An End-to-End Testing Ecosystem for 5G

The TRIANGLE Testing House Test Bed

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***Abstract*— Connected mobile applications will be a dominant software component in the 5G domain. Ensuring a correct and efficient behavior of the applications and devices becomes a critical factor for the mobile communications market to meet the expectations of final users. The EU project TRIANGLE is building a framework to help app developers and device manufacturers in the evolving 5G sector to test and benchmark new mobile applications, devices, and services utilizing existing and extended FIRE testbeds. This framework will evaluate Quality of Experience and enable certification for new mobile applications and devices.**

Keywords—5G systems; testing; Quality of Service; Quality of Experience; Mobile Apps; Software Defined Networks; Business Network Applications

I. Introduction

Mobile communications is one of the areas with the biggest growth in the Information and Communication Technologies (ICT) market, and it is expected to reach 4.7 billion mobile devices connected to the Internet by 2020 [1], with an overall economic revenue of $373 billion in 2017 in the smartphone market alone [2]. Connected apps will be a major software component in this huge ecosystem. At the same time 5G systems will become the de facto connecting technology standard for the majority of the devices. Ensuring a correct and efficient behavior of the applications and devices becomes a critical factor in meeting the expectations of end users. This represents a great opportunity for European enterprise providing innovative testing tools based on realistic testbeds with 5G capabilities. In that way, testing activities will complement other 5G research and innovation activities helping to maintain the traditional European leadership in the mobile communications arena.

While radio related certification of mobile devices has a strong standards based ecosystem thanks to the collaboration among the European Telecommunication Standards Institute (ETSI), 3rd Generation Partnership Program (3GPP), Global Certification Forum (GCF), vendors and test houses, there is still a lack of consensus on the benchmarking or testing methods at the apps level. The Key Performance Indicators (KPIs) and techniques to perform such kind of testing for apps could be rather different than the certification methods associated with 3GPP standards for mobile devices (user equipment or UEs), partially due to the proprietary nature of many widely used apps, lack of a testing methodology and lack of standardized interfaces. The actors involved in producing and exploiting mobile apps are different in number and categories compared with those involved in mobile device manufacturing and integration. Thousands of Small and Medium Enterprises (SMEs) build apps compared to the few big vendors who build smartphones. Therefore, existing solutions for testing apps represent a very fragmented market with many ad-hoc tools associated to vendors.

From a technical point of view, the key issue is to base the testing of apps and mobile devices in real but controllable conditions (testbeds) that simulate/emulate realistic 5G scenarios as defined by Next Generation Mobile Networks (NGMN) [3]. Testbeds that combine proper realistic hardware and software, are currently provided in Europe by the FIRE project, but do not cover the new 5G scenarios.

From a market point of view, traditional test houses, that are key actors in the success of mobile technologies, could be playing again a leading role in the definition and exploitation of a new generation of tools for the emergent ecosystem of mobile apps plus devices in the 5G ecosystem. Other players like research institutes, innovative SMEs, test equipment industry, device vendors, etc., will also be necessary to develop such solutions.

II. The TRIANGLE Project

The "5G Applications and Devices Benchmarking" (TRIANGLE) project [4] is a European Union (EU) funded project within the framework of the "Horizon 2020" (H2020) initiative under FIRE/FIRE+ objective devoted to Future Internet Research and Experimentation. The project started in January 2016 and has an expected duration of three years. Among its partners there are laboratories, SMEs, test equipment suppliers and academia. The primary objective of the TRIANGLE project is to promote the testing and benchmarking of mobile applications and devices in Europe as the industry moves towards 5G and to provide a pathway towards certification in order to support qualified apps and mobile developments using FIRE testbeds as testing framework.

TRIANGLE is developing a framework that facilitates the evaluation of the Quality of Experience (QoE) of new mobile applications, services and devices designed to operate in the future 5G mobile broadband networks. The framework will exploit existing FIRE facilities adding new facilities when necessary. The project will identify reference deployment scenarios, will define new KPIs and QoE metrics, will develop new testing methodologies and tools, and will design a complete evaluation scheme. The project will develop a framework to ensure users QoE in new challenging situations, especially those due to heterogeneous networks and considering the role software will have in the new 5G ecosystem. The framework, will also provide the means to allow certification and obtain a quality mark for the applications, services and devices which are compliant with the requirements and test specifications developed in the project but also extendable to other FIRE test solutions. This will allow vendor differentiation, especially among startups and SMEs, in the current globalized and competitive market as well as further visibility of FIRE facilities. The framework, methods and tools developed during the project will focus on providing the mechanisms to incorporate new wireless technologies and topologies envisaged in 5G and contribute to the new ecosystem.

