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Secured autonomic traffic management for a Tera of SDN flows

TeraFlow

D1.3: First Project Periodic Report

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Abstract

This Deliverable provides a summary of the progress of technical activities and management aspects in the first project year of the TeraFlow project, i.e. from January 2021 to December 2021.

Besides reporting on the technical work, this Deliverable also summarises management-related aspects and the status of effort consumption.

[End of abstract]

Revision History

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Disclaimer

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EXECUTIVE SUMMARY

This Deliverable presents the first project periodic report for the TeraFlow project. Firstly, we present a summary of the progress of the technical work and the project achievements. We start by summarising the progress towards the project objectives, and later we summarise the progress per work package.

Dedicated attention is given to the WP6 objective that is to maximise the impact of the project, facilitating the adoption of its results. After Deliverable D6.1, that gave the project's strategy towards dissemination, communication, collaboration, and standardisation, D6.2 is the second Deliverable produced this year, providing an initial assessment of the market environment and opportunities for TeraFlow and reporting on the various activities that TeraFlow partners are conducting, following the strategy described in D6.1, to ensure that the project findings and results influence the B5G/6G community and the relevant standards. In this periodic report, we summarise the relevant results. The impact achieved with these activities has been recently presented to the TeraFlow Advisory Board (17th December 2021), whose members gave very positive feedback, as well as some guidance for future work on how to ensure sustainability of the TeraFlow SDN controller after the end of the H2020 TeraFlow project.

Later in this Deliverable, an overview is provided of the project management related tasks and the administrative issues attended to during Year 1. This overview includes the recommendations of the Advisory Board, Grant agreement amendments, resources and spending, updated risk management, project deviations, and project virtual meetings.

The preparation of Deliverables has been monitored and quality checks have been made. All project Deliverables and Milestones due in the reporting period have been reached. Details are given in the final section of this report.

Table of contents

List of Figures

List of Tables

Abbreviations

5G PPP	5G Infrastructure Public Private Partnership
ABNO	Application-Based Network Optimisation
API	Application Programming Interface
AI	Artificial Intelligence
B5G	Beyond 5G
CI/CD	Continuous Integration / Continuous Delivery
CNF	Containerised Network Function
DLT	Distributed Ledger Technology
DWDM	Dense Wavelength Division Multiplexing
ECA	Event Condition Action
ETSI	European Telecommunications Standards Institute
gRPC	Google Remote Procedure Call
IDC	Inter-Domain Component
IETF	Internet Engineering Task Force
IP	Internet Protocol
ITU	International Telecommunications Union
KPI	Key Performance Indicator
L2	Layer 2
L2VPN	Layer 2 Virtual Private Network
L3	Layer 3
L3VPN	Layer 3 Virtual Private Network
MANO	Management and Orchestration
MEC	Multi-access Edge Computing
M	Month (as M12)
ML	Machine Learning
MS	Milestone (as MS4.1)
MW	Microwave
NBI	Northbound Interface
NFV	Network Functions Virtualisation
NOS	Network Operating System
NSC	Network Slice Controller
OLS	Optical Line System
ONF	Open Networking Foundation
ONOS	Open Network Operating System
OS	Operating System
OSM	OpenSource MANO
OSS/BSS	Operation Support System/Business Support System
P4	Programmable Protocol-independent Packet Processor
PC	Project Coordinator
PCE	Path Computation Element
PCEP	Path Computation Element communication Protocol
PM	Person-Month
RPC	Remote Procedure Call
SBI	Southbound Interface
SDN	Software Defined Network
SDO	Standards Development Organisation
SLA	Service Level Agreement

SR	Segment Routing
T	Task (as T3.1)
TE	Traffic Engineering
TED	Traffic Engineering Database
TIP	Telecomm Infra Project
TM	Technical Project Manager
TNS	Transport Network Slice
VIM	Virtualised Infrastructure Manager
VM	Virtual Machine
VNF	Virtualised Network Functions
WIM	WAN Infrastructure Manager
WP	Work Package (as WP6)
Y	Year (as Y2)
ZTP	Zero-Touch Provisioning

1 Progress of Technical Work and Achievements

In this section, we present a summary of the progress of the technical work and the project achievements. We start by summarising the progress towards the project objectives, and later we summarise the progress individually per work package breakdown.

1.1 Summary and Progress Towards Project Objectives

Objective 1 "Adoption of SDN by telecom operators": a) Accelerate innovation in transport (optical and microwave) and IP networks and ultimately help operators provide better connectivity for communities all around the world; b) Beyond 5G integration with L3VPN/L2VPN up to the network edge; and c) Automated service management for transport network slices.

This objective is mainly in scope of WP2, reported in D2.1, but has also been significantly progressed within WP3, WP4, and WP5 with the following key results over the reporting period:

- Use cases have been proposed for the TeraFlow SDN controller. They are classified into the following topics: inventory, topology, service, transport network slicing, monitoring, traffic engineering, automation, policy enforcement, ML-based security, distributed ledger and smart contracts, compute integration, and inter-domain.
- A complete set of requirements for the TeraFlow SDN Controller have been introduced. They have been classified as functional and non-functional, and they cover the proposed use cases.
- We have presented an architecture for the TeraFlow SDN controller. First, we have provided an overall view of the architecture. Secondly, we have presented each detailed component architecture, with a special focus on RPC and data models involved. Finally, we have presented several workflows that involve multiple component interaction.
- The TeraFlow OS has been implemented following the cloud-native architecture concept. The software is divided into micro-services that execute specific tasks and collaborate through messages to achieve the end goal for which the software is designed. In TeraFlow OS, the communication between components is based on gRPC. We defined different RPC methods and messages and grouped them by micro-service. Deliverables D3.1 and D4.1 describe the architectural details of each component, the interface they expose, and some preliminary experimental results validating their stand-alone functionalities. At time of writing, integration is performed and the expected release date for release 1 is February 2022.
- The TeraFlow OS is able to process a request for an L3VPN over a DWDM network, and deploy the necessary underlying network resources using the Transport API, as well as to configure the necessary routers using OpenConfig and NetConf protocols.

Objective 2 "Provide a novel SDN controller for Beyond 5G networks that evolves network flow management to cloud-scale requirements in order to support a 10x increase of connectivity services": a) Design, development, and demonstration of a novel revolutionary cloud-native Network Operating System; b) Introduction of a new architecture to support massive IoT and new mobility paradigms; and c) Adoption of novel protocols for inventory, alarms, telemetry, and provisioning.

This objective is mainly in scope of WP3, reported in D3.1, but has also been significantly progressed within WP2 and WP4 with the following key results over the reporting period:

- Ten (10) core TeraFlow OS components are designed and (partially) implemented following state-of-the-art software development and packaging techniques in the form of independent cloud micro-services. These micro-services are managed via Kubernetes, offering the following services: Context management, monitoring, traffic engineering, auto-scaling, load-balancing, device and service integration, automation, policy management, and slice management. Currently, the following SDN device types are supported: emulated, OLS ONF Transport API, ONF TR-532 microwave, NETCONF/OpenConfig, and P4 whiteboxes.

- These micro-services communicate with each other via a well-defined gRPC-based message bus, while exposing additional APIs (e.g., REST) to external entities or services.
- TeraFlow leverages the scalability merits offered by Kubernetes to provide independent, per-component scaling and load-balancing features as well as roll-back software recovery and on-the-fly software package upgrades.

Objective 3 "Easily integrate the TeraFlow OS with distributed computing (including Multi-access Edge Computing) enable multi-tenancy and inter-domain connectivity through Transport Network Slices": a) Integration with telco cloud and MEC; b) Provisioning of multi-tenant transport network slices; and c) Inter-domain provisioning of connectivity services.

This objective is mainly in scope of WP3 and WP4 with the following key results over the reporting period:

- TeraFlow has defined a transport network slice (TNS) in D3.1 as a set of endpoints (e.g., CEs), a connectivity matrix between subsets of these endpoints, and service level behaviours requested for each sender on the connectivity matrix[2]. The connectivity between the endpoints might be point-to-point, point-to-multipoint, or multipoint-to-multipoint. Often these slices will be used to satisfy network behaviour defined in a Service Level Agreement (SLA). A preliminary YANG data model for deploying TNS using TeraFlow has been proposed with TeraFlow input[3]. Moreover, an initial preliminary analysis of the mapping possibilities between the requested TNS and the underlying network resources has also been published by TeraFlow partners[4].
- Integration with telco cloud and MEC has been tackled in D4.1 by considering the necessary interactions between an externally-selected NFV Orchestrator and the TeraFlow OS at the time of automatically deploying network services embracing both compute (e.g., VNFs or CNFs) and networking (i.e., wide-area network) resources. Specifically, the NFV Orchestrator and the TeraFlow OS interact according to a client-server relationship. The selected NFV Orchestrator is the ETSI OpenSource MANO (OSM). A preliminary design for the TeraFlow Compute Component has been proposed, considering the interface required by ETSI OSM. The preliminary results of the deployment of the Compute Component of the TeraFlow OS validate the creation of a connectivity service demanded by the NFV Orchestrator (OSM) supporting a specific network service instantiated between two remote VIMs. At the time of writing, we are currently working on some support and backwards-compatibility issues of the latest OSM release 10 when triggering the creation of the connectivity service to the Compute Component (i.e., relying on the REST API).

[2] Farrel, A., Gray, E., Drake, J., Rokui, R., Homma, S., Makhijani, K., Contreras, L. M., and J. Tantsura, "Framework for IETF Network Slices", IETF draft TEAS Working Group, August 2021. Work in progress. Available from: https://datatracker.ietf.org/doc/draft-ietf-teas-ietf-network-slices

[3] X. Liu, et al., "IETF Network Slice YANG Data Model", IETF draft TEAS Working Group, July 2021. Work in progress. Available from https://datatracker.ietf.org/doc/draft-liu-teas-transport-network-slice-yang/

[4] A. Alcalá, S. Barguil, V. López, L. M. Contreras, C. Manso, P. Alemany, R. Casellas, R. Martínez, D. Gonzalez-Perez, X. Liu, J.M. Pulido, J.P. Fernandez-Palacios, R. Muñoz, R. Vilalta, Multi-layer Transport Network Slicing with Hard and Soft Isolation, in Proceedings of The Optical Networking and Communication Conference & Exhibition (OFC), 6-11 June 2021, virtual event.

- The design of the Inter-Domain Component (IDC) is based on three use case workflows which have been defined in MS2.1. These workflows include service preparation and activation, service modification, and synchronisation of service monitoring data between domains. We have identified and amended interactions that involve the IDC and provided an overview of the resulting IDC architecture. Preliminary results have been presented in D4.1 considering the amount of information that a control plane element sends to elements in remote domains. To experiment with different abstraction models, we selected the following three well-known options: transparent, Virtual Node (VNode), and Virtual Link (VLink).

Objective 4 "Secure operator network": a) Cyberthreat analysis and protection; b) Distributed ledger technologies.

This objective is mainly in scope of WP4, reported in D4.1, with the following key results over the reporting period:

- The fundamental procedures of the Centralised Cybersecurity Component have been implemented. The preliminary performance and scalability results of the modules using a supervised and an unsupervised learning model have been published in two conference papers.
- The fundamental procedures of the Distributed Cybersecurity Component have also been implemented and the modules composing the component have been validated.
- The Distributed Ledger Technology (DLT) Component has been implemented based on the modular architecture of Hyperledger Fabric. In addition, a conference paper has been published presenting a Blockchain-based architecture to provide SDN actions to configure connectivity services in transport domains.

Objective 5 "Generate impact and standardisation of project results. Support the 5G PPP programme": a) Advertise the TeraFlow OS, make it available as open source, and foster industry adoption of its features; b) Communication and dissemination of TeraFlow results to appropriate stakeholders; and c) Promote and actively drive standardisation and multi-vendor interoperability events.

This objective is mainly in scope of WP6, reported in D6.2, with the following key results over the reporting period:

- Creation of TeraFlow visual identity and website (https://www.teraflow-h2020.eu/), the main communication channel used by the project to deliver relevant content to external audiences.
- Creation and maintenance of the project's social media accounts on Twitter (@TeraFlow_h2020 with 164 followers at M12) and LinkedIn (https://www.linkedin.com/company/teraflow-h2020 with 69 followers at M12), used for promotion and increase of interactions among key target audiences.
- Creation of the TeraFlow YouTube channel to present the progress of the technical development and its results in a visual way with 9 videos posted in the first year (https://www.youtube.com/channel/UCz86mcBvscgA4tS_voXokyQ).
- Design and production of different types of communication material (posters, social media banners, brochure, newsletter), which have been used at events for increasing visibility of the project.
- Publication of news in partners own websites and other related projects or initiatives (OSM, 5G PPP), as well as specialised websites/magazines and media.
- Active development of 20 papers and their presentation at important conferences (OFC 21, EuCNC/6G Summit, ONDM 21, ECOC 21, CNSM 21, IEEE NFV-SDN 21, OMNET++ Community

Summit, PSC 2021, NetCentric 2021, NoF 2021, NGON DCI 2021, etc.) and publication in journals (IEEE networks, MDPI Photonics).

- Participation in external events and organisation of own events/workshops in collaboration with other initiatives and projects (OSM ecosystem day or 5G PPP webinars, for example) or co-located within bigger and renowned venues (like MWC 21), reaching over 3000 persons with different roles and from different backgrounds such as researchers, academics, industry, and standardisation bodies (Figure 1).

- *Figure 1: Social Media Banners*

- To ensure the sustainability of the project results and uptake by third parties, TeraFlow partners are deepening the open-source exploitation strategy: design and develop a new generation SDN open-source controller and contribute with it back to the community.
- TeraFlow partners are closely discussing with ETSI OSM developers to accomplish a functional integration between the OSM latest release and the TeraFlow OS architecture. Other open-source projects that TeraFlow is aligning with are ONF and HyperLedger, so that their users can leverage TeraFlow for research and innovation activities.
- TeraFlow is taking part in relevant working groups in SDOs (ETSI, ITU, ONF, OpenConfig, IETF and TIP), and other industry fora, contributing with related documentation to help forming strategies and ensure that TeraFlow objectives are met.

1.2 WP2 - Use Cases, Requirements, Architecture, Business Model Analysis, and Data Models

WP2 sets the necessary foundations for the TeraFlow OS and it is organised into four distinct areas through the WP2 tasks:

- Task 2.1: Use case definitions and requirements.
- Task 2.2: Architecture.
- Task 2.3: Business model analysis.
- Task 2.4: TeraFlow OS data models.

1.2.1 Task 2.1: Use Case Definitions and Requirements

D2.1 has presented the use cases proposed for the TeraFlow SDN controller. They are classified into the following topics: inventory, topology, service, transport network slicing, monitoring, traffic engineering, automation, policy enforcement, ML-based security, distributed ledger and smart contracts, compute integration, and inter-domain. Figure 2 provides the classification typology.

These use cases refer to multiple network technologies covering IP, Optical, and Microwave. Optical and Microwave are deployed as transport networks, while IP is intended to provision L3VPN services.

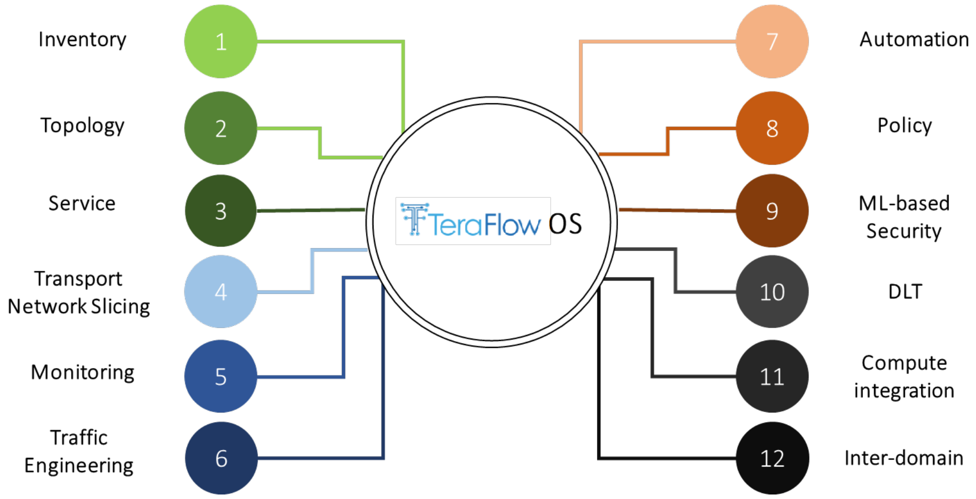

Figure 2 Use case classification according to D2.1

In Table 1, the relationship between the proposed use cases and the D5.1 scenarios. This matrix will ease specific demonstrations in the scope of WP5. Please refer to D5.1 for a clear description of the proposed scenarios:

- Scenario 1: Autonomous Network Beyond 5G.
- Scenario 2: Inter-domain.
- Scenario 3: Cybersecurity.

Table 1 Scenario – Use case matrix

	Autonomous Network Beyond 5G	Inter-domain	Cybersecurity
Inventory	X	X	

Topology	X	X	X
Service	X	X	X
Transport network slicing	X	X	
Monitoring			X
Traffic Engineering	X		
Automation	X		
Policy	X		
ML-based security			X
Distributed ledger and smart contracts		X	
Compute	X		
Inter-domain		X	

Moreover, different requirements for the TeraFlow SDN Controller have been introduced. They have been classified as:

- Functional Requirements: These describe what the system must or must not do, and can be thought of in terms of how the system responds to inputs. They are ordered using the same use case topics.
- Non-functional Requirements: These are requirements that specify criteria that can be used to judge the operation of a system rather than specific behaviours. They are contrasted with functional requirements that define specific behaviours. The described non-functional requirements include Performance, Usability, Scalability, Security, Reliability, and Portability.

1.2.2 Task 2.2: Architecture

Figure 3 provides an overview of the TeraFlow OS architecture. The TeraFlow OS is a cloud native SDN controller that is composed of multiple micro-services. Micro-services interact with each other using a common integration fabric. Moreover, in the context of B5G networks, the TeraFlow OS can interact with other network elements, such as NFV and MEC orchestrators, as well as an OSS/BSS. The TeraFlow OS controls and manages the underlying network infrastructure, including transport network elements (optical and microwave links), IP routers, as well as compute nodes at edge or public cloud infrastructures.

TeraFlow core micro-services are tightly interrelated and collaborate to provide a complete smart connectivity service. Once a Transport Network Slice request is received, the Slice Manager translates this request to the Service Component. Moreover, the slice request is recorded by the DLT Component in the blockchain. The Service Component computes the necessary connectivity services and requests the necessary network element configuration (e.g., using NETCONF, P4, OpenFlow), or interacts with underlying SDN controllers through the Device Management Component. These configurations are also recorded using the DLT Component. Policies per flow are computed in the Traffic Engineering (TE) Component and verified, and network elements are monitored for anomalous behaviour in the Automation and Policy Management Components. The Context Manager is responsible for handling the distributed non-relational database that contains all necessary information (including slice and/or flow requests, network topology, and network element configuration).

