H2020-ICT-688712

Project: H2020-ICT-688712

Project Name:

5G Applications and Devices Benchmarking (TRIANGLE)

Deliverable D5.3

Results of Known experiments and First Open Call

Date of delivery:	30/11/2017	Version:	1.0
Start date of Project:	01/01/2016	Duration:	36 months

Deliverable D5.3

Results of Known experiments and First Open Call

Project Number:	ICT-688712
Project Name:	5G Applications and Devices Benchmarking
Project Acronym	TRIANGLE

Document Number:	ICT-688712-TRIANGLE/D5.3
Document Title:	Results of Known experiments and First Open Call
Lead beneficiary:	University College London
Editor(s):	Niall Roche (UCL)
Authors:	Andrea F. Cattoni (KEYD), Cesar Augusto Garcia (UMA), Almudena Diaz Zayas (UMA)
Dissemination Level:	PU
Contractual Date of Delivery:	30/11/2017
Work Package Leader:	Niall Roche (UCL)
Status:	Final
Version:	1.0
File Name:	TRIANGLE_Deliverable_D5.3_FINAL

Abstract

The Triangle Project ran two Open Calls for the purposes of gathering feedback from real-world users of the Testbed and to increase the capabilities of the Testbed. These results of calls provided valuable feedback to the consortium on the benefits available from using the Testbed and also in identifying issues and improvements to the Testbed for future users.

Keywords

Open Call; Experiment; Extension

Executive summary

The TRIANGLE project ran two Open Calls in 2017. The first Open Call (OC1) was for experimenters to use the TRIANGLE Testbed infrastructure with experiments starting in April 2017 and completing in September 2017 (October 2017 for one). These experiments comprised two Mobile Apps and one Connected device.

The Second Open Call (OC2) was for extensions to add additional functionality to the TRIANGLE Testbed. The selected extension began in May 2017, with a first release of the technology delivered by end of September 2017 for the second release of the Triangle Testbed (R2) and will have a upgraded offering in January 2018 which will be as well integrated as part of R2 functionality.

The experiments were a great success with each of the experimenters getting quality results on how their applications performed under a set of network conditions. This report gives and overview of the experiment setup, results and the business benefits derived from using the TRIANGLE Testbed. The output of these early testbed users with real world usage requirements has provided valuable feedback to the consortium on improvements that are planned for future TRIANGLE Testbed versions. Work is already underway to incorporate this feedback into the testbed for future users.

This deliverable generalizes the information captured by the experimenters. The Individual experiments results are kept confidential as they are directly related to the specific experiment application or products.

Contents

List of Figures

List of Tables

1 Introduction to TRIANGLE Open Call process

This document outlines the results of the first set of Open Calls for the TRIANGLE Testbed. The Open Call process is outlined as well as a description of the applications that were received and the applicants that were selected by the selection committee.

The main objective of the first Open Call (OC1) [3] is testing the TRIANGLE testbed with **Experiments** that are co-created with companies such as application developers and device manufacturers. Example experiments could include application developers testing 5G scenarios such as low latency to facilitate VR, or an IoT device maker who wants to benchmark their devices against other low power devices. The experiments will help developing the TRIANGLE Testbed as a whole to match the needs of experimenters, and will evolve the technical integration in the TRIANGLE Testbed at the University of Malaga (Spain).

The second Open Call (OC2) [4] is for testbed **Extensions**, where the main objective is adding additional capabilities to the TRIANGLE Testbed to facilitate extensions. The extensions will help improve the TRIANGLE Testbed as a whole to match other needs of experimenters. Extensions will evolve the existing TRIANGLE testbed and integrate with additional TRIANGLE Testbed components.

For more information about the current capabilities of the testbed and what types of experiments it can run see the testbed overview at [2].

1.1 Open Call Timeline

The Open Call revised timeline is presented in the table below. Orange indicates where a delay has occurred. In the case of OC1&2 there was a delay of 3 months due to the increased time to develop the release 1 of the Testbed (R1). In each Open Call period the diagram below shows that there is a period foreseen as a setup phase. In this setup phase, experimenters are getting familiar with the Testbed, access technical information and complete the legal contract review before experiments begin.

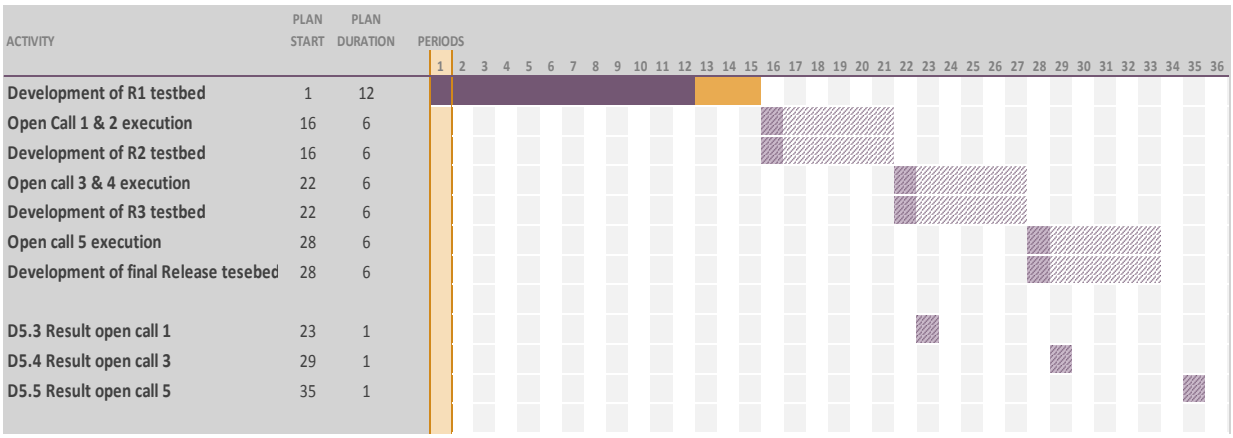

Figure 1: Open Calls Timeline

At the end of each open call, a period is planned in which experimental data is process and consolidated into a report which is shared with the consortium. Extract of the reports are included in the public deliverable such as this one.

1.2 Open Call 1 & Open Call 2 Applications Summary

A summary of the Open Call 1 and 2 applications is shown in the table below

Open Call	**Interested**	**Official Applicants**	**Selected**
Open Call 1	23	18	3
Open Call 2	12	2	1

Table 1: Open Calls summary

1.3 Briefing and Evaluation Calls

As per the Open Call process defined in D5.1, the consortium decided to select 6 independent evaluators to help in the selection process. They come from diffeernt background such as from academia and industry, all releated to telecommunication. The list of selected evaluators has been shared with the EC project officer but is kept confidential to protect their anoymity.

After the deadline for presenting applications, the consortium had a briefing call on 14th of November 2016 outlining the TRIANGLE Testbed to the evaluators. The call took place over WebEx and was recorded for an expert evaluator who was unable to attend the call. This call addressed the project and what makes a good experiment and extension for the project.

After explaining the TRIANGLE Testbed and the scoring criteria, the evaluators began the process of evaluating the applications that were assigned to them, over the course of a week.

Evaluators were encouraged to add notes, where relevant, to the applications; but these notes would not be visible to the applicants, only to other evaluators.

Each evaluator scored the applications that they were assigned to according to the agreed criteria. The chairman evaluated the scores and presented the applications with the highest score to the consortium for Technical and Privacy & Ethics review.

1.4 Technical Review

Each selected application was later evaluated based on the technical feasibility of using the TRIANGLE Testbed. The TRIANGLE Technical Review Committee can refuse applications based on the result of the technical review when proposals are deemed to be unfeasible.

Each selected applicant was requested to develop an extended proposal with more technical detail than the original proposal in order to achieve more clarity. An email exchange between the Technical Review Committee and each applicant was setup to discuss any potential technical issues. In addition, each applicant had a call with the Technical Review Committee members. This call helped identifying any potential technical limitations with the experiment or extension.