A. *Why TRIANGLE?*

During recent years the estimated mobile traffic growth has resulted in several wireless testbeds. Indeed this estimation grows year after year but is not reflected in the small number of FIRE wireless testbed users. The main reason for this situation is the design of the FIRE testbeds themselves, which are network centric. FIRE testbeds are too focused on network configuration and have very complex and sophisticated configuration mechanisms, while the experimenters are not familiarized with the complex setup of the network resources and most of the time end up using only the default configuration. Based on our experience running the federation of PerformLTE testbed [5], we have identified that testbed users spent most of their time gaining access to all the low level parameters that impact the user traffic transport performance. They lack enough know-how on setting these parameters to generate a consistent experimentation scenario, which can be frustrating for them.

The main idea underpinning the methodology to be used in the design and development of the TRIANGLE test framework is to ensure that the end user is not overwhelmed by the complexity of the overall testbed by not being exposed to all the details, which requires multi-disciplinary knowledge (protocols, radio propagation, software, etc.) to fully understand. To overcome the need for multi-disciplinary knowledge, TRIANGLE will ensure an abstraction of the underlying networking technologies by offering:

- a high level configuration layer (personality) which calls on detailed scenario definition; and
- a flexible framework architecture to incorporate new 5G networking topologies as they become available

The project will design a set of high level configurable scenarios that can be reproduced and whose final testing output is a Behavior Indicator or Quality Mark, which defines how well the product (application or device) behaves when used in a realistic network, including energy consumption and model-based runtime checking of the apps and devices. It will be possible to modify the scenarios by means of a scenario editor, with an Application Protocol Interface (API) and a Graphical User Interface (GUI) to setup very complex scenarios. This scenario editor will be able to load pre-defined scenarios and generate scenarios based on 5G use cases covering KPIs of interest for each one of them.

The project will provide a framework with different layers of abstraction using, when possible, commercial configuration interfaces as well as experimentation standards, including those provided by Fed4FIRE [6]. Where needed, advanced users will be exposed to deeper configuration details and flexibility.

B. *The TRIANGLE Approach*

TRIANGLE intends to address the needs of three test bed user profiles within a single test framework: an advanced Researcher, a Device Manufacturer, and an App Developer. The project's testing approach is portrayed in Figure 1.

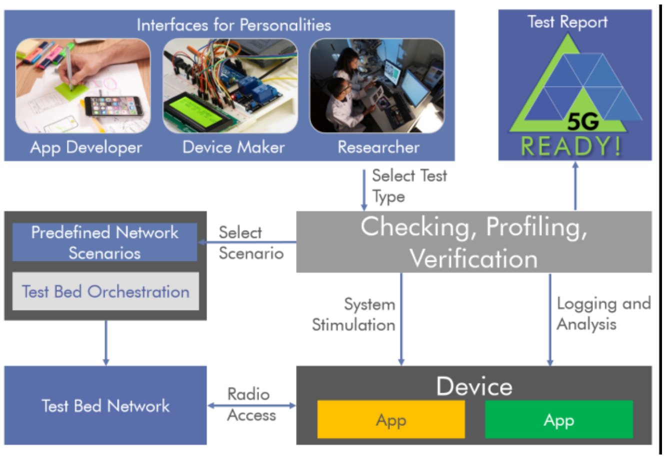

Figure 1 - The TRIANGLE approach for providing a unique certification grade

1) *Researcher Profile*

The most extended personality on FIRE wireless testbeds today is the Researcher personality, especially researchers who are working on protocols and network technologies. This personality is interesting but only represents a small group of possible testbed users. These users will be looking for the ability to fine tune low level parameters; test adaptation within the network layers; create new use case scenarios, etc.; in general to verify the functionality of lower communication layers.

