in the Consortium and partners are all committed to work for the consecution of the objective.

After the discussions around TeraFlow exploitation, the Consortium gives an overview of the partners' interest in the different TeraFlow EPs:

Table 8: Partners interest in the different TeraFlow exploitation packages

Partner	EP1: TFS E2E	EP2: TFS – TECH	EP3: TFS – DC	EP4: TFS – NL
CTTC	X	X		X
TID	X	X		X
INF		X		
SIAE		X		
NEC	X	X		
ATOS	X	X	X	X
TNOR	X	X		
CHAL		X		
UPM		X		
VOL		X		
NTNU	X			
UBI		X		
STR		X		
ODC				X
ADVA	X	X		

CTTC will explore, devise, and validate/assess more advanced multi-technology route and resource selection algorithms in EP1. That is, in additional to those heuristics available and used in the TeraFlow project (e.g., energy-aware routing, resource and service constrained shortest routing, etc.) the Path

Computation component may become (as de facto) a server supporting AI/ML assistance to the whole controller. In other words, the Path Computation will be enhanced to derive a dedicated AI-server (by de facto) offering training of specific network models and providing diverse and multi-objective path and resource selection prediction. CTTC will also focus on specific technological solution for intra-/inter- Data Centre networking in EP2. Finally, CTTC will evaluate the possibility of using TFS-NL for establishing a Neutral Lab for inter-operability tests in CTTC premises, in conjunction with operators and vendors involved in the project.

TID will be part of ETSI TFS community even when TeraFlow project is finished, with a view to the evolution of this component to be aligned with market trends and our company's strategy. This work will be done under the financial support of other research projects. TID has created the steps to deploy L2VPN, L3VPN and ACL services following OpenConfig standards and YANG models. Once they are standardised and technically validated, TID will exploit this result by implementing these services in its transport networks both in EP1 and EP2. Finally, TID also intends to support Neutral Lab in order to improve its inter-operability and multi-vendor tests.

INF will focus in EP2. INF will use the TeraFlowSDN XR constellation Driver plugin to manage Infinera XR transceiver modules p2p and p2mp constellations via Infinera IPM (Intelligent Pluggables Manager) controller. TeraFlowSDN provides reference design how integrate IPM as hierarchical controller for XR optical services. TeraFlowSDN provides also open framework/solution for XR modules dual-management (data side services and optics services) service opportunities to demonstrate network operators together with help of 3rd party router NOS/HW vendors hosting XR transceiver modules. 3rd party vendors may develop their own device drivers to TeraFlowSDN to interface for their NOS or controllers or even using OpenConfig model to support dual management solution. INF provided TAPI variant service for configuring optical side configuration for XR constellations as well WEB-GUI configuration service inside TeraFlowSDN.

SIAE will use the Microwave (MW) Device Driver Plugin of the TeraFlow SDN controller to validate and to prove equipment and intermediate SDN controller full compatibility with standard SBI data models, aligning with EP2. The prove of full compliancy is an advantage for the Telco Operator when selecting MW Radio among others that doesn't provide the same set of models and capabilities. Another business opportunity is the development of new Microwave specific use cases that the NetApp can offer on top of TeraFlow SDN controller.

NEC aligns with EP1 and EP2. DLT solutions can be provided both E2E and in specific technological domains. TFS-E2E might use DLT for inter-connectivity scenarios and TFS-TECH might be used for traceability.

ATOS, as system integrator is willing to perform integration tasks in any of the four exploitation scenarios. ATOS is incubating the Monitoring component to be extended and evolved in new projects and is regularly presenting its capabilities to the Atos TMT business unit to follow up touch points and potentially incorporate it into one of the company's product roadmaps when it is more mature. ATOS will be part of ETSI TFS community even when TeraFlow project is finished, with a view to the evolution of this component to be aligned with market trends and our company's strategy. This work will be done under the financial support of other research projects. In fact, there are future plans with CTTC to work on a new feature of the Monitoring component: persist KPIs and alarms setting consistent in a migration to “context" database.

TNOR plans to exploit the result and propose practical solutions to add the inter-domain component into the management and control platform and enhance the operations of TNOR transportation networks using TFS-E2E and TFS-TECH. TNOR has started to work on green inter-domain Path Computation, where the abstracted topology used can vary according to the available energy-aware functionalities on the inter-domain links, as well as on the allowable performance degradation by the user (as a "green intent" that could become a part of the service order) with corresponding rewards/incentives. Results from the initial work are promising and foreseen to drive sustainable behaviours of users and other stakeholders in the (B)5G ecosystem. TNOR plans to continue the work on green business models, generalizing the work to end-to-end services and layered architectures.

