




DIGITAL MANUFACTURING PLATFORMS FOR CONNECTED SMART FACTORIES

D3.2 Connectivity Technologies for Autonomous Quality

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Abstract: D3.2 factsheet describes the connectivity technologies developed in T3.1 with the goal to address the reliability and high-speed and requirements for autonomous quality ZDM applications.




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HISTORY

Version	Date	Modification reason	Modified by
0.1	11/01/2021	First version.	Daniel García Sánchez (TID)
0.2	22/01/2021	Integration of CEA work, upgradable plan, updated tid-kube5g documentation.	Daniel García Sánchez (TID)
0.3	25/01/2021	Added conclusion and internal review.	Thi Minh (CEA)
1.0	25/01/2021	Peer review version.	Daniel García Sánchez (TID)
1.01	09/02/2021	Requested changes by peer review included.	Daniel García Sánchez (TID)
1.02	25/05/2021	Change whole document structure and span some chapters to address comments from reviewers.	Daniel García Sánchez (TID)
1.03	15/06/2021	Included business perspective and driving requirements sections.	Thi Minh (CEA), Daniel García Sánchez (TID)
1.04	25/06/2021	Peer review changes required, included reference section.	Thi Minh (CEA), Daniel García Sánchez (TID)
1.0	29/11/2021	Second peer review changes; executive summary without images and tid-kube5g lab testing results.	Daniel García Sánchez (TID)

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Executive summary

This document provides a description of the main networking technologies developed in task 3.1 and the main features provided. Both solutions are the results of partners knowledge background and the analysis done in previous deliverable D3.1, which provided an extensive study about wired and mobile technologies focused on the communication requirements for ZDM. Hereafter, both solutions are briefly explained.

Tid-kube5g

The TID solution provides an end-to-end deployment and configuration of virtualization infrastructure and open-source Long Term Evolution (LTE)/5G core for industrial environment.

The TID solution software is stored in QU4LITY GitHub at *tid-kube5g*¹ repository.

tid-kube5g architecture is composed by 4 main blocks:

- Public cloud: used to deploy and host management plane of the platform, as well as of components of 5G network such as HSS/HLR/Auc,
- Telco edge: the solution is able to deploy resources at private cloud at the same manner as it does at public cloud, so Telco edge platform is also addressed.
- Industrial venue: edge location at customer premises where the 5G-NSA network (MME, SGW, PGW) and services are deployed fully integrated to leverage local breakout benefits.
- CI/CD orchestration: key part of the solution in charge of deploying and configuring mobile core and services.

The solution relies on a Continuous Integration/Continuous Development (CI/CD) and orchestration pipeline to ease deployment and operational processes. The design of these processes has been done following guidelines of DevOps culture to enable fast re-deployment and evolution of the services as well as simplifying operation activities, which is one of the key OPEX aspects in telco-grade mobile deployments.

It provides a one-click infrastructure and solution deployment supporting several venues: industrial sites, edge and cloud locations. It assumes the mobile radio access network (RAN) is already deployed, but this could be partially automated and included in the solution in the future.

CEA TSN network

The CEA management solution for IEEE 802.1 Time Sensitive Network (TSN) comprises the following TSN standards: IEEE 802.1AS, 802.1Qbv, and 802.1Qcc.

¹ <https://github.com/qu4lity/tid-kube5g>

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Inside IEEE 802.1Qcc, there are two main components, namely Centralized User Configuration (CUC) and Centralized Network Configuration (CNC).

- IEEE 802.1AS provides time synchronization at sub-microsecond accuracy among Ethernet TSN nodes, which were presented in our previous work [1],
- IEEE 802.1Qbv provides Quality of Service (QoS) scheduling and guarantees the performance of TSN deterministic communications,
- CUC is defined in IEEE 802.1Qcc, allowing to collect data requests and data publishers' characteristics and constraints from end-nodes. CUC also exports list of streams that will be exchanged in the network. Figure 2 depicts the Qcc fully centralized architecture, where End-station talker and End-station listener are also connected to CUC,

CNC is also defined in IEEE 802.1Qcc, enforcing reservation of resources in the network using TSN standards based on streams.

Both solutions have been demonstrated at local laboratories and demo videos have been provided to the QU4LITY private repository.

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1. Introduction

WP3 task 3.1 aims to design a prototype infrastructure for an industrial Zero Defect Manufacturing (ZDM) environment to provide high-speed and reliable connectivity of information technology (IT) systems, machines, and other field devices in the factory. Previous work devoted for D3.1 analysed the state-of-the-art technologies used for wired and wireless devices at the shopfloor. Besides, a survey about the main networking technologies currently used by QU4LITY partners at their laboratories and production lines was carried out. Based on such studies, the main suitable technologies were selected: IEEE 802.1 TSN for wired networks, and 5G for ubiquitous connectivity and real time mobile communications.


D3.2 covers this prototype infrastructure proposing an open, agile solution which enables mobile infrastructure and edge deployments based on containerized applications with TID's tid-kube5g and addresses the real-time wired needs of production lines with CEA's TSN controllers.

Both solutions will be partially tested in QU4LITY's experimental facilities; FFLOR and Automotive Smart Factory (ASF) will host CEA and TID testing, respectively. This work will be further reported in WP6 task 6.2.

WP3 D3.2 comprises the digital enablers described at Table 1.

Digital Enabler	Partner	Description
TSN network	CEA	TSN management solution for 802.1AS and 802.1Qbv.
Tid-kube5g	TID	One-click deployment of a disaggregated 5G cloud-native E2E network.

Table 1 – Digital enablers

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1.1 Scope and purpose

This document aims to describe the process carried out to develop the digital enablers for industrial connectivity and the solutions themselves developed under task 3.1. Additionally, it aims to describe the rationale and key driving requirements for industrial connectivity from both infrastructure and user perspective.

1.2 Methodology

The methodology followed in task 3.1 to produce these enablers attends to 3 main stages:

- Initial analysis of available state-of-the-art technologies at D3.1,
- Gathering of requirements and final selection of technologies based on QU4LITY partners background and current used networking technologies,
- Actual development of connectivity solutions.

1.3 Relation Deliverable D3.1 (Version 1)

This first release of D3.1 aimed to provide an insight on the most suitable connectivity technologies available for a factory network, notably those that fulfil new Industry 4.0 and ZDM application requirements. It puts special focus on the high density and low power mobile technologies standardized by the 3rd Generation Partnership Project (3GPP); current mobile technologies and upcoming Fifth Generation (5G) networks aimed for industrial Internet of Things (IoT) devices are evaluated. In addition, a report on the connectivity needs and requirements of the QU4LITY pilots was delivered.


The information provided, from both study and report, set the basis for the following development to provide a prototype network infrastructure based on the 2 solutions finally developed by CEA and TID, which cover the end-to-end industrial connectivity from fieldbus to Cloud, addressing ZDM requirements.

1.4 Relation to Other Deliverables

This deliverable is bound to **WP6 D6.3**, which will serve as continuation and will include the related testing results, conducted in experimental facilities, of the solutions presented in this document. Future work details and next steps on the QU4LITY project are described in the following sections.

1.5 Deliverable Structure

This document begins by introducing the scope and purpose of the deliverable in the project, providing a brief description of the methodology used to achieve this goal and the relation with other deliverables. Before addressing the enablers, a list of the key driving requirements for connectivity infrastructure from both networking and user perspective is delivered. It continues providing a description of the main

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networking technologies developed in task 3.1, including the business and technology perspectives and further documentation on how to access the solutions. Eventually, sections of the future work, which is currently in progress, and main conclusions are provided.

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2. Driving Requirements and Reference Use Cases

This section provides a description of the main needs and drivers considered to select the developed networking technologies at task 3.1.

2.1 Driving Requirements for connectivity infrastructures supporting ZDM use cases.

Connectivity infrastructures supporting ZDM use cases need to cope with a high number of concurrent real-time and high data consuming devices. Key drivers to support these new services are described in the following points:

- **High-speed and reliable connectivity:** current industrial devices need to maintain reliability while providing new connectivity by upgrading in a sustainable fashion its hardware and software. ZDM applications demand production lines to become smart manufacturing floors supporting these new connectivity technologies enabling heterogeneity and guaranteed high-speed.

5G mobile technology enables these requirements and specifically addresses such need of heterogeneity, high-speed and massive connections with its main groups of use cases; enhanced mobile broadband (eMBB), massive machine-type communication (mMTC), and ultra-reliable low-latency communications (URLLC).

These ensure equivalent quality of service as wired technologies and enable massive number of heterogeneous devices to be connected at the same time. It is essential to the vertical that wireless mobile devices perform equally as if they were directly wired to the production line connectivity bus.

- Besides mobile 5G technology, **TSN** is also an important enabler for high-speed and reliable connectivity. TSN provides high-speed connectivity for the digital shopfloor in order to support critical real-time communications. Then, these real-time communications allow to remedy the potential problems or optimize the manufacturing on-line e.g., minimize defects on-line.
- The ZDM environments also require **flexible and dynamic management**, which can be potentially provided by TSN, especially 802.1Qcc Network Configuration with the support of SDN. TSN provides flexibility and reconfigurability to future digital shopfloors. The most important objectives are low time-to-integrate and on-the-fly control. Flexible and reconfigurable networks in the future factories will leverage various automation solutions, allowing these solutions to adapt dynamically to the operational conditions and requirements.

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- **Technology upgradation and digitalization:** TSN potentially provides low-cost connectivity and upgradable technologies. Take Profinet-TSN integrating and upgrading as an example, it is known that through studying information collected from pilots, most of industrial partners are using Profibus and Profinet for fieldbus network. Therefore, Profinet-TSN integration is a demanding requirement toward autonomous quality. Since the specifications for Profinet are open and standardized, any manufacturer can build and sell devices. PROFINET International (PI) certifies the conformance of devices to Profinet standard. Then, the devices' producers support the device's upgrade, either software/firmware or hardware upgrade, for conforming to new Profinet specification version. In several special cases, the hardware upgrade could be replaced by software/firmware update, depending on the devices' compatibility/capabilities and user requirements.