2) *Device Manufacturers Profile*

Device manufacturers will have a more general system performance level interest in the testbed to understand the capability of the overall device compared to other reference devices. Today, the number of smart-phone manufacturers is

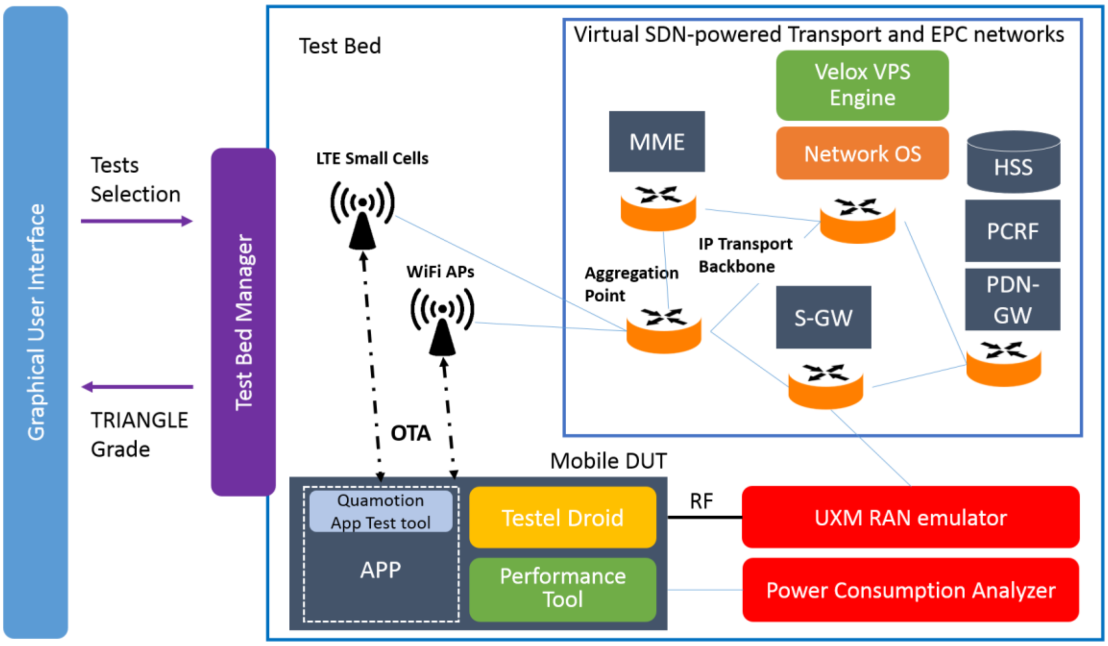

Figure 2 - The TRIANGLE test bed architecture

rather limited, but with the upcoming Internet of Things (IoT) and device variety, we anticipate the numbers to grow rapidly. The skill and knowledge of these device makers is also changing from being a fully integrated in-house developer (with all components in house) towards a more system level integrator type that relies on modules and chipsets from external suppliers.

3) App Developer Profile

These pure software personalities are the largest target population for TRIANGLE. These are usually start-up companies who wish to develop an app based on a great idea and need platforms to validate its functionality and its performance under challenging radio conditions. The app developer, not being a telecom engineer, typically does not care about the network details and radio propagation challenges. The developer typically assumes the wireless connection is a reliable data pipe with characteristics similar to a wired one. TRIANGLE will provide a framework to test the impact of realistic data network capability on the app as well as the app impact on the network resource usage.

C. Open to experimenters

The test framework developed within the project will be accessible to the developer community, mostly European initially and internationally later on. During the project, access to the test framework will be organized via open calls, where TRIANGLE will seed 15 Open Call Experiments focused on applications from innovative SMEs and entrepreneurs. These Open Call Experiments will be used to seed the market for benchmarking and certification towards 5G. In addition the TRIANGLE project will be available for device testing from UE vendors and/or Mobile Network Operators. The TRIANGLE mark will be given with the benchmark measurements obtained.

III. TRIANGLE TEST BED

The main core of the TRIANGLE project is the test bed that will allow all the different users to run tests in a controlled environment that encompasses all the elements of the telco chain. An overview of the main elements that compose the test bed is shown in Figure 2.

A. Mobile Device Monitoring

In order to measure the KPIs perceived by the end device and the end user, several tools are needed on the smartphones to be tested. Such Monitoring tools are internally developed by TRIANGLE partners and available to experimenters.