CHAL, as an academic institution, has already exploited the attack inference component in several activities such as proof-of-concept demonstrations and scientific publications. CHAL plans to continue leveraging the attack inference component by testing and extending its functionalities to other types of ML-based monitoring and prediction tasks, so will focus on TFS-TECH. There is also a potential to exploit this component in other scientific projects such as the Celtic-Next AI-NET PROTECT project. Finally, as a member of the ETSI TFS TSC, CHAL will continue to contribute to this component. CHAL also performed several exploitation activities targeting the centralized attack detector. This component takes advantage of the attack inference component in order to monitor, detect, classify, and mitigate attacks. In the future, this module also has the potential to be exploited in other projects such as the Celtic-Next AI-NET PROTECT. Moreover, as a member of the ETSI TFS TSC, CHAL plans to support and evolve the functionalities of the centralized attack detector, targeting functionalities that are relevant to the community. CHAL, as a member of the ETSI TFS TSC, intends to further support and extend functionalities of the attack mitigator with features relevant to the community. Moreover, as an academic institution, CHAL plans to enhance the attack mitigator, including novel functionalities that incorporate state-of-the-art attack mitigation strategies.

UPM will exploit TFS-TECH, via providing security mechanisms, such as distributed attack detection and mitigation in IP domain.

VOL wanted to follow TFS-TECH, but due to bankruptcy terminated its involvement with TeraFlow.

NTNU plans to continue joint research with the partners regarding the TFS-E2E, with dedicated focus on inter-domain component, both from a technological and business-driven perspective. For that, NTNU aims to leverage the existing implementation to explore mechanisms and solutions reducing latency and increasing reliability for multi-domain communications, and to explore the implications on the business eco-system. For that we define follow-up research projects to be submitted to national and international calls.

UBI focuses on TFS-TECH exploitation plan with specialized focus on P4 switch control and management. To this end, specific components and plugins have been addressed and will be jointly exploited.

STR focuses on TFS-TECH with specific interest in PCEP control through TE component.

ODC exploitation interest involve TFS-NL due to standards interoperability expertise.

ADVA will concentrate on TFS-E2E for providing E2E demonstration and support of their multiple product lines, as well as it is interested in exploiting TFS-TECH for both IP and optical specific network domains.

4.2.2 Drivers and challenges for the implementation of the exploitation roadmap

In our aim to create an E2E SDN orchestrator for operators, the TFS community is aware of the main challenges. Shifting to a new environment based on TFS would require much investment for newcomers, as big companies already have their proprietary solutions. To overcome these barriers, at least to a certain extent, we believe that, in the first year after finalizing the project (2024), we should focus on the system integrator's engagement and participation in the TFS community. This implies that we should put effort into promotion and dissemination among this type of stakeholders. Project partners have been very active in communication and dissemination activities. The leadership of T6.1 (ATOS) and TFS Marcom have been fully supportive of dissemination and engagement efforts, so partners are on the right track in this respect.

Telco Operator partners believe they can play a key role in realising this vision by using and showing system integrators that TFS can be used as a Reference Implementation for a vendor-agnostic controller. In fact, Telefónica is already introducing TFS specifications (interfaces, UCs, data models) in its procurement processes. For example, if they need to buy IP routers, they ask vendors to comply with the specific data models that TFS handles. Operators also believe this should not be an individual effort and see the relevance of coordinating with other telco operators. They are already doing this at TIP-MUST, agreeing on the TFS specifications. And, in this sense, partners believe that another step in this direction, will be to write a white paper about TFS alignment with TIP-MUST, where an analysis of interfaces and prioritization of work should be presented. Operator partners have their views on the continuous maintenance of the controller. Furthermore, they are convinced that the TFS community should also participate actively in the relevant standardisation fora to spot new UCs for TFS and address them fully standardised to give a strong common message to the industry that will avoid fragmentation.

For this objective to materialize, vendor partners see other challenges. HW Vendors may be resistant to implement open SBI and reduce lock-in because they would risk losing quota of market share. They of course want to increase the number of devices installed in networks and need a powerful reason to be TFS compliant. Partners acknowledge that TFS will need more development in the SBI, identifying and implementing new use cases that are not provided by the competition and are attractive for operators. This is a driver for vendors to dedicate efforts towards the implementation of the SBI Data Models requested by TFS innovative UCs.

One of the steps in the roadmap is organising a PoC in an operators' lab. Partners understand that a PoC is not a product and will not be field-ready, but, in any case, it has a lot of very valuable properties for operators, vendors, and system integrators:

- Proof of applicability and completeness of base standards/specifications
- Reference model for understanding the standards
- Conceptual architecture for future developments
- Framework for demonstrating validity of investment in software projects
- Toolset for developing test cases
- Environment for experimenting with use cases and YANG extensions
- Platform for an operator to use when specifying the features and functions that they want in a developed product

So, a PoC is considered by the partners as a good way to boost the adoption of TFS among operators and thus get vendors and other players to join the community, taking a further step towards creating a market-ready product.