2 Received Applications

2.1 OC 1 Experiments

The selected applicants in Open Call 1 were:

Company	Country	Application Area
D-Cube	Greece	Multi-party real-time 3D immersive interaction
Thininside	Italy	Home health and care services using wearable devices
atSistemas	Spain	Tourist-oriented mobile application with streaming of content HD content delivered in real-time AR

Table 2: OC 1 Experiments

2.2 OC 2 Extensions

The selected extensions in Open Call 2 were:

Company	Country	Application Area
TNO	The Netherlands	Provision of MANO and – wherever needed – SDN functionalities to the TRIANGLE testbed; 2) further enhancement of MANO functionalities with features for deeper control and assistance of MPEG-based VR applications

Table 3: OC 2 Extensions

3 Open Call Experiments Results

3.1 Results of Open Call 1

The Open Call completed on September 30th 2017. One applicant needed more time and ran experiments beyond the original timeline to finish by 31st October 2017. In total, three successful set of experiments where conducted. The results of these experiments as documented by each of the Experimenters are outlined in the following section.

3.1.1 atSistemas: Experiment - 5MARCAS

Experiment Summary

"The experiment titled 5MARCAS consisted on testing a data-intensive, network capability-intensive mobile app over the TRIANGLE Testbed.

The aforementioned mobile app is 5MARCAS mobile app (formerly City Tour Worldwide). It was developed by atSistemas and provides end users with Augmented Reality features for tourism services. The former mobile app was originally designed and implemented to rely on an initial fetching stage based on a Wi-Fi-dependent pre-download of all assets required to serve the overlaying supplemental information to be viewed by end users.

For the purpose of this experiment, a revamped version of City Tour Worldwide was generated in order to harness the full potential of 5G connectivity to fetch the required assets on-the-fly and on-demand.

The testing aimed to assess the performance of this Augmented Reality mobile app while serving High Quality audio-visual content in real-time (All assets are real-time downloaded from cloud).

The performance was assessed according to the terms listed below:

- user experience,
- energy and resource consumption,
- latency and bandwidth,
- stability

Experimenter feedback

"The outcomes of the experiment have provided us with priceless insights on specific indicators regarding: user experience; device resource consumption; and network usage.

Those insights, in turn, have helped us to be better prepared to design, develop and deliver similar mobile apps that perform smoothly in 5G networks. Likewise, we have now valuable information to feed our marketing actions in order to properly inform our partners and potential customers.

Preparatory work has also been undertaken in order to have our mobile app qualified to obtain the upcoming TRIANGLE MARK whenever such certification is made available by TRIANGLE Consortium.

The experiment also allowed us to provide feedback to TRIANGLE Consortium on the use of the testbed. The timely provision of both technical and personnel resources by TRIANGLE Consortium have been essential for us to carry out this experiment.

Overall, running this project has been an enrichening experience for our company according to: the insights obtained; access and use of a state-of-the-art benchmarking testbed; and the tremendous opportunity to collaborate and discuss ideas with partners of TRIANGLE Project."

Experiment Preparation and Design

The TRIANGLE team worked with atSistemas to determine how to adapt their application to be suitable for automated end-to-end testing. This is more difficult than most mobile app scenarios as the app is designed for an Augmented reality use case, which provides unique challenges. Some of these challenges included the separation of the camera capture and general AR functionality from the network activity for accurate measurements and performance. Also, the location aspects of the application had to be carefully managed. To achieve accurate results the Testbed had accurate GPS emulation added to support future AR applications. Some assistance from the TRIANGLE team was needed to support the experimenters as this application was using AR and was developed using a hybrid approach of embedding a web browser inside a native Android application, instead of a pure native application. This assistance was necessary for the experimenters to integrate calls to the instrumentation library from within the hybrid a web framework. In addition, the team assisted in recording interactions for playback using the QuaMotion tool that was difficult to do in a standard way due to the non-standard AR user interface.

The TRIANGLE team assisted in finding workaround to address all of the above issues and with these workarounds in place there were no issues in testing the resulting experiment. Overall by refactoring the application and the TRIANGLE team assisting in identifying suitable measurement points using the Instrumentation library, atSistemas commented that their app was better structured for testing in general and particularly for network based testing.

Experiment timeline

The following table illustrates the timeline for the experiment. atSysistemas needed to make a number of changes to their application to get it ready for testing. These changes took place during the initial setup and contracting phase during a period of one and a half months. These changes included revamping the current City Tour Worldwide mobile app to be able to support new interesting features such as:

1. Ability to view updated cloud hosted AR assets
2. Efficient use of device storage
3. Wi-Fi independency

Once these modifications were made to the app and the team had read the documentation for the Triangle Portal they indicated that they were able to get familiar with the portal in half a day. The timeline below illustrates a breakdown of the set of tasks that were completed after the initial setup phase.

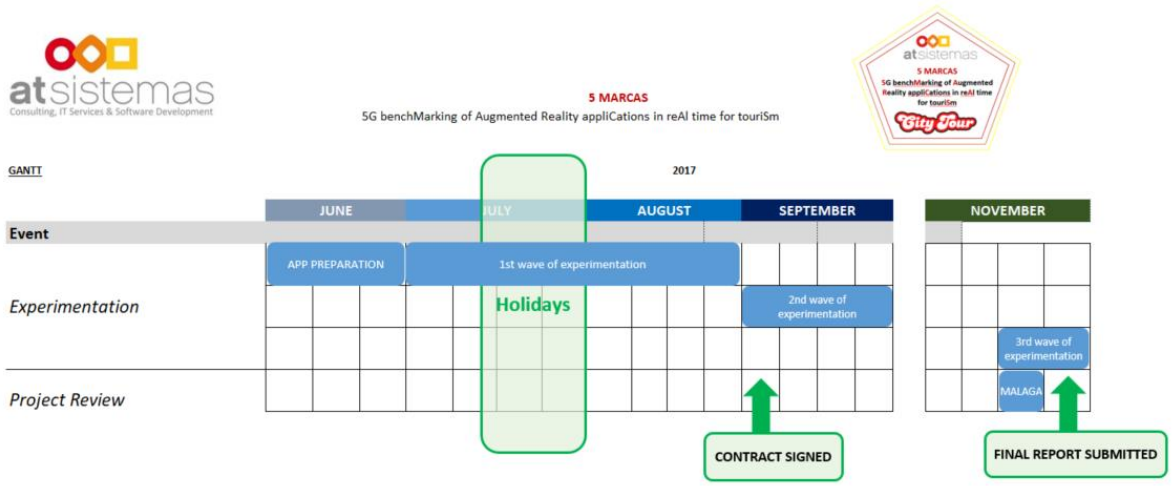

Figure 2: 5MARCAS experiment timeline

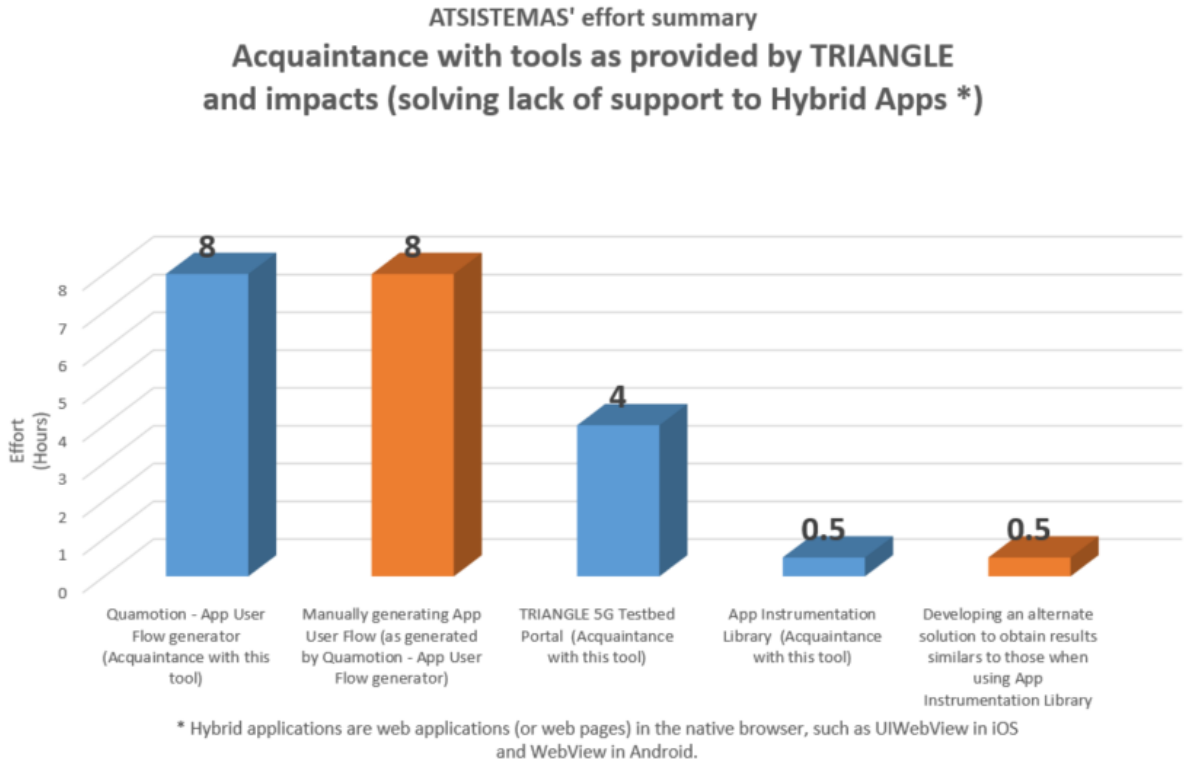

Figure 3: 5MARCAS Experiment effort estimation

Key results and Insights gained from Testing

The overall assessment from atSistemas can be summarised as follows:

As a result of the overall comparison of the results collected after having the mobile app tested over 3G and over TRIANGLE Testbed, atSistemas asserts that:

- The new functional design implemented in 5MARCAS mobile app exhibits the limitations of current mobile access technologies. 5MARCAS mobile app is able to perform satisfactorily when harnessing all the potential offered by future 5G Networks in terms

of connectivity.

- The urban scenario of interest for 5MARCAS which is described by a section of a city which typically is in the center of the city and contains buildings considered valuable for historical or architectural reasons. Such relevant urban scenario was fully supported by the 5G network as emulated by TRIANGLE.

Moreover, the results surpassed our expectations since they have shown that 5MARCAS can also perform satisfactorily in other scenarios beyond those pertaining to urban environments. The fully compliant behaviour of 5MARCAS was consistent throughout all those other scenarios even though they offered unfavourable connectivity conditions.

The favourable insights collected throughout 5MARCAS experiments provided atSistemas with the competitive advantage of being able to design and deliver mobile solutions to our clients with the guarantee of full compliance with user experience as expected in the upcoming 5G environments.

Business benefits

Given the fact that the main motivation of 5MARCAS experiment was the possibility to test the redesigned 5MARCAS mobile app on a 5G network, atSistemas indicated the following:

- "The main asset was the access to controlled 5G Network Scenarios. High-speed access networks are, in principle, available nowadays in selected city locations, nonetheless, experimenting in the required scenarios considered within our experiment was not easily achievable by our company in a regular context.
- From the experiment, and the results obtained out of it, the main value perceived is the knowledge acquired by us on the behaviour of our mobile app while being used under different network scenarios in 5G.
- We have been able to collect tangible answers to a number of questions about the co-relation of asset consumption (on-the-fly and on-demand) and different access conditions.
- In order to prepare the 5MARCAS experiment we have been able to generate a working version of our mobile app following a new functional design.
- With the results collected from 5MARCAS experiment we have gained knowledge to device possible adaptations of future mobile app, not only those providing Augmented Reality service. The adaptations are mainly focused on ensuring uploading/downloading tasks to complete and consist on evaluating the: adjustment of timeouts; perform operation in the background to also contribute to user experience.
- All the knowledge acquired in 5MARCAS project can now be poured out on our future commercial development projects. Initially on those projects involving Juliá Group, the original client of the mobile app that motivated this project.
- Moreover, our technical knowledge in developing mobile solutions in general (beyond simply Augmented Reality mobile apps) has gained a priceless competitive advantage on the upcoming opportunities to be brought by 5G network availability. This advantage also extends to our commercial skills to define business models accordingly with upcoming network scenarios."

TRIANGLE testing value identified

According to atSistemas:

If it wasn't for the TRIANGLE Testbed, atSistemas wouldn't have been able to develop solutions for the upcoming trend of data-demanding and connectivity-demanding apps to be needed in the environment of 5G networks.

atSistemas would have continued with the current mobile app functional designed based on pre-fetching stage to load assets into the mobile app.

A revamped version of the original City Tour Worldwide would not been developed by us.

Testing the new functional design implemented in 5MARCAS mobile app would be nonsense considering the current available access networks.

Moreover, the lack of mechanisms to control different network scenarios would prevent us from collecting insights to be consider in our future work while developing new solutions for upcoming 5G networks.

It is virtually impossible to collect useful insight if there were no availability of a high performance mobile network testbed like TRIANGLE with the capability to control a highly heterogeneous environment, ensure security and trust, identity, and privacy."

TRIANGLE benefits identified

This experiment provided some challenges for the Testbed to support as the application was a hybrid app, based on AR, so not a traditional app flow and also required GPS emulation. This experience was useful in helping the Testbed to meet the needs of a wide variety of application technologies.

Planned further use of the Testbed

atSistemas indicated that they are interested in carrying on with the use of TRIANGLE testbed in the future, specifically to take advantage of new Network Scenarios which will be available for 2nd release. They re-started additional experiments in November, re-using the installation of their app for OC1 but now relying on R2 of the testbed.

3.1.2 D-Cube: Experiment - 5G Spacewars

Experiment Summary

"A next generation immersive media streaming application was benchmarked and evaluated within TRIANGLE. The TRIANGLE Testbed was used to assess various visual quality levels and production conditions with respect to their effect on the performance of the application. This assessment was also conducted after varying the network conditions in order to also extract tangible results related to its adaptation in sub-optimal networks. Valuable knowledge was extracted that not only improved the application's performance but also offered important knowledge about the quality levels that can be achieved, as well as directions for future areas of improvement and particular network functionalities that will be required at its eventual deployment.

This was accomplished after analysing the results offered by the TRIANGLE Testbed which were acquired remotely through an efficient and automatic testing environment and in emulated realistic conditions. Considering that this experiment was about live streaming next-gen media content, besides application modifications to allow for measurement logging and KPI calculation, the complete end-to-end streaming pipeline had to be tested. Therefore, a simulated streaming environment was set up and hosted in the TRIANGLE Testbed facilities that reproduced live content recordings. In this way, remote experimentation was achieved for a largely challenging setting, live streaming VR media demonstrating the capabilities of an appropriately orchestrated testbed.

With next-gen immersive media slowly becoming a reality, efficient testing, benchmarking and network performance understanding of such novel applications is mandatory for their successful deployment, highlighting the importance of powerful and flexible testbeds that can offer data and measurements that closely resemble those experiences in realistic conditions."

Experiment Preparation and Design

Prior to the experiment commencing the Triangle team worked with D-Cube to establish what QoE characteristics they were looking to test and how the Testbed could best achieve their testing needs. The team worked with them on the UX of their application to modify it to achieve a better User Experience and to make the application easier to be automated from a test and measure perspective. The use of network slicing was also discussed and offered as a standalone activity while this functionality was added to the testbed during Release 2, but ultimately this was not used but may be for future experiments as outlined below in the section of future use of the Testbed.

Experiment timeline

The following table illustrates the timeline for the experiment, the company indicated that they were able to get setup their experiment less than one week.