1) Performance Tool

5G test scenarios will require high resolution for reporting target QoS KPIs. In order to extend the measurement capabilities of other tools like iperf, TRIANGLE will provide up to layer 7 SDU packet resolution in the computation of data performance KPI thanks to the integration of the AT4 wireless Performance Tool. This tool is composed of two components, Controller and Agents (data endpoints), and uses proprietary mechanisms to synchronize the Agents and provides accurate one-way measurements. This tool includes a built-in traffic generator with the capability of generating constant rates, ramps, loops and statistical traffic patterns which is something of utmost importance for setting up the desired environment in terms of varying traffic loads (e.g., for measuring LTE-U impact on Wi-Fi networks). Additionally, this tool has the ability to automate some mobile Apps on Android devices and measuring relevant QoE KPI such as YouTube buffering occurrences.

2) TestelDroid Mobile Monitoring App

TestelDroid [7] is a software tool that enables passive monitoring of radio parameters and data traffic in Android-based devices. Logging is implemented as an Android service that can be running in the background logging all the information while the application under test is being executed. This functionality enables monitoring of the traffic information generated by any application, which extends the testing to a very wide range of use cases. The parameters to be logged (network, neighbor cells, GPS, traffic) can be flexibly configured using the SCPI interface.

3) Power Consumption Analyser

In order to provide a complete overview of the performance of the App or the Device under test, it is nowadays unthinkable not to include an analysis of the energy consumed by the device during the test. For this reason TRIANGLE plans to provide accurate measurement consumptions thanks to the N6705B Power Analyzer by Keysight Technologies. The instrument allows the provision of DC voltage to the device and accurately measures the drawn current to verify how much power is required by each app and network operation over time.

B. Network Emulation

The test bed comprise also a network emulation that spans from the Radio Access Network (RAN) to the core of the LTE system. All the available tools are orchestrated as well, to provide the highest degree of experimentation flexibility to the test bed user.

1) UXM RAN emulator

An essential component in the testbed is an instrument capable of emulating multiple cellular networks in a controlled manner. To that end, TRIANGLE envisions the usage of the UXM Wireless Test Platform device by Keysight Technologies, which supports multiple radio access technologies (multi-RAT), including GSM/GPRS, UMTS and LTE-Advanced networks (i.e., 2G, 3G and 4G). The UXM features include intra-RAT and inter-RAT handovers, protocol debugging, IP end-to-end delay and throughput measurements, and performing RF conformance tests. Finally, it should be noted that the UXM also features an advanced fading engine with the main channels models defined by 3GPP [8].

2) Over-The-Air LTE Small Cells

UMA lab currently offers an indoor deployment of three LTE 2,6GHz FDD cells, one pico-cell by Alcatel-Lucent and two small cells from Athena wireless. In the context of TRIANGLE this deployment will be updated with new small cells supporting more flexible configurations, including Carrier Aggregation. The use of attenuators and switches will allow controlled experimentation in this commercial based setup, including intra-LTE handovers and LTE-Wi-Fi offloading. Scenarios with several devices can be also reproduced if required to test some apps.

3) EPC Emulator

The Enhanced Packet Core (EPC) is the core of LTE networks, and it will also play a central role in pre-5G deployments that include for instance LTE to Wi-Fi offloading. The EPC is a component with functions like controlling which devices are allowed to attach to the network, supporting mobility (handover) or routing traffic to/from the Internet. UMX emulator already integrates a subset of this functionality. UMA lab brings Polaris Networks EPC to the project. Thus, the Project will support some scenarios with small cells, that provide real but non-controllable radio propagation conditions, and others based on the UXM emulator, which provides controllable radio propagation conditions, connected to Polaris EPC through standard 3GPP interfaces.

4) Virtual Path Slicing Engine

Software Defined Networks (SDN), Network Function Virtualization (NFV) and OpenFlow [9] [10] are techniques that provide high flexibility and can cut costs in the packet data networks. Virtual Path Slicing (VPS) is a method that has evolved from studies like [11] on how to implement end to end QoS in packet networks. RedZinc has implemented a VPS engine that can steer traffic on the edge of the network based on the request of the application and coordinate this traffic steering with other autonomous systems. In traditional 3GPP EPC the VPS engine can provide services to the application layer and invoke them using the Rx interface in the Policy Charging Rules Function (PCRF) of the EPC where differentiated QoS Class Identifier can be used for different service levels.