At the application level of upgrading process, PI envisions that the transition is highly transparent at the application levels. PI proposes to expand Profinet with the TSN capabilities in Layer 2, retaining the applications on the higher levels [2]. Since TSN is defined on Layer 2, Profinet as application protocol can predestine. In other words, the high-layer applications can be migrated to the new technology incrementally and seamlessly [3]. Like PI, The Profibus User Organization (PNO) aims to integrate the TSN capabilities to the current systems without changing the user interface to the network. This integration process is expected to be similar to the migration from Profibus to Profinet.

2.2 Driving Requirements and overview of user needs on connectivity infrastructures.

The need of connectivity to support ZDM applications can be seen through the needs of factory services and applications. The ZDM applications require reliable communications with low delay and jitter. Critical applications such as motion control and automation process require guaranteed times for their commands. In other words, the commands must be delivered to end systems within bounded time. The ZDM applications also require the networks to be flexibly self-configurable while maintaining seamless connectivity. For example, to minimize plant downtime the networks must reconfigure in response to new operational conditions (e.g., traffic pattern) or incidents (e.g., breakdown).


The key requirements the industrial user demands concerning connectivity infrastructures are broken down below:

- **High performance connectivity:** high wireless throughput is critical to connect devices generating great amount of data. Quick flaw detection and quality control based on computer vision are good examples for this, as they require mobile or nomadic connections with the high network capacity needed to transmit high-definition video streams,
- **Low latency** between devices and applications for real-time control and automation. 5G has improved the latency that is experienced in the wireless hop

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and, particularly when coupled with edge computing, can improve up to two orders of magnitude in latency performance versus traditional solutions. Applications like worker safety controls, that detect and avoid dangerous situations that the workforce may encounter benefit from this short latency to prevent the hazards in the workplace,

- **Data sovereignty** meant as the capacity that enables the companies to guarantee a high data quality throughout the complete lifecycle of the data, including availability, usability, consistency, integrity and security. It is needed to comply with the regulations that increasingly require controlling where the data is stored and processed, ensuring it does not leave a specific region. This is particularly critical for data that requires a high level of protection due to their nature as health data or industrial confidential information,
- Ownership and control over the full **management cycle of the network**, so that they lead the processes to sign-up devices into the network, to decide where and how to deploy the components either on-premises, on the operator edge or even in the public cloud infrastructure and to detect and troubleshoot issues by themselves. Taking into account the availability and uptime requirements, i.e., for production processes at factories might lead up to 99.999% of the time, being able to own, control and manage their private networks is key,
- **Seamless multi branch operation**, to cope with the different sites and facilities where the modern productive processes are split. This includes the secure connectivity amongst branches and private datacenters to guarantee full end-to-end management of complex processes. The heterogeneous nature of them makes it difficult to for the customer operations team to provide support and optimize their working status,
- **Disaster and recovery procedures**, including fallback connectivity using the operator public cellular network to guarantee service continuity during possible outages and application and data store redundancy.

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3. QU4LITY connectivity infrastructures

This section provides an overview of the main features, and its components, of the two different solutions developed at task 3.1.

3.1 Tid-kube5g

Tid-kube5g solution relies on a Continuous Integration/Continuous Development (CI/CD) and orchestration pipeline to ease deployment and operational processes. It uses open-source technologies and languages widely adopted by the industry which are described further in this section. Figure 1 provides a general overview of the tid-kube5g architecture, parts and goals.

TID One-click disaggregated 5G cloud-native E2E network- Architecture

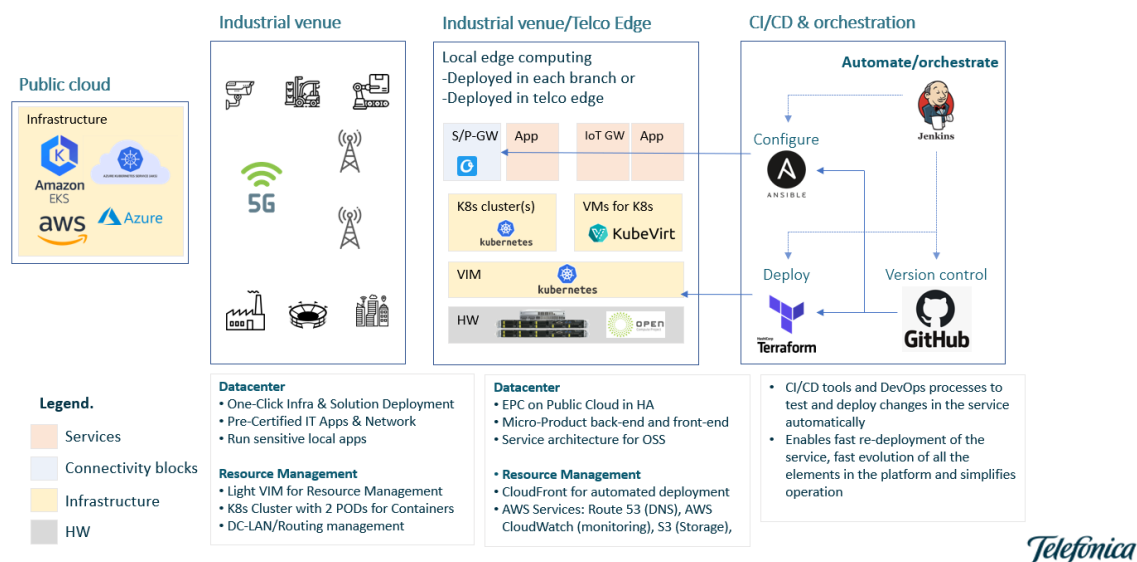



Figure 1 – TID solution architecture

Tid-kube5g leverages a set of languages enabling infrastructure as code and open-source tools to provide the following features:

- **Host bootstrapping:** the solution is ready to work either on clean bare metal servers or hosted virtual machines (VM). The goal OS is automatically installed and configured at the servers or VMs used, these just need to be identified using Preboot eXecution Environment (PXE) (pixicore),
- **Infrastructure deployment:** Kubernetes (K8s) is automatically deployed and configured to use an architecture defining 1 master and 3 worker nodes,
- **K8s networking configuration:** Multus Container Network Interface (CNI) plugin configuration to enable multi-NIC containers. Multus CNI is a meta-plugin for Kubernetes that enables attaching multiple network interfaces to pods. Usually, a Kubernetes pod has one only network interface. Multus can

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be understood as a meta-CNI plugin able to call other CNI plugins. Other CNI plugins that can be potentially used to configure the network. The code repository has mostly used Flannel, but this is not limited to the use of other plugins such as calico,

- **Application onboarding:** Open5GS User Plane Function (UPF) function is registered at Telefonica local registry,
- **Service deployment:** both mobile core functions and a speed test application for demo purposes are deployed,
- **Service configuration:** 3rd party business applications are provisioned in the cluster created. This enables local data breakout to provide optimized throughput and reduced network delay to enable critical time-sensitive industrial services and improve user-experience.

A summary of the specific development done by TID during the second phase of QU4LITY project is shown in Table 2. It contains the tool, a brief description of each development and files concerned within tid-kube5g repository. Further description and details are provided in this document within 3.1.1 Digital enabler overview section.

Tool	QU4LITY development	Files
Jenkins	TID has developed 12 pipelines to build multiple environments and automated demonstrations,	pac folder
Ansible	TID has developed multiple Ansible roles to configure infrastructure (e.g., K8s orchestrator infrastructure installation and configuration), VNFs (e.g., full open-source EPC and CUPS mobile core) and service applications, these last for validation and demo purposes e.g., EPC or UPF configurations, speed test application.	iac folder
Terraform	TID development leverages Terraform to build 4 different environments at AWS (development, demo), on premise using bare-metal servers, or a virtualized infrastructure on top of KVM.	iac folder
Packer	TID cooks 2 different VM images with Packer which are used during the different deployments. This also helps to separate between resource development and infrastructure deployment, and to control the whole development process.	iac/packer folder
AWS	Different developments have been done leveraging AWS SQS service to trigger different related deployments.	iac/bash

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	Depending on the queue message, it launches one pipeline or other to concatenate deployment flow.	
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Table 2 - TID development at QU4LITY

3.1.1 Digital enabler overview

TID tid-kube5g implements a suitable telco-flavoured CI/CD pipeline to deploy an infrastructure compatible with disaggregated network functions and industrial applications. During the second phase of QU4LITY project, and as second deliverable of task D3.2, TEF has leveraged the following tools for different developments included in tid-kube5g that are described below along with a brief technological description of each tool.

- Source Code Management - GitHub.

GitHub is used as control version tool, along with git well-known best practices. GitHub is a cloud-managed code version control platform using Git. GitHub is widely used by programmers to publicize their work or for other programmers to contribute to projects, as well as to promote easy communication through features that report issues or merge remote repositories (issues, pull request, etc.).

TID has used Github to control development, keep track of changes and register bugs using a private repository stored at GitHub.

- **Pipelines as code (*pac*) - Jenkins:**

The orchestration tool used to deploy the whole solution is Jenkins. The repository contains a pac folder with all the pipelines as code files developed during QU4LITY project. The pipelines are k8s-demo.groovy and k8s-development.groovy. It can be seen there is a separation of demo and development scenarios, in both groovy files, inventories and SSH configuration (which must be filled with each scenario specifics).

TID has developed 12 Jenkins pipelines to perform an automated K8s cluster provisioning on bare metal servers (corenet1 and corenet2 laboratory servers in demo case) leveraging Ansible playbooks. Once the provisioning is finished, this pipeline sends a message to Amazon Web Services (AWS) Simple Queue Service (SQS) queue containing ("k8s-deployed") in order to trigger next steps, such as installing mobile core network functions or deploy applications.