In this roadmap, another key point is to find additional funding when the TeraFlow grant ends to help turn the results obtained into a marketable product. Partners have sought opportunities to participate and include TFS in joint research projects with other projects or consortia related to developing 6G communication technologies. These projects have specific funding for developing open tools and technologies where TFS can play a role. Partners are looking at this opportunity because operators admit that they would pay a basic licence to cover maintenance of this market-ready controller plus an additional licence for each device being controlled. The open programmability that TFS provides brings open competition to the ecosystem. Operators could introduce new UCs to be handled by the controller using their own resources or they could have it done by other members of the ecosystem, that see the development of the workflows needed for these new UCs as another source of revenue. And, as explained in D2.2 [4] concerning TFS business models, it is not only customization and adaptation to operators' specific requirements that can be monetized: additional or complementary services like premium technical support, consulting and training around the open-source result are also in the spotlight of the partners.

In the case of the TFS Neutral Lab roadmap, we would need to lead the way as there are few examples of working Neutral Labs. We anticipate that power balance will be difficult, and there is a need for multiple operators' interest for this business ecosystem to boost and be sustainable. However, partners see clearly that there is a business opportunity for them to develop the testing tool to check if IP, microwave, or optical devices are implementing the standard interfaces requested by operators. Operators are asking vendors to support the relevant interfaces in the network devices. To validate if they have implemented them correctly or not, the approach could be to connect the devices to the TFS controller, that is using these interfaces. A project partner or member of the TFS community could take the TFS code and develop the tool or offer it as a service. Besides, the service could be offered to an operator, or a neutral lab composed of different operators that federate and share the tool. In our roadmap to get to that point, we confirm the need to propose interoperability tests in the mid-term.

5. Liaison and 5GPPP Relationship

Partners' current involvement and participation in existing working groups (WGs) is presented in Table 9. These have been the responsible people attending meetings on behalf of TeraFlow and requesting the Consortium their contributions to the different WGs. This section details the most significant contributions to the different boards and WGs.

Table 9: 5G-PPP Working Groups

WG	Partner
5G Architecture	TNOR
SN WG	CTTC
TMV	ODC
Pre-Standards	ODC
VSC	TNOR
Steering Board	CTTC
Technical Board	TID, CTTC

5.1. Steering and Technical Boards

Both CTTC and TID have contributed as Project Manager and Technical Manager to coordinate contributions in the scope of steering and technical boards. We think this is a necessary effort to work with other projects together as a program, thus maximizing the impact of European R&D in beyond 5G.

5.1.1 5GPPP Reference figure

We have participated in the elaboration of Figure 44 as the reference figure for 5GPPP Phase3 projects, prepared by 6GStart CSA.