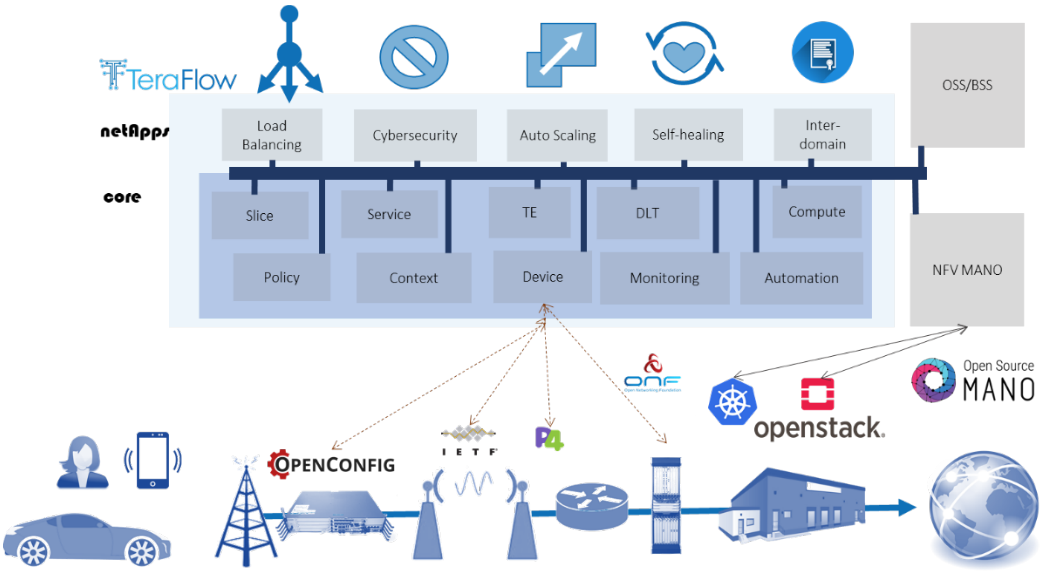

Figure 3 TeraFlow OS architecture

TeraFlow netApps consume TeraFlow core micro-services. The TeraFlow netApps provide the necessary carrier-grade features with a dedicated focus on: load-balancing, cybersecurity, auto-scaling, self-healing, and inter-domain smart connectivity services. Load-balancing allows the distribution of flow and slice requests among the micro-services component replicas. The Cybersecurity Component provides AI/ML-based mechanisms to detect network intrusions and harmful connections, and it provides countermeasures to security incidents. Moreover, the Cybersecurity Component will be able to protect itself against adversarial attacks that try to spoof the detector's ML Components. The Auto-Scaling Component focuses on the autonomous replication of micro-services to support high numbers of incoming requests. The Self-Healing Component monitors micro-services and per-flow status to apply healing mechanisms (e.g., component restart, flow redirection) both from a control and a data plane perspective. Finally, the Inter-Domain micro-service allows the interaction of a TeraFlow OS instance with peer TeraFlow OS instances which manage different network domains.

1.2.3 Task 2.3: Business Model Analysis

In Task 2.3, we have conducted a stakeholder and ecosystem analysis of the TeraFlow OS system, collaborating with Task 6.3. In our analysis we have relied on frameworks sourced from theories on platform ecosystems and technological innovation systems. Together, the frameworks offered well-known structures and driving factors in a growing ecosystem. The data input to our analysis have been the initial TeraFlow submission, the TeraFlow partners' exploitation plans, and published literature. We especially appreciated the input from open-ended interviews with partners. The preliminary analysis suggested roles and relationships in the TeraFlow OS ecosystem and elaborated on the enabling and blocking mechanisms for the further evolution of the ecosystem, documented in D2.1 – Preliminary requirements, architecture design, techno-economic studies and data models. Figure 4 presents relevant roles and relationships for the TeraFlow OS from one operator's perspective.

Further data will be collected and analysed in Year 2 of T2.3 to better report on challenges stakeholders will meet in seeking to succeed with the business of transport network slices and the

TeraFlow open-source operating system. The ambition is to conduct dynamic simulations of the market in which the TeraFlow OS operates if this continues to be a suitable approach.

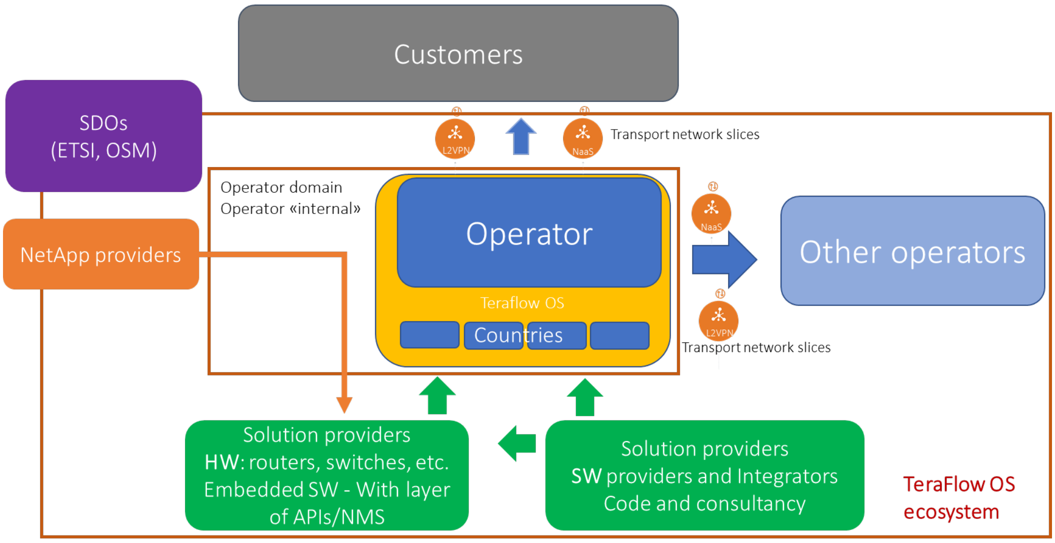

Figure 4 Roles in the TeraFlow OS ecosystem: perspective of one operator

1.2.4 Task 2.4: TeraFlow OS Data Models

In this task, we have identified the selected data models to be used as both external (including Northbound and Southbound) and internal interfaces.

The external interfaces are the ones offered to be consumed from external components of TeraFlow and typically use NETCONF or RESTCONF protocols. Several interfaces are proposed to be used as NBIs, being summarised in L3/L2 network models, Traffic Engineering (TE) tunnels, and IETF Transport Network Slices. The SBIs focus on device communication and more information about them is provided in D3.1 – Device component architecture description. Currently, we have included the following SBIs: ONF Transport API, ONF TR-532 Microwave, ONOS P4, and emulated OpenConfig device.

Google Remote Procedure Calls (gRPC)[5] is a protocol based on HTTP/2 as a transport protocol and it uses protocol buffer encodings for transported messages and data models. As it is based on HTTP/2 and uses byte-oriented encoding, it introduces low latency. gRPC has been used in highly scalable and distributed systems. It has been decided to use gRPC as the internal protocol in the TeraFlow SDN Controller. All defined internal protocol buffers are part of the TeraFlow SDN source code, and they are available at https://gitlab.com/teraflow-h2020/controller/-/tree/develop/proto

1.2.5 Impact of COVID-19 on WP Activities

After doing a first assessment of the potential COVID-19 impact, and given the progress in WP2's activities so far, WP2 partners do not foresee delays. Specifically, the major WP2 objective through the first year of the project (i.e., D2.1) was delivered on time, while the technical activities in WP2 are also on track. Similarly, for the upcoming Year 2 activities no delays are foreseen due to COVID-19.

[5] E. Breverman et al., Optical Zero Touch Networking—A Large Operator Perspective, OFC 2019.

1.3 WP3 - Life-cycle Automation and High-Performance SDN Components

WP3 bridges key gaps in state-of-the art SDN controllers in four distinct areas organised as WP3 tasks:

- T3.1: High-performance control plane operations through a revolutionary cloud-native network operating system (NOS) design, based on distributed and fully disaggregated micro-services.
- T3.2: Native support for key transport technologies, such as Internet Protocol (IP), optical, and microwave (MW), as well as emerging next-generation SDN technologies, such as the programmable protocol-independent packet processors (P4).
- T3.3: Automated, zero-touch provisioning (ZTP) of network services and NOS lifecycle operations.
- T3.4: Multi-tenant network slicing as a service coupled with SLA requirements.

1.3.1 Task 3.1: High-Performance SDN Framework

This task is devoted to design, develop, and test acceleration techniques that enable the TeraFlow OS controller to provide high-performance flow management from a control plane perspective. This workspace is bundled into three main cloud-native components that will be implemented as fully disaggregated micro-services belonging to the TeraFlow OS core: i.e., the Context Management, Monitoring, and Traffic Engineering Components. More details on this task are provided in D3.1.

The Context Component aims to create a global picture of the network environment by storing concrete attributes and configurations of the network elements present in the network environment under the command of the TeraFlow OS. In this scenario, scalability is key to allowing the processing of huge information flows to build complex network contexts. To meet this challenge, the backend of the Context Component stores and manages the configurations and attributes of the elements in a No-SQL database to optimise concurrent access or in an in-memory database, depending on the users' needs. In this phase of the project, the No-SQL database is implemented in Redis. As for the frontend, this component presents two different interfaces for retrieving and exporting data to create the context. Firstly, the gRPC interface exports a set of RPC methods intended to allow the rest of the TeraFlow OS component to interact with the Context Component. And secondly, it provides a REST-based interface that allows external systems, such as OSS/BSS, to track the status of the corresponding network elements among other read capabilities. Preliminary results have demonstrated the full functionalities implemented, both for the backend and frontend sides.

The Monitoring Component aims at collecting and storing metrics or composite KPIs from different parts of the system. These metrics are stored in a time series data base and include the lifecycle of the micro-services, and the connectivity of network services/slices or the network devices. This information is available to external entities using a gRPC-based subscription method that relies on a management database for storing the subscription-related information. At the current stage of the project the metrics database and the management database have been implemented using InfluxDB and SQLite respectively including all the necessary logic and interfaces for registering, monitoring, and collecting data from TeraFlow devices. The Monitoring Component is constantly listening for new events or changes in the Context Component to automatically create new metrics and KPIs. For data collection, the Monitoring Component relies on the TeraFlow Device Component that interfaces with the SDN agents and sends the KPI samples to the Monitoring Component over gRPC.

The Traffic Engineering Component is in charge of setting up and optimising the Segment Routing (SR) paths of the TeraFlow infrastructure building a Traffic Engineering Database (TED) from the topology data exposed by the TeraFlow Context Component and synchronising it with the SR Label Switched Paths known by the routers. When new/optimised SR paths are requested the Traffic Engineering Component establishes communication with the TeraFlow routers through the Path Computation Element (PCE), establishing the requested SR paths using the PCE communication Protocol (PCEP). At this moment, there is a partial implementation of the Traffic Engineering Component including an Erlang-based PCE with the inherited scalability and resiliency properties of this programming language. Although the PCE implementation is not yet completed and integrated with the rest of the TeraFlow components, the current implementation has been demonstrated at the 2021 IEEE NFV-SDN conference.

In conclusion, this section summarises the technical activities of Task 3.1 during the first year of the project, expecting for the second year a further development of the Context Management, the Monitoring, and the Traffic Engineering Components in order to fulfil the high-performance capabilities required by the TeraFlow OS.

1.3.2 Task 3.2: Hardware and L0/L3 Multi-layer Integration

This task has focused on two design overviews, the northbound and southbound interfaces, and preliminary results of the core TeraFlow OS components: the Device Component and the Service Component.

The **Device Component** is in charge of interacting with the underlying network equipment. Different protocols and data models might be needed to manage the network equipment. For this reason, the Device Component provides a Driver API that enables developers to implement new drivers and integrate them into the TeraFlow OS. The component consists of a gRPC-based NBI exposed to the rest of the TeraFlow OS components, and a set of SBIs that interact with different network equipment using appropriate protocols and data models. In between, the Device Servicer block dispatches the incoming requests and interacts with the SBI Driver API to choose the appropriate driver for each network device. The SBI Driver API enables the Device Component to be extended to use different protocols and data models to communicate with various types of programmable devices. The available driver plugins are listed below:

- An emulated driver plugin for testing purposes.
- An OLS ONF Transport API driver plugin.
- An ONF TR-532 microwave driver plugin.
- A NETCONF/OpenConfig driver plugin for packet routers.
- A P4 driver plugin for next-generation whitebox switches.

A set of unit tests has been defined for the Device Component. In D3.1, we report the results of the tests illustrating those operations and features for the released components that operate correctly. Note that some of the drivers are work in progress, thus only the tests for the Device Driver API, the Emulated Device Driver, and the OpenConfig Device Driver are reported.

The **Service Component** is in charge of managing the life-cycle of the connectivity services established in the network. Different service types could be requested and different protocols and data models might be used to configure the network equipment. For this reason, the Service Component implements a Service Handler API that enables network operators to precisely define the service types they need to support and the behaviour for each of them.

The component consists of a gRPC-based NBI exposed to the rest of the TeraFlow OS components, and a Service Servicer block that dispatches the incoming requests and interacts with the Service Handler API to choose the appropriate handler for each service type requested. Given that the Service Component needs to know about the state and details of the existing connectivity services and the devices supporting them, it makes use of the Context Management Component to store and retrieve up-to-date details about the devices and the services using the Context Management gRPC interface. The Service Handler interface enables network operators to extend the Service Component to support different service types and use different protocols and data models to configure the devices. Currently, an L3VPN service using OpenConfig (L3NM-OC) is under development. In D3.1 we report preliminary results for the Service Component skeleton. Note that Service Handlers are work in progress, so no specific service is being tested right now.

1.3.3 Task 3.3: SDN Automation

T3.3 is in charge of two core TeraFlow OS components, i.e., the Zero-Touch Provisioning (ZTP) and Policy Management Components, both of which aim at automating crucial tasks of the TeraFlow SDN controller.

The ZTP Component, also titled the Automation Component, provides the means, in the form of RPCs, to automatically (i) onboard a new device (i.e., ztpAdd RPC), (ii) reconfigure an already onboarded device (i.e., ztpUpdate RPC), and (iii) remove an onboarded device (i.e., ztpDelete RPC) or all of the onboarded devices (i.e., ztpDeleteAll RPC). In addition to those key functions, the Automation Component also exposes two read-only RPCs that allow other TeraFlow OS components to access the current state of devices and the roles associated to the various devices. Apart from the main automation services, the Automation Component exploits a publish-subscribe TeraFlow OS mechanism to dynamically associate components with relevant events that require immediate actions, through a dedicated Events API. D3.1 demonstrates detailed workflows that show how the Automation Component reacts upon certain events to automatically provision device onboarding, device update, and device deletion operations. Moreover, D3.1 provides preliminary results related to (i) the realisation of unit tests for testing internal processes of the Automation component, (ii) the correct spawning of the Automation server offering automation services to the TeraFlow OS, and (iii) an example invocation of a key automation service (i.e., ztpAdd RPC) which automatically adds a new device in the network.

The initial version of the TeraFlow Policy Management Component utilises an emerging technique called “Event Condition Action” (ECA) to provide event-driven policy management. ECA policy enables actions to be automatically triggered based on when certain events in the network occur while certain conditions hold. Using the ECA policy model, the TeraFlow Policy Management Component translates a network operator’s high-level network policy statements into a correct set of low-level instructions that realise this policy across the various network elements. To meet this objective, the Policy component offers RPC methods that allow a client to (i) express and add a new policy (i.e., policyAdd RPC), (ii) update an already applied policy (i.e., policyUpdate RPC), and (iii) revoke an applied policy (i.e., policyDelete RPC). In addition to those key functions, the Policy Management Component also exposes three read-only RPCs that allow other TeraFlow OS components to access the current state of policies associated to the various devices or services. Specifically, the Policy component allows a client to query a single policy rule using a policy rule ID (GetPolicy), or to query a list of policy rules by device ID (i.e., GetPolicyByDeviceId) or service ID (i.e., GetPolicyByServiceId). Apart from the main Policy services, the Policy Management Component exploits a publish-subscribe TeraFlow OS mechanism to dynamically associate components with relevant events that require immediate actions. This is the role of the "Events API". The current implementation of the Policy Management Component does not yet provide support for this API, this is work planned through the second year of the TeraFlow project. D3.1 demonstrates a detailed workflow that shows how the Policy Management Component installs a new policy, while some preliminary results are provided in the form of (i) unit tests and (ii) the correct spawning of the Policy server offering policy management services to the TeraFlow OS.

1.3.4 Task 3.4: Transport Network Slicing and Multi-tenancy

This task has provided a Transport Network Slice definition. A transport network slice consists of a set of endpoints (e.g., CEs), a connectivity matrix between subsets of these endpoints, and service level behaviours requested for each sender on the connectivity matrix. The connectivity between the endpoints might be point-to-point, point-to-multipoint, or multipoint-to-multipoint. Often these slices will be used to satisfy network behaviour defined in a Service Level Agreement (SLA).

The TeraFlow slicing architecture uses the Network Slice Controller (NSC) to realise a transport network slice using physical and virtual network resources provided by the underlying network controllers. In the TeraFlow project, these controllers manage both optical and packet resource domains. Several NBIs for the Slice Component have been studied.

D3.1 provides preliminary results obtained with the support of an ABNO orchestrator to trigger the multiple interfaces to deploy hard isolated slices[6] (Figure 5). These preliminary results have allowed us to decide the which data models to use for the TeraFlow OS implementation.

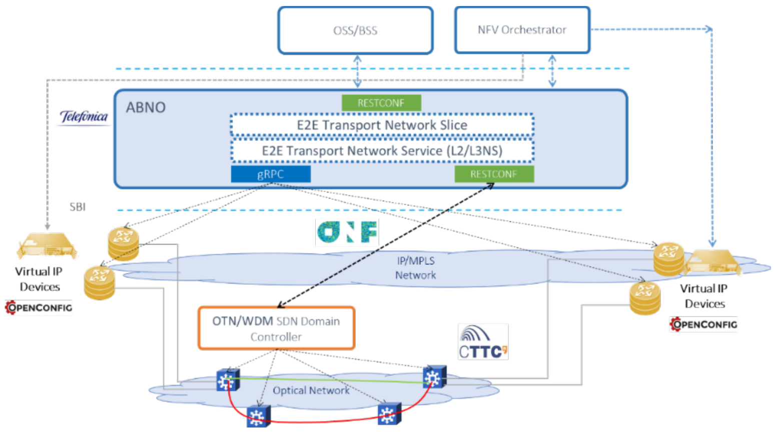

Figure 5 Slicing preliminary architecture presented at OFC21.