The full list of pipelines developed, and its behaviour is described below:

- tid-kube5g demo environment (demo-build/destroy.groovy). This demo deploys a mobile core using CUPS. This pipeline contains the stable version of tid-kube5g demo,

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- tid-kube5g development environment (development-build/destroy.groovy). This development environment refers to develop or feature demo branches. Non-stable deployments for testing new demo features,
- tid-kube5g PXE (pxe.groovy). This pipeline installs clean Ubuntu SO on two laboratory servers in order to install K8s on top of them. It is the first step of the full demo pipeline and triggers other K8s installation pipeline by sending a message to SQS AWS queue,
- Speedtest demo (speedtest/destroy.groovy). This pipeline creates a simplified demo that executes just the speedtest on K8s. Speedtest is a third-party application used to validate the possibility of running other applications on top of the K8s cluster that runs the LTE/5G network,
- SQS polling pipeline (test_sqs.groovy): This pipeline is the one in charge of polling SQS messages. It enables the pipeline triggering for the final demo. Depending on the queue message, it launches one pipeline or other to concatenate demo flow.
- Demo images builder (vpec_ami_build and vupf_docker_build): These files are the ones that creates two images used for tid-kube5g deployment,
 - vEPC_ami creates the AWS AMI we will use for the Public Cloud instance that runs CPF of mobile network. Basically, it runs an Ubuntu image which runs a Docker-Compose with CPF components (HSS, MME, WebUI, MongoDBs) that will be used by demo-build Terraform files. This software and config are written in Docker-Open5GS repo.
 - vUPF creates the User Plane Function images for demo environment. It controls UPF Docker lifecycle by building the images and pushing them to Telefonica private Registry.

In order to execute full tid-kube5g demo some pipelines are concatenated by SQS messaging controlled by test_sqs.groovy. Other pipelines are built on their own, such as builders or speedtest ones.

Demo flow works as follows:

1. Jenkins' baremetal create pipeline is executed. It points to pxe.groovy so new SO is installed on target K8s machines (in demo case, corenet1 and corenet2 (baremetal servers); master and worker for K8s demo),
2. After a while, both machines restart and send a message to SQS queue: "machine installed",
3. SQS pipeline (test_sqs.groovy) is automatically launched and triggers next pipeline according to the message received,
4. Next pipeline is the one in charge of installing all necessary software and networking requirements to run K8s on top of these servers, so that K8s-demo.groovy (from a different repo) is executed. When it finishes, a SQS message is sent to queue again: "K8s deployed",
5. Once again, SQS pipeline has an important role to play by launching demo_create pipeline (demo-build.groovy),

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6. Demo build pipeline is automatically triggered and install all Apps on K8s (on-premises Open5GS UPF and 3rd party apps) and on Public Cloud (Open5GS CPF).

- **Infrastructure as code – Terraform**

Terraform is a tool for building, changing, and versioning infrastructure safely and efficiently. Terraform can manage existing and popular service providers as well as custom in-house solutions. Terraform language is used to describe either infrastructure and applications, it builds a plan to get track of all resources to be deployed and stores its state so they can be updated, progressively modified, or destroyed at any time.

During QU4LITY project TID has developed Terraform descriptors to deploy tid-kube5g cluster on top of an OpenNebula private cloud infrastructure. The repository also uses Terraform as its infrastructure deployment automation tool to build the cloud disaggregated part. This optional stage deployment part brings up all the cloud assets needed to handle the on-site data plane function and applications. Alternatively, as future work, tid-kube5g could extend the use of Terraform to support provisioning K8s and furthermore, to use Rancher.

- **Artifact builder: Packer**

tid-kube5g uses Packer as its image builder tool. Packer is an open-source tool for creating identical machine images for multiple platforms from a single source configuration. Packer is lightweight, runs on every major operating system, and is highly performant, creating machine images for multiple platforms in parallel. Packer does not replace configuration management like Chef or Puppet. In fact, when building images, Packer uses tools like Chef or Puppet to install software onto the image.

- **Provisioning and configuration tool - Ansible:**

Ansible is an open-source software for provisioning, configuration and management tool enabling infrastructure as code. It is used to execute automatically and remotely operations at many components of the infrastructure and service.

Tid-kube5g uses Ansible as configuration tool and is based on a role-based structure. The folder contains a main YAML file (e.g., bootstrap.yml) which triggers other YAML roles for the installation. That means making the code more modular and human-readable. These configuration files are the last steps of tid-kube5g demo, it begins with a K8s deployment, and then deploys the UPF and 3rd party Apps, such as S/P-GW, PCRF, Speedtest or any Computer Vision App.

There are split config files for local development deployment and demo deployment. Ansible file is the same for both, but target hosts are different

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(KVM hosts in local deployment vs physical servers for demo environment), inventory and SSH files change:

- Inventory_5G and ssh_config_5g files are the one used for demo environment with corenet1 as master and corenet2 as worker,
- Inventory-inventory_st and ssh_config are the ones used for local deployments with Kernel-based Virtual Machine (KVM) hosts. Both environments are deployed by the same YAML file, onpremise.yml.

Apart from demo Ansible playbooks, PXE playbook can be found too. This PXE playbook (pxe.yml) is the one in charge of installing new operating system on top of target K8s servers. It is the first step of tid-kube5g deployment. PXE uses the role which sends queries to IPMI lab endpoints to manage these servers from remote agents.

- **AWS SQS²**

AWS SQS is a fast, reliable, scalable, fully managed message queuing service. It enables to decouple the components of a cloud application simply and cost-effectively. SQS enables tid-kube5g to trigger the optional cloud deployment at AWS by sending a message to the queue within the AWS account configured containing *k8s-deployed* so next steps are triggered. These include deploying mobile core functions at cloud, deploying all functions on-site is also supported, and further service applications. Once main mobile core functions are ready, the user plane function is deployed at the edge site. Precisely, the SQS message let the code synchronize the deployment contained in a second repository called *awesome-5g-hacking*.

- **Virtualization infrastructure - Kubernetes (K8s³)**

Kubernetes is an open-source platform for managing containerized services with a powerful ecosystem. Kubernetes services, support, and tools are widely available and adopted. tid-kube5g uses K8s as orchestrator to load declarative applications such as mobile functions and services.

TID development within tid-kube5g takes advantage of Ansible and OpenShift libraries to provision the complete K8s infrastructure.


- **Open5GS – Mobile Core**

The mobile solution used for testing and demo purposes is Open5GS⁴. This is an open-source solution fully operative for LTE which is currently under

² <https://aws.amazon.com/sqs/>

³ <https://kubernetes.io/docs/concepts/overview/what-is-kubernetes/>

⁴ <https://github.com/open5gs/open5gs>

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development for 5G technology. It offers different flavours and the one leveraged at tid-kube5g is based on microservices.

The microservices approach enables the repository to change practically seamlessly the mobile core provider in an easy way, just switching to a different descriptor file. This open-source solution has been selected for the shake of demo purposes, but other commercial vendors could substitute this part.

3.1.2 The business perspective

Private networks are one of the key elements for the digital transformation of the industrial sector in the following 1-3 years. They enable all the pieces required to measure, automate and improve the industrial processes including not only the high-performance network but also the computing environments to host and run the business applications. This makes them critical systems that, on the one hand, are key for keeping the daily business operations running and in the other hand manage and store some of the most critical and sensitive pieces of information of the company. Thus, private networks must be secure by design.


TID envisions the private networks offering can be broken down into four concatenated elements: Cellular 5G connectivity, Local edge compute platform with local breakout, Value added apps for enterprise transformation and a management platform with a holistic view of all its components.

5G sits at the heart of this offering bringing secure Gbps wireless connectivity with enhanced capabilities to connect massive number of IoT devices with low latency. The implementation of 5G in businesses has originated through Private 5G Edge, which was formerly defined as dedicated connectivity, coupled with edge compute to implement use cases with strict security, performance or control needs. The impact for these use cases can be estimated in more than trillions of USD worldwide according to KPMG [4] and today are mainly centered around industry 4.0 (manufacturing/logistics) to automate operational processes. However, the impact is expected to go well beyond as the technology evolves with a transversal impact in all verticals, for example creating new unique immersive retail/entertainment experiences.

3.1.3 The technological perspective

tid-kube5g aims to be a one-click solution to deploy from bottom to top the infrastructure of an open industrial private mobile network. TID has developed it during the second phase of QU4LITY project and sets the basis of a private 5G network product for industry which continues its development.

tid-kube5g includes a microservices infrastructure hosting a disaggregated mobile core network with the ability to integrate with Cloud providers and deploy service applications. The repository comprises a set of scripts using Ansible, Terraform, Groovy and other tools to bootstrap bare metal servers or VMs (the repository is also ready to handle a deployment leveraging the opensource OpenNebula cloud

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infrastructure and could be adapted to use other platforms), configure them, install Kubernetes and deploy an LTE or 5G core on top. Besides, it is ready to deploy a service application and configure the breakout routing needed to work properly.

Industrial services require integration work to be done. This work will be demonstrated in WP6 at ASF experimental facility integrating Innovalia's remote quality assessment solution. The repository also requires customizing and configure the objective inventory where resources are going to be deployed as well as proper credentials. The solution uses groovy pipelines included in the repository, which are triggered from a Jenkins instance.

3.1.4 Documentation

Access Instructions

This repository is available at QU4LITY GitHub repository **tid-kube5g**. Access must be requested to project management team. tid-kube5g leverages a set of open-source tools and frameworks and it is not a licensed product.

Experiment Setup and Results

Telefonica's Connectivity Innovation laboratory was used for validation stage of the tid-kube5g solution. Once the CI/CD orchestration layer finished the deployment of the virtualization infrastructure, the mobile network components and the service application, a basic testing was conducted to assess the correct functioning of both mobile network and sample application e.g. Speed test, as well as the connectivity integration between them which is provided as code within deployment pipeline.