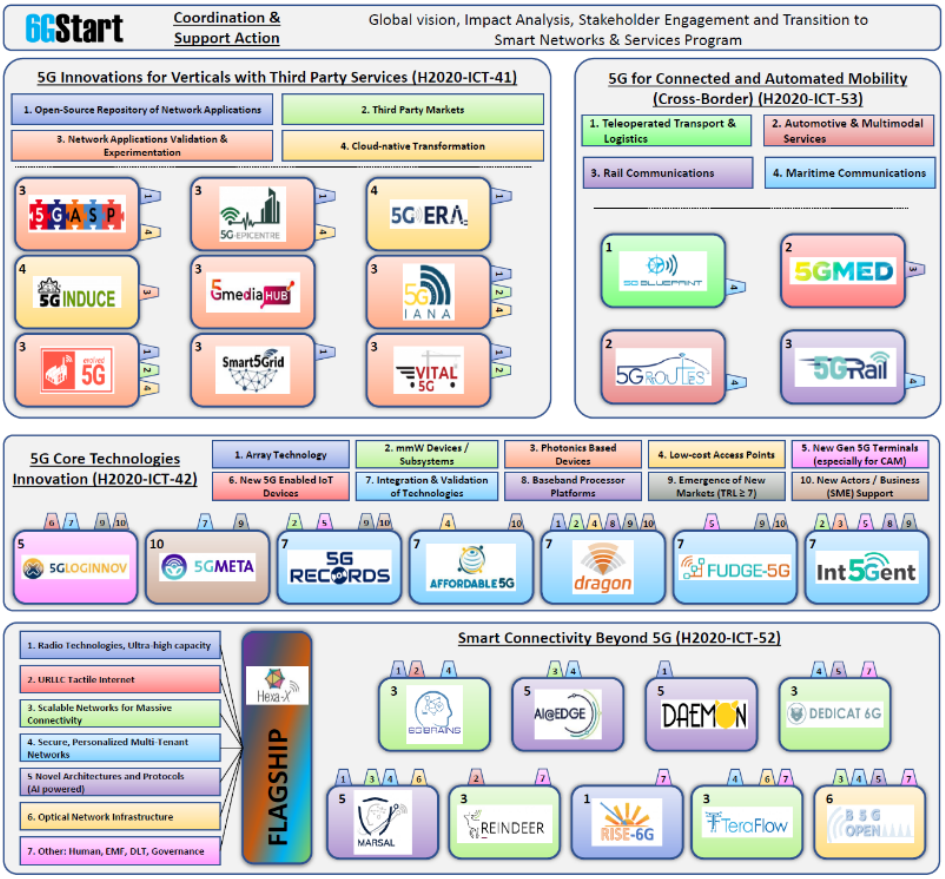

Figure 44: 5GPPP Reference Figure 2023

5.1.2 The European 5G Annual Journal 2023

TeraFlow has contributed to the 7th and last issue of the European 5G Annual Journal, released at the end of May 2023. TeraFlowSDN and multiple use cases are presented to illustrate the benefits of our proposed solution.

5.1.3 Workshop on 6G by Hexa-X and ICT-52

On January 18th and 19th, 2023, the Workshop[45] organized by Hexa-X and ICT-52 projects was presented. It was a fully virtual and open to all workshop by Hexa-X and other European projects from ICT-52 call. TeraFlow contributed with the following presentation:

- TeraFlow: Do we need yet another SDN controller? Use cases for a novel cloud native SDN controller for beyond 5G networks, Ricard Vilalta (CTTC) 15 min.

5.2. Architecture WG

This Working Group aims to establish a shared platform that enables the exchange of ideas and promotes discussions among 5GPPP projects that focus on developing architectural concepts and components.

There has been active participation in conference calls and activities of this working group, like the contribution to the 6G Book and the 6G architecture landscape white paper, further details are provided in the following subsections.

Besides putting TeraFlowSDN into a context of transport network configuration, service provisioning, orchestration (incl. integration with OSM) and automation, we have pointed to further work in the need for specialized connectivity handling, customer-facing logical networks, mesh connectivity and directions for standardization.

5.2.1 6G Book - TOWARDS SUSTAINABLE AND TRUSTWORTHY 6G Challenges, Enablers, and Architectural Design

TeraFlow has contributed to Chapter 5 and 7 [7] of 6G Book organized by Hexa-X and Architecture 5GPPP WG.

Authors: Ömer Bulakçi (ed.), Xi Li (ed.), Marco Gramaglia (ed.), Anastasius Gavras (ed.), Mikko Uusitalo (ed.), Patrik Rugeland (ed.), Mauro Boldi (ed.)

Publisher: Boston-Delft: now publishers[46]

[45] https://hexa-x.eu/ict-52-workshop-on-6g-2023/
[46] https://www.nowpublishers.com/article/BookDetails/9781638282389

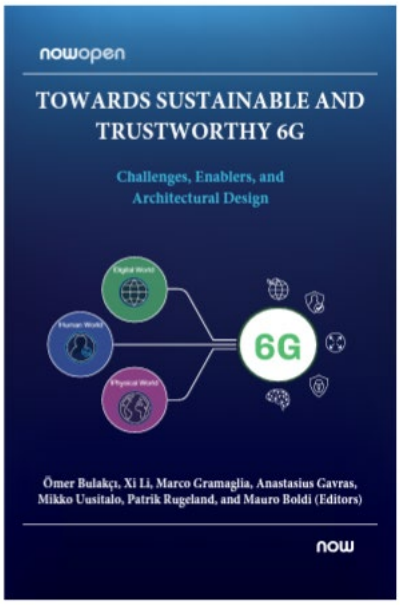

Figure 45: 6G book

5.2.2 6G Architecture Landscape – European Perspective

TeraFlow has contributed to this white paper from the 5G Architecture Working Group[47] (February 2023). This white paper summarizes the main findings from the European research landscape on the vision of the 6G architecture. Such a design vision is derived from around 45 projects starting from October 2020 in all relevant areas of 5G while paving the way towards 6G.

TeraFlow contribution is the description of the ETSI TeraFlowSDN controller for providing logical networks as a service.

5.3. Software Networks WG

TeraFlow has contributed to the white paper: "Network Applications: Opening up 5G and beyond networks"[48], September 2022.

This paper aims to demystify the concept of Network Applications. Different Network Applications implementations have been conducted considering various API types and different levels of trust between the verticals and the CSP. TeraFlow has contributed to describing multiple data modelling languages and control and management protocols. Moreover, the white paper also includes TeraFlow architecture.

5.4. TMV WG

The 5GPPP TMV WG develops test and measurement methods, test cases, procedures, and KPI formalisation and validation, ranging from R&D to early-stage deployments for 5G, beyond 5G, and

[47] https://5g-ppp.eu/wp-content/uploads/2023/02/Whitepaper-final-version-rev1.pdf
[48] https://5g-ppp.eu/wp-content/uploads/2022/10/Software-Network-WG-Network-Applications-2022.pdf

6G networks. The group brings together industry stakeholders, researchers, and experts to identify and develop innovative solutions that leverage 5G capabilities.