1.3.5 Impact of COVID-19 on WP3 Activities

After doing a first assessment of potential COVID-19 impact, and given the progress in WP3's activities so far, WP3 partners do not foresee delays. Specifically, the major WP3 objective through the first year of the project (i.e., D3.1) was delivered on time, while the technical activities in WP3 are also on track with most of the components being ready for a demonstration at OFC 2022. Similarly, for the upcoming Year 2 activities no delays are foreseen due to COVID-19.

[6] A. Alcalá, S. Barguil, V. López, L. M. Contreras, C. Manso, P. Alemany, R. Casellas, R. Martínez, D. Gonzalez-Perez, X. Liu, J.M. Pulido, J.P. Fernandez-Palacios, R. Muñoz, R. Vilalta, Multi-layer Transport Network Slicing with Hard and Soft Isolation, in Proceedings of The Optical Networking and Communication Conference & Exhibition (OFC), 6-11 June 2021, virtual event.

1.4 WP4 - Network Security and Interworking Across B5G Networks

WP4 is responsible for the design and development of the TeraFlow OS Security and Integration Components. While WP3 focuses on the **core** TeraFlow OS components, WP4 focuses on the **security and integration** related TeraFlow OS components. To tackle the security and integration aspects, WP4 has been structured into three tasks namely T4.1, T4.2, and T4.3.

- The first task (i.e., T4.1) is concerned with cyberthreat analysis and protection, and is targeted towards designing and implementing an advanced cybersecurity solution.
- The second task (i.e., T4.2) describes the design and development of a Distributed Ledger Technology (DLT) focusing on distributed ledgers and smart contracts to secure 5G networks.
- The third task (i.e., T4.3) provides the means for integrating the TeraFlow OS into beyond 5G (B5G) networks.

1.4.1 Task 4.1: Cyberthreat Analysis and Protection

In the first year of the TeraFlow project the following activities were carried out:

Task T4.1 is concerned with the design of cyberthreat analysis and protection solutions to be integrated in the TeraFlow OS. These solutions are crucial for protecting TeraFlow's network infrastructure in the SDN domain against sophisticated attacks at the optical, network, and transport layers. The work done was split into two different components: the Centralised Cybersecurity Component and the Distributed Cybersecurity Component. The activities developed in the context of the first component aimed at designing scalable and reliable ML-based mechanisms to continuously assess the security status of the optical channels. The second component proposed a distributed ML-based solution to provide scalability to the TeraFlow OS when performing real-time attack detection over L3 flows.

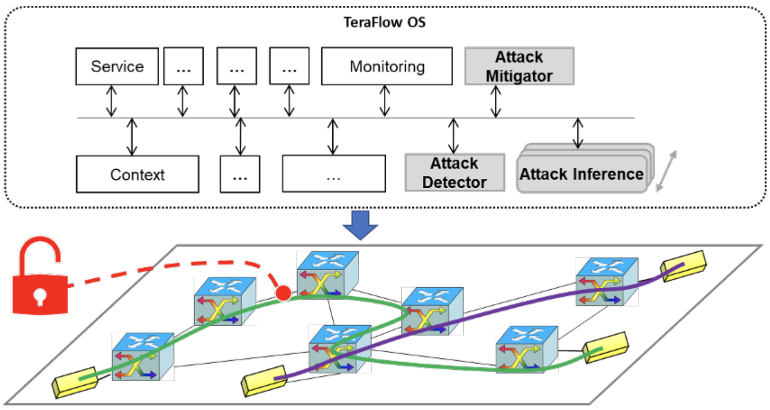

Figure 6 Centralised Cybersecurity components

The Centralised Cybersecurity Component focuses on detecting and mitigating the security threats that target the physical layer in optical networks. For this purpose, the component continuously assesses the security status of the optical services currently deployed under TeraFlow OS management. In the first year, an internal architecture for the Centralised Cybersecurity Component was defined taking into account the particularities of this component and the most advantage of the micro-service architecture adopted by the TeraFlow OS. The resulting architecture is illustrated in Figure 6. The fundamental procedures of the Centralised Cybersecurity Component were implemented in the v1 code freeze. In this initial release, the three modules composing the component (Attack Detector, Attack Inference, and Attack Mitigator) were implemented, and their internal communication was validated. In addition, the preliminary performance and scalability results of the developed modules using a supervised and an unsupervised learning model were reported in two conference publications.

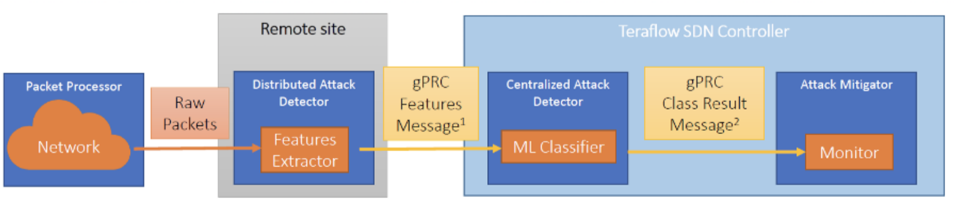

Figure 7 Distributed Cybersecurity components architecture

The Distributed Cybersecurity Component focuses on the capture, identification, and mitigation of network threads, implementing a protection layer that takes into account the scalability issues that can appear when multiple L3 attacks have to be detected in real-time. The Distributed Cybersecurity Component consists of three main modules (Distributed Attack Detector, Centralised Attack Detector, and Attack Mitigator), illustrated in Figure 7. The distributed attack detection and mitigation workflow provides the TeraFlow OS with a continuous assessment of the security status of IP services. At the end of the first year, the Distributed Cybersecurity Component had its fundamental procedures implemented for the code freeze (v1). In this initial code release, the three modules composing the component were implemented along with the corresponding interfaces, and their internal communication was validated.

1.4.2 Task 4.2: Distributed Ledger and Smart Contracts

In the first year of the Teraflow project ending in December 2021, the following activities were completed:

1. Design, development, and implementation of the DLT (Distributed Ledger Technology) Component.
2. Blockchain-Based Connectivity Provisioning in Multiple SDN Domains.

1.4.2.1 DLT Component

The DLT Component as illustrated in Figure 8 is used to record, register, and retrieve information. It provides the following functions:

- To provide a trustworthy and resilient platform for storing, querying, and processing critical data about network resources.
- To record information such as software status (e.g., software/firmware version) and runtime information (e.g., remote attestation, tamper detection).
- To allow the collaboration among multiple TeraFlow OS nodes by sharing the SDN resources available in their transport network infrastructures.

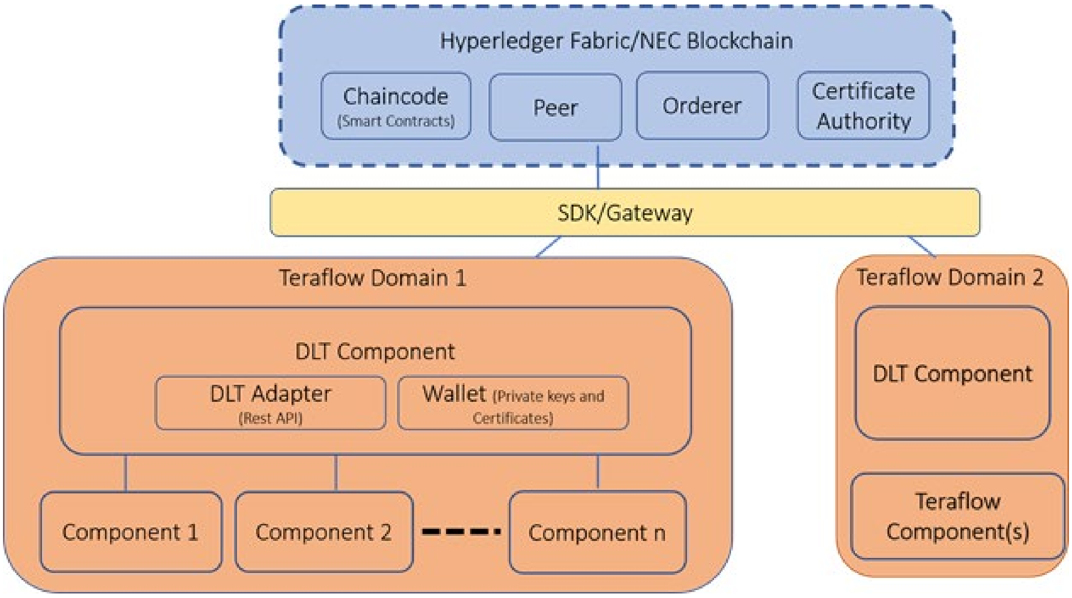

Figure 8 DLT Component design and interface with multi-domain architectures

1.4.2.2 Blockchain-Based Connectivity Provisioning in Multiple SDN Domains

Hierarchical SDN architectures are used to manage the co-existence of multiple domains by having an element on top. A collaborative relationship between domains, might solve this issue. Blockchain can become the key element for this change to happen. A set of papers have been published in different conferences to present a Blockchain-based architecture to provide SDN actions to configure connectivity services in transport domains. The results presented in the papers show that the use of Blockchain is a promising candidate for inter-domain SDN control. The papers were presented in the 2021 International Conference on Optical Network Design and Modeling (ONDM) and the 2021 Optical Fiber Conference (OFC).

1.4.3 Task 4.3: Interworking Across Beyond 5G Networks

Two main activities have been conducted during the first year of the project to support the interworking of the deployed TeraFlow OS with external entities aimed at addressing selected scenarios featuring Beyond 5G networks:

- Establishment of network services involving both cloud and networking resources.
- Setting up inter-domain connectivity services.

1.4.3.1 Compute Component

The Compute Component has been designed and been deployed within the TeraFlow OS architecture to enable the interaction with a Network Function Virtualisation (NFV) Orchestrator. The selected implementation of the NFV Orchestrator is the ETSI OSM. Thus, the TeraFlow OS Compute Component acts as a frontend element which, via a defined RESTful API, handles the lifecycle of the connectivity services demanded by the OSM. The goal, as illustrated in Figure 9, is that the OSM coordinates the deployment of the Virtual Network Functions (VNFs) and Containerised Network Functions (CNFs) over the cloud premises. Then, it relies on the TeraFlow OS to roll out the connectivity services interconnecting the deployed VNFs/CNFs hosted in remote cloud premises.

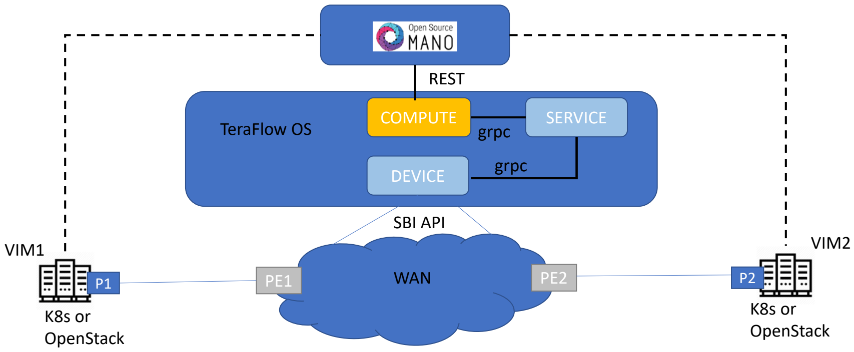

Figure 9 OSM and TeraFlow OS interaction for the deployment of Network Services

The following operations at the Compute Component are supported to accomplish the OSM -TeraFlow OS interworking: i) Gather network connectivity services status; ii) Create network connectivity services (specifying network resource and service requirements); iii) Delete network connectivity services; and iv) Update existing network connectivity services.

1.4.3.2 Inter-Domain Component

The main goal of the Inter-Domain Component (IDC) is to enable the automatic deployment of dedicated QoS-aware inter-domain connectivity services between peer TeraFlow OS instances managing different network domains. To this end, an architecture has been proposed for the IDC as shown in Figure 10. The architecture aims at supporting service preparation and activation encompassing multiple domains, service modification, and the synchronisation of selected service monitoring data for SLA assurance.

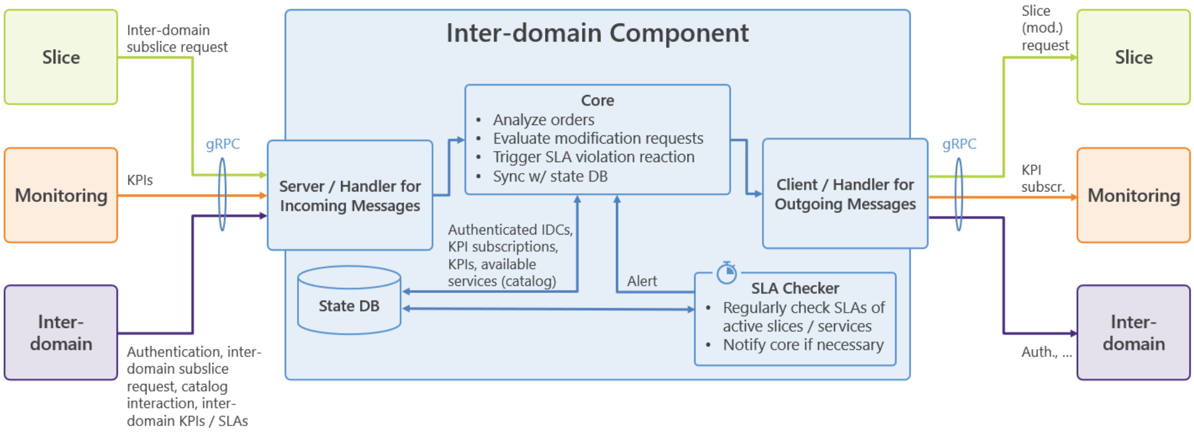

Figure 10 Architecture of the Inter-Domain Component within the TeraFlow OS

1.4.4 Impact of COVID-19 on WP Activities

After doing a first assessment of potential COVID-19 impact, and given the progress in WP4's activities, WP4's partners do not foresee delays, and expect that the outline objectives will be completed in line with the schedule.

1.5 WP5 - Prototype Integration, Demonstration, and Validation

WP5 is responsible for performing the TeraFlow OS integration, followed by experimentation, validation, and evaluation using a range of benchmark indicators. We concentrated on the following main objectives during the first year of the project. First, we defined the scenarios for the experimental activities, the prototype features deemed relevant in each of the scenarios, and the testbeds at the partners' premises to test the prototype functionalities. Second, we evaluated options and selected the tool chosen to coordinate the prototype development and integration process. Third we provided a reference architecture for the TeraFlow OS components to be developed followed by the methodology to develop, integrate, test, and release each artifact produced by TeraFlow.

1.5.1 Task 5.1: Infrastructure and Testbeds

The project identified three scenarios representing some of the challenges posed by B5G networks, namely: Autonomous Network Beyond 5G, Automotive, and Cybersecurity. For each one of the scenarios, we identified: the main technical challenges, the features required (i.e., from the TeraFlow OS point of view), the TeraFlow OS component to be developed to provide these features, and, finally, the use cases of interest to be investigated to validate and benchmark the performance of the TeraFlow OS prototype. More details on the challenges, components, and use cases for each scenario are available in D5.1. In parallel with the scenario work, we also ran an inventory of the testbed infrastructures at each partner’s premises. This work was essential to define the testbed setups for each of the scenarios under study. A description of the three testbed setups is available in D5.1. Finally, we surveyed and evaluated some options for the qualification platform to be used in the project. The two primary candidates were Jenkins and GitLab CI/CD, two of the most widely adopted CI/CD solutions on the market. The final choice was for GitLab CI/CD, in part because GitLab acts as a single source of truth since, i.e., in addition to CI/CD, it offers source code management, version control, and code documentation (among other features) in a single application. More details on the comparison work can be found in D5.1.

1.5.2 Task 5.2: TeraFlow OS Integration

The work in this task focused initially on the definition of the reference component architecture to develop the TeraFlow OS components. The TeraFlow OS is implemented following the cloud-native architecture concept. The software is divided into micro-services that execute specific tasks and collaborate through messages to achieve the end goal for which the software is designed. In the TeraFlow OS, the communication between components is based on gRPC. We defined different RPC methods and messages and grouped them by micro-service. D3.1 and D4.1 describe the architectural details of each component, the interfaces they expose, and some preliminary experimental results validating their stand-alone functionalities.

The general architecture of the TeraFlow OS components using the default project language, i.e., Python 3, is detailed in D5.1, where we also describe the folders and files available within the TeraFlow OS source code folder. The deliverable also shows the structure of files and folders that should be created to implement a hypothetical component that follows the reference architecture using Python 3. However, since the components are independent of each other and communicate among themselves through standard gRPC messages, variations in programming language and project structure might be introduced when needed, depending on the partner's expertise responsible for implementing a component. The task also looked into the methodology to develop, integrate, test, and release the artifacts produced by TeraFlow. The proposed method comprises four complementary tiers: functional architecture and pipeline, TeraFlow CI/CD infrastructure, good practice and hints for CI/CD usage, and release time plan. The methodology is described in detail in D5.1 where, in the end, we also provide installation instructions to deploy the TeraFlow OS software. Finally, another important outcome to report is a demo presentation scheduled for OFC 2022 in March 2022. The demo will showcase to the public the first prototype of the TeraFlow OS with three main features in mind: Zero-touch device bootstrapping, L3VPN connectivity service management, and network monitoring (see Figure 11).

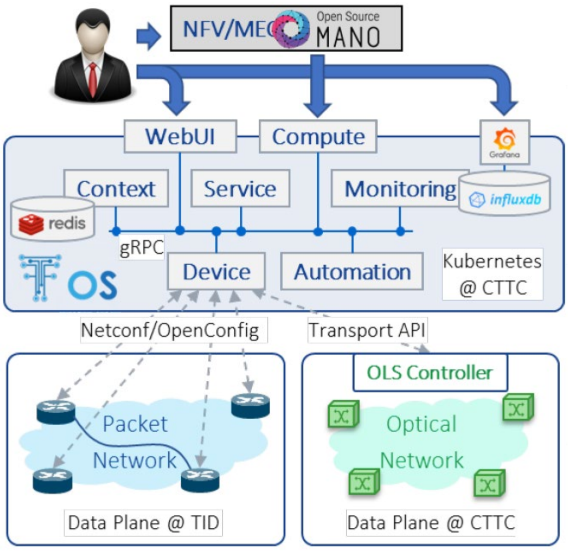

Figure 11 Demo Architecture with the TeraFlow OS components

1.5.3 Task 5.3: Use Case Integration and Demonstration

We are currently working on the development and integration of the main component of the TeraFlow OS prototype. The integration and demonstration activities are scheduled to start in M16.

1.5.4 Task 5.4: Performance Assessment and KPI Validation

The performance assessment and KPI validation activities are scheduled to start in M21.

