H2020-ICT-688712

Project: H2020-ICT-688712

Project Name:

5G Applications and Devices Benchmarking (TRIANGLE)

Deliverable D6.4

TRIANGLE Project Metrics and collection of triangle Technical Publications

Date of delivery:	31/12/2018	Version:	1.0
Start date of Project:	01/01/2016	Duration:	36 months

Deliverable D6.4

TRIANGLE Project Metrics and collection of Triangle Technical Publications

Project Number:	ICT-688712
Project Name:	TRIANGLE Project Metrics
Project Acronym	TRIANGLE

Document Number:	ICT-688712-TRIANGLE/D6.4
Document Title:	TRIANGLE Project Metrics and collection of Triangle Technical Publications
Lead beneficiary:	Redzinc
Editor(s):	Jeanne Caffrey(RedZinc)
Authors:	All consortium members
Dissemination Level:	PU
Contractual Date of Delivery:	31/12/2018
Work Package Leader:	REDZ
Status:	Final
Version:	1.0
File Name:	TRIANGLE_Deliverable_D6.4_ FINAL

Abstract

This deliverable describes the project metrics used in TRIANGLE to measure the success of the project as well as the list of scientific articles, published in international journals which have been published on the TRIANGLE website. The document also include the contribution to the standardisation bodies.

Keywords

Metrics, scientific articles, papers, published, journals, international, success, standardisation

Executive summary

This deliverable report on the TRIANGLE project metrics, the list of scientific articles published in international journals and the contributions to the standardisation bodies. All technical papers have been published on the TRIANGLE website in line with the open access policy.

The TRIANGLE scientific articles are meant for dissemination and visibility purpose on the website, in international journals and presented at conferences and events throughout the project. These articles reflect on the project progress, share results and contribute to the state of the art in the domain.

The project metrics are there to measure the success of the project and its progress against a set of specific objectives.

The report itself is created for audit trail purpose.

Contents

1 Project Metrics

Project metrics are a collection of measurable metrics and objectives used to measure the progress and achievements of the TRIANGLE project. The set of metrics was defined at the project definition stage and refined at the start of the project. On a yearly basis, these metrics have been updated up until the end of the 3-year project.

By the end of the project, it is intended to have fulfilled all the objectives or at a minimum to have understood and explained the cause of any non-fulfilment of the metric.

The metrics will first be explained in detail, including the reporting on the progress and achievements in section 1.1. It is then finally presented in a summarized form in section 1.2

1.1 Metric reporting

Metric 1: Reduce the cost of testing mobile application and devices (from the point of vew of applications running on them) by 5% from 2016 to 2018.

The cost of the test per unit will vary from one company to another. We do not have a reference cost to compare in TRIANGLE as this is the first time that this type of testing and certification has been done on 5G devices and applications. However, we can make certain assumptions about the costing and draw some useful conclusions for this metric.

For instance, testing in Perfecto https://www.perfectomobile.com/plans-pricing starts at $15 per hour *but without providing any radio functionality*. This amounts to $130,000 per year if the testbed is used continually.

On the other hand, for an LTE device, DEKRA charge €30,000 per band and €20,000 for each field trial per band. This is for 20 hours per week. If more hours are needed, then extra payment is made by the hour.

TRIANGLE is doing testing with radio access where the application developer can use the hardware and software infrastructure. We are changing the approach of pure conformance tests to include a wider test coverage focused on performance test. These tests are more elaborate and provide more insight than a pass-fail criteria. This additional time spend on testing is however mitigated by a very high-test automation keeping the overall cost at the same level. Test cases can also be re-used across scenarios and service models. An average certification test on the Triangle platform lasts between 1 and 2 days in function of the quantity of services and test scenarios.

TRIANGLE also enabled additional testing capabilities (service and performance level) which could not be tested before in an end to end context at application layer taking in to account all the contributors to the end-user QoE.

Metric 2: Quantifiable increase of the quality of the applications developed

At the end of Year 1 we could not give any quantity as we had not tested any applications. However, from year 2 onwards, when the tests were carried out and bugs were identified the quality of the application increased. During the experiments over Years 2 and 3, experimenters found software bugs in their app thanks to TRIANGLE testing. This is captured in the experimenter feedback.