Today, 5G networks are being widely rolled out in various deployment environments, with multiple configurations, for serving diverse public and vertical sector needs. While deployed 5G networks are still under evaluation to prove their capabilities and potential in commercial and operational environments, the requirements and KPIs are being discussed for 6G systems to properly steer the 6G research and innovation activities. To this end, besides clearly defined KPIs, it is vital to identify methodologies and tools to evaluate them even at early research stages so that the 6G technologies can be properly validated.

In June 2022, we contributed to the 5G-PPP TMV Working Group white paper "Beyond 5G/6G KPIs and Target Values"[49]. This work provides an early analysis of possible Beyond 5G/6G KPIs based on current work and perspectives from ICT-52 projects, seeking to understand the level to which existing definitions in standard documents will apply to 6G and to identify, at early stages, gaps and new candidate KPIs for being standardized for 6G systems. Authors: Nielsen, Lars (ed.); Gavras, Anastasius (ed.); Dieudonne, Michael (ed.); Mesogiti, Ioanna (ed.); Roosipuu, Priit (ed.); Houatra, Drissa (ed.); Kosmatos, Evangelos (ed.) (Daniel King is contributor on behalf of TeraFlow).

More recently, in May 2023, TeraFlow has contributed in the whitepaper continuation "Beyond 5G/6G KPI Measurement"[50]. Authors: Dieudonne, Michael (ed.); Wang, Hua (ed.); Mesogiti, Ioanna (ed.); Kosmatos, Evangelos (ed.) (Daniel King is contributor on behalf of TeraFlow).

5.5. Pre-Standards WG

The 5GPPP Pre-Standards WG is crucial in driving early collaboration and research in developing 5G standards. It brings together key stakeholders, including industry, academia, and standardisation organisations, to discuss and contribute to developing technical specifications and concepts that will shape the future 5G standards.

We regularly updated the WG on TeraFlow activity during the project, especially related to the IETF and ETSI TeraFlowSDN. These updates were incorporated into the quarterly WG updates and yearly reports. The updates to the WG also provided visibility and discussion of important TeraFlow standards developments across H2020 projects.

5.6. VSC WG

TeraFlow partners are engaged in the 6G IA Vision and Societal Challenges working group, and its sub-working groups such as Business Validation, Models, and Ecosystems. In TeraFlow's project span, working groups have published white papers on European Vision for the 6G Network Ecosystem [5], and more recently 5G and Beyond 5G Ecosystem Business Modelling [6], May 2023. TeraFlow has been a place where technological disruptions and ambitions have been addressed, as well as accompanying ecosystems and business models. Thus, partners have taken care to share and direct learnings into these 6G IA working groups to the best of the community.

[49] https://doi.org/10.5281/zenodo.6577506
[50] https://doi.org/10.5281/zenodo.7963247

5.7. EUCNC contributions in 2022

Several contributions were made for EUCNC22[51], as it is the best place to position 5GPPP projects and impact the community.

5.7.1 Special Session: Redesigning Transport Networks for 6G: From the cell site to the core

Figure 46: Ricard Vilalta and Ramon Casellas at special session in EuCNC23

Network operators are only slowly adopting Transport SDN deployments, aiming at network automation across multiple network segments and technologies, while enabling the integration of cell sites with the network core. Several barriers are currently blocking the full adoption of this technology and to fully enable network automation. It is key to define the use cases, workflows and supporting architectures with standard interfaces that can operate in greenfield and brownfield deployments, spanning all involved networking layers, from the access to the long-haul.

On the one hand, the integration with L3VPN/L2VPN up to the network edge requires a clear network programmability framework to provide cloud scale network management capabilities, where the TeraFlow framework will deal with current network devices and provide a solution up to the edge.

[51] https://www.eucnc.eu/2022/www.eucnc.eu/programme/index.html

On the other hand, Multi-Band (MB) Optical networking expands the available capacity of optical fibres, by enabling transmission within S, E, and O bands, in addition to commercially available C+L bands (with a potential 10x transmission capacity increase with respect to C-band). Yet, the underlying technologies need to be developed: the availability of MB transmission will lead to a complete redesign of the end-to-end architecture, removing boundaries between network domains, reducing electronic intermediate terminations, and providing a network continuum between X-haul/access, aggregation, metro, and core segments. The corresponding SDN control plane needs to be significantly extended to support MB elements and a 'domain-less' network architecture, and rely on physical layer abstraction, impairment modelling, and pervasive telemetry data collection to feed AI/ML algorithms that will thus lead to a Zero-Touch networking (ZTN)

The session is organized as a set of technical presentations from key actors and experts in the field of transport networks. The proposed list of speakers tries to highlight both the role of industry (operators, and vendors) as well as academia. The session ends with a 20 min panel discussion and lasts 1h40.