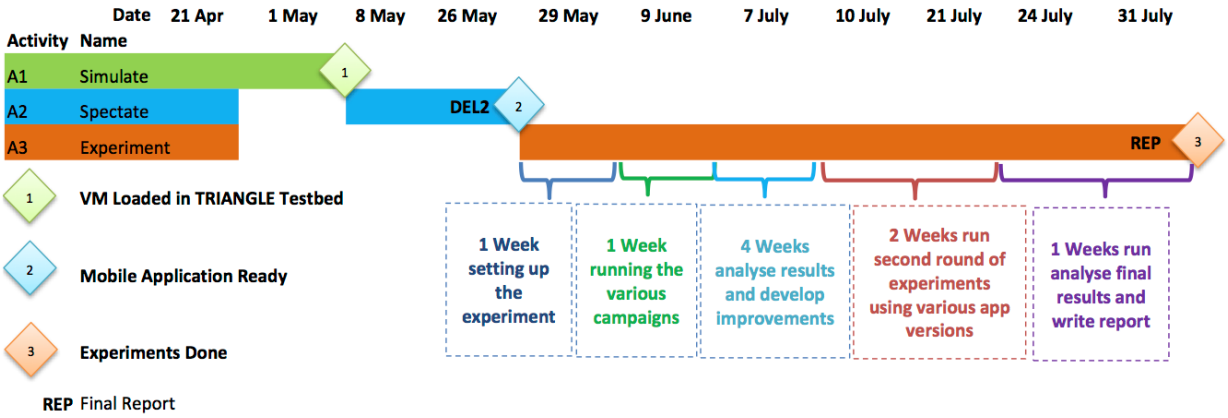

Figure 4: D-Cube Experiment timeline

Key results and Insights gained from Testing

As a result of the testing D-Cube described the following as a brief summary of the results that they determined that the knowledge they acquired will greatly help in designing adaptation solutions (e.g. adaptive streaming, toggling VBR, offering spectating guidelines, etc.) for sub-optimal network conditions

Business benefits

According to D-Cube, they indicated that the following benefits were realised:

"By experimenting through an actual testbed, invaluable knowledge was acquired because the collected data closely resemble to data collected in realistic conditions. This knowledge offered a better understanding of the limitations of the spectating application and any issues that would arise during its actual deployment. As a result, a better estimate of the optimal application's parameters with respect to its Quality of Experience and the underlying network conditions was made. This in turn helped to refine and tune the application accordingly by also implementing

many different solutions and to any problems that manifested and testing them to ascertain their effectiveness.

After conducting the TRIANGLE Testbed experiments, various algorithmic and systemic parameterisations were tested. This led to the selection of different levels of service, consisting of the visual quality and bandwidth measures, with emulated data which are closer to realistic deployment conditions instead of artificial or simulated ones. The experimentation also offered guidelines on how to improve the application as various issues that were identified after analysing the received data were resolved. Further, the acquired knowledge will be used in all possible implementations of the time-varying mesh data streaming application, be it either to mobile phones, headsets or even desktop computers. Further, the technical measurements that were acquired will allow for more informed future SLA agreement negotiations.

TRIANGLE testing value identified

According to D-Cube: “Driven only by internal testing and experimentation inside the lab (i.e., unrealistic conditions), the application’s streaming performance would be seriously be affected by playback freezing and would in general offer a worse Quality of Experience (QoE) when deployed in realistic network conditions mainly due to lack of knowledge of fine parameter tuning.”

TRIANGLE benefits identified

This experiment provided some challenges for the Testbed to support as the application was the first application deployed beyond the simple test applications that the Testbed had run previously. It was also the first experiment where an experimenter had deployed a backend into VMs that were deployed in the Testbed. Similar to the hybrid app from atSistemas, there were some initial issues as this app was developed in the Unity framework, which created issues for the UI automation and Instrumentation components. This experience was useful in helping the Testbed to support alternative application development frameworks and in experimenters configuring a backend connected to the testbed.

Planned further use of the Testbed

D-Cube have indicated that they would be prepared to use the TRIANGLE Testbed in the future to evaluate new algorithms and also to take advantage of new Testbed functionality. One area that the D-Cube were interested in exploring since the experiment has completed was to test at higher bandwidths and corresponding higher throughputs such as 60 Mbps. The existing experiment ran at 40 Mbps which was the limit for that scenarious which is reasonable constraint for existing networks. D-Cube and the Consortium are working to facilitate this test if there is sufficient Testbed availability to accommodate it.

3.1.3 Thinkinside: Experiment - Health5G@Home

Experiment Summary

“The Health5G@Home experiment aimed at validating the ability of 5G technology to effectively enable the delivery of advanced home health and care services. The experimenter (Thinkinside srl) has developed a suite of telemonitoring and telecare services for remotely controlling fragile patients. The services are currently deployed with customers in nursing homes, where they are used to enhance the quality of care while optimising the associated costs.

While nursing homes is a profitable market segment for telemonitoring and telecare services, we have been actively investigating the possibility of expanding the reach of our services to the home health & care market, where they could deliver high value for healthy ageing and independent living. Yet a technology barrier is represented by the need of reliable and high-available Internet connectivity, which is typically not present in many elderly people's home. In this sense, we believed 5G could represent the most convenient bearer to become a game changer by allowing us to extend our offer with a pre-packaged solution for the home setting.

The experiment included a set of measurements (carried out first remote and then on-the-spot in Malaga) on the performance offered by 5G networks in terms of reliability and latency. The experiment showed that 5G is able to deliver appropriate performance, able to meet the requirements set forth by our service. The technical feasibility was therefore positively evaluated. Activities are currently on-going to assess the economic feasibility of the proposed set of services."

This company were delayed in starting using the TRIANGLE Testbed and had some issues internally in their VM configuration and in synchronising timestamps that were external to the testbed.

Experiment Preparation and Design

The TRIANGLE team worked with Thinkinside to redesign their application to make it easier to test from an end to end perspective. The testing involved both devices to a backend deployed in VMs connected to the Testbed to accurately control latency and also to a live backend on the public Internet. The TRIANGLE University of Málaga team assisted Thinkinside to connect to and configure the VMs that contained the backend and also when the team were physically present in the lab in Malaga, to connect physical devices to the Testbed.

Experiment timeline

The following table illustrates the timeline for the experiment. The timing of the activities is indicated in the following GANTT chart below. The experiment ran from May 31st.

#	Title	W22	W23	W24	W25	W26	W27	W28	W29	W30	W31	W32	W33	W34	W35	W36	W37	W38	W39	W40	W41	W42	W43	W44	W45	W46	W47	W48
A.1	Learning and training																											
A.2	Platform configuration and setup																											
A.3	Remote experiments and troubleshooting																											
A.4	On site experiments																											
A.5	Analysis and reporting																											

Figure 5: Thinkinside Experiment timeline

Key results and Insights gained from Testing

Together with the physical deployment in that lab and replaying simulated packets captures of sessions, Thinkinside were able to get valuable feedback on the impact of latency in their application. The experiment was a success for them as they were able to gather valuable information about how their application performed over differing levels of latency as they were concerned about latency inside and Outside of the Operator Core network and were able to test

different configurations and the impact on QoE. They were able to accurately determine, and quantify the impact of, the following measurements:

1. Total received/sent traffic in bytes and packets
2. Data rate (in bytes/s)
3. HTTP Errors
4. One way latency (OWL)
5. Round Trip Time (RTT)

Business benefits

According to Thinkinside the business benefits can be summarised as follows:

- Testing with TRIANGLE allowed an assessment of the technical feasibility of a 5G version of our HealthIN product.
- They gained working knowledge on the network performance attainable from a 5G system.
- Direct value: technical feasibility assessed, working knowledge gained
- Timeframe: depends on availability of 5G products on the market, on our side it would take about one-two months to complete and engineer the integration.
- The results could be applied to other scenarios as well, in particular we have been discussing internally whether it could be a suitable solution for pilot projects in the area of Industry4.0 (where we track how production lots and workers move in shop floor to monitor and analyse the execution of industrial workflows). Using a self-contained edge device with 5G connectivity (without the need to connect to the industrial network to reach out to the public Internet) could ease the realization of small-scale pilot projects and the acquisition of customers.

TRIANGLE testing value identified

According to Thinkinside:

“Without TRIANGLE, we would not have been able to test the technical feasibility of using 5G connectivity to take our healthcare segment to the new market of home care. We believe that this could provide us a competitive edge over our competitors”.

They went on to add that “TRIANGLE fit a timely need for our company. We thought 5G could – in principle – could give us the opportunity to develop a new product, but we had neither access to an experimental infrastructure nor the budget required to properly prioritize it internally.”

Thinkinside also made extensive use of TAP during their experiment and were quite complementary about its ease of use and good documentation and examples and the support they received from the Triangle team in working with it.

Thinkinside were generally quite happy about the degree and speed of the support they received from the Triangle team in getting their unique setup configured and in interpreting the results.

TRIANGLE benefits identified

As this experiment differed from the other uses of the testbeds which primarily involved mobile apps and traditional UE with access from the TRIANGLE portal, this experiment was initially challenging to support. Nevertheless, the experiment was a great success and the resulting knowledge has improved the Testbed's ability to support IoT devices.