Bugs were quite diverse, from usability issues, to an application which could not work under certain conditions. Testbed users have taken this feedback to understand the boundary conditions where the QOE was acceptable and see if the design could be adapted to push these boundary conditions. Other users have improved the use of some inherent smartphone functionality thanks to the robotic arm 3D testing.

Metric 3: Quantifiable reduction of testing cycles

At the end of Year 1 we could not give any quantifiable result on this metric as we had not tested any applications or device yet.

However, at the end of the project we can say that reduction of testing cycles took place. There was a very clear case during the project where one experimenter was of the opinion that he had a functional device to start with. The device had been presented once to a live network and connected. However, when the device was presented to the testbed, no test could be accomplished. After different measurements and discussion with the experimenter, it was demonstrated that the device was not able to attach to different network conditions. The experimenter did a major redesign of his device and came back for testing.
Based on the breadth of the feedback shared by TRIANGLE with the experimenter, he was able to redesign his device much more efficiently. The device was made operational and carried on to successfully pass the relevant tests on the TRIANGLE testbed.

Metric 4: Market penetration of the TRIANGLE testing framework

The market penetration of the TRIANGLE approach to performance testing and QoE measurement, depends heavily on industry acceptance. This acceptance can be 'forced' through standardisation bodies, where passing certain types of test become a mandatory step before commercialisation or deployment. During the project, TRIANGLE made different contributions to the standardisation body such as 3GPP, CTIA and GCF in order to increase the chance of having the approach being widely accepted.

GCF plays a quite important role as it is the operator certification forum. Member operators define the type of operator approval test which they feel are necessary to successfully roll out devices and services to their network. The Global Certification Forum (GCF) for wireless industry has accepted 4 contributions on the TRIANGLE testing framework by the end of the project.

NGMN, a network operator centric forum also accepted the concept and approach proposed by TRIANGLE. Contributions were included in the definition of the testing framework for the NGMN 5G pre-commercial networks trials released in January 2018.

More information on the standardisation impact is available in section 3.

Metric 5: 15 SMEs with apps will be funded to test their apps on the project framework

At the end of Year 1 of the project 3 SME applications were selected out of 18 in the first open call. 9 SMEs had been funded for testing by the end of Year 2. By the end of Year 3 in the project 16 SME applicants have been selected for using the testbed with their devices and applications. One extra SME benefited from the testbed as external user.

In addition to these 16 SMEs, the consortium tested a video streaming device "BlueEye" from RedZinc. This device and application went first through the final TRIANGLE certification. More information on the "BlueEye" device certification can be found in D5.8

Here is the list of Open Call Waves, SMEs applicants and SMEs selected:

Open Call	# of SME applying	# of SME selected
1	18	3
3	12	5
4	1	1
5	2	2
6	5	5
Total	38	16

Metric 6: A minimum of 6 device models (brands) and a maximum of 30 models will be used in trials processes

Having a representative set of smartphone devices connected to the testbed is crucial to ensure that tests performed on applications are relevant. Different models may mean different test results which can be due to the operating system or some smartphone hardware design choices.

Originally, the project had expected to have 6 different brands with about 30 models. During the project, after an analysis of the market, we rapidly concluded that starting with iOS and Android would cover a large part of the installed base.

A second issue was the need to connectorized the devices. In order to ensure proper measurement, battery and RF signals have to be connectorized to the testbed. Such connection is, for the more recent devices, becoming very challenging given the high integration.

TRIANGLE has spent resources learning how to connect the internal antennas and battery of Samsung devices. We therefore connectorized multiple devices from that brand to have a diversity of operating system versions and model.

TRIANGLE has included 8 devices from 4 brands which is deemed appropriate to demonstrate the TRIANGLE concept.

The project decided not to incur extra unnecessary costs by adding several additional device & models. This would not contribute to the project objective and only increase the project cost.

Metric 7: Each use case will have minimum of 100 and a maximum of 1,000 users, thus a maximum of 10,000 user trials over all use cases

TRIANGLE decided early on to go with end-to-end testing rather than testing based on real users. This metric has therefore been abandoned.

Metric 8: Network scenarios will be developed across 3 service models: commercial, safety of life and public regulated

The original idea behind this metric was to focus the test framework on 3 expected key services in 5G: commercial services, safety of life and public regulated services. During the project period however, it was identified that focusing only on these 3 types of service model would limit the reach and impact of the project. An alternative strategy was developed to focus the project on defining domains where use cases can be mapped based on the service capability of the app or device under test.