- Introduction to the session, session chairs, Ricard Vilalta and Ramon Casellas (CTTC) 10min.
- Invited: An operator's perspective on SDN control for transport networks, Oscar González (Telefónica), 20min.
- Introducing white boxes and network orchestration at the cell site, Lluis Gifre (CTTC), 10min.
- Multi-Band Optical Networking, achievements and challenges, Antonio Napoli (Infinera), 10min.
- Automation and policy management for network orchestration, Georgios Katsikas (Ubitech), 10min.
- The role of AI/ML in Intent Based Networking and Closed Loop Optical Networks, Luis Velasco (UPC), 10 min.
- Cloud-native Security in Transport Networks, Carlos Natalino (Chalmers University), 10min
- Discussion, 20min.

5.7.2 Workshop: The 6G workshop series by Hexa-X

The European 6G flagship research project Hexa-X (H2020 ICT-52) has worked towards building the foundation for a future 6G system and exploring a plethora of technical enablers. The research in the project has consolidated the views of the 25 partners from leading academic institutions and industry players and conducting leading edge technological exploration and development related to enhanced radio performance and combined communication and localization/sensing; Connected intelligence with integrated AI/ML; Network evolution expansion, exploring new network architectures and novel verticals. As such, the workshop addressed the conference tracks '6G Enabling Technologies' and '6G Visions', by providing a consolidated view of the 6G research from the major European players. The workshop provided an opportunity to solidify Hexa-X's position as a leading 6G project on a global scale, showcasing the work done with presentations and live demos. It provided an opportunity to connect and align with the 6G research performed elsewhere. This was accomplished by inviting other ICT-52 6G technical enabler projects to present and through an open call for technical contributions.

Session 3 – Connecting intelligence (90 min):

- AI-driven communication & computation co-design Miltiadis Filippou (Intel) [20 min + 5 min Q/A].

- Design of service management and orchestration functionalities – Josep Martrat and Ignacio Labrador (Atos) [20 min + 5 min Q/A].
- TeraFlow: ML-based attack detector for TeraFlow OS – Alberto Mozo (UPM) and Antonio Pastor (Telefonica) [15 min + 5 min Q/A].
- 6G BRAINS: Bringing Reinforcement Learning to Communication and Networks – Victor Gabillon (Thales) [15 min + 5 min Q/A].

5.7.3 TeraFlow Booth

Figure 47 TeraFlow booth at EuCNC2022

5.8. EUCNC contributions in 2023

The 2023 EuCNC & 6G Summit[52] put together two telecommunications conferences: EuCNC (European Conference on Networks and Communications), supported by the European Commission, and the 6G Summit, which originated from the 6G Flagship programme in Finland, one of the very first in its area. The conference is sponsored by the IEEE Communications Society (ComSoc), the European Association for Signal Processing (EURASIP) and the European Association on Antennas and Propagation (EurAAP).

Several activities have been prepared to maximize TeraFlow's impact.

[52] https://www.eucnc.eu/programme/

5.8.1 Special Session: Novel technologies in disaggregated packet-optical networks to support 6G

6G supposes a new challenge to disaggregated networks. Network capacity increase, and thus new CAPEX investments shall be overcome by OPEX reduction through network automation. The digitization of network operations can help to reduce operational costs and improve service agility. Optical fibre infrastructure continues to expand, becoming nearly ubiquitous. Smart society infrastructures can improve services for all while reducing their cost. Overcoming the green challenge is critically important for the planet and the network's sustainability. At the same time, the business environment continues to change, and this can have major impacts on the network. To enable autonomous network management, techniques such as intent-based management, knowledge graph for fault management, and network information gathering can be used. Novel optical technologies such as multi-band, SDM, flexi-grid, and F5G can tackle the stringent network requirements of envisioned 6G networks. The special session presents contributions from 5GPPP/SNS/CL4 research communities, with the aim of facilitating discussion, and exchange of ideas and practices, and successfully promotes innovative solutions towards network automation to support 6G requisites.

- Introduction to the session, session chairs, Ricard Vilalta and Ramon Casellas (CTTC) 10min.
- Invited: An operator’s perspective on 6G requirements for Transport Networks, Pablo Armingol-Robles (Telefónica), 20min (TeraFlow).
- An operators’ perspective on the migration to multi-band networks, Emilio Riccardi/Marco Quagliotti (TIM), 10min (B5GOpen).
- Towards ultra-low energy and secure optical networks, Tolga Tekin (IZM Fraunhofer), 10min (ALLEGRO).
- Scaling Capacity in support of Beyond 5G networks, Filippo Cugini (CNIT), 10min (SEASON).
- Flexibly Scalable Energy Efficient Networking, Raul Muñoz (CTTC), 10min (FlexScale)
- Discussion, 20min.