Planned further use of the Testbed

Thinkinside have discussed further use of the TRIANGLE Testbed at later stage of their development if there is availability. This will be based on an analysis of the financial feasibly and the timeline for the actual rollout of 5G networks.

3.2 Results of Open Call 2: Extension - TNO

Open Call 2 is still ongoing at the time of writing this report, with TNO adding their extension to the Testbed as outlined below. A first release was ready by end of September 2017 to be included in R2 currently they have completed the implementation and test of the integration of TAP with the MANO element of the extension using OpenStack and starting to integrate DANE with this. The remaining work going on will be migrated into R2 as well when available end of January.

The selected extension from TNO has 2 parts, MANO and DANE, the benefits include:

- Adding support for next generation multimedia streaming applications.
- Including VR and tactile internet.
- Provision of MANO and SDN functionalities to the testbed.
- Further enhancement of MANO functionalities with features for deeper control and assistance of MPEG-based VR applications.

3.2.1 MANO

Extension will include an Orchestrator (MANO) integrating with SDN infrastructure, provided by TRIANGLE and/or modified by TNO as necessary.

Introducing a MANO opens the opportunity for further expansion of the TRIANGLE testbed be letting experimenters plugging-in additional modules, such as measurements module or security threats detector

3.2.2 DANE

Further enhancement of MANO functionalities with features for deeper control and assistance of MPEG-based VR applications.

Network element (called DANE) implementing the upcoming MPEG DASH SAND standard

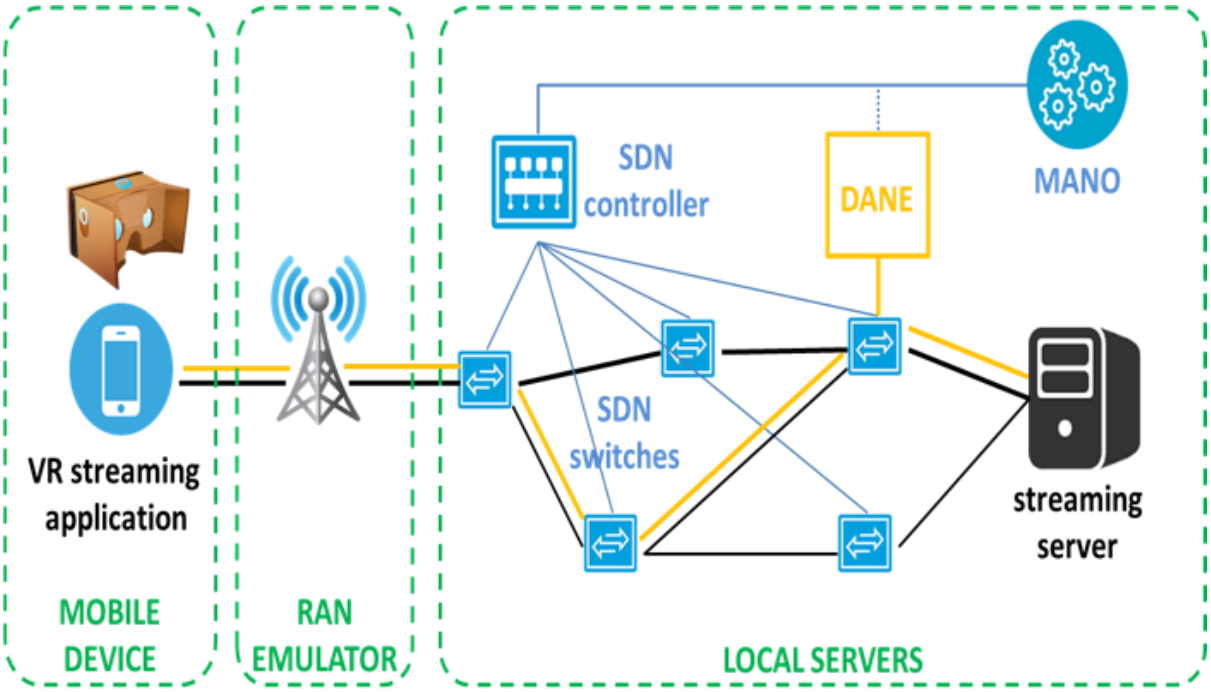

Figure 6: Architecture of TNO Extension

3.2.3 Expected Impact

The objective of the extension is to enable 5G networks to support next generation multimedia streaming applications, such as Virtual Reality (VR), building towards more immersive use cases like Tactile Internet. To enable this, superior management and network orchestration (MANO) functionalities and end-to-end testing are essential.

The extension develops along two directions: 1) provision of MANO and – wherever needed – SDN functionalities to the TRIANGLE testbed; 2) further enhancement of MANO functionalities with features for deeper control and assistance of MPEG-based VR applications.

The first extension will allow the TRIANGLE testbed to offer to its users the ability of running experiments orchestrating the management of programmable 5G networks. Our extension will include an Orchestrator (MANO) integrating with SDN infrastructure, provided by TRIANGLE and/or modified by us according to the needs – see testbed integration section. Introducing a MANO opens the opportunity for further expansion of the TRIANGLE testbed be letting experimenters plugging-in additional modules, such as measurements module or security threats detector. The MANO will enable these modules to work in a coordinated way, and avoid one interfering with the others.

The second extension will integrate management and assistance of VR streaming apps tightly within the 5G network, by introducing in the TRIANGLE testbed a novel network element (called DANE) implementing the upcoming MPEG DASH SAND standard. This standard defines a communication channel between streaming apps and network elements (DANEs). TNO will interface the DANE with the MANO in order to enable application management (performed via DANE) to fall under MANO control.

By programming the MANO to coordinate the usage of SDN resources and app behaviour, the solution will yield higher network efficiency and superior application QoS. This is especially important for upcoming streaming services, such as VR, characterized by stringent, real-time dependent, QoS requirements. Additionally, the DANE-MANO interface has not yet been specified in the MPEG DASH SAND standard, and would be a unique feature of the TRIANGLE testbed.

The two extensions proposed will allow testbed users to test next generation multimedia services under different levels of management and control: only SDN management via MANO; only application management via DANE; management and orchestration of network and application using DANE and SDN coordinated by MANO.

In line with the TRIANGLE guidelines (deliverable D2-1), TNO will measure the following KPIs: network resource usage (down/up-link in active mode), user experience (playback experience – using parameters as defined in the MPEG DASH SAND spec, response time, time to render VR environment, data usage), network adaptation (ability to handle low bandwidth, network delay, connection losses, ability to adapt streaming quality to network condition).

3.2.4 Relation to 5G

The expected ability of 5G network to deliver advanced, chained services for multiple tenants in the on-demand way will introduce an unavoidable complexity. To assure meeting the high bandwidth and low latency targets, 5G is foreseen to be largely a software network, using advanced MANO functionalities. Any testbed which wants to offer realistic conditions for 5G test needs to provide experimenters with the ability to orchestrate real-time network and cloud resources for 5G services. To align with this requirement, our first extension proposes to integrate a standard-based, state-of-the art MANO.
One of the ideas behind 5G is also extensibility: no one can predict now all kinds and flavors of functions and services to be offered. Rather, a modular architecture supported by well-defined

interfaces is the way to go. Our second extension makes a step forward exactly in this direction: introducing a new application management element (the DANE), and interfacing it with the MANO. The aim of this extension is to allow the MANO to make more efficient use of the network while at the same time improving the application QoS, thereby allowing the network to get closer to realizing the targets set for 5G. Furthermore, pervasive video (including VR) and tactile internet (which can be considered an evolution of VR) are mentioned by the NGMN as the representative use cases of two of the eight identified 5G use cases families. This is also in line with TRIANGLE's 5G vision. A similar vision has also been expressed by 5G-PPP, which recognizes "Media & Entertainment" as an essential "vertical sector" of 5G. Finally, Cisco forecasts that multimedia applications will generate 82% of the network traffic by 2020 and that VR traffic will increase 61-fold between 2015 and 2020. Hence, it is important for any future Internet architecture proposal (and 5G in particular) to support the requirements of VR and multimedia streaming applications in general.

3.3 Summary of Results of Open Call 1 & 2

The consortium felt that both OC 1 and 2 went well and continue to go well in the case of TNO. The TRIANGLE consortium had a number of technical challenges to face in supporting the diverse setup of application areas and ensuring that the testbed was ready to support these application types.