When reconsidering the metric based on this definition, a target value of greater than 10 classes was established as to be achieved by the end of the project. At the end of the project, the current status is that 12 classes have been developed which have all been accepted by NGMN.

In D2.2 and in D2.7, detailed information can be found about the use cases & domains.

Metric 9: Select 5 company contributions on 5G certification and work to incorporate them in framework with a major certification body (such as GCF) in line with the "Test once, use anywhere" approach.

Over the project period, the consortium has presented 4 contributions to GCF, 1 contribution to NGMN, 3 contributions to 3GPP and 3 contributions to CTIA. More information is available in section 3 of this document.

Metric 10: Number of press news and presentations made and number of technical papers published

At the end of the project, 2 major press releases have been released. TRIANGLE participated in 35 events with booth, 18 presentations and 13 technical papers. 53 news items were published on the website. 11 newsletters were published and sent to the mailing list, with one final newsletter due at the end of project review period.

Metric 11: Commercial impact in meeting the needs of industry stakeholders

The fact that applications are being made to use the TRIANGLE testbed is proof that this type of testing and certification is needed. Again, this is the first time that this type of testing and certification has been done on 5G devices and applications so the extent of the impact remains to be seen and will be further explored in the business planning part of the project. A number of SMEs and institutions have applied for testing using the TRIANGLE testbed services.

The business plan has been defined in detail and reported in D6.1.

Metric 12: Number of FIRE testbeds, testing houses and certification bodies interested in the usage/access to TRIANGLE tools and framework. Success cases will be demonstrated

- Fed4FIRE+ : two experiments coming from allbesmart and nemergent and funded by Fed4FIRE+ were executed on top of Triangle thanks to the agreement between the two projects

- 5Genesis (KPI computation and measurement, test scenario). 5Genesis is considering using TAP and the test plans approach in TRIANGLE for validation of KPIs. 5Genesis is also considering to support TAP technologies for a common testing framework in the 5GPPP Testing, Measurement and KPI computation working group

An original target of interested bodies was set at 6 entities. At the end of the project we have achieved 12 entities and bodies with clear interaction objectives.

- GCF (contribution to the standard idea of openLab, as reported above)
- NGMN (interest in the framework as reported in the NGMN paper)
- Dekra (as partner but mainly as a test house active in the certification and device test market)
- A company competing with Dekra requested access which was declined
- Fed4FIRE+ where two experiments coming from allbesmart and nemergent and funded by Fed4FIRE+ were executed on top of Triangle thanks to the agreement between the two projects
- SME: Nemergent, project PERCEEVAL
  Activity: PERCCEVAL aims to evaluate the performance of MCPTT ecosystem in terms of KPIs (different delays and energy constraints) over both traditional and MEC-enabled

>=4G scenarios, and to provide insights of main sources for e2e delay and possible optimization paths
- 5G PPP (where TRIANGLE contributed to the development of the 5GPPP roadmap and the definition of the KPI for testing the phase 3 projects. There is also the potential use of TAP as a common testing framework for the 5GPPP Testing)
- 5G VINNI (contribution to the KPI computation and measurement, test scenario). TAP will be used for the test orchestration and automatic deployment of test infrastructure.
- 5Genesis (contribution to the KPI computation and measurement, test scenario). 5Genesis is considering using TAP and the test plans approach in TRIANGLE for validation of KPIs. 5Genesis is also considering to support TAP technologies for a common testing framework in the 5GPPP Testing and measurement working group.
- Finally, 3 external users took advantage of the testbed. Name will remain confidential.

We have visibility in Fed4Fire+, from emails confirming that we should offer TRIANGLE-UMA as part of the testbeds to the open callers. We also should include 5G PPP, not users, but they accept TRIANGLE as part of the 5G community (references in the Roadmaps and link in the 5GPPP main page). And now, we could also include 5G VINNI and 5Genesis projects as beneficiaries of previous work in TRIANGLE.

Metric 13: Number of technical support inquiries

We are targeting a low number of technical support inquiries as we expect the process to be easy to use for the applicant. We had a total of 66 support related issues on the testbeds via the Redmine issue tracking tool.

Redmine is a free and open source, web-based project management and issue tracking tool. It allows users to manage multiple projects and associated subprojects. It features per project wikis and forums, time tracking, and flexible, role-based access control.