Note these are just validation tests to quickly assess correct functioning of the whole CI/CD orchestration. The test suite provided here do not aim to assess real performance limits of the solution, which will be conducted further on.

Mobile testing tool

To conduct tid-kube5g mobile connectivity testing, Spirent Landslide product was the core network testing tool selected during validation stage and used to stress the platform and validate the results. It comprises 2 elements:

- Test Administration Server (TAS) which acts as controller and must be publicly accessible from Internet,
 - Stores the test cases designed with Landslide Client,
 - Exposes RESTFUL API for automation,
 - Handles and registers Spirent licenses.
- Test Server (TS) which is the real testing module VM simulating nodes and generating traffic.

At least 1 TS element must be deployed as minimum, but more than 1 can be deployed depending on testing requirements. These components were deployed at local laboratory at COTS servers on top of KVM virtualization manager.

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TS deployed at Connectivity Innovation Laboratory is shown at Figure 2.

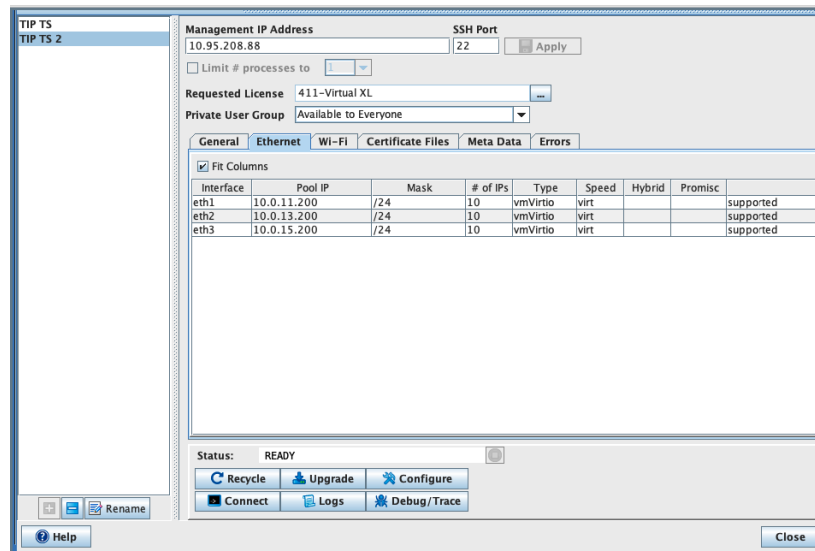


Figure 2. Test Server configuration details.

The license used for testing is described as Virtual XL allowing 1 TS server, Figure 3 shows the license applied at TS details. It comprises the MME Nodal module required for 5G-NSA mobile core testing.

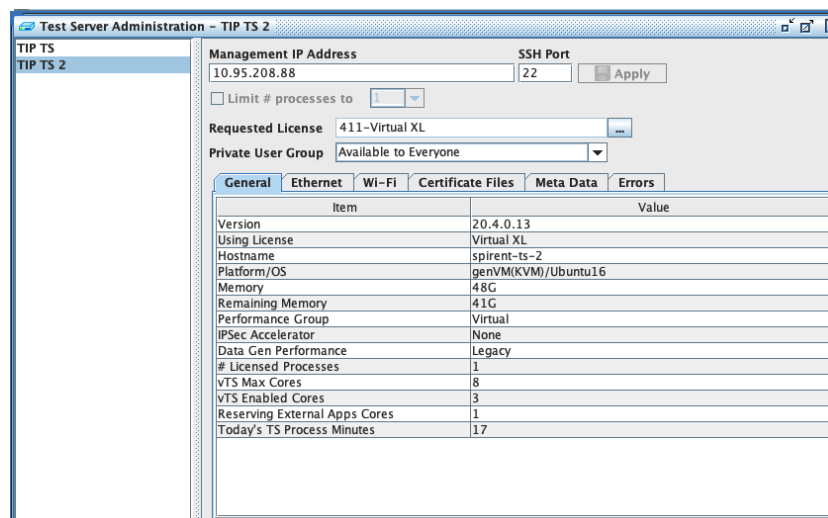



Figure 3. Spirent licensing used for tid-kube5g testing.

Such license enables the required 5G-NSA testing of the mobile core. Specifically, the system under test (SUT) comprises MME, SGW and PGW. Figure 4 shows the diagram loaded when developing the test behaviour.

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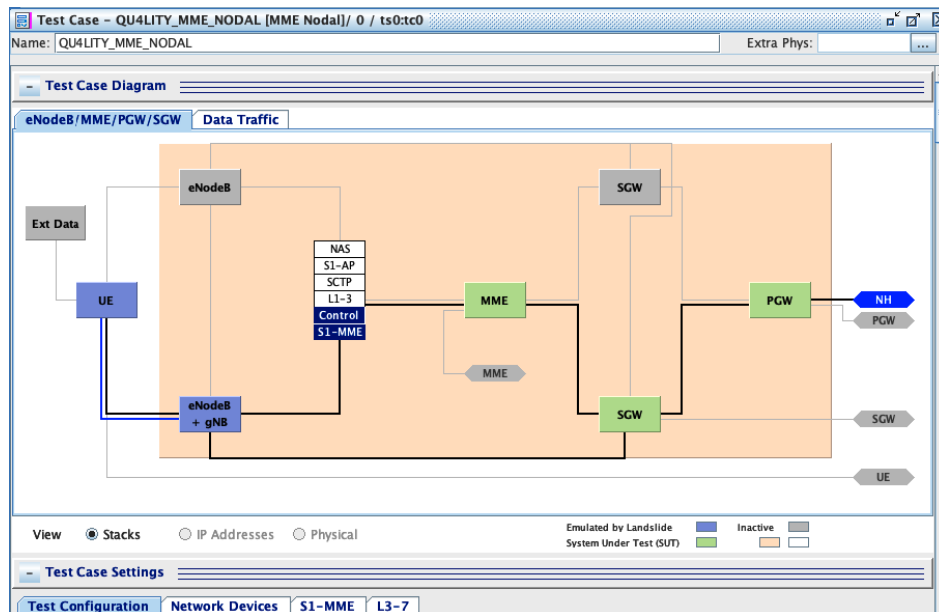


Figure 4. Spirent MME Nodal test architecture.

Testing architecture

Figure 5 shows the testing architecture used at Telefonica's Connectivity Innovation laboratory. Deployer server is used to host the CI/CD deployer to orchestrate infrastructure installation and configuration at Infra servers at the low part of the image. Spirent testing tool is also deployed locally at a different server simulating eNB/gNB and UEs.

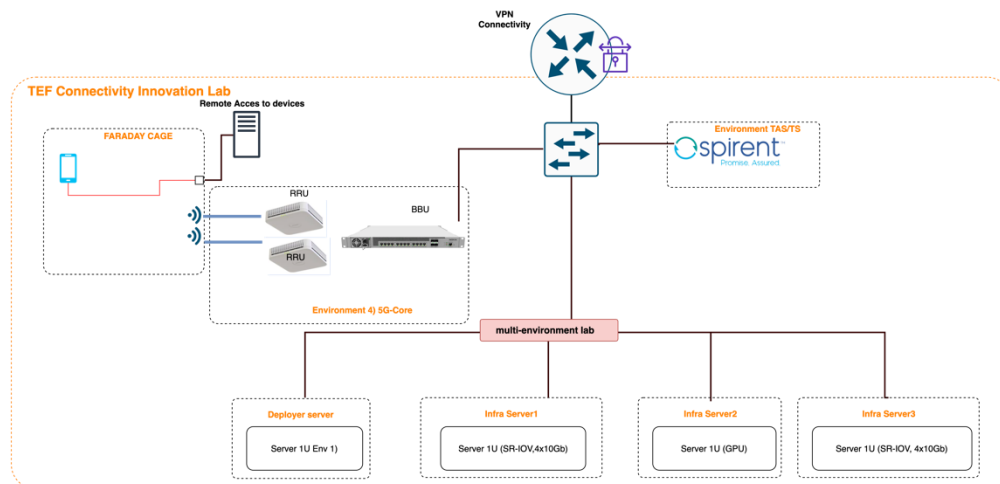


Figure 5. Connectivity Innovation laboratory architecture.

Testing suite

The basic testing suite used to validate the deployment aims to test:

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- The basic operation of a set of 1000 UEs provisioned during deployment generating a reasonable bandwidth of 100 kbps,
- IoT-like traffic generation to assess if the platform copes with data burst typically found at industrial environment,
- The correct connectivity integration of an application after deployment and configuration as well as the maximum bandwidth a single UE can generate through the mobile core deployed.

These tests are formally described as follows:

- Basic connectivity test - 1000 UE Attach at 100 kbps per session:

Description	<ul style="list-style-type: none"> - 1000 devices permanent attached during 10 minutes, - When attached, permanent bidirectional UDP traffic at 100 kb/s stream is generated.
Expected results	<ul style="list-style-type: none"> - 1000 average simultaneous sessions during stable phase, - 100 Mbps average bidirectional during stable phase.
KPI	<ul style="list-style-type: none"> - Throughput (Peak "L3 Client-> Total Bits/Sec") - Delay (Average "L5-7 Client -> Basic Data Message Round Trip Delay (P-I) (micro-sec)") - Active Sessions during stable phase (Average "Test Summary-> Sessions Established")
Attach rate	25.0 attachments/sec
Spirent Test type	Session Loading Test

Table 3. Tid-kube5g Test 1 basic connectivity definition.