C. App testing

In order to test the apps running on the mobile devices thoroughly, the user interaction needs to be taken into account. TRIANGLE takes advantage of several approaches in this respect, considering both real and simulated user interactions. These approaches are complementary and result in a greater coverage of tests and app-related KPIs.

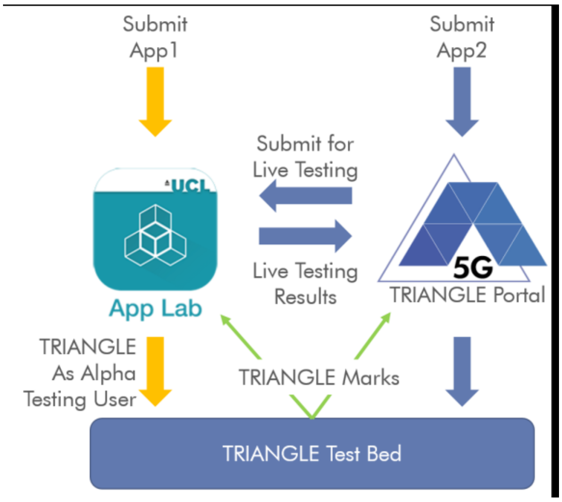

Figure 3 - Live Testing Interaction via App Lab

1) App Lab live environment

TRIANGLE will use App Lab, a high level platform developed by UCL for distributing mobile apps to a large- scale testbed for pre-commercial testing and validation services. App Lab provides a private app store offering in-the-wild rapid user field-testing to UCL staff and students. App Lab is comprised of a server portal for application upload, management and distribution and native mobile client apps for both Android and iOS devices. App Lab uses analytics tools to track how users' interact with apps in the real world. By examining the results of app usage, test cases which mimic actual users' behavior can be derived and executed in a variety of network conditions in the TRIANGLE testbed as showed in Figure 3.

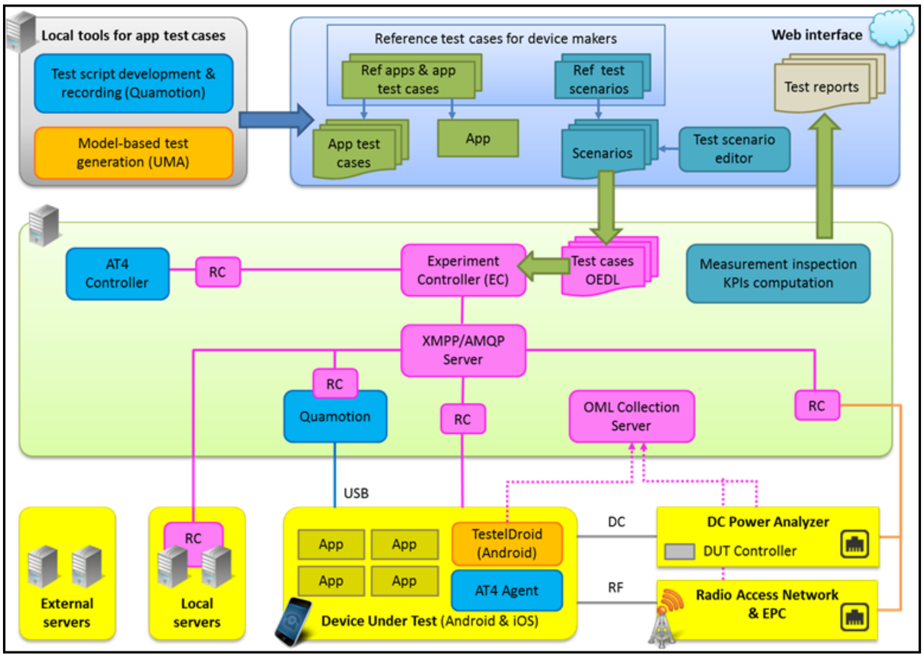

Figure 4 - The TRIANGLE test bed orchestration system

2) Quamotion test automation tool

TRIANGLE will also use Quamotion test automation tool which provides the ability to write and execute automated tests for Android and iOS applications. Execution can be performed without any manual interaction. Not only gestures and keyboard interactions but also the full lifecycle of the application can be automated, i.e. installing, launching, terminating. This set of actions is exposed to the overall test orchestrator such that the end-user actions can be synchronized with various network events, e.g. unstable network connection in train. Quamotion will also add recording capability to increase the efficiency in the process of writing test cases. Each step performed on the device is recorded and translated automatically into an action as part of a test script.