1.2 Metric Summary table

Project metric	End of project target value	Status at the end of the project
1. Reduce the cost of testing mobile application and devices (from the point of view of applications running on them) by 5% from 2016 to 2018.	Keep costs same but increase test coverage	Automation has increased the test coverage for same cost. Triangle has also enabled additional testing capabilities (service and performance level) which could not be tested before.
2.Quantifiable increase of the quality of the applications developed.	At least 1 bug fix per applicant	We got feedback from experimenters that they found bugs in their app thanks to TRIANGLE. Given the confidentiality of the experiment, this is not further reported.
3.Quantifiable reduction of testing cycles.	Reduce by 10%	Positive feedback was received by experimenters confirming that by using the testbed, device and application quality was increased. The complete feedback received from the testbed led to a reduction in the testing cycles which is higher than 10%.
4.Market penetration of the TRIANGLE testing framework.	GCF dependent	NGMN have accepted the concept. Presentation and initial support at GCF. Intention to continue the work with 3GPPP beyond the project duration.
5. SMEs with apps will be funded to test their apps on the project framework	15 SMEs	16 SMEs funded + 1 unfunded.
6. A minimum of 6 device models (brands) and a maximum of 30 models will be used in trials processes.	6 device models/brands 30 models	8 devices (5 Samsung, 1 iPhone, 1 Nexus 6, 1 HTC One Plus models) from 4 brands (Samsung, Apple, Google, HTC)
7. Each use case will have minimum of 100 and a maximum of 1,000 users, thus a maximum of 10,000 user trials over all use cases	10,000 users	TRIANGLE decided early on to go with end-to-end testing rather than test real users. This metric was therefore abandoned.

8. Network scenarios will be developed across 3 service models: commercial, safety of life and public regulated.	3 service models >10 classes	Triangle defined instead of the 3 service models a large set of test cases classified in classes which can map to these services. 12 classes developed and accepted by NGMN. All class details have been defined in D2.2.
9. Select 5 company contributions on 5G certification and work to incorporate them in framework with a major certification body (such as GCF) in line with the "Test once, use anywhere" approach.	5 company contributions	4 GCF contributions; 1 NGMN paper; 3 3GPP contribution; 3 CTIA contributions
10. Number of press news and presentations made and number of technical papers published.	2 press releases 10 news items 30 events including 12 presentations 8 technical papers	2 press releases 53 news items 35 events including 15 presentations 13 technical papers
11.Commercial impact in meeting the needs of industry stakeholders.	To be defined subject to open calls/applicants	See D6.1
12. Number of FIRE testbeds, testing houses and certification bodies interested in the usage/access to TRIANGLE tools and framework. Success cases will be demonstrated.	6	12
13. Number of technical support inquiries.	<10/tester	Total Redmine issues 121 -> 42 bugs including 6 high priority (experimenters & ext.)

2 Scientific Publications

2.1 Overview of the scientific publications

Here is the list of scientific papers produced in the lifetime of the project.

	DOI	Type	Publication Title	Authors	Conference Title		Publisher	Location	Year	Status of papers
1	10.1109/ EuCNC.2 016.7561 053	Publication conference proceedings	"An end-to-end testing ecosystem for 5G"	A. F. Cattoni et al.	2016 European Conference on Networks and Communications (EuCNC)	Annual	EuCNC. This is available on IEEExplore.	Athens	2016	Published
2	10.13052 /jge1904- 4720.633	Publication conference proceedings	An End-to-End Testing Ecosystem for 5G the TRIANGLE Testing House Test Bed	A.F. Cattoni et al.,	Journal of Green Engineering, Vol. 6, Issue 3	Annual			2016	Published
3		Chapters in books	FIRE book	TRIANGLE consortium	Proceedings of the 24th Jornadas de Concurrencia y Sistemas Distribuidos (JCSD 2016)	Annual	JCSD	Granada	2016	Submitted
4	N/A	Books/ Monographs	Benchmarking as a Service	TRIANGLE consortium		One-off			2016	
5		Publication conference proceedings/ workshop	Advanced testing of mobile applications and devices	TRIANGLE consortium	IFIP/IEEE International Symposium on Integrated Network Management	Annual		Lisbon	2017	In press
6		Article in Journal	A formal approach to automatically analyze extra-functional	Ana-Rosario Espada, María-del-Mar Gallardo, Alberto Salmerón,	Software Testing, Verification and Reliability		John Wiley & Sons, Ltd.		No Year	Under review

