F5G Proof of Concept:

General Information and

List of PoCs

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# 1 Introduction

The ISG F5G proposes an end-to-end ecosystem for the fixed network leveraging the fibre to everywhere paradigm. The ISG F5G targets a broad application area enabling new and/or enhanced services to residential and business users, to telecom operators and service providers, to industry digital transformation and any other areas that may be identified along F5G system development. Therefore, an F5G system has the flexibility and adaptability to be able to serve various applications and services with different traffic characteristics and cover a variety of performance and functional requirements needed for different deployment scenarios.

Proof of Concepts (PoC) are an important tool to demonstrate the F5G system as a viable technology. Results from PoCs may guide the work in the ISG F5G by providing feedback on interoperability and other technical challenges. The public demonstration of these ISG F5G concepts will help build commercial awareness and confidence in the ISG approach, and develop a diverse, open F5G ecosystem. A single PoC demonstration will impact its immediate audience, but a cumulative set of successful PoCs will provide industry momentum for ISG F5G concepts.

The purpose of the present document is to keep the information on PoCs and listing the status of the PoC activities in the ETSI ISG F5G.

The present document is a living document regularly updated to reflect the changes in the ETSI ISG F5G with regards to PoCs. The document is located in the open area under <https://docbox.etsi.org/ISG/F5G/Open/PoC_Material>

For details of the PoC framework please refer to [1].

# 2 References

For the purposes of the present document, the following references apply:

NOTE: While any hyperlinks included in this clause were valid at the time of publication ETSI cannot guarantee their long term validity.

[1] ETSI ISG F5G, F5G Proof of Concept Framework, V1.1.1, June 2021

# 3 PoC Framework Documents

The ETSI ISG F5G Proof of Concept (PoC) Framework GS describes the full ISG F5G PoC activity process, roles, responsibilities, acceptance criteria, etc. It is encouraged to present the results/demos of a PoC at conferences, events, and at F5G meetings.

The latest version of the F5G Proof of Concept Framework document [1] can be downloaded here: <https://www.etsi.org/deliver/etsi_gs/F5G/001_099/009/01.01.01_60/gs_F5G009v010101p.pdf>

For convenience of the PoC Teams, direct links to the F5G PoC Proposal/F5G PoC Report Templates can be found under <https://docbox.etsi.org/ISG/F5G/Open/PoC_Material>

# 4 PoC Review Team

**Description of the role of the PoC Review Team (from [1]).**

* Providing guidance and support during the creation of PoC proposals;
* Evaluating PoC proposal conformance with the acceptance criteria declaring the acceptance/refusal of each PoC;
* Notifying acceptance/refusal of each PoC in the ISG\_F5G@list.etsi.org' mailing list and allow for 10 days for remote consensus approval (no objections received).
* Compiling the accepted PoC Proposals and Reports and making them available to the ISG F5G;
* Monitoring the PoC project timelines, and sending the appropriate reminders to the PoC Teams (for expected contributions, PoC report, etc.).

**PoC Review Team Members**

* ISG F5G Chair
* ISG F5G Secretary
* ETSI Technical Officer
* Rapporteur of Use Cases Documents
* Rapporteur of PoC Framework

# 5 List of Proof of Concepts

The following list of PoCs shows the current status and contains to the PoC proposals and the PoC report when finished. Only approved PoC will be added to the public list.