As part of the evaluation process each testbed user is required to give their feedback on their experience using the testbed and suggestions that they may have for improving the testbed. Since the first batch of experimenters were the first real users of the testbed it was inevitable that these users encountered some issues, especially at the outset of testing that are normal when real world usage of a new platform. In general, the issues found were small in terms of the seriousness and in most cases, quickly resolved by the technical support team, mainly UMA.

Suggestions for improvements are one of the key motivations for having early users and the consortium was happy to receive these suggestions and plan to address some of the suggestions in upcoming Testbed releases, or in some cases, these have already been addressed. A summary of these suggestions, as well as of the issues identified, is listed in the following sections.

3.3.1 Support during the experiments

All the experimenters complemented the ease and efficiency of the support process during the experiment. Each Experiment had a corresponding project created in Redmine and individuals from each experiment team were added to the project in various roles.

Each Experiment also had a member of TRIANGLE assigned to be the main liaison on technical issues and to coordinate testbed access based on testbed availability. In future large parts of this process are planned to be automated, with the ability to book through a calendar interface for booking time slots, with some checks to ensure testbed availability and operational state before access is branded and an experiment can start. In the event of a technical issue, the Experimenter logged an issue on Redmine and the TRIANGLE liaison contact assigned the issue to an appropriately individual to resolve or to clarify with the reporter. In some cases, email and occasionally phone calls were scheduled to resolve issues or to clarify questions more efficiently.

3.3.2 General Experiment administration and communication

In addition to a technical lead for each experiment UCL coordinated and finance, admin, reporting and contracting tasks. Each Experimenter indicated that this aspect of the project was

good to adequate. One experimenter commented that “The follow-up meetings were appropriated and perfectly scheduled according to our expectations for an experiment with short timeframe”.

Another experimenter mentioned that: “The administrative work was clear and timely, greatly alleviating the experimenters of any non-technical work that might obstruct the smooth conducting of the experiments. Further, feedback was also timely and targeted, with solutions usually being provided in a matter of minutes. While there was a delay to the starting of the experiment, the process was smooth from start to end.”

3.3.3 Documentation

The main source of Documentation to support experiments is a combination of public documents on the TRIANGLE website that describe the testbed and its components and in a shared Redmine project that is accessible to all registered users that have been assigned Redmine accounts for experiments.

Overall it was commented that the documentation was adequate and at the level expected for a non-commercial service, but that more work would be needed in the following areas:

1. More support for non-Windows users was also flagged as a welcome improvement.
2. Documentation that is more understandable to individuals without knowledge of the underlying network details, for example users form the app development community and not networking engineers.
3. Adding a glossary of terms and for specification for measurement units, log file names (SMU, DUT, etc) and column headers of CSVs would be helpful.

3.3.4 Summary of recommendations for Improvement

In this Section, the summary of all the issues and wishes provided as feedback by the Experimenters is presented. The TRIANGLE consortium has identified, in order to address such feedback, three action types defined as follows:

[1] Part of TRIANGLE Testbed Release 2 (R2)

[2] Planned in TRIANGLE Testbed Release 3 (R3)

[3] Will not be act upon in the frame of the EC project

In the case of [3], certain requests from the experimenters are well received but deemed outside of the scope of the EU research project context. As an example, a request to support many phone brands would not add value for the research portion of the project but would be mandatory feature for a commercial release of such testbed. We are therefore making a difference between requests which are research content and requests which are deemed important for a commercial service but which will not be developed or released in the frame of the TRIANGLE EU project.

Testbed Component	**Issue**	**Suggestion**	**Action**
Testbed Portal	Multiple (3) Timestamp formats are in use requiring parsing for timestamp comparison in post-processing	Modify timestamps in logging to single format	[1], [2] Partly available in Rel2 due to TAP full integration, to be improved
Testbed Portal	Name of the Experiment Campaign not included in the device_log filename	Modify the device_log filename or contents to include the output of the Experiment Campaign	[2]
Testbed Portal	zipped campaign log files must be downloaded one by one, making analysis difficult	Portal should provide options to download all campaigns results for a particular campaign in batch (ZIP file).	[1]
Testbed Portal	Portal and log files produced does not provide further detailed information on results of Campaign Executions. The resulting files device_log.txt and associated measurements are not too easy to interpret by personnel not directly involved in 5G network jargon,	Provide a high level summary of the experiment outcome that would be understandable to, those experimenters who are mobile app developers without deep wireless networking knowledge	[2], [3] Part will be covered by the inclusion of TRIANGLE KPIs processing. More advanced "analytics/reporting" is not part of the project.
Testbed Portal	Logging level not configurable	Experimenters should be able to define somehow the level of verbosity of log files.	[3] logging is designed for full access. KPI reporting should replace need for look into logs
Testbed Portal	Removal of campaigns is not possible	Experimenters should be able to delete campaign runs which are not useful for the experiment. E.g. when error is thrown and it is not attributable to mobile app being tested.	[1]

Testbed Component	Issue	Suggestion	Action
Testbed Portal	Errors were produced because components running behind the Portal or even the testing device had no internet connectivity available during testing	Experimenters should be able to verify the health of the platform prior to executing a Campaign	[2] Initial basic functionalities
Testbed Portal	Experimenters would like to able to better communication references to specific errors detected by associated a Campaign execution ID to the Redmine issue creation	add an integration between Testbed Portal and Redmine so that experimenters should be able to create issues right at the Test Portal whenever they detect any problem.	[2] Initial basic functionalities
Testbed Portal	When errors in Experiment Campaign execution happen, no hints on reason of error are displayed.	Add additional error handling and reporting capabilities to indicate the source of issues	[2], [3] some basic capabilities provided, advanced “troubleshooting” not part of the project.
Testbed Portal	Experimenters are forced to enter into Details page in order to be able to check the Execution ID in order to map the device_log file and its corresponding Experiment Campaign execution	the Execution ID should be included in the headers featured within the Portal section listing the Campaign executions	[2]
Testbed Portal	If a comments field is enabled for each Campaign created it would be helpful to add that are useful to remember on each campaign or execution	Add a comments field to store relevant contextual comments for a campaign	[2]
Testbed Portal	The output timezone is not configurable and Experimenters are forced to make an additional computing on results obtained.	Add user defined timezone customisation as it is now, CTU time is available only. This will need to be consistent across all outputs and logs	[2]

Testbed Component	Issue	Suggestion	Action
Testbed Portal	No evidence of distinction of Mobile Devices on user equipment in logging	Update logging to indicate device type that is logging the data	[2] KPI processing DB should avoid users to use logs.
Testbed Portal	Booking of testbed was not implemented	Add calendar timeslot booking and automated testbed status checking	[2]
Testbed Portal	Help section on Portal was not implemented	Add help content to the portal	[2]
Testbed Portal	Certification campaigns features were not available on the Testbed Porta	Add Certification functionality	[2]
Testbed Portal	Experimenters must wait until campaign execution finishes, then download log files, review file contents and finally determine whether the execution went right or not	Portal should be able to provide a screen for experimenters to view live generated data and to modify if the experiment is progressing ok. This could be similar to how Amazon AWS Device Farm works	[1] Portal shows progress bar and red/green status. [2] will allow basic error reporting. [3] live data not foreseen.
Testbed Portal	Experimenters should be able to view (live) the screen of the terminal being used on campaign execution to see any abnormal behaviour	Add screen capture and display in the portal as per how Amazon AWS Device Farm works	[1], [2] remote screen already available that can be captured. Will be integrated in Rel'3.
Testbed Portal	Portal should provide graphical visualization tools: charts, comparative views, etc.	Add additional view options to compare experiments and to summarise experiment outputs	[2] Triangle mark and simple visualization. [3] More advanced visualization not foreseen.