1.5.5 Impact of COVID-19 on WP Activities

Given the progress in WP5's activities, WP5's partners do not foresee delays.

2 Progress on Dissemination, Standardisation, and Exploitation

The WP6 objective is to maximise the impact of the project, facilitating the adoption of its results. After deliverable D6.1, that gave the project's strategy towards dissemination, communication, collaboration, and standardisation, D6.2 was been the second deliverable produced this year, providing an initial assessment of the market environment and opportunities for TeraFlow and reporting on the various activities that TeraFlow partners are conducting, following the strategy described in D6.1, to ensure that the project findings and results influence the B5G/6G community and the relevant standards. In this section, we summarise the results.

The impact achieved with WP6 activities has been recently presented to the TeraFlow Advisory Board (17th December 2021). The Advisory Board members gave very positive feedback, as well as some guidance for future work on how to ensure sustainability of the TeraFlow SDN controller after the end of the H2020 TeraFlow project.

2.1 Task 6.1: Stakeholder Engagement, Communication, and Dissemination

T6.1 will elaborate, maintain, and execute the dissemination and communications plans during the whole life of the project, involving a series of specific activities such as stakeholder identification, branding definition, creation of digital channels, newsletters, social media management, participation in events, publications in journals and conferences, among many other activities that will allow TeraFlow to inform various key audiences about the progress and results of the project, while also engaging with them to promote the uptake of results.

The TeraFlow strategy considers both dissemination and communication activities. The first refers to the public disclosure of the results to various stakeholders such as research peers, industry, potential end-users, policymakers, standardisation bodies, among many others which could adopt and integrate the results into their work. On the other hand, communication covers the promotion of the action and results to many audiences including the media and the public to build strong relationships and reach society as a whole.

D6.1, submitted in M4, presented the communication and dissemination strategy created for TeraFlow to support the sustainability, commercialisation, and further use of the project's results while also raising awareness and increasing visibility about the motivation of the project, its progress, and all the various activities that are performed throughout the life of the TeraFlow funding. The deliverable presents a three-phase strategy that will drive the execution of activities and messages used to reach out the different stakeholders identified

During 2021, Phase 1 has been focused on raising awareness about the project, its motivation, the objectives, consortium, expected outcomes, and other topics relevant to set the pace for the upcoming phases supported by the availability of technical results. With the release of v1 of the TeraFlow OS, Phase 2 will strive, from January 2022 until December 2022, to inform key target audiences about the progress of the project and actively engage with them in different venues to support the validation of both technical and business concepts. The last six months of the project will be devoted to Phase 3 aiming to promote the uptake of TeraFlow results among potential end-users and early adopters with more commercially-oriented activities and material developed.

Moreover, a specific chapter in D6.2 submitted in M12, reported on all the dissemination and communication activities executed between M1 and M11 of the project. The various actions and metrics corresponding to M12 will be included in the subsequent deliverable reporting the actions performed until M30.

Within the first year of the project, the consortium partners and this task have been working towards the achievement of specific dissemination and communication objectives such as:

- Ensuring maximum visibility and awareness of TeraFlow, its progress, and results, among key target audiences by delivering relevant content via digital channels.
- Boosting online and offline visibility by creating valuable content in different formats.
- Disseminating the research and technological knowledge of the project by developing, submitting and publishing scientific papers and specialised articles at conferences and in journals.
- Attracting potential users, customers, early adopters, and related initiatives to support the exploitation strategy, validate business models, and promote the uptake of results through the organisation and participation at events, demo sessions, workshops and other activities.

Specifically, within the first year, the consortium has actively participated at various events, conferences, standardisation meetings, and by submitting multiple scientific papers to renowned journals and conferences. Moreover, partners have leveraged various opportunities to liaise with related projects and organise workshops to raise awareness about the project.

To support the participation of partners and give visibility to the multiple activities executed, TeraFlow has promoted all of these on the project website and social media accounts which by the date of development of this document have reached a significant number of followers and metrics indicating that the content developed is attractive and therefore well received by audiences.

The activities to be executed within Phase 2 of the project, starting January 2022, will aim to support and promote the launch of the TeraFlow OS as a main Milestone reached within that period, and to inform and engage with key stakeholders. The availability of more mature and robust results encompassed with the release will allow the setup of more business-oriented activities that can be leveraged by the business modelling and exploitation tasks to gather feedback and validate plans which will meet the expectations and needs of these groups.

2.1.1 TeraFlow Digital Ecosystem: Website and Social Media Channels

The project website (https://teraflow-h2020.eu/) was created on Drupal CMS considering various SEO best practices and requirements for enhancing the organic positioning on search engines, such as the monitoring and analysis of keywords, increasing the number of internal and external links, and fulfilling accessibility requirements to offer valuable content to visitors regardless of the type of device they use to visit the website.

The website is the main communication channel used by the project to inform external audiences of the motivation, progress, knowledge, and various activities aiming to raise awareness and increase the visibility of the action. During the first-year, various content has been uploaded to the website in different sections, although it is expected that some structural and content modifications will be made to support the launch of TeraFlow OS at M13. In a similar way, the Blog section will be launched in 2022 with a first Blog post on the TeraFlow OS. The content presented in this section will cover a wide range of topics covered by the project technologies and components to communicate the technical progress and share the knowledge of the partners through relevant content.

Google Analytics is used for monitoring and measuring relevant metrics that allow us to understand how many people are accessing the website and if the content is well received. The metrics achieved until M11 are:

- Unique visitors: 2,793.
- Sessions: 3,172.
- Page views: 5,019.
- Average session duration: 00:54.

More information about the users profiling and behaviour can be found at D6.2.

Another essential part of TeraFlow's digital presence are the social media accounts on Twitter and LinkedIn, which are used to promote and give visibility to specific actions and work done within the project to keep audiences informed and establish interactions and relationships with other projects, initiatives, standardisation bodies, etc.

The Twitter account (@TeraFlow_h2020) is used to promote general information about the project progress with a special focus on publications, news and events. Content about different topics is posted regularly in order to provide followers with relevant information, and also information posted by other accounts is retweeted and liked as a way to generate interaction with key accounts while also amplifying the scope of the content offered by TeraFlow. Several best practices are being followed to boost the positioning of the account and have better metrics in terms of engagement rates and impressions.

Between M1 and M11, a total of 188 tweets have been made by the TeraFlow account. From the total, 93 correspond to original content posted from the account, and 95 have been done via retweeting or through interactions with other accounts. This demonstrates a good balance of content about the project and content related to the topics of interest which are being shared. From this, we can highlight the variability of content and interaction with other accounts for paving the way for potential collaborations in the future. Other important metrics achieved within M1 and M11 are:

- Retweets: 199.
- Likes: 451.
- Followers: 159.
- Engagement Rate: 1,7%.
- Impressions: 54,200.

TeraFlow's LinkedIn company page (https://www.linkedin.com/company/teraflow-h2020) works more towards professional audiences and allows us to connect the project with specialised profiles that could be potentially interested in the results of the project. The frequency of posting on LinkedIn is less in comparison to Twitter, but at the same time, the length and information included in these posts cover what can be covered by 3-4 Tweets. Some B2B best practices are being followed as well to provide the followers with valuable content in a more attractive and effective way.

In the case of LinkedIn, in Phase 2 we will aim to strengthen thought leadership with the use of the content for Blog on the website which will be also shared through this channel. The metrics achieved between M1 and M11 are:

- Visitors: 250.

- Page views: 408.
- Impressions: 2,724.
- Engagement Rate: 4%.
- Followers: 69.

On the other hand, TeraFlow has a YouTube channel (https://www.youtube.com/channel/UCz86mcBvscgA4tS_voXokyQ) where various audio-visual materials are uploaded whenever a recording of an event or a video is produced to showcase different aspects of TeraFlow and its progress. Until M11, eight videos have been uploaded with a total of views of over 190. All the videos available on the YouTube channel, are also uploaded on the project website and have been highly promoted among social media channels.

2.1.2 Communication Material

Between M1 and M11, TeraFlow produced different types of communication material which have been used at events for increasing visibility of the project and position the visual identity of the project.

D6.1 and D6.2 show all the material created:

- PPT Template.
- Project Overview PPT.
- Poster Template.
- Virtual backgrounds.
- Newsletter Template.
- Social Media banners.
- TeraFlow Poster.
- TeraFlow Newsletter #1.

More communication material will be produced throughout the life of the project to support raising awareness about TeraFlow and to provide useful content to external audiences in an attractive graphical way. Even though, at the development of D6.1, we foresaw the preparation of a flyer and a promotional video about the project's ambition, concept, and expected results, it was decided to focus this production and development effort to communicate one of the most important Milestones of the project: the 1st release of the TeraFlow OS.

2.1.3 Journal Publications and Conference Scientific Papers

Generating impact and disseminating the project's findings and results among research and academic communities has been mainly done through the development of papers and their presentation at important conferences and publication in journals. All papers are uploaded to the project website and ZENODO Community whenever the PDF becomes available at the respective conferences' proceedings or publication of the journal. Moreover, this content is promoted through social media and included in the project's newsletter.

From the total of 20 publications, 18 publications were done at conferences with OFC 2021, EuCNC 2021, ECOC, and PSC2021 being some of the most important. Moreover, the type of publications varied from research paper to demo paper, workshop, and in some cases, invited paper. Regarding Journals, 2 publications were published at IEEE Networks and MDPI Photonics. Table 2 presents the 20 scientific papers that have been submitted and published between M1 and M11.

Table 2 Scientific papers

Type	Title	Authors	Title of the Journal/Proc./Book	Link
Conference	End-to-End Network Slice Stitching using Blockchain-based Peer-to-Peer Network Slice Managers and Transport SDN Controllers	Pol Alemany, Ricard Vilalta, Raul Muñoz, Ramon Casellas and Ricardo Martínez	OFC 2021 - The Optical Networking and Communication Conference & Exhibition	https://ieeexplore.ieee.org/document/9489482
Conference	First Scalable Machine Learning Based Architecture for Cloud-native Transport SDN Controller	Carlos Manso, Noboru Yoshikane, Ricard Vilalta, Raul Muñoz, Ramon Casellas, Ricardo Martínez, Cen Wang, Filippos Balasis, Takehiro Tsuritani, Itsuro Morita	OFC 2021 - The Optical Networking and Communication Conference & Exhibition	https://ieeexplore.ieee.org/abstract/document/9489435
Conference	Multi-layer Transport Network Slicing with Hard and Soft Isolation	A. Alcalá, S. Barguil, V. López, L.M. Contreras, C. Manso, P. Alemany, R. Casellas, R. Martínez, D. González-Pérez, X. Liu, J.M. Pulido, J.P. Fernández-Palacios, R. Muñz3, R. Vilalta	OFC 2021 - The Optical Networking and Communication Conference & Exhibition	https://zenodo.org/record/4756977#.YaUCd9DMJnK
Conference	TeraFlow: Secured Autonomic Traffic Management for a Tera of SDN Flows	Vilalta, Ricard; Muñoz, Raül; Casellas, Ramon; Martínez, Ricardo; López, Víctor; González de Dios, Óscar; Pastor, Antonio; Katsikas, Georgios P.; Klaedtke, Felix; Monti, Paolo; Mozo, Alberto; Zinner, Thomas; Øverby, Harald; González-Díaz, Sergio; Lønsethagen, Hakon; Pulido, José-Miguel; King, Daniel	European Conference on Networks and Communications & 6G Summit (EuCNC/6G Summit)	https://zenodo.org/record/5089970#.YaUCwtDMJnJ
Conference	Autonomous Security Management in Optical Networks	Carlos Natalino, Andrea Di Giglio, Marcho Schiano, Marija Furdek	OFC 2021 - The Optical Networking and Communication Conference & Exhibition	https://ieeexplore.ieee.org/document/9489575

Conference	Blockchain-Based Connectivity Provisioning in Multiple Transport SDN Domains	Pol Alemany, Ricard Vilalta, Raul Muñoz, Ramon Casellas, Ricardo Martínez	ONDM 2021 25th International Conference on Optical Network Design and Modelling	https://ieeexplore.ieee.org/document/9492411
Conference	Demo paper: Operationalizing partially disaggregated optical networks: An open standards-driven multi-vendor demonstration	E. Le Rouzic, A Lindgren, S. Melin, D. Provencher, R. Subramanian, R. Joyce, F. Moore, D. Reeves A. Rambaldi, P. Kaczmarek, K. Weeks, S. Neidlinger, G. Agrawal, S. Krishnamoha, B. Raszczyk, T. Uhlar, R. Casellas, O. Gonzalez de Dios, V. Lopez	OFC 2021 - The Optical Networking and Communication Conference & Exhibition	https://ieeexplore.ieee.org/document/9489763
Conference	Demo paper: Scalable for Cloud-native Transport SDN Controller Using GNPy and Machine Learning techniques for QoT estimation	Carlos Manso, Ricard Vilalta, Raul Muñoz, Ramon Casellas, Ricardo Martínez	OFC 2021 - The Optical Networking and Communication Conference & Exhibition	https://ieeexplore.ieee.org/document/9489436
Journal	Field trial of programmable L3 VPN service deployment using SDN-Based Multi-domain Service Provisioning over IP/Optical network	Samier Barguil, Victor Lopez, Cristyan Manta-Caro, Arturo Mayoral Lopez De Lerma, Oscar Gonzalez De Dios, Edward Echeverry, Juan Pedro Fernandez-Palacios, Janne Karvonen, Jutta Kemppainen, Natalia Maya, and Ricard Vilalta	IEEE networks	https://ieeexplore.ieee.org/document/9508928
Conference	Special Session: Autonomous Network Management towards 6G. Cloud-Native SDN Network Management for Beyond 5G Networks with TeraFlow	Ricard Vilalta, Raul Munoz, Ramon Casellas, Ricardo Martínez, Juan-Pedro Fernandez-Palacios, Georgios P. Katsikas, Thomas Zinner, Harald Øverby , Sergio Gonzalez-Diaz, Hakon Lønsethagenk , Jose-Miguel Pulido, Daniel King, Nicola Carapellese	European Conference on Networks and Communications & 6G Summit (EuCNC/6G Summit)	https://zenodo.org/record/5089908#.YaXXQtDMJnJ

Conference	Workshop: From 5G to 6G Automated and Intelligent SecuriTy: FAST. Cloud-Scale SDN Network Security in TeraFlow	Alberto Mozo, Antonio Pastor, Carlos Natalino, Marija Furdek, Rahul Bobba, Raul Muñoz, Ramon Casellas, Ricardo Martinez, Juan Pedro Fernández-Palacios, Ricard Vilalta, Stanislav Vakaruk	European Conference on Networks and Communications & 6G Summit (EuCNC/6G Summit)	https://zenodo.org/record/5089918#.YaXXtdDMJnJ
Conference	Optical Network Telemetry with Streaming Mechanisms using Transport API and Kafka	R. Vilalta, R. Casellas, R. Martínez, R. Munoz, A. Gonzalez-Muñiz, J.P. Fernandez-Palacios	2021 European Conference on Optical Communication (ECOC)	https://ieeexplore.ieee.org/document/9606002
Conference	Scalable Physical Layer Security Components for Microservice-Based Optical SDN Controllers	Carlos Natalino, Carlos Manso, Ricard Vilalta, Paolo Monti, Raul Muñoz, Marija Furd	2021 European Conference on Optical Communication (ECOC)	https://zenodo.org/record/5500101#.YaXYfdDMJnK
Conference	First Demonstration of Dynamic Deployment of SDN-enabled WDM Virtual Network Topologies (VNTs) over SDM networks	C. Manso, R. Muñoz, F. Balasis, R. Casellas, R. Vilalta, R. Martínez, C. Wang, N. Yoshikane, T. Tsuritani, I. Morita	2021 European Conference on Optical Communication (ECOC)	https://ieeexplore.ieee.org/document/9606167
Journal	Packet Optical Transport Network Slicing with Hard and Soft Isolation	S. Barguil, V. López, L.M. Contreras, O. González de Dios, A. Alcalá, C. Manso, P. Alemany, R. Casellas, R. Martínez, D. González-Pérez, X. Liu, J.M. Pulido, J.P. Fernández-Palacios, R. Muñoz, R. Vilalta	MDPI Photonics	https://www.mdpi.com/2076-3417/11/13/6219/pdf
Conference	Using 5G QoS Mechanisms to Achieve QoE-Aware Resource Allocation	Marcin Bosk, Marija Gajic, Susanna Schwarzmann, Stanislav Lange, Riccardo Trivisonno, Clarissa Marquezan, Thomas Zinner	2021 17th International Conference on Network and Service Management (CNSM)	https://dl.ifip.org/db/conf/cnsm/cnsm2021/1570733570.pdf
Conference	Demo paper: Scalable and Resilient Network Traffic Engineering Using Erlang-based Path Computation Element	Sebastien Merle, Juan Pedro Fernández-Palacios, Oscar González de Dios, Lluís Gifre, Ricard Vilalta, Peer Stritzinger	VII IEEE Conference on Network Function Virtualization and Software Defined Networks (IEEE NFV-SDN 2021)	https://demossdn2021.github.io/#demonstrations (Not

				published yet)
Conference	Invited paper: Role of monitoring and analytics in next generation optical networks	Ll. Gifre, F. Boitier	2021 European Conference on Optical Communication (ECOC)	https://ieeexplore.ieee.org/document/9605997
Conference	HTBQueue: A Hierarchical Token Bucket Implementation for the OMNeT++/INET Framework	Marcin Bosk, Marija Gajic, Susanna Schwarzmann, Stanislav Lange and Thomas Zinner	8th OMNeT++ Community Summit, Virtual Summit	https://summit.omnetpp.org/2021/assets/pdf/OMNeT_2021_paper_8.pdf
Conference	SDN Control Architectures for WDM over SDM (WDMoSDM) Networks	R. Muñoz, N. Yoshikane, C. Manso, R. Casellas, R. Vilalta, R. Martínez, F. Balasis, C. Wang, T. Tsuritani, and I. Morita	Photonics in Switching and Computing 2021	https://zenodo.org/record/5520861#.YaXcndDMJnJ

The consortium continues developing papers to share the work done within the project and demonstrate its progress and results at important venues targeting key stakeholders. Some of the conferences where TeraFlow aims to present papers and workshops in Y2 are: EUCNC, OFC2022, ONDM, and ECOC2022.

Until now, we can highlight the submission and acceptance of four papers to OFC2022, including a demo paper: "Demonstration of Zero-touch Device and L3-VPN Service Management using the TeraFlow Cloud-Native SDN Controller" which will demonstrate zero-touch device bootstrapping, monitoring, and L3VPN service management using our novel OS SDN controller prototype.

2.1.4 Other Content

The development of content targeting beyond scientific and academic communities is essential to raise awareness about the project and connect with industrial stakeholders that could act as end-users of the TeraFlow results. Some non-technical content was produced to communicate the achievement of Milestones and results to a wider audience. These include press releases and news entries at the project or partners' websites.