			properties in mobile applications	Pedro Merino, Laura Panizo						
7	10.1145/ 3092282. 3092298	Publication conference proceedings/ workshop	Guided test case generation for mobile apps in the TRIANGLE project: work in progress	Laura Panizo, Alberto Salmerón, María-del-Mar Gallardo, Pedro Merino	Proceedings of the 24th ACM SIGSOFT International SPIN Symposium on Model Checking of Software	Annual	ACM	New York, NY, USA	2017	Published
8	https://do i.org/10.1 007/978-3-319-95678-7_12	Publication conference proceedings/ workshop	TRIANGLE Portal: An User-Friendly Web Interface for Remote Experimentation	Almudena Díaz-Zayas, Alberto SalmerónMoreno, Gustavo García Pascual, Pedro Merino	International Conference on Remote Engineering and Virtual Instrumentation	Annual	Springer	Duesseld orf	2018	Published
9	10.1109/ CAMAD. 2018.851 4947	Publication conference proceedings/ workshop	TRIANGLE: a Platform to Validate 5G KPIs in End to End scenarios	Almudena Díaz Zayas, Andrea Cattoni, Carlos Cardenas, Janie Baños, Pedro Merino, Michael Diedonne	2018 IEEE 23rd International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (CAMAD)	Annual	IEEE	Barcelon a	2018	Published
10	https://do i.org/10.1 155/2018 /6202854 .	Publication	QoE Evaluation: The TRIANGLE Testbed Approach	Almudena Diaz Zayas, Laura Panizo, Janie Baños, Carlos Cárdenas, and Michael Dieudonne	Wireless Communications and Mobile Computing	Special Issue	Hindawi		2018	Published
11	TBA	Publication	An Empirical NB-IoT Power Consumption Model for Battery Lifetime Estimation	Lauridsen, M., Krigslund, R., Rohr, M., Madueno, G.	IEEE Vehicular Technology Conference 2018	Fall	IEEE	Chicago	2018	Published

12	TBA	Publication	Analytical Modeling and Experimental Validation of NB-IOT Device Energy	Pilar Andres-Maldonado, Mads Lauridsen, Pablo Ameigeiras, Juan M. Lopez-Soler	IoT Journal	Annual	IEEE		2019	Submitted
13	TBA	Publication	Impact of Propagation and Network Scenarios on Measured Quality of Experience	Hua Wang, German Corrales Madue, Marek Rohr, Michael Dieudonne, Janie Baños, Carlos Cárdenas, Pablo Aurelio Romero Hierro	13th European Conference on Antennas and Propagation	Annual	IEEE		2019	Accepted

2.2   Abstract of the main publications

2.2.1 EuCNC Papers

EuCNC 2016 was the 25th edition of a technical conference series in the field of telecommunications, sponsored by the European Commission. The 2016 edition was co-organized by the University of Piraeus and the Institute of Communications and Computer Systems (ICCS). EuCNC is an annual event. The conference is one of the most prominent communications and networking conferences in Europe, which efficiently brings together cutting-edge research and world-renown industries and businesses. EuCNC attracts more than 600 delegates each year and an exhibition space of more than 1,500 m2. The conference focuses on various aspects of 5G communications systems and networks, including cloud and virtualisation solutions, management technologies, and vertical application areas. It targets to bring together researchers from all over the world to present the latest research results, and it is one of the main venues for demonstrating the results of research projects, especially from successive European R&D programmes co-financed by the European Commission.

TRIANGLE successfully submitted the paper and presented at European Conference on Networks and Communications (EuCNC), 27-30 June 2016, Athens, Greece entitled "An end-to-end testing ecosystem for 5G".

Abstract— Connected mobile applications will be a dominant software component in the 5G domain. Ensuring a correct and efficient behaviour 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 an

2.2.2 Green Engineering Journal

Green Engineering publishes original, high quality, peer-reviewed research papers and review articles dealing with environmentally safe engineering including their systems. Paper submission is solicited on: 1. Theoretical and numerical modeling of environmentally safe electrical engineering devices and systems 2. Simulation of performance of innovative energy supply systems including renewable energy systems, as well as energy harvesting systems 3. Modeling and optimization of human environmentally conscientiousness environment (especially related to electromagnetics and acoustics) 4. Modeling and optimization of applications of engineering sciences and technology to medicine and biology 5. Advances in modeling including optimization, product modeling, fault detection and diagnostics, inverse models 6. Advances in software and systems interoperability, validation and calibration techniques. Simulation tools for sustainable environment (especially electromagnetic, and acoustic) 7. Experiences on teaching environmentally safe engineering (including applications of engineering sciences and technology to medicine and biology) All these topics may be addressed from a global scale to a microscopic scale, and for different phases during the life cycle.