Testbed Component	**Issue**	**Suggestion**	**Action**
Testbed Portal	Unclear when errors in execution of given Campaigns were due to problems associated with the experiment or issues with the testbed itself	The portal may need to have a background process that monitors itself for errors or components that do not respond and update the user interface so that the user is aware that there is a potential issue	[2], [3] some basic capabilities for error checking in Rel'3. Self-healing not foreseen by the project.
Testbed Portal	Cancelled booking slots are underutilising testbed resources that could be used by other users. This can reduced throughput when all resources are effectively up and running.	Booking section should be flexible enough to allow for cancelling allocated slots and inform (publish-subscribe paradigm) other interested experimenters about new availability of experimenting slots.	[2] More advanced paradigms will be in Rel'3.
Testbed Portal	Experimenters should be able to perform search and filter on campaign executed. E.g.: by entering the Execution ID.	Add a search filter to allow searching for Campaigns by a number of attributes including Execution ID	[2]
Testbed Portal	Every time an experimenter wants to create a new Experiment Campaign they are required to upload the JSON file corresponding to the App User Flow	The Portal should allow for reusing App User Flows already uploaded in previous Experiment Campaigns.	[1], [3] App flows associated to Test Cases are already recyclable. Custom library will not be supported.

Testbed Component	**Issue**	**Suggestion**	**Action**
Testbed Portal	Selecting the device to execute a campaign requires manual involvement to ensure that the required device is connected to the testbed	Testbed should allow for agile testing device selection with experimenters being able to choose from multiple devices. Following philosophy of Amazon AWS Device Farm	[1], [2]. RF switches avoiding manual involvement are already integrated. Continuous updates to testbed setup ongoing
Testbed Portal	Single devices are only able to connect to the Testbed at any one time.	Several testing devices (Samsung Galaxy S3, Samsung Galaxy S7, etc.) should be connected to testbed simultaneously	[1], [2] see previous comment
Testbed Portal	experimenters are forced to wait until campaign execution finishes if they detect an undesired behaviour of either device or experiment execution itself	Campaign execution should have an option be aborted by the user in the event of a mistake or error detected	[2]
Testbed Portal	Content on sections on the “Campaign executions” page should be automatically updated to show the most up-to-date status of running campaign	Campaign execution page on Testbed Portal should be more responsive using AJAX-style updates	[2]
Testbed Portal	Experimenters should be able to manipulate radio access. For instance, simulating connectivity failures on specific times during a Campaign execution	This feature should be either live during an ongoing Campaign execution Or as described in an input file similar to App User Flow. This new file could be called Network Behaviour flow.	[1], [3] the feature is available only on Researcher profile. No plan to include any live nor flow execution via portal.

Testbed Component	**Issue**	**Suggestion**	**Action**
Testbed Portal	The Portal should provide experimenters with tools to effectively co-create or collaborate with other experimenters or Testbed managers.	Experimenters should be able to control the sharing of results of campaign executions Experimenters should be able to verify the results of the campaign executions against those results obtained by other colleagues Experimenters should be able to provide feedback to colleagues	[3] User community not foreseen. Data protection and IP protection was considered highest priority.
Testbed Portal	A FAQ section could be useful for experimenters	Add a link to the FAQ on the website and also on Redmine to the portal	[2]
Testbed Portal	The error reporting as no indication and/or reasons were given, leaving the experimenters with the only option of contacting the TRIANGLE consortium for support through Redmine.	Add additional error reporting capabilities to the Experiment Controller and potentially make the output available in the Triangle portal	[2] will allow basic error reporting.
Testbed Portal	documentation for the 1 second latency when sending a command to the phone to avoid any future issues with respect to command spamming increasing the duration of the experiment,		Unclear request
Testbed Portal	an adjustable logcat size to allow for heavier KPI logging in longer sessions,		[2], [3] Part will be covered by the inclusion of Triangle KPIs processing. More advanced filtering is not part of the project.

Testbed Component	**Issue**	**Suggestion**	**Action**
Testbed Portal	Custom KPI logging of multiple measurements,		Unclear request. [1] supports custom measurement collection in researcher profile (TAP SDK)
Testbed Portal	Network condition parameterisation through the Portal		[1], [3] the feature is available only on Researcher profile. No plan to include parametrization via portal.
Testbed Portal	Indicative error messages after a failed campaign execution		[2] will allow basic error reporting.
Testbed Portal	De-coupling of the user flow and uploaded application to allow for extra user flow testing with the same application version in a more efficient way,		[3] version changes can include GUI changes. It would not be reliable.
Testbed Portal	Only one user flow being associated with only the uploaded application and only for that specific version is a very strict and rigid design that should definitely be updated to allow for higher flexibility	Add ability to associate multiple test scripts per campaign?	[2]
Quamotion	Unity2D applications cannot harness the automation tool's most powerful functionalities of action recording	Additional documentation can be added to describe how to develop custom flows	[1] Documentation is available on how to create custom user flows when recording was not possible
Quamotion	Limited support for hybrid apps	Add additional support for hybrid apps	[2]
Quamotion	Documentation is mainly oriented to Windows users	Add documentation for other platforms including Mac OS	[2]
Quamotion	UTF-8 encoding for the user flow files		[1] Encode script in UTF-8 when exporting

Testbed Component	**Issue**	**Suggestion**	**Action**
Quamotion	a Webdriver document offering help on how to transmit commands from a PowerShell shell to the phone to accomplish custom user flow creation,		[1] transformation script available [2] custom script upload (e.g. powershell, python)
Instrumentation Library	Limited support for hybrid apps	Add additional support for hybrid apps	[2]
Devices	While the availability of mobile phone brands was sufficient for testing more devices for testing would be great	Add additional devices to the Testbed	[2]
General	tools only support apps developed for Android	Tools should support both popular mobile Operating Systems (Android and iOS)	[1], [2] continuous support from existing testbed

Table 4: Summary of recommendations for Improvement

Business Benefits and TRIANGLE Business Model

In addition to the technical and usability feedback each Experimenter also provided feedback on the financial benefits for them as a company and their competitiveness and also on the financial model for the TRIANGLE Testbed to operate as a commercial service in the future. The output of this input is not addressed in this document as it has been explored in more detail in the Business Plan for the Testbed, which is explored in D6.1.

4 Additional use of the Testbed outside of Open Calls

During the Open Call the TRIANGLE Testbed was also used by other users who had not applied, or been selected for the Open Call. This was done to maximise feedback from early testers. These testbed users used the testbed when the main experimenters did not require testbed access and have a second tier or priority to the testbed than those companies selected from the Open Call process. The TRIANGLE Consortium hopes to maximise testbed use and to extend the access of companies to the Testbed, on an unpaid basis and when not in use.

This can be facilitated as the Testbed has additional resources in the Keysight lab in Denmark (distributed testbed feature) and some spare devices in the UMA lab. The TRIANGLE website now has a link on the top level to request Testbed Access and there is a short form for companies to fill out if they wish to request access.

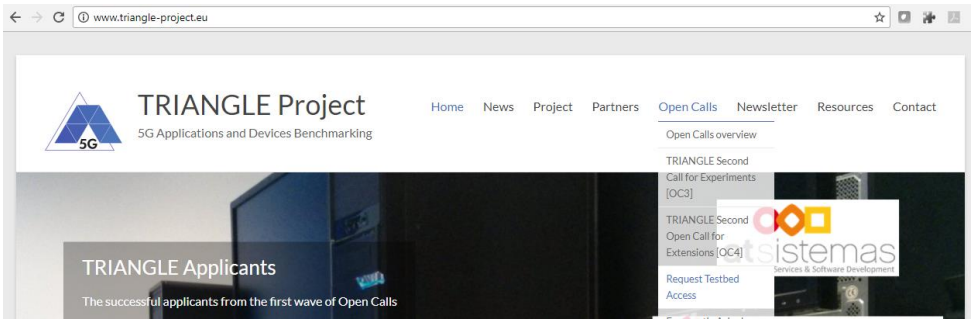

Figure 7: TRIANGLE webpage with access testbed button

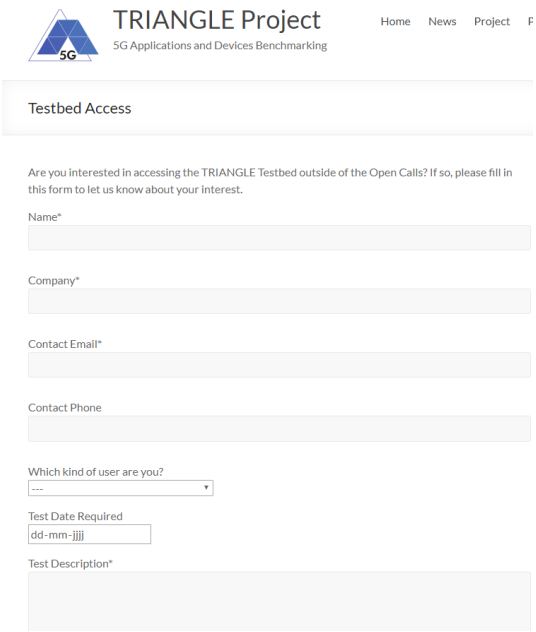

Figure 8: TRIANGLE webpage with Testbed access form

At the time of writing this report the use of the TRIANGLE Testbed by other companies outside the Open Call process is at an early stage and is too early to have meaningful outputs for this report. We intend to have feedback from these external users in the next Deliverable D5.4.