NOTE: The status can be submitted, agreed, running, or finished.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Nr | Short Description | Status | Refer to Proposal | Refer to  Final Report |
| 1 | Industrial PON |  |  |  |
|  | This PoC demonstrates the Industry PON use case in a real customer factory environment. This customer is a sheet metal manufacturing enterprise. This enterprise is committed to realizing production automation and intelligent R&D capability. They have a strong demand for digital and intelligent production line. The following are the problems to be solved:   * Today’s production network is complicated and unreliable, which may potentially damage the equipment. * To prepare the network infrastructure for intelligent applications such as machine vision in production line. * Current production network cannot be accessed directly from office area, therefore requires optimization * There is insufficient video surveillance in the whole industry park area.   **Results:**  The Industrial PON system has been installed and runs on the shop floor and in the office area of a metal sheet production company.  Several applications are tested including an industrial ONUs connected for a fibre to the machine (FTTM) communication/industrial production network, surveillance network, and the office communication network.  The manufacturing company need to improve the digitalization of the production presses including logistics, quality control, production monitoring and visualization, and Industrial PON is a prerequisite to achieve this.By deploying industrial PON, the new network can meet the needs of service requirement:   * The production network topology is improved. Before industrial PON deployment, the production network topology was complicated and network managing was unclear, the network is unreliable and the network connection maybe lost, which may potentially damage the equipment. * Some intelligent applications such as machine vision in production line can be deployed because of the industrial PON’s large bandwidth and low latency capabilities. * The production network can be accessed directly from office area. * A large number of video surveillance stations is deployed in the whole industry park area and are connected via industrial PON. * The operator is responsible for network operation and maintenance, and enterprise no longer needs to pay attention to network operation.   PoC demonstration was performed at the "Guanghua Cup 2022" which is biggest optical network application innovation competition in China and hosted by CAICT. | finished | [F5G(21)000259](https://docbox.etsi.org/ISG/F5G/05-CONTRIBUTIONS/2021/F5G(21)000259_PoC_Proposal_Joint_demonstration_for_industrial_PON_scenario.docx) | [F5G(22)011023](https://docbox.etsi.org/ISG/F5G/05-CONTRIBUTIONS/2022/F5G(22)011023_PoC_status_update.pptx)  (intermediate report)  [F5G(23)013016](https://docbox.etsi.org/ISG/F5G/05-CONTRIBUTIONS/2023/F5G(23)013016_PoC_Report_Joint_Demonstration_For_Industrial_PON.zip)  (final report) |
| 2 | Telemetry Streaming |  |  |  |
|  | This PoC demonstrates enhanced traffic monitoring and fine granular telemetry streaming solutions for optical access networks. In other words, the PoC focuses on the use case of traffic monitoring and data analytics and demonstrates a full Machine Learning (ML) pipeline comprising telemetry retrieval from data sources (i.e., Optical Line Terminal (OLT)), telemetry broker, real time write/read to/from Time Series Databases (TSDB), telemetry consumption by the ML models for traffic forecasting, and eventually the ML-assisted solution. The ML-assisted solution targets Quality of Experience (QoE) as well as operation and maintenance improvement of the optical access networks.  **Results:** The PoC has been performed and results have been presented, published and demonstrated at various events:   * NGON & DCI World, 2022, Barcelona, Spain. * Demonstration at ECOC 2022, Basel, Switzerland. (see the recorded demo at https://www.youtube.com/watch?v=5moNFa7uhzc) * Demonstration F5G Meeting #74, 2022. * 2nd Colloquium on FRONT-EDGE – Future Optical Networking: The Edge, collocated with (CSNDSP’22), Porto, Portugal. * 6G Research and Innovation Cluster (6G-RIC) Flagship Project Plenary Meeting, Berlin, Germany, 13-16 June, 2022 (<https://6g-ric.de/>)   The PoC contributed to the F5G Telemetry Work Item and the AI-based Prediction and Analysis part of the F5G architecture. | finished | [F5G(22)000035r1](https://docbox.etsi.org/ISG/F5G/05-CONTRIBUTIONS/2022/F5G(22)000035r1_PoC_Project_Proposal__Precise_Traffic_Monitoring_and_Telemet.docx) | F5G(22)[000130](https://docbox.etsi.org/ISG/F5G/05-CONTRIBUTIONS/2022/F5G(22)000130_Final_Report_and_Demonstration_of_PoC__Precise_Traffic_Monit.zip) |
| 3 | Optical Service Networks |  |  |  |