3) Model Based Testing

Another alternative considered in the project is model-based testing. Instead of writing test scripts manually with sequences of user actions, e.g. pressing a button, entering some text, app developers can provide a high-level description of the intended workflow. Test cases can be automatically generated from this description, achieving a high coverage of realistic usage scenarios. These models may also be based on crowdsourced data, such as observed user interactions from live tests, including tests run using App Lab.

IV. TEST BED ORCHESTRATION AND MANAGEMENT

The orchestration and management architecture of the testbed will be based on OMF (Orbit Management Framework) [12]. OMF allows the definition of repeatable and automatable experiments using an OEDL definition language. OEDL is a domain-specific language defined for the description of an experiment's execution. OEDL provides a set of experiment-oriented commands and statements which can be used to define the tests, the measurements and the graphical results. These OEDL scripts are interpreted by the Experiment Controller (EC), which orchestrates the resources present in the testbed during the execution of experiments. Each resource in the testbed is managed by a Resource Controller (RC), which will translate the actions defined in the experiment into the specific control commands understood by the resources. Measurement data during experiment execution will be collected via OML in a central server. OML provides a programming library for easy application instrumentation and a collection point, a server which stores measurements in an experiment database.

TRIANGLE testbed orchestration based on OMF is shown in Figure 4, starting with the definition of the app test cases by the app developer in the top left. The app test cases may be defined in several ways. .

Once the test cases and the network scenarios, have been completely defined, they can be executed in the testbed. The RC associated with the device under test interacts directly with the Android and iOS devices over USB in order to install the apps and run the app test cases. In order to coordinate the execution of the different tools involved in the testbed an RC for each one of them will be deployed. These RCs allow the tools to be controlled as part of the test, and receive commands from the experiment controller to fetch and execute a particular test case.

During the tests, the monitoring and performances tools will collect all the measurement results from all layers and measurement points present in the testbed. The results are passed to the Measurement inspection and KPI calculation, which outputs the final test report.

V. PRELIMINARY TESTS AND MEASUREMENTS

The components provided by some partners have already been integrated into a version 0 of the TRIANGLE testbed. As an exercise the testbed has been used to evaluate the performance of a YouTube video playing on a mobile device, under different radio channel characteristics. An agent that drives the YouTube API was manually installed on the device and the device was connected to the UXM LTE network emulator via a coaxial cable and from there to the YouTube server via internet. The performance tool was controlled remotely to run the agent and record KPIs using the algorithms proposed in [13]. Some preliminary results are shown in Figure 5 (good channel) and Figure 6 (bad channel), which display the quality of the video and the recording time over time. Under good channel conditions (EVA 200; SNR 20), a large percentage of the video is downloaded in high resolution, and the MOS score obtained is high (3.89) resulting from the low number of re-bufferings (0) and zero re-buffering time (0). Under relatively bad channel conditions (EVA200 SNR 10) a small percentage of the video is downloaded in high resolution and the MOS obtained is very low (2.036), resulting from large number of re-bufferings (12) and long re-buffering time (51.716 s). The video used has a length of 5 minutes and resolutions ranging from 1080p to tiny.

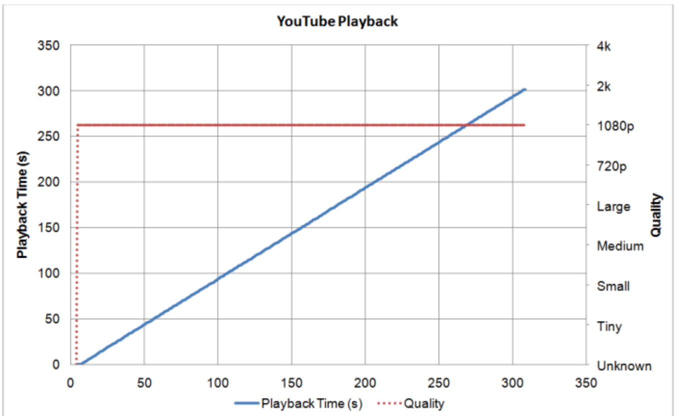

Figure 5 - Playback time and quality versus time under good propagation conditions (EVA200 SNR20)