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- IoT burst use case test:


Description	<ul style="list-style-type: none"> - 500 devices. - Permanently attached. - 10Mbps bidirectional burst UDP traffic during 10s followed by 90s without traffic.
Expected results	<ul style="list-style-type: none"> - 500 simultaneous sessions, - 1Gbps of peak traffic (10 MNs/sec*10sec of traffic*10 Mbps).
KPI	<ul style="list-style-type: none"> - Throughput (Peak "L3 Client-> Total Bits/Sec"), - Delay (Average "L5-7 Client -> Basic Data Message Round Trip Delay (P-I) (micro-sec)"), - Active Sessions during stable phase (Average "Test Summary-> Sessions Established").
Attach Rate	10.0 attachments/sec
Test type	Sequencer

Table 4. Tid-kube5g Test 2 burst definition.

- Application test - Speed test:

Description	<ul style="list-style-type: none"> - 1 device permanently attached performing speed test to local Speed Test application for 12 minutes. - The UE attempts to get the maximum throughput through the platform (Mobile Core and Application).
Expected results	Maximum achievable throughput per UE.
KPI	<ul style="list-style-type: none"> - Throughput (Average "Test Summary-> Sessions Established").
Attach rate	25.0 attachments/sec
Spirent Test type	Capacity Test

Table 5. Tid-kube5g Test 3 Speed test definition

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Above test suite is developed at Spirent Landslide. A library called QU4LITY is generating which includes a test session per test case as shown in Figure 6.

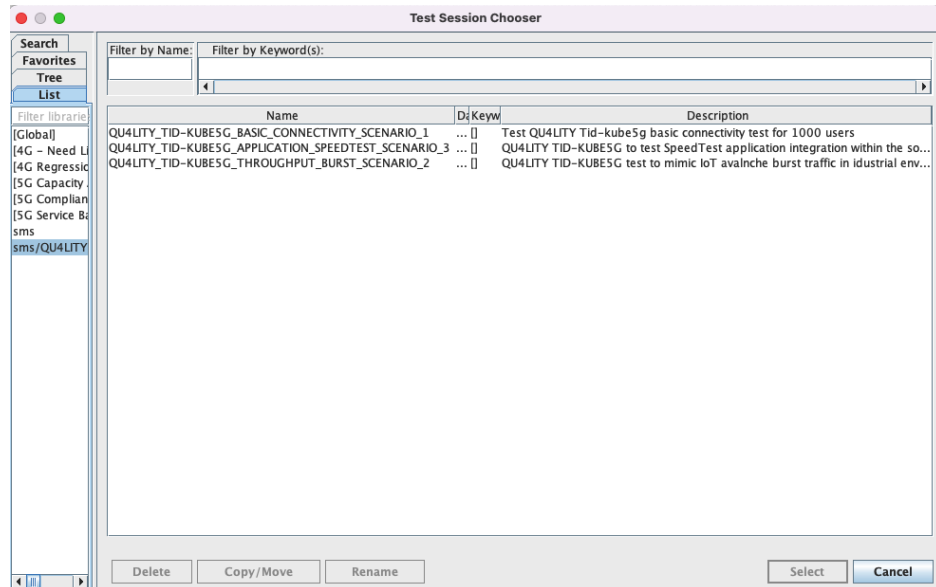


Figure 6. QU4LITY Tid-kube5g test suite.

Test results

Hereafter are listed the results obtained during the execution of the test suite described above. All have been conducted manually and are planned to be automated with Robot Framework suite to conduct performance testing automatically within CI/CD pipeline.

- Basic connectivity test - 100 UE Attach results:

Throughput result should be 100 kbps * 1000 UEs which equals 100 Mbps. Figure 7 shows the Spirent graph generated. It shows 100 Mbps maintained during the whole duration of the tests.

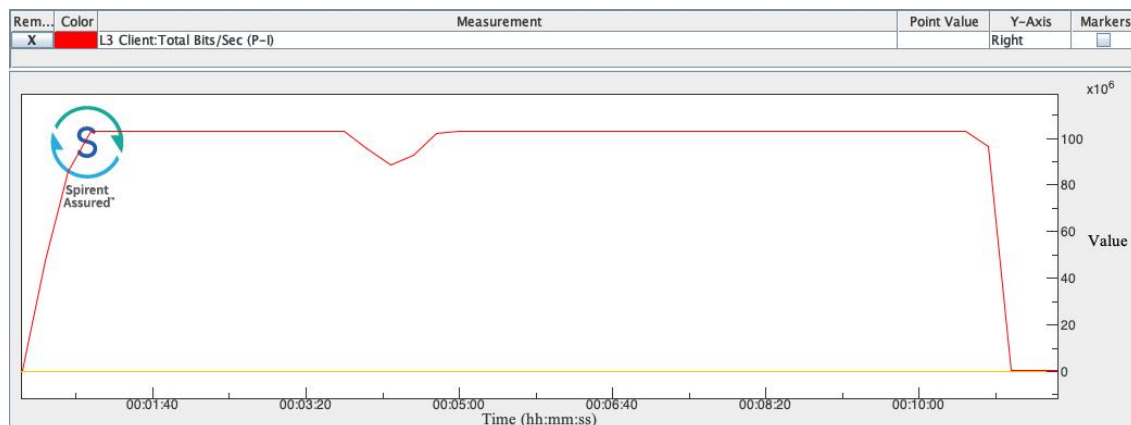



Figure 7. Basic connectivity test throughput result.

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Expected and resulted concurrent users are 1000 UEs, which are the total of UEs provisioned during deployment. Figure 8 shows the concurrent total users generated during the test.

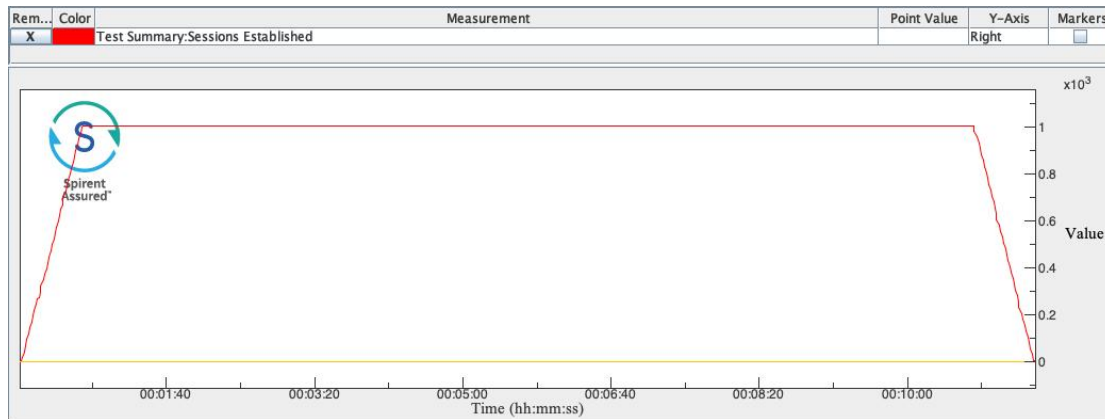


Figure 8. Basic connectivity test session established result.

- IoT burst use case test result:

The aggregated result obtained was of 250 Mbps at each burst of 2,5 minutes of throughput with 500 UEs as shown at Figure 9. This maximum throughput is limited by the current test setup available in Telefonica Laboratory.

Lab router has a limitation of 1 Gbps in one of the links used with RJ45 interface and both client and server traffic goes to the same VM so traffic obtained at TS must be multiplied by 4 ($4 * 250 \text{ Mbps} = 1 \text{ Gbps}$).

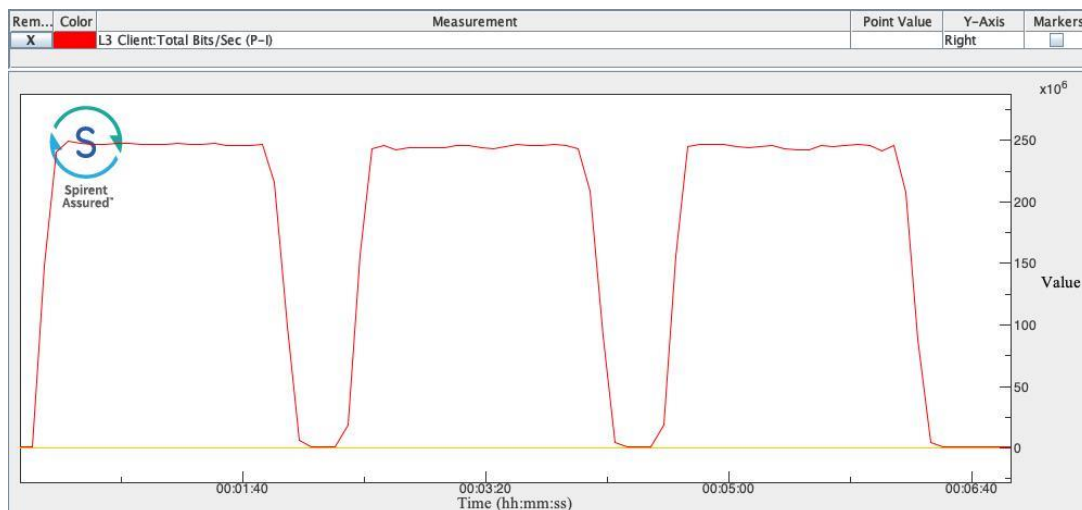

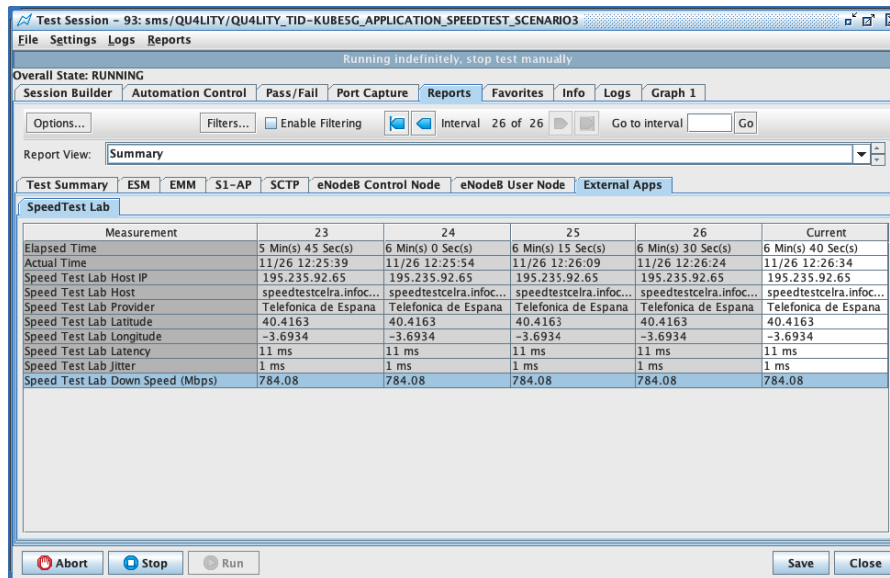


Figure 9. QU4LITY burst test 2

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- Application test – Speed test results:

Figure 10 and Figure 11 shows the results obtained by 1 UE spanned during 12 minutes, it was accomplished a stable rate of 784 Mbps with 11 ms of latency.