5.8.2 TeraFlow booth

A complete set of novel dissemination material was prepared, including three use case posters and an architectural roll-up. On-screen, we had a demonstration of TeraFlowSDN performed at the last OFC 2023.

Figure 48 TeraFlow booth at EuCNC2023

5. Overall impact achieved

TeraFlow project has achieved outstanding success thanks to a clear vision of its objectives and the close collaboration of committed partners, whose strategic interests are perfectly aligned with this vision. In addition, well-designed communication, dissemination, standardisation and exploitation plans were implemented from the outset, which has contributed significantly to its massive impact and extraordinary reach.

The project has demonstrated a significant impact on the field of mobile communications and the development of the next generation of networks, 6G. Through its main result, TFS, an open-source, micro-service based, cloud-native SDN controller for beyond 5G/6G networks that focus on autonomous network and compute integration, ML-based cybersecurity, and trusted multi-tenancy, TeraFlow is laying the foundation for a future of vendor-agnostic advanced connectivity and related innovative applications.

Communication and dissemination activities have been fundamental to sharing the project's advances, results and discoveries. Effective **dissemination** of information has contributed to generating a more open and transparent research ecosystem, where researchers can learn from each other and build on existing work. The project's dissemination activities have involved publishing scientific articles in peer-reviewed journals, presenting at conferences, workshops and relevant events, participating in panel discussions, and creating video demos. Of particular note were:

- The organization of the FIRA'22 Workshop on SIGCOMM 2022 on Future of Internet Routing & Addressing (22nd August 2022) with more than 50 attendees.
- The participation in events such as NextworkX 2022 (20th October 2022), with its ETSI-Hackfest in the form of a tutorial with TFS Release 1, allowing around 50 participants to get hands-on experience, and to provide feedback on new features for its second release.
- The achievements obtained at Layer123 2022 (7th December 2022), where TeraFlow received the Layer123 Network Transformation 'Upstart of the Year' Award that recognized the quality of the work done and ETSI strategy to provide new software development tools and practices to an evolving standardization ecosystem. Approximately 100 people attended the presentation "Fostering innovation in Transport Networks with ETSI TeraFlowSDN controller"
- TeraFlow's presence at OFC 2023 (5th March 2023), where the project had a high participation with a large number of accepted papers, high attendance (over 200 people) and outstanding demonstrations with a global reach.
- Participation in events such as EuCNC & 6G Summit (both 2022 and 2023 editions, with approximately 50 and 100 attendees, respectively) and IEEE-ICC (28th May 2023 with more than 100 people attending) has also been relevant, with presence in a project booth, presentations, and complementary activities.
- As the final event in the framework of the project, TeraFlow has achieved a huge impact in the prestigious international conference IEEE NetSoft 2023 (19th June 2023), organizing the 1st International Workshop on Data Plane Programmability to Slicing Automation for Softwarized Infrastructures towards 6G (DataSlice 2023) and the 2nd TFS Hackfest co-organised with ETSI's Centre for Testing and Interoperability with more than 20 people actively participating.

These participations have allowed TeraFlow to expand its visibility and establish important connections in the telecommunications industry. In parallel, developing **communication** material such

as posters, brochures, presentations and dissemination through digital media, like blogs and social networks, has been key to reaching a wider audience and sharing project information effectively.

On many occasions there has been **collaboration** and knowledge sharing with other research and development projects in the 6G field, with the aim of fostering synergies, sharing best practices, and promoting joint progress in this area. One of the most recent collaborations that we can mention is one of CHAL, as a member of the Celtic-Next AI-NET project, discussing the possibility of taking advantage of the ETSI TeraFlowSDN Controller as the SDN controller to be used in the final demonstration of the AI-NET PROTECT subproject. Several other projects, like DEDICAT 6G and HEXA-X-II, also incorporate TFS into their research. In this line, a call for presentation for TFS ecosystem day (next 18th October 2023) has been published, expecting contributions from at least eight SNS projects.

Another key aspect of the project is the contribution to **standards and open-source** projects. 6G technology is an area in constant evolution, and the definition of standards plays a fundamental role in its development and widespread adoption. TeraFlow promotes active participation in working groups, technical committees or relevant forums of standardization bodies, influencing and contributing to the definition of the standards that will shape the future of 6G technology. In this aspect, we can highlight the collaborations with the IETF, also with many ETSI ISGs (ZSM, NFV, MEC, mWT, SAI, ENI) to demonstrate the proposed standard solutions faster, with the Open Networking Foundation, and OpenConfig. In addition, open-source collaboration is being encouraged, such as in ETSI OpenSourceMANO, with many hours of coding in TFS and OSM to get the whole ecosystem integrated and working well together, also in Hyperledger and the ONOS Project, facilitating the sharing of code, tools and resources between projects, which accelerates the pace of development and promotes the reuse of innovative solutions.