The first press release (https://www.teraflow-h2020.eu/news/1st-official-press-release) was published on the project website and promoted through a dedicated social media campaign also using external accounts from partners and related initiatives to maximise the impact and reach. Moreover, the publication of information related to TeraFlow on external sites (media, partners website, event websites, etc) is an important part of the link-building strategy which contributes to enhancing the organic positioning of the website. Between M1 and M11, thirty-seven publications were done on different external websites reaching an estimated audience of more than 1 million people. All these publications are presented in the Content Strategy section of D6.2.

On the other hand, TeraFlow has a bi-annual newsletter to communicate the progress to subscribers of the list and other audiences following the project. Until the date of development of this deliverable, only issue #1 had been produced, with the second issue programmed for mid/end-January 2022 to leverage the launch of TeraFlow OS and promote this important Milestone in all the channels we have at our disposal.

2.1.5 Events, Workshops, and Demos

Participation in external events and the organisation of TeraFlow's own events/workshops in collaboration with other initiatives and projects or co-located within bigger and renowned venues, has contributed to raising awareness of the project, increasing visibility of the work that is being done, and potentially engage with key stakeholders.

Between M1 and M11, TeraFlow has participated and/or organised 21 events reaching over 3000 stakeholders with different roles and from different backgrounds such as researchers, academics, industry, standardisation. The type of participation and format has varied across presentations, invited talks, booth, demo sessions, workshops, webinars, etc. All events have been uploaded to the website and highly promoted on social media channels. Whenever it has been possible, also recordings of virtual presentations and the slides have been uploaded to each event entry on the website to provide added content to visitors. Table 3 lists the 21 events where TeraFlow has participated. For more information, see the table with more information in D6.2.

Table 3 Events

Event Name	Description	Estimated # of persons reached	Link
3rd ONFIRE Symposium	Victor Lopez from Telefónica gave the presentation “Optical white boxes design and programmability using GNPy”.	30	https://www.teraflow-h2020.eu/events/3rd-onfire-symposium
TIP OOPT MUST: Operators Driving SDN for Transport Adoption and Acceleration	Presentation of work related to TeraFlow by Victor Lopez. This event formally introduced the TIP OOPT MUST subgroup, providing a view to the optical industry what this subgroup will achieve.	50	https://www.teraflow-h2020.eu/events/tip-oopt-must-operators-driving-sdn-transport-adoption-and-acceleration
OSM Ecosystem Day	TeraFlow in the OSM ecosystem by Dr. Ricardo Martínez, Senior Researcher, CTTC This presentation tackles the adoption and integration of the OSM within the Teraflow project solution.	50	https://www.teraflow-h2020.eu/events/osm-ecosystem-day
5G-PPP Webinar: Europe accelerates towards 6G	The webinar was held in two parts, where all projects presented their vision of 6G in the first part as the motivation for their projects and the technical challenges they are	400	https://www.teraflow-h2020.eu/events/5g-ppp-webinar-

	addressing to move towards 6G in the second part. TeraFlow was one of the participating projects, represented by Ricard Vilalta, Project Coordinator and Senior Researcher at CTTC. Recordings of the webinar are available at TeraFlow's YouTube channel and website: - https://youtu.be/YjASBzEcKCg - https://youtu.be/xg9HQNczjhc		europe-accelerates-towards-6g
MASTEAM Seminar: Software define control of optical networks	Ricard Vilalta presented TeraFlow at a talk to the masters students in Applied Telecommunications and Engineering Management from Universidad Politecnica de Catalunya - Castelldefels School of Telecommunications and Aerospace Engineering (EETAC).	50	https://www.teraflow-h2020.eu/events/presentation-software-define-control-optical-networks-upc-eetac
CodeBeam STO 2021	After an overview of what is Software Defined Networking, Traffic Engineering, and the protocols involved, Sebastian Merle from Peer Stritzinger introduced the project's architecture, concerns, constraints, and challenges. Then a live demo showed the progress so far. Finally, he presented the open-source projects created or improved as part of the development.	350	https://www.teraflow-h2020.eu/events/codebeam-sto-2021
The Optical Networking and Communication Conference & Exhibition (OFC 2021)	TeraFlow was featured through the presentation of 4 papers and 2 demo papers: 1. End-to-End Network Slice Stitching using Blockchain-based Peer-to-Peer Network Slice Managers and Transport SDN Controllers 2. First Scalable Machine Learning Based Architecture for Cloud-native Transport SDN Controller 3. Multi-layer Transport Network Slicing with Hard and Soft Isolation 4. Autonomous Security Management in Optical Networks 5. Operationalising partially disaggregated optical networks: An open standards-	200	https://www.teraflow-h2020.eu/events/optical-networking-and-communication-conference-exhibition-ofc-2021

	driven multi-vendor demonstration 6. Scalable for Cloud-native Transport SDN Controller Using GNPy and Machine Learning techniques for QoT estimation		
EuCNC | 6G Summit	TeraFlow was featured through the following: - Paper presentation “TeraFlow: Secured Autonomic Traffic Management for a Tera of SDN Flows” – Recording available at YouTube Channel and website: https://youtu.be/ZuSIW0aVMmY - Special session: “Autonomous Network Management towards 6G. Cloud-native SDN Network Management for Beyond 5G Networks with TeraFlow” – Recording available at YouTube Channel and website: https://www.youtube.com/watch?v=I9paWb_nhXI&t=91s Workshop: “From 5G to 6G Automated and Intelligent SecuriTy: FAST. Cloud-Scale SDN Network Security in TeraFlow”	500	https://www.teraflow-h2020.eu/events/teraflow-participating-eucnc
25th International Conference on Optical Network Design and Modelling (ONDM 2021)	TeraFlow organised a 2-hour workshop titled: “Micro-service based autonomic traffic control in 5G and beyond”. The recording is available at the project’s YouTube Channel and website: https://youtu.be/3XFojZUepsQ	100	https://www.teraflow-h2020.eu/events/ondm-2021
MWC21	TeraFlow was featured at the CTTC booth, represented by our Project coordinator Ricard Vilalta, who demonstrated the main concepts of the TeraFlow SDN controller to the interested audience through the demo TeraFlow: A scalable Cloud-Native SDN Controller for Transport Networks.	300	https://www.teraflow-h2020.eu/events/mobile-world-congress
IETF-111 side meeting	TeraFlow participated at the "Evolving and Revitalizing the Internet" side-meeting co-located within IETF-111. IETF participants occasionally organise side meetings to discuss topics of interest to some portion of the IETF community. In this case, Adrian Farrel	30	https://www.teraflow-h2020.eu/events/public-side-meetings-ietf-111

	from Old Dog Consulting and a member of the TeraFlow Consortium hosted and moderated the 90-minute meeting.		
OMNET++ Community Summit	The paper "HTBQueue: A Hierarchical Token Bucket Implementation for the OMNeT++/INET Framework" written by Marcin Bosk, Marija Gajic, Susanna Schwarzmann, Stanislav Lange and Thomas Zinner, was presented on September 8th. The recording of the presentation is available at the project website.	100	https://www.teraflow-h2020.eu/events/omnet-community-summit-2021
Photonics in Switching and Computing 2021 (PSC 2021)	Raul Muñoz from CTTC presented the paper "SDN Control Architectures for WDM over SDM (WDMoSDM) Networks" within the Session Network Control and Management II that took place on September 29 from 11:30 to 13:30 EDT.	80	https://www.teraflow-h2020.eu/events/photonics-switching-and-computing-2021
Nit Europea de la Recerca	TeraFlow was showcased through a poster at the European Corner.	100	https://www.teraflow-h2020.eu/events/nit-europea-de-la-recerca
ECOC 2021	TeraFlow participated with various activities during the event: - Workshop: "Applications for IMDD and Coherent in Short Reach Systems" - Paper presentations: "First demonstration of dynamic deployment of SDN-enabled WDM Virtual Network Topologies (VNTs) over SDM networks" – "Scalable physical layer security components for Microservice-based Optical SDN controllers" – "Role of monitoring and analytics in next-generation optical networks"	400	https://www.teraflow-h2020.eu/events/ecoc21
17th International Conference on Network and Service Management (CNSM 2021)	TeraFlow was featured at the presentation of the paper "Using 5G QoS Mechanisms to Achieve QoE-Aware Resource Allocation", where our partners from NTNU participated in the development. The complete list of authors include: Marcin Bosk, Marija Gajic, Susanna Schwarzmann, Stanislav Lange, Riccardo Trivisonno,	150	https://www.teraflow-h2020.eu/events/17th-international-conference-network-and-service-management

	Clarissa Marquezan, and Thomas Zinner. The presentation was held on October 26th at 14:45. Recording is available at the project website.		
NetCentric 2021	Adrian Farrel held a presentation on "IETF Network Slicing" mentioning TeraFlow within the discussion of solution architectures	50	https://www.teraflow-h2020.eu/events/net-centric-2021-conference
12th International Conference on Network of the Future (NoF2021)	Paolo Monti and Carlos Natalino from Chalmers held the Tutorial Session: Network automation - challenges, enablers and benefits, where TeraFlow was mentioned	80	https://www.teraflow-h2020.eu/events/12th-international-conference-network-future-nof-2021
TIP OOPT MUST H2 Public Webinar	A panel of expert speakers, including our partner Oscar Gonzalez de Dios from Telefonica as leading operators, presented updates in Q1-Q3 as well as the main project metrics to date, including the green-lighting of the TIP Test & Validation framework around defined use cases implementations, a key step in awarding the TIP Ribbons and Badges that will play a critical role in accelerating the pace of commercial deployments. The recording of the session is available at the project's website.	50	https://www.teraflow-h2020.eu/events/tip-oopt-must-h2-2021-public-webinar
IEEE Conference on Network Function Virtualization and Software Defined Networks 2021	Within this conference, the paper "Scalable and Resilient Network Traffic Engineering Using Erlang-based Path Computation Element" was presented by Sebastien Merle from Peer Stritzinger at the Demo Track on November 11th between 12:00 and 14:00CET.	50	https://www.teraflow-h2020.eu/events/ieee-conference-network-function-virtualization-and-software-defined-networks
NGON DCI 2021	TeraFlow organised the workshop "TeraFlow: Utilizing Optical Network Slicing to Connect Clouds for Autonomic 5G and Beyond Services". The session took place on November 19th between 13:15 and 14:00 and consisted of three presentations and a panel session with our partners from Old Dog Consulting, Telefónica, Telenor and CTTC	150	https://www.teraflow-h2020.eu/events/ngon-dci-world-2021

2.1.6 Key Performance Indicators (KPIs)

Dissemination and communication activities performed by TeraFlow and its consortium partners have been successful between M1 and M11 of the project. The different set of activities established, the participation in events, the submission of papers, and the increasing digital visibility that the project has got are perfect indicators that we are reaching the objectives set and we are successfully raising awareness of the project.

Table 4 presents the communication and dissemination KPIs established to measure the success and effectiveness of the strategy presented on D6.1 which have been closely monitored to timely identify any deviations or determine if any other actions should be executed to guarantee the effective accomplishment of these.

Table 4 Communication and dissemination KPIs

Type	KPI	Total Target by M30	Achieved by M11
Website	Unique Visitors	5.000	2.834
	Average Time	2:00	0:54
	Page Views	10.000	5.019
	Blog and News entries	20	4
Twitter	Tweets	360	93
	Retweets	800	199
	Likes	1.500	451
	Followers	250	144
	Engagement Rate	≥ 1.2%	1.7%
	Impressions	100.000	54.200
LinkedIn	Page Views	2.000	408
	Visitors	400	250
	Reactions	≥ 1.2%	4%
	Followers	100	69
Marketing Material	PPT – Scientific/Technical Dissemination Material	3	2
	Brochure	3	0
	Videos	2	0
	Press Releases	3	1
	Newsletters	5	1
Scientific Dissemination	Scientific Publications	25	20
	Articles in specialised magazines/journals	10	4
	Posters	5	1
Events	Workshops organised	2	3
	Attendees to the project workshops	25	+50
	Demo events	10	5
	Events and presentations where the project will be presented	20	21
Others	Liaisons and joint activities with other projects, communities, initiatives, etc (e.g., website links, workshops, newsletters, social media, etc.)	20	15

All of the KPIs achieved during the first eleven months of the project are a perfect indicator that the consortium and the T6.1 will not have any deviations and the strategy will be followed as it has been defined on D6.1 and the activities for Y2 will be developed according to D6.2. The following summary, also presented on D6.2, describe some of the main actions to be executed in 2022:

- Revamp of the website with new content and structure giving maximum visibility to the TeraFlow OS release.
- Launch of the Blog with relevant content covering the different topics addressed by the project to strengthen our digital positioning.
- Increase the frequency of publication to at least 2 tweets per week and 3 LinkedIn posts per month.
- Continue identifying relevant accounts to interact and enhance collaboration for cross-project promotion in these channels.
- Support the launch of the TeraFlow OS with the development of a multiple communication materials and contents to be uploaded to the website and promoted via social media accounts from the project, partners' and 3rd parties such as 5G PPP.
- Continue delivering updates on the progress of the project via the newsletter.
- Continue developing and submitting scientific publications to relevant conferences and specialised journals.
- Leverage collaboration opportunities with other H2020 projects for the organisation of workshops and events.
- Continue participating in various events to raise awareness about the project.

2.2 Task 6.2: Standardisation and Open-source Software Activities

2.2.1 Standardisation

ETSI ISG PDL

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

The TeraFlow project is already part of the PDL work items **MI/PDL007 Research Landscape** and **GR/PDL-008 Research and Innovation Landscape** where NEC is rapporteur. TID chairs the group and is planning to contribute on smart contract applicability to network management and auditability, and to the issues related to multi-ledger interactions. ODC is supporting the activities of NEC and TID with reviews and discussions of the work.

ETSI ISG ZSM

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

TeraFlow plans to bring results in transport network automation (**GS ZSM 003, GS ZSM 008**) based on the work in scenario 1 Beyond 5G networks. We are studying the feasibility to run a Proof-of-Concept based on ZSM006-PoC Framework. A contribution from TNOR based on the Automotive scenario and inter-domain module has been approved and included in **ETSI ZSM-011** draft (Section 4.3.1. Automotive use case).

ETSI ISG mWT

Participants: SIAE

SIAE collaborates in the activities of Work Items WI#24 and WI#25, and will actively promote relevant outcomes from TeraFlow for a possible standardisation roadmap. In the timeframe of the project, SIAE has participated in the following ETSI Plugtests™ activities:

- 2nd mWT Plugtests™ (March 2020 - Sophia Antipolis, France).
- 3rd mWT Plugtests™ (November 2020 - Remote activities due to COVID-19).

ETSI ISG SAI

Participants: TID and UPM

TID and UPM are monitoring this group and plan to contribute in some work items and potential PoC from the cybersecurity scenario. Some possible topics include: Securing AI problem statement (ETSI GR SAI 004), AI threat ontology, Data supply chain report, Mitigation strategy report, and Security testing of AI. In particular, TID and UPM plan to align the research activities on the development of resilient ML components to adversarial attacks, that were planned in T4.1 for the second year, with their potential contributions to SAI.

Telecom Infra Project

Participants: Telefónica (Oscar González-de-Dios, Victor López, Juan-Pedro Fernández-Palacios), SIAE

The MUST (Mandatory Use Case Requirements for SDN for Transport), co-chaired by Telefonica, has the main goal of driving the adoption of SDN standards for IP/MPLS, Optical and Microwave technologies. MUST has defined an open SDN architecture, which is followed by Teraflow. Each MUST track defines the requirements that the devices have to support.

Telecom Infra Project: TIP OOPT MUST subgroup – IP track

Telefonica is leading the activities of the IP track of the MUST subgroup. The subgroup is delivering the specification of the OpenConfig and IETF YANG-based data modes that need to be used in controllers and devices. In that regard, Teraflow is directly contributing to complete the gaps of the YANG models that are used in the specification. In that regard, the contribution of Teraflow is key to have the required functionalities in the standards. Note that TIP MUST does not produce new standards, but points to the relevant IETF/OpenConfig models.

Telecom Infra Project: TIP OOPT MUST subgroup – Wireless Backhaul

SIAE is following the activities of this working group and is participating in meetings to ensure the compatibility of its products with the requirements and providing feedbacks to the operators, based on many years of experience in the field of wireless backhaul.

ONF

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

With a key objective of developing a cloud native and scalable SDN controller, standardisation efforts related to the development of data models and interfaces enabling a hierarchy of controllers are clearly in scope of TeraFlow research and standardisation work. In this sense, the Optical Networking Foundation (ONF) Open Transport Configuration & Control (OTCC) project aims to promote common configuration and control interfaces for transport networks in SDN. One 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).

The contributions from TeraFlow members CTTC and Telefonica are related to the refinement of data models enabling “clients” (such as parent controllers, orchestrators, operators’ OSS/BSS) to request connectivity services with focus on the optical transport networks (OTN) and the so called “photonic media layer”. In particular, the contributions are related to: i) the specification of use cases covering fundamental operations such as (constrained) provisioning of Digital Signal Rate (DSR), or OTN services – both for the digital (ODU/OTU) as well as the optical (OTSi / Media channel) layers, path computation, OAM or fault management; ii) the definition of workflows and model usages to subsequently solve such use cases; iii) the refinement of data models to take into account additional requirements or gaps identified by the aforementioned use cases, resulting in a continuous evolution towards future TAPI releases; and iv) the editing and publication of the TAPI Reference Implementation Agreement (RIA) v1.1 [25] (both for the RESTCONF based NBI as well as for Streaming), which constitutes a self-contained document providing guidelines, model usage examples, and practical considerations.

Considering the “network layering” that TeraFlow envisions, such a 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 SBI to consume the services provided by dedicated per-domain optical controllers).

It is worth noting that more specific technical contributions related to the technology-specific aspects (such as physical impairments, optical performance monitoring, or extensions to support multi-band networking) will be addressed by the companion project H2020 B5G-OPEN, while TeraFlow will address additional work items from a client perspective. It is expected that both projects will continue with a fruitful collaboration in this regard.

SIAE is member of the ONF and participates in the standardisation in the Open Transport Configuration & Control (OTCC) activities carried on by the “5G xHaul” working group, which mainly involves the definition and upgrade of interfaces/models for microwave transport. In this context, SIAE participated in several Proof of Concepts (PoCs), focused on demonstrating the capabilities and benefits of utilising a common Information Model for multi-vendor control of wireless network elements through open management interfaces, as documented in the technical report TR-532.

As a result of the TeraFlow efforts, some of the existing interfaces/models may be improved or new ones might be created. In case such outcomes get considered by the Consortium for a possible standardisation, SIAE will actively promote them to the ONF standardisation roadmap.