|  | This PoC demonstrates the F5G optical service networks by combining 10G-PON and next generation OTN technologies to carry premium home services. The demo specifically showed the Cloud Virtual Reality (Cloud VR) application, which requires stringent guaranteed network performance including high bandwidth, low latency and jitter, low packet loss rate. In particular, the PoC also shows a solution for dynamic on-demand provisioning and adapting the premium network service with protocols running between the user’s home and the cloud.  **Results of Version 1:**  The PoC Version 1 was demonstrated at OFC 2022  Contribution were made to the F5G architecture  The PoC shows that the concept is working for the first scenario, other more complex scenarios and use cases will follow.  **Results of Version 2:**  The PoC demonstration showed multiple users accessing from different ONUs requesting to run Cloud VR applications, the servers for which are deployed in different Cloud DCs.  The demonstration shows that the AggN Edge OTN node is selected correctly for different users who are requesting different Cloud VR applications deployed in different Cloud DCs, and the traffic of the Cloud VR service is directed to the OTN AggN correctly after the OTN service connection is created.  In both Ver1 and Ver2 of the PoC, the users can play with the Cloud VR applications smoothly, indicating that the performance of the E2E network satisfies the experience requirements of the Cloud VR application.  The PoC Ver2 demo has been shown at ECOC’22 and ACP’22.  Venue: ACP 2022, Shenzhen, China; Industry Forum -- Session1: All Optical Transport Network in F5G and Beyond; Saturday, 5 November 2022, 9:00-12:20  Prof. Yongli Zhao from BUPT gave a presentation on “Next-Generation Optical Networks for Cloud Service”, and summarized the progress and achievement of this PoC and the related standards in ISG F5G. | V1 finished  V2 finished | [F5G(22)000039r1](https://docbox.etsi.org/ISG/F5G/05-CONTRIBUTIONS/2022/F5G(22)000039r1_PoC_proposal__Optical_Service_Networks_for_Cloud_VR_Applicat.docx) | [F5G(22)000049r1](https://docbox.etsi.org/ISG/F5G/05-CONTRIBUTIONS/2022/F5G(22)000049r1_Summary_of_PoC_v1_of__Optical_Service_Networks_for_Cloud_VR_.zip) (report of V1)  [F5G(22)012029r1](https://docbox.etsi.org/ISG/F5G/05-CONTRIBUTIONS/2022/F5G(22)012029r1_PoC_Report_of_F5G_PoC__3__Optical_Service_Networks_for_Cloud.zip)  (final report) |
| 4 | Edge/Cloud-based Visual Inspection for Quality Assessment of Products | | | |
|  | This interactive PoC demonstration presents an AI-based vision analysis, implemented on an edge cloud for a visual inspection scenario of additive manufactured artefacts in production processes.  The PoC focuses on demonstrating different features such as an end-to-end manufacture control loop, comprising of an industrial camera – edge cloud – robot arm, connectivity between all these components via a passive optical network (PON), including fiber-to-the-camera and fiber-to-the-robot, and an AI-based video analytics/vision analysis of customizable 3D-prints on the edge cloud consisting of a full video-edge-robot pipeline.  As a result, a general low-latency ML-based video processing-pipeline will be implemented to access video data from the demo environment as fast, as detailed, and as reliable as possible. A middleware interface will be also implemented to communicate real-time information between the video processing components, the robot actuators and a user interface.  The software will be first developed and tested in our lab setting using video-recorded training data, then tested iteratively, followed by the integration into the final interactive demo use case within the F5G OpenLab at Fraunhofer HHI.  As a result, the object detection and inspection video application components will be integrated into the demo setup. The PoC is expected to produce tangible results to contribute to the F5G use cases “Cloud-based visual inspection for automatic quality assessment in production” and “Industrial PON” specifications.  **Report of Version 1:**  The key contributions reported here are fourfold: 1) demonstrate a low-latency ML-based video processing-pipeline for the end-to-end manufacturing control loop 2) study the capabilities of PON in an industrial setup 3) collect multiple KPIs to study latency and environmental sustainability 4) experimental demonstration and performance validation of the developed solutions in the F5G OpenLab at Fraunhofer HHI premises in Berlin.  Vision inspection is the process of sorting out good items from bad items in the quality control stage of production using machine vision models. The evolution towards edge/cloud-based vision inspection requires broadband connectivity between the Visual Inspection Station (VIS) and the edge-cloud.  In this work, we focus on a scenario in which an XGS Passive Optical Network (XGS-PON) testbed is used to connect the VIS to the edge-cloud. We have built an experimental testbed with an XGS-PON that is used to connect a VIS to an edge cloud following the specification provided by ETSI and ITU-T. The testbed comprises an Optical Line Terminal (OLT) which exposes one XGS port. The XGS port serves three Optical Network Units (ONUs) to which are connected two Basler industrial-grade cameras with adjustable bandwidth according to the 10 GigE Vision standard and a robotic arm. The uplink of the OLT is connected to an aggregation switch that provides the connectivity to the edge cloud. All the elements described are powered via a smart Power Distribution Unit (PDU) which allows power consumption monitoring (Fig.1).  