Thanks to its remarkable technical results and a good communication and dissemination strategy, the TeraFlow project has achieved an important milestone by creating a strong community around its outcome, with the support and endorsement of ETSI. The creation of this community, known as the ETSI Open-Source Group for TeraFlowSDN (TFS), had a significantly positive impact on the **sustainability and exploitation** of the project results. Instead of relying solely on an internal development team (the project partners), there is now an entire community working on the future development and enhancement of the SDN controller aiming at benefiting from its capabilities. This means that diverse perspectives, expertise and resources are available to drive the evolution of the controller releases, addressing the evolving needs of all stakeholders. In addition, by connecting the project results to a recognized SDO such as ETSI, a solid foundation is established for continued industry adoption. This provides confidence to potential users and developers, encouraging greater utilization and contributions to the community. The ETSI TeraFlowSDN community also enables collaboration and knowledge sharing among its members, promoting innovation and the co-creation of solutions that go beyond the initial capabilities of the TeraFlow project. The community makes available to its members all the necessary documentation like guides, tutorials, walkthroughs and even a TFS virtual machine to prepare the environment, perform some example experiments, implement new code and contribute to the community back. The goal was to make the process easy as we are certain that the more members join the community, the potential for the development of new functionality and use cases will expand further, ensuring that the project's results continue to evolve in the future.

For TeraFlow project partners, the community expands the reach and influence of their results, opening up new market opportunities. By being part of this community, they have access to an expanded network of contacts and resources, enabling them to establish business relationships,

strategic partnerships, and collaboration opportunities with other players in the telecom industry. In addition, they leverage the knowledge and resources available in the community to improve their own products and services, giving them a competitive advantage. By having an entire community working on developing and improving the SDN controller, they increase the likelihood that it will be adopted and used in various contexts and applications, creating business opportunities, and expanding the potential market for their TeraFlow-based solutions and services.

On the 2nd of February 2023, ETSI Open-Source Group for TeraFlowSDN announced the 2nd release of TFS, with a big focus on the scalability and resilience of the controller. Shortly after this, the TFS community announced their commitment to the implementation of TIP's Mandatory Use Case Requirements for SDN for Transport (MUST) in the TFS controller. This move will position TFS as a reference implementation in the Telecom Infra Project Open Optical & Packet Transport group (TIP OOPT), which will make it possible to accelerate the adoption of SDN standards for IP/MPLS, Optical and Microwave transport technologies, one of the main objectives of MUST. The invaluable support of the project advisory board has been fundamental to this success.

6. Conclusions and next steps

As can be concluded from this and previous WP6 deliverables, the TeraFlow project has achieved outstanding success thanks to its clear vision, the collaboration of committed partners and the implementation of effective communication, dissemination, standardization and exploitation plans.

TeraFlow has created an SDN controller based on open source microservices as the main outcome (TFS), which is having a significant impact in the field of mobile communications and in the design and development of 6G networks. In turn, communication and dissemination activities, including scientific publications, conference presentations and participation in relevant events, have been fundamental for the visibility of TFS in the community. The project has contributed to relevant standards and open-source projects, fostering collaboration and resource sharing. In this regard, engaging with key organizations such as TIP MUST has provided TeraFlow with increased exposure and collaboration opportunities, facilitating industry adoption of SDN standards for IP/MPLS, optical and microwave transport technologies. In fact, the implementation of TIP MUST requirements in TeraFlow's SDN controller has positioned TFS as a reference implementation, accelerating the validation of future network equipment and the development of innovative services.

The creation of a community around TFS, supported by ETSI, ensures sustainability and exploitation of the results. Project partners are exploring new business models that exploit SDN as a core component and are benefiting from new market opportunities, while the community drives the continued development of the SDN controller, for example, by incorporating TFS into other projects within the SNS framework, with up to eight projects utilizing and further developing TeraFlow's work.

In addition, the contribution of the project's Advisory Board has been crucial to TeraFlow's success. Their experience and expertise have helped guide the project's development, ensuring its relevance in the industry. The project has laid the groundwork for future advances in the field of smart networks and has established strategic alliances to promote collaboration between different communities and organizations.

In conclusion, TeraFlow represents an important step towards the future of telecommunications, enabling the deployment of advanced services and applications to improve connectivity and user experience. With the third release close on the horizon, still, as the next steps, the costs and challenges of integration tasks should be further explored. To this end, we recognize the need for a new project focused on integration costs and further research work. This would enable the exploration of potential challenges and costs associated with integrating TeraFlow's solutions into existing network infrastructures, while also fostering continued research and innovation in the field.

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