IETF

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

Teraflow partners (Telefonica and ODC) are actively contributing to the network operation in OPSA (Operations and Management Area) Working Group. The participation has led to contributions of YANG models for the management and control of several types of VPNs, including L3VPNs, Virtual Private Wires (VPWs), and Ethernet-VPNs (EVPNs), considering aspects of topology, management of client routes, and security parameters.

Key technology areas of TeraFlow include Network Slicing (NS) and Traffic Engineering (TE). Within the IETF, the TEAS (Traffic Engineering and Signaling) Working Group is responsible for defining the TE architecture and the associated protocols and data models. In addition, Teraflow partners (Telefonica and ODC) are contributing in multiple drafts that acknowledge the project.

The IETF Internet-Drafts (working documents) that have direct contributions from TeraFlow partners, and most of which acknowledge the project, are listed below:

- "**Challenges for the Internet Routing Infrastructure Introduced by Changes in Address Semantics**" URL: https://datatracker.ietf.org/doc/draft-king-irtf-challenges-in-routing/
- **"A Survey of Semantic Internet Routing Techniques",** URL: https://datatracker.ietf.org/doc/draft-king-irtf-semantic-routing-survey/
- "**Framework for Use of ECA (Event Condition Action) in Network Self-Management",** URL: https://datatracker.ietf.org/doc/draft-bwd-netmod-eca-framework/
- "**A YANG Data model for ECA Policy Management",** URL: https://datatracker.ietf.org/doc/draft-ietf-netmod-eca-policy/
- "**Instantiation of IETF Network Slices in Service Providers Networks**" URL: https://datatracker.ietf.org/doc/draft-barguil-teas-network-slices-instantation/
- **"A Layer 2 VPN Network YANG Model",** URL: https://datatracker.ietf.org/doc/draft-ietf-opsawg-l2nm/
- **"A Layer 3 VPN Network YANG Model",** URL: https://datatracker.ietf.org/doc/draft-ietf-opsawg-l3sm-l3nm/
- **A YANG Model for Network and VPN Service Performance Monitoring,** URL: https://datatracker.ietf.org/doc/draft-ietf-opsawg-yang-vpn-service-pm
- "**A Layer 2/3 VPN Common YANG Model",** URL: https://datatracker.ietf.org/doc/draft-ietf-opsawg-vpn-common
- **"IETF Network Slices",** URL: https://datatracker.ietf.org/doc/draft-ietf-teas-ietf-network-slices/
- **"Applicability of Abstraction and Control of Traffic Engineered Networks (ACTN) to Network Slicing",** URL: https://datatracker.ietf.org/doc/draft-ietf-teas-applicability-actn-slicing/
- **“Extensions to the Access Control Lists (ACLs) YANG Model”,** URL: https://datatracker.ietf.org/doc/html/draft-dbb-netmod-acl-00

Partners have also identified several Internet-Drafts which are of interest to TeraFlow, but are not directly worked on currently by project principles; however, this may change over time as the work becomes more relevant for TeraFlow. The IETF “drafts-of-interest” include:

- "**YANG Data Model for Slice Policy**", URL: https://datatracker.ietf.org/doc/draft-bestbar-teas-yang-slice-policy/
- **IETF Network Slice Controller and its associated data models**" URL: https://datatracker.ietf.org/doc/draft-contreras-teas-slice-controller-models/
- "**IETF Network Slice Use Cases and Attributes for Northbound Interface of IETF Network Slice Controllers**" URL: https://datatracker.ietf.org/doc/draft-contreras-teas-slice-nbi/
- "**IETF Network Slice YANG Data Model**" URL: https://datatracker.ietf.org/doc/draft-liu-teas-transport-network-slice-yang/
- **"Framework for Use of ECA (Event Condition Action) in Network Self Management" URL:** https://datatracker.ietf.org/doc/draft-bwd-netmod-eca-framework/

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

We expect several of these documents to progress throughout the project. In addition, individual documents and working group documents will be published as IETF standards documents (RFC status), highlighting the project's leading technology and industry impact.

ITU-T FG-AN

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

The TeraFlow project is designing and building several components that will be relevant to FG-AN use cases in the future. The TeraFlow partner ODC is following the output from the FG-AN effort and will highlight potential FG-AN use cases to the TeraFlow partners that might be solved using the TeraFlow platform.

OpenConfig

Participants: TID (Oscar González-de-Dios)

Teraflow IP/MPLS based use cases use OpenConfig YANG data models at the SBI of the Teraflow SDN controller (via the device driver). Telefonica is an active member of OpenConfig and has provided the following contributions with YANG code that fills the gaps found by Teraflow while working to support the use cases:

- OpenConfig EVPN YANG model to provide Layer 2 connectivity, including the modelling of Ethernet segments. The contribution is documented in https://github.com/openconfig/public/blob/master/doc/evpn_use_cases.md, and covers the following technologies:
    - 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 IRB.
- Ethernet counters. These are Ethernet-related information that are read from the Teraflow SDN controller.

Also, there are a set of contributions in progress:

1. Keychains and authentication of routing protocols. This is necessary for the Teraflow network creation use cases.
2. Extensions of the ACL YANG model. Can be used for the Attack Mitigator Component.

2.2.2 Open-Source

TeraFlow SDN Controller

Participants: All

One of the key objectives of the TeraFlow SDN Controller is to design and develop a new generation of SDN Controller and contribute it to the open-source Community. The partners are working to have a release of a basic version of a fully functional SDN controller using an Apache 2 License in January 2022. This release will have support for transport connectivity services, topology, and inventory.

To have a successful release, we have prepared a set of guidelines showing how to configure a computer or use a VM to run the TeraFlow OS.

The guidelines are available here: https://gitlab.com/teraflow-h2020/controller/-/wikis/home

ETSI OpenSource MANO

Participants: TID (Diego Lopez), ATOS, NTNU (Katina Kravleska), CTTC (Ricard Vilalta), TNOR (Pål Grønsund)

The TeraFlow OS leverages the current OSM solution with the aim of attaining tight integration with OSM acting as a WAN Infrastructure Manager (WIM) (i.e., SDN controller). This enables the OSM to request the TeraFlow OS to deploy connectivity services between Virtual Network Functions (VNFs) hosted at remoted cloud facilities (NFVI-Pops).

In this regard, in the organised session OSM-MR#10 Ecosystem Day (March 10th, 2021), the TeraFlow project uses cases and objectives were presented to the OSM community to outline the interest of the project in using such a MANO solution as an external entity with which to interact. Indeed, currently TeraFlow partners are holding discussions with OSM developers to accomplish a functional integration between the latest OSM release and a component of the TeraFlow OS architecture referred to as the Compute Component. By doing so, the Compute Component will be the front-end of the whole TeraFlow OS enabling the incoming connectivity service operations (e.g., creation, deletion, and updating) to be triggered by the OSM. To this end, an API between the OSM and the Compute Component is targeting the lifecycle management of the connectivity services fulfilling the requirements (e.g., bandwidth, latency, etc.) needed to roll out the network services orchestrated by the OSM.

ONF ONOS and Stratum

Participants: UBI (Georgios P. Katsikas)

UBITECH is leading the P4 activities within TeraFlow. P4 support in the TeraFlow SDN controller is done through a device driver plugin (i.e., as an individual part of the Device Component) which will bridge the TeraFlow controller within ONF's Stratum OS.

Through the P4 device driver plugin, P4 switches will be able to register to the TeraFlow SDN controller, thus allow the SDN controller to program the switches' parsers and in turn to manage their match-action tables. For the needs of TeraFlow, UBI plans to first test the P4 device driver plugin with existing P4 software switches, such as the bmv2 switch provided by ONF as a mininet extension. When the device driver plugin becomes functional, UBI will perform a similar testing procedure on a state-of-the-art hardware P4 device, namely the upcoming Tofino-2 switch by Intel (former Barefoot networks). As this switch is currently in pre-production stage, there is no validated testing procedure so far. UBI aims to use the TeraFlow P4 device driver to test this switch and share experiences with the P4 community (i.e., ONF Stratum and ONOS) in the form of testing reports, potential issues raised on Stratum's github pages, and/or bug fixes in Stratum/ONOS network operating systems. Our goal is to exploit the active ONF P4 channels to advertise TeraFlow's P4 activities and thus attract P4 users that could leverage TeraFlow for research and innovation activities, while keeping backward compatibility with ONF Stratum and the ONF developments in general.

HyperLedger

Participants: NEC (Ghassan Karame)

The blockchain technology developed for the DLT Component of the TeraFlow OS (like improved consensus algorithms) is of interest for Hyperledger Lab. Specifically the MinBFT project, which allows achieving Byzantine fault-tolerant consensus with fewer consenting nodes and less communication rounds compared to the conventional BFT protocols.

2.3 Task 6.3: Exploitation and Sustainability of Results

During the first year of the project, T6.3, in coordination with WP2 activities on stakeholders and ecosystems, has analysed the main TeraFlow target, the network operator, as well as other actors needed for the TeraFlow ecosystem to flourish, their motivations, and the interactions between them.

Partners have used the Value Proposition Canvas tool in an internal workshop conducted in April 2021 to analyse the network operator “jobs”, deep-dive into the main “pain” points, and understand the “gains” they want to achieve or the concrete benefits they are seeking. After that, partners have reflected on how the project’s main result (the TeraFlow OS SDN controller) can alleviate, or even eliminate, network operator pains and maximise outcomes and benefits.

To better understand the TeraFlow OS ecosystem, a document template was used to collect the partners' motivation for participating in the project. Later, all the partners were interviewed with regards to this ecosystem, the role that they take, possible business models, and barriers/drivers for adoption.

Also in the scope of the exploitation activities in WP6, an environment analysis from different perspectives (political, economic, social, and technological) was conducted highlighting the factors that can influence, positively or negatively, the success of the project. This activity has allowed us to build on the TeraFlow OS added value stemming from the market analysis and the identification of our main competitors: to enable network programmability in vendor-agnostic transport networks in the new 5G use cases.

All partners have declared what their planned contribution to the development of the controller would be, depending on their profile (academic, industry, etc.) and their strategy. This information has been included in the TeraFlow IP Registry, an Excel file, to monitor partners’ IP in the project and to pave the way for a future joint exploitation of the TeraFlow OS controller.

Following the environment and SWOT analysis, the partners of the Consortium have used a second template to reflect on the business opportunities they identify as a result of their participation in the TeraFlow project.

2.4 Task 6.4: Liaison Activities and 5G PPP Collaboration

In this section, we detail the participation in the 5G PPP Programme, including Working Groups (WG). This includes contributions to joint program publications, Global 5G events, joint demos, and workshops, etc.

Partners’ current involvement and participation in existing WGs is presented below.

WG	Partner
5G Architecture	TNOR
SN WG	CTTC

SME	UBI
TMV	ODC
Security	CTTC, TID
Pre-Standards	ODC
VSC	TNOR
Steering Board	CTTC
Technical Board	TID

Steering and Technical Boards

Steering and Technical Boards help the alignment of the multiple 5G PPP projects and their coordination. Apart from the regular meetings, TeraFlow has supported the following main activities:

- Ricard Vilalta participated in the 5G PPP Webinar "Europe accelerates towards 6G" on 16/03/2021
- Participation in elaboration of material for ICT-52 projects dissemination (i.e., brochures, leaflets, websites).
- EUCNC 2021
  - Research paper on TeraFlow use cases: "TeraFlow: Secured Autonomic Traffic Management for a Tera of SDN Flows"
  - Workshop: "From 5G to 6G Automated and Intelligent SecuriTy: FAST"
  - Special Session 8: "Autonomous Network Management towards 6G"

Architecture WG

TNOR, with support from CTTC, has followed the Architecture WG. TeraFlow was presented to the WG by CTTC. In this period, the WG has developed and delivered a new whitepaper (5G PPP – View on 5G Architecture V4.0). This was the main activity. TeraFlow contributed to sections addressing new (transport) network concepts (Logical Network as a Service, Transport Network as a Service) and anticipated provisioning, deployment, configuration, and management topics.

Software Networks WG

TeraFlow is closely monitoring and contributing to this WG's activities. Firstly, the project was introduced to the group, and currently contributions have been made to the whitepaper regarding the network API: "From VNF to API: Opening up 5G and beyond networks".

SME WG

Currently, there is no relevant activity for TeraFlow to report. However, UBITECH is actively trying to identify opportunities for further engagement and collaboration.

TMV WG

This is a relatively new 5G PPP WG, and the current focus is to agree on a set of use cases and coordinate discussion. ODC participates in this activity and is reporting status as progress is made.

Security WG

TeraFlow participates in the 5G IA Security Working Group in order to be updated with the latest trends and actions done by 5G PPP projects that focus on security aspects. Currently this working group is working on a set of four whitepapers and TeraFlow aims to contribute to two of them that focuses on Network Slicing and Distributed Ledger Technologies with Blockchain as its most known example:

- Access control mechanisms in distributed 5G environments
- SDN/NFV virtualisation, 5G Slicing and Security Considerations

Pre-Standards WG

The 5G PPP Pre-Standardisation Working Group is developing a standardisation roadmap and highlighting regulatory topics for 5G. TeraFlow has several active efforts on standardisation, including ETSI, 3GPP, IETF, and other relevant standards bodies. ODC is attending and participating in this WG and providing updates on TeraFlow standardisation activity to other WG participants. In addition, there may be standards collaboration between 5G PPP projects in the future.

VSC WG

VSC vicechair: Håkon Lønsethagen (TNOR)

- BVME SG (Business validation, models and ecosystems).
    - Hanne Stine Hallingby (TNOR), chair
    - Esther Garrido (ATOS), participant
        - Ideas and concepts from TeraFlow shared: ecosystem approach to markets, enabling interoperability and market attractivity
    - Recent whitepaper published: 5G ecosystems
- Horizon Europe Vision SG, (also known as the Smart Network Vision subgroup)
    - Contributors: Lønsethagen and Hallingby (TNOR)
        - Ideas and concepts shared: Full interoperability with open interfaces, enabling (new) cross-domain concepts and services, which in turn unleash business opportunities and ecosystem evolution
    - Recent whitepaper: European vision for the 6G Network vision Ecosystem

2.5 Impact of COVID-19 on WP Activities

There has been some negative impact due to COVID-19 restrictions. This is particularly true due to cancelled events and virtualisation of some other events. Virtualisation reduces the possibility of networking and discussions among researchers. This has impact on dissemination, communication and standardisation activities, but it is not considered critical to the success of the project. Similarly, exploitation activities will also be negatively impacted since it will be harder to set up testbeds, and collaborate to carry out exploitation plans.

3 Project Management and Administrative Issues

This section provides an overview of the project management related tasks and the administrative issues attended to during Year 1. It also describes the recommendations of the Advisory Board, Grant agreement amendments, Resources and Spending, updated risk management, project deviations, and project virtual meetings.

3.1 Summary

WP1 Project Management has taken care of the administrative tasks, quality assurance, management of risks and ethics, the technical management of the project, and the organisation of Advisory Board activities. The timely kick-off of project activities and their overall coordination, ensuring participation from all project partners, contractual matters and the provision of collaborative tools are examples of that.

The project officially started on 1 January 2021. The kick-off meeting was successfully held virtually on 21/01/21. The main objective was to get a common understanding on how the overall goals can be achieved, and to plan how to start with concrete activities. Further meetings have been organised - an overview of all meetings is given in section 3.7 below.

The TeraFlow Consortium Agreement was concluded on 20/12/20 and the signature sheets have been collected from all partners.

The first pre-payment was received from the EC and the respective shares were transferred to the project partners in mid-January 2021 after the partners had provided their bank account details.

TID being the Technical Project Manager, has taken care of the overall technical management of the project and technical coordination between work packages. The task also included the monitoring of WP activities and of technical work progress, the contribution to reports, and organisation and chairing of Project Board meetings. While this task was with Victor López in the first months, it was handed over to Juan Pedro Fernández-Palacios at the end of April 2020, due to Victor's departure from TID. In November 2021, Oscar González-de-Dios took over the responsibility of interim technical manager, due to long-term sick leave of Juan Pedro.

The PC and TM, together with Quality Manager have jointly taken care of the quality assurance of project results.

Conference calls have been held regularly on a project level and on a WP-level in order to get status updates, facilitate coordination between WP activities, to discuss the technical activities, but also to achieve early identification of any potential issues or risks.

A Management Plan has been prepared (D1.1) as a practical guideline to facilitate the management of the project for all TeraFlow participants. It sets down and explains all contractual rules and management procedures, e.g., for production of Deliverables. It also provides information regarding project tools, quality assurance, and project reporting procedures.

A number of tools have been deployed to support the communication and collaboration in the project. These include:

- Several mailing lists (all partners, one per WP, financial and legal matters, etc.) and corresponding mailing list archives.

- A Web-conferencing system (Microsoft Teams) available 24/7 for conference calls
- A workspace for document storage and joint editing (Microsoft Teams)
- Excel and Word Templates for partners' quarterly report of their work, efforts spent, and expenses made.
- An Excel document for keeping an overview of all project dissemination activities.

Templates for project documents have been prepared, including templates for Deliverables, presentations, and meeting minutes.

TeraFlow has also achieved strong presence at 5G PPP Programme level. 5G-I SB and TB activities and meetings were attended by the Project Coordinator and Technical Manager. On overall level, project representatives participate to 5 Working Groups of the PPP, providing direct contributions from TeraFlow.

The COVID-19 restrictions have also an impact on the TeraFlow project activities. Details are reported in below section 3.6.

Finally, preparations for the first project review have been started. The review date and virtual format have been agreed. An agenda has been proposed to the Project Officer and reviewers which has also been confirmed.

The sections below provide more detailed information on a number of activities in scope of WP1.

3.2 Advisory Board Activities

TeraFlow has setup an Advisory Board (AdvB). Its main purpose is to get advice on the direction of TeraFlow's technical work and on the best ways for exploiting the project results and creating innovations. The setup process started in September 2021 with the search for suitable AdvB member candidates, considering the members in the original proposal.

As of November 2021, the AdvB has 3 highly qualified members with complementary backgrounds and expertise (see Table 5).

Table 5 Members of TeraFlow Advisory Board

#	Name	Organisation	Job Title
1	Noboru Yoshikane	KDDI Research	Senior Manager of Photonic Transport Network Laboratory
2	Silvia Almagia	ETSI	Technical Expert - ETSI's Centre for Testing and Interoperability
3	Diego Mari	TIP OOPT	Technical Lead - Open Optical Packet Transport Project Group

The Advisory Board meeting took place virtually on December 17th, 2020, at 9:00 AM. Due to technical issues, Diego Mari was unable to attend, so the questions for him were sent to him offline. The relevant minutes, as well as a summarised transcription of the questions and answers discussed during the meeting are included in Appendix BAdvisory Board – Minutes and Summary of Questions and Answers.