To illustrate the potential of dedicated high-speed connections we implemented a network slicing configuration for each VIS element (robot and cameras). The schematic of the testbed and the network slicing configuration are shown in Fig.1, while a physical setup is shown in Fig. 2.    Fig.1: testbed architecture  IMG_8682.PNG  Fig. 2: physical setup of testbed  The PoC Version 1 was demonstrated at  • F5G Workshop at ECOC 2023, Glasgow, Scotland, Oct 2023  • Digital with Purpose Event, Lisbon, Portugal, Oct 2023  • NetworkX Event, Paris, France, Oct 2023 | finished | [F5G(23)014025r2](https://docbox.etsi.org/ISG/F5G/05-CONTRIBUTIONS/2023/F5G(23)014025r2_PoC_Edge_Cloud-based_Visual_Inspection_for_Quality_Assessmen.docx) | [F5G(23)016013](https://docbox.etsi.org/ISG/F5G/05-CONTRIBUTIONS/2023/F5G(23)016013_Report_on_the_PoC_Proposal_for_Edge_Cloud_based_Vision_Inspe.docx) (final report) |
| 5 | Edge/Cloud-based Control of Automated Guided Vehicles | | | |
|  | This PoC demonstrates the concept of cloud-based control of automated guided vehicles (AGVs) and robots in a factory workshop environment, based on an underlying Passive Optical Network (PON) infrastructure. The PON is set up between the Fraunhofer HHI (F5G OpenLab) and Fraunhofer IPK (a research manufacturing site).  In order to demonstrate the performance of the PON, parts of the AGV and robot control software are migrated to an edge cloud at HHI, while the components/hardware to be controlled (AGVs and robots) are located at Fraunhofer IPK. The cloud-based AGV and robot controls are shown in two simplified scenarios. The simple pick & place task is demonstrated with a marker-based localization of the robot arm on the AGV relative to a stationary object. In this case, the marker-based localization functionality is executed on the edge cloud.  The features of this PoC include an end-to-end AGV control loop and cloud-based control of robots, powered by a PON-based fiber connectivity between the edge cloud and production site, where the factory shop floor is served by WiFi-enabled ONUs.  **Final Report**  The POC consists of the following services based on the ROS 2 framework:  - AGV interface: running on the AGV-edge  - Arm interface: running on AGV-edge  - Camera interface: running on the AGV-edge  - Gripper interface: running on the AGV-edge  - Navigation: running on cloud (edge DC)  - Image recognition and analysis: running on cloud (edge DC)  - Motion planning for robotic arm: running on cloud (edge DC)  - Visualization of planning scene: running on HMI-edge at shop floor  - Orchestration of the scenario: running on cloud (edge DC)  Fig1 shows an overview of the entire setup. The setup involves an AMR comprising an AGV (MiR 100), a robot arm (UR 5), a camera (Microsoft Azure Kinect), and gripper (Weiss IEG 76-030). As HMI in the shop floor a laptop is used. The shop floor is provided broadband connectivity through an XGS-PON testbed with multiple WiFi ONUs and industrial ONU. When it comes to the edge/cloud, there is one Virtual Machines (VMs) setup. The services are distributed on this VM.  Fig. 1: Components and network architecture.    Fig. 2: Components of the robot: mobile base (blue), manipulator (yellow), camera (green), gripper (red)  **The steps in the workflow execution contain the following**   1. Turn-on the robot 2. Get the command to fetch a part in the shelve (navigate there and fetch it)     Fig. 3: Robot extracts part from a material shelf   1. Navigate to Milling Machine based on the map     Fig. 4: Map view of robot (bottom left) in shop floor, computed navigation path in green   1. Release part using cloud-based calculation of the robot arm movement     Fig. 5: Robot inserts part into CNC mill fixture    Fig. 6: Visual Motion Planning environment on the VM  **Results Network KPIs**  The testbed for the use-case spans over two different sites, one at Fraunhofer HHI and one at Fraunhofer IPK. IPK runs a factory shop floor in which the AGV and the robots run. We have installed several WiFi ONUs and one Industrial ONU at IPK for the purpose of this demo. The OLT however is located at HHI and the ONUs at IPK are connected to a single XGS-PON port of the OLT. The uplink of the OLT in then connected to the EdgeCloud through an aggregation switch as shown in the figure. We have used our telemetry framework to record the traffic exchanges between the shop floor and the EdgeCloud. In this section, we look into the traffic pattern recorded while carrying out the demo.      **PoC at Various Events**  F5G PoC demonstration has been conducted on several occasions as part of events and face-to-face meetings, such as:   * a recorded PoC demonstration was presented to the ETSI ISG F5G member during the 17th F2F plenary meeting, on 20.02.-23.02.2024. * a recorded PoC demonstration was presented as part of a panel talk as well as in a show floor program in OFC 2024, on 25.03.2024 and 26.03.2024, respectively, in San Diego, California. * a recorded PoC demonstration is presented to the visitors of HHI booth in Hannover Messe 2024. | finished | [F5G(23)014026r1](https://docbox.etsi.org/ISG/F5G/05-CONTRIBUTIONS/2023/F5G(23)014026r1_PoC_Edge_Cloud-based_Control_of_Automated_Guided_Vehicles.docx) | [F5G(24)017039r2](https://docbox.etsi.org/ISG/F5G/05-CONTRIBUTIONS/2024/F5G(24)017039r2_Report_on_the_PoC_Proposal_for_Edge_Cloud-based_Control_of_A.docx) |