5 Conclusion

The TRIANGLE project had foreseen the presence of Open Calls in order to test the usability of the testing service and get insight from potential customers about the business viability and technical and commercial interest on the market.

During the second year of the project two Open Calls have been opened for submission, evaluated, and executed. As a result, the project financed three experiments and one testbed extensions.

The experiments were focused on much diverse use cases, from Content Streaming, to Augmented Reality, to Medical IoT data handling. This diversity allowed the consortium to get insight on which are the potential critical and killer applications while the ecosystem is moving towards 5G. Furthermore, all three experiments, selected through an external panel of experts, are coming from SMEs. As a matter of fact, most of the experiments and extension submissions were coming from SMEs, showing how market-wise the SME ecosystem is getting ready for tackling the 5G financial market.

While these first insights are important, they represent only an initial set that will be expanded with the following wave of Open Calls that has been already closed and it is getting ready for execution at the time of writing.

A testbed extension has also been selected to improve the networking and service side of the testbed, incorporating the initial capabilities for supporting NFVs and NFV testing into the testbed. This extension makes the TRIANGLE testbed leaping forward towards a more 5G-focused testing system.

References

[1] f6s platform (http://f6s.com)

[2] TRIANGLE Technical overview (http://triangle-project.eu/tools)

[3] TRIANGLE Open Call 1 overview (http://www.triangle-project.eu/open-calls-open-call-1/)

[4] TRIANGLE Open Call 2 overview (http://www.triangle-project.eu/open-calls-open-call-2/)

[5] EU scoring criteria http://ec.europa.eu/research/participants/data/ref/h2020/call_ptef/ef/h2020-call-ef-ria-ia-csa_en.pdf.

[6] https://aws.amazon.com/device-farm.

6 Appendix A – Experiment Application Questions

1. Experiment lead: full name
2. Experiment lead: email address
3. Experiment lead: country of residence
4. Experiment lead: your registration number (national ID or passport number)
5. Experiment lead: Participant Identification Code (PIC) issued by the European Union (or a business registration extract for organisations)
6. Are you applying to the TRIANGLE open call on behalf of an organisation (business, research or other)? If yes, details for that organisation: name, registration number and registered address.
7. Please enter the names of all of your team members, along with their countries of residence (proof of eligibility will be required in the case of successful applications).
8. What is the title of your experiment idea?
9. Describe your idea and testing objectives from using the TRIANGLE testbed, outline what KPIs are to be measured (3000 characters)
10. Describe how your idea benefits from 5G technologies. (2000 characters)
11. Outline your planned activities in a list and your timeplan. (1500 characters)
12. If you wish to support your plan with a (max 1 page) pdf planning document, you may upload that document, this is not mandatory but is useful.
13. Which of the TRIANGLE testbed components do you intend to experiment with and how you will use them? You can find more info about the Tools and Data sources from http://www.triangle-project.eu/tools. (6000 characters)
14. Does your experiment proposal intend to use any data that may be protected under EU privacy laws? (Yes/No with more detail required if the answer is “yes” If “yes” you must include any considerations around ethics and privacy.) (200 characters)
15. Outline who will benefit from your idea. (500 characters)
16. Describe your Experiment Group, how are you organised, what skills and resources do you have. (3000 characters)
17. Upload your budget for the project, using the template provided http://www.triangle-project.eu/experiments/BudgetTemplate.xls.

7 Appendix B – Extensions Application Questions

1. Experiment lead: full name
2. Experiment lead: email address
3. Experiment lead: country of residence
4. Experiment lead: your registration number (national ID or passport number)
5. Experiment lead: Participant Identification Code (PIC) issued by the European Union (or a business registration extract for organisations)
6. Are you applying to the TRIANGLE open call on behalf of an organisation (business, research or other)? If yes, details for that organisation: name, registration number and registered address.
7. Please enter the names of all of your team members, along with their countries of residence (proof of eligibility will be required in the case of successful applications).
8. What is the title of your experiment idea?
9. Describe your idea and testing objectives from using the TRIANGLE testbed, outline what KPIs are to be measured (3000 characters).
10. Describe how your idea benefits from 5G technologies. (2000 characters)
11. Outline your planned activities in a list and your timeplan. (1500 characters)
12. If you wish to support your plan with a (max 1 page) pdf planning document, you may upload that document, this is not mandatory but is useful.
13. Which of the TRIANGLE testbed components do you intend to experiment with and how you will use them? You can find more info about the Tools and Data sources from http://www.triangle-project.eu/tools. (6000 characters).
14. Does your experiment proposal intend to use any data that may be protected under EU privacy laws? (Yes/No with more detail required if the answer is “yes” If “yes” you must include any considerations around ethics and privacy.) (200 characters).
15. Outline who will benefit from your idea. (500 characters).
16. Describe your Experiment Group, how are you organised, what skills and resources do you have. (3000 characters).
17. Upload your budget for the project, using the template provided http://www.triangle-project.eu/experiments/BudgetTemplateExtensions.xls
18. Please add any additional documents that you feel would be helpful (this is not required).

8 Appendix C – Open Call process

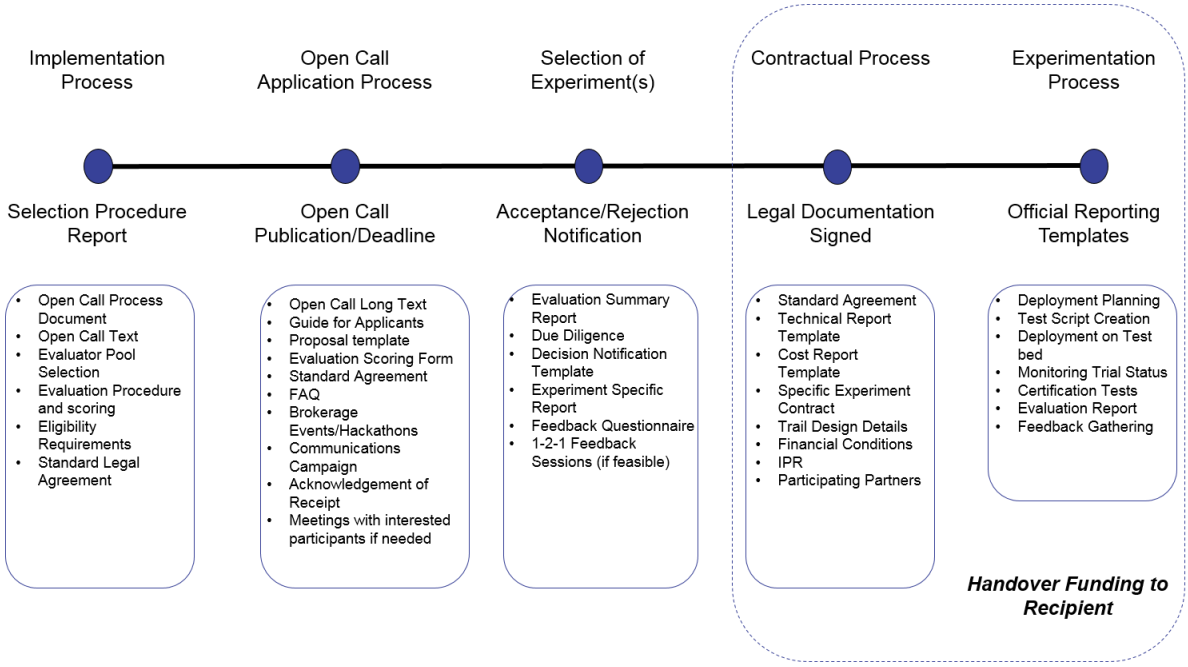

Figure 9: Open call process