The Advisory Board gave very positive feedback, proposed international events where TeraFlow can be presented, motivated the TeraFlow partners to contribute to the ETSI work groups with proof-of-concept proposals, and to the Open Source MANO project with bug fixes and new features. Additionally, they gave very interesting feedback on how to ensure sustainability of the TeraFlow SDN controller after the H2020 TeraFlow projects ends. Finally, the intention of open sourcing the TeraFlow OS components had very good feedback.

3.3 Grant Agreement Amendments

Three Grant Agreement Amendments have been prepared in the first year. In this section, we provide an overview of the proposed changes.

- The first GA Amendment (finished: 3/8/2021) was initiated by TeraFlow to make a number of small changes. ATOS IT introduced an affiliate company named Atos Spain SA (in short ATOS SP) as a linked third party in the consortium. ATOS SP is a company of the Atos group that offers business and IT services consulting as well as vertical solutions in financial, utilities, and telecom services. ATOS IT shares projects and activity with its affiliate ATOS SP in the project. Due to the nature of some of the project tasks, the expertise of members of both organisations are needed. Moreover, CTTC and TID exchanged effort due to the departure of the Technical Project Manager. CTTC is responsible for D2.1 and MS1. CTTC assumes more workload on WP1 and WP2.
- The second GA Amendment was initiated by TeraFlow due to Volta departing from the consortium (25/10/2021). Volta Xarxa S.L. lost its only customer, Volta Networks Inc, as Volta Networks Inc is ceasing its operations.
- The third GA Amendment is related to the inclusion of ADVA in the TeraFlow consortium to provide the necessary activities due to VOLTA's departure (28/12/2021). It includes ADVA addition to the consortium incorporating NOS activities after VOLTA termination.

3.4 Resources and Spending

In TeraFlow, the effort of each partner (in PM) was initially planned linearly over the duration of each respective task where a partner has effort allocated. From experience this is a good approximation of actual spending to be expected, although it is often observed that partners backload their efforts in EC projects, i.e., consume below average in the first half and above average in the second half of the project. Nevertheless, any deviation that might come up needs to be checked to see whether the deviation is highlighting any issue in work progress, or whether the linear planning was simply not appropriate.

The chart below (Figure 12) gives an overview of the planned versus reported efforts of the TeraFlow beneficiaries in the first year of the project (M1-M12).

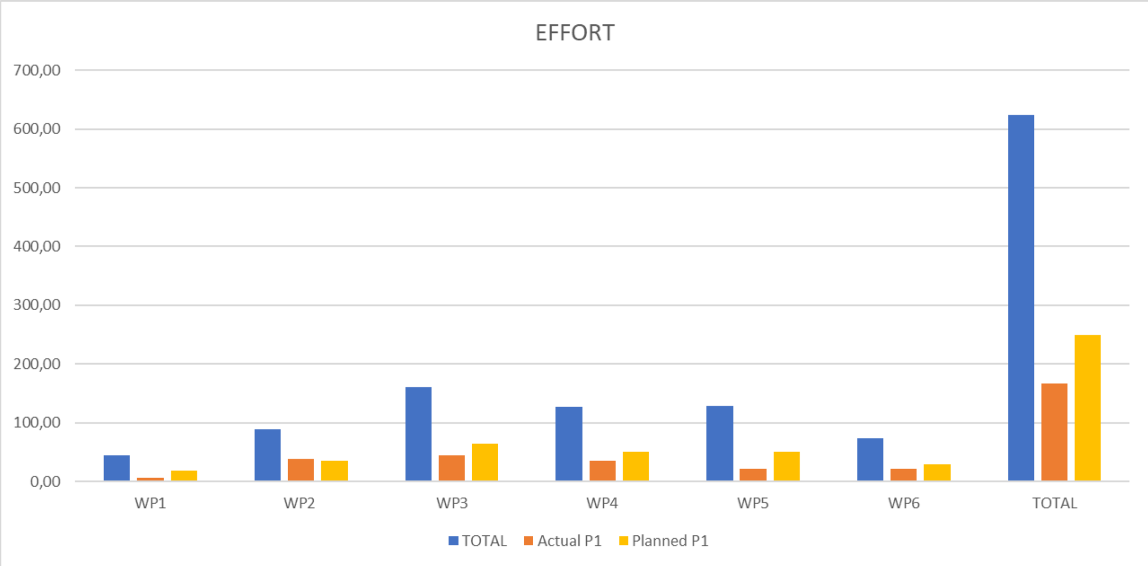

Figure 12 Consumed PMs per WP

Overall, the project has underutilised the planned effort: Of a total of 624 PM planned, about 167 PM were actually spent. This percentage, as said above, is not unusual for H2020 projects at this point in time, i.e., after 12 months, in particular in a project like TeraFlow where large efforts will be required in the second half of the project for the development and experimentation activities.

Nevertheless, the individual deviations of partners have been scrutinised in order to identify whether there is any reason pointing to a problem that needs to be addressed, and also in terms of whether the deviation will have any impact on the progress of project activities or the future work. Details have been provided on a WP-level in the individual WP report sections. Figure 13 and Table 6 give a detailed overview of the consumption of efforts in the reporting period.

Effort usage will be further monitored in order to detect any problems well in advance of becoming critical.

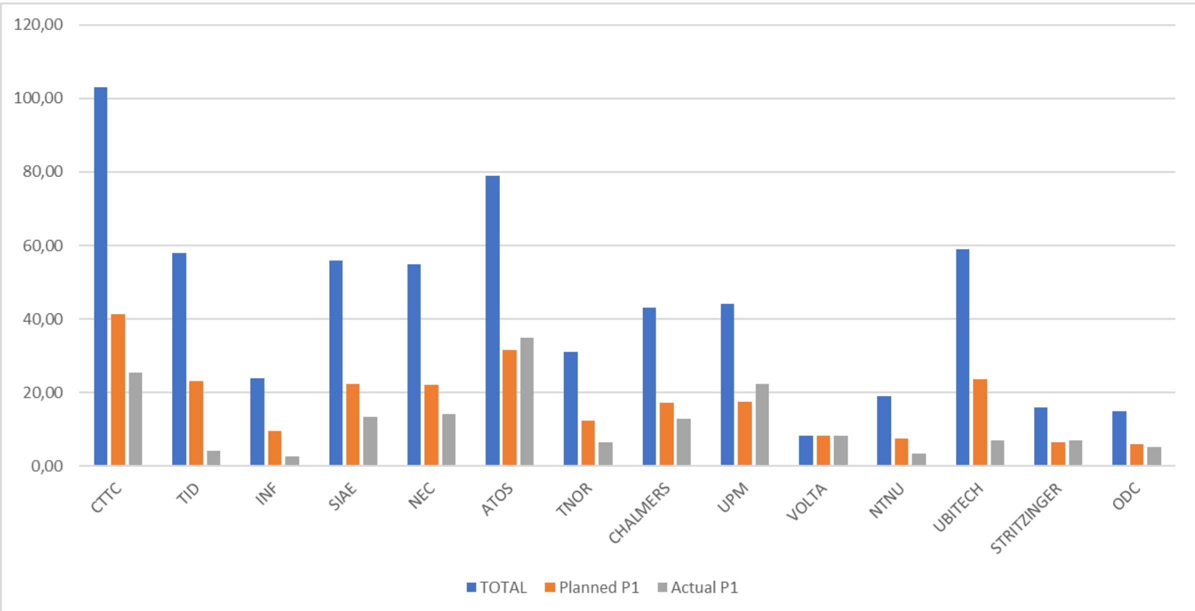

Figure 13 Consumed resources per partner

	TOTAL PM	Planned P1 PM	Actual P1 PM
CTTC	103,00	41,2	25,45
TID	58,00	23,2	4,07
INF	24,00	9,6	2,65
SIAE	56,00	22,4	13,40
NEC	55,00	22	14,27
ATOS	79,00	31,6	34,89
TNOR	31,00	12,4	6,45
CHALMERS	43,00	17,2	12,79
UPM	44,00	17,6	22,46
VOLTA	8,30	8,30	8,30
NTNU	19,00	7,6	3,49
UBITECH	59,00	23,6	6,91
STRITZINGER	16,00	6,4	7,05
ODC	15,00	6	5,05

Table 6 Planned vs actual effort in P1

3.4.1 Effort deviations justification per partner

3.4.1.1 CTTC

The deviation for CTTC is fundamentally due to the delay in the incorporation of some additional personnel to the project. Moreover, CTTC took further responsibilities due to amendment 1, which resulted in deviation from the allocated resources. This situation will be fixed in 2022 and 2023.

3.4.1.2 Telefónica I+D

The deviation for Telefónica I+D is fundamentally due to the delay in the incorporation of some additional personnel to the project which, due to internal procedures, have not been able to be incorporated before. There is no technical justification associated with the deviation; it has been a purely organisational and resource allocation issue.

3.4.1.3 Infinera

Because of change in business priorities, Infinera used the available resources for other work in 2021 and could not use resources for TeraFlow as much as was originally planned. This situation will be fixed in 2022 and 2023.

3.4.1.4 SIAE

The **planned linear distribution** of PM in the budget explains part of the deviation in SIAE statement, as the actual effort is more flexible than forecasted distribution during the months, and this particularly in the first period of the project. Actual delays are due also to COVID-19 restrictions, with a lot of people working at home offices, with negative impact on the efficiency of the activity especially during the first phases of the project, where coordination of the team is essential. This issue nowadays being solved, SIAE is going to match all its targets in terms of PM efforts in the following months.

During the first months, **senior personnel of SIAE was involved in the project much more than the forecasted average**, while technical personnel will be involved with a higher % during the following periods. **This explains the actual rate of personnel costs**, higher than the average PM rate of the project. Therefore, this deviation also will be solved during Y2 and Y3.

3.4.1.5 Telenor

The Telenor deviation in the resource consumption is related to two reasons. First, the planned PM is based on a linear distribution while in practice less resource is spent in the beginning and more resource is needed in the middle phase. Given that WP3 kicked off in M6, underspending is expected in Y1 (M6 – M12) because more resources will be spent in Y2 and Y3. Second, in Y1, TNOR was mainly involved in T3.4 (network slicing), which was not very active due to the change of partner. More activities will be carried out in Y2, which will require more resource consumption.

Second, TNOR mainly contributed to T4.3, the inter-domain component. In Y1, the consortium focused on the core and basic components of TeraFlow OS and has not yet addressed the multi-domain deployment. Therefore, our main activities were on the design of the inter-domain component and requirements on other components. In Y2, more work will be done to investigate the interaction with other components and move towards actual development and deployment. A significant amount of resource will be consumed to that purpose.

3.4.1.6 NTNU

At the beginning of the project, NTNU internally planned its resource distribution with emphasis on the 2nd year of the project. Given the start of WP3 and WP4 (M6) and the involvement of the staff in teaching duties during the 2nd half of 2021 it was already expected to contribute less than a linear estimate. It is expected that the tasks within WP3 and WP4 will be significantly pushed forward during Y2.

3.4.1.7 UBITECH

UBITECH's identified deviation of the declared personnel costs and effort for the first year of the project is based on the linear distribution of the planned effort in time. However, this is not the case concerning the actual involvement of UBITECH personnel in project activities. During the first year of the project (conceptualisation, design, and research), only senior personnel of UBITECH (holding PhDs) have been involved in the project causing an average PM rate of the declared actual personnel costs and effort consumption to be increased by ~25% (if compared to the average PM rate used during the proposal preparation). It is expected that personnel with lower rates (technical staff and developers) are going to be engaged in the project during the next two years, for taking part in implementation and piloting tasks.

UBITECH's effort in WP4 is solely on T4.3. The plan in this task is to investigate efficient mechanisms to bridge SDN with legacy networks, ultimately enabling TeraFlow to bridge inter-domain, potentially geo-distributed deployments. As the main concern in Y1 has been a basic functional behaviour of all TeraFlow components, the consortium has not yet addressed multi-domain deployments, thus the plan is to contribute to T4.3 throughout the second year of the project. In Y1, UBI has participated in all WP4 meetings and discussions and performed a thorough review of D4.1. In Y2, UBI will investigate relevant Kubernetes plugins to allow setting up geo-distributed TeraFlow testbeds atop Kubernetes and the TeraFlow SDN controller.

3.4.1.8 Old Dog Consulting

ODC's contribution to WP3 is planned across all four tasks, but more than 50% of the effort was planned for T3.4 (Network Slicing). This task has suffered from the departure of Volta from the consortium and so is lagging somewhat. Additionally, the overlap between this task and T6.2 (Standards and Open Source) may have led to some ambiguity in reporting the work done to advance the project's view of network slicing within the IETF (and specifically in draft-ietf-teas-ietf-network-slices). It is envisaged that significant work will be picked up in the next few months both on SDN and network slicing as work is firmed up on concepts of "intent-based networking" and "network slicing" and as that work is propagated into the standards efforts.

3.4.1.9 ADVA Optical Networking

ADVA joint formally the consortium by end of December 2021 and ADVA will start its activities by January 2022.

3.5 Updated Risk Management

The situation regarding potential project risks, as listed in the Grant Agreement, has been regularly reviewed by both TM and PC as well as in project plenary meetings. An updated risks table has been included as an appendix (Appendix A Updated Project Risks Table), where some detailed comments on the state of play for each risk can also be found.

3.6 Deviations, Delays and Remedial Actions / Impact from COVID-19

Until the end of this reporting period (M12) the project has achieved all Deliverables and Milestones according to plan, as shown in section 4.

However, the COVID-19 restrictions have had a negative impact on the progress of TeraFlow activities. While, overall, the project activities can and do continue, they progress with reduced efficiency and some delay. This is caused by the fact that hardly any of the partners have been able to access their regular workplaces for many months (i.e., most work from home office) especially labs and development environments.

In spite of this situation, all TeraFlow activities are currently progressing, and all Deliverables and most Milestones are expected to be achieved on time. However, as under the current restrictions (physical) access to the partners' testbeds is restricted, WP5 activities might get severely impacted if the restrictions continue to exist long into 2022.

3.7 Project Virtual Meetings and Other Key Events

Due to the COVID-19 pandemic no face-to-face meetings could be organised. To keep track of the project activities and ensure its proper behaviour, the PM and TM decided to have a monthly regular plenary meeting, as well as bi-monthly per WP-based meetings. Dedicated meetings have also been held as needed. Per-partner meetings have also been realised between PM, TM, and partners in order to properly address partner contributions.

Table 6 lists all major project meetings and conference calls. Side meetings between partners have also been held for specific topics and are not covered in the list.

Table 7 Project virtual meetings and other key events

Event	Date	Purpose	Participants
Kick-off Meeting	21/01/2021	Project kick-off. Align partners' contributions. Discuss architecture.	All

Plenary	26/02/2021	Use cases per scenario, Grouping categories, Requirements, Architecture, Data Models, WP6 Activities and Events	All
WP2-WP6	12/03/2021	Use cases per scenario, Grouping categories, Requirements, Architecture, Data Models, Standards, WP6 Activities and Events	WP2, WP6 members
Plenary	26/03/2021	MS2.1, MS3.1, MS5.1, D6.1, WP6 Activities and Events	All
WP2	09/04/2021	MS2.1	WP2 members
Plenary	30/04/2021	MS2.1, MS3.1, MS5.1, WP6-T2.3 relationship, WP6 Activities and Events	All
WP2	21/05/2021	MS2.1	WP2 members
WP3	21/05/2021	MS3.1, MS3.2	WP3 members
WP4	12/05/2021	T4.3	WP4 members
WP3	21/05/2021	WP3 Components, Task-level components, Towards a common WP3 component template	WP3 members
WP4	21/05/2021	WP4 contributions to MS2.1	WP4 members
Plenary	28/05/2021	MS2.1, MS3.1, MS5.1 Infrastructures. Continuous integration approach, CI/CD, WP6 Activities and Events	All
WP2	04/06/2021	MS2.1 Architecture, Data models	WP2 members
WP3	09/06/2021	Status and pending contributions for MS3.1, WP3 Component updates	WP3 members
Plenary	18/06/2021	MS2.1, MS3.1, MS5.1, Monitoring, WP6 Activities and Events	All
WP3	23/06/2021	MS3.1 status, WP3 Component updates	WP3 members
T4.1	07/07/2021	T4.1	T4.1 members
Plenary	16/07/2021	D2.1, D3.1, D4.1, D5.1, WP6 Activities and Events	All
Plenary	10/09/2021	D2.1, WP5 CI/CD Tests, tutorials, D3.1, D4.1, WP6 Activities and Events	All
WP3	15/09/2021	D3.1 status and timeline, Next steps towards Code Freeze v1	WP3 members

WP4	15/09/2021	D4.1 status and timeline, Next steps towards Code Freeze v1	WP4 members
Plenary	01/10/2021	T2.3, OFC demo, D3.1, D4.1, WP6 Activities and Events	All
WP3	13/10/2021	VOLTA replacement, Status per Task, TeraFlow CI/CD	WP3 members
WP3	27/10/2021	Status per Task, D3.1 Status	WP3 members
WP4	27/10/2021	T4.1: Optical physical layer security components	WP4 members
Plenary	29/10/2021	ADVA Replacing VOLTA, D2.1, OFC Demo, D5.1, D3.1 Status, D4.1 Status, D6.1, WP6 Activities and Events	All
WP3	10/11/2021	Status per Task, D3.1 Status	WP3 members
WP4	10/11/2021	Interdomain	WP4 members
WP3	24/11/2021	Status per Task, MS3.2 Status, D3.1 Status	WP3 members
Plenary	26/11/2021	D2.1, OFC Demo, D5.1, D3.1 Status, D4.1 Status, D6.1, WP6 Activities and Events	All
WP3	08/12/2021	Status per Task, MS3.2 Status, D3.1 Status	WP3 members
Plenary	10/12/2021	D2.1, OFC Demo, D5.1, D3.1 Status, D4.1 Status, D6.1, WP6 Activities and Events	All

4 Status of Deliverables and Milestones

The preparation of Deliverables has been monitored and quality checks have been made. All project Deliverables and Milestones due in the reporting period have been reached. Details are given in Table 7.

Table 8 Deliverable status – due in the reporting period

Deliv. Number	Deliverable Title	Lead beneficiary	Planned due date	Submitted
D1.1	Management plan	CTTC	28/02/21	25/02/21
D6.1	Dissemination, Communication, Collaboration and Standardisation Plan	ATOS	30/04/21	30/04/21
D1.2	Quality assurance plan and data management guide	CTTC	30/04/21	30/04/21
D1.5	Data Management Plan	CTTC	30/09/21	28/09/21
D2.1	Preliminary requirements, architecture design, business models and data models	CTTC	31/12/21	31/12/21
D3.1	Preliminary evaluation of Life-cycle automation and high performance SDN components	UBITECH	31/12/21	29/12/21
D4.1	Preliminary evaluation of TeraFlow security and B5G network integration	NEC	31/12/21	29/12/21
D5.1	Testbed setup and prototype integration report	CHALMERS	31/12/21	29/12/21
D6.2	Market and business opportunities analysis and intermediate report on Dissemination, Communication, Collaboration, and Standardisation	ATOS	31/12/21	31/12/21
D1.3	First project periodic report	CTTC	31/12/21	31/01/22

Table 8 gives an overview of the status of Milestones achievements that were due in the reporting period.