2.2.3 FIRE book Chapter: 24th Jornadas de Concurrencia y Sistemas Distribuidos

Book chapter: Building the Future Internet through FIRE. 2016 FIRE Book: A Research and Experiment based Approach. This book details the Future Internet. It is available on Amazon books.

Abstract: The Internet as we know it today is the result of continuous activity for improving network communications, end user services, computational processes, and information technology infrastructures. The Internet has become a critical infrastructure for the human being

by offering complex networking services and end-user applications that together have transformed all aspects, mainly economical, of our lives. Recently, with the advent of new paradigms and the progress in wireless technology, sensor networks, and information systems, and the inexorable shift towards the everything-connected paradigm— first known as the Internet of Things and lately envisioning into the Internet of Everything— a data-driven society has been created. In a data-driven society, productivity, knowledge, and experience are dependent on increasingly open, dynamic, interdependent, and complex Internet services. The challenge for the Internet of the Future design is to build robust enabling technologies, implement and deploy adaptive systems, and to create business opportunities which consider increasing uncertainties and emergent systemic behaviors where humans and machines seamlessly cooperate.

2.2.4 White Paper Benchmarking as a Service

This white paper was presented as a FIRE Book Chapter and is available on the TRIANGLE website: https://www.triangle-project.eu/wp-content/uploads/2018/04/FIRE-book-chapter-2017.pdf

Abstract: The FIRE 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. Connected apps will be a dominant software component in the 5G telco domain. Ensuring a correct and efficient behaviour of the applications and devices becomes a critical factor for the mobile communications market to meet the expectations of final users. While radio related certification of mobile devices has a strong standards-based ecosystem there is still a lack of consensus on the benchmarking or testing methods at the apps level. 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 for apps and devices. At the same time the methodology to be used in the design and development of the TRIANGLE test framework will ensure that the testbed end user is not overwhelmed by 561 562 Triangle: 5G Applications and Devices Benchmarking the complexity of the overall testbed by providing an intuitive high level configuration layer for the experiments and a flexible framework architecture to incorporate new 5G networking topologies as they become available.

2.2.5 IEEE International Symposium in Integrated Network Management

The 15th IFIP/IEEE International Symposium on Integrated Network Management (IM 2017), was sponsored by the IEEE Communications Society and IFIP Working Group 6.6. Held in odd-numbered years since 1989, IM 2017 followed the 28-year tradition of IM as the primary IEEE Communications Society's forum for technical exchange on management of information and communication technology focusing on research, development, integration, standards, services, and user communities. IM 2017 focuses on the theme "*Integrated Management in the Cloud and 5G Era*", that aims at capturing the emerging approaches and technical solutions for dealing with 5G and cloud infrastructures, as well as associated services and applications.

2.2.6 Software Testing, Verification and Reliability

Software Testing, Verification and Reliability (STVR) is an international journal, publishing 8 issues per year. It publishes papers on theoretical and practical issues of software testing, verification and reliability. The goal of the journal is to publish high-quality papers that help researchers, educators and practitioners understand cutting edge results. The journal is the premier outlet for research results on the subjects of testing, verification and reliability. Readers will find useful research on issues pertaining to building better software and evaluating it.

The journal is unique in its emphasis on theoretical foundations and applications to real-world software development. The balance of theory, empirical work, and practical applications provide readers with better techniques for testing, verifying and improving the reliability of software.

2.2.7 24th ACM SIGSOFT International SPIN Symposium on Model Checking of software

Guided Test Case Generation for Mobile Apps in the TRIANGLE Project: Work in Progress∗

ABSTRACT: The evolution of mobile networks and the increasing number of scenarios for mobile applications requires new approaches to ensure their quality and performance. The TRIANGLE project aims to develop an integrated testing framework that allows the evaluation of applications and devices in different network scenarios. This paper focuses on the generation of user interactions that will be part of the test cases for applications. We propose a method that combines model-based testing and guided search, based on the Key Performance Indicators to be measured, and we have evaluated our proposal with an example. Our ultimate goal is to integrate the guided generation of user flows into the TRIANGLE testing framework to automatically generate and execute test cases.