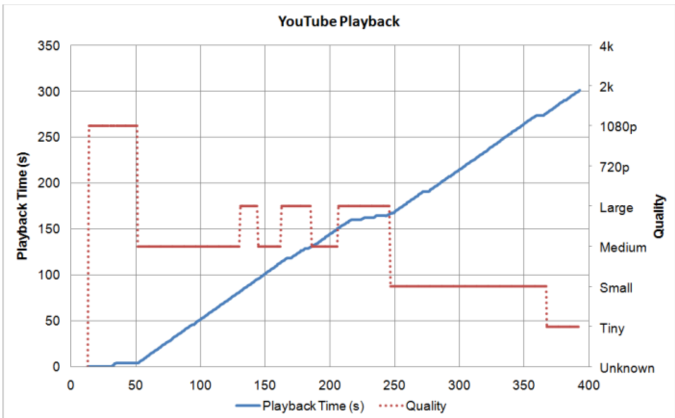

Figure 6 - Playback time and quality versus time under bad propagation conditions (EVA200 SNR10)

VI. Conclusion

TRIANGLE is a research project that brings together SMEs, labs, test equipment vendors and academia, with the goal of providing an end-to-end testing ecosystem for Apps, devices, and services targeting the future 5G system. The test framework will be based on existing FIRE infrastructure and new elements for completing the ecosystem will be added to expand the testing possibilities offered by the test bed. In order to facilitate the exploitation of the test bed not only by researchers but also by App developers, device vendors, and other players in the telco market, the project will implement abstraction layers fitting the interest and knowledge of each profile. To show the potential of the test framework, some preliminary results of the impact of radio propagation conditions on a well known service installed in one mobile have been presented.

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References

[1] "The Rise of the Enterprise in the Smartphone Wars," Goldman Sachs, December 3, 2013.

[2] "Forecast Analysis:Mobile Phone Production and Semiconductors, Worldwide, 3Q13 Update," Gartner, October 28, 2013.

[3] NGMN 5G White Paper, NGMN, Feb 2015.

[4] TRIANGLE project official website www.triangle-project.eu

[5] A. Díaz-Zayas, C. A. García-Pérez, Álvaro M. Recio-Pérez, and P. Merino, "PerformLTE: A testbed for LTE testing in the Future Internet," in The 13th International Conference on Wired and Wireless Internet Communications, Lecture Notes in Computer Science (LNCS) 9071, Springer, 2015, pp. 313–326

[6] Wauters, Tim, et al. "Federation of Internet experimentation facilities: architecture and implementation." European Conference on Networks and Communications (EuCNC 2014). 2014.

[7] Álvarez, A. Díaz-Zayas, P. Merino, F. Javier Rivas Tocado "Field measurements of mobile services with Android Smartphones ," in Consumer Communications and Networking Conference (CCNC), 2012 IEEE , pp.105-109, 14-17 Jan. 2012

[8] 3GPP TS 36.101. "User Equipment (UE) Radio Transmission and Reception." 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).

[9] ETSI Network Functions Virtualisations White Paper #3. October 14 2014

[10] McKeown, Nick, et al. "OpenFlow: enabling innovation in campus networks." ACM SIGCOMM Computer Communication Review 38.2 (2008): 69-74.

[11] Braun, Torsten, Michel Diaz, José Enríquez Gabeiras, and Thomas Staub. End-to-end quality of service over heterogeneous networks. Springer Science & Business Media, 2008.pending

[12] T. Rakotoarivelo, M. Ott, G. Jourjon, and I. Seskar, "OMF: a control and management framework for networking testbeds," ACM SIGOPS Operating Systems Review, vol. 43, no. 4, pp. 54–59, 2010.

[13] F. Lozano, et al., "Network Performance Testing System Integrating Models for Automatic QoE Evaluation of Popular Services: YouTube and Facebook", Wireless Personal Communications, Springer US (DOI = 10.1007/s11277-015-2479-y).