Test Session - 93: sms/QU4LITY/QU4LITY_TID-KUBE5G_APPLICATION_SPEEDTEST_SCENARIO3

File Settings Logs Reports

Running indefinitely, stop test manually

Overall State: RUNNING

Session Builder Automation Control Pass/Fail Port Capture Reports Favorites Info Logs Graph 1

Options... Filters... ☐ Enable Filtering Interval 26 of 26 Go to interval Go

Report View: Summary

Test Summary ESM EMM S1-AP SCTP eNodeB Control Node eNodeB User Node External Apps

SpeedTest Lab

Measurement	23	24	25	26	Current
Elapsed Time	5 Min(s) 45 Sec(s)	6 Min(s) 0 Sec(s)	6 Min(s) 15 Sec(s)	6 Min(s) 30 Sec(s)	6 Min(s) 40 Sec(s)
Actual Time	11/26 12:25:39	11/26 12:25:54	11/26 12:26:09	11/26 12:26:24	11/26 12:26:34
Speed Test Lab Host IP	195.235.92.65	195.235.92.65	195.235.92.65	195.235.92.65	195.235.92.65
Speed Test Lab Host	speedtestcelra.infoc...	speedtestcelra.infoc...	speedtestcelra.infoc...	speedtestcelra.infoc...	speedtestcelra.infoc...
Speed Test Lab Provider	Telefonica de Espana	Telefonica de Espana	Telefonica de Espana	Telefonica de Espana	Telefonica de Espana
Speed Test Lab Latitude	40.4163	40.4163	40.4163	40.4163	40.4163
Speed Test Lab Longitude	-3.6934	-3.6934	-3.6934	-3.6934	-3.6934
Speed Test Lab Latency	11 ms	11 ms	11 ms	11 ms	11 ms
Speed Test Lab Jitter	1 ms	1 ms	1 ms	1 ms	1 ms
Speed Test Lab Down Speed (Mbps)	784.08	784.08	784.08	784.08	784.08

Abort Stop Run Save Close

Figure 10. Speed test table results.

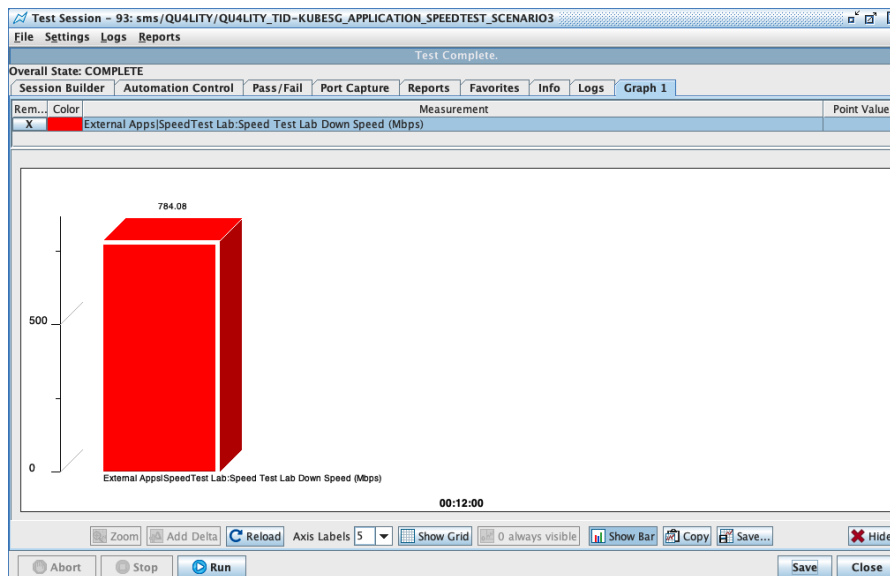



Figure 11. Speed test throughput results.

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Quick Start Guide

All steps to run and try are available at [tid-kube5g](https://github.com/qu4lity/tid-kube5g)⁵.

Content Available

Full content available at [tid-kube5g](https://github.com/qu4lity/tid-kube5g)⁵.

3.1.5 Deployment and Use in QU4LITY Pilots/Exp-Fac.

Related to the immediate future and in the scope of QU4LITY project, TID, AIC and Innovalia have defined a joint work to showcase the work developed in the project. The use case defined aims to remotely assess quality of automotive pieces leveraging Innovalia's software while using 5G and edge technologies. This work will be conducted in QU4LITY's experimental facility Automotive Smart Factory (ASF) and results will be reported in the scope of WP6.

3.1.6 Future work

At the time the current version of [tid-kube5g](https://github.com/qu4lity/tid-kube5g) was developed, only LTE access and core mobile solutions were at our disposal. 5G technology was under development and commercial solutions were not available on the market yet. During this time, the 5G technology has been partially adopted and developed (first commercial handsets are already available, RAN vendors begin to release their new products, etc.) as well as open-source projects have released new versions supporting the new 3rd Generation Partnership Project (3GPP) core interfaces and the defined service-based architecture.

TID aims to integrate and test 5G technology within the defined pipeline of [tid-kube5g](https://github.com/qu4lity/tid-kube5g) besides including, testing and supporting business applications on top of it.

3.2 CEA management solution for TSN

CEA utilises SDN to implement an IEEE 802.1Qcc-compliant solution that manages and configures a TSN network. During development conducted during QU4LITY project, CEA has put focus on the management and configuration of two key TSN standards, namely IEEE 802.1AS and IEEE 802.1Qbv. A testbed of end-nodes and switches has also been setup for this purpose.

IEEE 802.1AS allows to synchronize the clocks of the network nodes with sub-microsecond accuracy. Then, given that the nodes' clocks were synchronized, IEEE 802.1Qbv allows scheduling the network streams and protecting the performance of TSN streams from best-effort streams. The processes of IEEE 802.1AS and IEEE 802.1Qbv are configured by an SDN-based management tool, complying with the standard 802.1Qcc

⁵ <https://github.com/qu4lity/tid-kube5g>

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3.2.1 Digital enabler overview

CEA's TSN management solution is based on evolved standards to provide deterministic features for Ethernet networks. TSN is a collection of mechanisms developed for IEEE 802.1. These mechanisms aim at ensuring (i) synchronization among TSN equipment, providing (ii) low packet loss rates, and (iii) low and stable end-to-end latencies.

IEEE 802.1Qcc standard describes how to manage and configure TSN network. The model of the CEA TSN management solution based on 802.1Qcc is described in Figure 12. In this picture, the data plane includes three switches, two end-nodes, i.e., one talker and one listener, whereas the control plane includes CNC and CUC.

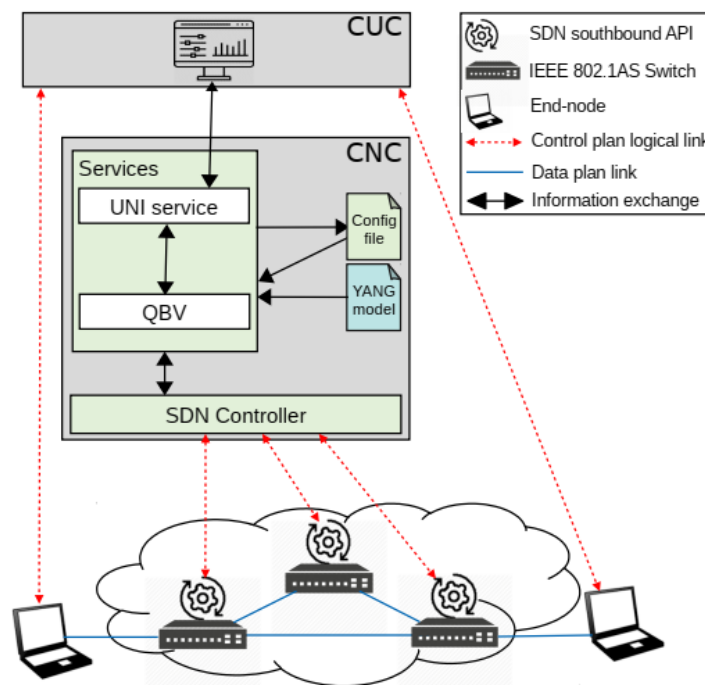



Figure 12 – TSN networking model.

The CNC is a centralized component that configures network resources on behalf of TSN applications or users. The CUC (Figure 13) oversees discovering end-nodes, retrieving end-node capabilities and user requirements, then configuring TSN in end-nodes. The CUC exchanges information with the CNC to configure TSN on behalf of the corresponding end-nodes.