2.2.8 International Conference on Remote Engineering and Virtual Instrumentation

International Conference on Remote Engineering and Virtual Instrumentation (REV) is an annual IAOE conference. REV is an annual conference covering topics on online & remote engineering, virtual instrumentation and applications. Like other conferences, REV offers various tracks and simultaneous sessions, tutorials and workshops.

The first REV was held in Villach, Austria in 2004. It operates under the auspices of the International Association of Online Engineering (IAOE).

REV's venue changes every year, and the categories of its program vary. Historically REV has combined the presentation of academic papers with comparatively practical experience reports, panels, workshops and tutorials.

2.2.9 2018 IEEE 23rd International Workshop on Computer Aided Modelling Paper

The International Workshop on Computer-Aided Modeling Analysis and Design of Communication Links and Networks (CAMAD) provides a forum for discussion of recent developments on analytical and simulation tools and techniques for the performance evaluation of communications systems. It was launched in 1986, being held every 2 years until 2006, often in cooperation with flagship IEEE Communication Society conferences (Int. Conference on Communications – ICC, Global Telecommunication Conference – GLOBECOM). Since 2006, the workshop has been held once every year motivated by the ever increasing interest in this hot research and development field with last venues organized in Trento (CAMAD'06) and Pisa (CAMAD'09) as a stand-alone events, in conjunction with IEEE PIMRC 2007 in Athens, Greece (CAMAD'07) and co-located with the ICC 2008 in Beijing, China. From 2009, CAMAD is an IEEE Communications Society portfolio event.

2.2.10 Wireless Communications and Mobile Computing

Wireless Communications and Mobile Computing is part of an exciting new pilot partnership between Wiley and Hindawi. From 1st January 2017, the journal will become fully open access. *Wireless Communications and Mobile Computing* will remain a Wiley title but will be published and hosted by Hindawi, and will benefit from Hindawi's experience and expertise in

publishing open access titles. *Wireless Communications and Mobile Computing* will continue to undergo a rigorous peer review process ensuring that quality remains high.

The accepted paper presents the TRIANGLE testbed approach to score the Quality of Experience (QoE) of mobile applications, based on measurements extracted from tests performed on an end-to-end network testbed. The TRIANGLE project approach is a methodology flexible enough to generalize the computation of the QoE for any mobile application. The process produces a final TRIANGLE mark, a quality score, which could eventually be used to certify applications.

2.2.11 IEEE Vehicular Technology Conference 2018

The 2018 IEEE 87th Vehicular Technology Conference was held 3–6 June 2018 at the Porto Palácio Congress Hotel, in Porto, Portugal. This semi-annual flagship conference of the IEEE Vehicular Technology Society brought together individuals from academia, government, and industry to discuss and exchange ideas in the fields of wireless, mobile, and vehicular technology.

VTC2018-Spring featured world-class plenary speakers, tutorials, technical as well as application sessions, and an innovative Industry Track, which will feature panels and presentations with industry leaders sharing their perspectives on the latest technologies.

2.2.12 IEEE IoT Journal

The IEEE IoT Journal (IoT-J), launched in 2014, publishes papers on the latest advances, as well as review articles, on the various aspects of IoT. Topics include IoT system architecture, IoT enabling technologies, IoT communication and networking protocols, IoT services and applications, and the social implications of IoT. Examples are IoT demands, impacts, and implications on sensors technologies, big data management, and future internet design for various IoT use cases, such as smart cities, smart environments, smart homes, etc. The fields of interest include:

- IoT architectures such as things-centric, data-centric, service-centric architecture, CPS and SCADA platforms, future Internet design for IoT, cloud-based IoT, and system security and manageability.
- IoT enabling technologies such as sensors, radio frequency identification, low power and energy harvesting, sensor networks, machine-type communication, resource-constrained networks, real-time systems, IoT data analytics, in situ processing, and embedded software.
- IoT services, applications, standards, and test-beds such as streaming data management and mining platforms, service middleware, open service platform, semantic service management, security and privacy-preserving protocols, design examples of smart services and applications, and IoT application support.