| 6 | End-to-end Management and Control for Building Cloud AR/VR Service | | | |
|  | This PoC demonstrates the feasibility of deploying an end-to-end management and control system (defined in F5G-006/F5G-027) for a F5G network architecture composed of an optical access network segment and an optical transport network segment (F5G-014) to deploy a Cloud AR/VR gaming use-case (F5G-008/F5G-018). To demonstrate this use case, the target F5G network management domain (MD) will be integrated with an end-to-end service orchestrator and a cloud MD, by deploying cross-domain user-driven E2E services (ZSM-002 and ZSM-008) with CAMARA services. The solution of this PoC will leverage and extend open-source projects including ETSI TeraFlowSDN (TFS).  **Report Version 1**  The testbed, illustrated in Figure 1, is composed of specialized hardware equipment including an Optical Network Terminal (ONT) equipment at user premises, connected to an Optical Line Terminal (OLT) equipment that concentrates connections from many users. Then, the OLT is connected to a specialized OTN Edge Provider Equipment (PE) that is connected to an OTN mesh composed of 2 OTN Switches. Finally, the OTN Switches are connected to an Aggregation Edge equipment that brings access to the Virtual Machine Gaming Servers deployed on top of COTS Servers through an OpenStack cloud resource manager.  A collage of several images of a computer  Description automatically generated  Figure 1. Testbed Data Plane Architecture  Regarding the control and management plane, the architecture is depicted in Figure 2. It follows a hierarchical model where the Cloud VR Game Developer (top) issues a request to the CAMARA Application manager in order to manage the Gaming Application and its connectivity. Below, ETSI OSM is used to configure the cloud computing resources through OpenStack APIs, and to orchestrate the connectivity services between the User VR Equipment and the Central Gaming Servers through the ETSI TeraFlowSDN controller.  A diagram of a computer network  Description automatically generated  Figure 2. Control and Management Plane  The overall workflow used to deploy the Gaming Service is sketched in Figure 3. The workflow starts when the Game Developer requests the installation of its Gaming Servers in the cloud infrastructure (labelled as 1 in Figure 3). This interaction is triggered through the CAMARA NBI endpoints that in turn, triggers the appropriate requests to the OpenStack cloud resource manager (labelled as 2 in Figure 3) resulting in the creation of the server instances. Whenever the Gaming Servers and Applications are ready, the Game Developer can accept requests from the Game Client/User through CAMARA to orchestrate the creation of new user-requested Game App Flow Sessions targeting the Game Servers (labelled as 3 in Figure 3). A QoD request to CAMARA to create the Application Flow session. This request results in a IETF Network Slice request, labelled as 4 in Figure 3. The IETF Network Slice request is then translated by the E2E MD into an IETF L3VPN Service Delivery request, labelled as 5 in Figure 3, in order to establish a L3VPN, through ETSI TeraFlowSDN, between the User Equipment and the Game Server Virtual Machines. After the successful deployment of the connectivity services, the Gaming App becomes ready to play.  A black background with white text  Description automatically generated  Figure 3. Workflow to deploy Gaming Service  **External Presentations**   * F5G PoC demonstration has ben conducted at MWC 2024 on February 26-29, 2024 in Barcelona at CTTC booth (Hall Congress Square Stand CS220 booth #37) | Agreed & Running | [F5G(23)016011](https://docbox.etsi.org/ISG/F5G/05-CONTRIBUTIONS/2023/F5G(23)016011_F5G_end-to-end_management_and_control_for_Building_Cloud_AR_.docx) | [F5G(24)017043](https://docbox.etsi.org/ISG/F5G/05-CONTRIBUTIONS/2024/F5G(24)017043_ISG_F5G_PoC_report_on_end-to-end_management_and_control_for_.docx) (report version 1) |

# Change History

| Date | Version | Information about changes |
| --- | --- | --- |
| July 2021 | 0.0.1 | First publication of the document after approval (F5G Meeting F5G-CC-#37) |
| February 2022 | 0.0.2 | Update of PoC list with submitted and agreed PoCs |
| August 2022 | 0.0.3 | Updated |
| March 2023 | 0.0.4 | Updated with final reports for the PoCs |
| June 2023 | 0.0.5 | Addition of the 2 PoCs agreed at F5G plenary #14 |
| December 2023 | 0.0.6 | Addition of PoC #6 and report of V1 of Poc #4 (after plenary#16) |
| March 2023 | 0.0.7 | Addition of reports of PoC #5 and PoC #6 (after ISG F5G plenary#17) |