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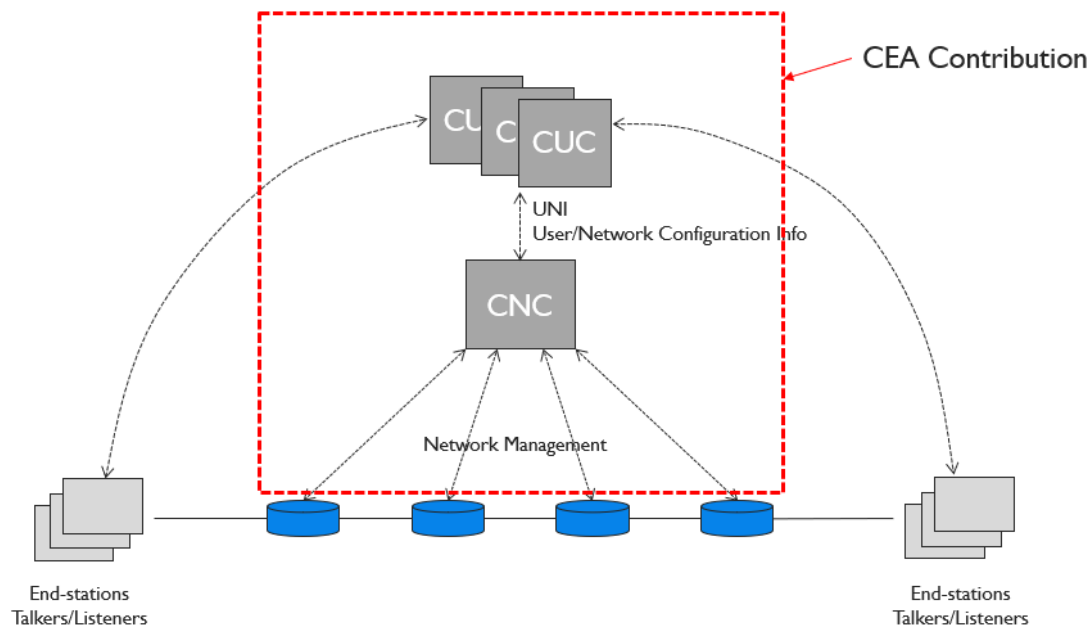


Figure 13 –IEEE 802.1Qcc architecture.


The SDN controller and the TSN-related SDN services act as a CNC entity. The SDN controller communicates with the devices and services through SDN southbound and northbound protocol, respectively. This controller logically connects to all devices, having a global view of the network. The services run on top of the controller, providing functionalities such as monitoring devices, deciding new configuration, and executing time synchronization.

3.2.2 The business perspective

In general, the industrial network market is shifting from Fieldbus to Ethernet-based solutions, with 20% annual growth of Ethernet-based solutions compared to -5% of Fieldbus in 2019⁶. Particularly in the project consortium, most of the industrial partners are using Profibus and Profinet, which are also Ethernet-based technologies. On the other hand, TSN, a new Ethernet-based technology, is developed and adopted rapidly in industrial communication. For example, in 2019, Profinet spec 2.4 integrated TSN while in 2020, 3GPP Rel-16 integrated TSN 802.1AS. As a result, TSN is expected to be an important enabler in future industrial networks.

With the emerging of Industry 4.0 and its concepts of quality, e.g., ZDM and Autonomous Quality, the future industrial networks shall satisfy two important requirements: (i) fast/real-time communications, and (ii) flexible and reconfigurable management. As a result, there is a rapidly growing market in which TSN fulfils the ZDM requirements. Therefore, in the context of the project, we developed a solution that flexibly manages the TSN network, focusing on 802.1AS Time Synchronization and 802.1Qbv Traffic Scheduling.

⁶ HMS, "Industrial network market shares 2019", 2019

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3.2.3 The technological perspective

Figure 3 describes the implementation that has been conducted within the context of QU4LITY project. Specifically for the shake of development and validation, CEA has setup a network with 802.1AS-compliant end-nodes and 802.1Qbv-compliant switches at its local laboratory. Then, it has been implemented onto these devices the software that support IEEE 802.1AS, 802.1Qbv and 802.1Qcc standards. CUC and CNC are 802.1Qcc components which communicate with each other using RESTCONF. The functionalities of CUC and CNC are described as follows.

- CUC:
 - Collects data requests and data publishers' characteristics and constraints from end-nodes,
 - Exports the list of streams that will be exchanged in the network.
- CNC:
 - Enforces reservation of resources in the network using TSN standards based on streams constraints,
 - Uses an SDN (Software-Defined Network) approach,
 - Communicates with the switches using SDN-based southbound protocol to configure and monitor the switches.

The proposed solution includes several TSN services that interwork together to provide proper TSN configurations. The two main services of 802.1AS are ASMonitoring and TSNservice.

- ASMonitoring: this service monitors, via controller, the network devices, computes proper values for AS parameters, and generates AS configuration file for each device,
- EthernetTSN: this service takes the generated files and sends them to the devices via the controller. The talker is the grand master (GM), which provides clock reference to other devices.


The two main services of IEEE 802.1Qbv are UNI and Qbv services.

- UNI: this service takes information streams from CUC, validates against UNI Yang model, then sends to Qbv service,
- Qbv: it validates the information from UNI service and translates such information to hardware-specific configuration i.e., switches' gate configuration.

3.2.4 Documentation

Access Instructions

CEA TSN solution cannot be accessed publicly from outside, it can only be observed and verified on-site at CEA's laboratory in Palaiseau, Paris Area, France. CEA also

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plan to showcase this solution at FFLOR demonstration, within the context of QU4LITY project. The on-site access is done on-request via the CEA team contacts:

- Minh-Thuyen Thi (minh-thuyen.thi@cea.fr),
- Siwar Ben Hadj Said (siwar.benhadjsaid@cea.fr),
- Michael BOC (michael.boc@cea.fr).

Experiment Setup and Results

CEA experiment workflow is described as follows: it is firstly run 802.1AS to synchronize the clocks, so 802.1Qbv can be run afterwards, since its functionalities rely on the synchronized clocks of 802.1AS. Besides, ASMonitoring and TSNservice services, 802.1Qbv services as in Figure 12, are used for managing and configuring 802.1AS.

To evaluate the performance of time synchronization, it is measured the offset between the clock of each node and the clock of GM. In Figure 14, it can be seen that the clocks of GM and the listener are synchronized to each other. Before that, the difference between two clocks is in the order of million seconds. Inside the above sub-chart of Figure 14, although the curve appears to be completely horizontal before dropping down, the clock time of the listener indeed increases. This is because the measurement is at the scale of million seconds. Similarly, inside the below main chart, although the drop-down curve appears to be completely vertical, the clock time indeed decreases over real time (as seen in the above sub-chart). After synchronization, the two clocks practically tick at the same rate.

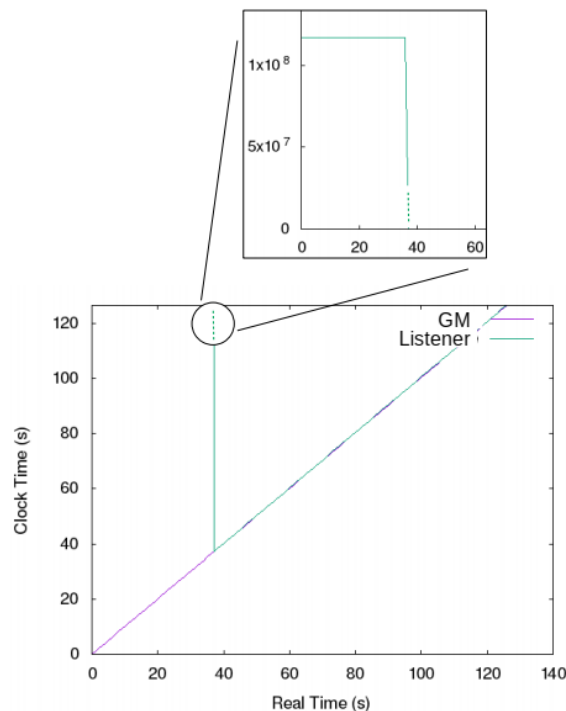


Figure 14 – Clock of listener and GM during synchronization.


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Figure 5. Clock of listener and GM during synchronization.

In Figure 15, when a device is synchronized, the offset between it and the GM is on the scale of hundred nanoseconds. This is a tight accuracy for local area network, compared to other works in the literature, which have the offset “on the microsecond scale”, as stated in [5]. More results about 802.1AS experiment can be found in [1].

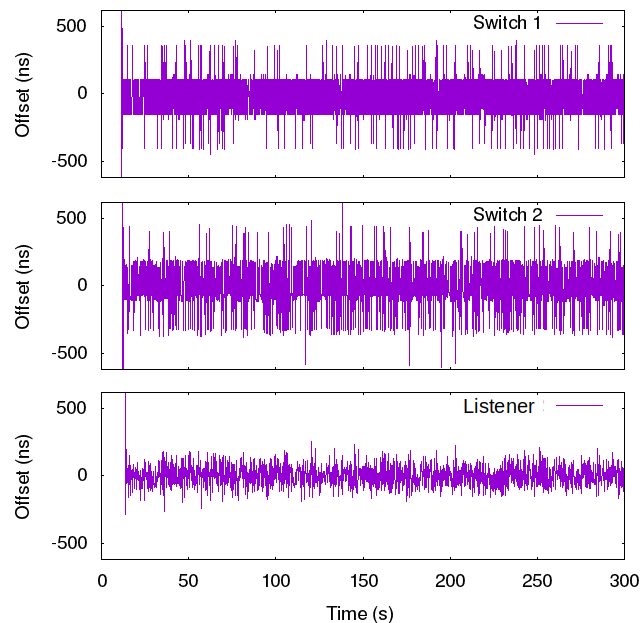



Figure 15 – Time offset between each node and GM.

The experiment workflow for 802.1Qbv is as follows:

- CUC defines talker and listener for the network streams, then sends stream information to CNC,
- CNC validates information, generates configurations, and sends configurations to network nodes,
- The network nodes apply configurations.

After the network nodes apply configurations, the impact of new configurations on can be seen on the network streams.