2.2.13 13th European Conference on Antennas and Propagation

EuCAP2019 will take place from 31 March to 5 April 2019 in Krakow, Poland. EuCAP is run under the auspices of the European Association on Antennas and Propagation (EurAAP). Attracting almost 1400 attendees it is one of the two largest conferences in antennas and propagation in the world. It will be the 13th edition of the conference, which promotes not only new trends in antenna theory, techniques, and technology, but also closer relations among academia, research centres, and industry. To that aim, tools such as application tracks, industrial workshops, technical tours, and, above all, a large exhibition, have been implemented.

The TRIANGLE paper has been accepted for publication and presentation at EuCAP2019 The paper explains the TRIANGLE testbed approach to score the Quality of Experience (QoE) of mobile applications, based on measurements extracted from tests performed on an end-to-end network testbed. The TRIANGLE project approach is a methodology flexible enough to generalize the computation of the QoE for any mobile application. The process produces a final TRIANGLE mark, a quality score, which could eventually be used to certify applications.

3 Contribution to the standardisation bodies

3.1 3GPP & CTIA on MIMO OTA

The 3rd Generation Partnership Project (3GPP) is a collaboration between groups of telecommunications associations. 3GPP standardization encompasses Radio, Core Network and Service architecture. 3GPP technologies are constantly evolving through Generations of commercial cellular / mobile systems and since the completion of the first LTE and the Evolved Packet Core specifications, 3GPP has become the focal point for mobile systems beyond 3G such as 5G. The Wireless Association, originally known as the Cellular Telephone Industries Association (CTIA), is an international industry trade group representing all wireless communication sectors including cellular, personal communication services and enhanced specialized mobile radio. CTIA Certification verifies wireless device conformance to global technical specifications such as 3GPP and 3GPP2.

3GPP is continuing to develop the performance requirements for MIMO OTA using the MPAC test method. As part of that process, alignment of labs providing performance data needs to be demonstrated. TRIANGLE has made 3 contributions to the 3GPP standardization and a further 3 contributions to the CTIA Working Programme in the way of papers. These papers provide measurement results for three MPAC labs across MPAC and RTS systems using different alignment devices, AAD_1 and AAD_2 and also PAD_1 which used to be part of the AAD pool but is now a performance alignment device PAD_1.

3.2 GCF on the TRIANGLE QoE approach

The Global Certification Forum (GCF) is the organisational backbone to GCF Certification. Founded in 1999, this membership organisation brings together technical experts from the world's leading Manufacturers, Operators and the Test Industry. Together members define the certification requirements that really work for the industry - because they have been developed by the industry. Any product incorporating cellular mobile connectivity can be certified.

The GCF scheme evolves in sync with developments in mobile technologies and the changing needs of the industry. It is the only wireless product certification scheme that covers multiple technologies such as LTE (3GPP), 3G UMTS (3GPP), GSM (3GPP), CDMA2000 (3GPP2). GCF is of course looking into 5G today.

As such, the link with GCF is quite important for the Triangle project exploitation plan. Having a blessing from GCF as valid test methodology would greatly increase the value of the testbed. GCF, originally requested to be part of the advisory board prefer to stay independent and welcomes input from Triangle to be included in their test specifications. This engagement method is understandable given the fact they need to be seen as independent party. Engaging with industrial companies in such consortium would not ensure this independence.

During the project, 3 official contribution where submitted and presented to a wide audience. Aside these official presentations, multiple side meetings participation did happen to gain momentum on the concept and approach.

Two meetings took place with the Global Certification Forum at their member meetings in the first year of the project. The first meeting in which Triangle took part, was on 6-8 Dec 2015 in Dubai, UAE before the project officially started. At this meeting, a presentation around the objective of Triangle was done. An agreement in the engagement way was reached between the GCF members and Triangle. Regular presentations with update on the project progress where agreed with GCF to follow up on the progress of the project. The decision from GCF to accept such interaction did frustrate some of our industrial competitors.

The second GCF meeting was in Bristol in the UK (21-23rd of June 2016) where Triangle represented by DEKRA gave insight into the first results obtained by the consortium. The meeting attracted interest from large operator who requested to continue the efforts.

The final official presentation at GCF took place in San Diego at the Steering Group 11 – 13 December 2018. The QoE approach as developed by the consortium was presented and discussed. We expect further work with GCF beyond the end of the project.

Figure 1: TRIANGLE presentation at GCF meeting in San Diego