Table 9 Milestone achievement – due in the reporting period

Mile-stone No.	Milestone Title	WP	Lead benefic	Planned due date	Achieved	Comments
12	Establish Web & social presence	6	ATOS	28/2/21	26/2/21	Small Report available as MS6.1
3	Study of technical aspects of relevant SDN, Cloud-native	3	ATOS	30/4/21	1/7/21	Small report available as MS31. Delay was agreed with PO, due to the fact that the WP3 was not started by delivery date. This has no

	and SDO solutions					impact in the project plans, as it was an error in the proposal scheduling.
1	Initial use case definition, requirements and architecture for v1	2	CTTC	30/6/21	1/7/21	Small report available as MS2.1.
8	Infrastructures, Continuous integration approach	5	CHALMERS	30/6/21	5/7/21	Small report available as MS5.1
4	Code freeze for TeraFlow OS WP3 components (v1)	3	UBITECH	31/10/21	10/12/21	Small report available as MS3.2. Delay with the intention to give more time to consolidate the internal data models and features that will be available for TeraFlow release 1. This extra time has allowed us to consolidate a better software product and it has not limited in any way the evolution of the project.
6	Code freeze for TeraFlow OS WP4 components (v1)	4	NEC	31/10/21	10/12/21	Small report available as MS4.1. Delay with the intention to give more time to consolidate the internal data models and features that will be available for TeraFlow release 1. This extra time has allowed us to consolidate a better software product and it has not limited in any way the evolution of the project.
9	TeraFlow OS v1	5	ATOS	31/12/21	31/01/22	Integration has taken longer than expected. In order to plan a proper release, schedule has been slightly moved. Small report available as MS5.2.

5 Conclusions and Next Steps

In this Deliverable, we have provided the current progress of technical work and achievements, the progress on dissemination, standardisation, and exploitation, and also included project management and administrative issues.

The project is starting its Year 2 activities with a good set of technical achievements, and it will follow the Advisory Board and reviewers' recommendations in order to maximise the achievements and the impact of the project.

Appendix A Updated Project Risks Table

There are a number of risks that have been identified and could threaten the implementation of the TeraFlow work plan and its successful conclusion. A list of measures is proposed for each identified risk in order to ensure the achievement of the project objectives. The risks listed in Table 9 will be monitored during GA and SC meetings.

Table 10 Updated project risk table

Management			
Partners are not reacting as expected or lack of communication	L	ALL	Use more interactive communication means. E.g. use the real time communication systems when e-mail is not enough. Regular SC meetings will prevent partner isolation. For the design and integration activities, more than one competent partner is part of the consortium.
COVID19 situation is persistent in time	L	ALL	Most of the activity of the project is based on Software Networks, which requires less laboratory access and can be done mainly at remote locations. Experimental activities might include longer delays, which can be counteracted with proper planning. Dissemination activities might be affected and more virtual activities (i.e., webinars, virtual conferences/workshops) will be planned.
Cost/time overrun	L	1	Management will check on spending and ensure budget compatibility of activities. One means for stabilising budget and activities will be the regular adjustments to the work plan as described in WP1. Continuous monitoring of spent effort and budget by the PC will ensure that unexpected spending will be discovered in a timely manner.
Technical			
Delays in architecture and requirements by WP2 slow down the design and implementation	L	2	A basic architecture design with a minimum set of requirements will be composed by WP2 (and communicated to WP3/4) prior to the end of this task.
Unrealistic use cases	L	2,5	A lot of detail and relationship with the proposed concept and architecture has been provided so no big deviations are expected. During the architecture phase, the requirements will be settled and the architecture will focus on providing the set of requirements. In case some requirements are unrealistic, a novel approach will be discussed.
Partial P4 automation due to missing just-in-time (JIT) P4 compilation by target switches.	H	3	The WP3 members that will undertake P4 automation will consider a viable alternative. Instead of JIT compilation of P4 code by the target device, one can provide (i) the output of the P4 compiler (e.g., BMv2 JSON or Tofino binary/context JSON) and (ii) a P4Info file required by the P4Runtime, as inputs to TeraFlow.
Lack of standardised southbound abstractions for edge processing devices (e.g.,	L	3	The TeraFlow consortium considers this matter more as an opportunity rather than a risk. Specifically, this issue will be raised at the very early stages of the architecture design and requirements, with a primary goal being the definition of NBI/SBI abstractions that will ultimately cover emerging edge devices, such as GPUs and Smart NICs.

GPUs, Smart NICs)			
Static resource allocation of certain devices (e.g., P4), as will be performed by the L0/L3 TeraFlow OS component, may impact TeraFlow OS elasticity	M	3	The WP3 members that will undertake L2/L3 deployments using P4 devices may work around this risk using two distinct alternatives. First, P4 resources can be provisioned a priori based on the maximum expected demand. Second, a dynamic alternative to avoid static resource pre-allocation would be to use P4C-XDP.
Insufficient integrated security mechanisms	L	3, 4	WP2 will focus on security and privacy requirements of TeraFlow OS components. In particular, for the distributed ledger component, which will be developed in WP4, special care will be taken with respect to its security and privacy, since it stores and handles critical data.
Insufficient performance (in particular, scalability) of the blockchain of the distributed ledger component	M	4	WP4 has allocated resources with work items in T4.2 dedicated to the performance and scalability of blockchains. Note that the distributed ledger will use permissioned blockchains and utilise satellite chains, which are able to achieve higher throughputs in terms of the processed transactions per second than, e.g., permissionless blockchains.
Threat detectors fall short, e.g., by incorrectly identifying non-malicious network traffic as sophisticated attacks	M	4	WP4, specifically T4.1, will address the impact of false-positive and false-negative rates on security alarms raised by the security modules by defining and properly dimensioning attack detection windows and thresholds.
Prototype integration not successful or takes a longer time than planned	L	5	Try to leverage as much as possible existing solutions, giving priority to the definition of common interfaces as fast as possible and have the prototype using them.
Problems during the integration process prevent implementation of the prototype in the testbeds	M	5	We leverage the modularity of the proposed solution allowing partial integration of the prototype.
Delays in WP3 and WP4 slow down the integration work	M	5	Direct integration of the WP5 teams within WP3 and WP4 allows identification of crucial details relevant for the development and integration.
Impact			
Failure of project dissemination, and exploitation objectives.	L	6	Continuous assessment of real outcomes of exploitation activities aimed at verifying engagement and promotion of benefits of the project. A first draft of the dissemination plan and communication guidelines D6.1 early in the work plan (M4), as well as continuous monitoring and reporting of the activities by the T6.1 leader, will help partners to be on track.

			Additionally, the project counts on the support of the Advisory Board that is giving expert advice and guidance for future work on how to ensure the sustainability of TeraFlow OS.
Insufficient alignment with SDO/OSS	L	6	Continuous monitoring of relevant standardisation bodies (T6.2) by at least one TeraFlow partner involved in WP3, 4, and 5. Additionally, the T6.2 leader is not only making sure that TeraFlow follows certain standards, but is also identifying improvements to them, including new aspects from TeraFlow developments that could be incorporated by SDOs to the mentioned standards.
Alignment with premature / expired IETF drafts	H	3,6	The Policy Management component of the core TeraFlow OS is based on an ambitious, yet premature IETF draft about event-driven policy management using the Event-Condition-Action (ECA) model. The same situation holds for the Slicing Component, which is based on the IETF Network Slice YANG Data Model. In case that these drafts do not advance as expected, there is a high risk for this component to be eventually outdated with respect to standardisation.
Integration with current 5G PPP results	L	3, 4, 5	TeraFlow partners represent the majority of Software Networks based 5G PPP projects and have a proven track record of adoption of results. Apart from the SB and TB, there is at least one representative from the project involved in the relevant 5G PPP WGs (5G Architecture, SN, SME, TMV, Security, Pre-standards, VSC) attending the meetings and following the activities to find synergies and align results.
Upstream contributions to open-source software communities are difficult to be accepted by them	M	6	TeraFlow partners are involved in the majority of OSS technical committees. If a new feature cannot be included upstream, TeraFlow contributions will published with an Apache 2.0 license.

Appendix B Advisory Board – Minutes and Summary of Questions and Answers

Date/Hour: 17/12/2021 at 09:00-11:00
Organiser: Ricard Vilalta
Attendees:

External Advisors	Noboru Yoshikane (KDDI Research), Silvia Almagia (ETSI), ~~Diego Marí (TIP OOPT)~~
TeraFlow	Ricard Vilalta, Lluis Gifre (CTTC); Oscar González de Dios (TID); Georgios Katsikas (UBITECH); Rahul Bobba (NEC); Carlos Natalino (CHALMERS); Esther Garrido (ATOS); Håkon Lønsethagen, Hanne K Hallingby, Min Xie (TELENOR); Stanislav Lange (NTNU); Sami Petteri Valiviita (INFINERA); Nicola Carapellese (SIAE).

NOTE: Diego Mari had a problem receiving the invitation to the meeting. Questions for Diego will be directed to him offline.

Introduction:

- Ricard Vilalta initiated the Advisory Board meeting and presented the external advisors.

WP1 & WP2:

- Ricard introduced the TeraFlow project and presented the WP1.
- Oscar presented the WP2.

Questions for the Advisory Board:

- "How to contribute between TeraFlow and TIP documents? Is there some form of Acknowledgement?"
  - [Oscar] There are a lot of documents being produced in TIP and we have good synergies. We think that we can contribute and provide valuable inputs. Question mainly for Diego.
  - [Ricard] Provide questions offline to Diego so he can join on the report.
- "From the requirements perspective, which kind of interfaces shall TeraFlow support?"
  - [Ricard] Noboru, from these requirements perspective, do you miss some significant southbound or northbound interface?
  - [Noboru] For the southbound interfaces in your controller, specially to control optical transport networks, Netconf is necessary.

WP3:

- Georgios presented the WP3.

Questions for the Advisory Board:

- "SDN Performance: Do you consider appropriate the architectural approach with micro-services?"
  - [Noboru] The proposed micro-services-based architecture is on the right direction because scalability is one of the important characteristics of the network controllers.
- "Hardware Integration: Any missing feature?"

- [Georgios] Do you think we are missing any key features, especially with regards to hardware?
- No specific answer to this question.

- "Automation: Are there network automation trends we are missing? What policy types would you like to see being supported by a controller?"
  - [Georgios] Do you think there are very important policy types to be considered in Year 2 as potential policies to be supported by TeraFlow.
  - [Noboru] For automation, one missing part is how to manage, for example, automatic restoration. Do you considered to implement a restoration function in this automated SDN controller?
  - [Georgios] Reported in Milestones in WP2, we foresee for Year 2 to exploit existing Kubernetes features such as rollback recovery (e.g., in case of mistakenly applying a software upgrade, enable rollback mechanism to recover a stable version of the affected component). This can be seen as a way to mitigate errors coming from links and broken device configurations.
  - [Ricard] Maybe we can prioritise that for Year 2. I think it makes a lot of sense.
- "Slice management: Which draft/standards do you think will have importance during 2022?"
  - [Ricard] Noboru or Silvia, comments on the transport slicing part? How do you see the current standards?
  - [Noboru] I do not have an appropriate answer to this question.
  - [Silvia] I do not have an answer either. I would have a look to 3GPP to see what they are doing. I think they are aligned with external bodies in terms of slicing implementation so I would not expect to see any conflicting solutions there.
  - [Ricard] Question more for Diego; he is working within TIP on these topics.

WP4:

- Rahul presented the WP4.

Questions for the Advisory Board:

- "Relation of ML-based security with ETSI SAI?"
  - [Silvia] Involved in several ETSI groups, but for SAI I do not know. I can put you in touch with the people driving the work / help you to join the group.
  - [Ricard] Diego and UPM working on it, I think we can expect some collaboration.
- "Current contributions with ETSI PDL. Possibility of a PoC?"
  - [Rahul] NEC is part of ETSI PDL. We have explored the possibility of having a PoC. Are there are any opinions on that? Is that the right place to have a PoC.
  - [Silvia] Not personally involved in PDL. She has been investigating PoC framework. They have a number of running/completed PoC's. Very good idea to explore the PDL aspects through a PoC. I would encourage the PoC submission. I can help in setting up the proposal, and making sure its timely considered and reviewed by the group.
  - [Ricard] Perfect to align with PDL for a PoC. Very nice output for Year 2 / end of the project.
- "Contribution to ETSI OSM. "
  - [Silvia] Quite involved in OSM. Many European projects use OSM, provide feedback and new features, which is very welcome. Keep OSM aware of what you are doing. You already provided a high-level presentation to OSM with the goals of the project. When things get concrete or you need concrete feedback, join the workshops,

technical courses, and/or technical community calls. If you have something that you think would be valuable for OSM, present it to the community as Ricard did with network slicing.
    - [Ricard] We are debugging and fixing the inter-domain part of OSM, but we have not succeeded. We will contribute, so you will see people from CTTC, like Lluis, contributing with bug fixes. When we reach the stage of having it ready, we will ask you for specific presentation in one of the OSM days.
- Extra question regarding ETSI ZSM (from Ricard)
    - [Ricard] I wanted to ask you about ZSM if you are following the activity.
    - [Silvia] Yes, from far away. Helping the PoC Mgmt Group to review and drive feedback to the PoC proposals. I was taking notes about automation in WP3. Same PoC proposal can be submitted to different groups (ZSM, PDL). Very good to give visibility to this project and get feedback from the ZSM community.
    - [Ricard] For us it's very important to align ETSI activities to TeraFlow. I think for automation we have this configuration of devices that might be an interesting PoC for ZSM. Our intention: provide a couple of PoC's to ETSI to show how TeraFlow is very well related to their activities.
    - [Silvia] Great news. I can help with putting together the proposal, review, and to make sure you fulfill the criteria for acceptance.
    - [Ricard] I think these two activities for Year 2 are possible.

WP5:

- Carlos presented the WP5.

Questions for the Advisory Board:

- "Are the scenarios representative enough?"
    - [Noboru] For SC1, I have just a clarification about network environment. Are you assuming multiple vendor environments?
    - [Carlos] Yes, we have different southbound interfaces (P4, OpenConfig, NetConf, etc.) That will enable us to have multi-vendor deployments.
    - [Ricard] I think the interdomain scenario would fit quite well in the PDL PoC. The scenario demonstrating automation, should be quite aligned with the ZSM.
    - [Silvia] Yes, that makes a lot of sense.
- "List of UCs: anything missing?"
    - [Carlos] Have we missed some scenario that is currently, or that you think that in the future, will be relevant. Is there anything missing?
    - [Noboru] As mentioned in WP3, you have a plan for the management mechanisms for network restoration. I think it's a good combination to demo in large vendor environments.
- "Which KPI are the most critical to assess in each scenario? "
    - [Carlos] We'll be analysing critical metrics, like latency, bandwidth, and bitrate. Do you think there is any other KPI that should be included?
    - [Ricard] Do you know, Silvia, which kind of evaluations/KPI's needs to be done typically in PoC's?
    - [Silvia] No, I think each framework defines what they call PoC topics (areas within the technology where they are looking for specific feedback). These PoC topics may list specific KPIs. I can share the links to these frameworks and the links to these PoC

topics. I will help you to explore and eventually put you in touch with people who can help you to identify the KPI's.

- "Any feedback on the timeline? Y1: testbed setup and TeraFlow integration. Y2: integration work (cont.) + UC deploy and demo + initial performance eval. Y3: performance eval. (cont.) and KPI validation."
    - No specific answer to this question.

WP6:

- Esther presented the WP4.

Questions for the Advisory Board:

- "How to relate TeraFlow with current SDOs?"
    - [Silvia] We've gone through it through the morning. Bringing contributions, feedback, and PoC proposals, I think is a very pragmatic way of starting a conversation and probably identifying touchpoints and points where the communities can help each other.
- "How to ensure sustainability of TeraFlow SDN controller after H2020 TeraFlow ending?"
    - [Silvia] The intention of open sourcing TeraFlow is a quite good way to ensure it lasts. For a software to survive it needs to be used. The easier it is to be used and enhance, the more chances it will have to survive. To have a project hosted by ETSI, it's important to find relevant touchpoints with ETSI work. I've been watching the list of specifications you're consuming and contributing to. There are a lot in IETF and in ONF, but I'm also hearing that there's touchpoints with ETSI ZSM, PDL, and SAI. I think it's important to leverage on those; we will need to answer "why at ETSI?"
    - [Ricard] For me it's good to have this as a conclusion of this Advisory Board so that we need to grant sustainability to the project and don't end up the project only with a GitHub account.
- "Please identify opportunities to present TeraFlow"
    - [Noboru] OECC/PSC 2022 will be held in Japan in July. If you don't mind, please submit a paper to the conference.
    - [Silvia] We have opportunities in Open Source MANO ecosystem days. We can host webinars as ETSI webinars and present PoC reports. Everything starts with bringing a PoC proposal and having it approved by the target group.
- "Which are the strengths and the weaknesses of the proposed controller?"
    - No specific answer to this question.
- "How can TeraFlow help to bridge the gap between multiple SDOs?"
    - No specific answer to this question.
- "Which can be TF possible business models? "
    - No specific answer to this question.

Demo:

- Lluis presented the OFC'22 Demo.

Questions for the Advisory Board:

- "Which technologies do you think are missing in this demo?"
    - No specific answer to this question.
- "Which use cases would it be interesting to demonstrate on this scenario?"

- [Noboru] I'm interested in provisioning time. How long will it take to complete end-to-end provisioning in this demo including the optical layer?
- [Lluis] It depends on the devices. I would say in the order of few seconds. In terms of the overhead added by the TeraFlow OS controller it should be much lower. The idea is to have a platform that is scalable and is high performant.
- [Noboru] I'm also interested in how to validate the scalability of the SDN controller in this demo.
- [Lluis] In this first demo, validation of scalability is not a target. We have the plan to address that in a future paper/demo. For instance, we will load the controller with an automated connectivity request generator. All the components in the TeraFlow OS architecture are being monitored to compute the amount of time and number of requests dispatched per component. With that and Kubernetes self-scaling capability we can assess scalability of the platform.
- [Noboru] Thank you for your answer.

* "In which other industrial events do you think it might be relevant to perform this demo?"
  - [Ricard] Maybe the idea is to have plans for the next year demos. You have said that automation and recovery is very important. That might be one way to go.
  - [Noboru] Yes
* "Which enablers might facilitate the adoption of TeraFlow in your networks?"
  - No specific answer to this question.