The experiment defines two network streams, one TSN stream and one best-effort stream. Figure 16 describes best-effort and TSN streams.

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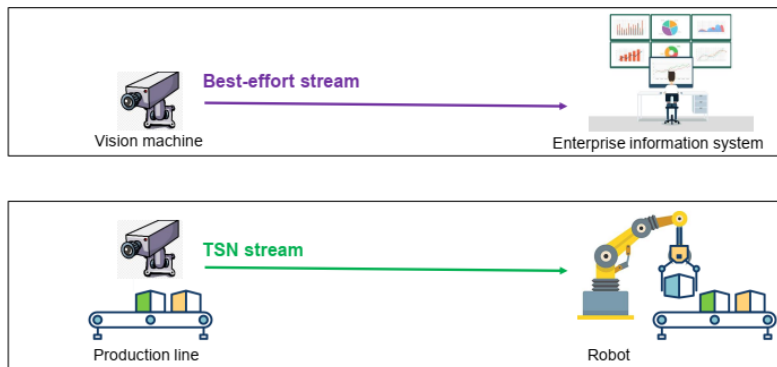


Figure 16 – TSN experiment network streams.

The CUC defines talker and listener endpoints as shown in Figure 17

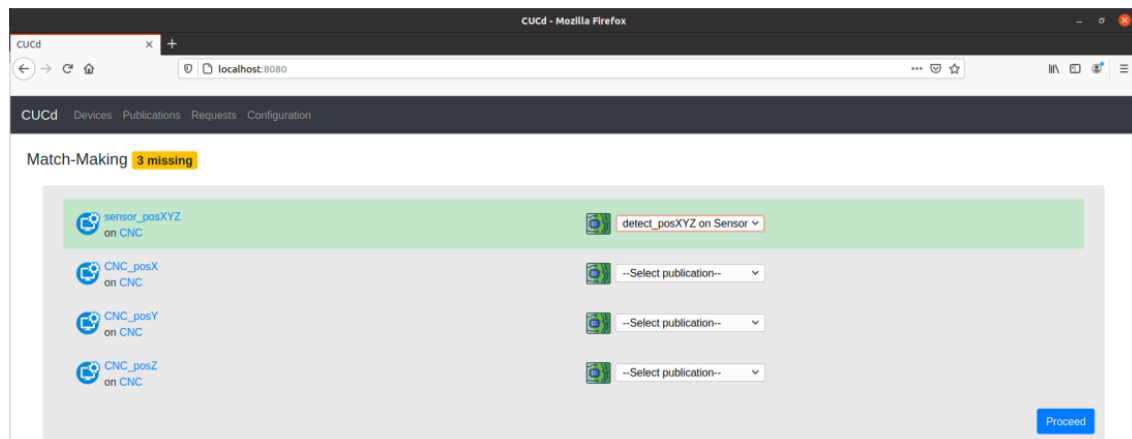



Figure 17 – Talkers and listeners definition at CEA TSN solution.

Before applying 802.1Qbv configuration, the transmission latency of two streams is similar, as shown at Figure 18, since there is no prioritization.



Figure 18 – Similar latency values without TSN applied.

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Once 802.1Qbv standard is applied, the latency of the TSN stream is kept low, while the latency of best-effort stream grows. Figure 19 shows this behaviour.

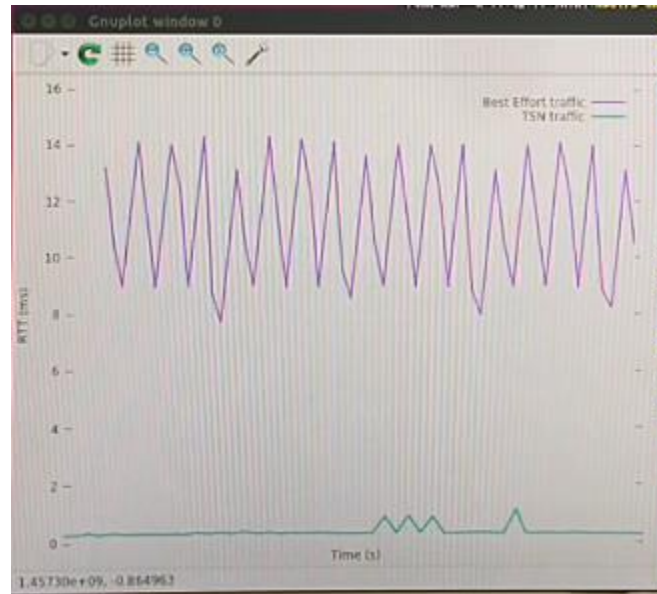


Figure 19 – Latency with 802.1Qbv.

It can be observed that the new 802.1Qbv configuration protects the performance of the TSN stream. In the context of autonomous quality, this stream could be the communication between a vision machine and a robot. The real-time communication would allow the robot to react rapidly when there is a defect detected by the vision machine.

3.2.5 Deployment and use in QU4LITY Pilots/Exp-Fac.

CEA's TSN solution is planned to be showcased at FFLOR platform, in which a TSN network for a production line is demonstrated. The real-time traffic between the sensors and the robots is transmitted through the TSN switches and all devices are configured and monitored by SDN-enabled Qcc-compliant controller. With the support of 802.1AS and 802.1Qbv, the real-time traffic is scheduled so as to protect it from best-effort traffic.

3.2.1 Future work

FFLOR platform is going to be enhanced in the scope of WP6 to support CEA TSN solution. In the upcoming months, the infrastructure needed to support the TSN architecture will be provided.

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4. Conclusions

4.1 Tid-kube5g

This work evaluates the feasibility of leveraging K8s clusters for deploying cloud-native connectivity services in next-gen networks of primal importance for Industry 4.0. It has revealed the additional necessary CNI plugins needed (e.g., Multus) and provide an automated way of managing the whole lifecycle of the tid-kube5g deployment. It is expected this work can shed some light on the additional necessary CNI plugins that are needed to handle telco-grade network payload (e.g., Stream Control Transmission Protocol (SCTP)).

The code illustrating the usage of tid-kube5g is available at tid-kube5g⁷. As future work it is planned to continue the experimentation to handle additional networking and Enhanced Platform Awareness (EPA) complexities not included natively on K8s.


Tid-kube5g solution was demonstrated at TID lab automatically deploying a speed test application and leveraging Telefonica LTE mobile access to showcase the potential of the repository. A video of the whole demonstration has been provided to QU4LITY private repository. It shows a fresh infrastructure deployment from scratch performing the following steps:

- Bootstrap of physical servers,
- Deployment of local K8s orchestrator,
- Configuration of K8s,
- Configuration of SDN controller and meta CNI controllers,
- Cloud infrastructure deployment at AWS (full Open-source LTE mobile core)
- Local mobile data plane deployment (Open5GS UPF),
- RAN interconnection,
- Speed test application deployment,
- Manual test from a real 4G device.


4.2 CEA TSN Controllers

CEA has presented an SDN-based solution for managing and configuring TSN, currently focusing on IEEE 802.1AS, IEEE 802.1Qbv, and IEEE 802.1Qcc. CEA designs, implements, then evaluates the performance of time synchronization [1] and TSN scheduling. In this document, it is mainly presented the TSN scheduling evaluation for the scenario of ZDM, in which the performance of TSN stream is protected from the best-effort stream. The implementation of configuration process complies to 802.1Qcc in the aspects of stream definition, YANG models validation, UNI service.

⁷ <https://github.com/qu4lity/tid-kube5g/tree/tid-kube5g>

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For future works, CEA will consolidate and enhance this implementation by adding new automating features such as automatically generating new configurations according to the dynamics of the system.

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References

- [1] S. B. H. S. a. M. B. M. -T. Thi, ""SDN-Based Management Solution for Time Synchronization in TSN Networks"," in *ETFA*, 2020.
- [2] PROFIBUS Nutzerorganisation e.V. (PNO), "The goals of integration of TSN into Profinet URL," February 2018. [Online]. Available: <https://www.profibus.com/newsroom/press-releases/the-goals-of-integration-of-tsn-into-profinet>.
- [3] ""Integration of TSN in PROFINET Makes Great Strides"," 2019. [Online]. Available: <https://profinews.com/2017/12/integration-of-tsn-in-profinet-makes-great-strides>. [Accessed May 2020].
- [4] KPMG, "Move to 5G telecom networks will unlock US \$4.3T in economic value," [Online]. Available: <https://home.kpmg/ca/en/home/media/press-releases/2019/05/move-to-5g-networks.html>.
- [5] A. D. T. K. I. M. M. M. a. G. K. P. Volgyesi, ""Time synchronization services for low-cost fog computing applications," in 2017. IEEE,, " *International Symposium on Rapid System Prototyping (RSP)*, p. 57–63, 2017.

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List of Abbreviations

Acronym	Abbreviation
ASF	Automotive Smart Factory
CI/CD	Continuous Integration/Continuous Development
CNI	Container Network Interface
CNC	Centralized Network Configuration
CUC	Centralized User Configuration
DMZ	Demilitarized Zone
eMBB	enhanced Mobile BroadBand
EPA	Enhanced Platform Awareness
Iac	Infrastructure as code
IoT	Internet of Things
IRT	Isochronous Real-Time
IT	Information Technology
KVM	Kernel-based Virtual Machine
K8s	Kubernetes
LTE	Long Term Evolution
mMTC	Massive Machine-Type Communication
OSI	Open Systems Interconnection
pac	Pipelines as code
PI	PROFINET International
PXE	Preboot eXecution Environment
RAN	Radio Access Network
RT	Real-Time
SCTP	Stream Control Transmission Protocol
SDN	Software Defined Network
TSN	Time Sensitive Network
UPF	User Plane Function
URLLC	Ultra-Reliable Low-Latency Communications
VLAN	Virtual LAN
VM	Virtual Machine
YAML	Yet Another Markup Language
ZDM	Zero Defect Manufacturing
3GPP	3rd Generation Partnership Project

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